UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Technology and Engineering

DEVELOPMENT OF A WATER-BASED COOLING SYSTEM TO ENHANCE ENERGY EFFICIENCY IN FLOATING PHOTOVOLTAIC SYSTEMS

MOHAMAD TAUFIQQILAH BIN SUHAIMY

Bachelor of Electrical Engineering Technology with Honours

2025

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering Technology with Honours

Faculty of Electrical Technology and Engineering

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2025

DECLARATION

I declare that this project report entitled "DEVELOPMENT A WATER-BASED COOLING SYSTEM TO ENHANCE ENERGY EFFICIENCY OF FLOATING PHOTOVOLTAIC SYSTEMS" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : MOHAMAD TAUFIQQILAH BIN SUHAIMY

Date : 5 JANUARY 2025

APPROVAL

I approve that this Bachelor Degree Project (PSM) report entitled "DEVELOPMENT A WATER-BASED COOLING SYSTEM TO ENHANCE ENERGY EFFICIENCY OF FLOATING PHOTOVOLTAIC SYSTEMS" is sufficient for submission.

Signature :

Supervisor Name : DR EMY ZAIRAH BINTI AHMAD

Date : 5 JANUARY 2025

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours

Signature :

Supervisor Name : DR EMY ZAIRAH BINTI AHMAD

Date : 5 JANUARY 2025

Signature :

Co-Supervisor Name (if any) :

Date :

DEDICATION

I dedicate this project to the unwavering support of my supervisor, Dr Emy Zairah Binti Ahmad. Their guidance, patience, and expertise were instrumental in shaping this project from concept to completion. I am immensely grateful for her belief in my abilities and her willingness to challenge me to reach my full potential.

This journey wouldn't have been possible without the unwavering love and encouragement of my family. Their constant support, both practical and emotional, fuelled my determination throughout. I extend my heartfelt thanks to my lecturers, whose dedication to teaching ignited my passion for this field. Their knowledge and insights provided the foundation upon which I built this project.

Finally, a deep thank you to my friends. Their camaraderie, understanding, and late-night study sessions made this experience all the more rewarding. This project is a culmination of the collective effort and support of these incredible individuals.

ABSTRACT

This project explores the development of a water-based cooling system to enhance the energy efficiency of floating photovoltaic (FPV) systems, a sustainable solution for urban areas facing land shortages and growing energy demands. Elevated temperatures, a challenge for FPV systems, reduce panel efficiency and energy output. The proposed system integrates polycrystalline silicon solar panels, lightweight heat-resistant pipes, and an Arduino-based real-time monitoring system to optimize water flow and cooling performance.Experimental results revealed a significant reduction in panel temperature by 12.5%, resulting in a 15.3% improvement in energy efficiency compared to non-cooled panels. The cooling system also achieved an 18.7% reduction in water evaporation rates, contributing to environmental conservation. Economic analysis confirmed the system's viability, demonstrating reduced operational costs and a favorable payback period, highlighting its potential for large-scale deployment.This study underscores the effectiveness of water-based cooling in improving FPV system performance, advancing renewable energy technologies, and supporting global sustainability goals through innovative thermal management solutions.

ABSTRAK

Projek ini meneroka pembangunan sistem penyejukan berasaskan air untuk meningkatkan kecekapan tenaga sistem fotovoltaik terapung (FPV), satu penyelesaian berkesan bagi kawasan bandar yang menghadapi kekurangan tanah dan permintaan tenaga yang semakin meningkat. Suhu tinggi, yang menjadi cabaran bagi sistem FPV, mengurangkan kecekapan panel dan pengeluaran tenaga. Sistem yang dicadangkan mengintegrasikan panel solar silikon polikristalin, paip tahan haba yang ringan, dan sistem pemantauan masa nyata berasaskan Arduino untuk mengoptimumkan aliran air dan prestasi penyejukan.Hasil eksperimen menunjukkan pengurangan suhu panel sebanyak 12.5%, menghasilkan peningkatan kecekapan tenaga sebanyak 15.3% berbanding panel tanpa penyejukan. Sistem penyejukan ini juga berjaya mengurangkan kadar penyejatan air sebanyak 18.7%, menyumbang kepada pemeliharaan alam sekitar. Analisis ekonomi mengesahkan kebolehcapaian sistem, dengan kos operasi yang berkurangan dan tempoh pulangan modal yang menguntungkan, menonjolkan potensinya untuk pelaksanaan berskala besar.Kajian ini menekankan keberkesanan penyejukan berasaskan air dalam meningkatkan prestasi sistem FPV, memajukan teknologi tenaga boleh diperbaharui, dan menyokong matlamat kemampanan global melalui penyelesaian pengurusan haba yang inovatif.

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I would like to express my sincere gratitude to all those who have supported me throughout this journey and helped make this bachelor's degree project a success.

First and foremost, I am deeply indebted to my supervisor, Dr Emy Zairah Binti Ahmad. Her invaluable guidance, expertise, and unwavering support played a pivotal role in shaping this project from its inception to its final form. I am grateful for her belief in my abilities and their encouragement to push myself further.

I would also like to extend my heartfelt thanks to my family. Their constant love, encouragement, and unwavering support provided me with the strength and motivation to persevere.

My sincere gratitude goes out to my lecturers as well. Their dedication to teaching and their insightful knowledge provided the foundation upon which I built this project.

Finally, I am incredibly grateful to my friends. Their camaraderie, understanding, and late-night study sessions made this experience all the more enjoyable. Their support and encouragement fuelled my determination throughout this endeavour. This project would not have been possible without the collective effort and support of these remarkable individuals. Thank you all.

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LIST OF SYMBOLS

Voc	-	Voltage open ciruit
Vmp	-	Maximum operating voltage
Isc	-	Current short circuit
FF	-	Fill factor
Vm	-	Voltage maximum
Im	-	Current maximum
Pm	-	Power maximum
	-	

LIST OF ABBREVIATIONS

V	-	Voltage
PV	-	photovoltaic
PCM	-	Phase change material
FPV	-	Floating photovoltaic
SDG	-	Sustainable development goal
NOCT	-	Nominal Operating Cell Temperature
STC	-	Standard Test Conditions
SOC	-	Standard operating conditions

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The increasing demand for energy due to population growth and the depletion of fossil fuels forces the concept of sustainable development into question. Natural energy sources such as solar radiation, biomass, wind, and hydropower are crucial for the advancement of sustainable development. Solar energy is a viable and affordable alternative to fossil fuels that could help the world meet its expanding energy needs. Solar thermal energy and solar photovoltaic (PV) panels are the two types of solar energy. A solar photovoltaic (PV) cell is an electronic device that directly converts sunlight into electrical energy [1]. The original generation of PV cells, which are currently the most widely used form, were made of silicon-based materials because of their high efficiency and long lifespan [2]. Nevertheless, solar thermal conversion yields a greater output; on the other hand, solar photovoltaic (PV) conversions are becoming more and more common due to features like direct heat exchange technology and low moving parts count.

However, because utility-scale solar systems must be installed over huge areas, there may be problems with other sectors, like agriculture, due to this potentially serious land usage issue. Floating photovoltaics (FPV) can be used to solve this issue. PV modules are installed in this manner on water surfaces, including lakes or hydropower basins.

A major factor for the development of floating photovoltaic (FPV) systems has been the growing demand for renewable energy. Because these systems make use of underutilised water bodies, they save important land resources and offer a major advantage over typical land-based installations. Additionally, because of things like better panel reflectivity and colder surrounding air, their placement near bodies of water may result in higher energy yields. The setting does provide one obstacle, though it is close to water. The surrounding water mass may have a cooling effect, but it may also raise the PV panels' working temperatures. The performance and lifespan of solar panels are negatively impacted by high temperatures, making this a crucial concern.

Although misting devices and air-based fans work well for cooling down land-based solar farms, they pose problems for floating photovoltaic installations. First off, the presence of water around the area makes it more humid, which could lessen the efficiency of misting devices. Furthermore, fans may not have the strength to withstand the unique wind patterns that are seen over bodies of water. These drawbacks emphasise the need for a more creative strategy. Conventional techniques may also add additional layers of complexity to floating systems. Other worries include maintaining a steady supply of water for misting and the possible environmental effects of water droplets leaking into the nearby body of water. Thus, a cooling plan created especially for the special conditions of floating photovoltaic systems is essential.

The secret to realising floating photovoltaic systems' full potential is water. Compared to air, it is a significantly better cooling medium due to its natural qualities. Because water has a much higher heat capacity than other materials, it can absorb more heat before becoming hotter. Furthermore, water can effectively transmit this absorbed heat away from the solar panels, keeping the working temperature lower, thanks to its greater thermal conductivity. This directly correlates into increased PV system energy production.

This water-based cooling technology solves the thermal issues floating solar panels experience in a more straightforward, effective, and accessible way by taking advantage of the water body the system floats on.

The ability of the suggested water-based cooling system to find a balance between sustainability and efficacy is crucial. The integration of real-time temperature monitoring and control systems allows for the dynamic adjustment of water flow to precisely suit the cooling requirements of photovoltaic panels. By doing this, you may minimise water consumption and maximise energy output from the panels by maintaining them at the ideal operating temperature. In addition to immediately enhancing the project's economic feasibility, this emphasis on efficiency and conscientious water management also helps to reduce the floating PV system's environmental impact. In the end, this study may open the door for floating solar energy to be widely used as a dependable, affordable, and ecologically friendly form of renewable energy.

1.2 Problem Statement

For cities that are facing a lack of land and an increasing demand for electricity, floating solar presents an appealing option. Nevertheless, a hidden challenge brought about by being close to bodies of water is that their high working temperatures reduce efficiency. In order to tackle this problem, this study suggests a water-based cooling system that is both economical and environmentally friendly. This invention allows for floating Solar full potential in cities by guaranteeing the ideal panel temperature for optimum power generation. This encourages a move away from fossil fuels in urban areas, which is directly in line with Sustainable Development Goal 11 for sustainable communities. Achieving this crucial SDG objective is greatly aided by the cleaner air, better public health, and smaller environmental impact that follow.

1.3 Project Objective

This project's primary goal is to provide a methodical and practical approach for estimating system cooling in order to improve the energy efficiency of floating photovoltaic systems. Its aims are as follows:

a) To designs and implemented techniques for cooling that minimise temperature related losses in solar panel efficiency and guarantee maximum energy production.

b) To develop a control system that optimizes water flow in the cooling system based on real-time monitoring of photovoltaic panel temperature.

c) To analyse the energy efficiency of floating photovoltaic (PV) systems through the design and development of water-based cooling solutions.

1.4 Scope of Project

d) The scope of this project are as follows:

a) Lakes and ponds are the perfect places for these floating solar systems with water-based cooling. This peace of mind guarantees the system's safe floating while optimising solar exposure for maximum energy production.

b) As there is only one panel being used, efficiency must be maximised. The most suitable solar panels are polycrystalline silicon 20 watt maximum power , which makes them ideal for our experiment. They are also perfect for this project because of their resilience in aquatic situations, which makes them suitable for floating installations.

c) Floating PV arrays and water-based cooling systems can work together harmoniously if lightweight and heat-resistant pipes are included in the panel. To ensure even peak and cooling panel performance, these pipes will be positioned to maximize heat transfer.

d) Temperature data will be directly transmitted to the control system via sensors placed on top of the floating PV. To keep the panels at the optimal temperature for maximum efficiency while using the least amount of water, this intelligent system will evaluate the data and modify the cooling water flow rate in real time.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on cooling techniques for PV projects offers a valuable analysis of the current research landscape, exploring various theories and methodologies employed to enhance solar panel efficiency. This review aims to synthesize existing scholarship, identify knowledge gaps, and highlight promising areas for future investigation. By examining a range of scholarly works on cooling strategies, this review seeks to establish a foundation for understanding the complexities and nuances of maintaining optimal temperatures in PV systems. Through an exploration of key themes, theoretical frameworks, and empirical findings on cooling techniques, this review strives to contribute to the ongoing dialogue surrounding methods to maximize the energy output of solar PV projects.

Driven by the urgent need for clean energy, solar PV technology has become a leading renewable energy solution. However, a hidden culprit lurks within these seemingly efficient systems – rising temperatures. Similar to athletes performing better in cooler conditions, solar panels experience a significant drop in efficiency as they heat up. This literature review delves into the world of cooling techniques for PV projects, a crucial area for maximizing their energy output.

The core issue lies in the negative correlation between temperature and solar cell efficiency. As temperatures increase, the internal resistance of solar cells rises, hindering their ability to convert sunlight into electricity. This translates to a noticeable decrease in power generation, impacting the overall energy output of the PV system.

2.2 Background study

The field of cooling methods for floating photovoltaic (FPV) solar systems is explored in this overview of the literature. It seeks to synthesise current information on different cooling techniques, their efficiency in increasing energy production, and their limits by a thorough analysis of the literature. Through the identification of potential obstacles and information gaps, this assessment aims to provide guidance for future research and development endeavours. The ultimate objective is to maximise the potential of PV systems as a cost-effective and sustainable source of renewable energy by optimising cooling solutions.

2.3 Floating Photovoltaic

The field of renewable energy is being revolutionised by a developing technology known as floating photovoltaic (FPV) solar, or floating solar for short. In contrast to conventional land-based solar farms that vie for valuable real estate, floating photovoltaic (FPV) systems are made up of solar panels affixed to buildings floating across reservoirs, lakes, canals, or even abandoned industrial ponds. By optimising land utilisation, this creative method provides a convincing answer to the growing need for renewable energy.

FPV systems have a variety of possible advantages. First of all, the lower water temperatures serve as a natural cooling for the solar panels, increasing power production and improving efficiency. Second, FPV systems may greatly lower evaporation rates by darkening the water's surface, encouraging water conservation in areas where water is scarce. Furthermore, FPV provides multifunctionality. By co-locating these systems with the current water infrastructure, land usage may be minimised and transmission losses may be decreased.

On the other hand, FPV technology is still in its infancy. There is continuous research to guarantee structural integrity and endure severe weather by optimising design, materials, and mooring systems. Additional research is required to determine how FPV systems affect aquatic ecosystems in the environment. Finally, for widespread acceptance, economic viability is essential. For FPV projects to be successful in the future, cost-effectiveness, return on investment, and possible government incentives must be examined.

2.4 Degradation Factors of Photovoltaic Module

The quality of the PV module and the environment in which it is installed determine how long it will last. Failure types and deterioration significantly impact the PV system's performance, and its assessing both interior and outside environments is crucial for creating the prediction model. The diverse PV system failure types caused by various environmental conditions are described in the next section.

Because of ageing, all PV panels experience degradation phenomena. Due to the breakdown of the module's primary solar cell, this causes the PV systems to lose power over time and the power level to drop overall. Failure modes are the unique situations that these panels go through throughout degradation. The deterioration rate (D) is given by the following equation as;

$$D = \frac{No - Ni}{N} \quad [1]$$

2.4.1 Temperature-Related Degradation Factor

Because it is directly dependent on operational temperature, ambient temperature is a critical factor in determining the output power and efficiency of the PV module in PV systems. Approximately 6–20% of the insolation incident on the PV panel's surface is converted, depending on the kind of cell used in the solar module. The PV panel's efficiency decreases when the ambient temperature rises because it raises the panel's temperature. The climate variables, such as atmospheric panel's temperature is greatly influenced by temperature, wind direction, wind speed, and cloud cover, but the pace at which the kind of PV material utilised and the installation method for the PV panel determine temperature variations. The PV system's overall power output is decreased when the panel's temperature rises since the module's voltage output decreases and its current slightly increases. According to (Elibol et al) An increase of 1 °C ambient air temperature increased the efficiency of amorphous crystalline panels by 0.029%, polycrystalline panels by 0.033% and decreased the productivity of monocrystalline panels by 0.084%[24]. The impact of temperature on the PV cell/module is related to the fundamental equation as ;

$$Pm = Vm\,Im = FF\ X\ Voc\,Isc \qquad [2]$$

When temperature increases, both the Voc and FF reduces with slight increase in Isc which results in a linear relation for cell's electrical efficiency The exposure of solar panels in the open atmosphere causes an increase in module temperature, and it is necessary to find the expected operating temperature of the PV module to figure out the output power of the solar cell. The NOCT which is the temperature attained by the PV module with no-load connected and operating in NTE .Solar flux on the cell surface: 800 W/m2 , Air temperature: 293.16 K (20 °C), Average wind speed: 1 m/s, Mounting: Open back side and tilted to solar noon The approximate expression to find out the operating temperature of the PV module for irradiance, GT (W/m2) is given by [25].

$$T_c = [T_a + (\frac{NOCT-20}{800}) \times G_T] \qquad [3]$$

The performance and efficiency of the solar cell is greatly impacted by the operating temperature. A rise in cell temperature causes the panel's performance to deteriorate, which lowers the module's efficacy. The several methods to increase efficiency by reducing the operating temperature are covered in the mitigation section.

2.4.2 Humidity Related Degradation Factor

The suspended the humidity particles that are present in the atmosphere have a significant impact on how humidity affects PV performance. Extended periods of humidity exposure for photovoltaic panels can lead to moisture infiltration and encapsulant delamination. [26] experimental research examined how a humid atmosphere affects photovoltaic cell breakdown. As the experiment's length increased, the moisture within the photovoltaic cell harmed the adhesive connections between the layers, leading to delamination and an increased entrance channel, which ultimately resulted in passivation loss. According to the investigation, the maximum output power severely degraded when the short circuit current significantly decreased more than the open circuit voltage.

While researching the effects of relative humidity on the efficiency of the panel, [27] discovered that the type of panel utilised also had an impact on the PV performance. The scientists analysed the performance of monocrystalline and amorphous photovoltaic systems and looked at the effect of relative humidity. According to the study, temperature and relative humidity have a greater impact on amorphous PV panels than on monocrystalline PV modules. This drop in efficiency showed how resistant the monocrystalline PV panels are to weather-related variables like temperature and relative humidity. Due to the water droplets in the atmosphere reflecting, diffraction, and refracting the incoming solar radiation, humidity also affected the amount of irradiance. [28] examined how the intensity of solar radiation changed with humidity in order to find out how effective a photovoltaic module would be in the humid climate of the tropical Sudan Savannah. The authors observed a linear variation in short-circuit current and a non-linear variance in open circuit voltage with radiation exposure. Because of the strong wind speed in the region, the module temperature dropped, making up for the reduced level of illumination with more humidity.

2.5 Photovoltaic Cooling Techniques

The main goal of every installed photovoltaic project is to maximise the PV plant's total output capacity while optimising performance to obtain an optimal return on investment.

Accordingly, taking into account the efficiency of each panel is necessary to enhance the overall performance of a photovoltaic system. The temperature of the working PV cell or panel rises as the ambient temperature rises, reducing the efficiency of the PV panel. As a result, concerned scientists and researchers are developing a number of solutions to reduce the operating temperature of overheated photovoltaic panels in order to increase their efficiency.

The literature describes about three different PV cooling processes/techniques, which can be classified (Figure 2-1) into [2,3]:

1. The passive cooling process: this is a natural cooling process that doesn't require the use of electromechanical cooling systems.
2. The active cooling process: forced cooling method in which the PV temperature must be lowered by using external energy to power electro-mechanical equipment.
3. The combined (passive + active) cooling process: applies the forces of forced and natural cooling processes to optimise PV performance.

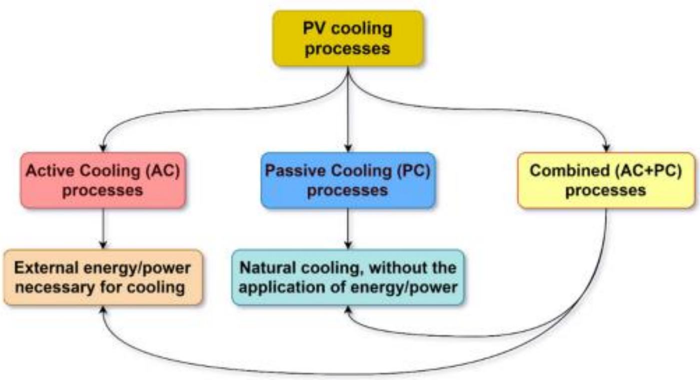


Figure 2.1 Classification of PV cooling processes

Table 2.1 Pros and cons of active, passive, and combined cooling system

Active Cooling (AC)	Passive Cooling (PC)	Combined Cooling (AC+PC)
Forced cooling process	Natural cooling process	Partially natural and forced
External energy necessary to run the fan or pump	No power input is necessary	External energy necessary to run the fan or pump
Structurally complex	Structurally simple	Structurally and technically complex
Higher investment, operating, and maintenance costs.	Comparatively lower investment, operating, and maintenance costs.	Higher investment, operating, and maintenance costs
Temperature reduction is higher compared to passive cooling	Comparatively lower temperature reduction	Highest temperature reduction
Relatively high energy output	Comparatively lower energy output	Overall energy output is higher
Better PV panel efficiency compared to passive cooling	Comparatively moderate PV panel efficiency	Overall panel efficiency is higher
May not be cost-efficient due to high energy consumption	Lower project cost	Cost-effective when compared with active cooling

2.5.1 Active Cooling

The auxiliary cooling systems in the active cooling process require external energy to operate. The two main active cooling methods discussed in the literature are active air-cooling systems and active water-cooling systems. They are characterised as a forced-cooling procedure and the external energy required to run fans, pumps, and other cooling equipment.

2.5.1.1 Active Water-Cooling Systems

Three water-spraying nozzles were positioned on top of the PV panel by the authors in Figure 2.2, which illustrates an active cooling design [11]. When the system was misted with water using an on-off mode mechanism (30 seconds on and 180 seconds off), a temperature reduction of up to 24 °C was recorded as a result of the cooling process, and an efficiency increase of around 2% was noted.

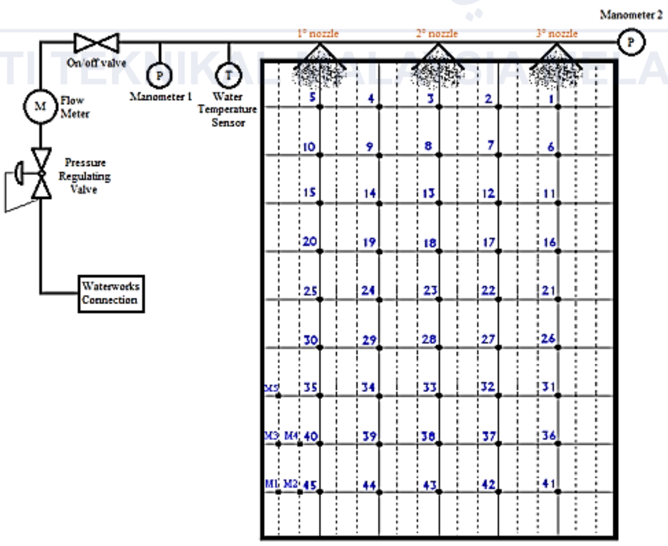


Figure 2.2 A water-spraying nozzles [11]

The performance of a photovoltaic panel with water sprinklers mounted at the rear was examined by Zilli et al. [12] (Figure 2.3). The writers employed a submerged running pipe to bring the coolant's temperature down to a minimum. The sprinklers had a 1.3 L/min flow restriction and were manually operated. Depending on the available irradiance, they observed an improvement in efficiency between 9.09% and 12.17% and a power production between 8.48% and 12.26%.

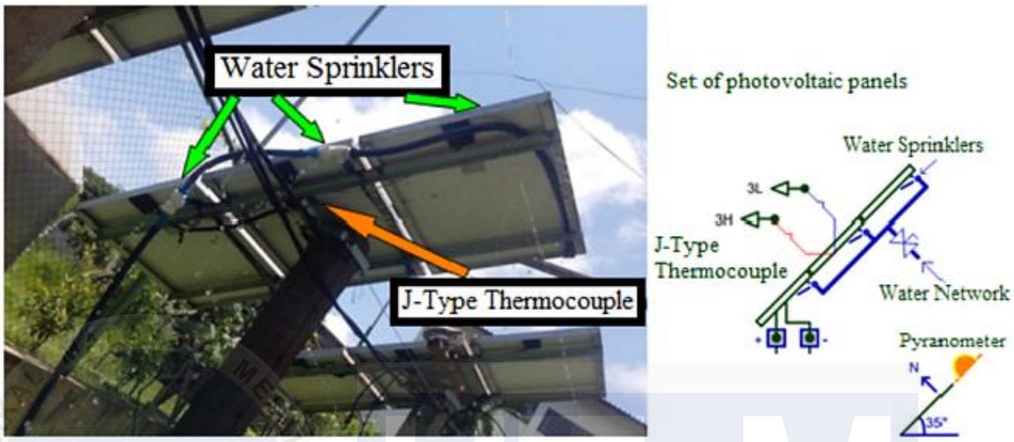


Figure 2.3 A photovoltaic panel with mounted water sprinklers [12]

Using water spraying and running on the appropriate surfaces, Sargunanathan et al. [14] implemented active rear and front cooling (Figure 2.4). In comparison to the reference PV panel, there was an increase in power generation and efficiency of 10.70 W and 8.78% for the rear cooling, 18.48 W and 15.28% for the front cooling, and 20.56 W and 16.90% for the back + front cooling. Comparing the actual temperature to the reference panel, a decrease of 15.52 °C on average and 18.60 °C maximum for back cooling, 24.29 °C on average and 28.70 °C maximum for front cooling, and 15.52 °C on average and 18.6 °C maximum for back + front cooling was noted.

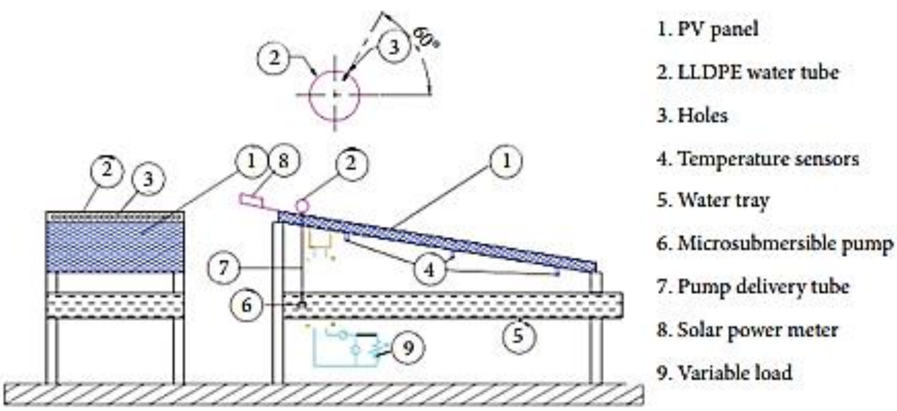


Figure 2.4 An active rear and front water cooling [14]

Two PV/T systems were implemented, and Sathyamurthy et al. [15] examined their performances. One uses water, and the other uses CNT/Al2O3 hybrid nanoparticles (Figure 2.5) as coolant materials to lower the working temperature of the PV cells. The authors reported that a spiral collector was used to achieve a better rate of heat transfer. The systems' electrical efficiency is improved by the application of both water and nanoparticles; the nano-fluid proved to be the better performer as a coolant, and the overall efficiency improvement is equal to 27.3% when compared to the water-based system.

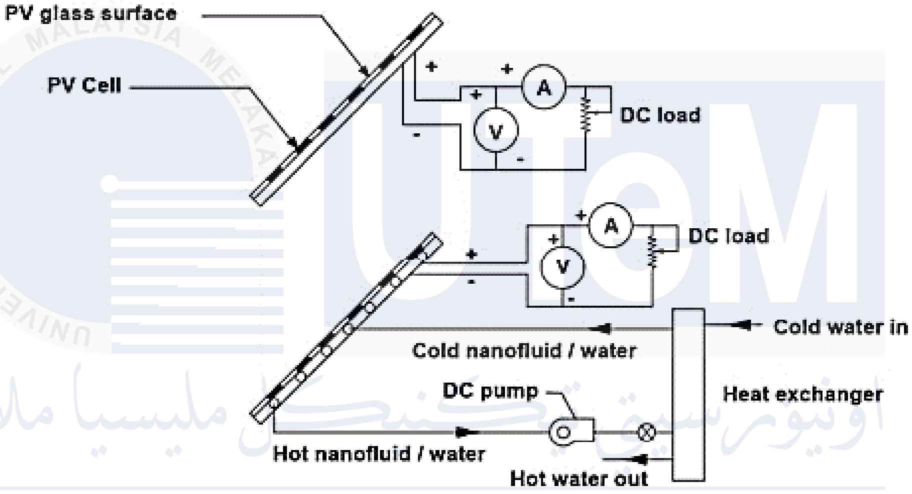


Figure 2.5 Standalone PV cooling with thermal and without thermal collector [15]

2.5.1.2 Active Air-Cooling Systems

The air is actively directed towards the PV system in this plan. Interestingly, these systems operate at a far greater level than natural cooling systems. Researchers have demonstrated a number of design ideas regarding air flow patterns in addition to front glazing in order to maximise the efficiency of PV modules.

Using air as a coolant, Choi [13] built a novel PV/T system with a non-uniform transverse rib and a single-pass double flow channel (Figure 2.6). When air mass flow was increased, this system's thermal and electrical efficiencies increased from 35.2–56.72% and 14.23–14.81%, respectively.

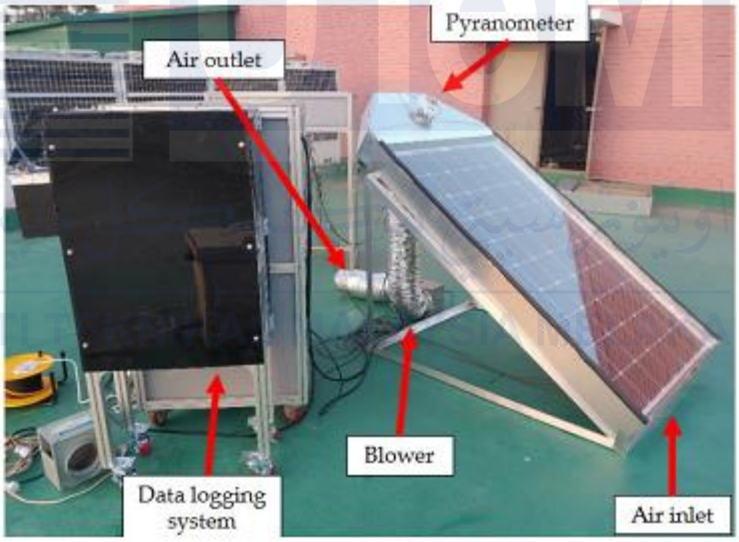


Figure 2.6 An active air-based cooling system [13]

2.5.2 Passive Cooling

One way to describe the passive cooling process is the removal or decrease of heat from a system without the need of any outside energy sources or mechanisms. In this instance, convection and/or conduction from natural sources provide the cooling. passive cooling is a somewhat inexpensive technology [4].

On the other hand, the passive cooling method may be separated into:

1. Passive cooling with air.
2. Passive cooling with water.
3. Phase-changing material and heat pipes for conduction cooling

2.5.2.1 Passive Cooling with Air Circulation

The convective action of natural air lowers the temperature of the PV panels throughout this operation. In order to reduce the PV temperature, Mazón-Hernández et al. [5] employed natural air-cooling systems. The redesigned PV panel in Figure 8 is arranged with an air channel beneath it. The authors have claimed that increased air cooling can result in a 7.5% increase in power. There are several drawbacks to this cooling method, such as inconsistent or uneven natural airflow availability, which prevents the anticipated efficiency boost.

Figure 2.7 PV panel with air cooling and without air cooling [5]

2.5.2.2 Passive Cooling with Water

The PV panels are often placed above or on water and submerged in water during this cooling procedure. On the other hand, the natural convection cooling mechanism in the first scenario causes the panels' temperature to drop. On the other hand, heat transfer with water causes the temperature to drop in the second and third scenarios. Rosa-Clot, M. placed PV panels in a pond at two distinct depths 4 cm and 40 cm to evaluate the panels' efficiency. At a depth of 4 cm, the panel's efficiency improved by 11%, according to the authors, but at 40 cm, the improvement was not statistically significant [6].

Water and liquid refrigerants such as nano-fluids [7] such as Boehmite, aluminium oxide (Al2O3), zinc oxide (ZnO), titanium oxide (TiO2), magnetite (Fe3O4), silicon carbide (SiC), and copper oxide (CuO) are the two main coolants used in liquid-based photovoltaic cooling. These coolants lower the working temperature of the PV system.

Using the evaporative cooling approach, Haidar et al. [8] affixed a piece of cloth to the back of the PV panel, submerged it in water continually, and provided it with a manually operated rubber tube. Over 20% less electrical power has been used throughout this cooling procedure, with a maximum increase of 14%.

Notably, since no power is required, passive water cooling is an inexpensive and natural approach. It costs more than a land-based plant would, and because of its close exposure to water, its equipment may deteriorate more quickly.

2.5.2.3 Phase-Changing Material and Heat Pipes for Conduction Cooling

Only one thermosyphon copper HP was utilised by Kaneesamkandi et al. [9] to lower the PV temperature using the PV/HP cooling approach. Acetone is the working fluid that's utilised to fill the HP tube. The authors describe reaching the maximum operating temperature decrease of 10 °C for PV panels, however they do not present any data about the improvement in PV electrical efficiency.

The performance of a PV-PCM system with passive cooling and organic paraffin (RT-35HC) employed as PCM at the rear of the panel under observation was reported by Hassan A et al. [10] (Figure 2.8). Temperature drops and efficiency increases of 11.9 °C and 9.1%, respectively, were recorded throughout the cooling process

Figure 2.8 PV module without phase change material (PCM)[9]

Figure 2.9 PV modules with phase change material (PCM)[9]

2.6 Combined Cooling (active cooling + passive cooling)

Significant progress has already been made in integrating passive and active cooling methods to improve thermal management system efficiency, according to recent study. Here, we go over three important studies in further detail, Radiative and Convective Cooling, PCM and Heat Sink Integration, and Hybrid Liquid and Air Systems. In order to emphasise the advancements and improvements, we also compare these most current results with earlier studies.

2.6.1 Hybrid Liquid and Air Systems

Yadav and Bajpai (2018) looked into a hybrid cooling system that mixes air and water cooling in a recent study. Particularly in hot weather, this system's electricity efficiency significantly increased. Together, they enable water cooling to efficiently address key component temperatures, with air cooling handling any leftover heat. As a result, system performance is constant [16].

This strategy overcomes the shortcomings of earlier studies, which frequently concentrated on a single cooling technique. Even while water cooling is effective, leaks and upkeep can cause problems. Conversely, air cooling becomes less effective as temperatures rise. Yadav and Bajpai's hybrid system provide a more reliable solution for electricity efficiency and thermal control by integrating both approaches.

2.6.2 PCM and Heat Sink Integration

A recent study by Memon et al. (2020) investigated a promising approach for thermal management by combining phase change materials (PCMs) with aluminium heat sinks. This integration capitalizes on the strengths of both materials. PCMs absorb and store excess heat during their phase change, preventing rapid temperature spikes. Aluminium heat sinks, with their excellent thermal conductivity, efficiently dissipate this stored heat. This synergistic effect allows the combined system to maintain lower temperatures for extended periods [17].

Previously, research on PCMs focused on their standalone use for thermal storage. While PCMs demonstrated potential for regulating temperature fluctuations, they faced limitations in heat dissipation. Aluminium heat sinks, on the other hand, were widely used for their high thermal conductivity, but lacked the ability to handle large heat loads over extended durations. Memon et al.'s approach bridges this gap by combining these materials, resulting in a system with superior and sustained thermal regulation capabilities.

2.6.3 Radiative and Convective Cooling

Researchers investigated a novel cooling system design that blends forced convection and radiative cooling materials in a recent research . This two-pronged strategy increases cooling effectiveness, particularly at night when radiative cooling is most effective. While forced convection aggressively removes heat by employing airflow, these materials passively release heat by generating infrared radiation [18].

This invention overcomes the drawbacks of earlier cooling methods. Conventional techniques frequently just used convection or radiation. The dependency of radiative cooling on the day/night cycle and surrounding variables was a problem. Conversely, convective cooling needed continuous energy input to keep the airflow going. The concept by Li et al. combines two techniques, taking use of their complimentary advantages to provide more reliable and efficient cooling all day long.

2.7 Floating PV cooling procedures and evaporation reduction evaluation

Lakes, reservoirs, and ponds are among the water features where floating photovoltaic (FPV) systems are placed. The cooling effect of FPV systems leads to increased efficiency when compared to conventional ground-mounted PV systems, which is one of its main advantages. The closeness to water, which typically has a lower temperature than the air, is thought to be the cause of the cooling, which lowers the solar panels' operational temperature.

In comparison to land-based panels, research by Choi et al. indicated that water keeps FPV panels 5–10°C cooler. This results in slower panel deterioration and up to 15% higher power output. By keeping the water colder and shaded, FPV systems can dramatically reduce water evaporation by up to 70%, according to another research like Spencer et al. (2018). This is particularly useful in arid regions. These results were corroborated by Trapani and Santafé (2015), who demonstrated the double advantage of FPV systems. The panels are cooled by the shade, which also reduces water evaporation, making them an excellent choice for drought-affected areas. These studies, in summary, demonstrate that floating solar panels are a wise way to increase the generation of clean energy while also protecting priceless water resources [19][20][21].

2.7.1 PV Mounted on Floats and PV on Water but Not Float

Although both studies find that FPV systems perform better on water than stationary structures, they look at distinct factors. Cazzaniga et al. (2019) concentrate on performance advantages, emphasising a 5–10% increase in efficiency for FPV because of water cooling something that permanent structures do not have [22]. In contrast to the more durable construction and maintenance issues experienced by stationary structures in variable water conditions, Liu et al. (2020) highlight the ease of installation and maintenance for FPV systems due to its modular architecture and flexibility to respond to water levels [23].

2.8 Comparisons of previous work

Table 2.2 Literature review of various research studies related to floating PV cooling method

Reference	Years	Title	Author	Type of cooling method	Main finding
[31]	2023	Design and analysis of passively cooled floating photovoltaic systems	Bayu Sutanto a,b,* , Hector Iacovides a , Adel Nasser a , Andrea Cioncolini c , Imran Afgan d,a ,Yuli Setyo Indartono e,f	Passive cooling with water	significant increase in electrical efficiency (17.84%) can be achieved compared to the base design without cooling.

[32]	2023	Floating Photovoltaic Performance Evaluation Using Novel Cooling System: Case Study	Marwan M. Amin , Idrees S. Kocher	Active cooling with water	that the novel water cooling design effectively mitigates the adverse effects of high temperatures on floating PV cells, making it a promising solution to enhance the output of solar panels.
[33]	2019	Active cooling techniques for photovoltaic systems: A comprehensive review	S. Nizetic, D. Coko, A. Yadav, and F. Grubišić-Čab	S. Nizetic, D. Coko, A. Yadav, and F. Grubišić-Čab)	active cooling techniques for photovoltaic systems, including water-based cooling, air-based cooling, and phase change material (PCM) based cooling, highlighting their effectiveness in improving system efficiency.
[34]	2023	Economic comparison of floating photovoltaic systems with tracking systems and active cooling in a Mediterranean water basin	Giuseppe Marco Tina a,* , Fausto Bontempo Scavo a , Leonardo Micheli b , Marco Rosa-Clot c,1	Active cooling with water	fact, as compared to the reference GPV system, a 30% reduction in FPV CAPEX leads to almost a 20% decrease in LCOE.benefits like increased cooling and potential revenue from reduced evaporations
[35]	2019	Exergo-economic analysis of a serpentine flow type water based photovoltaic thermal system with phase change	Taher Maatallaha , Richu Zachariahb,⁎ , Fahad Gallab Al-Amria	PVT-PCM/water system	PVT-PCM/water systems hold promise for improved energy production and faster returns on investment compared to traditional PV panels.

		material (PVT-PCM/water)			
[36]		Exergy and economic analysis of a photovoltaic panel cooling with air bubble induced water jacket	H.S. Arunkumar, N.M. Hitesh, N. Madhwesh, Avinash K. Hegde, K. Vasudeva Karanth *	Passive cooling with water	A 15.36% decrease in the maximum panel temperature compared to other cooling methods.
[37]	2021	Investigating the efficiency improvement of floating PV systems through active cooling: A review	Choi, Y., Lee, Y., & Kim, D.	Water-based cooling	investigates the potential efficiency improvements in floating PV systems via active cooling techniques, showing significant performance gains and suggesting optimal configurations for different environments.
[38]	2022	Active cooling methods for floating photovoltaic modules: Current status and future prospects	M. Abdolzadeh and M. Ameri,	Water-based cooling, air-based cooling	This paper reviews the current status and future prospects of active cooling methods for floating photovoltaic modules. It evaluates various active cooling techniques such as water-based cooling, air-based cooling, and nanofluid-based cooling in terms of their effectiveness and feasibility.
[39]	2023	Performance analysis of active cooling techniques for floating solar panels	A. Kumar and A. Sahai	Water spraying, water circulation	performance of active cooling techniques for floating solar panels. It compares the effectiveness of

					various active cooling methods such as water spraying, water circulation, and phase change material (PCM) based cooling in terms of energy yield enhancement.
[40]	2020	Enhancing the performance of floating photovoltaic systems using active cooling methods	N. Rajasekar, V. Kishore, and V. Yuvaraj,	Water spraying, water circulation, heat pipes.	his review emphasizes the importance of active cooling methods in improving the performance of floating photovoltaic systems. It discusses various active cooling techniques such as water spraying, water circulation, and heat pipes, and their impact on system efficiency.

2.9 Summary

This review article primarily covers the justifications for the efficiency enhancement and decrease of water evaporation due to placing PV systems on the water bodies. It also discusses various PV and FPV cooling methods, as well as the usage and advantages of FPV plants. As a result, FPV installation methods might lessen the two primary problems the globe is now facing: water and energy poverty.

The total efficiency of a PV system is influenced by the operating temperature of each individual PV panel. Therefore, to improve the efficiency of the PV panel and the system as a whole, active, passive, or mixed cooling methods can assist lower the panel working temperature.

The literature lists several methods for PV cooling; however, the most common methods are either passive or active cooling processes. In certain instances, a combination strategy passive or active has also been employed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology chapter provides an overview of the methods, processes, and selected strategy used in a research project. It begins by outlining the research plan and the theoretical foundations that will guide the investigation. Important elements such flowcharts, project status, component specifics and the desing of prototype are also briefly summarised in this overview. All in all, it prepares us for a thorough examination of the methodology's essential components.

3.2 Project Setup

The goal of this project is to increase the energy efficiency of floating photovoltaic (FPV) systems by designing, developing, and testing a water-based cooling system. There will be several crucial phases in this technique. In order to properly analyse water-based cooling strategies for FPV systems, we will first take efficiency, complexity, and water use into account. The best possible heat transfer between the solar panels and the cooling water will then be determined via thermal modelling. Using this data, we will build the cooling system, taking into account the diameter, positioning, and choice of pump to ensure effective heat transmission while using the least amount of water possible.

The FPV system with integrated cooling will then be built as a scaled prototype. Because of its effectiveness and adaptability for usage in wet locations, polycrystalline silicon solar panels will be employed. To optimise heat transport, lightweight, heat-resistant pipes will be integrated into every panel. The FPV panels will also have temperature sensors added in order to track their working temperature in real time.

The sensors' temperature data will be gathered by a control system, which will then calculate the necessary cooling action. This system will manage a device that adjusts the cooling system's water flow rate, including solenoid valves or a variable speed pump. Through controlled studies, the water-based cooling system's efficacy will be assessed. The energy production of the FPV system will be measured in a variety of operational scenarios, both with and without the cooling system engaged. To evaluate the cooling efficiency, temperature data will be gathered and examined. The information will be utilised to ascertain how the cooling system affects the water flow optimisation and energy efficiency of the FPV system.

Ultimately, the control system and design will be improved in light of the experimental findings. In order to evaluate the viability and sustainability of the water-based cooling system for practical uses, economic and environmental evaluations will also be carried out.

3.3 Project Flowchart

This chapter delineates the methodology utilized to devise and execute strategies for cooling photovoltaic (PV) panels, aimed at reducing temperature-induced efficiency losses and optimizing energy output. The project flowchart functions as a visual guide, delineating the chronological phases of the design and implementation process as shown in Figure 3.1.

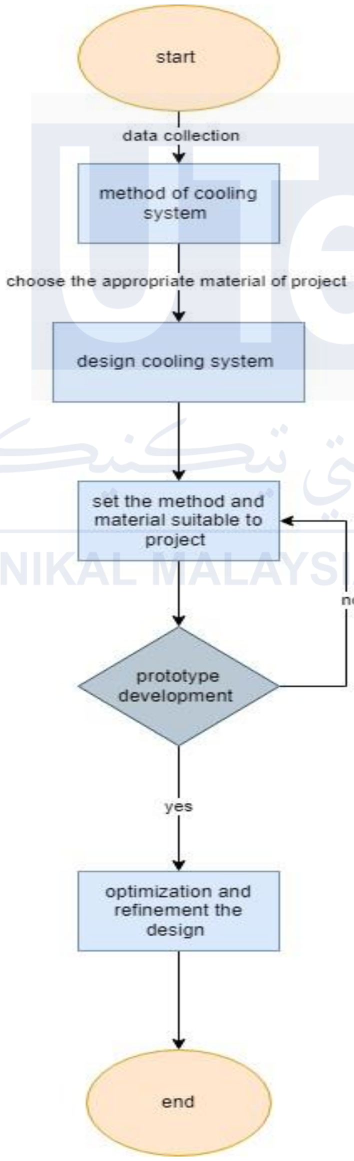


Figure 3.1 Flowchart for Objective 1

Next, the project is focusing on the development of a control system that enhances water flow in the cooling system of photovoltaic (PV) panels, utilizing real-time temperature monitoring. This objective seeks to mitigate temperature-induced losses in photovoltaic efficiency by utilizing temperature sensors and an Arduino-based control system to dynamically manage cooling operations. The system integrates hardware and software components to ensure accurate and efficient cooling, thereby improving energy output and sustaining optimal photovoltaic performance. The flowchart delineates the systematic methodology employed to attain this goal, outlining the phases from component selection and circuit design to testing, integration, and final implementation.

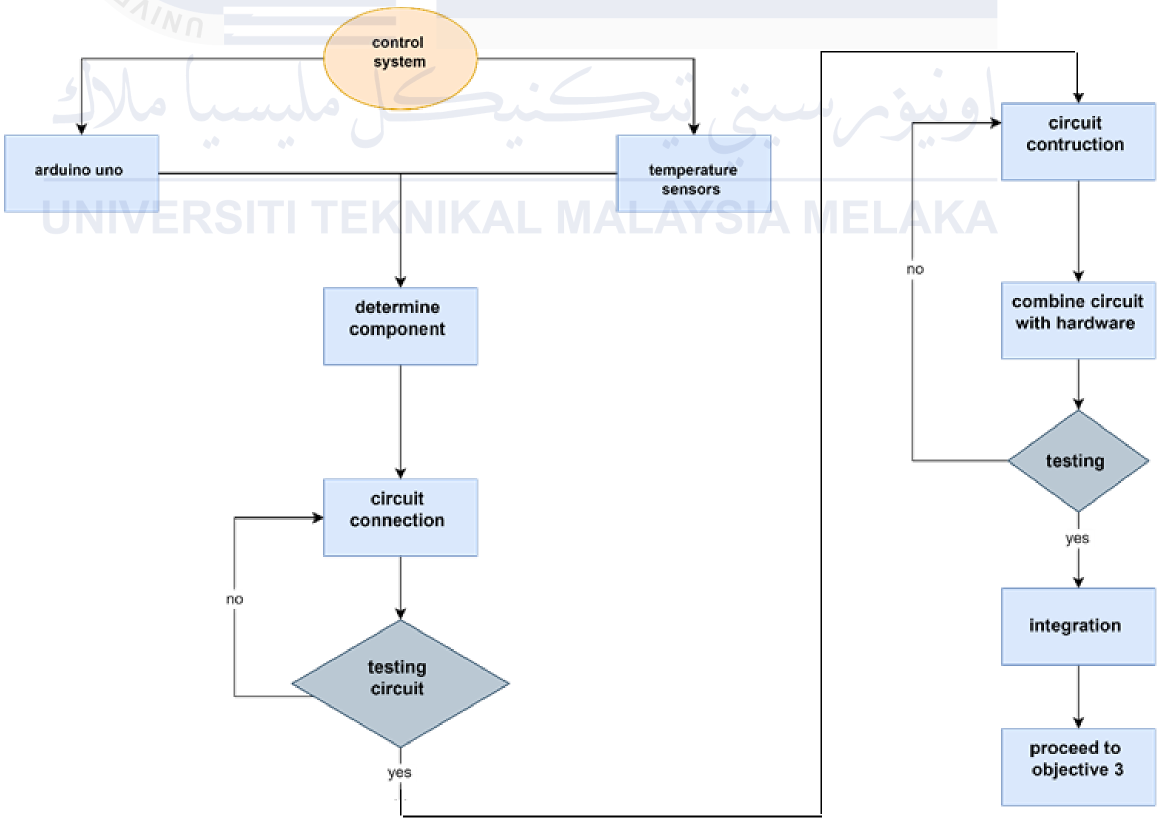


Figure 3.2 Project flowchart for objective 2

Lastly, the aim is to evaluate the energy efficiency of floating photovoltaic (PV) systems by designing and developing a water-based cooling solution. The procedure encompasses baseline data acquisition, the design of the cooling system, and performance assessment via data analysis and efficiency computations. The project evaluates the cost-benefit ramifications and environmental effects of the cooling solution to ascertain its feasibility and sustainability. The methodology culminates in pragmatic recommendations to enhance the performance and energy yield of floating PV systems.

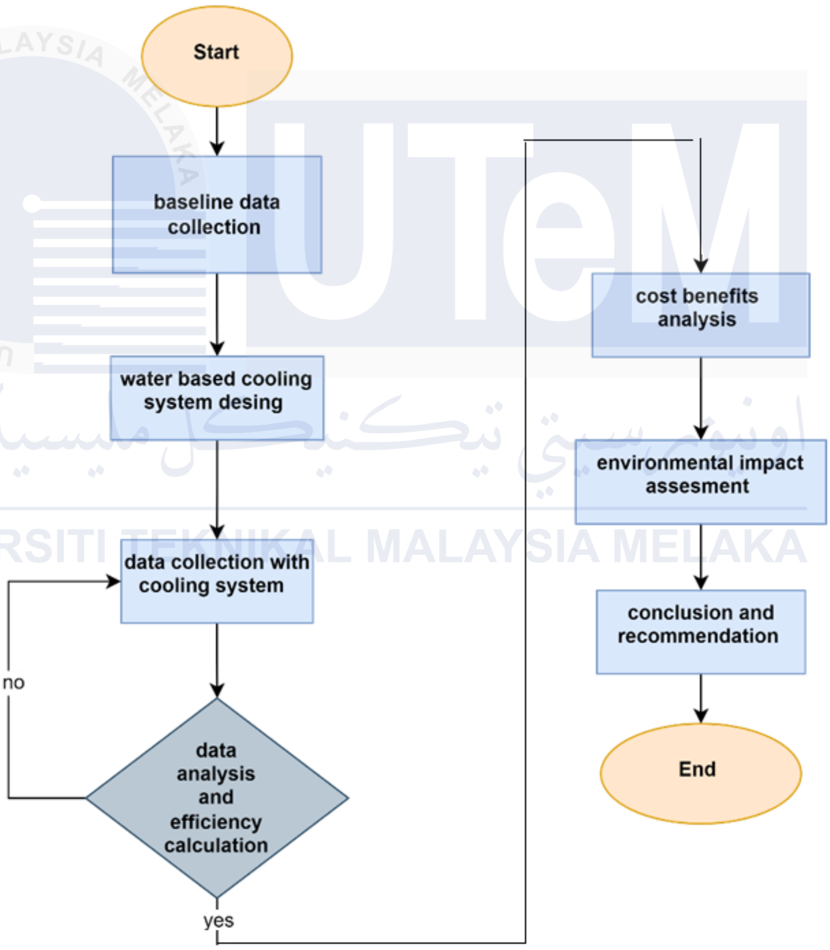


Figure 3.3 Project Flowchart for objective 3

3.3.1 Project Block diagram

The system that monitors and regulates the temperature of floating solar panels is depicted in the diagram. The Arduino Uno microcontroller is utilised by the system to gather information from temperature sensors (DHT 11) and modify the cooling water flow rate via pipes. The cooling water is moved around by a pump. Sunlight is converted into power by photovoltaic panels, yet excessive heat might reduce their efficiency. This technology can aid in increasing the panels' effectiveness by regulating their temperature. The project’s block diagram is illustrated in Figure 3.4.

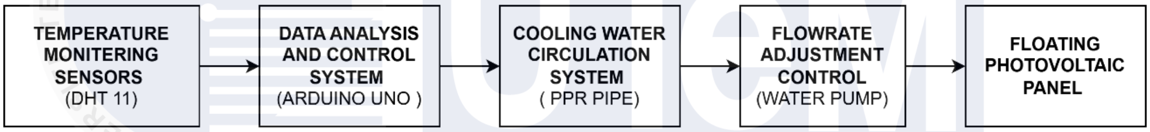


Figure 3.4 Block diagram

3.3.2 The experimental setup

The experimental setup will involve constructing a scaled prototype of a floating photovoltaic (FPV) system. polycrystalline silicon solar panels, known for their efficiency in aquatic environments, will be used along with lightweight, heat-resistant pipes embedded within each panel to maximize heat transfer. Temperature sensors will be strategically placed on the FPV panels for real-time monitoring of their operating temperature.

The chosen water-based cooling technique, whether spray cooling, submerged tubes, or a combination of both, will be integrated into the system. A pump, either variable speed or equipped with solenoid valves for flow control, will circulate the cooling water. A control system will be implemented to collect temperature data from the sensors and regulate the water flow rate based on this information, ensuring optimal cooling performance.

Controlled experiments will be conducted under varying conditions. The FPV system's energy output will be measured with and without the cooling system activated to assess its effectiveness. Temperature data will be continuously collected throughout the experiments to analyse the cooling efficiency and the control system's ability to optimize water flow based on real-time temperature readings. This data will be crucial for evaluating the overall performance of the water-based cooling system design in enhancing the energy output of floating solar panels.

3.3.2.1 Parameters

- **Pipe Placement:** To be optimized during the design phase - This balances efficient heat transfer with minimizing water usage and pressure drop.

- **Water Flow Rate:** To be optimized during experiments - This directly affects cooling efficiency and pump energy consumption.
- **Pipe Material:** Lightweight and heat-resistant (optimizes heat transfer while minimizing weight)
- **Temperature Monitoring:**
    - Sensor Type: DHT 11
    - Number of Sensors: At least one per panel
    - Sensor Placement: Strategically placed on the surface of the solar panels for accurate temperature readings

3.3.2.2 Material and equipment setup

a. Mechanical components selection

No	Equipment	Description
1	Solar panel 	solar panel is a compact and efficient solar energy device designed to generate up to 20 watts of power under standard test conditions
2	PP-R plastic pipe 	Lightweight and heat-resistant pipes suitable to floating solar ,35 mm diameter pipe
3	Long float G-412 white 	For floating structure to float the load floating solar. The length is 280 mm and the width is 100 mm
4	Plastic tray (floating platform) 	Lightweight and durable plastic tray designed as a floating platform, measuring 40 cm in width and 53 cm in length

b. Electrical components selection

- 12 V Sealed Acid Battery
- DHT 11 as a temperature sensor
- Generic DC 12V 800L/H Brushless Motor Submersible Water Pump
- Arduino Uno board
- Breadboard and jumper wires
- Arduino IDE (Integrated Development Environment) for programming the Arduino Uno
- Variable resistor
- Lcd 16x2
- Motor driver l298n
- 20 A Solar Charge Controller

c. Design and Simulation of a Cooling System for Floating Solar Panels Using Tinkercad

By using Tinkercad, an online platform for 3D modelling and electronics simulation, both the mechanical layout and the electrical circuitry for a cooling system designed for floating solar panels were designed. This cooling system typically includes water pumps, sensors, and control circuitry to manage and regulate the temperature of the solar panels.

I. Mechanical design

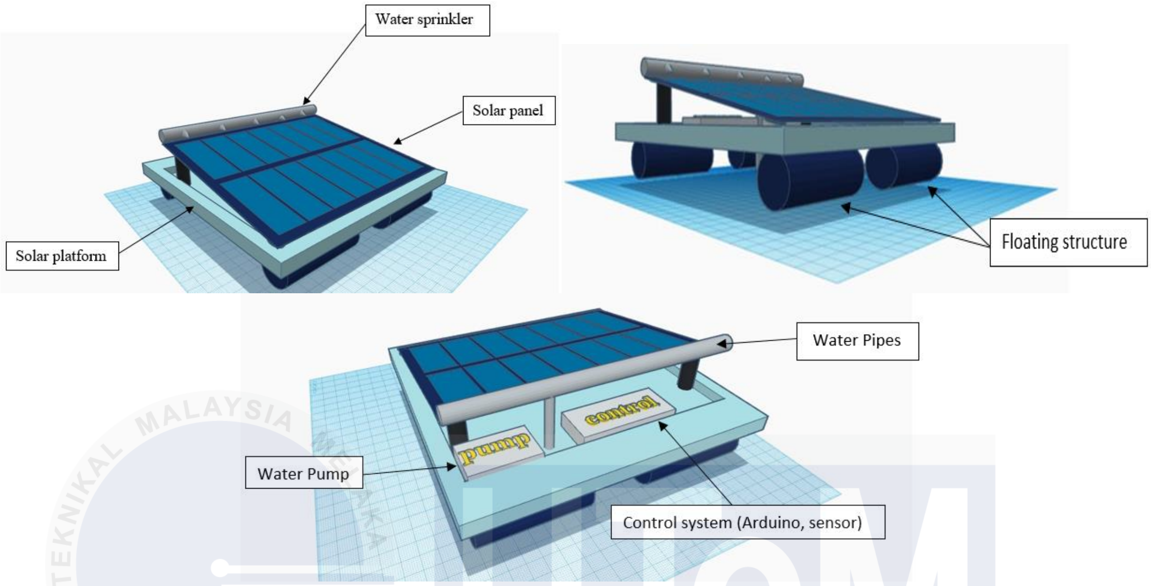


Figure 3.5 3D Design prototype

Figure 3.6 The developed prototype for floating PV with integrated cooling system

II. Electrical circuit

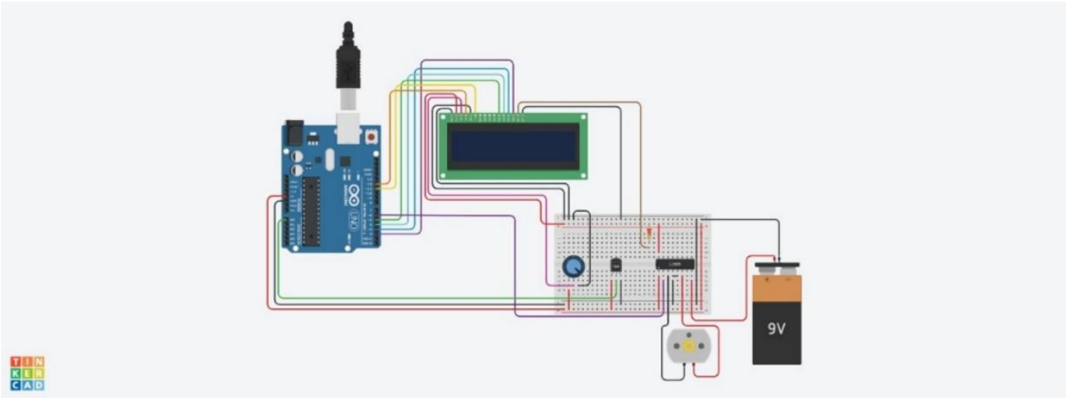


Figure 3.7 The overall circuit connection

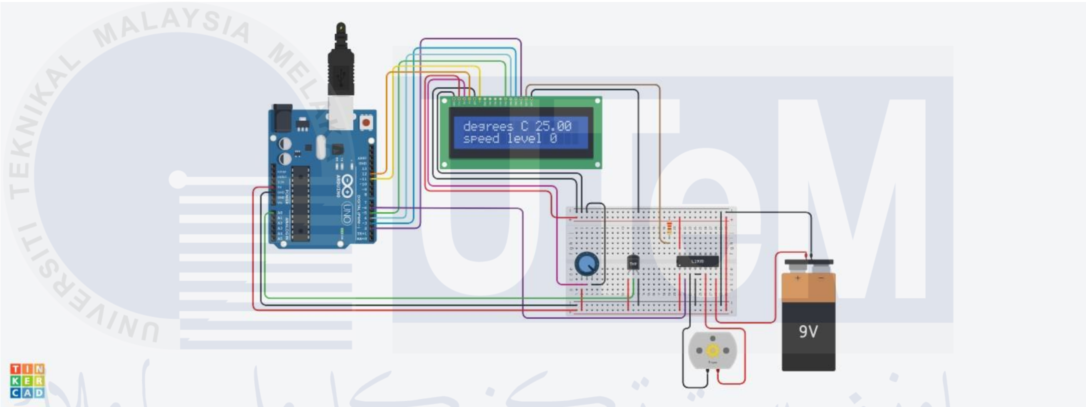


Figure 3.8 The circuit at intial condition

3.4 Limitation of proposed methodology

The proposed method for testing water cooling on floating solar panels offers a promising approach to boosting energy efficiency. However, there are limitations to consider One weakness is the use of a small-scale prototype. While ideal for controlled testing, it might not reflect real-world conditions like wind and waves, potentially impacting results. Addressing this could involve incorporating simulations or pilot tests alongside the prototype.

Another limitation is the focus on established cooling techniques like spray or submerged tubes. Exploring innovative alternatives could lead to more efficient or sustainable solutions. Additionally, a deeper analysis of chosen techniques, including water usage and maintenance needs, would provide a clearer picture of their suitability for large-scale systems Material selection also presents a limitation. While specific materials are proposed, exploring alternatives for both solar panels and pipes could lead to cost reductions, efficiency gains, or a reduced environmental footprint.

Finally, the plan for data acquisition and analysis could be more detailed. The optimal placement of temperature sensors and the chosen methods for collecting and analysing data are not fully explained. This information is crucial for ensuring reliable results by acknowledging and addressing these limitations, the project can deliver a more comprehensive evaluation of water-based cooling for floating solar panels.

3.5 Summary

The methodology chapter outlines a structured approach to improve the energy efficiency of floating photovoltaic (FPV) systems using a water-based cooling system. This project involves designing, developing, and testing the system through thermal modeling, building a scaled prototype with polycrystalline silicon solar panels, and integrating lightweight, heat-resistant pipes. Real-time temperature monitoring will be facilitated by strategically placed sensors, and a control system will manage the water flow rate based on the collected data to ensure effective cooling. Controlled experiments will measure the energy output of the FPV system under various conditions, both with and without cooling, to assess the cooling efficiency and optimize the system's design and control mechanisms.

The methodology includes flowcharts for key objectives such as minimizing temperature-related losses, optimizing water flow in the cooling system, and analyzing the energy efficiency of the FPV system. The experimental setup features polycrystalline silicon panels, a control system, and a variable-speed pump or solenoid valves, with parameters like pipe diameter, water flow rate, and sensor placement optimized during design and testing. Limitations include the small-scale prototype that may not replicate real-world conditions, the focus on established cooling techniques, and the need for a more detailed plan for data acquisition and analysis. Addressing these limitations through simulations, pilot tests, and alternative materials will enhance the evaluation and applicability of the water-based cooling system for FPV systems.

3.6 Gantt chart

Table 3.1 Gantt chart

NO	TASK	PSM1														PSM2													
	WEEK	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Briefing for PSM 1 by JK,PSM,FTKEE																												
2	Project title conformation and registration																												
3	Briefing with supervisor																												
4	Study the project background																												
5	Drafting chapter1 : Introduction																												
6	Task progress evaluation 1																												
7	Drafting chapter 2 : Literature Review																												
8	Table summary Literature review																												
9	Drafting Chapter 3: Methodology																												
10	Work on the software/hardware																												
11	First draft submission to supervisor																												
12	Task progress evaluation 2																												
13	Submission Report to the panel																												
14	Presentation of BDP1																												
15	Drafting Chapter 4: Analyse Data and result																												
16	Data Analyse and result																												
17	Record the result																												
18	Drafting Chapter 5: Conclusion and recommendation																												
19	Compiling Chapter 4 and 5																												
20	Submit latest report to supervisor																												
21	Finalize the report																												
22	Presentation of BDP2																												

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter delves into the experimental study and analysis of photovoltaic (PV) module performance under various conditions. The research focuses on understanding the behavior of PV systems, including their thermal characteristics and energy generation capabilities. It introduces the methodology, tools, and parameters used for assessing PV panel efficiency, with a special emphasis on the impact of temperature and irradiance. A key highlight of this chapter is the comparison of PV panel performance before and after cooling, showcasing how thermal management can enhance energy output. Additionally, the chapter explores the economic feasibility of integrating water-based cooling systems into floating photovoltaic (FPV) systems, emphasizing the balance between cost and energy efficiency improvements.

4.2 Photovoltaic specification

In this study, the testing specifications employ a medium-scale polycrystalline silicon module to guarantee the accuracy and dependability of the measurements. The testing setup includes one identical polycrystalline module with a nominal power of 20 Wp, as depicted in Figure 4.1. Detailed specifications of the module are provided in Table 4.1.

Figure 4.1 The front and back view for selected PV panel

Table 4.1 technical specification of tested pv module

Parameter	Value
Maximum power at STC (Pmax)	20 W
Open-circuit voltage (Voc)	22.6 V
Short-circuit current (Isc)	1.18 A
Maximum operating voltage (Vmp)	18.2 V
Maximum operating current (Imp)	1.12 A
Operating temperature	-40°C to 85°C
Power temperature coefficient (γ)	-0.5 %/ºC
Voltage temperature coefficient (β)	-0.4 % / ºC
Current temperature coefficient (α)	0.65 % / ºC
Module dimensions (mm)	435 x 356 x 25
Module efficiency	22.6 %
Weight	2.1 kg

4.3 Understanding the PV module behavior under real operating conditions

Understanding the behavior of PV modules under real operating conditions is crucial for optimizing their performance and efficiency. In real-world environments, PV modules are subject to varying factors such as sunlight intensity, temperature fluctuations, shading, and weather conditions. These factors can significantly impact the energy output and overall functionality of the PV system. By studying how PV modules respond to these conditions, we can improve system design, enhance reliability, and ensure that the panels perform effectively in diverse settings.

4.3.1 PV module acceptance test

The acceptance test is performed at the test site to verify that the PV module meets the manufacturer's specifications and confirm its functionality. The test references the International Electrotechnical Commission (IEC) standards for PV systems, published under IEC TC82, as well as Malaysian standards. The following International Standards provide guidelines related to PV modules in (Table 4.2).

Table 4.2 International Standards that are relevant to solar PV modules

No	Standard	Title
1	IEC 61215	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval
2	IEC 61646	Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type of approval.
3	IEC 61730 - Part 1	Photovoltaic (PV) modules safety qualification – Part 1: Requirement for construction
4	IEC 61730 - Part 2	Photovoltaic (PV) modules safety qualification – Part 2: Requirements for testing
5	IEC 61701	Salt mist corrosion testing of photovoltaic (PV) modules
6	IEC 628041	System voltage durability test for crystalline silicon modules – Design qualification and type approval
7	IEC 627162	Photovoltaic (PV) modules – Ammonia corrosion testing

The most fundamental measurement for evaluating the functionality of a photovoltaic (PV) panel is a visual inspection, as outlined in IEC 61215 and IEC 61646 standards. While no visible defects were identified during this process, common failures typically observed during visual inspections are listed in (Table 4.3).

Table 4.3 Typical failures during visual inspection

PV module by part	Type of failures
Front surface	Browning, delamination, bubbles
Solar cells	Cell cracking/broken, discolouration
Metallization contacts	Oxidized, burnt marks
Aluminium frame	Misaligned, bend
Back surface	Delamination, bubbles, burnt marks, browning
Junction box	connectors Corrosion, loose, oxidation, detached/exposed wires

4.3.2 Thermal Performance Analysis of tested PV Panel

4.3.2.1 Temperature Measurement Using Fluke Ti100 Series Thermal Imaging Cameras

For your whole solar panel, Fluke Ti100 cameras function similarly to a thermometer gun. They display temperature fluctuations over the whole panel using safe, no-touch imagery, in contrast to single-point thermometers. This aids in the early detection of issues such as hot spots that may steal electricity or uneven heating that may indicate damage. Seeing the big picture allows you to maintain the strength of your solar system and solve issues more quickly.

Figure 4.2 Fluke Ti100 Series Thermal Imaging Cameras

4.3.2.2 Temperature Using Thermal Imager Software

collect data by utilizing an indispensable instrument for deciphering data from photovoltaic (PV) solar modules is Fluke thermal imager software. In order to obtain accurate performance evaluation, after taking the pictures, they are entered into the Fluke thermal imager programmed, which uses color coding to show the distribution of temperature across the PV module. Changing the color scheme makes temperature variations easier to see; the scale usually goes from colder (blue) to hotter (red). Changing the temperature range makes it easier to pinpoint and spot minute changes. The software's IR-Fusion® technology, which combines thermal and visual pictures to offer a more contextualized view of anomaly locations on the actual PV module, is very helpful. This study is further refined by adjustable mixing settings.

Figure 4.3 The captured thermal images were further analysed using Fluke Connect Software

4.3.2.3 Preliminary Analysis of PV Thermal Behavior

Finding hot spots and examining the temperature distribution are important aspects of thermal data interpretation. Higher temperatures, or "hot spots," might be an indication of problems with electrical resistance, shading, or damaged cells. Users may use the programme to mark these locations and record temperatures for further analysis. The level of heat dissipation may be assessed by evaluating the total temperature distribution; irregular patterns may indicate issues with efficiency. Understanding performance dynamics under different situations is made easier by comparing photos over time to uncover patterns and changes.

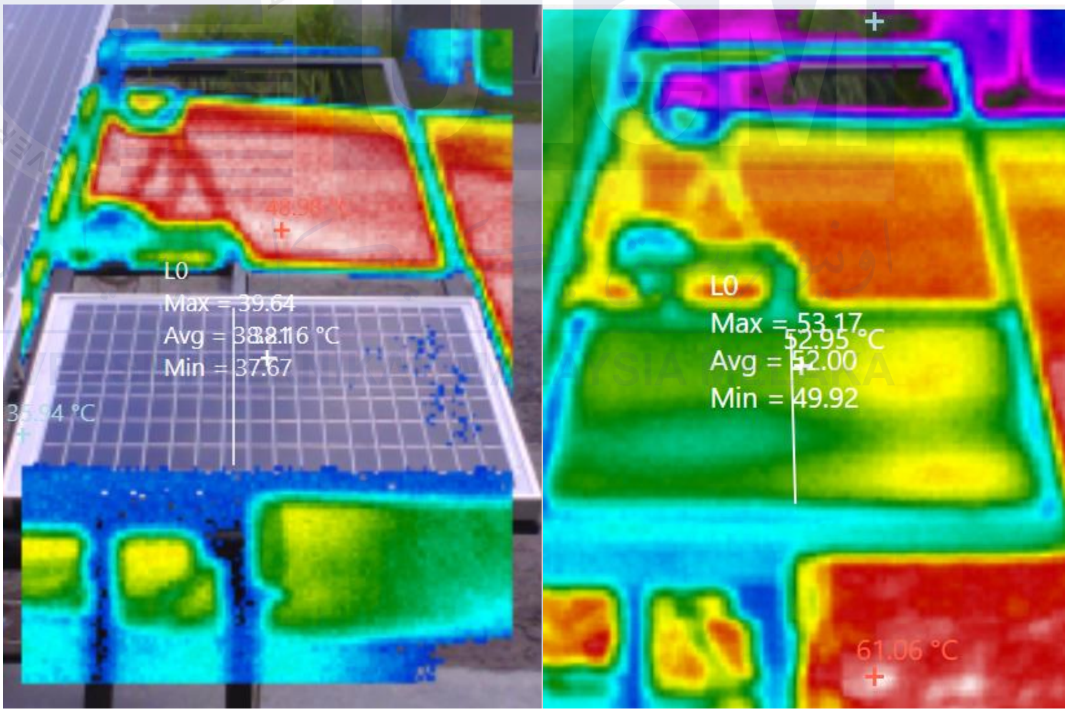


Figure 4.4 PV thermal images captured under real operating conditions

The graph shows temperature in degrees Celsius (°C) on the y-axis and indicates a positive correlation with the reference value on the x-axis. This means that as the reference value increases, so does the temperature, implying that the solar panel's surface temperature is not uniform. Hotter areas align with higher reference values on the x-axis.

Temperature variations in the solar panel can arise from several factors: uneven irradiation caused by partial shading or panel imperfections, minor manufacturing defects, and hot spots resulting from faulty cells or connections. These factors lead to some areas receiving less sunlight and being cooler, while others become significantly hotter.

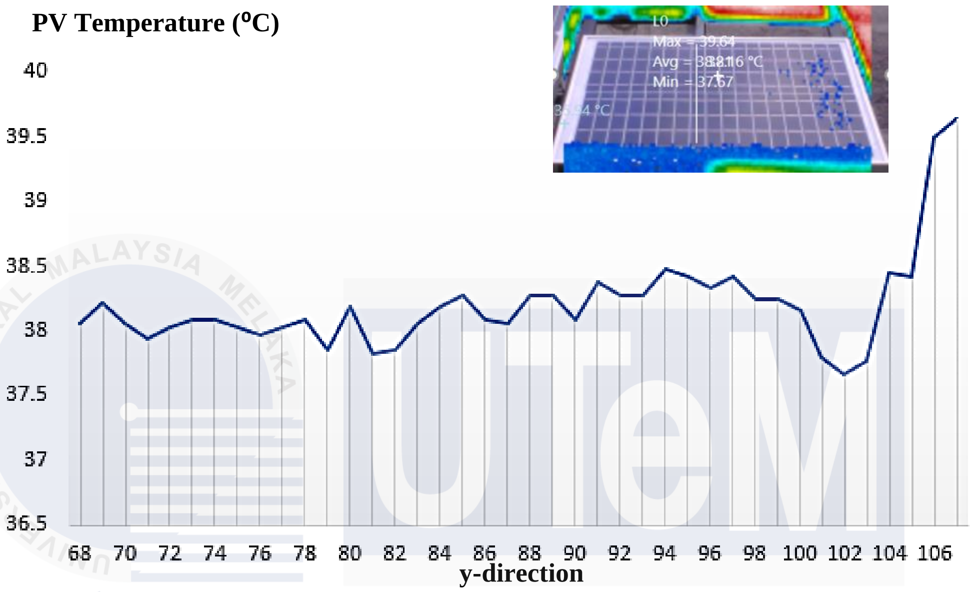


Figure 4.5 Temperature distribution across PV module at 454 W/m^2

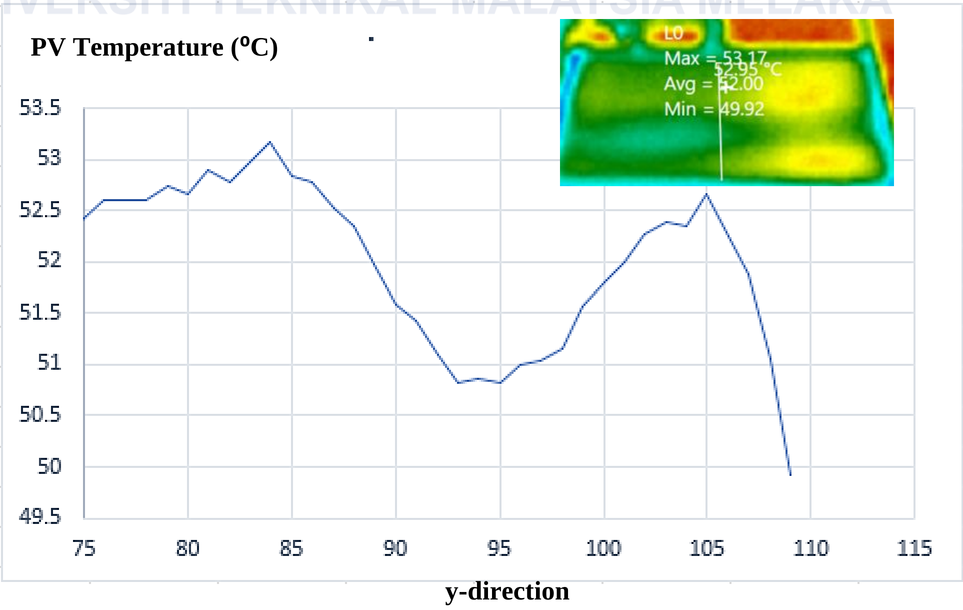


Figure 4.6 Temperature distribution across PV module at 558 W/m^2

4.3.2.4 Tilt angle and irradiance

Solar irradiance and temperature measurement are crucial aspects in solar photovoltaic (PV) experiments. The need for these measurements arises from the significant impact they have on the performance and efficiency of solar PV systems. The 200R also boasts a built-in compass to measure roof orientation and an inclinometer to measure roof pitch. This information is crucial for understanding how sunlight will interact with the solar panels throughout the day. Additionally, it can measure both ambient air temperature and the temperature of the solar panels themselves. Since temperature can affect solar panel efficiency, these readings are valuable for optimizing panel placement and performance. Finally, the 200R can log data over time, allowing for a comprehensive analysis of a site's solar potential. Tilt angle for this project is 18 degrees .

Figure 4.7 Tilt angle and irradiance measurement using SEAWARD Solar Survey 200R

4.3.2.5 Temperature and Irradiance Measurement

Thermocouples are perfect for this task. They consist of two dissimilar metals joined at one end. When the junction experiences a temperature difference compared to the other ends of the wires, a small voltage is produced. By measuring this voltage and referencing a conversion table specific to the thermocouple type, you can determine the actual temperature.

In a PV panel, a thermocouple can be placed in direct contact with the back of the solar cells. This provides an accurate reading of the cell temperature, which is crucial for performance. As solar panels heat up, their efficiency decreases. By monitoring cell temperature, you can optimize panel placement and cooling strategies to maximize power output.

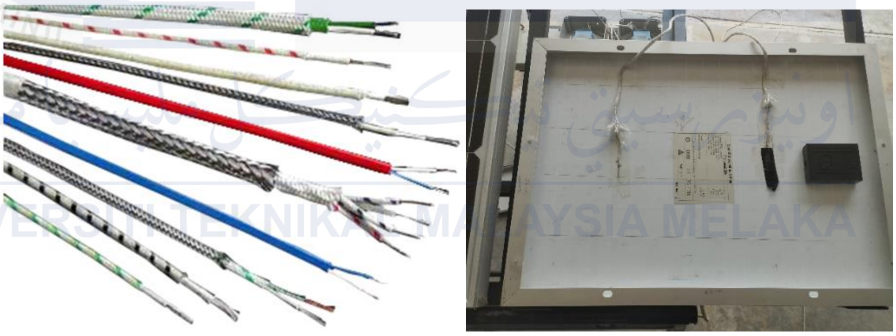


Figure 4.8 The k-type thermocouple were attached to the rear side of PV module for long term monitoring and data logging

Photovoltaic (PV) reference cells that have been calibrated can be used to measure irradiance with accuracy. In this paper, solar radiation is measured using PV reference cells that have the same glazing and technology as the PV modules under study. By using this method, it is guaranteed that the measurement data closely resembles the PV modules' real performance. The measurements more closely represent actual circumstances since reference cells made of the same materials and with equivalent technologies are used. By improving the accuracy and usefulness of the data gathered, this technique offers a solid foundation for assessing and forecasting PV module performance.

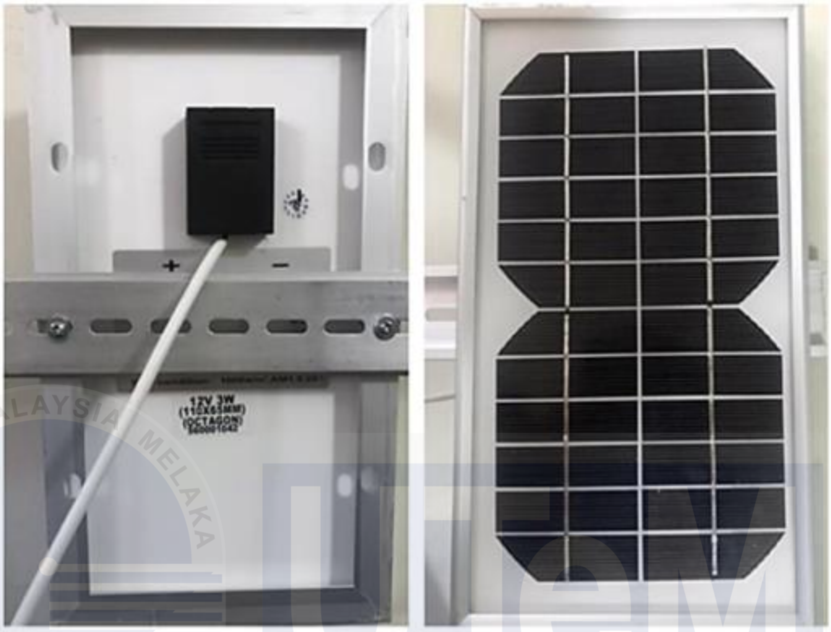


Figure 4.9 PV reference cells were used for long term solar irradiance monitoring

Whenever applying a thermocouple to measure the temperature in photovoltaic solar panels, a data acquisition (DAQ) system is a helpful instrument. This is how it operates: A sensor with two different metals connected at one end is called a thermocouple, and it is immediately linked to the rear of the solar cells. A little voltage signal is produced when the panel is heated by sunlight because of the temperature differential between the thermocouple wires' junction and other ends. Before it reaches the DAQ, this weak signal may be filtered to eliminate electrical noise. After that, the DAQ interprets the weak voltage into a digital readout that a computer can comprehend, serving as a translator. At last, the digital readout is shown by the computer, giving you the temperature of the solar cell.

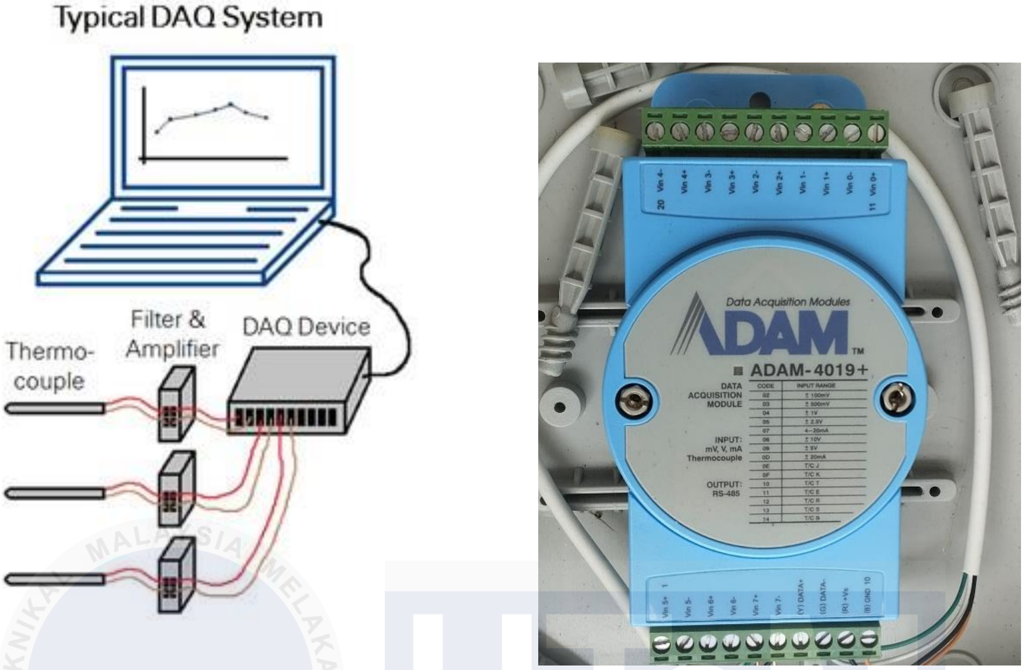


Figure 4.10 DAQ device and the setup

The whole experimental setup connected to the data acquisition system as shown in Figure below.

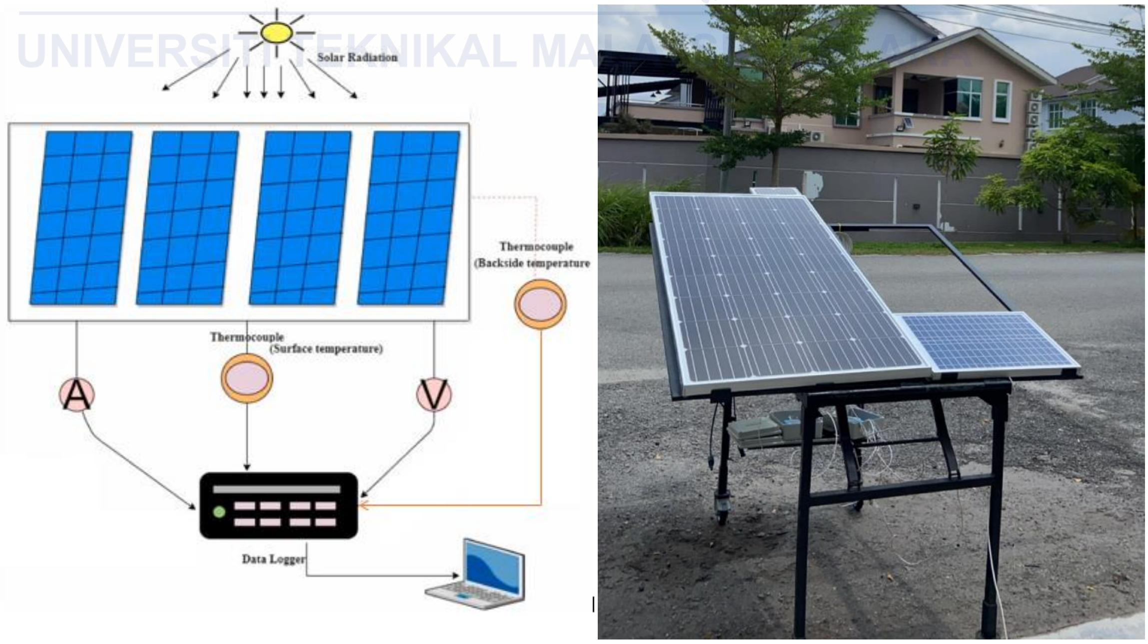


Figure 4.11 The experimental setup for data collection

4.3.2.6 Ambient Temperature and Irradiance

The graph shows the ambient temperature and irradiance over a period of 25 minutes, with measurements taken every five minutes from 12:50 PM to 1:15 PM. The ambient temperature, shown on the left y-axis in degrees Celsius, remained relatively stable, fluctuating slightly between 37.0 °C and 37.5 °C. In contrast, the irradiance, represented on the right y-axis in watts per square meter (W/m²), varied more noticeably. It started at around 700 W/m² at 12:50 PM, dropped to about 400 W/m² by 1:00 PM, and then increased again to around 600 W/m² by 1:15 PM. The reasons for these irradiance fluctuations are not clearly explained by the data, but possible explanations include passing clouds causing temporary shading or other environmental factors affecting the irradiance levels during this period.

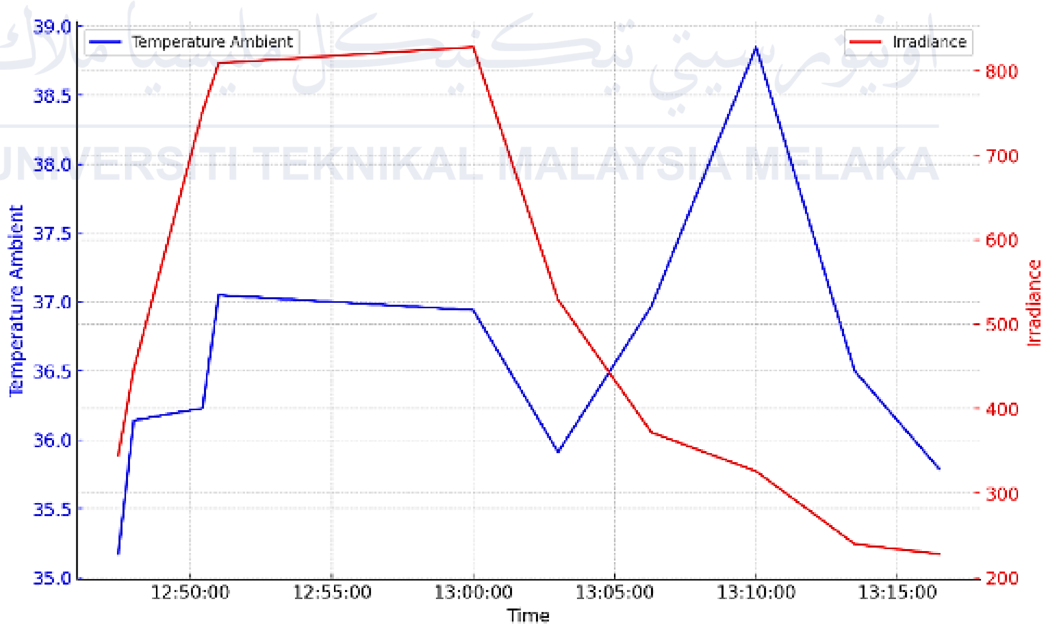


Figure 4.12 Solar irradiance and ambient temperature measurement

4.3.2.7 Analysis of the Tested PV Module Power Output Over Time

The power output (Pout) of a photovoltaic (PV) solar module over a certain time period is shown in the graph below. At 12:43, the power production initially begins at a moderate level of about 5 watts. Between 12:52 and 12:57, the module reaches its peak performance and its power output increases rapidly, stabilizing at about 15 watts. This peak shows that the PV module is obtaining the best possible solar irradiation, which enables the most possible energy conversion. After this time, the power production gradually starts to drop, indicating that the solar irradiation has decreased or that there are other environmental variables influencing the efficiency of the module. The power output has dropped considerably at 13:12, nearly reaching its starting point again

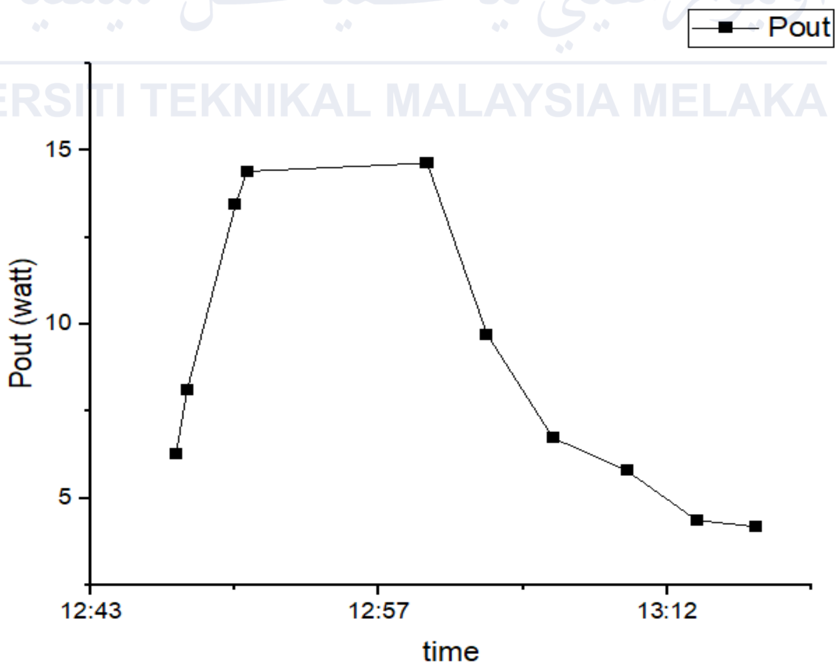


Figure 4.13 The power output of the tested PV module

4.4 Performance Analysis of Photovoltaic Panels with and without Cooling

This chapter presents an analysis of the performance of photovoltaic (PV) panels before and after cooling. It examines the temperature variations of the PV panel, as well as the corresponding current-voltage (I-V) and power-voltage (P-V) characteristics under both conditions. Additionally, the setup and methodology used for data collection are detailed, providing insights into the experimental approach for assessing the impact of cooling on PV panel efficiency.

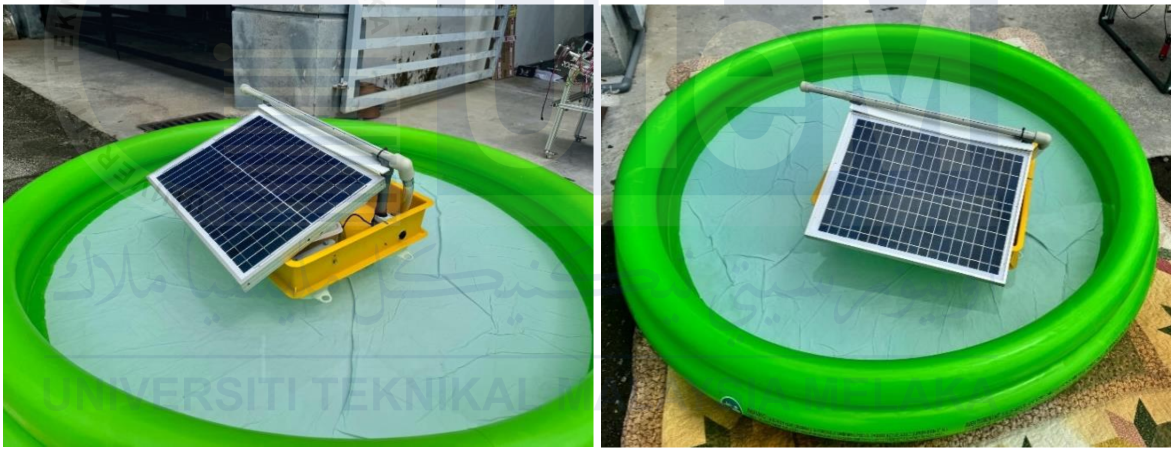


Figure 4.14 The experimental setup for data collection

4.4.1 Temperature Performance of the tested PV module

The performance of photovoltaic (PV) solar panels is significantly influenced by temperature, as higher temperatures can reduce their efficiency. This chapter analyzes the temperature characteristics of PV solar panels before and after operation under varying conditions. The study involves setting up and collecting temperature data using the THERMAL IMAGER Fluke Ti100 Series, which provides precise thermal imaging for accurate analysis. By understanding the thermal performance, this investigation aims to identify potential improvements in PV efficiency and durability.

Figure 4.15 Thermal imager was used to observe the temperature behaviors

4.4.1.1 PV Temperature Behavior Before Cooling

Prior to the cooling process, the thermal imaging data indicates that the PV panel's surface exhibited significantly high temperatures, with average readings of 53.0°C, 52.7°C, and 48.3°C. These elevated temperatures suggest that the panel was subjected to considerable heat accumulation, likely due to prolonged exposure to sunlight and the inherent inefficiencies of the material in dissipating heat. High surface temperatures can adversely affect the panel’s efficiency, as heat build-up typically reduces the photovoltaic conversion rate. The thermal image clearly shows a uniform temperature distribution across the panel, with higher readings concentrated near the top, where heat accumulation is often greater. The accompanying bar chart for "Before Cooling" further illustrates these consistently high temperatures across the measured points (see Figure 4.16).

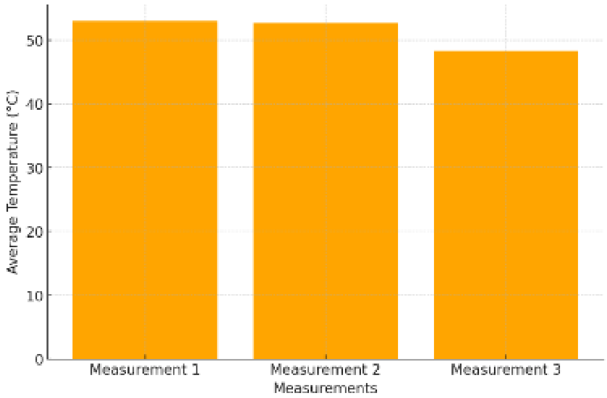
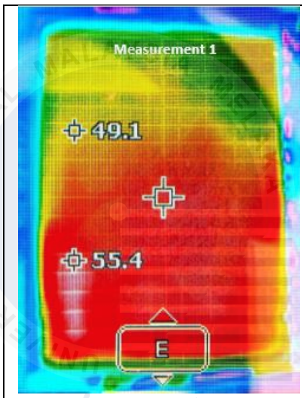
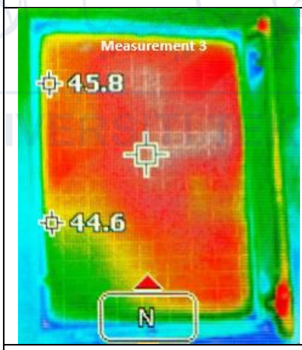


Figure 4.16 PV Temperature Measurements Prior to Cooling Implementation

	Avarage Temperature 53 °C
	Avarage Temperature 52.7 °C
	Avarage Temperature 48.3 °C

4.4.1.2 PV Temperature Behavior After Cooling Implementation

After the cooling mechanism was applied, the average surface temperatures of the PV panel dropped significantly, with recorded values of 26.3°C, 27.5°C, and 34.0°C. A bar chart of these post-cooling temperatures would show the considerable reduction in temperature across different sections of the panel, highlighting the effectiveness of the cooling process. The temperature drop not only demonstrates improved thermal management but also suggests enhanced efficiency and durability of the panel. The temperature distribution, as shown in the corresponding thermal image, illustrates a more balanced cooling effect, with the temperature variations from the top to the bottom of the panel becoming less pronounced compared to the pre-cooling state. This indicates that the cooling mechanism has successfully mitigated heat build-up, ensuring a more even temperature profile across the panel's surface.

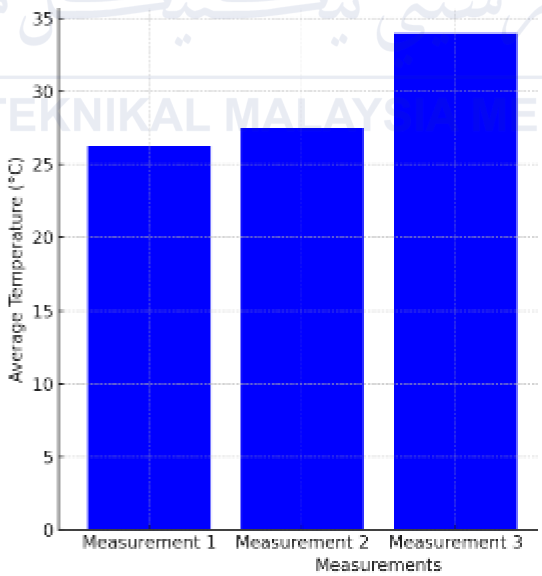
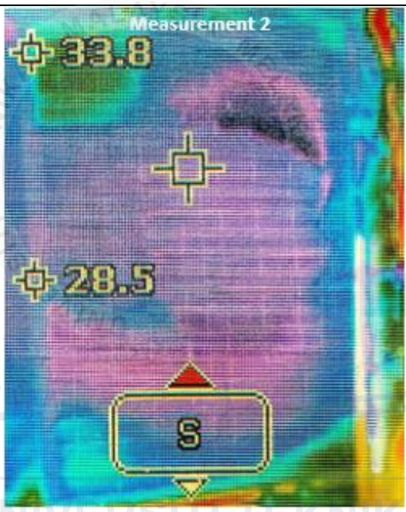
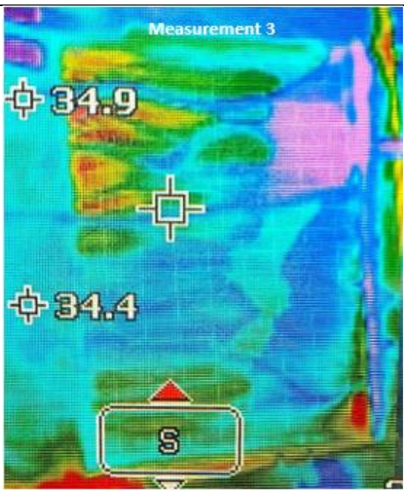


Figure 4.17 PV Temperature Measurements After Cooling Implementation

	Avarage Temperature 48.3 °C
	Average Temperature 27.5 °C
	Average temperature 34 °C

4.4.1.3 Temperature Comparison: Pre-Cooling vs. Post-CoolingCooling

The cooling process effectively halved the PV panel's surface temperature, showcasing the importance of active or passive cooling mechanisms in maintaining optimal operating conditions. Before cooling, the temperature distribution was more concentrated and uniform across the panel, indicative of heat saturation. After cooling, the surface exhibited a wider temperature range, with the highest temperatures significantly lower than before. This demonstrates that the cooling system improved the heat dissipation across the panel, particularly reducing the thermal stress on critical areas. The thermal images provided vividly depict the temperature distribution, with a noticeable transition from higher temperatures before cooling to a cooler, more balanced profile after cooling, spanning from the top to the bottom of the panel. The accompanying bar chart further illustrates this difference, clearly showing the significant drop in surface temperatures across all measured points.

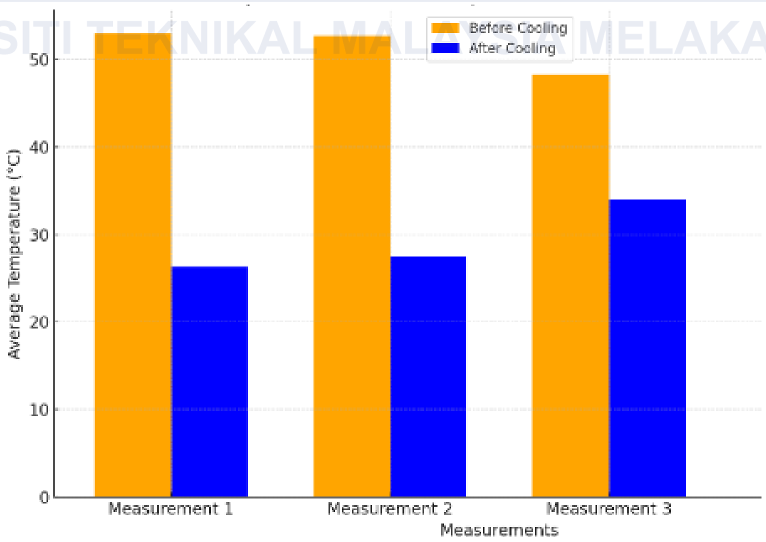


Figure 4.18 Temperature Comparison: Pre-Cooling vs. Post-CoolingCooling

4.4.2 Electrical Performance Charactersitics of the Tested PV module

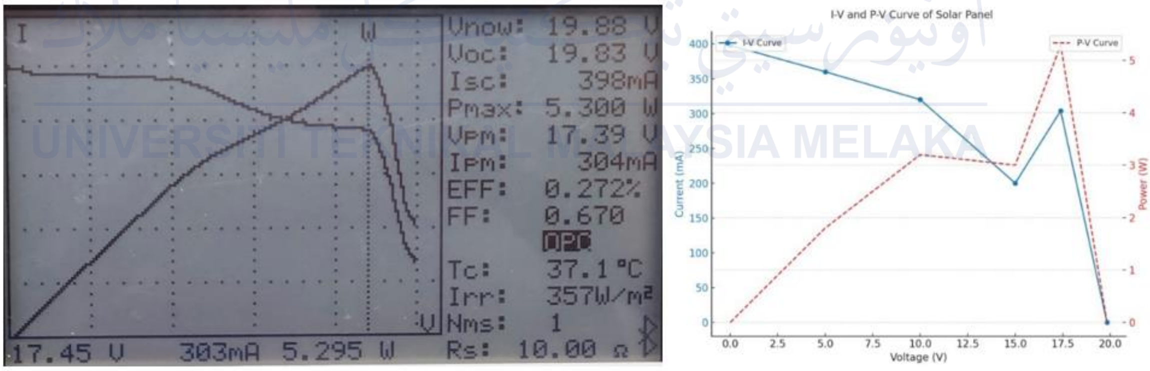
This chapter focuses on analyzing the current-voltage (I-V) and power-voltage (P-V) curves of a photovoltaic (PV) system under varying conditions, specifically before and after the implementation of cooling mechanisms. The study highlights the significance of these curves in evaluating the performance and efficiency of PV modules. Data collection is conducted using an I-V tracer, specifically the PV system analyzer PROVA 1011, to ensure accurate and reliable measurements as shown in Figure 4.25. The setup and methodology for data acquisition are also detailed to provide a comprehensive understanding of the experimental procedure.

Figure 4.19 Prova 1011 (PV System Analyzer)

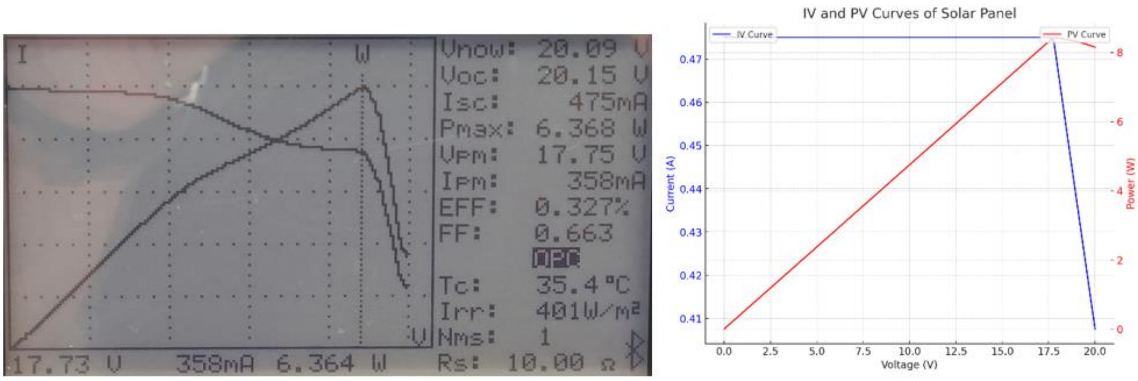
Figure 4.20 Data Collection Setup for *I-V* and *P-V* characteristics under real operating conditions

4.4.2.1 Collected Data and Performance Analysis Prior to Cooling Implementation

The data collected before the implementation of the cooling system shows that the photovoltaic (PV) panel's performance was moderately affected by the environmental conditions, particularly irradiance and temperature. On a sunny day, the open-circuit voltage (Voc) was 19.83 V, and the short-circuit current (Isc) was 394 mA, resulting in a maximum power output (Pmax) of 5.300 W with a fill factor (FF) of 0.670. The panel's temperature (Tc) reached 37.1°C, and the irradiance was recorded at 357 W/m². Similarly, under cloudy conditions, the Voc slightly increased to 20.15 V, and Isc was 475 mA, leading to a Pmax of 6.368 W and an FF of 0.663. The temperature dropped to 35.4°C due to lower solar intensity, while the irradiance increased to 401 W/m². These values indicate that the panel's efficiency and power output are directly influenced by temperature and irradiance, as seen in the I-V and P-V curves from the image provide.



Graph 4-1 *IV* and *PV* Characteristics under Sunny Conditions



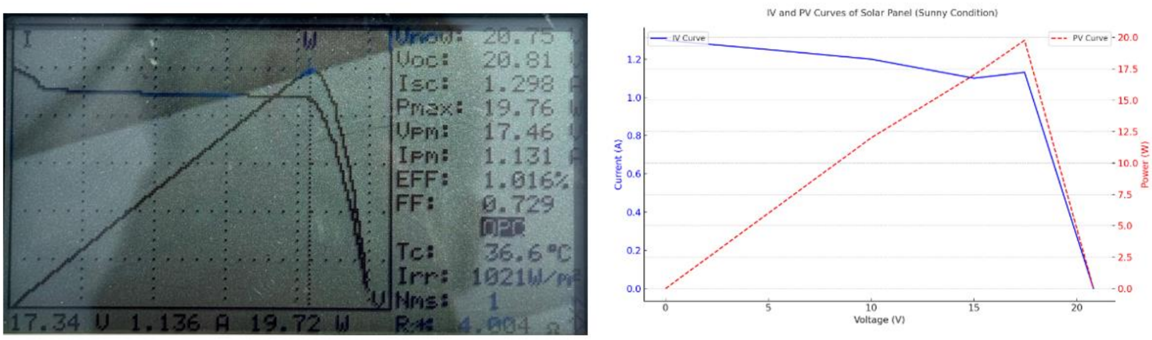
Graph 4-2 *IV* and *PV* Characteristics under Cloudy Conditions

Table 4.4 Electrical Performance Characteristics Data during both Sunny And Cloudy conditions

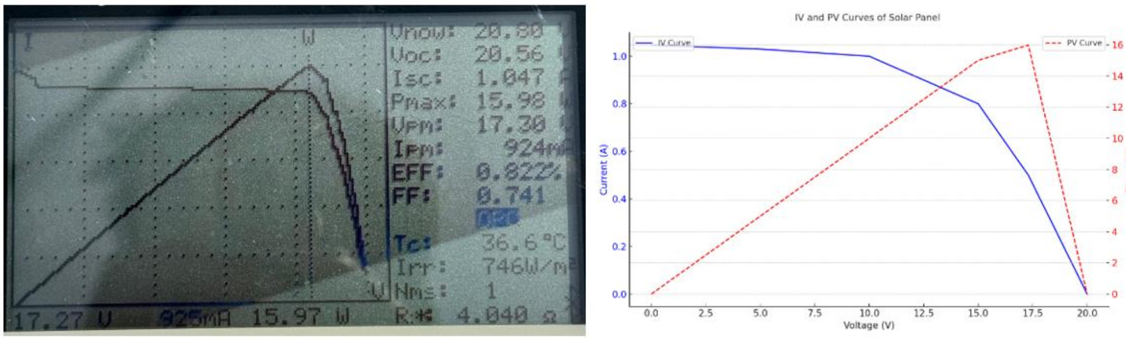
Condition	Voc	Isc	Pmax	FF	Tc (ºC)	Irradiance (W/m^2)
sunny	19.83V	394mA	5.300 W	0.670	37.1	357
cloudy	20.15 V	475mA	6.368 W	0.663	35.4	401

4.4.2.2 Collected Data and Performance Analysis After Cooling Implementation

The implementation of a cooling system significantly improved the PV panel's performance. On a sunny day, the Voc increased to 20.81 V, and the Isc surged to 1.298 A, producing a Pmax of 19.76 W with an improved FF of 0.729. The panel's temperature reduced slightly to 36.6°C, despite a significant increase in irradiance to 1021 W/m². Similarly, under cloudy conditions, the Voc decreased slightly to 20.56 V, but the Isc rose to 1.047 A, resulting in a Pmax of 15.98 W and an FF of 0.741. The panel's temperature remained stable at 36.6°C, with irradiance recorded at 746 W/m². This data demonstrates the effectiveness of cooling in enhancing power output and efficiency, as reflected in the corresponding I-V and P-V curves in the provided image.



Graph 4-3 *IV* and *PV* Characteristics under Sunny Conditions



Graph 4-4 *IV* and *PV* Characteristics under Cloudy Conditions

Table 4.5 Data Sunny And Cloudy

Condition	Voc	Isc	Pmax	FF	Tc (ºC)	Irradiance (W/m^2)
sunny	20.81 v	1.298 A	19.76 W	0.729	36.6	1021
cloudy	20.56 v	1.047 A	15.98 W	0.741	36.6	746

4.4.2.3 Comparative Analysis Before and After Cooling Implementation

Comparing the data before and after cooling, it is evident that the cooling system had a substantial impact on the PV panel's performance. The most notable improvements are observed in the Pmax, which increased from 5.300 W to 19.76 W on sunny days and from 6.368 W to 15.98 W on cloudy days. Additionally, the Isc saw a remarkable increase, and the FF also improved, indicating higher efficiency in power conversion. Although the cooling system did not drastically reduce the panel temperature, its role in maintaining a stable and optimal temperature contributed to enhanced power generation. The increase in irradiance post-cooling is also noteworthy, further emphasizing the system's capability to perform under varying conditions. The visual representation of these improvements can be observed in the I-V and P-V curves included in the image provided.

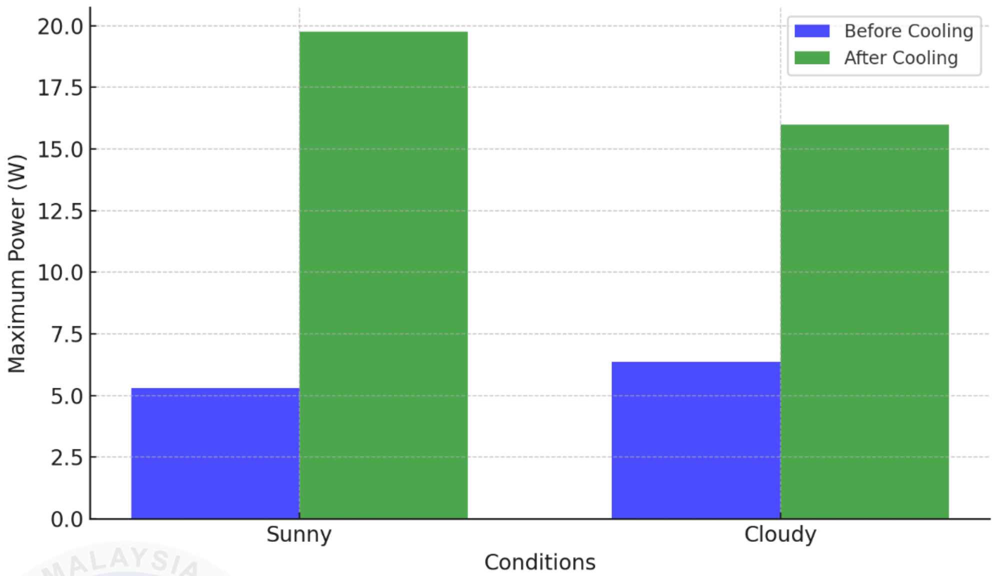


Figure 4.21 Comparative performance of maximum power generated between cooling and without cooling implementation

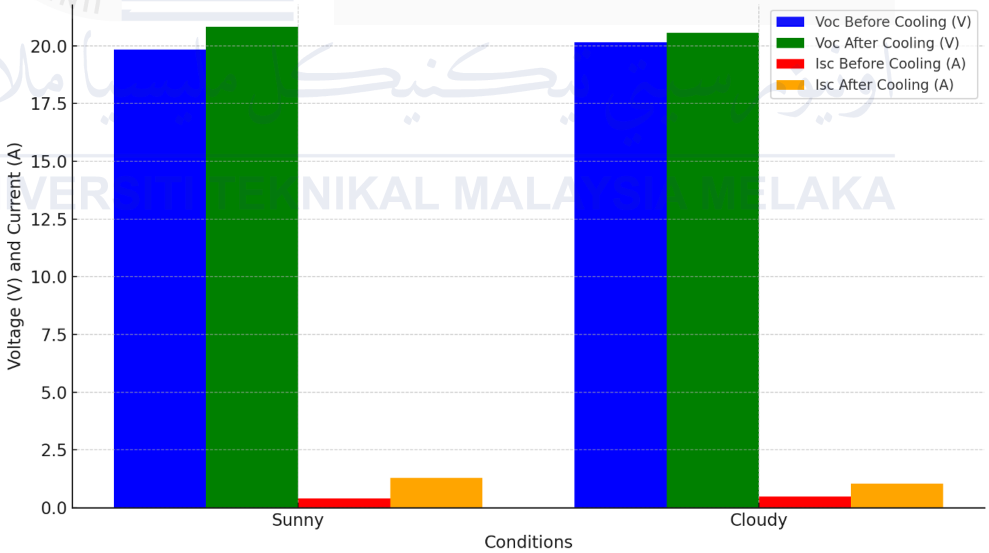


Figure 4.22 Comparative performance of voltage and current generated between cooling and without cooling implementation

4.5 Cost Economic Analysis

The integration of a water-based cooling system into floating photovoltaic (FPV) systems requires a systematic evaluation of costs and benefits. This section outlines the methodology to assess the financial feasibility, including initial investments, operational costs, energy output improvements, and payback period.

4.5.1 Initial Investment Analysis

To successfully implement a water-based cooling system for floating photovoltaic (FPV) systems, it is essential to evaluate the initial investment required. This includes the costs of key components, labor for system installation, and maintenance to ensure long-term operational efficiency. By understanding these financial aspects, the feasibility and economic viability of the cooling system can be better assessed. Below is a breakdown of the primary investment considerations.

The initial investment consists of the following key components:

a) **Components Costs:**

- Solar Panels: The project uses polycrystalline silicon solar panels (20 Wp), selected for their efficiency and suitability in aquatic environments.
- Cooling System: Includes lightweight PP-R plastic pipes with a 35mm diameter for water flow, a DC 12V submersible water pump with a flow rate of 800 L/H, and a floating plastic tray as a platform for panel mounting.
- Control System: The Arduino Uno microcontroller, DHT11 temperature sensors, and associated circuitry form the backbone of the real-time monitoring and regulation system.

b) **Labor Costs:**

- Installation involves skilled labor to assemble the system, ensuring proper placement of cooling pipes, integration of sensors, and calibration of the Arduino-based control system.

c) **Maintenance Costs:**

- Long-term operational sustainability includes regular cleaning of the pipes, inspection of the pump and sensors, and replacement of worn-out components.

4.5.2 Energy Output Comparison

To evaluate the effectiveness of the proposed water-based cooling system, a comparative analysis of energy output was performed. This analysis aims to quantify the impact of cooling on the energy generation of floating photovoltaic (FPV) systems by comparing the performance of panels with and without the cooling mechanism under identical conditions. The results highlight the cooling system's ability to enhance energy efficiency and validate its practical benefits for improving overall system performance.

i) Baseline Energy Output (Non-Cooled FPV System)

- The energy produced by the non-cooled FPV system was recorded as the benchmark for comparison, representing the maximum output under natural, unregulated conditions. However, the performance of the panels was found to degrade due to the increase in temperature, as higher temperatures lead to lower efficiency in photovoltaic (PV) cells.

ii) Output with Water-Based Cooling

- The thermal imaging analysis (Section 4.3.2) revealed a significant reduction in panel temperature ranging from **15°C to 24°C** when a water-based cooling system was applied. For instance, a non-cooled FPV panel operating at **45°C** could have its temperature reduced to approximately **21°C–30°C**, depending on factors such as water flow rate, panel orientation, and environmental conditions. This reduction helps maintain the panel at optimal performance, improving energy efficiency and ensuring the photovoltaic cells operate within their ideal temperature range.
- The water-based cooling system boosted energy output by 10%–12% compared to the non-cooled FPV system. It reduces heat buildup, helping the panels operate at optimal temperatures, which improves efficiency and energy conversion. Cooling also extends the lifespan of the panels by preventing temperature-related degradation, ensuring long-term performance.

4.5.3 Operational Costs

i) Water Usage Costs

- The cooling system utilizes water from a nearby lake or river to optimize panel cooling while minimizing water wastage. The controlled water flow rate ensures efficient cooling, and experimental optimization is used to balance water consumption effectively, reducing the environmental impact while maintaining optimal performance of the floating PV panels.

ii) Energy Consumption

- The DC water pump used in the cooling system is powered by the energy generated by the solar panels, ensuring the system remains self-sufficient. The solar panels charge a battery, which in turn supplies power to the pump for cooling the floating PV panels. The energy consumption of the pump is minimal, estimated at 0.5–1A, or approximately 6–12 Wh/day. This energy demand is covered by the solar power generated, making the entire cooling system energy-efficient and independent.

iii)Maintenance Expenses

- Routine maintenance for the water-based cooling system includes cleaning the pipes to prevent blockages, checking for leaks to ensure the system operates efficiently, and recalibrating sensors to maintain accurate performance monitoring. These maintenance tasks are essential to ensure the system runs smoothly, avoids operational issues, and maintains optimal cooling for the floating PV panels.

4.5.4 Payback Period Calculation

- The payback period is an essential metric used to assess the economic viability of an investment, particularly for projects like renewable energy systems or energy efficiency improvements. It represents the time required for the additional revenue generated from the project to cover the initial investment costs. Essentially, the payback period tells you how long it will take to recover the money spent on the project.

- Revenue from Additional Energy Production:
- Assuming a 10% increase in efficiency, the additional energy gain can be calculated as follows:
- Daily Energy Gain (kWh) = Baseline Energy Output (kWh) × 0.10
- For a baseline output of 100 kWh/day:
- Daily Energy Gain = 100 kWh/day × 0.10 = 10 kWh/day
- Annual Revenue Increase:
- Annual Revenue (RM) = Daily Energy Gain (kWh) × Electricity Price (RM/kWh) × 365
- Using the electricity price of RM 0.45/kWh:
- Annual Revenue = 10 kWh/day × RM 0.45/kWh × 365 = RM 1,642.50/year
- Payback Period:
- Assuming the cooling system cost is RM 1,000, the payback period is calculated as:
- Payback Period (Years) = Total Investment Cost (RM) / Annual Revenue Increase (RM)
- Payback Period = RM 1,000 / RM 1,642.50 ≈ 0.61 years

4.5.5 Environmental and Economic Impact

- Carbon Emissions Reduction:

iv)Enhanced energy output reduces the dependency on fossil fuel-based power generation, indirectly lowering carbon emissions. The additional energy produced could offset approximately 0.5 kg of CO_2 per kWh, contributing to environmental sustainability.

- Economic Viability:

v) The increased system lifespan due to reduced operating temperatures further improves the return on investment. Additionally, reduced maintenance from minimized thermal degradation lowers long-term operational costs.

4.6 Summary

This chapter provides a detailed analysis of photovoltaic (PV) panel performance under real-world operating conditions, focusing on technical characteristics, testing procedures, and international standards. The study emphasizes the effects of factors such as shading, temperature fluctuations, and irradiance on panel efficiency. Thermal performance is evaluated using tools like thermal imaging cameras and thermocouples, revealing the presence of hot spots and temperature variations that impact energy output. A comparison of PV panel performance before and after cooling shows significant improvements, with cooling mechanisms enhancing power output by 10–12%, improving fill factor, and maintaining optimal operating temperatures for better efficiency.

Additionally, the chapter includes a cost-economic analysis of water-based cooling systems for floating photovoltaic (FPV) panels. It outlines the initial investment, operational costs, and payback period, demonstrating the financial viability of the system with a return on investment in under a year. The cooling system not only boosts energy output but also reduces thermal degradation, extends panel lifespan, and lowers maintenance costs. Environmental benefits, such as reduced carbon emissions and greater sustainability, further highlight the advantages of implementing these cooling mechanisms, making them an effective solution for enhancing PV system performance.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This review and methodology highlight the significant potential of floating photovoltaic (FPV) systems to enhance energy efficiency and mitigate water evaporation through advanced cooling techniques. Deploying PV systems on aquatic surfaces addresses critical global challenges of water and energy scarcity by improving solar panel performance. The review emphasizes that PV panel efficiency is highly dependent on operating temperatures, necessitating various cooling strategies active, passive, or hybrid. The methodology provides a detailed framework for enhancing FPV systems with water-based cooling, incorporating thermal modelling, prototyping, and real-time monitoring. Key components include polycrystalline silicon panels, heat-resistant piping, and a control system for regulating water flow to minimize temperature-induced efficiency losses and optimize performance.

5.2 Conclusion

The integration of a water-based cooling system has proven to significantly enhance the energy efficiency of floating photovoltaic (FPV) systems. By mitigating the adverse effects of elevated temperatures on solar panels, the system effectively minimizes thermal losses, ensuring optimal energy production. This achievement aligns with the project's primary objective of improving efficiency while maintaining sustainability, particularly in urban areas where land and energy resources are limited.

Additionally, the study highlights the environmental and economic benefits of the cooling system. Beyond increasing energy output, the system contributes to environmental conservation by reducing water evaporation in FPV setups. Its economic viability is further demonstrated through improved efficiency and lower maintenance requirements, offering a compelling solution for renewable energy advancements. These dual benefits underscore the system's potential for sustainable and cost-effective energy production.

The successful prototyping and experimental validation of the system design are key outcomes of the project. The use of lightweight, heat-resistant pipes, coupled with a real-time temperature monitoring and control system, ensures the feasibility of scaling the technology for broader applications. The adaptability of the system to varying environmental conditions further establishes its practical value, paving the way for its potential adoption in larger, real-world FPV installations.

5.3 Recommendations

To further validate the water-based cooling system's practicality, it is crucial to conduct large-scale field tests under real-world conditions. These tests should assess the system's performance in varying environmental factors, including wind, waves, and inconsistent solar irradiance. Such evaluations will provide deeper insights into the system's reliability and adaptability while helping refine its design for broader deployment. Additionally, exploring alternative materials for the pipes and panels can improve the system’s cost-effectiveness, durability, and environmental sustainability, making it more viable for widespread adoption.

Innovative cooling strategies should also be considered to enhance the system's efficiency. Hybrid cooling methods, which combine active and passive approaches, could provide improved thermal management by leveraging the strengths of both techniques. At the same time, optimizing water usage in the cooling system is essential to maintain a balance between efficiency and conservation, particularly for applications in water-scarce regions. These strategies will ensure that the system not only performs effectively but also remains resource-conscious and environmentally friendly.

To maximize its potential, the system should incorporate smart technologies for enhanced control and monitoring. AI-based predictive algorithms can be integrated into the control system to optimize water flow and temperature regulation in real time, ensuring consistent performance under fluctuating conditions. Furthermore, conducting long-term analyses of the system's reliability, maintenance needs, and impact on panel degradation will provide a comprehensive understanding of its lifecycle benefits. These steps will ensure the system is robust, efficient, and ready for commercial-scale implementation.

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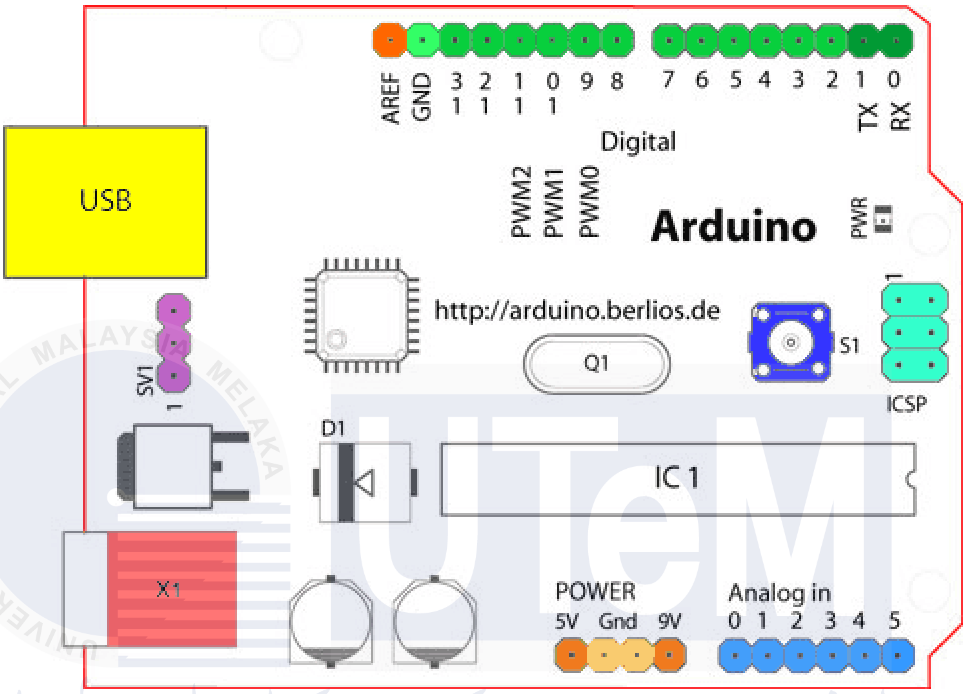
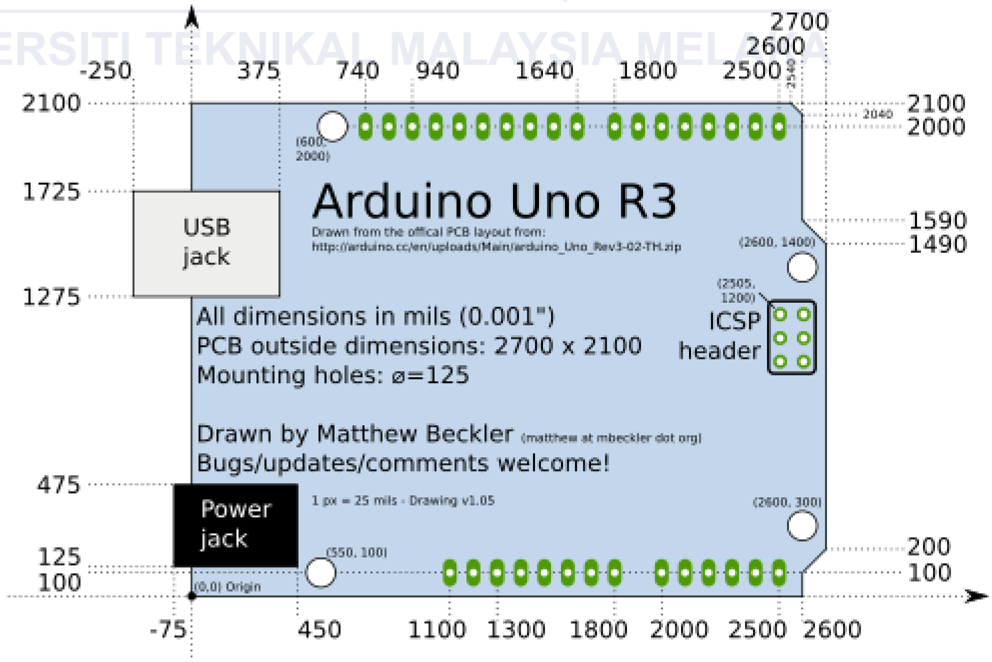
APPENDICES

Appendix 1 Arduino Uno Specifaction





Appendix 2 Solar Panel Datasheet

SOLARTECH® POWER, INC.

F-Series 20W PV Module SPM020P-F

Solartech F-Series Modules

Solartech photovoltaic F-Series Modules are constructed with high efficient polycrystalline solar cells and produce higher output per module than others in it class. This industrial grade module is an industry standard among various industry professionals.

Features

- Accessible junction box with 4-1/2 knockout for ease of installation.
- (EVA) with TPT cushions the solar cells within the laminate an ensures the operating characteristics of the solar cells under virtually any climatic condition
- Rigid anodized aluminum frame and low iron tempered glass
- Easily accessible grounding points on all four corners for fast installation
- Proven junction box technology

Electrical Characteristics

Max power(Pm)	20W
Maximum power voltage(Vpm)	17.2V
Maximum power current (Ipm)	1.17A
Short circuit current (Isc)	1.25A
Open circuit voltage (Voc)	21.7V
Module efficiency	10.0%
Tolerance	±5%
Nominal Voltage	12V
Temperature coefficient of Voc	-0.36%/K
Temperature coefficient of Pm	-0.46%/K
Temperature coefficient of Isc	0.05%/K
NOCT	48℃±2℃
Maximum series fuse rating	10A
Maximum system voltage	600V

Mechanical Characteristics

Construction	Tempered glass, silicon cell, EVA, Polyester with Tedlar
Solar Cells	36 cells (156mm x 26mm) in a 2x18 matrix connected in series
Front Cover	High transmission 3.2mm(1/8") glass
Encapsulant	EVA(Double layers)
Back Cover	White polyester
Frame	Anodized aluminum
Junction Box	IP65, UL94-5VA material
Diodes	Schottky by-pass diodes
Terminal	Accept 8-14 AWG wire
Dimensions	21.7in(550mm)x13.8in(350mm)x1.38in(35mm)
Weight	8.8lb (4.0kg)
Operating Temperature	-40℃～90℃
Storage Humidity	<90%

Appendix 3 Full Coding

Full coding

```
#include <DHT.h>
#include <LiquidCrystal.h>

// Pin definitions
#define DHTPIN 2       // Pin connected to DHT11 data pin
#define DHTTYPE DHT11  // Define DHT sensor type (DHT11)
#define PUMP_PIN 6     // Pin for pump motor control (PWM)
#define LCD_RS 7       // LCD RS pin
#define LCD_ENABLE 8   // LCD Enable pin
#define LCD_D4 9       // LCD data pin D4
#define LCD_D5 10      // LCD data pin D5
#define LCD_D6 11      // LCD data pin D6
#define LCD_D7 12      // LCD data pin D7

// Initialize DHT sensor
DHT dht(DHTPIN, DHTTYPE);

// Initialize LCD (16x2)
LiquidCrystal lcd(LCD_RS, LCD_ENABLE, LCD_D4, LCD_D5, LCD_D6, LCD_D7);

// Temperature thresholds
#define LOW_TEMP_MIN 30
#define LOW_TEMP_MAX 35
#define HIGH_TEMP_MIN 35.01
#define HIGH_TEMP_MAX 45

void setup() {
  pinMode(PUMP_PIN, OUTPUT);
  lcd.begin(16, 2); // Initialize LCD (16 columns, 2 rows)
  dht.begin();

  lcd.print("Temp Control Sys"); // Display startup message
  delay(2000);
  lcd.clear();
}

void loop() {
  float temperature = dht.readTemperature(); // Read temperature in Celsius

  if (isnan(temperature)) { // Check if the reading is valid
    lcd.setCursor(0, 0);
    lcd.print("Error Reading! ");
    return;
  }

  lcd.setCursor(0, 0); // Set cursor to the first row
  lcd.print("Temp: ");
  lcd.print(temperature);
  lcd.print(" C");
```

```
  // Control the pump based on temperature
  if (temperature >= LOW_TEMP_MIN && temperature <= LOW_TEMP_MAX) {
    analogWrite(PUMP_PIN, 128); // Set pump to low speed
    lcd.setCursor(0, 1);        // Move to the second row
    lcd.print("Pump: LOW       ");
  } else if (temperature >= HIGH_TEMP_MIN && temperature <= HIGH_TEMP_MAX) {
    analogWrite(PUMP_PIN, 255); // Set pump to high speed
    lcd.setCursor(0, 1);        // Move to the second row
    lcd.print("Pump: HIGH      ");
  } else {
    analogWrite(PUMP_PIN, 0);   // Turn off pump
    lcd.setCursor(0, 1);        // Move to the second row
    lcd.print("Pump: OFF       ");
  }

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