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PERFORMANCE ASSESSMENT OF A SOLAR MODULE UNDER DIFFERENT WEATHER CONDITIONS THROUGH SIMULATION AND EXPERIMENTAL VALIDATION; A CASE STUDY OF A 2.5 MW SOLAR POWER PLANT AT NAVRONGO, GHANA

RUDOLF ANYOKA NYAABA

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BY
RUDOLF ANYOKA NYAABA

Thesis Submitted to the Department of Physics of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in Partial Fulfilment of the Requirements for the award of Doctor of Philosophy Degree in Physics.

FEBRUARY 2024

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ………………… Date: ………………………

Name: Rudolf Anyoka Nyaaba

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of the thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:…………… Date:……………………

Name: Prof. Baah Sefa-Ntiri

Co-Supervisor's Signature:……………… Date:……………………

Name: Dr. Alfred Owusu

ABSTRACT

The global agenda of increasing the amount of renewable energy used in many nations and organizations is to harness solar energy from solar photovoltaic (PV) cells or systems. However, the generation of power through PV systems is highly affected by the weather conditions. This study is to assess the performance of a JKM 295P-72 solar module in terms of its maximum power output and power output performance efficiency under different weather conditions. Two JKM295P-72 polycrystalline solar modules were used for the outdoor experimental setup for each weather condition - one as the control and the other as the experimental module. The electrical characteristic curves were generated through MATLAB, R2018a simulation of equivalent circuit model equation of the PV module. The results indicate that the solar module is best performed during its clean (control) state with a performance efficiency of 17.4 % and a maximum power output of 282. 8 W; followed by the harmattan module with a performance efficiency of 16.12 % and power output of 259.1 W. This was followed by the dry-windy and then by the rainy weather conditions. The reductions in power output and the reduction in module efficiency under each of the weather conditions were determined. Reasons accounting for the differences in performance under the different weather conditions have been presented. Finally, the relationship between power output, efficiency and solar irradiance has also been highlighted. The performance results for the two consecutive years during which the study was conducted were highly correlated. This study will enable managers of the solar power plant to make informed decisions on the expected output power generated under different weather conditions.

KEY WORDS

Efficiency

Irradiance

Photovoltaic cell

Photoelectric effect

Solar module

Weather conditions

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DEDICATION

To my pillar of strength, my beloved wife, Mrs. Anasthasia Akambonga and to my children.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
IT	Information Technology
TPES	Total Primary Energy Supply
I_{sc}	Short circuit current
V_{oc}	Open circuit voltage
P_{mpp}	Maximum power point
I-V	Current- voltage
P-V	Power- voltage
CSP	Concentrated Solar Power
DC	Direct Current
AC	Alternating Current
SI	Solar Irradiance
T_{pv}	Panel temperature
T_{am}	Ambient Temperature
VRA	Volta River Authority

CHAPTER ONE

INTRODUCTION

The study points out the limited energy supply in the world, in particular, Ghana due to rapid population growth. It also examines the advantages of solar energy resources as an alternative to producing electrical power to augment the traditional sources, the fossil fuels which have been used over several years and are almost depleted to meet the high demand for power consumption. Besides, chapter one examines the problem statement which necessitated the conduct of this research. The objectives of the research have been stated which serves as a guide for the conduct of the research. The significance of the research has been highlighted as well as the limitations and the delimitations of the research.

Background to the Study

According to the World Energy Council (2013) the world has undergone a dramatic transformation in the past two decades, fueled by technology. This rapid advancement, particularly in information technology (IT), has impacted not only our thinking but also our daily lives. One crucial consequence is the ever-increasing demand for electricity, which powers virtually all technologies. This trend is expected to continue as the world's population grows and development progresses.

In 1993, renewable energy was playing in the minor leagues. Only the veterans, hydropower and biomass, got individual attention. However, solar energy and wind energy were lumped together as "Other Renewables," showing their lack of star power. Back then, renewables were barely a blip on the energy radar, overshadowed by the fossil fuel giants. Reasons accounting for this lack of recognition were that renewables were still young and unproven. They were expensive, and the rules of the game favored their established competitors. Plus, people weren't as worried about the environment back then. In this 21st century, renewables have hit the big leagues, thanks to technological breakthroughs, falling costs, and supportive policies. While hydropower and biomass are still strong contenders, solar, wind, and other newcomers are stealing the show.

This historical perspective highlights the incredible journey of renewables and emphasizes the key factors driving their success. It also hints at the exciting potential for these young stars to shine even brighter in the future (World Energy Council 2013)

From powering our homes to generating electricity, the world relies on diverse energy sources. These can be broadly categorized as renewable (like solar), fossil (like coal), and nuclear. Fossil fuels, formed from ancient life, are substantial but ultimately limited. While they've historically dominated our energy mix, the focus is shifting towards renewable sources due to their sustainable nature. While fossil fuels like coal, oil, and gas have long been our main energy source, they're finite and have environmental consequences. Renewable resources, like the traditional hydropower and wood fuels used for heating, are naturally replenished. Today, we're increasingly turning to modern renewables like wind, solar, and geothermal energy for a more sustainable future.(Rothleder et al., 2017).

Before independence, Ghana's electricity relied heavily on dotted diesel generators used by private entities like factories and hospitals. The Akosombo dam marked a turning point, bringing large-scale hydropower and even allowing power exports to nearby countries. Faced with power cuts, Ghana launched a reform in the late 1990s, inviting private companies to share the burden of electricity generation. This was aimed to address the growing demand of electrical energy, which had jumped up to 52% between 2006 and 2016, even though installed capacity was more than doubled during that time. Despite these efforts, Ghana continues to grapple with power supply issues. Despite ongoing power challenges, Ghana has exciting opportunities to tap into its vast renewable energy potential, particularly for solar power. Recognizing this, the country established crucial regulatory frameworks, including the ground breaking Renewable Energy Act of 2011 (Kumi, 2017). Our reliance on fossil fuels for industry is wreaking havoc on our planet's ecosystems and livelihoods. To save our Earth, we must urgently reduce greenhouse gases like carbon dioxide and methane by switching to renewable energy sources. This will not only protect natural habitats but also ensure a healthier future for generations to come. While many renewable energy sources exist, solar power shines brightest in terms of potential, yet most of this solar superpower remains untapped. Through the magic of the photovoltaic effect, sunlight transforms into electricity, offering a clean and abundant energy source waiting to be fully harnessed. (Mandadapu & Vedanayakam, 2017).

Ghana is overflowing with renewable energy potential - from sunlight and wind to waste and water flow, the 2011 Renewable Energy Act recognizes various ways to harness these never-ending resources. Hydropower, solar farms, wind turbines, and even technologies using waves and tides are all options for Ghana to achieve a sustainable energy future. Ghana's abundant sunshine offers a powerful solution to its electricity challenges. With a staggering 35 exajoule solar potential, the country could generate 100 times her current needs, estimated at 53,000 MWh annually. This translates to utilizing an average daily solar radiation of 4.4-5.6 kWh/m^2 to produce clean, sustainable energy. Harnessing this potential could significantly surpass current power demands. Sunshine varies across Ghana, with Kumasi averaging 5.3 hours and Wa averaging 7.7 hours daily. Northern, Upper East, Upper West, and parts of Volta and Brong-Ahafo regions hold significant potential for solar energy due to their high average radiation of 4.0-6.5 kWh/m^2/day. (Aboagye et al., 2021).

One cannot overstate the benefits of solar energy. Direct conversion of solar radiation into electricity, the absence of mechanical moving parts, noise, high temperatures, and pollution are a few of these benefits. PV modules have an incredibly long lifespan, and the sun provides a limitless, free energy source. A PV cell's power rates range from microwatts to megawatts, making it an incredibly versatile energy source. (Goetzberger & Hoffmann, 2005).

The economic and environmental benefits of using photovoltaic cells to convert solar energy into electricity have led to a growing interest in developed and developing nations to increase funding for photovoltaic systems in order to increase their efficiency in recent years. Studies by Mekhilef et al. (2012) and Kazem & Chaichan (2015) reveal that photovoltaic cell performance isn't just about the cell itself. Dust, humidity, temperature, and even air flow can play a surprising role. This emphasizes the need for comprehensive research that not only investigates the cell's material and design but also considers these important environmental factors. Northern and Upper Eastern of Ghana face harsh weather and dust conditions, known to hinder solar panel efficiency (Jha & Tripathy, 2019). However, these regions gleam brightly in terms of solar potential, receiving the highest amount of sunlight in the country. Places like Navrongo experience 7.7 to 12.6 hours of sunshine daily, making them ideal for generating substantial solar energy to supplement Ghana's energy needs. Balancing the challenges with this remarkable potential is crucial for maximizing solar energy utilization in these regions.

Climatic conditions in Northern Ghana

Ghana's climate, like many tropical regions, is defined by two distinct seasons: the wet and dry seasons (Ghana Travel Weather Average, 2013). The timing of these seasons varies slightly across the country. In the north, the rainy season is from April to mid-October, while the south experiences its downpours from March to mid-November (Ghana Travel Weather Average, 2013).

Despite its tropical location, Ghana boasts of a relatively mild climate for its latitude (Ghana Travel Weather Average, 2013). However, the harmattan, a dry desert wind blowing from December to March, brings a unique twist to the north. This wind, lowering humidity and causing hotter days and cooler nights, is a defining feature of the Ghanaian winter (Nsiah-Gyaba et al., 2010).

Average daily temperatures in Ghana paint a picture of warmth: 30°C (86°F) during the day and 24°C (75°F) at night, with relative humidity hovering between 77% and 85% (Ghana Travel Weather Average, 2013). The south, however, experiences a bi-modal rainy season, with showers spiking in April-June and September-November (Ghana Travel Weather Average, 2013). In the north, squalls mark the transition from dry to wet, occurring in March and April, followed by occasional rain until the August-September peak (Nsiah-Gyaba et al., 2010). Rainfall varies across the country, ranging from 78 to 216 centimeters (31 to 85 inches) annually (Ghana Travel Weather Average, 2013).

Statement of the Problem

There have been power fluctuations in Ghana of recent years that adversely affect both domestic and industrial consumers of electrical energy. The 2.5 MW solar power plant at Navrongo, a town in the Upper East Region of Ghana is a grid fed that contributes to electricity supply to the nation. However, the plant is faced with harsh weather conditions, such as harmattan, dry-windy and rainy. It is envisaged that the efficiency and power output of the facility could be affected negatively by these weather conditions.

Purpose of the study

The purpose of the research is to gain in-depth understanding of the environmental effects on the performance of a solar module at the northern part of Ghana through simulation and experimental validation. Moreover, the study is to predict the maximum power output of the solar module under any weather condition at any given time. Additionally, the study is to estimate the efficiency of the module under any weather condition through the module electrical characteristics.

Research Objectives

The main objective of the study is to evaluate the performance of a photovoltaic (PV) module (JKM295P-72) of the 2.5 MW solar power plant at Navrongo under the stated conditions as stated in the research problem. The specific objectives of the study are outlined below:

1. To simulate and assess the performance of the module based on weather conditions such as dust particles (harmattan) and water droplets (rain).

2. To experimentally validate the simulated behavior patterns of the key parameters (current, panel temperature, voltage and power) of the solar module under different daily weather conditions for two continue year.
3. To simulate the electrical characteristics of the PV module under the experimental weather conditions (Harmattan, Rainy, and Dry-Windy), using computer MATLAB, R2018a. coding.
4. To evaluate the average maximum power output and efficiency of the module under the various weather conditions.

Significance of the Study

The significance of this research cannot be over emphasized. In particular, this could be seen at two fronts, vis-a-viz; industrially, and research and development. Industrially, it is going to benefit production industries around the 2.5 MW solar power plant at Navrongo. This is because the simulated model produced will be used to predict the power output at any point in time of any weather condition. This will helps minimize production losses as industry owners will plan how to go about their production schedules. Additionally, this will benefit research and development.

Delimitations

This study is delimited to the assessment of the performance of a solar module (JKM295P-72) at the Navrongo 2.5 MW solar power plant. The research is also delimited to the evaluation of the effects of the three weather conditions (dry, rainy and harmattan) on the I-V and P-V characteristics of the solar module at Navrongo in the northern part of Ghana.

Limitations

The overall outcome of the study might be limited by the following factors: First, the unstable weather and atmospheric conditions might affect the outcome of the study due to its outdoor nature. Additionally, systematic errors of the measuring instruments could be another factor. Moreover, the lack of modern equipment for data taking could be an additional factor which could affect the outcome of the study. Lastly, frequent human interference in the data-taking process might have introduced some errors in the data.

Organization of the Study

The study is organized in five chapters. Chapter one gives the introduction of the study. In this chapter, the background of the study has been explained. Besides, the problem statement, the objectives, the significance, the delimitations and the limitations of the study have all been explained. Chapter two is the literature review which covers the theoretical, conceptual as well as the empirical frameworks of the study. It seeks to review relevant literature in the study area in order to lay a foundation for this study. It spans the broader to the focused perspective of the study area. Chapter three covers the methodology of the study. It describes at the instrumentation used as well as the procedure used in collecting data for the study. Chapter four elucidates results and discussion of the data collection. The data is organized in various tables and figures for analysis and discussion. The fifth chapter of the thesis spells out the conclusions, recommendations as well the areas for further research. The final part of the thesis is the list of references cited in the study followed by pages of appendices.

CHAPTER TWO

LITERATURE REVIEW

Introduction

Solar energy has emanated as a vital component in the global pursuit of sustainable and renewable energy sources. Its inexhaustible and environmentally friendly nature makes it a compelling solution for addressing the pressing issues of energy security and climate change. The efficacy of solar energy generation depends not only on the inherent qualities of photovoltaic modules but also on the dynamic environmental conditions under which they operate (Amaral et al., 2015). This intersection of technological performance and environmental variability is a subject of paramount importance in the quest for sustainable energy solutions. In the context of solar energy systems, understanding how solar modules perform under varying weather and atmospheric conditions is fundamental to their efficient utilization.

As the deployment of solar energy technology continues to expand worldwide, so too does the necessity for empirical insights into the performance characteristics of photovoltaic modules across diverse environmental scenarios. Solar modules are subjected to a multitude of environmental factors such as temperature fluctuations, irradiance variations, humidity levels, and the potential accumulation of atmospheric particulates soiling effects (El-Shaer et al., 2014; Nashih et al., 2015; Tress et al., 2019; Sharma and Goyal, 2021; Karafil et al., 2016; Mustapha et al., 2013; Rao et al., 2014, Weber, 2020; Zaoui et al., 2015).

The choice of Navrongo as a case study is not incidental, but rather a strategic one. Ghana, as a rapidly developing nation, is actively embracing solar energy as a source of power generation, capitalizing on its abundant solar resources. The Navrongo solar power plant stands as an embodiment of this transition and offers an ideal platform to explore the performance of solar modules within the unique climatic and atmospheric conditions prevalent in the region. This literature review aims to provide a comprehensive understanding of how solar modules perform under the dynamic weather and atmospheric conditions found in Navrongo, Ghana.

By reviewing the existing body of literature on this topic, we seek to identify research gaps and set the stage for this investigation, which will contribute not only to the theoretical knowledge of solar module performance but also to the practical advancements in solar energy technology in real-world applications. The following sections of this review will explore various factors affecting solar module performance, discuss previous studies in this field, elaborate on the significance of solar energy in Ghana and the theoretical frame of solar power production in general.

Energy Resources and their Global Significance

In the contemporary world, energy resources play an important role in sustaining and driving the growth of society. They are indispensable to meeting the ever-increasing demands for transportation, heating, electricity, and industrial operations on a global scale (Kober et al., 2020). The significance of energy resources to the planet can be approached from several angles. Firstly, energy resources are often regarded as the cornerstone of economic progress (Shang et al., 2023). Power support businesses, infrastructure, and drive industries, enabling the production and delivery of goods and services. Access to affordable energy is closely linked to elevated living standards, increased investments, and a boost in economic output. Likewise, Qazi et al. (2019) emphasize that energy resources have a direct impact on the quality of life for individuals and communities. They provide the energy required for heating, and electricity, as well as appliances, lighting, and cooling systems, thus influencing access to healthcare, education, sanitation, and cooking services. Reliable and affordable energy plays a vital role in improving the well-being of the populace, reducing poverty, and fostering social development.

Furthermore, the research underscores the importance of energy supplies in maintaining global connectivity, particularly through transportation systems such as automobiles, trucks, ships, and aircraft that facilitate the movement of people and goods over vast distances (Dudley, 2019; Liu & Lee, 2020). Energy also fuels communication networks, supporting the internet, mobile devices, and data centers, thereby enabling international communication and information sharing. However, it is important to acknowledge that the choice and use of energy resources have a profound impact on the environment. Fossil fuels, including coal, oil, and natural gas, have been the primary energy sources for many years, but their production, combustion, and emissions have adverse effects on the air, water, climate, and ecosystems (Resniova and Ponomarenko, 2021). To address these environmental challenges, a transition to cleaner and more sustainable energy sources, such as nuclear power and renewable energy (solar, wind, and hydropower), is imperative.

Over-reliance on foreign energy supplies poses a risk to the security and sovereignty of a country (Oliveira-Pinto et al., 2020). Diversifying energy sources to include local production and renewable energy can reduce vulnerability to supply disruptions, price volatility, and geopolitical conflicts

(Khan et al., 2023). For sustained economic progress and national security, a secure and reliable energy supply is essential (Bibi et al., 2020). The urgent need to address climate change is increasingly recognized, with energy resources playing a pivotal role in mitigating greenhouse gas emissions, the primary contributors to global warming (Kalair et al., 2021). To minimize atmospheric greenhouse gas concentrations and mitigate the adverse impacts of climate change, a shift to low-carbon and carbon-neutral energy sources is imperative (Wang et al., 2021).

The influence of energy resources extends across global economic, educational, societal, and health systems. Specific country examples demonstrate how energy resources shape these systems, from fueling economic growth and sustaining industries to enhancing social well-being, improving educational environments, and supporting healthcare facilities. Access to reliable, sustainable and affordable energy is a fundamental element for ensuring the overall development and prosperity of nations, particularly emerging economies like Ghana. The economy of Ghana heavily relies on energy supplies to power its infrastructure, businesses, and industries, supporting industrial growth, manufacturing, and the extraction of natural resources. The accessibility of energy resources is vital for economic development, investment attraction, and job creation across various sectors. The diverse energy resources in Ghana, including natural gas, hydroelectric power, and solar potential, contribute to energy security, reduce import dependency, and stimulate local economic activity.

Conversely, ensuring quality education in Ghana faces challenges due to the lack of access to reliable energy in many areas. Access to electricity is vital for optimal learning, enabling the use of technology, digital materials, e-learning platforms, and online learning. Initiatives like the Ghana Energy Development and Access Project aim to bring electricity to schools in rural areas, thereby enhancing the learning environment and providing students with essential learning resources. From a societal perspective, electricity is crucial for improving living conditions, lighting homes, running appliances, and sustaining communication technology. It promotes social interactions, facilitates access to information and entertainment, and enhances the overall quality of life. Poor access to power in rural regions can hinder social development initiatives, as shown by the impact on the Rural Electrification Project's goal of expanding electricity coverage. Increased access to electricity supports healthcare services by enabling the use of medical equipment, the construction of healthcare facilities, and the refrigeration of vaccines and medications, ultimately improving healthcare outcomes.

Energy Resources, Access and Challenges in Ghana

The energy environment in Ghana is notably traditional fossil fuel-based energy sources coexist with a growing emphasis on renewable energy sources. According to the Ministry of Energy and Natural Resources, the major energy resources in Ghana are hydroelectric power, fossil fuels, thermal power and some renewable energy resources including solar energy and, biomass. Biomass in particular, which includes forestry byproducts and agricultural waste is a sustainable energy source in Ghana frequently used for cooking and heating in rural areas. There have been investigations on the possibilities of wind energy along the coastline of Ghana. The Ayitepa Wind Farm is the first kind of wind energy utilization in Ghana, which is currently under construction and is anticipated to help Ghana achieve its targets for renewable energy.

Ghana has undertaken several initiatives to enhance access to energy. The Rural Electrification Project, the Renewable Energy Master Plan, and the National Electrification Scheme were launched to help increase access to energy in underserved areas and rural communities in Ghana. While Ghana has made strides in various aspects of energy production, several challenges persist, including inconsistent electricity supply in some areas, high energy costs, inadequate transmission and distribution infrastructure, and limited access to modern energy services in remote regions (Owusu-Manu et al., 2021). Ghana has implemented laws, regulations, and measures to attract investments, stimulate private sector participation, and promote renewable energy projects (Kuamoah, 2020) to address these issues and advance sustainable energy development. The commitment by Ghana to sustainable energy and ongoing efforts to tackle these challenges are pivotal in ensuring its population has access to reliable, affordable, and environmentally friendly energy sources.

Investments, Challenges and Opportunities in Renewable Energy Sources

The government of Ghanaian has demonstrated its dedication to developing renewable energy through several programs, legislation and policies. These include the Renewable Energy Act of 2011, the creation of the Renewable Energy Fund, and the Renewable Energy Master Plan, all of which seek to draw funding, offer incentives, and foster an atmosphere that is supportive of renewable energy projects ((Kuamoah, 2020)). Investment in renewable energy in Ghana has also been significantly influenced by the private sector. Companies from abroad and locally have invested in initiatives including solar farms, wind farms, and mini-hydropower plants. Public-private collaborations are advocated as a way to pool knowledge and resources for the advancement of renewable energy sources (Nyasapoh et al., 2022). International organizations and development partners have helped Ghana promote renewable energy. Financial organizations like the World Bank and the African Development Bank support renewable energy projects with finance and technical help, boosting investment and capacity building (Mahama et al., 2021).

Accessing enough finance is one of the biggest obstacles to the growth of renewable energy in Ghana. Investment may be hampered by high upfront costs, protracted return times, and perceived dangers related to renewable energy projects. For the sector to get greater investment, removing financial obstacles and granting access to inexpensive financing alternatives are essential. Technical difficulties have arisen while integrating sporadic renewable energy sources into the current electrical infrastructure. The potential of renewable energy must be maximized by ensuring grid stability, modernizing transmission and distribution infrastructure, and applying smart grid technology. Although Ghana has made strides in creating rules and regulations for renewable energy, it is essential to ensure uniformity, clarity, and openness in the legal system. A favorable climate for renewable energy investment may be created by streamlining permitting procedures, removing regulatory bottlenecks, and offering long-term benefits.

Ghana has a considerable solar energy potential thanks to its year-round sunshine. Decentralized and utility-scale solar power generating expansion therefore offers significant investment potential. Solar farms, rooftop solar systems, and solar-powered mini-grids in distant places all fall under this category. Ghana's coastal regions provide advantageous wind resources for the production of wind power. Creating utility-scale wind farms and investigating the possibility of offshore wind can help the nation meet its goals for renewable energy. Ghana has an abundance of biomass resources, including organic waste and agricultural waste. By using these resources for bioenergy and waste-to-energy initiatives, waste management issues may be resolved and renewable energy can be produced. Ghana's hydropower potential is unexplored, especially for small- and mini-hydropower plants. Decentralizing and installing small hydropower plants can help with the production of sustainable energy

Solar Energy

The core of the solar energy concept is using the radiant energy from the sun to generate, store, and use electric energy. Solar energy has emerged as a crucial renewable energy source in the quest for a sustainable and environmentally friendly future. Research conducted by (Yang et al., 2022)) indicates that solar energy is a viable and abundant alternative as the world battles the consequences of climate change and the depletion of fossil fuel reserves. The advantages, applications, and potential of solar energy help to lessen the negative effects on the environment, promote energy independence and speed up economic growth. Experts in energy resources agree that solar energy is an inexhaustible resource due to its dependence on the sun which provides an abundant supply of energy ((Gong et al., 2019)).

The sun can reportedly provide all of the world's energy needs and then more, offering a long-term solution to the planet's expanding energy demand(Verduci et al., 2022). Furthermore, solar energy, in contrast to fossil fuels, is a pure source of energy that produces little greenhouse gases and, as a result, does not contribute to air pollution, acid rain, or water contamination (Rabaia et al., 2021). As a result, solar energy is a green option for decreasing climate change and safeguarding the environment for future generations. With decreased reliance on imported fossil fuels, countries may increase their energy security and self-sufficiency. Therefore, nations may diversify their energy sources and lessen their susceptibility to volatile global energy markets by harnessing their abundant solar resources.

Photovoltaic (PV) technology, which employs solar cells Fang et al. (2021) to convert sunlight directly into electricity, is the foundation of solar energy. Large-scale solar farms or rooftop PV installations may supply power to homes, businesses, and even entire cities. Due to decreasing solar panel costs and rising efficiency, solar PV is becoming more accessible and economically feasible. Solar thermal systems, on the other hand, reduce the need for electricity or fossil fuels by harnessing the sun's energy to generate heat, which is then used to heat water for domestic and commercial use. In a manner akin to this, Concentrated Solar Power (CSP) facilities focus sunlight using mirrors or lenses to produce steam that drives turbines to produce energy on a larger scale.

According to various study findings, solar energy is suitable for off-grid people and remote areas with limited access to power. For instance, freestanding solar systems, such as solar lanterns and microgrids, that provide affordable and dependable electricity for lighting, communication, education, and healthcare not only improve the quality of life but also stimulate socioeconomic growth, according to Jebli et al. (2021). These reasons have led to the recent rapid expansion of the solar energy sector supporting economic development and the creation of jobs, particularly in developing countries (Hosseini and Wahid, 2020). A wide range of job possibilities is created by investments in solar energy infrastructure, manufacture, installation, and maintenance, from specialized labour for research and development to supporting a green economy and boosting local industries (Kou et al., 2022).

Solar energy allows individuals to overcome energy poverty and creates pathways for business, healthcare, education, and general socioeconomic improvement Irfan et al. (2021) by offering affordable, decentralized power options. This has also played a significant role in facilitating developing regions' access to electricity. The advancement of solar energy technology is continually driving innovation and efficiency advances. Currently, studies are being conducted to develop more efficient solar cells, enhance energy storage technologies, and look into innovative materials. Due to these advancements and expanding economies of scale, solar energy will become even more competitive and inexpensive in the global energy market.

Solar Power Production and Global Perspective

Solar power production from a global perspective has experienced remarkable growth in recent years, with increasing recognition of its potential as a clean and sustainable energy source. According to Agyekum and Velkin (2020) the global trend holds significant implications for Africa, including Ghana, as the continent strives to meet its energy needs, drive economic growth, and combat climate change. Here is an overview of solar power production from a global perspective, its link to Africa, and its relevance to Ghana.

Several countries, such as China, the United States, India, and countries in Europe, have emerged as leaders in solar energy deployment (Amo-Aidoo et al., 2022). The cumulative installed solar capacity globally has increased exponentially, adding to a more diversified and sustainable energy mix. Nonetheless, the global perspective on solar power production has undergone a remarkable transformation in recent years. For instance, solar power has emerged as a frontrunner to fight climate change and fulfil the rising energy demands of a rapidly expanding global population as the globe struggles with the urgent need to transit to clean and sustainable energy sources (Ibrahim, 2013). It has caused a worldwide boom of installations that has never before occurred. Despite the difficulties caused by the COVID-19 epidemic, the International Energy Agency (IEA) reports that solar photovoltaic (PV) capacity increased by an astounding 18% in 2020. Declining prices, technical developments, favourable legislation, and rising environmental consciousness all contribute to this expansion (Agyekum, 2021).

Since solar energy is a clean, renewable resource that produces electricity without releasing greenhouse gases or other dangerous pollutants, it has several major benefits for the environment. Due to this quality, solar energy generation is an essential part of worldwide efforts to slow down global warming, lessen reliance on fossil fuels, and move towards a low-carbon economy (Mekhilef et al., 2012). Solar power may be used at a variety of scales, from modest residential rooftop systems to huge utility-scale solar farms, and it offers unmatched scalability and adaptability. Due to its adaptability, solar energy may meet a variety of energy demands, whether in isolated, off-grid places or heavily populated cities.

The modular nature of solar PV technology also allows for easy capacity expansion, making it a viable option for addressing increasing energy demand in a rapidly growing world (Aboagye et al., 2021). It also stimulates local economies, creates jobs, and fosters technological innovation necessary for manufacturing and installation to operation and maintenance. In this regard, the solar industry generates employment opportunities across the value chain. As solar power becomes more mainstream, it also attracts investments and drives research and development, leading to further cost reductions and efficiency improvements.

Additionally, by lowering dependency on imported fossil fuels and diversifying the energy mix, solar power generation promotes energy security and independence. This will increase a nation's energy security while lowering its susceptibility to geopolitical threats and price volatility (Flammant et al., 2021). Decentralized energy options provide communities and people more power, especially in places with sparse or nonexistent grid infrastructure. By promoting energy availability, this feature of solar power generation raises the standard of living and expands socioeconomic possibilities for disadvantaged communities. Solar power generation does have certain drawbacks despite its many advantages. For instance, to maintain a consistent and dependable power supply given the intermittent nature of solar energy owing to fluctuations in sunshine availability, effective energy storage systems are needed.

Additionally, even though energy storage technology has seen considerable breakthroughs, more work has to be done in this area to increase storage capacity, boost effectiveness, and lower prices (Balana et al., 2021). The upfront cost of building solar power systems presents another difficulty. Although the cost of solar PV technology has drastically decreased recently, it still presents a barrier in some areas, especially in low-income neighborhoods.

To overcome this obstacle and increase the accessibility of solar energy for everyone, access to inexpensive financing choices and encouraging regulations are essential (Odoi-Yorke and Woenagnon, 2021). However, the future of solar energy generation is bright and has a great deal of promise.

According to studies, solar power output is accelerating as more and more organizations, industries, and people are realizing how urgent it is to combat climate change and achieve sustainable development goals. Solar energy will become increasingly more competitive with conventional energy sources thanks to technological breakthroughs, improved efficiency, and economies of scale (Asante et al., 2023).

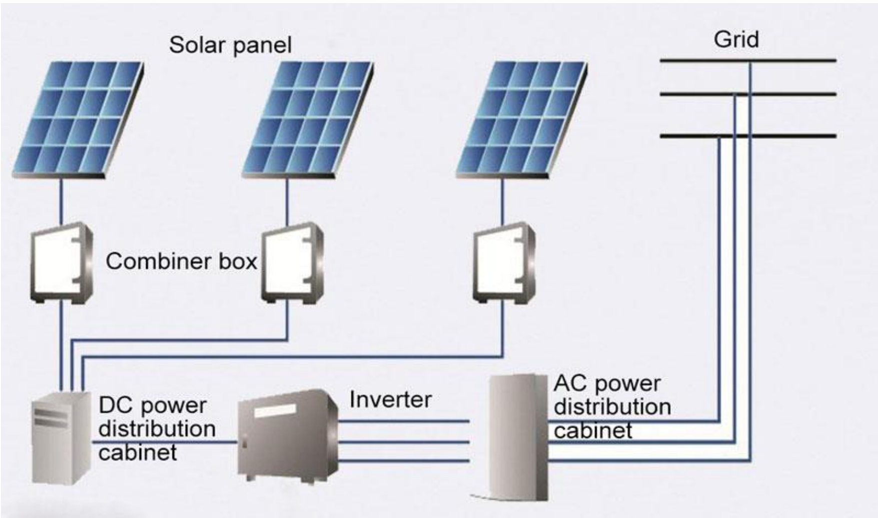


Figure 1: A typical solar power generation set up (Source: https://www.inverter.com/6-factors-affecting-solar-power-system-efficiency)

Figure 1 demonstrates the process of typical solar power generation. When solar radiation is incident on the solar panels, the photon energies in the sunlight is absorbed by the electrons on the surface of the solar cell. Those electrons whose binding energies are less than the photon energies are displaced causing direct (DC) current generation. The current generated is collected by the combiner boxes and is directed into the DC power distribution cabinet. The DC is converted into alternating current by an inverter and is stored in an AC distribution cabinet

Factors that affect Solar Power Production

The solar panel modules are exposed to the natural environment for a long time, and factors such as wind, irradiance, humidity, water droplets from rainfall and temperature can affect the performance of a solar cell. Irradiance, wind, temperature and so on will change the photoelectric performance efficiency of solar panels (cells). Some of these factors are described as follows:

Geographic Location

Every location receives different quantity of sunshine each year. The amount of sunshine depends on the latitude, longitude, time, and regional weather. Areas that are closer to the equator generally receive more sunlight and therefore have a higher solar energy production potential (Agbo et al., 2015). This information can be used to design a cost-effective solar array by calculating the quantity of solar radiation received at a chosen site.

Time of Day and Season

The amount of sunlight reaching the earth's surface varies throughout the day. Solar energy production is highest during midday and in the summer months when the sun is higher in the sky and days are longer. During early morning, late afternoon, and in the winter when the sun is lower in the sky and days are shorter the solar energy production is lower in comparison. Research reveals the different factors that can affect the efficiency of solar panel mounting systems. Such factors have been studied to either increase or decrease the power production from the sun intensity, cloud cover, relative humidity and heat buildup. When the sun is at its peak (intense) usually midday, the most solar energy is collected; therefore, there is an increase in the power output. Cloudy days contribute to the decrease in sunlight collection effectiveness since clouds reflect some of the sun’s rays and limit the amount of sun absorption by the panels (Gordo, 2015).

Shading

A clear and bright day will lead to high production of solar energy as compared to the days when there are clouds. The energy generation is not 0%. It gets lowered but still energy production happens. It depends mainly on the efficiency of the solar panels. Total or partial shading conditions have a significant impact on the capability of a solar cell delivering energy and may result in lower output and power losses. Cells in a solar panel are usually connected in series to get a higher voltage and therefore an appropriate production of electricity.

Shading presents some limitations to the operations of a solar cell. In fact, when a single solar cell is shaded, the current of all the units in the string is determined by the unit that produces the least current. When a cell is shaded, the whole series is virtually shaded too. (Geetha and Usha, 2022; Mustafa, 2020). Among factors militating against the efficiency of a PV module 'shading' emerges as the most potent determinant of PV module efficiency. In particular, altering the shaded area on a PV module surface—by a quarter, half, and threequarters—correspondingly leads to power reductions of 33.7%, 45.1%, and 92.6%. Conversely, the presence of water droplets exhibited an inverse effect, inducing a temperature drop in the PV panel (Mustafa et al., 2020)

Dust

The effect of dust on the photovoltaic module surface had been studied by Ndiaye etal (2013) under Sahelian environment. The impact of dust on the I-V and P-V characteristics of PV modules after an exposition year under Sahelian conditions without cleaning was emphasized. In the study, it was also shown that the relative differences of PV module performance parameters between the case where the modules were not cleaned after an exposition a year under Sahelian environment and the case where they were cleaned after one year under the same environment. The study results revealed that P_{max}, I_{max}, I_{sc} and FF were the most affected performance characteristics by the dust deposits on the surface of the PV modules surface (Ndiaye et al., 2013).

Comparative study of total of seven dust samples has been carried out at three radiation levels of 650, 750 and 850 W/m^2 with different dust sample weights. Due to the accumulation of dust particles on the surface of solar PV systems, output power is reduced to a large extent. It is concluded that a small layer of dust itself reduces PV system efficiency to a large extent (Ndiaye et al., 2013; Bhol & Ali, 2015).

Temperature

PV modules typically experience temperature increases during operation due to the absorption of sunlight and inadequate heat dissipation. Temperature influences the efficiency of the photovoltaic cell due to the intrinsic characteristic of semiconductor material. The Temperature has a direct impact on the performance of a solar PV module (Tress et al., 2019) Higher temperatures can lead to decreased efficiency and power output.

Concept of Solar Power Production

Figure 2 is A schematic diagram of a solar cell showing all its component parts. The main parts are the top surface layer coated with antireflective material, where the solar radiation incident the cell and where the electrons are generated (n-type). The holes, however, are contained in the p-type the back electrical contact layer. There are also the top and bottom layers to separate the two charges and external circuit through which the current flows.

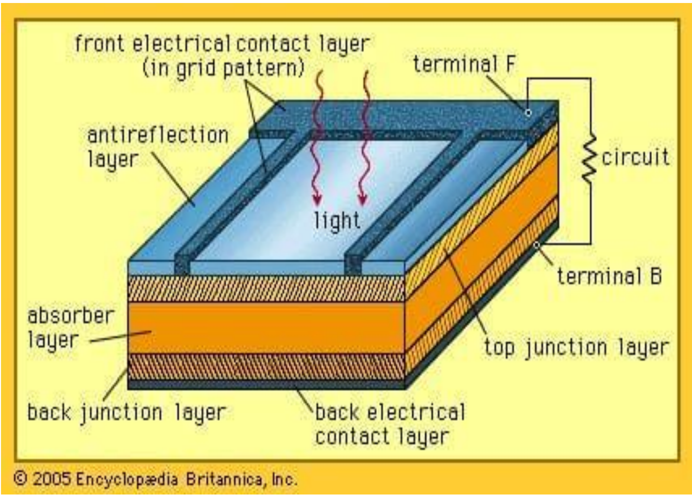


Figure 2: A schematic diagram of a solar Cell (Ashok, S. et al 2023).

Ashok, S. et al (2023), stated that solar cell (also called photovoltaic cell), is any device that uses the photovoltaic effect to directly converts light energy into electrical energy. Most solar cells are made from silicon due to the lower cost and the relatively higher increasing efficiency since the materials range from amorphous (monocrystalline) to polycrystalline to crystalline (single crystal).

They are semiconductors that are essential for converting sunlight into electricity, providing a clean, plentiful, and reliable energy source (Kim et al., 2021). Solar cells are contributing to accelerating the shift towards sustainable in the future, according to several studies that have examined their relevance, working theory, uses, and future prospects. For instance, Fukuda et al. (2020) observed that solar cells are essential to the worldwide search for sustainable energy sources for a number of reasons, including its ability to harness the sun's unbounded power to produce an endless supply of energy.

Studies have shown that solar cells help reduce dependency on finite fossil fuels and subsequently reduce the environmental effect related to their extraction and burning by converting sunlight into electrical energy (Liu et al., 2020). Solar cells also play a crucial role in lowering carbon footprints and battling climate change since they create power without emitting greenhouse gases, making them a clean and low-carbon alternative to traditional energy sources. These qualities solve one of the biggest issues with the increasing demand for electrical energy.

For instance, it makes it possible for people, communities, and even entire countries to produce their own power, so enabling energy independence. As a result, there is less reliance on centralized energy infrastructure and power production becomes decentralized. It also increases energy security and self-sufficiency while fostering independence from the erratic markets for fossil fuels. (Yoo et al., 2021). Solar cell utilization makes distributed generation possible and makes it possible to produce energy at the point of consumption.

This feature gives communities, especially those in distant or underdeveloped locations, the ability to receive energy and enhance their quality of life without the need for a robust grid infrastructure (Wu et al, 2021).

Scalability and adaptability are two further advantages of solar cells, according to research by the International Energy Agency (IEA, 2020). According to the paper, solar cells are used on a range of sizes, from modest home systems to substantial solar farms. Their adaptability enables a variety of uses, from supplying electricity to large towns or regions to powering individual homes and businesses.

Types of Solar Cells

There are many different varieties of solar cells, often known as photovoltaic cells, each of which uses certain components with unique properties. For renewable energy technologies to advance and solar energy performance efficiency to be maximized, it is crucial to comprehend the many types of solar cells and the materials that make up their corresponding components. The many types of solar cells' distinctive properties are provided by composite materials (IEA, 2020):

1. Crystalline Silicon Solar Cells: Solar cells made of crystalline silicon are the most popular and economically dominating form. They are renowned for their effectiveness, dependability, and durability. Two varieties of crystalline silicon solar cells exist:

    i. Monocrystalline Silicon: High-purity silicon is used to create a single crystal structure for the cells. It has great efficiency, rounded edges, and a consistent black appearance. Monocrystalline cells operate well in both high- and low-light environments.

ii. Polycrystalline Silicon: The cells are composed of several broken or rough crystals that have a blue appearance. Although less efficient than monocrystalline cells, polycrystalline cells are produced from less costly technology.

2. Thin-Film Solar Cells: Compared to crystalline silicon cells, the thin semiconductor layer used in these cells allow for flexibility and cheaper manufacturing costs. The primary varieties of thin-film solar cells include:

i. Cadmium Telluride (CdTe): These cells offer exceptional efficiency, cheap production costs, and great performance in low-light situations since they are made of a thin layer of cadmium telluride semiconductor. They are commonly utilized in substantial solar energy installations.

ii. Copper Indium Gallium Selenide (CIGS): The cells are made of a thin coating of selenium, gallium, copper, and indium. High efficiency, adaptability, and exceptional performance in low-light situations are all features of the cells. They are appropriate for a variety of uses, such as solar systems incorporated into buildings.

iii. Amorphous Silicon (a-Si): These cells are flexible, light, and operate well in low light because of their non-crystalline silicon construction. They may be incorporated into a range of surfaces, including curved or flexible ones.

Solar Cell Materials and their Characteristics

Solar cells are constructed using semiconductor materials that exhibit the unique property of functioning as conductors in the presence of energy and as insulators in other situations. Currently, the dominant technology for solar cell production relies on silicon-based materials, which have evolved into the most mature and widely adopted choice (Solak and Irmak, 2023). Semiconductor materials used in solar cell manufacturing can be categorized into three main types: crystalline, multi-crystalline, and amorphous semiconductors (Solak and Irmak, 2023).

The crystalline silicon (c-Si) features a regular atomic arrangement, making it the most expensive among semiconductor materials due to its ordered structure. The multi-crystalline or polycrystalline silicon (poly-Si) consists of regions of crystalline Si separated by grain boundaries, where atomic bonding is irregular. Amorphous silicon (a-Si) lacks a structured atomic arrangement, resulting in areas within the material containing unsatisfied bonds.

Photovoltaics (PV)

Solar energy research has attracted a significant attention for several decades, with the photovoltaic effect being discovered by French scientist Becquerel in 1839 (Lincot, 2017). This marked the beginning of significant developments in photovoltaics. In 1954, the United Kingdom initiated its first project to produce electricity using photovoltaic technology, led by Heywood. The photovoltaic effect occurs when photovoltaic cells absorb photons of light, subsequently releasing electrons that can be harnessed as electric current (Slaoui, 2017). A photovoltaic module typically comprises of multiple solar cells constructed from semiconductor materials, such as silicon which are interconnected electrically and secured within a frame. A photovoltaic module represents the amalgamation of multiple cells housed within a single frame. Beyond this, a solar array is formed by grouping several modules, as illustrated in Figure 3.

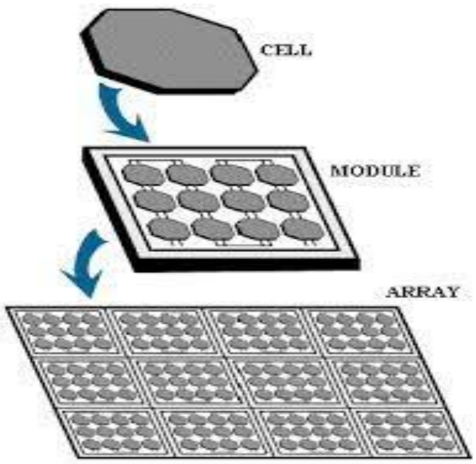


Figure 3: Photovoltaic array assembly (Anteneh and Alene, 2020)

Figure 3 displays how solar cells are arranged. A number of solar cells are arranged into a solar module and the number of solar modules are arranged into arrays. These arrangements are informed by the amount of solar power that is required to be generated for a particular purpose.

Photovoltaic (PV) technology is experiencing continuous advancement. The application of new advanced materials, driven by considerations of cost, performance, and fabrication, has led to the emergence of successive generations of solar cells (Dada and Popoola, 2023; Solak and Irmak, 2023; Slaoui, 2017; Lincot, 2017).

The P-N Junction

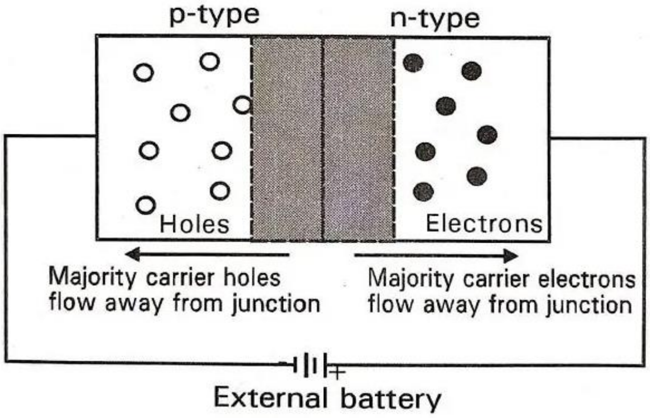


Figure 4: Reverse Bias of a PN Junction (Attia, 2020)

Figure 4 illustrates how a P-N Junction woks in relation to a photovoltaic cell. When two semiconductors, specifically P-type and N-type, come into contact, as seen in Figure 4 above, a P-N junction is formed. Depending on the type, each type's impurities add an excess of positive (holes) or negative (electrons) charge carriers: P-type in P-type, N-type in N-type. A specific set of events that appear when a P-N junction forms are as follows:

- Depletion Region: At the intersection, the excess charge carriers from both sides disperse, creating a depletion area. Positive and negative ions form as a result of the diffusion of electrons and holes in this region, creating an electric field that prevents further diffusion.
- Barrier Potential: In the depletion region, a potential differential known as the barrier potential or built-in potential appears. This potential impedes the flow of charge carriers across the junction.
- Forward Bias: When a voltage is supplied with the negative terminal connected to the N-type side and the positive terminal connected to the P-type side, the barrier potential is lowered, allowing charge carriers to cross the junction and resulting in a current flow.

- Reverse Bias: Applying a voltage in the opposite direction prevents charge carriers from moving across the junction, raising the barrier potential.

Photoelectric/Photovoltaic effect

When a material absorbs electromagnetic radiation, electrically charged particles can be released from within or outside of it. This phenomenon is called the "photoelectric effect". The effect is commonly defined as the ejection of electrons from a metal plate under light. To give a broader definition, radiant energy can be described as infrared, visible, ultraviolet, X, or gamma radiation; the substance might be a solid, liquid, or gas; and in addition to electrons, the expelled particles could also comprise ions, which are electrically charged atoms or molecules. The phenomena had a major influence on the development of contemporary physics of light—particle versus wavelike behavior—because of the fascinating questions it presented about the nature of reality. (Britannica Encyclopedia, 2023).

Working Principle of PV Cells

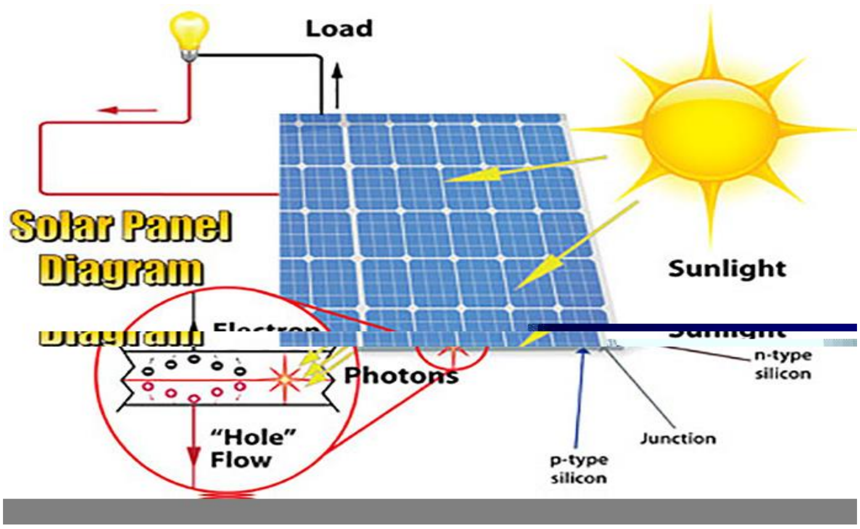


Figure 5: Diagram of Photoelectric Effect (Tortoreli, 2017)

Solar panels work similarly to ordinary diodes, but instead of using electricity, they harness the power of light through a process called the photovoltaic effect. This effect basically allows light particles (photons) to accident electrons in the panel, creating an electric current. The solar cell is the primary power conversion component of a photovoltaic (PV) system (IEA, 2020). Direct current is produced by the PV cell interacting with sunlight, as shown in Figure 5. The D.C. is then transformed via an inverter. By attaching the electric load to the output terminals, one can convert the electrical current into an alternating current (A.C.). (Kant and Singh, 2022). The following are the main operational characteristics of the PV cell:

- Absorption of Photons: The semiconducting material in the solar cell absorbs photons when sunlight, which is made up of them, strikes it. The material's electrons are given off more energy as a result of this absorption, producing electron-hole pairs.
- Electron Flow: Electric current is produced by the separated electron-hole pairs. Metal connections on the top and bottom of the cell allow the flow of electrons to be controlled and converted into useful electricity.
- Electrical Load: Lighting, appliances, and battery charging are just a few examples of the many electrical loads that may be powered by the electricity generated. Batteries or the grid can be used to store any extra electricity that isn't being used.

PV Models

PV models are mathematical equations that represent the equivalent electrical circuit of a PV module. These models are simulated in computer programs which describe how PV cells, modules, arrays, and whole PV systems behave electrically. PV models are effective instruments for the planning, evaluation, and improvement of solar energy systems. Researchers, engineers, and system operators may measure performance, estimate energy generation, and weigh the effects of numerous factors using these models, which replicate the behaviour of PV systems (Fan et al., 2022). The models mimic the current-voltage (I-V) characteristics, power production, and other crucial PV system parameters using a variety of equations, algorithms, and data. PV models enable the study and optimization of PV system performance by capturing the subtleties of solar cell activity.

Basic Operational Parameters of PV Modules

In the world of solar power, scientists use different kinds of mathematical models to understand how solar panels work (Li et al., 2021). These models are like blueprints, helping us predict how much electricity a panel will generate under different conditions.

One common approach is to build an equivalent circuit model, which basically imagines the panel as a bunch of simpler electrical components like resistors and diodes. This helps us calculate the current and voltage the panel produces for different loads (think of a load as anything using the electricity). These models are especially useful because they can capture the entire relationship between current and voltage (the I-V curve) under different conditions, like varying sunlight or temperature.

It is crucial to comprehend the fundamental characteristics of solar cells to assess their performance and maximize their efficiency. The following are the basic characteristics and operational parameters of PV modules.

- Open-Circuit Voltage (V_{oc}): The highest voltage a solar cell can generate while there is no external load connected is known as the open-circuit voltage. It symbolizes the electric potential difference between the solar cell's terminals while the circuit is open. The materials utilized, the bandgap energy, and the temperature all affect the V_{oc}.
- Short-Circuit Current (I_{sc}): The greatest current that passes through a solar cell when its terminals are short-circuited is known as the short-circuit current. It shows the solar cell's maximum current output when there is no external resistance. The Isc is influenced by variables like incident light intensity, light absorption efficiency, and internal quantum efficiency.
- Maximum Power Point (M_{PP}): The maximum power point (M_{PP}) represents the operating point of a solar cell that maximizes the power output. It occurs at a specific combination of voltage and current, where the product of the two is highest. The M_{PP} is crucial for determining the optimal load resistance to extract the maximum power from the solar cell.
- Fill Factor (FF): The ratio of a solar cell's maximum power output (at the MPP) to the sum of its open-circuit voltage and short-circuit current is known as the fill factor (FF), which measures how well a solar cell converts incident light into electrical power. The FF gives a sign of the

solar cell's quality and is influenced by things like series and shunt resistances, material characteristics, and fabrication methods.

- Efficiency (η): One important factor that measures a solar cell's capacity to transform sunlight into electrical energy is its efficiency. It is an indicator of the highest output to incident solar power ratio. The qualities of the material, the design of the solar cell, and the manufacturing procedures all have an impact on how efficient a solar cell is. More sunshine is converted into useful power when efficiency is higher.
- Temperature Coefficient: The fluctuation in solar cell performance caused by temperature changes is referred to as the temperature coefficient. On the open-circuit voltage, short- circuit current, and total power output, it measures the impact of temperature. The term percentage change per degree Celsius (%/°C) is commonly used to denote the temperature coefficient. Assessing the effect of temperature on solar cell performance and optimizing system operation both benefit from understanding the temperature coefficient.

These fundamental variables offer important information about the functionality and characteristics of solar cells. They aid in the selection of the best solar cell technologies for certain applications and direct the design, assessment, and optimization of solar energy systems. The efficiency and efficacy of solar cells may be further increased by boosting these characteristics through the use of new materials, enhanced manufacturing processes, and system optimization, encouraging the wide use of clean and sustainable solar energy (Tang et al., 2019).

Types of PV models

The Single-Diode Model

This is a mathematical model which is widely used to represent the electrical behaviour of PV cells and modules due to its precision and simplicity. They describe the current voltage (I – V) characteristics of a PV cell or module using a single-diode equation and provide valuable insights into their performance. Single-diode models (SDM) take into account variables like series and shunt resistances, short-circuit current, open-circuit voltage, and reverse saturation current. They strike a balance between accuracy and computational efficiency, making it suitable for system-level simulations. The SDM assumes that a single diode can effectively represent the behavior of a PV cell, enabling the calculation of current, voltage, and power output under various operating conditions (Wang et al., 2020; Tang et al., 2023; Ndegwa et al., 2020). The SDM is based on several key assumptions and equations.

Three equivalent circuit models are available to describe the single-diode model (Wang et al., 2020; Tang et al., 2023; Ndegwa et al., 2020). The ideal solar cell is the first which is illustrated in Figure 7, often referred to as the 1M3P model (Single Mechanism, Three Parameters). In this idealized model, a solar cell can be represented as a p-n junction in parallel with a current source that corresponds to the photo carriers generated. The three essential parameters for this model include the illumination current associated with the photoelectric effect (I_{pv}), the reverse bias saturation current for the diode (I_S), and the diode ideality factor (n).

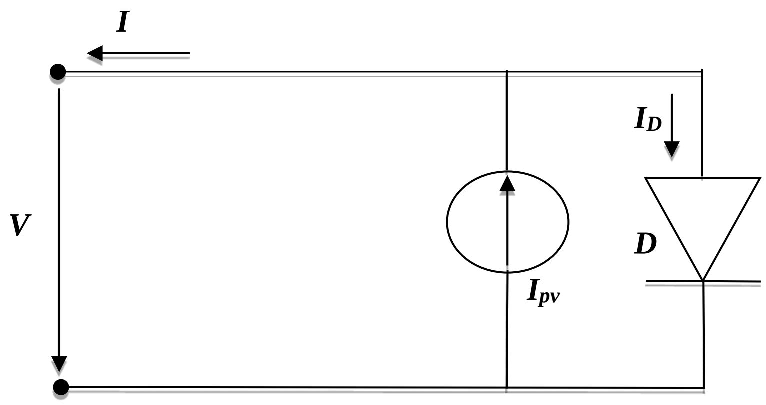


Figure 6: Ideal single-diode model of a solar cell (Nashih et al., 2015)

Figure 6 is a schematic diagram of an ideal single diode model of a solar cell. The model equations for the solar are derive from the diagram as follows:

$$I = I_{PV} - I_D \tag{1}$$

$$I_D = I_S \left(e^{\frac{qv}{nK_B T}} - 1 \right) \tag{2}$$

Where I is the output current, I_{pv} is the photocurrent of panel, I_D is the diode current, is k_B the Boltzmann constant, $(1.38062 \times 10^{-23} m^2 kgs^2 K^{-1})$, q is the modulus of the electron charge $(1.602 \times 10^{-19} C)$, T is the thermodynamic temperature of the P-N junction and V is the output voltage. I_s is the saturation current of the diode. The current associated with the photoelectric effect is directly proportional to the solar irradiance (SI) and to the solar cell active area (A_c).

To enhance the efficiency of the model, a series resistance can be introduced, as depicted in Figure 7. This is known as the 1M4P model (Single Mechanism, Four Parameters) and accounts for the impact of contacts through a series resistance (R_S). The unknown parameters in this model include I_{PV}, I_S, n and R_S.

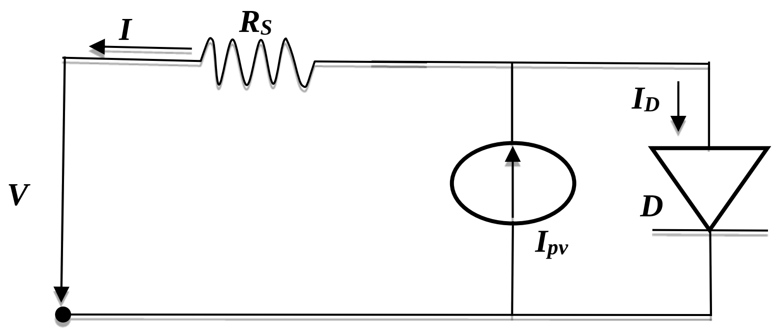


Figure 7: Circuit diagram of Single-diode model 1M4P of a solar cell (Nashih et al., 2015)

The existing models, such as the 1M3P (Single Mechanism, Three Parameters) and 1M4P (Single Mechanism, Four Parameters), though useful, may not offer the level of accuracy required as they overlook certain real factors in solar cells. To achieve a more precise and realistic representation of solar cells, the 1M5P model (Single Mechanism, Five Parameters) has been developed and is illustrated in Figure 8. This model introduces the concept of a parallel shunt resistor (R_{Sh}) to account for leakage currents, thereby addressing these real-world factors. The five key parameters in this model include I_{pv}, I_S, n, R_S, and R_{Sh}.

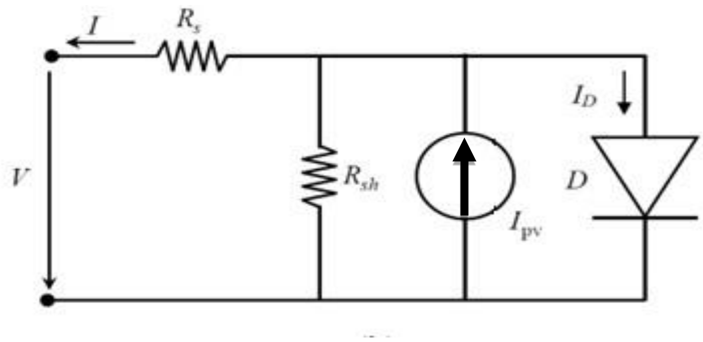


Figure 8: Real single-model of a solar cell (Nashih et al., 2015)

Using Kirchhoff's law, the current expressions are deduced as equations (3) and (4):

$$I = I_{PV} - I_D - I_{Sh} \tag{3}$$

$$I = I_{PV} - I_S\left(e^{\frac{q(V+IR_S)}{nK_BT}} - 1\right) - \frac{V+IR_S}{R_{Sh}} \tag{4}$$

$$I_s = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right)-1} \tag{5}$$

$$I_{pv} = (I_{pv,n} + K_i\Delta_T)\frac{G}{G_n} \tag{6}$$

where, $I_{sc,\,n}$ is the short circuit current under normal standard conditions

The Double-Diode Model

Two-diode models enhance accuracy by incorporating a second-diode equation. They provide a more precise representation of PV cell behaviour by considering factors like recombination losses and light-induced degradation. These models are particularly beneficial for applications that require highly accurate power output estimates, especially in challenging environmental conditions. This model incorporates the consideration of generation and recombination rates within the transition region of a p-n diode by introducing an additional diode in parallel.

This dual-diode approach becomes significant especially under certain thermal conditions, such as in high band gap semiconductors. At low irradiance and reduced temperatures, the double-diode model, as depicted in Figure 9, offers more accurate curve characteristics compared to the single-diode model. However, it comes with increased complexity in calculations due to the presence of two unknown diode quality factors, expanding the number of equations and parameters.

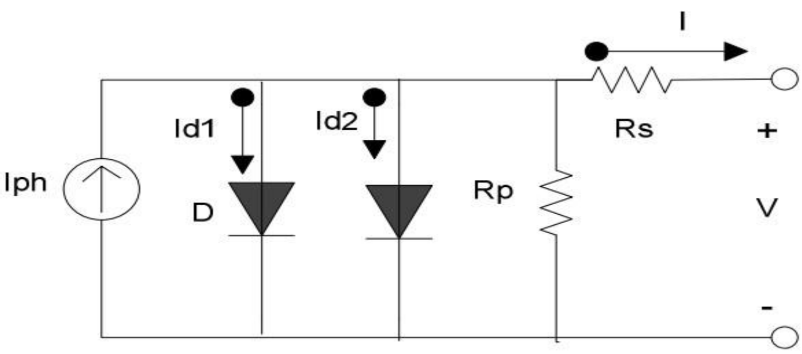


Figure 9: Circuit diagram of Double-diode model of solar cell

The current expressions in double-diode model are expressed in equations (7) and (8) as;

$$I = I_{PV} - I_{D1} - I_{D2} - I_{Sh} \tag{7}$$

$$\mathrm{I} = \mathrm{I_{PV}} - \mathrm{I_{S1}}\left(\exp\left(\frac{\mathrm{q(V+IR_S}}{\mathrm{n_1K_BT}}\right)\right) - \mathrm{I_{S2}}\left(\exp\left(\frac{\mathrm{q(V+IR_S}}{\mathrm{n_2K_BT}}\right)\right) - \frac{\mathrm{V+IR_S}}{\mathrm{R_{sh}}} \tag{8}$$

Where n_1, n_2, I_{S1} and I_{S2} are the ideality factor and the saturation current of the first and second diodes, respectively and R_{Sh} is represented by R_P.

Computer simulations

Computer simulations offer a remarkable way to explore the intricacies of real-world systems without the constraints of physical experimentation. They achieve this by creating meticulously crafted digital mirrors that reflect the behaviors of complex systems—from the mundane to the extraordinary (Humphreys, 2014). At the heart of a simulation lies a mathematical model, meticulously crafted to capture the essential relationships and interactions within a system (Humphreys, 2014). This model, encoded as a computer program, becomes the digital blueprint for simulating its behavior. Once executed, the simulation meticulously calculates and mimics the system's responses to various conditions and stimuli. The resulting mathematical dynamics mirror the behavior of the real system, generating valuable data for analysis and prediction (Gualtieri & Tarassov, 2023). To enhance understanding, many simulations employ computer graphics to create vivid visual representations of the system's behavior. These dynamic visualizations—like animations or interactive models—illuminate complex processes and patterns in a visually intuitive way (Gualtieri & Tarassov, 2023). By carefully adjusting individual components within a simulated model, researchers can observe and predict how these alterations ripple through the entire system. This capability is invaluable for optimizing designs, anticipating potential failures, and testing hypotheses before real-world implementation (Gualtieri & Tarassov, 2023).

Computer simulations are programs that run various mathematical scenarios to determine the potential scope or impact that a particular scenario could have. A computer simulation uses mathematical equations to model possible real-world scenarios, products or settings and create various responses to them. It works by duplicating the real-life model and its functions, and once the simulation is up and running, the simulation creates a record of what is being modeled and its responses which is translated into data (Anon., 2023).

Electrical characteristic curves (I–V and P-V) of PV module

The I-V (current-voltage) curve of a PV string serves as a graphical representation of its energy transformation capability under the prevailing conditions of irradiance and temperature. This curve illustrates the various amalgamations of current and voltage at which the string could operate or be loaded, assuming that the irradiance and cell temperature remain constant.

Figure 10 illustrates typical I-V (current-voltage) and P-V (power-voltage) curves, along with the critical points on these curves. The P-V curve is derived from the measured I-V curve.

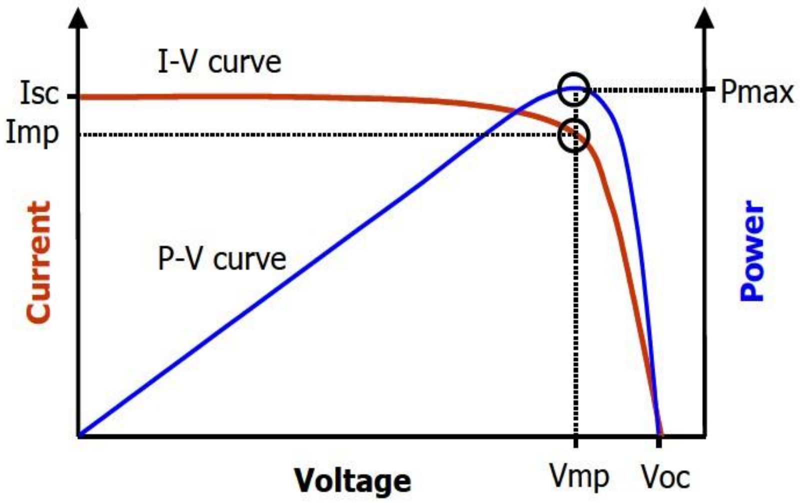


Figure 10: I-V and P-V curves of a PV device (Ndiaye et al., 2013)

The current flowing through the solar cell when the voltage across it is zero is known as the short-circuit current, denoted as I_{SC} (at short-circuit condition; load $R_L = 0\ \Omega$). When V = 0 V, equation (4) becomes:

$$I_{SC} = I_{PV} - I_s\left(\exp\left(\frac{qI_{SC}R_S}{nK_BT}\right) - 1\right) - \frac{I_{SC}R_S}{R_{sh}} \quad (9)$$

The short-circuit current (I_{SC}) is due to the creation and collection of light-generated carriers. In an ideal solar cell, the short-circuit current is equivalent to the light-generated current, denoted as I_{PV} (Tivanov et al., 2005). Consequently, I_{SC} stands for the highest current that a solar cell is capable of producing. The open-circuit voltage (V_{OC}), on the other hand, is the maximum voltage that may be obtained from a solar cell when there is no current flow. It displays the amount of forward bias caused by the light-generated current at the solar cell junction. When I = 0 A, its value can be found using equation (5), as shown in equation (9):

$$V_{OC} = \frac{nK_BT}{q} In\left(\frac{I_{PV}}{I_S} + 1\right) \tag{10}$$

The saturation current (I_s) is influenced by recombination processes within the solar cell and open circuit voltage (V_{OC}) serves as an indicator of the extent of recombination within the device.

The point on the curve where the product of current and voltage achieves its maximum value is known as the Maximum Power Point (MPP), and it is denoted by the symbols (Imp, Vmp). This is the point at which the solar array produces the most electrical power. The 'knee' of the curve is usually where this ideal point lies. The power connected to the diode is stated as follows in accordance with the power convention:

$$P = -VI \tag{11}$$

This number is negative in the PV quadrant of the stationary current-voltage characteristic. The device is active in this area, as indicated by this negative value, or, alternatively, the solar cell is delivering electricity, which is determined by equation (12):

$$P = -P_{Cell} = V\left(I_{pv} - I_S\left(e^{\frac{q(V - IR_S)}{nK_BT}} - 1\right) - \frac{V + IR_S}{R_{Sh}}\right) \tag{12}$$

Researchers frequently use the fill factor (FF) in the literature as a useful statistic to evaluate a solar cell's performance in relation to its theoretical maximum. Any factor that diminishes the fill factor (FF) concurrently reduces the output power by decreasing (I_{mp}, V_{mp}), or both. The I-V curve serves as a valuable tool in identifying the nature of these losses. The influences of series losses, shunt losses, and mismatch losses on the I-V curve are illustrated in Figure 11.

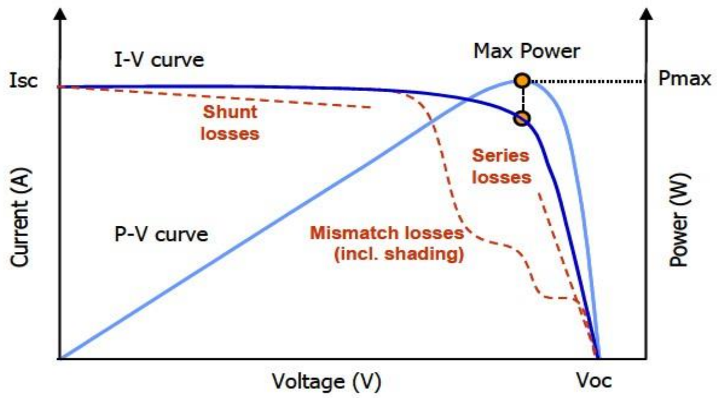


Figure 11: Several categories of losses that can reduce PV array output

On a solar cell, only a part of the incident solar energy is converted to electrical power. Equation 13 represents this performance efficiency as η, which changes based on the kind of solar cell. Generally speaking, a PV module's efficiency is lower than a single solar cell's. This discrepancy results from a module's surface area not being entirely covered by cells (Al-Naser et al., 2013).

$$\eta = \frac{FFI_{SC}V_{OC}}{P_{in}} = \frac{I_{mp}V_{mp}}{P_{in}} \tag{13}$$

Where P_{in} is the power of the incident light.

Effects of Environmental Factors on the Performance of Solar PV Module

As solar photovoltaic (PV) technology continues to play a pivotal role in the transition toward cleaner and more sustainable energy sources, it becomes increasingly important to evaluate the environmental factors that can influence the performance of PV modules. Understanding how environmental conditions, such as temperature, irradiance, soiling, and shading, impact the efficiency and output of PV modules is paramount for optimizing their performance and maximizing energy generation (Soliman et al., 2020). This study delves into the environmental effects on the performance of solar PV modules and underscores the significance of assessing and mitigating their influence.

Effect of Irradiance and Temperature

Solar irradiance (G), the amount of sunlight reaching the PV module, is a critical environmental factor that affects PV module performance. Higher irradiance levels generally result in increased power output. Variations in solar irradiance due to factors like cloud cover, atmospheric conditions, and shading can cause fluctuations in PV module output. Monitoring and analyzing irradiance patterns help understand energy generation patterns, optimize system design, and select appropriate PV module technologies for specific locations (Heath et al., 2020; Tress et al., 2019; Sharma and Goyal, 2021; Karafil et al., 2016; Zaoui et al., 2015). It has a significant impact on current-related parameters. An increased light intensity is accompanied by a linear increase in both the maximum current and the short-circuit current. Thus, concentrating devices such as booster mirrors and Fresnel lenses can be used to increase a module's photocurrent, short-circuit current, and maximum current values.

Additionally, temperature has a direct impact on the performance of a solar PV module (Tress et al., 2021). Higher temperatures can lead to decreased efficiency and power output. PV modules typically experience temperature increases during operation due to the absorption of sunlight and inadequate heat dissipation. The temperature coefficient, a parameter specific to each PV module, quantifies the change in performance with temperature (Carron et al., 2019). It is essential to consider temperature effects during system design, module placement, and thermal management strategies to minimize efficiency losses and maintain optimal operation (Mustafa et al., 2020). These effects can be quantified using equation (14).

$$\left(I_{SC}\right)_{G,T} = \left(I_{SC}\right)_{STC}\left(1+\alpha_{rel}\left(T-T_{STC}\right)\right)\frac{\left(G\right)_{G,T}}{G_{STC}} \tag{14}$$

Where STC is the standard test conditions

$\left(T_{STC} = 25^{0}C \text{ and } G_{STC} = 1000Wm^{2}\right)$ and α_{rel} is the relative current temperature coefficient.

Zaoui et al. (2015) conducted a study to examine how environmental factors affect photovoltaic panel performance, or the panel's power, current, and voltage characteristics. A conventional 55W rated output power solar panel was used for the experiments. In order to compare the simulated and experimental values, the simulation was carried out using MATLAB, R2018A, by integrating the manufacturer's data. The panel temperature and power were related to the irradiance and other external parameters, according to the results of the experimental and simulation study. In addition, the efficiency of photovoltaic panels varies with temperature.

Similar research was conducted by Islam (2014) to determine the effect of irradiation on different parameters of monocrystalline photovoltaic solar cells and to assess its performance with the change in irradiance in reality. The paper also presented an analysis of solar irradiation effect on efficiency, Fill Factor, open circuit voltage (V_{oc}), Short circuit current (I_{sc}) and parasitic resistance of the solar cell. The results of the study suggest that as the solar insolation keeps on changing throughout the day, similarly I-V and P-V characteristics vary with the increasing solar irradiance. The results also indicated that both the open circuit voltage and the short circuit current increase with irradiance and temperature and hence the maximum power point varies. Moreover, it was observed that the fill factor was gradually rising with increasing irradiance.

Besides, the open circuit voltage was very low with increase in irradiation. Additionally, it was again observed that the power output as a function of irradiance for the monocrystalline module varies with Solar irradiance. Finally, it was also observed that efficiency was rising with increasing solar irradiation.

Islam (2014) conducted another simulation studies to examine the effects of temperature and the solar radiation on the PV module power. According to the simulation results, panel voltage slightly increases slightly with irradiance while panel current grows proportionately with the amount of solar energy. In a similar vein, panel power rises in direct proportion to solar radiation. Conversely, panel temperature causes a proportionate drop in panel voltage and a slight increase in panel current. Because the rate of voltage decline is greater than the rate of current increase, panel power falls. The findings suggest that situations with high solar radiation levels and cold temperatures are more suitable for the measured power values.

Sharma (2021) in their research analyzed the effects of solar insolation and temperature on PV cell characteristics. The study aimed to investigate and comprehend the impact of temperature and solar insolation intensity on the IV and PV characteristics using a single-diode solar cell model. In addition, the study evaluated how temperature and solar irradiation fluctuations affected electrical characteristics such the PV module's performance efficiency, fill factor, s/c current, and o/c voltage. The outcome of the research revealed that when the solar irradiance increases at a constant temperature, the output current increases, which leads to an increase in output power.

Similarly, as temperature changes for constant irradiance, the output voltage decreases. Which results in a decrease in output power and therefore inefficiency. Finally, simulation results show a strong nonlinearity behaviour of the PV cell. The IV curve shows that, as temperature increases, o/c voltage reduces and its corresponding maximum output power also decreases. The PV curve shows the similar change as in solar cell power when the light intensity remains constant.

According to Ndiaye et al, (2013) the most important electrical characteristics of a PV module are the I-V and P-V curves, short-circuit current (Isc) open-circuit voltage (Voc) the fill factor (FF) and the maximum power output Pmax. The energy conversion capacity of a photovoltaic string (or module) under current, temperature and irradiation circumstances is described by its I-V (current-voltage) curve. The curve, conceptually speaking, represents the voltage and current combinations at which the string might be used, or "loaded," provided that the cell temperature and irradiance were maintained constant. Fill factor helps determines the performance and the quality of the solar cell. The closer the ratio approaches one (1) the more quality the cell is.

Effect of Dust

The effect of dust on solar panels have been a subject of extensive study over the years. Bhol et al., (2015) studied the effects of the dust on the current (I)- Voltage (V) and Power (P) – Voltage (V) characteristics of the PV system which revealed that the accumulation of dust on the PV module decreased the amount of irradiance reaching the surface of the module causing loses in the power produced. Also the study revealed that dust deposition in humid conditions leads to the formation of sticky mud on PV cells, resulting in power generation reductions of up to 60-70%.(Bhol and Ali 2015). Similar studies conducted by Hussain et al., (2017) examined the impact of air dust particles on the performance of PV modules.

In desert areas where sunlight is most abundant and where a solar array plan can be established, dust accumulation can reduce the power efficiency of solar modules and panels by up to 60%. This was discovered by comparing seven dust samples taken at three radiation levels of 650, 750, and 850 W/m2 with different dust sample weights (Hussain et al., 2017). Additionally, a study on the impact of dust deposition on solar panel performance was conducted by Rao et al. (2014). Dust deposition was shown to have little effect on solar systems' open circuit voltage. Nonetheless, dust deposition has an impact on the short circuit current, ranging from 4–5% in the outdoor test bed to 30–40% in the interior configuration. Considering the size of the plants, this decreases in current output and the ensuing decrease in power production from dust represent a massive loss of electrical power and a financial loss to solar power plants. Additionally, Chanchangi et al. (2020) conducted an analytical indoor experimental investigation with an emphasis on PV surface materials and attributes to examine the impact of soiling on PV. An extensive indoor experimental examination of the impact of 13 different dust samples on PV performance was reported in the research. According to the study, one of the elements impacting PV generation and performance degradation is the characteristics of dust. Additionally, research was done to find out how sensitive different solar photovoltaic systems are to the environment in Qatar, specifically in terms of dust, temperature, and relative humidity. The efficiency of the amorphous and monocrystalline silicon is more severely compromised by dust collection than by temperature or relative humidity in the panel, according to the data.

Rao (2014) studied the effects of dust on panel performance by simulating panel I-V characteristics under various soiling scenarios in an outdoor experimental test-bed. The investigation included panel experiments in an outdoor test-bed as well as an interior setup. By measuring the I-V characteristics of two similar panels that were subjected to the same insolation and ambient temperature, one panel kept dust on its surface while the other was cleared of dust, it was possible to examine the impact of dust on panel performance. According to the study, dust deposition has little effect on solar systems' open circuit voltage. On the other hand, dust deposition has a 30–40% impact on the short circuit current in the indoor setting and a 4-5% impact in the outdoor test-bed. Considering the size of the plants, this decreases in current output and the ensuing decrease in power production due to dust represent a massive loss of electrical power and a financial loss for photovoltaic power plants.

Ndiaye (2013) looked into how dust affected the surface of solar modules in a Sahelian setting. The effects of dust after a year of exhibition in Sahelian settings without cleaning on the I-V and P-V properties of PV modules were emphasized. The study also demonstrated that there are typically very large differences in the relative PV module performance parameters between the cases where the modules are cleaned after one operation year in a Sahelian environment and those where they are not cleaned after an exposition year. The performance characteristics mainly impacted by dust deposits on the PV module surface are P_{max}, Imax, Isc, and FF. As a result, dust significantly affects how well photovoltaic solar panels operate. This is due to the fact that every simulation study and experiment in the literature suggests that dust buildup on the PV module's surface lowers the quantity of solar radiation that reaches its surface. Additionally, the temperature of the module's surface is raised by the dust piling on the surface. As a result, the current and voltage values—two key factors influencing a PV module's performance—decrease when irradiance declines and temperature rises. This suggests that the module's overall performance, efficiency, and power output are reduced. The Effect of Colour and Shading on the Performance of PV Module

Other environmental factors of interest in solar PV performance are colour and shading. Research work conducted by Bhol et al., (2015) focused on a series of experiments to validate alterations in the I-V (current-voltage) and P-V (power-voltage) characteristics of the PV system. The results indicated that PV technology is influenced by the red colour of light more than the rest of the colour of light due to its longer wavelength and energy. Additionally, the results indicated that the shading of solar cells/panels in a network affects the overall performance of a module significantly. In Mustafa et al., (2020) studies on the effect of four environmental factors (dust accumulation, water droplets, bird droppings, and partial shading) on PV performance, the outcome indicated that shading caused the worst impact on PV module performance efficiency. It was reported in the study that when the shaded area on the PV module surface was altered by a quarter, half, and three-quarter shade, the corresponding reduction in power were found to be of 33.7 %, 45.1 %, and 92.6 % respectively.

Effects of Water Droplets and Humidity

Among the environmental factors which affects the performance of a PV module is the water droplets on its surface. Sources of water droplets on solar panel are humidity, rainfall and dew. Humidity is the concentration of water vapour present in the air. Relative humidity is an influencing factor that is responsible for the accumulation of tiny water droplets and water vapour on solar panels from the atmosphere. Water droplets can refract, reflect or diffract sunlight away from solar cells and reduces the number of direct components of solar radiation hitting them to produce electricity (Hasan, 2022).

Dew is water in the form of droplets that appears on exposed objects in the morning or evening due to condensation. As the exposed surface cools by radiating its heat, atmospheric moisture condenses at a rate greater than that at which it can evaporate, resulting in the formation of water droplets. Besides, dew formation refers to water vapour condensing on a surface at a temperature below the dew point temperature of the surrounding air or even above due to the presence of hygroscopic dust on the PV module glass cover and/or (ii) capillary effects. Dew formation results in droplet accumulation that eventually evaporates during the day upon warming of the air and direct heating by solar radiation (Hasan, 2022).

Relative humidity which refers to amount of water vapour contained in the atmosphere has significant influence on performance of a solar module Bhol and Ali (2015). For instance, Sulman et al., (2020) found that humidity negatively impacted the solar cells' life and quality. Their study also revealed that humidity also causes corrosion on the solar cell panel. Further studies conducted by Kazem and Chaichan (2015) portrays the impact of relative humidity on the output of solar photovoltaic (PV) module. The influence of relative humidity on air temperature, solar intensity and wind velocity data on the solar PV module was collected in Sohar City-Oman for the period from July to September 2015 for analysis. The results showed that relative humidity for the tested period highly affected the PV performance in terms of electrical characteristics. Thus, the PV's current, voltage and power output were decreased when the relative humidity increased

Mekhilef et al (2021) conducted another study to investigate the impact on efficiency of a photovoltaic module. They indicated that in analyzing the effect of humidity two points have to be considered. The first scenario is the effect of water vapour particles on the irradiance level of sunlight and the second scenario is humidity ingression to the solar cell enclosure. When the light interacts with water droplets may be refracted, reflected or diffracted. These effects plunge the reception level of the direct component of solar radiation. The study revealed that humidity alters the irradiance non-linearly and irradiance itself caused little variations in V_{oc} in a non-linear manner and large variations in I_{sc} linearly. The study further indicated that humidity degrades I_{sc} and V_{oc} which lowers the power output and efficiency respectively.

Mustafa (2020) did a study on environmental impacts on solar module performance. This study scrutinizes the reliability and validity of existing analyses that focus on the impact of various environmental factors on a photovoltaic (PV) system's performance. For the first time, four environmental factors (the accumulation of dust, water droplets, birds' droppings, and partial shading conditions) affecting system performance were investigated, simultaneously, in one study. However, results about the impact of water droplets on the PV panel had an inverse effect, decreasing the temperature of the PV panel, which led to an increase in the potential difference and improved the power output by at least 5.6 %.

Simsek (2021) carried out similar research to experimentally investigate the impact of droplets on the performance of solar photovoltaic (PV) cells due to dropwise condensation or rain falling on their cover. Dew formation occurs frequently in various climates including in semi-arid regions suitable for PV cell deployment. The outcome of their study pointed out that the presence of water droplets on the cover of solar cells can negatively affect cell power generation and efficiency due to optical effects. Their study also discovered that for incident angles $\theta i \leq 30^{\circ}$, the droplets did not affect the performance of the PV cells. However, for incident angles $\theta i > 30^{\circ}$, the presence of droplets caused the maximum power and energy performance efficiency of the PV cells to decrease significantly, particularly for large droplet contact angles and/or surface area coverage. Such performance degradation was attributed to the fact that the incident light was back-scattered through the droplets instead of being trapped by total internal reflection at the cover/air interface before being eventually absorbed by the solar cell. The study also shows that the hourly energy production of PV cells can decrease significantly with dew formation, based on actual weather conditions.

A study was carried out by Hasan (2022) to examine the impact of relative humidity on the performance of a photovoltaic module. The results of the study suggest that relative humidity is an influencing factor that is responsible for the accumulation of tiny water droplets and water vapor on solar panels from the atmosphere. Water droplets can refract, reflect or diffract sunlight away from solar cells and reduce the number of direct components of solar radiation hitting them to produce electricity. Additionally, the results indicate that radiation intensity varies non-linearly with humidity because of greater scattering angles with smaller water vapor particles. Long-term exposure in a humid atmosphere corrodes the PV modules due to the moisture ingression of the solar cell.

Long-term exposure to a humid atmosphere corrodes the PV modules due to the moisture ingression of the solar cell. Moreover, the high relative humidity creates the formation of sticky and cementing dust layers on PV surfaces that may cause soiling and result in low power output. The efficiency of solar cells increases from 9.7 % to 12.04 % when relative humidity is decreased from 60 % to 48 %. In terms of power, an increase in relative humidity by 20 % reduces the power generation by 3.16 %. Even though from literature the effects of these parameters on PV characteristics are demonstrated, there has not been any study in the guinea savanna region where weather conditions.

Chapter Summary

The theoretical as well as the conceptual literature of the study on photovoltaic modules have been reviewed. This aspect considered various theories and concepts regarding the development and performance of PV cells. Besides, literature on the empirical evidence of the study focuses on the impact of varying environmental conditions on the performance of the PV modules have also been reviewed. Several of the studies in the literature revealed that environmental conditions which affect the performance of solar cells are solar irradiance, temperature, dust, water droplets, shading, wind, color, humidity and dew. Among these factors, the prominent ones are the irradiance and that of the temperature. Changes in one of these two factors causes changes in the electrical characteristics (I-V and P-V) of the PV modules.

Most studies on the performance of PV cells have been conducted in different geographical areas in the world characterized by different climatic zones, environmental and weather conditions. Different climatic or atmospheric conditions portray different power outputs and efficiencies of the PV cells. The current study has been conducted in a semi-arid zone. This zone is defined by two major seasons — dry (harmattan) and rainy. These seasons are further defined by different mixtures of weather conditions such as dust, wind, water droplets, dew shading, different temperatures and solar irradiance.

This study is the first experimental research to be carried out to assess the performance of the solar modules in the study area (Navrongo-Pungu) in the Upper East of Ghana, West Africa where the 2.5 MW solar power plant is built. Besides, this research presents a unique module simulation that would generate the necessary electrical characteristics of the PV system which would help assess the power output, the efficiency as well as the overall performance of the PV system.

CHAPTER THREE

METHODOLOGY

Introduction

This chapter describes the study area and outlines the methodology used in carrying out the research. It includes the description of the experimental set-up of the PV modules and other instruments used in the study. The chapter further elucidates how simulated data representing the three weather conditions were taken and how the experimental data for the three weather conditions (i.e., dry-windy, harmattan and rainy seasons) were also taken. Besides, it also includes the description and the explanation of the simulation processes using MATLAB, R2018a. Description of the Study Area

Figures 12 and Figure 13 show the map of the study area and the location of the Navrongo Grid Fed Solar power plant, respectively. The power station is located in a town called Pungu which is about 8 km north-east of Navrongo on the stretch of Navrongo-Paga road. Navrongo is a few kilometers from the Ghana-Burkina-Faso border, at Paga. There are three major weather conditions in the area – harmattan, rainy and dry -windy conditions.

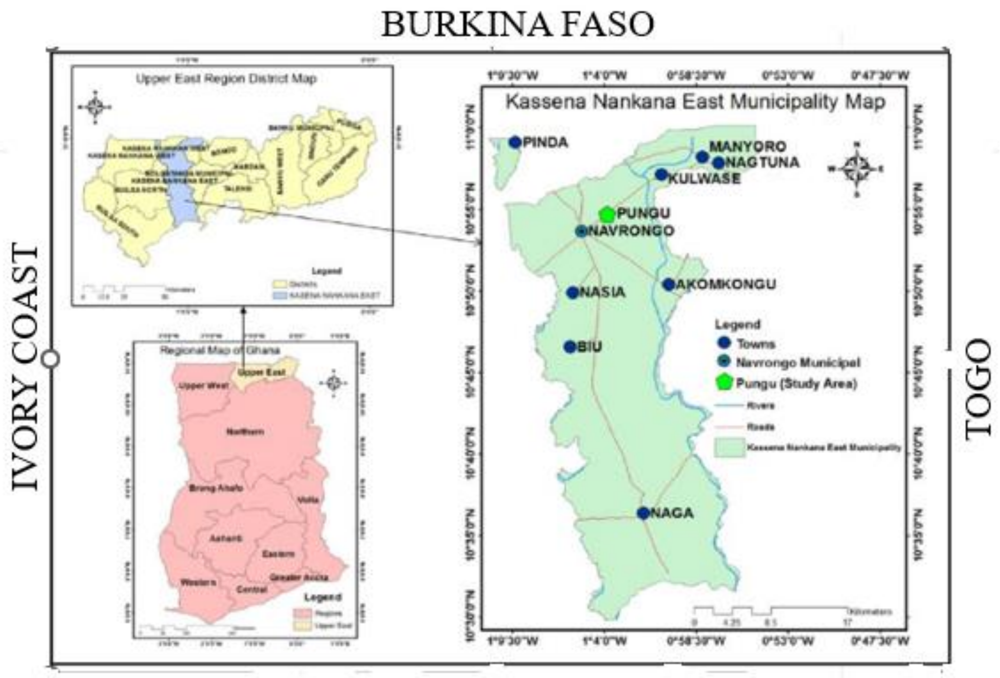


Figure 12: Map of Ghana showing the location of Pungu at Navrongo, the area (Ampedu, 2018)

Figure 13: Navrongo Grid Fed Solar Power Plant at Pungu (Vehe, 2021)

Instrumentation, Equipment and Experimental set-up

In this study, all the instruments used were obtained from the Volta River Authority (VRA). Photographs of some of the instruments and equipment used are shown in Figure 14.

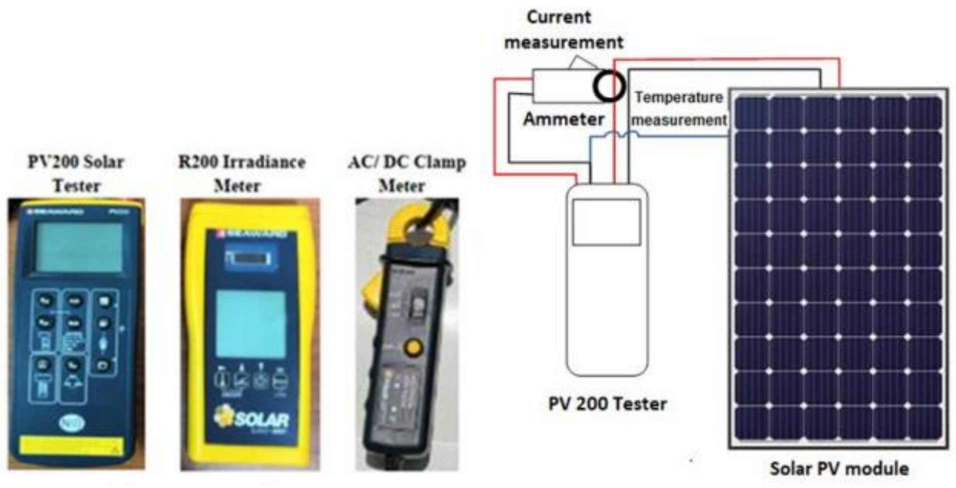


Figure 14: Photographs of measuring instruments

Figure 14 portrays a wired pictorial diagram of the experimental setup showing the layout of the various instruments for the measurements. The DC/AC clamp meter, the PV 200 Solar Tester and the R200 Irradiance meter are connected appropriately to the solar module for the different parameter measurements as already described above.

In the set-up shown in Figure 15, two JKM295-72 polycrystalline solar modules have been connected to some accessories to take various data. The experiment was conducted in the open (i.e. outdoor).

Figure 15: Experimental and control modules setup

Table 1: Data sheet of the JKM295P-72 PV module

Module specifications	Values
Maximum power voltage	32.6V
Maximum power current	8.15 A
Open circuit voltage	45.1V
Short circuit current	8.76A
Normal operating cell temperature	45(+/-)2
Maximum system voltage	1000VDC
Dimensions	195mm*992mm*40mm
Weight	26.5Kg
Radiation at STC	1000W/m2
AM	1.5
Efficiency	20.5%

The angle of tilt for the two modules was 11^{0} towards the south in line with the power plant panels (Figure 15). This tilt angle was determined to be the best angle that could harvest the maximum solar energy in a day, and it is in consonance with the geographical location of the power plant.

Tilt angle, Short circuit current (I_{sc}), Open circuit voltage (V_{oc}), Solar irradiance (SI), and Load current (I_L) measurements.

Figures 16a and 16b, illustrate the measurements of the tilt angle and circuit current (I_{sc}), open circuit voltage (V_{oc}), solar irradiance (SI), load current (I_L), respectively, using the solar survey 200R meter and PV200 tester and I-V curve tracer. The functions of these instruments are described as follows:

- Multimeters: two multimeters were used simultaneously for the measurement of current in amperes (A) and voltage measurements in volts(V).
- Solar Survey 200R meter: This device was used to take solar irradiance (SI) in watts per square meters (W/m^2), panel temperature (T_{pv}) in degree Celsius, ambient temperature (T_{am}) in degree Celsius, and tilt angle (Θ) in degree.
- Solar PV 200 Tester and I-V curve tracer: This instrument was used to take readings for short circuit current (I_{sc}) in ampere load current, open circuit voltage (V_{oc}) in volt, solar irradiance (SI) Watt per square meter.

Figure 16: Photograph of (a) tilt angle measurement and (b) testing measuring instruments

Simulation of the effect of Harmattan, Rainy and Dry conditions on the PV modules

Simulation experiments (Figure 17) were conducted to evaluate the effect of dust, water droplets and control environmental conditions on the PV modules to mimic the natural weather conditions of harmattan, rainy and dry weather conditions. In the simulation, the independent variables (water droplets and dust) were physically generated. In each of the conditions two separate panel modules were erected as previously described, one was used as a control set-up, and the other one for the independent variables. For each condition, the control panel set-up is as in (Figure 17a), dusty panel (Figure 17b) and that of water-droplets panel (Figure 17c). The simulation studies took place for a period of one month in May 2021 when the weather was dry and fairly stable. The parameters measured on the solar modules to assess the performance of the PV module were the solar irradiance, the short circuit current (I_{sc}), the open circuit current (Voc), the panel temperature (Tpv) and the ambient temperature (T_{am}). Each simulation was repeated for a week, and the average values taken.

The data was taken in one-hour interval daily from 7.00 am to 5.00 pm for two weeks for the control and the dusty panel, and another two weeks for the control and the water droplets panel. To mimic the harmattan weather condition, fine dust particles were uniformly spread on one of the panels and the second panel (control panel) (Figure 17b) was clean daily for a two-week period for the data to be taken. The data collected and processed data are shown in Appendix A and Appendix B, respectively.

Figure 17: A picture of (a) two installed solar modules, (b) dust particles spread on the left panel to mimic harmattan and (c) water sprinkled on one of the solar panels to mimic raining season

Experimental Data for the Three Weather Conditions

The general weather conditions in the study area which is in northern part of Ghana are segmented into three major conditions. These are the harmattan, the rainy and the dry-windy weather conditions. The harmattan is a hazy, dusty and cold period which spans from November to January each year. The rainy period is characterized by regular and occasional rain fall which runs from June to September in each year and the dry-windy condition runs from march to May which is normally marked with the blowing of strong winds which carries a lot of dust. During the experiment, two panels each were mounted in each weather condition; one as the experimental and the other one as the control module. A period of two months each was used for each condition and the corresponding data recorded. The data taking exercise was carried out in two years, 2021 and 2022 for the study. Data collected for each year, 2021 and 2022 are shown in APPENDIX C (Table C1-Table C3) and APPENDIX D (Table D1-Table D3) respectively. More so, processed data sets from the raw data from APPPENICES C and D for the stated weather conditions for the 2021 and 2022 can be found in APPENDICS E (Table E1-Table E3) and F (Table F1- Table F2) respectively. The experimental values of the control panel for all the parameters on all the tables in the appendices (APPENDICS A-F) are always high because that panel was always kept clean to minimize the effects of the weather conditions.

The months of March and April were used to take data for the dry-windy weather condition; August and September for the rainy weather condition because of regular rains during this period and finally, November to December for harmattan weather condition because of the severity of the harmattan during this period. For each of the conditions, an experimental solar module and a control module was always mounted and the data recoded for the essential parameters (the solar irradiance, the short circuit current, the open circuit voltage and the panel temperature) which were needed for the assessment of the impact of these environmental conditions on the performance of the solar modules.

Simulation of the Equivalent Circuit PV Model Characteristic Equations

To simulate the PV module, an equivalent single diode circuit-based diagram of a practical PV device including the series and parallel resistances is obtained as can be seen in Figure 18. A characteristic model equation of the PV module is derived from single diode circuit based equivalent diagram which is then implemented in a computer MATLAB, R2018a program for the simulation to occur (Villalva et al., 2009). The various parameters of the equation are explained below.

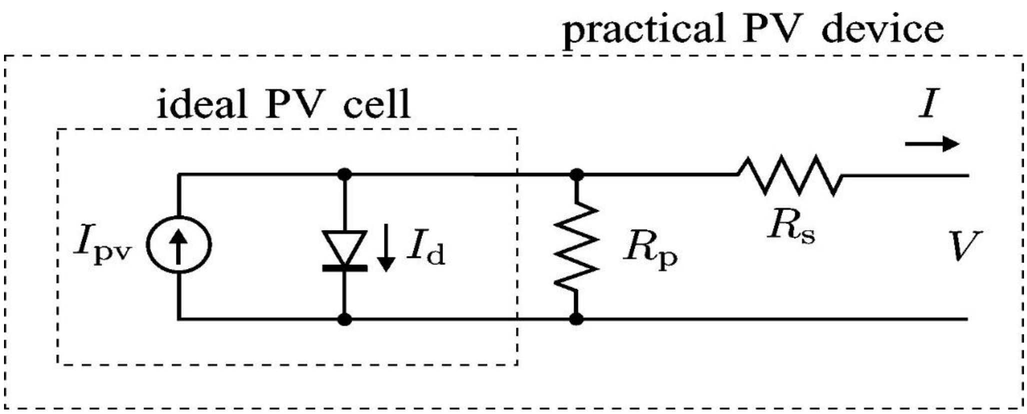


Figure 18: Single-diode model of the theoretical PV cell and equivalent circuit of a practical PV device

The characteristics equation for the above single diode equivalent circuit of the photovoltaic module is indicated in equation (15) below.

$$I = I_{pv} - I_o\left[exp\left(\frac{qV}{aKT}\right) - 1\right] - \frac{V + I_s R_s}{R_p} \tag{15}$$

Where,

$$I_{pv} = \left(I_{pv,n} + K_i \Delta T\right)\frac{G}{G_n} \tag{a}$$

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_s}{aK}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \tag{b}$$

$$I_{o,n} = \frac{I_{sc,n}}{exp\left(\frac{V_{oc,n}}{aV_{T,n}}\right) - 1} \tag{c}$$

$$I_o = \frac{I_{sc,n} + K_T \Delta T}{exp\left(\frac{V_{oc,n} + K_V \Delta T}{aV_T}\right) - 1} \tag{d}$$

Where, I is the output current of the module, I_o is the diode saturation current of the cell, q is the electron charge, K is the Boltzmann constant, T is the temperature of the p-n junction, a is the ideality factor constant, R_s is the series resistance that takes care of leakage current due to various contact points in the module, R_p is the parallel resistance takes care of leakage of current across the p-n junction, $I_{sc,n}$ is the short circuit current under normal conditions, V_{oc} is the open circuit voltage. The irradiance on the device surface is G, G_n is the nominal or reference irradiance, T_n is the nominal temperature, K_i is the temperature coefficient, $V_{oc,n}$ is the nominal voltage and K_V is the coefficient of variation of the voltage as a function of temperature, and $I_{s,}$ is the current across the series resistor, V_t is the thermal voltage of the module and E_s is the band gap energy of the semiconductor

The above PV model equations have been used to implement the computer MATLAB R2018a program in generating the I-V and P-V characteristics for the study. By varying the environmental parameters, (that is irradiance and temperature) in the simulated model code (Appendix F), different I-V and P-V characteristic curves have been generated. Temperature and irradiance are of particular importance in the study of PV module electrical characteristics, because their variations affect the performance of the module in complex ways. Some direct effects can be deduced from physical relations, but others can be only approximated using empirical equations (Petrone, 2017).

Assessing the Maximum Power Output and the Efficiency from the electrical Characteristics of the PV Module for 2021 and 2022 data, respectively

The electrical characteristics of a PV module are the I-V and P-V characteristics curves. The maximum power output and the efficiency determine the performance of the module under varying weather conditions, and this can be achieved in two ways:

Maximum power could be obtained from P-V graph on the maximum power point (Vmp, Pmp) using data cursor tool in the MATLAB, R2018a.V_{mp} is the maximum power voltage on the voltage axis and P_{mp} is the maximum power point on the power axis.

Besides, the Maximum power can be obtained from the knee point (Vmp, Imp) of the I-V curve also using the data curser in the MATLAB, R2018a.

Power Output

The following equations are used to evaluate the power output, the reduction in power output, the efficiency and the reduction in the module efficiency under the various weather conditions. The detail calculations for the performance assessment parameters above are presented in Appendix G, and the summary of the results are found in Table 6 in chapter Four.

$$\text{Fill Factor (FF)} = \frac{\text{maximum power of solar cell}}{\text{maximum power of ideal solar cell}} = \frac{\text{Imp x Vmp}}{\text{Isc x Voc}} \quad (16)$$

$$\text{Efficiency of panel } (\eta) = \frac{\text{Electrical power output of panel}}{\text{Ideal power input into the cell}} \text{ x } 100\% \quad (17)$$

Equation (17), can also be written as,

$$\text{Efficiency of panel } (\eta) = \frac{\text{Pout}}{\text{Pin}} = \frac{\text{Isc x Vov x FF}}{\text{SI xAc}} \text{ x } 100\% \quad (18)$$

$$\text{Reduction in power} = \frac{\text{Power of panel(STC)} - \text{Power of panel}}{\text{power of panel(STC)}} \text{ x } 100\% \quad (19)$$

$$\text{Reduction in Efficiency } (\eta) = \frac{\eta_{STC} - \eta_{EP}}{\eta_{STC}} \text{x}100\% \quad (20)$$

Where; η_{STC} = Efficiency of the module under standard test conditions

η_{EP} = Efficiency of the experimental panel

STC = Standard Test Conditions

The values of the parameters of the equations would be deduced from the P-V and I-V curves in Figure 31 and Figure 32, respectively.

To generate the I-V and the P-V characteristics for the module for performance assessment tests, the average peak irradiance for each of the three weather conditions have been tabulated in Table 2 for 2021 and 2022, respectively in chapter four (4). The irradiance values are fed into the coded model equation (1) in the MATLAB for the simulation to run. The generated P-V and I-V characteristics from which the performance of the PV module was assessed can be seen in Figure 28 and Figure 29 for 2021 and in Figure 32 and Figure 33 in 2022 respectively in chapter four.

Chapter Summary

This chapter has described the study area and the materials and methods used for the study. It has also described vividly the data taking procedures for both the simulation conditions that mimic the three weather conditions and that of the real experimental weather conditions. The chapter also outlined the model equations which were used for the simulations to generate the electrical characteristics for the performance analysis of the solar module under the various weather conditions. Finally, the chapter spelt out the power and efficiency equations which were used for the module performance assessment.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents the results and discussion of the simulation and experiments conducted in the study. The parameters included irradiance (SI), short circuit current (I_{sc}), open circuit voltage (V_{oc}), cell temperature (T_{pv}), ambient temperature (T_{am}), and power of the PV module. The data obtained were simulated in MATLAB, R2018a. to generate the Current-Voltage (I-V) and Power-Voltage (P-V) characteristics. To ascertain the performance of the power output and the efficiency of the module the I-V and P-V characteristics were used. In the ensuing sections the results are presented and discussed.

Effects of Simulated Environmental Conditions on Key Factors

The PV module was simulated for the various weather conditions where dust was used to represent harmattan, water droplets as rain and a control panel setup. The experimental validation of the simulation results on behavior pattern of some key environmental factors (such as, irradiance and ambient temperature) and parameters (e.g., short circuit current, open circuit voltage and panel temperature) of the PV module was done for natural weather conditions (harmattan, dry-windy, and rainy seasons). Computer MATLAB 2020a. -simulated I-V and P-V characteristic curves were generated.

The behavior patterns graphs for the key environmental factors and parameters of the PV module from the simulation are shown in Figure 19 to Figure 23. Figure 19 indicates the effect of the different weather conditions on solar irradiance against the time of day. It can be seen that the accumulation of dust particles on the panel had a greater effect on irradiance than that of the wet (water droplets) panel. In fact, dust particles obstruct a reasonable amount of solar irradiance from falling on the module surface than water droplets do. Similar results have been obtained by (Aly et al., 2019; Mustafa et al., 2020); Their investigation established that the accumulation of dust, shading, and bird fouling has significant adverse effect on PV current and voltage, and consequently, the PV energy.

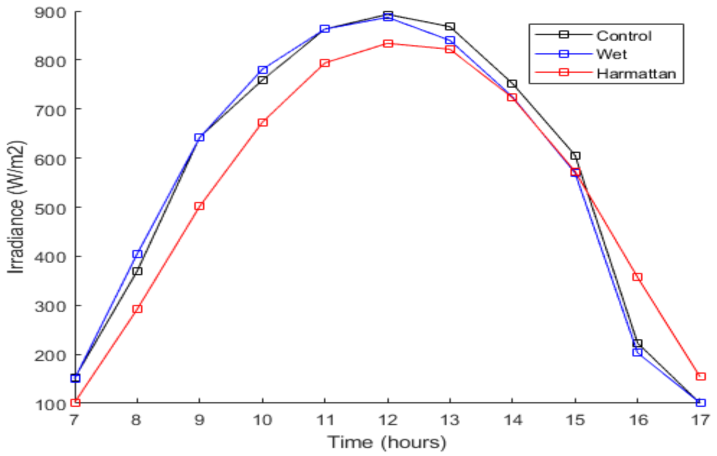


Figure 19: Simulated irradiance versus time-of-day

On the other hand, the effect on irradiance by the wet panel is almost the same as that of the control (dry) panel. It can be posited that water droplets are transparent to the sun rays and do allow the solar irradiance to reach the surface of the panel in almost the same way as the dry situation. Also, some parts of the sun rays are scattered reducing the amount of sunshine on the solar panel. It can also be seen from the figure that for all the weather conditions irradiance increases as the time of the day increases (from 7:00 am to 12:00 noon) and decreases after 12:00 noon. Islam (2014) conducted similar studies to assess the effect of irradiation on different parameters of monocrystalline photovoltaic solar cells and to assess its performance with the change in irradiance in reality.

The results of the study confirmed that as the solar insolation keeps on changing throughout the day, similarly I-V and P-V characteristics vary with the increasing solar irradiance.

Figure 20 portrays the effect of harmattan and rainy weather conditions on the short circuit current of the PV module. It shows that the harmattan weather condition had the greatest negative impact on the short circuit current followed by the rainy weather condition. This observation is in agreement with the findings reported by Mustafa et al. (2020) in a similar study.

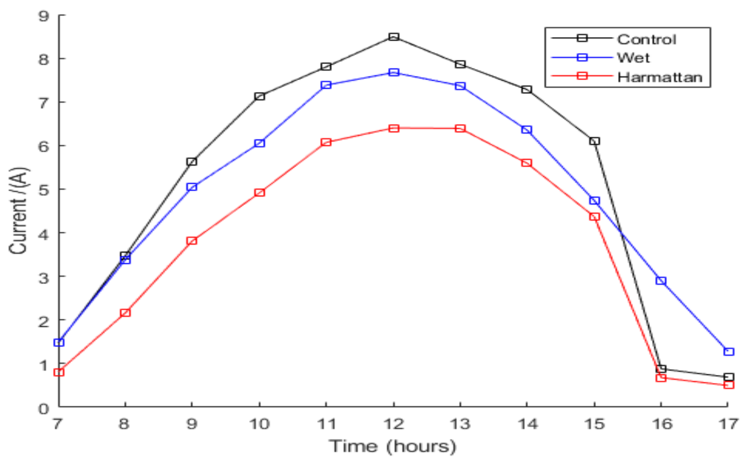


Figure 20: Simulated Short Circuit Current Versus Time of Day

The voltage time graph for the two major weather conditions and the control panel is show in Figure 21. It can be seen that open circuit voltage for the rainy and the control panels are higher than the open circuit voltage for the dusty panel or the harmattan panel. This is due to the fact that the temperature of those two panels is lower than the temperature of the dusty panel. This assertion is in agreement with studies conducted by (Hamad, 2020; Zaini et al., 2015; Zaoui et al., 2015).

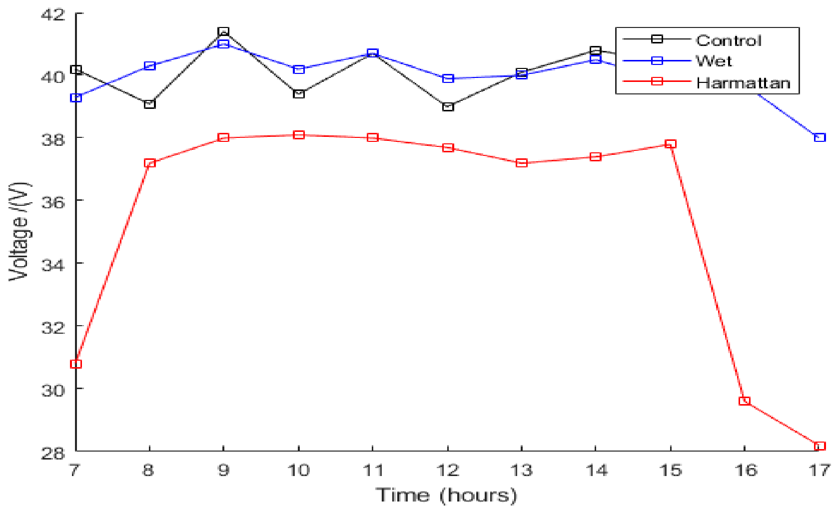


Figure 21: Simulated Voltage-Time graphs for varying weather conditions

The behavior pattern of panel temperature against time of day for the various weather conditions are outlined in Figure 22. It can be confirmed that the panel for the rainy season experienced a lower temperature than that of the harmattan and that of the panel used as the control, due to the cooling effect by the water. According to Tress et al. (2021), temperature has a direct impact on the performance of a solar PV module. Higher temperatures can lead to decreased efficiency and power output. PV modules typically experience temperature increases during operation due to the absorption of sunlight and inadequate heat dissipation.

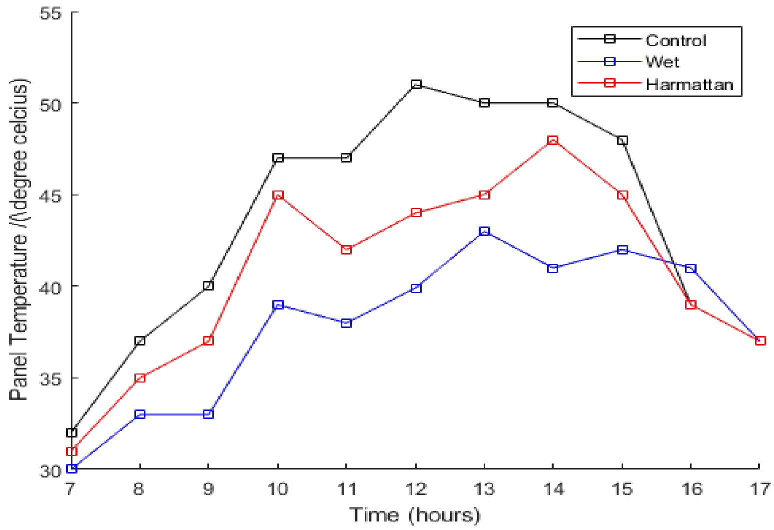


Figure 22: Simulated Panel Temperature versus Time of Day

The power output graphs for the harmattan, rainy and control weather conditions are shown in Figure 23. It can be seen that the power output by the control panel is the highest, followed by the panels in the rainy season and lastly by the harmattan season. The water droplets panel had a better performance than the dusty panel because the droplets of water on the panel caused cooling which subsequently lowered the panel temperature. A decrease in temperature caused an increase in panel voltage, hence increase in power output. Bhol and Ali, (2015) conducted similar experimental studies on the impact of environmental factors on the performance of a solar module. Their experimental data were used to calculate the efficiency and power output of the system. The result showed that the output power and efficiency were affected by environmental factors. Mustafa (2020) similar study on environmental impacts on solar module performance. The results which are in agreement with the current study revealed that the impact of water droplets on the PV panel had an inverse effect, decreasing the temperature of the PV panel, which led to an increase in the potential difference and improved the power output by at least 5.6%.

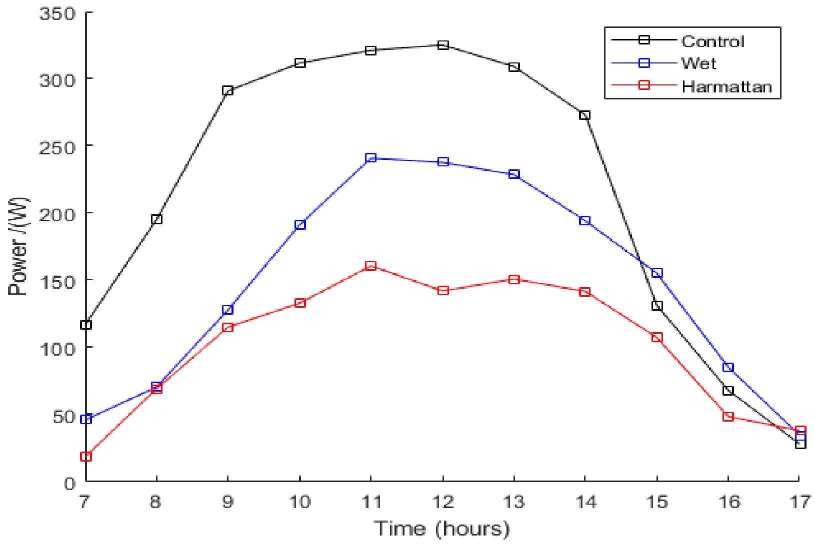


Figure 23: Simulated Power Versus Time of Day graphs

Experimental Validation

The real weather in the northern part of Ghana, specifically, Navrongo in the Upper East Region where the research was done, has three weather conditions. These conditions which were already explained in chapter three are harmattan, dry-windy and rainy weather conditions. The experimental results on the behavior pattern on the key environmental factors and key parameters of the PV module under the natural weather conditions slightly deviates from the behavior pattern of the simulated graphs. This is largely due the fact the weather conditions in each case are not the same. The comparison of the behavior pattern graphs for the key environmental factors and the key parameters of the PV module for both the simulated data and the experimental data is presented and discussed.

Figure 24 (A) shows the simulated behaviour pattern graphs for one of the key environmental factors (i.e. irradiance) under the three weather conditions and Figure 24 (B) shows the behaviour pattern graphs for the same key factor (Irradiance) under three experimental weather conditions. Considering Figure 24 (B) which is the experimental graph, the blue line, representing the wet or the rainy condition showed a negative effect on solar irradiance as compared to its performance in the simulated situation. This may be due to the abundance of water vapour and droplets in the atmosphere during the rainy season.

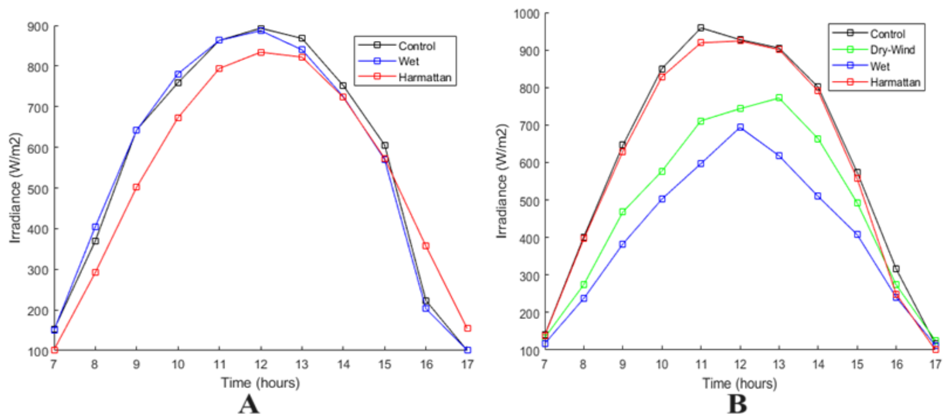


Figure 24: Comparison of Irradiance Versus Time of Day in Hours for (A) Simulated and (B) Experimental with varying weather conditions

Moreover, there is usually water droplets that form on the surface of the panel due to the presence of dew as well as high levels of humidity in the atmosphere. Additionally, the weather is almost always cloudy during the rainy season, and this may result in the negative effect of solar irradiance. All these factors scatter, reflect and refract the incoming solar radiation away preventing a significant amount of it from falling on the surface of the solar panel leading to poor performance of the solar module. However, in the simulated case, all these negative factors were virtually absent while mimicking the rainy season by sprinkling water on the surface of the panel. This mimicked method had less effect on the amount of irradiance reaching the panel. Bhol and Ali, (2015); Hasan, (2022); Kazem and Chaichan, (2015) conducted similar studies which are in agreement with the current study. It was found in their research results that the power produced by the panel is dependent on the solar irradiance and ambient temperature. Simulation results show that there is a direct proportionality between solar irradiation, temperature, output current and power of the photovoltaic module.

In the case of the effects of environmental conditions on open circuit current on an hourly basis throughout the day, Figure 25 (A) displays graphs of the simulated weather condition on the short current while Figure 25 (B) displays the effects of the experimental weather conditions on the short circuit current of the PV module. Since current correlates positively with irradiance, the behaviour of the effects of the real weather conditions on the current is in the same trend as the irradiance as explained earlier. The blue line represents the rainy condition PV module produced the least current due to the high humidity levels in the atmosphere, water droplets on the module surface due to the formation of dew and rain water and above all the presence of clouds in the atmosphere.

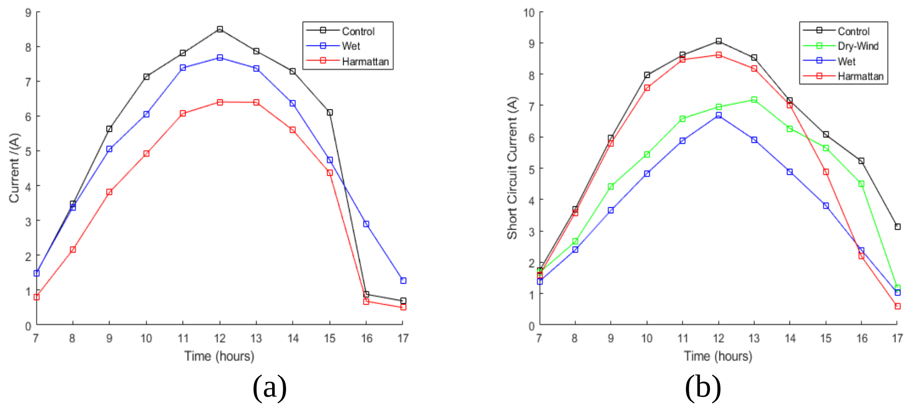
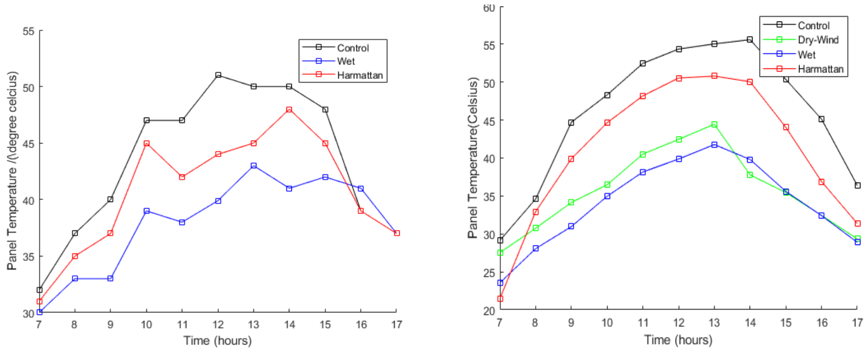


Figure 25: Current Versus Time of Day in Hours for (A) Simulated and (B) Experimental with varying weather conditions

Mustafa et al., (2020) conducted similar studies on the Impact of some environmental variables with dust on solar photovoltaic (PV) performance. The results from the research discovered that weather conditions (i.e., dust, relative humidity, rain, and snow) have a primarily negative effect on a PV panel's performance. The next weather condition that produced the least current in the PV module was the dry-windy weather condition. Considering the reasonable layer of sand and dust carried onto the module by the strong winds, less current was produced in the module due to the reflections of the irradiance by these layers.

The harmattan weather condition module which is the red line produced better current because there was less dust particle settlement on the module surface though the weather is usually hazy and dusty. Generally, the control or the clean module which is represented by the black graph on the experimental figure produced the highest current. Again, the results of this study are in good agreement with other studies (Bohol and Ali, 2015; Hasan, 2022; Kazem and Chaichan, 2015). Results from comparable research carried out by them exposed that PV's current, voltage and power output decreased when the relative humidity increased. The results imply that the PV panel efficiency is low during high relative humidity periods.

Average Panel temperature behaviour trends on an hourly basis under the various weather conditions for both simulation and the experimental measurements are shown in Figure 26 (A) and 26 (B) respectively. It can be seen that in both cases, the wet panel which represents the rainy weather condition experienced the lowest temperature due to the cooling effect of the water droplets. The dry-windy panel has the next lowest panel temperature followed by the harmattan weather condition and the highest panel temperature was experienced by the control panel.



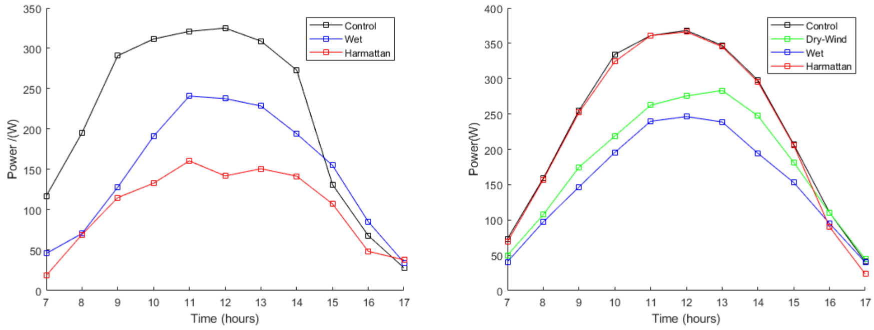
(a) (b)

Figure 26: Panel Temperature Versus Time of Day in Hours for (a) Simulated and (b) Experimental with varying weather conditions

Average Power output graphs for the PV module for both the simulated measurements and the experimental measurements under different weather conditions can be seen in Figures 27 (A) and 28 (B), respectively on an hourly basis every day from 7:00 am to 5:00 pm. It can be observed that the control panel which is the black graph in both the simulated and the experimental situations has the highest power output due to the fact that those panels are always kept clean throughout the study. The next highest power output in the module in the experimental figure is the harmattan condition module. This is because during the harmattan condition, atmosphere is always full of fine dust particles that cause scattering of the solar radiation and prevents a significant amount from reaching the surface of the solar module. Besides, the weather is always cold thereby lowering the panel surface temperature and this increases the voltage of the panel.

In the case of the wet panels which indicate rainy weather conditions and are represented by the blue graphs in both the simulated and the experimental figures. The wet (rainy) panel had the lowest power output in the experimental condition due to the negative atmospheric conditions (factors) encountered by the panel during the rainy period which were already explained in the previous parameters. However, the wet panel in the simulated case had a higher power output after the control panel because the mere sprinkling of water droplets on the panel devoid of negative atmospheric factors such as high levels of humidity, water droplets etc., rather caused cooling on the panel which increased the open circuit voltage of the panel. The increase in panel voltage led to an increase in the power output of the panel.

The third highest power output panel in the experimental figure is the dry windy weather condition. This condition is characterized by strong winds that put a lot of dust and sand particles on the surface of the panel. However, because cloudy atmospheric conditions were absent during the simulation period the module performed better in terms of power output than that of the rainy weather condition. Simsek (2021) carried out similar research to investigate experimentally the impact of droplets on the performance of solar photovoltaic (PV) cells due to dropwise condensation or rain falling on their cover. The outcome of the study indicates that the presence of water droplets on the cover of solar cells negatively affected the cell power generation and efficiency due to optical effects (i.e. reflection and refraction of solar radiation and non-absorption of solar light).



(a) (b)

Figure 27: Power Versus Time of Day in Hours for (a) Simulated and (b) Experimental with varying weather conditions

Experimental and Simulation of Electrical Characteristics of the module for 2021

The electrical characteristics of the PV module are the Current (I)-Voltage (V) and the Power (P)-Voltage (V) characteristics curves which are normally obtained through computer coding and simulation of the characteristic model equation. The characteristic model equation for the solar module is shown in equation (1) in chapter three (3). The simulated characteristic equation code is responsive to only solar irradiance and that of panel temperature.

Table 2 shows the average peak solar irradiance for each of the weather conditions during the experimental study. These average irradiance values were taken at the peak hour of the day (12:00 pm) for both 2021 and 2022 respectively. These irradiance values were then fed into a MATLAB, R2018a algorithm and subsequently, the corresponding P-V and I-V characteristic curves were generated for the various weather conditions. The P-V and I-V curves are shown in Figures 28 and 29, respectively for 2021 and in Figures 32 and 33 respectively in 2022.

Table 2: Average peak irradiance for three weather conditions for 2021 and 2022 at 12:00 pm each

Weather conditions	2021 Irradiance (W/m^2)	2022 Irradiance (W/m^2)
*Control	998.00	997.50
Harmattan	911.75	919.09
Dry-Windy	774.16	743.42
Rainy	616.20	597.02

Source: Researcher, 2024

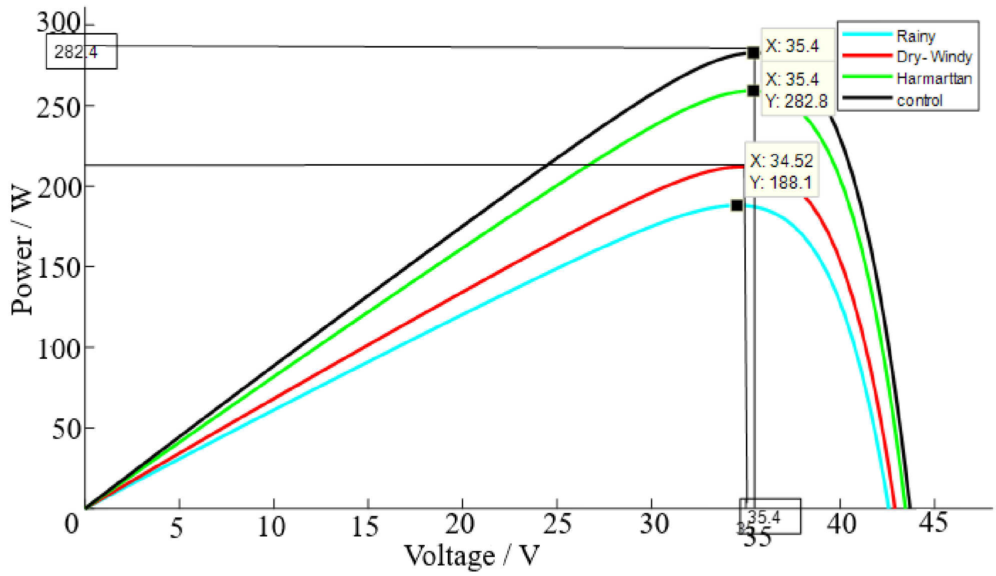


Figure 28: P - V characteristic Curve for Three (3) weather conditions, 2021

The P - V characteristic curves for each weather condition under the influence of its average irradiance recorded for a peak hour in a day in 2021 are shown in Figure 28. The control module recorded the highest value of average irradiance while the rainy weather conditions recorded the least value. The reasons accounted for these differences are as follows: the control panel was always kept clean and that prevented any particle (dust particles, water droplets or bird fouling etc.) from settling on the module surface. This allowed a large amount of solar irradiance to be captured on the module surface hence its highest irradiance values of 998.00 W/m^2 for 2021 and 997.50 W/m$_2$ for 2022 (Table 2). The harmattan weather condition was the next with higher irradiance values of 911.75 for 2021W/m^2 and 919.00 W/m^2 for 2022 (Table 2). This was because harmattan consists of hazy and cool weather. This hazy weather carries fine dust particles that settle on the module surface which still permit a larger amount of solar irradiance to reach the module surface. The third weather condition with the highest solar irradiance values was the dry-windy weather condition with irradiance values of 774.16 W/m^2 for 2021 and 743.42 W/m^2 for 2021. This weather condition is associated with strong winds carrying both sand particles of all sizes and fine dust particles as well, that settle heavily on the module surface. This settlement prevents a larger amount of sun rays from reaching the module surface, hence, the low irradiance values. Rainy weather conditions had the lower irradiance values for both 2021 and 2022. This was because this condition is normally characterized with heavy clouds that consist of gases and water droplets. These clouds block a larger amount of solar irradiance from been captured onto the module surface. Moreover, water droplets and dew which cover the module surface cause a lot scattering of the solar rays falling on the module surface.

The maximum power output for the module under each weather condition is obtained from the maximum point on each P-V characteristic curve (Figure 28), using MATLAB, R2018a. The maximum power output value for each weather condition is shown in Table 3 for both 2021 and 2022.

Table 3: Maximum power output of the PV module for the three weather conditions during 2021 and 2022.

Weather conditions	2021 Power output (W)	2022 Power output (W)
*Control/Clean	282.80	282.80
Harmattan	255.30	259.10
Dry-Windy	212.00	212.00
Rainy	164.50	185.10

Source: Researcher, 2024

It can be seen from Table 3 that the harmattan weather condition has the highest average power output of 255.30 W in 2021 and 259.1 W in 2022. This was because harmattan is associated with cool and hazy weather which allow only light and fine dust particles to settle on the module surface. The cool weather enhances module performance by increasing the open circuit voltage which leads to higher power output. The third weather condition with the highest power output of 212.00 W for both 20221 and 2022 was the dry-windy condition. This condition is characterized by heavy speedy winds which forcibly carry a lot both sand and dust particles onto the modules surface and these particles greatly prevent and scatter a larger amount of solar irradiance from falling onto the surface of the module. Lastly, the rainy condition was the module with the least solar irradiance and power output of 165.50 W for 2021 and 185.10 W for 2022. This condition consists of heavy cloudy conditions, heavy water droplets in the atmosphere, high humidity and dew. Besides, the module surface is covered with water droplets. All these factors block and scatter a substantial amount of solar irradiance from reaching the surface of the panel leading to low power output.

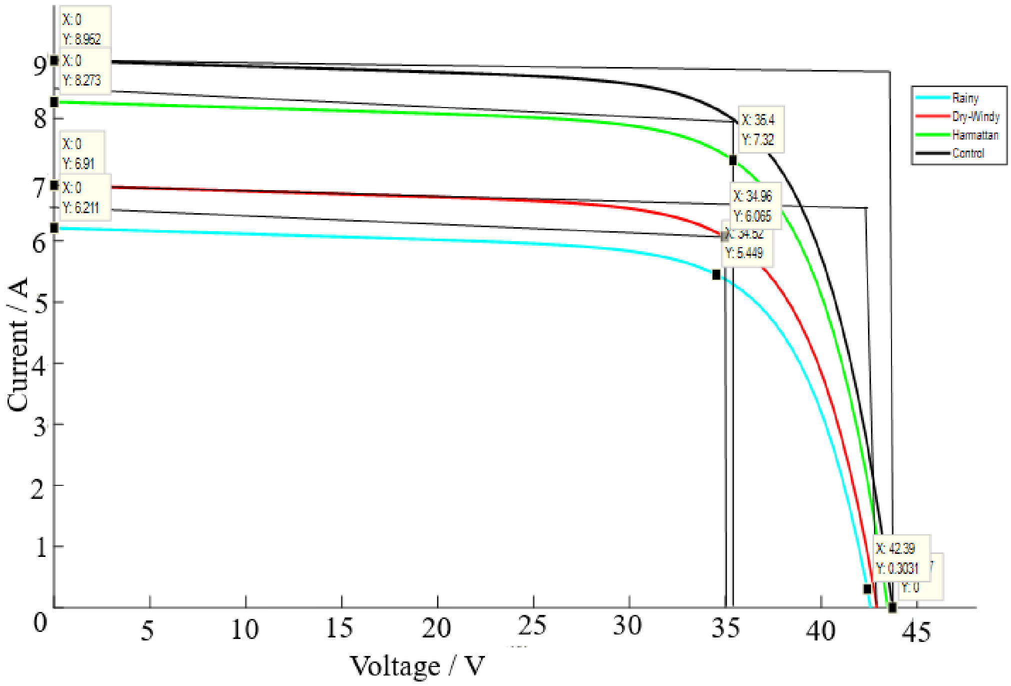


Figure 29: I - V Characteristic Curve for Three (3) weather conditions, 2021

Figure 30 is the I-V characteristic curves defined by the legends for the various weather conditions generated from the MATLAB simulation. The important parameters that contribute mainly to performance assessment of a solar module are the short circuit current (I_{sc}) and the open circuit voltage (V_{oc}) values and the maximum power output (P_{mp}) of a solar module. From Figure 29, it can be observed that the short circuit current values of the module under the various weather conditions are in the following decreasing order: Control is

8.95 A; Harmattan condition is 8.27 A; Dry-Windy is 6.91 A and Rainy condition is 6.21 A. Moreover, the open circuit voltage values for the module also follow the same decreasing order of 43.70 V, 43.26V, 42.82 V and 42.39 V for the control, harmattan, Dry-Windy and Rainy conditions respectively. The maximum power output for each weather condition which were already deduced in Figure 29 and kept in Table 3 also followed the same trend. These results from the figure indicates that the weather condition with the higher parameter values performs better in terms of power output and power output conversion efficiencies than under those weather conditions with lower parameter values. Similar study was conducted by Sharma (2021) in their research to analyze the effects of solar insolation and temperature on PV cell characteristics and to investigate and comprehend the impact of temperature and solar insolation intensity on the IV and PV characteristics using a single-diode solar cell model. The outcome of the research revealed that when the solar irradiance increases at a constant temperature, the output current increases, which leads to an increase in output power.

According to Khallaf et al. (2020), the performance of a solar module is significantly affected by weather conditions. They found that the short circuit current (I_{sc}), open circuit voltage (V_{oc}), and maximum power output (P_{mp}) of a solar module are all lower under rainy conditions than under sunny conditions. Kalogirou (2009) did similar studies and found that the efficiency of a solar module is also affected by dust accumulation. He found that a layer of dust can reduce the efficiency of a solar module by up to 30%. A summary of the assessment results of the module for 2022 is put in table 4.

Table 4: Summarized Results for the Different Weather Conditions – 2021

	Weather Condition				
Parameter	Module at STC	*Control	Harmattan	Dry-Windy	Rainy
Power output (W)	295.00	282.80	259.10	212.00	185.10
% Power reduction	0.00	4.00	12.12	28.14	37.25
Efficiency η (%)	20.50	17.40	16.12	13.38	11.89
Reduction in η (%)	0.00	15.12	21.37	34.68	42.00

Source: Researcher, 2024

Table 4 indicates the electrical power generated by the solar module under each specified weather condition in 2021. A maximum power output (282.80 W) was recorded for the control module while a minimum power output of (185.10 W) was recorded for the rainy condition module at 12:00 noon. The reasons for the differences have been explained earlier.

The computed efficiency of the control module was about 17.40 % (maximum) and 11.89 % (Minimum) was recorded for the module during the rainy weather condition. Consequently, there was a 4 % reduction in power output in the control module and 37.25 % reduction in power output for the module during the rainy weather conditions (Table 4). From Table 4, the efficiency of the module during the three weather conditions was less than the control module. This implies that the environmental weather conditions negative implications regarding the performance of a solar module.

In comparing power output and efficiency of the solar module, it was observed that as the weather conditions become more severe, the power output and efficiency of the PV module decrease. The Harmattan weather condition shows a relatively moderate impact as compared to dry-windy and rainy weather conditions. Analysis from the results suggest that the performance of the solar module is significantly affected by adverse weather conditions with rainy weather condition having the most substantial impact and the harmattan weather condition having the lesser negative impact on the performance of the solar module. Efficiency reduction percentage in the solar module is more pronounced during the rainy weather condition than in the other conditions which is also indicated in table 4 above.

Correlation Analysis of Power Output, Irradiance and Performance efficiency

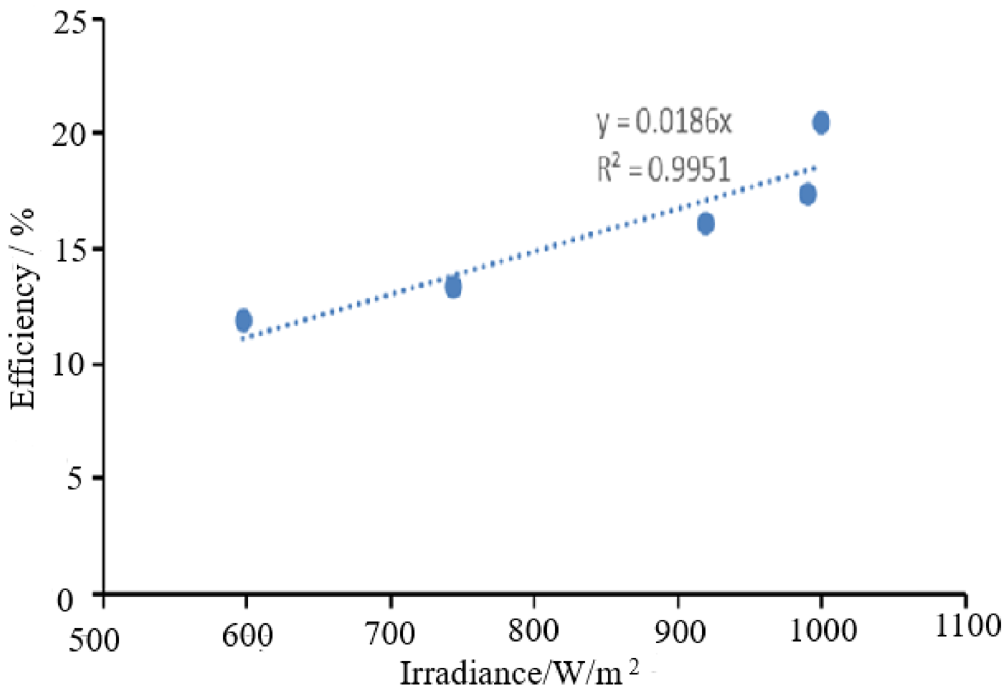


Figure 30: Correlation between efficiency and Irradiance/W/m ^{2}

Figure 30 shows the correlation between panel efficiency and irradiance which indicates a positive correlation (R^2 = 0.995). This implies that the efficiency and irradiance are linearly correlated. This shows that as the irradiance of the module increases the efficiency of the module also increases. This implies that the efficiency is dependent on the solar irradiance.

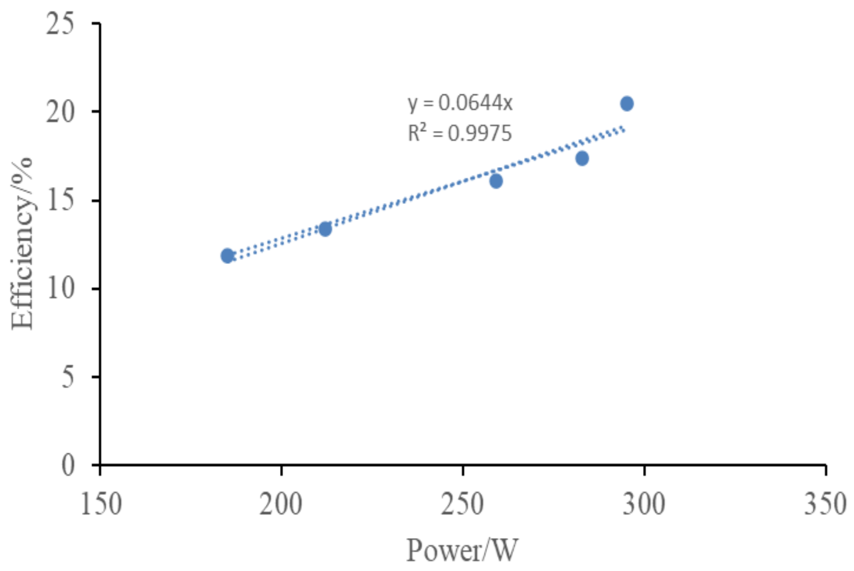


Figure 31: Graph of correlation between efficiency and power output

Figure 31 represents the correlation between the power output and efficiency of the PV module studied. From the Figure, power output and efficiency of the PV module are positively correlated (R^2 = 0.995). This indicates that as the efficiency of any solar module increases, the power output of the module also increases positively and the vice versa.

Experimental and simulation of electrical characteristics of the PV module for the year 2022

To further confirm the assessment performance of the JKM295T solar module, the experimental data taken in 2022 for the three weather conditions (Control, Harmattan. Dry-Windy and Rainy weather conditions) was analyzed. The average irradiance for the different weather conditions at their daily peak hour of 12:00 pm is tabulated in Table 5. The average peak irradiance for the control PV module was 998.00 W/m^2, whereas the harmattan, dry-windy and rainy weather conditions recorded lower values of 911.75 W/m^2, 774.16 W/m^2

and 616.20 W/m^2. This implies that there were unfavorable weather under rainy condition characterized by heavy clouds, heavy water droplets in the atmosphere, dew and high humidity which prevented adequate solar irradiance from falling on the panel surface; dry windy weather condition had the next worst impact on the panel. This was because the heavy winds at the time forcibly carried a lot of both sand dust particles onto the panel surface which obstructed the solar irradiance from reaching the panel surface and the harmattan impacted less negatively on the panel due to the fact that only light dust particles settle on the surface of the panel, besides, the cool weather during that time causes cooling on the panel which led to increase in open circuit voltage. These values have been used to generate the I-V and P-V characteristics curves for the different weather conditions of the PV module in Figure 36 and Figure 37 respectively using a MATLAB, R2018a for the simulation of the solar cell characteristics module equations (6) to (10).

Figures 32 and 33 represent the P-V and I-V characteristics curves, respectively for the three different weather conditions for the year 2022.

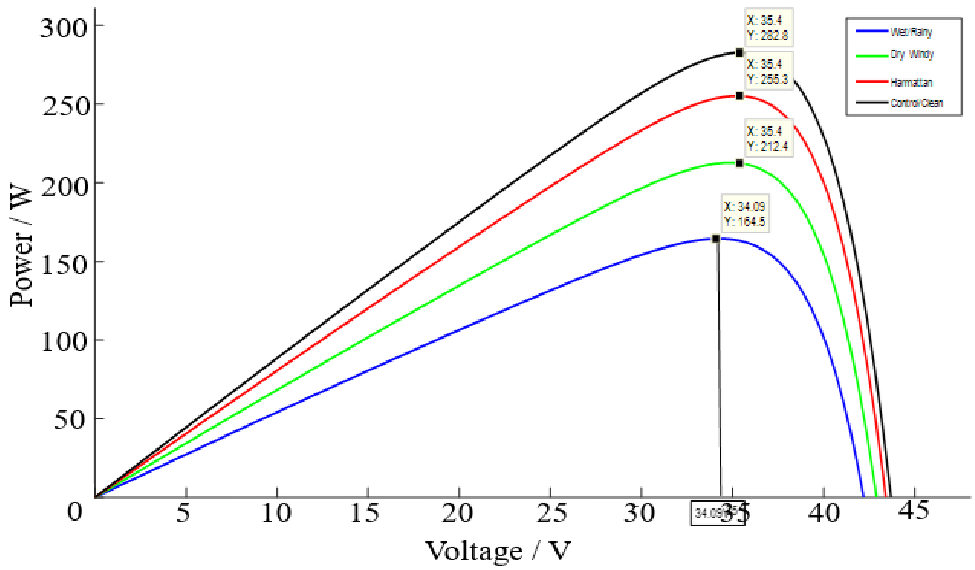


Figure 32: P-V characteristic curves for the (3) weather conditions, 2022

The average power output under each of the weather conditions is estimated from Figure 32 for the year 2022. It can be seen that the module under control condition is having the highest power output value of 282.8 W followed by the harmattan condition, the dry windy and dusty the rainy weather condition with a power output value of 164.50W. this implies that the module under the control weather conditions were not greatly impacted by the weather as compared to the solar module under the different weather conditions.

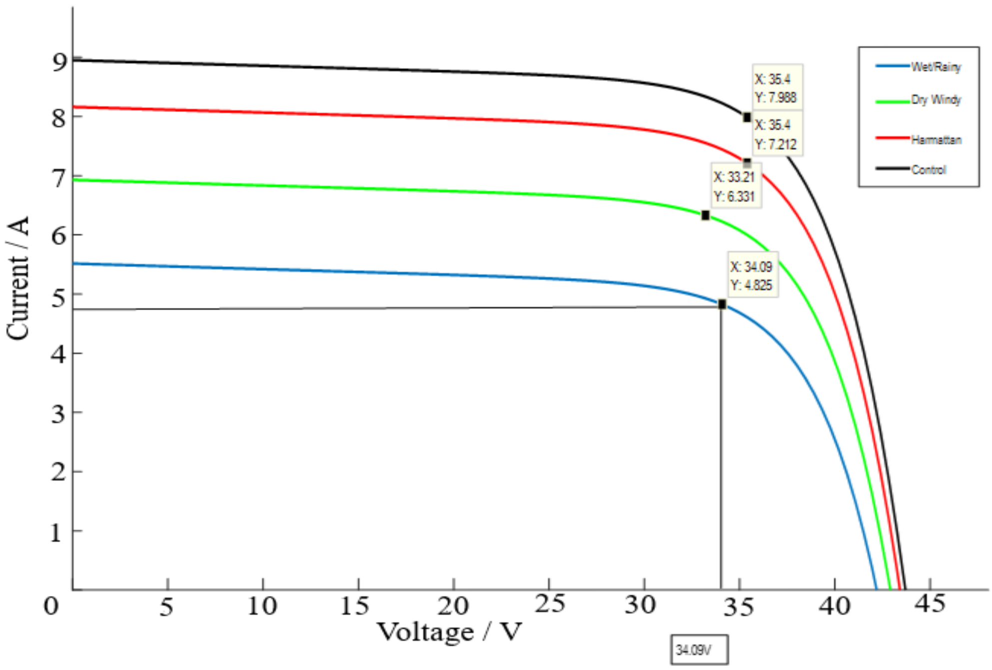


Figure 33: I-V characteristic curves for the P-V characteristic curves for the (3) weather conditions, 2022

The analysis of I-V characteristic curves of the various weather conditions of Figure 33 for the year 2022 follow the same trend as the analysis for the I-V curves in Figure 29 for 2021. Considering performance of the main parameters of the module, short circuit current (I_{sc}) values and the corresponding open circuit voltage (V_{oc}) values for the various weather conditions as determined from Figure 33 are in the following decreasing order:

control weather condition (8.95 A, 43.7 V); harmattan condition (8.16 A, 43.26 V); Dry-Windy (6.93 A, 42.83 V) and rainy condition (5.52 A, 41.96 V) (Mustapha et al., 2023; Darwish et al., 2013; Suman et al., 2022). The maximum power output for each weather condition which were already deduced in Figure 34 and kept in Table 5 also followed the same trend. These parameter assessment results for 2021 also confirmed that the weather condition with the higher parameter values performs better in terms of power output and power output conversion efficiencies than under those weather conditions with lower parameter values (Mustapha et al., 2023; Darwish et al., 2013; Suman et al., 2022). These observations are consistent with the findings of previous studies on the impact of environmental factors on PV module performance. For example, Mustafa et al. (2023) found that dust accumulation, high temperatures, and strong winds can significantly reduce the power output of PV modules. Similarly, Darwish et al. (2013) found that rainy weather can also have a negative impact on PV module performance due to the absorption and scattering of sunlight by raindrops. Suman et al. (2022) further reported that the power output of PV modules can decrease by up to 50% under rainy conditions.

The results of this study suggest that it is important to consider the environmental conditions in which a PV module will be operating when selecting and designing a PV system. In particular, it is important to choose a module that is able to withstand the expected environmental conditions and to design the system so that it can protect the modules from damage. The average maximum power output and power output performance efficiency for the module which were determined from the characteristic curves under the three weather conditions are tabulated in Table 6.

Table 5: Performance Results for the Different Weather Conditions – 2022

	Weather condition				
Parameter	Module STC	Control	Harmattan	Dry-Windy	Rainy
Power output (W)	295.00	282.80	255.30	212.00	164.50
Power Reduction Efficiency (%)	0.00	4.00	13.46	28.14	44.24
Efficiency, η (%)	20.50	17.52	16.01	12.08	10.35
Reduction in Efficiency, η (%)	0.00	14.54	21.90	41.07	49.51

Source: Researcher, 2024

The power output is highest at Standard Test Conditions STC (295.00 W) and decreases under different weather conditions. The Rainy weather condition recorded the highest reduction in power output (44.24 %) whereas STC recorded the least (0.00 %). The efficiency was maximum at the STC (20.50 %) while the minimum value was recorded in rainy weather conditions. The Rainy condition exhibits the highest reduction in efficiency (49.51 %). This implies that the rainy weather condition is characterized by more obstructive atmospheric weather conditions which negatively affect the performance of the module as compared to the other weather conditions. Performance Assessment Correlation of the Solar Module for the Years 2021 and 2022.

Table 6: Comparison of Results for the Different Weather Conditions – 2021 and 2022

Weather Condition / Parameter	2021					2022				
	Module At STC	*Control Condition	Harmattan	Dry Windy	Rainy	Module At STC	Control Condition	Harmattan	Dry Windy	Rainy
Power output(w)	295.00	282.80	255.30	212.00	164.50	295.00	282.80	259.10	212.00	185.10
Reduction in power output(w)%	0.00	4.00	13.46	28.14	44.24	0.00	4.00	12.17	28.14	37.25
Performance efficiency (%)	20.50	17.52	16.01	12.08	10.35	20.50	17.40	16.12	13.39	11.89
Reduction in efficiency (%)	0.00	14.54	21.90	41.07	49.51	0.00	15.12	21.37	34.68	42.00

Source: Researcher, 2024

From Table 6, the power output under the control or clean conditions for 2021 and 2022 was the same value of 282.8 W. Besides the percentage in power reduction for the module under the same control conditions for both years was 4%. This implies that the control conditions for the solar module for the study did not vary in both years (i.e. 2021 and 2022). Moreover, the power efficiency conversion for the module in 2021 was 17.52 % while that in 2022, was 17.40 % which made a difference of 0.12 % in favour of 2021, This indicates that there were more adverse weather conditions in 2022 which reduced the ability of the module to convert solar energy to electrical energy by 0.12 % compared to the same condition in 2021.

This observation was in agreement with the findings of Darwish et al. (2013), who reported that the power output of PV modules can decrease by up to 50 % under dusty conditions. The authors attributed this reduction to the scattering and absorption of sunlight by dust particles.

Additionally, there was higher percentage reduction in power output in 2021 of 13.46 % than in 2022 which was 12.17 % under the harmattan conditions. This means that the harmattan condition was more severe in 2021 than in 2022 which led to higher reduction in module efficiency of 21.90 % in 2021 compared to 21.37 % in 2022. These results were in agreement with the results of Mustapha et al (2023) and Darwish et al (2013) who conducted similar studies.

The higher reduction in power output and efficiency in 2021 than in 2022 under the harmattan condition was likely due higher concentration of dust particles in the atmosphere. The amount of dust particles in the atmosphere also depends on the north-east monsoon desert winds that blow into the savanna region of the country. The dust particles in the harmattan can reduce the amount of sunlight that reaches the PV module, thereby reducing its power output and efficiency.

From Table 6, it can also be seen that both power output and power conversion efficiencies of the module under Dry-Windy conditions for 2021 and 2022 were the same; which were in line with the results obtained for similar research conducted by Mustapha et al. (2023), Darwish et al. (2013) and Suman et al. (2022). This suggests that dry-windy conditions for both years did not vary much from each other.

Furthermore, the table portrays the percentage power reduction for the module in 2021 to be higher with a value of 44.24 % compared to the percentage of power reduction in 2022 with a value of 37.25 % under the Rainy conditions. This brought about the performance efficiency reduction in the module to be 49.51 % in 2021 and 42.00 % in 2022. This means the ability of the module to convert solar energy into electrical energy was higher in 2022 than in 2021 under the rainy weather conditions likely due to the fact that there were harsher weather conditions in 2021 than harsher weather conditions in 2022.

In both years on Table 6. the power output is highest at STC (Standard Test Conditions) and decreases under different weather conditions. The Rainy condition consistently shows the highest reduction in power output for both years. In 2021, the reductions in power output are generally higher compared to 2022 across all weather conditions. The largest difference is observed in the rainy condition, where the power output reduction is more pronounced in 2021 (44.24 %) than in 2022 (37.25 %) (Mustapha et al., 2023; Darwish et al., 2013; Suman et al., 2022).

This observation is consistent with the findings of Suman et al. (2022), who obtained similar results in their studies showing that when the solar irradiance increases at a constant temperature, the output current increases, which leads to an increase in output power.

Chapter Summary

Results of simulation of the weather conditions on the performance of key parameters of the JKM295P-72 solar module have been presented and discussed. It was found that the key parameters of the module did not perform well under the mimic harmattan condition as compared to the key parameters under the mimic rainy condition. Moreover, the experimental assessment of the module under the real weather conditions (harmattan, dry-windy and rainy) was done and the data used to validate the simulated data. The results indicated that the behavior pattern of the key parameters was almost the same in both cases (simulation and experimental) however, the experimental results slightly deviated from the simulated results due to different atmospheric conditions. Furthermore, the performance assessment of the solar module was done through computer simulation of the I-V and P-V characteristics of the module under the various weather conditions. The performance results were presented in terms of power output and power performance efficiency of the module under the various weather conditions.

It was again found that the module performed more poorly under the rainy condition for both power output and power performance efficiency.

Finally, the performance assessment results of the module under the different weather conditions for 2021 and 2022 were compared to ascertain the validity and the reliability of the assessment procedures. It was found the results for the two were highly correlated which indicated that the assessment for the two were in good agreement.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview

This purpose of the study was to assess the performance of a polycrystalline JKM 295P-72 solar module at the 2.5 M W solar power plant at Navrongo in the Upper East Region of Ghana. The assessment was based on the effects of the different weather conditions and environmental factors that negatively affect the performance of the solar modules. The main objective of the study was to be able to predict or estimate the power output and the efficiency of the module under any atmospheric or weather condition. A simulated different weather conditions assessment was initially conducted on the module performance which was subsequently validated by experimental studies. Moreover, the power output and efficiency of the module under different weather conditions was further estimated from the electrical characteristics (I-V and P-V curves) of the solar module.

Summary

The simulated performance assessment of the solar module indicates that from the weather conditions - (Harmattan and the Rainy weather conditions), the harmattan condition had the greatest adverse effect on the performance of the solar module due to the accumulation of dust particles which caused scattering of the solar irradiance that falls on the surface of solar module. Besides, it was found that the module under the rainy condition which was mimic with water droplets performed better in terms of power output due to the fact that the water droplets caused cooling, as well as, reducing the deposition of dust particles on the module surface. cooling in the module resulted in lower temperature in the module which boosted power output.

The experimental investigation on the module performance in terms of power output and performance efficiency from its electrical characteristics for the various weather conditions (Harmattan, dry windy, rainy and the control/clean) revealed the following results: the solar module under the clean or control weather condition produced the average highest power output of 282.2 W and power performance efficiency of 17.4 %. The next measurement was under the harmattan condition which produced a high average power output of 259.1 W and power performance efficiency of 16.12 %. the module. The module under the dry-windy condition was the third highest which generated an average power of 212.0 W and performance efficiency of 13.38 %. The worst performance of the module was under rainy conditions with an average power output of 185.1 W and a power performance efficiency of 11.89 %.

The research also found that power reduction in the module under the various weather conditions (harmattan, dry windy and rainy) measured against the control or the clean condition were 8.38 %, 24.8 % and 34.55 %, respectively. Moreover, the investigation showed that the reduction in efficiency in module for the harmattan, dry windy and rainy conditions were 7.83 %, 19.77 % and 31.66 %, respectively.

Considering the performance assessment of a solar module for two years, 2021 and 2022, under different weather conditions, the study revealed the following outcomes: the power output of the solar module is highest under STC conditions, at 295.00 W in both 2021 and 2022. The lowest power output is under rainy conditions which was 164.50 W in 2021 and 185.10 W in 2022.

The reduction in power output was also highest under rainy conditions, at 44.24% in 2021 and 37.25% in 2022. The lowest reduction in power output is under dry conditions, at 0.00% in both 2021 and 2022.

The performance efficiency of the solar module follows the same trend as the power output. The highest performance efficiency is under dry conditions, at 20.50 % in 2021 and 20.50 % in 2022. The lowest performance efficiency is under rainy conditions, at 10.35 % in 2021 and 11.89 % in 2022.

The reduction in efficiency is also highest under rainy conditions, at 49.51 % in 2021 and 42.00 % in 2022. The lowest reduction in efficiency is under dry conditions, at 0.00 % in both 2021 and 2022. Overall, the performance of the solar module is significantly affected by weather conditions. The power output and efficiency are highest under control conditions and lowest under rainy conditions. Dry- Windy and Harmattan conditions also have a negative impact on performance, but to a lesser extent than rain.

Conclusions

This study aimed to comprehensively assess the performance of JKM 295P-72 solar module under diverse weather conditions through simulation and experimental validations. Specifically, the study was to simulate the main weather conditions in the study area, validate the results with experimental data, and to estimate the module's efficiency and maximum power output through the module’s electrical characteristics.

The simulations which were performed in MATLAB, R2018a successfully generated I-V and P-V curves for the JKM295P-72 module across various weather conditions. The simulation process involved accounting for the dynamic nature of climatic factors, allowing for a realistic representation of the solar module's performance under changing weather conditions. In the validation phase, the simulated results were compared with experimental data, demonstrating a commendable alignment between the two datasets. This validation not only affirmed the accuracy of the MATLAB, R2018a. simulations but also reinforced the reliability of the model in predicting the module's behavior under different environmental circumstances.

The predictive capabilities of the model were further highlighted through the Fill Factor (FF) calculations derived from the I-V characteristic curves. These calculations provided valuable insights into the efficiency and maximum power output of the JKM295P-72 module under various weather conditions.

Furthermore, this study successfully achieved its objectives, contributing to the understanding of the JKM295P-72 solar module's behavior under the varying environmental conditions. The developed MATLAB, R2018a model not only serves as a reliable tool for researchers and practitioners but also established a foundation for further advancements in the field of solar energy system modeling and analysis. Overall, this research has contributed immensely to knowledge in academia and to industry.

In the light of the above, the module seems to perform poor in rainy condition than it is in other conditions. This could be due to the fact that during rain fall the illuminance is poor.

From the study, it has been shown that the module performance for the two years, 2021 and 2022, duly correlated. This further suggests that the validity and reliability of both the instrumentation and the assessment procedure used were high.

Nevertheless, the study revealed that the experimental results on the performance of the solar module cannot wholly validate the simulated results on the performance of the solar module due to the differences in the weather conditions chosen in the two study situations. Overall, the study was successful for achieving all its set objectives.

Recommendations

The following recommendations should be useful to stakeholders of the Navrongo Solar Power Plant if duly implemented.

The results of the study should inform the plant managers the need to find appropriate cleaning mechanisms and routine maintenance schedules for the solar modules under any weather condition to extract maximum power output from the solar power plant in the area.

Besides, the results of the study should be used to deepen the understanding of both industrial and domestic consumers of electricity in the plant catchment area about the effects of diverse weather conditions on solar power production.

Volta River Authority (VRA) should engage academia in partnership to undertake more research studies in their solar power plants to enhance maximum power production.

Further research should be carried to find a relationship between simulated weather conditions and that of real weather conditions.

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APPENDIX A: SIMULATED DATA FOR THREE WEATHER CONDITIONS

Table A1: Simulated data for dusty weather conditions

Date	Time	Irradiance (W/m^2)	Load Voltage (V)	Open Circuit Voltage (V)	Short Circuit Current (A)	Load Curren (A)	Power W	Panel Temperature (ºC)	Ambient Temperature (ºC)	Latitude (deg)
May 26. 2021	7:00 AM	150	30.8	30.8	0.81	2.6	0.08	31	36	357
	8:00 AM	405	37.2	37.2	2.16	2.7	0.1	35	42	350
	9:00 AM	642	38	38	3.81	2.7	0.1	37	37	353
	10:00 AM	781	38.1	38.1	4.91	2.4	0.09	45	44	354
	11:00 AM	863	38	38	6.07	2.8	0.09	42	47	349
	12:00 PM	887	37.5	37.7	6.4	2.2	0.08	44	45	341
	1:00 PM	840	37.3	37.2	6.39	2.1	0.07	45	49	354
	2:00 PM	725	37.4	37.4	5.59	2	0.07	48	49	339
	3:00 PM	570	37	37.8	4.37	1.9	0.07	45	54	347
	4:00 PM	203	29.8	29.6	0.68	2.3	0.06	39	43	355
	5:00 PM	101	28.3	28.2	0.5	2.8	0.07	37	39	350

Table A2: Simulated Data for Rainy Weather Condition

Date	Time	Irradiance (W/m^2)	Short Circuit Current (A)	Open Circuit Voltage (V)	Panel Temperature (ºC)	Ambient Temperature (ºC)	Latitude (deg)
May 26, 2021	7:00 AM	102	1.49	39.3	30	32	326
	8:00 AM	292	3.38	40.3	33	40	346
	9:00 AM	502	5.04	41	33	40	353
	10:00 AM	673	6.05	40.2	39	36	352
	11:00 AM	794	7.38	40.7	38	39	350
	12:00 PM	834	7.67	39.9	39.9	48	347
	1:00 PM	822	7.37	40	43	49	338
	2:00 PM	723	6.35	40.5	41	49	347
	3:00 PM	573	4.74	39.8	42	41	348
	4:00 PM	357	2.9	39.7	41	47	348
	5:00 PM	154	1.28	38	37	40	344

Table A3: Simulated Data for Control/Clean Panel

Date	Time	Irradiance (W/m^2)	Open Circuit Voltage (V)	Load Current (A)	Short Circuit Current (A)	Panel Temperature (^oC)	Ambient Temperature (^oC)	Latitude (deg)
May 26, 2021	7:00 AM	152	40.2	2.4	1.47	32	37	352
	8:00 AM	370	39.09	2.4	3.47	37	38	353
	9:00 AM	643	41.4	2.1	5.63	40	45	346
	10:00 AM	759	39.4	2.1	7.13	47	40	344
	11:00 AM	863	40.7	2.2	7.8	47	49	345
	12:00 PM	893	39	2.3	8.49	51	43	339
	1:00 PM	868	40.1	2.5	7.86	50	51	351
	2:00 PM	752	40.8	2.6	7.28	50	48	343
	3:00 PM	606	40.4	2.7	6.1	48	52	337
	4:00 PM	223	39.7	2.4	0.88	39	42	336
	5:00 PM	100	38	2.7	0.69	37	39	332

APPENDIX B: PROCESSED DATA FOR THE SIMULATED WEATHER CONDITIONS

Table B1: Average Irradiance for the three weather conditions (as in Appendix (A)

Time	Irradiance (of Dusty Panel) (W/m^2)	Irradiance (of Watery Panel) (W/m^2)	Irradiance (of Clean) Panel (W/m^2)
7:00 AM	150	102	152
8:00 AM	405	292	370
9:00 AM	642	502	643
10:00 AM	781	673	759
11:00 AM	863	794	863
12:00 PM	887	834	893
1:00 PM	840	822	868
2:00 PM	725	723	752
3:00 PM	570	573	606
4:00 PM	203	357	223
5:00 PM	101	154	100

Table B2: Average Short circuit current for the three weather conditions (as in appendix A)

Time	Short Circuit Current (Clean) (A)	Open Circuit Voltage (Dust) (V)	Short Circuit Current (wet) (A)
7:00 AM	3.00	1.15	0.63
8:00 AM	3.40	1.74/V	1.86
9:00 AM	5.34	3.14	3.00
10:00 AM	7.81	4.72	5.99
11:00 AM	8.15	5.95	7.16
12:00 PM	9.13	5.99	3.44
1:00 PM	6.83	5.82	3.9
2:00 PM	6.93	4.93	3.75
3:00 PM	2.6	3.97	2.85
4:00 PM	1.77	2.2	3.55
5:00 PM	0.75	0.91	1.13

Table B3: Average open circuit voltage for the three weather conditions (as in appendix A)

Time (hours)	Open Circuit Voltage (Dry) (V)	Open Circuit Voltage (Dusty) (V)	Open Circuit Voltage (Watery) (V)
7:00 AM	39	29.6	39.3
8:00 AM	39.8	37.3	40.2
9:00 AM	39.7	38.4	41
10:00 AM	39.9	38.9	39.7
11:00 AM	39.4	39.2	40.1
12:00 PM	38.9	38.4	41.7
1:00 PM	39.4	38.7	40.5
2:00 PM	39.4	37.8	39.1
3:00 PM	39	37.7	40.2
4:00 PM	38.5	38.2	38.8
5:00 PM	37.5	33.7	39.6

Table B4: Average Panel temperatures for the three weather conditions (as in appendix A)

Time	Panel Temperature - (Dusty) (ºC)	Panel Temperature (watery) (ºC)	Panel Temperature (Clean) (ºC)
7:00 AM	31	30	32
8:00 AM	35	33	37
9:00 AM	37	33	40
10:00 AM	45	39	47
11:00 AM	42	38	47
12:00 PM	44	39.9	51
1:00 PM	45	43	50
2:00 PM	48	41	50
3:00 PM	45	42	48
4:00 PM	39	41	39
5:00 PM	37	37	37

Table B5: Average Power of Module for the Three Weather Conditions (as in appendix A)

Time (hours)	Calculated Power/W (Dry)	Calculated Power/W(wet)	Calculated Power/W(Harmattan)
7:00 AM	117.00	18.65	46.00
8:00 AM	135.32	69.38	70.64
9:00 AM	211.99	115.20	128.11
10:00 AM	311.62	233.01	191.16
11:00 AM	321.11	280.67	240.97
12:00 PM	355.156	132.09	237.80
1:00 PM	269.10	150.93	228.73
2:00 PM	273.04	141.75	194.24
3:00 PM	101.40	107.45	155.23
4:00 PM	68.14	135.61	85.36
5:00 PM	28.12	38.08	34.67

APPENDIX C: EXPERIMENTAL DATA FOR THREE WEATHER CONDITIONS - 2021

Table C1: Dry-Windy Condition

MARCH DATA								APRIL DATA							
Date	TIME	SI W/m^2	ISC/ A	VOC V	TPV ºC	TA ºC	LAT deg	DATE	TIME	SI W/m^2	ISC A	VOC V	TP V ºC	TA ºC	LAT deg
01/03/2021								01//04/2021							
	7am	100	1.86	38.2	33	29	335		7am	119	1.8	39.6	27	29	350
	8am	212	1.91	39.9	35	30	337		8am	175	1.67	40.3	28	29	344
	9am	503	4.13	40.4	40	32	337		9am	105	0.8	40.3	28	30	349
	10am	662	5.91	40.4	42	31	336		10am	215	2.1	39.7	31	32	350
	11am	757	5.21	40.1	45	33	335		11am	277	2.76	39.2	33	36	349
	12pm	863	6.24	39.9	50	34	334		12am	463	4.3	38.9	41	39	344
	1pm	799	7.05	40.2	47	32	335		1pm	531	5.1	38.9	41	39	356
	2pm	513	4.93	39.1	50	36	335		2pm	595	5.7	38.8	47	47	348
	3pm	455	3.81	38.7	50	34	337		3pm	449	4.2	38.8	40	46	351
	4pm	178	1.71	38.3	42	30	336		4pm	262	2.5	38.7	38	43	345
	5pm	100	0.89	37.6	39	30	338		5pm	100	0.77	38.2	34	37	344
02/03/2021								02/04/2021							
	7am	365	2.84	40.1	34	30	334		7am	100	0.74	31.7	27	29	349
	8am	371	3.11	40.5	36	31	337		8am	190	1.89	40.1	28	31	349
	9am	657	5.47	40.6	42	30	336		9am	667	5.9	40.6	33	42	348
	10am	742	6.64	40.1	45	31	336		10am	545	4.95	38.9	35	42	343
	11am	832	7.74	39.8	49	32	337		11am	975	9	38.9	39	46	346
	12pm	919	8.14	38.8	55	40	335		12am	742	6.93	38.7	37	47	352
	1pm	883	7.79	38.3	54	39	336		1pm	768	6.94	38.5	40	51	346

2pm	777	6.77	38.8	55	40	336	2pm	577	5.38	38.2	39	51	349
3pm	547	4.53	38.9	50	38	336	3pm	552	5.22	37.8	42	54	353
4pm	230	2.49	38.7	44	31	338	4pm	300	3.23	37.4	38	49	356
5pm	100	0.66	37.1	38	30	339	5pm	137	1.42	35	36	45	345
03/03/2021							03/04/2021						
7am	280	2.42	40.3	33	32	340	7am	150	1.47	35.9	30	32	350
8am	320	2.64	40	35	33	348	8am	229	2.17	37.4	32	34	344
9am	416	3.69	40.5	38	36	339	9am	342	3.22	38.4	34	37	349
10am	759	6.55	40.5	45	38	337	10am	700	6.36	38.6	40	45	350
11am	923	8.22	39.8	48	40	336	11am	501	5.45	33.8	41	45	349
12pm	944	8.32	39.2	52	46	337	12am	634	6.53	38.1	43	49	344
1pm	912	7.97	38.2	56	48	336	1pm	628	4.53	38.2	43	48	356
2pm	824	7.18	38.1	60	51	335	2pm	555	5.6	37.6	43	49	348
3pm	660	3.29	36.9	54	50	338	3pm	359	3.47	36.9	44	49	351
4pm	312	2.88	38.6	48	38	338	4pm	257	2.59	36.9	39	43	349
5pm	139	1.39	37.9	42	37	336	5pm	100	0.96	33.1	36	40	350
04/03/2021							04/04/2021						
7am	100	0.32	36.8	25	22	322	7am	164	1.76	36.8	30	31	348
8am	100	0.34	37.7	27	25	340	8am	351	3.25	38.5	32	35	346
9am	100	0.75	39.2	26	26	336	9am	590	5.45	39.2	34	38	345
10am	146	1.27	40.1	27	23	339	10am	750	6.7	39	37	42	351
11am	332	3.02	40.8	33	30	340	11am	670	6.7	39	41	47	346
12pm	453	3.78	40.5	39	34	337	12am	790	7.9	38.6	42	50	347
1pm	613	5.36	39.9	47	38	336	1pm	670	6.98	38.4	43	49	346
2pm	609	5.2	39.5	47	36	336	2pm	588	4.97	37.8	42	52	343
3pm	409	3.68	39.6	43	39	337	3pm	381	3.66	37.5	40	45	350

4pm	295	2.71	39.6	40	32	337
5pm	100	0.79	38.1	34	32	339

05/03/2021

7am	100	1.24	36.7	31	24	336
8am	172	1.59	39.8	32	28	339
9am	669	5.74	40.7	40	34	337
10am	734	6.6	40.5	43	29	336
11am	809	8.43	39.6	49	28	336
12pm	780	6.2	39.2	49	46	336
1pm	900	7.68	38.3	55	43	336
2pm	783	6.7	38.8	52	42	335
3pm	592	5.21	38.7	50	43	336
4pm	360	3.14	38.5	49	34	337
5pm	100	0.68	36.4	42	36	338

06/03/2021

7am	100	2.1	40.3	28	26	336
8am	280	2.69	40.6	34	32	340
9am	472	4.35	40.3	41	38	338
10am	512	4.74	39.9	42	36	338
11am	652	6.07	39.9	47	42	337
12pm	740	6.91	40.1	48	41	338
1pm	582	5.58	40.3	41	46	337
2pm	812	6.52	38.9	48	43	336
3pm	446	4.41	40.3	41	39	337
4pm	370	3.55	39.8	42	37	338
5pm	149	1.63	39	37	34	339

4pm	284	1.97	37.1	39	44	350
5pm	100	0.86	32.3	36	40	357

05/04/2021

7:00 am	109	0.87	32.5	25	26	342
8:00 am	307	2.97	38.7	29	30	351
9:00 am	551	5.05	38.9	33	34	355
10:00 am	803	6.79	38.8	37	39	348
11:00 am	621	6.55	39.2	38	39	348
12:00 pm	350	5.84	38.7	38	43	357
1:00 pm	682	6.57	38.8	41	43	357
2:00 pm	571	5.66	38.2	39	46	358
3:00 pm	233	2.48	36.6	39	41	356
4:00 pm	100	0.95	32.1	35	40	346
5:00 pm	100	0.16	25.1	32	35	

06/04/2021

7:00 AM	100	2.03	40.3	32	28	340
8:00 AM	164	1.61	36.5	29	30	348
9:00 AM	400	3.56	38.7	32	38	353
10:00 AM	618	5.6	39.2	35	42	340
11:00 AM	780	7.12	39.2	38	45	347
12:00 PM	875	7.92	39	39	45	340
1:00 PM	856	7.78	38.7	42	48	340
2:00 PM	463	4.29	37.2	39	41	340
3:00 PM	637	5.88	38.1	43	48	340
4:00 PM	517	4.93	37.9	42	48	333
5:00 PM	164	1.59	35.4	37	43	334

07/03/2021						
7am	100	2.03	40.3	32	28	340
8am	212	6.01	40.7	40	36	338
9am	659	7.13	40.2	45	41	338
10am	793	7.46	40.9	46	38	342
11am	902	8.18	40	47	42	336
12pm	924	8.48	39.4	50	47	334
1pm	901	8.13	39.4	51	49	337
2pm	755	6.85	39.4	50	45	336
3pm	720	6.3	39.2	48	46	336
4pm	373	3.57	39.4	44	40	339
5pm	108	1.24	38.2	39	34	339
08/03/2021						
7am	200	2.3	38.4	36	28	329
8am	299	2.73	40.3	37	34	339
9am	624	5.47	40.2	43	38	338
10am	840	7.49	39.7	49	34	337
11am	910	8.22	39.4	50	46	336
12pm	924	8.34	38.4	58	49	336
1pm	842	7.56	38.1	57	50	335
2pm	700	6.9	38.3	53	49	335
3pm	606	5.44	38.2	56	51	336
4pm	562	4.78	38	48	38	336
5pm	100	0.13	33.4	37	32	339
09/03/2021						
7am	100	1.88	40	30	28	334
8am	203	1.99	40.4	31	26	339

07/04/2021						
7:00 AM	285	2.72	38.5	29	30	349
8:00 AM	281	2.79	38.5	32	33	349
9:00 AM	743	5.42	39	40	43	348
10:00 AM	715	5.46	38.2	42	45	343
11:00 AM	707	6.57	38.5	43	46	346
12:00 PM	671	7.92	39	41	42	352
1:00 PM	899	8.23	38.1	44	45	346
2:00 PM	728	6.62	38	45	49	349
3:00 PM	320	2.99	37.6	37	42	353
4:00 PM	147	1.66	36	34	39	356
5:00 PM	100	0.92	33.4	33	36	345
08/04/2021						
7pm	109	2.7	36.6	24	35	353
8:00 AM	414	2.4	38.7	31	37	353
9:00 AM	629	2.2	39	33	35	343
10:00 AM	783	7.81	39.1	35	36	344
11:00 AM	882	8.03	38.8	38	46	348
12:00 PM	1048	9.6	38.1	46	45	345
1:00 PM	741	7.48	38.6	43	46	350
2:00 PM	714	6.67	38.3	42	50	345
3:00 PM	272	2.88	37.3	37	43	350
4:00 PM	159	1.7	35.6	38	46	340
5:00 PM	100	0.72	30.9	37	35	351
09/04/2021						
7:00 AM	116	1.35	35.4	31	31	349
8:00 AM	397	2.72	38.3	34	37	343

	9am	576	6.52	40.6	36	31	338		9:00 AM	702	5.76	38.4	39	43	351
	10am	455	4.81	40.7	38	32	338		10:00 AM	754	6.42	38.4	41	43	356
	11am	976	7.7	40.1	44	41	336		11:00 AM	901	8.01	38.7	40	47	351
	12pm	533	4.66	40.2	41	40	337		12:00 PM	919	8.23	38.3	45	49	346
	1pm	650	8.19	41	43	42	336		1:00 PM	843	7.82	37.9	44	54	349
	2pm	790	7.36	40.4	45	43	336		2:00 PM	772	7.09	37.9	49	52	347
	3pm	590	5.37	40.3	42	38	336		3:00 PM	507	5.13	37.7	42	43	342
	4pm	350	3.46	40.1	39	36	337		4:00 PM	256	3.52	38.4	42	49	345
	5pm	130	1.24	38.9	36	32	338		5:00 PM	109	0.64	29.8	37	44	346
10/03/2021								10/04/2021							
	7am	100	2	40.1	32	30	324		7:00 AM	175	1.55	36.3	38	32	348
	8am	222	2.08	40.3	33	32	339		8:00 AM	402	3.46	38.3	36	40	346
	9am	668	3.76	39.8	39	33	337		9:00 AM	629	5.34	38.7	36	40	345
	10am	787	7.11	40.3	44	42	337		10:00 AM	800	7.06	38.7	39	42	351
	11am	977	8.87	39.7	48	44	336		11:00 AM	876	7.9	38.6	43	46	346
	12pm	963	8.67	39.5	50	46	337		12:00 PM	757	6.83	38.5	42	43	347
	1pm	882	8.07	39.1	53	51	335		1:00 PM	751	6.9	38.2	46	47	346
	2pm	768	6.86	39.1	53	50	336		2:00 PM	710	7.23	38.7	41	48	343
	3pm	603	5.54	38.7	52	49	334		3:00 PM	506	5.06	38.6	43	47	350
	4pm	292	2.78	38.8	45	43	337		4:00 PM	234	2.97	37.3	39	46	350
	5pm	100	1	37.5	42	38	339		5:00 PM	100	0.92	32.2	36	39	357
11/03/2021								11/04/2021							
	7am	100	2.52	40.1	32	30	334		7am	152	1.43	35.8	28	29	347
	8am	246	2.54	40.5	34	32	339		8am	207	37.3	37.4	30	33	344
	9am	616	5.62	40.8	39	31	338		9am	451	4.12	38.9	33	37	340

	10am	781	7.07	39.9	43	40	337		10am	720	6.77	39.3	38	43	336
	11am	1002	8.99	38.9	50	48	338		11am	749	7.17	38.7	40	43	348
	12pm	735	5.42	40	44	41	336		12pm	823	7.68	38.4	45	43	343
	1pm	437	3.38	37.8	45	43	337		1pm	808	7.71	38.4	42	48	344
	2pm	539	2.8	37.9	49	42	337		2pm	759	6.6	38.2	46	47	347
	3pm	665	6.19	39.3	51	50	336		3pm	275	3.09	37.4	39	42	343
	4pm	351	3.27	38.9	46	42	337		4pm	206	2.39	36.7	39	41	368
	5pm	100	0.61	37.2	36	32	339		5pm	100	1.28	32.7	36	40	345
12/03/2021								12/04/2021							
	7am	100	1.86	40	32	28	314		7am	206	1.77	36.8	29	33	351
	8am	193	1.89	42	30	29	317		8am	424	3.5	38.6	33	37	344
	9am	587	5.73	40.9	40	36	318		9am	665	5.46	39.1	35	43	344
	10am	413	4.37	40.5	38	34	312		10am	833	7.22	38.7	40	45	342
	11am	696	6.84	40.5	43	41	317		11am	909	8.08	38.2	43	43	343
	12pm	726	7.11	40.1	46	39	315		12pm	913	8.2	37.9	46	52	340
	1pm	903	8.51	39	53	50	313		1pm	844	7.8	38.1	45	45	352
	2pm	485	5.28	40.4	42	40	317		2pm	718	6.03	39.1	45	46	346
	3pm	457	4.6	38.7	50	46	312		3pm	501	5.13	37.7	44	48	341
	4pm	189	1.88	38.4	45	43	325		4pm	248	2.97	32.9	41	46	344
	5pm	100	0.68	37.1	39	34	321		5pm	100	0.7	30.5	39	43	345
13/03/2021								13/04/2021							
	7am	100	0.44	34	22	21	328		7am	200	1.58	35.9	32	35	350
	8am	100	0.47	39	23	20	340		8am	100	0.4	28	30	31	353
	9am	233	2.23	40.4	29	24	339		9am	100	0.63	30.4	28	28	344
	10am	348	2.63	40.3	33	28	338		10am	100	0.43	28.3	25	27	342
	11am	398	3.49	40.9	39	32	338		11am	100	0.4	27.9	25	28	346

	12pm	419	3.89	41.4	33	30	339		12pm	100	1.08	34	26	28	343
	1pm	508	4.43	40.4	38	34	338		1pm	170	1.66	36.6	30	30	350
	2pm	184	1.84	40.3	30	28	339		2pm	234	2.33	37.6	33	33	345
	3pm	173	1.36	40.2	28	24	338		3pm	342	2.49	37.6	33	35	345
	4pm	140	0.8	38.6	26	21	337		4pm	193	2.03	37	32	35	340
	5pm	100	0.45	36.7	24	20	336		5pm	113	1.23	34.7	31	34	340
14/03/2021								14/04/2021							
	7am	100	1.84	34	30	28	334		7am	176	1.46	35.8	30	35	345
	8am	200	1.85	40	34	32	338		8am	450	3.71	38.8	33	36	344
	9am	398	3.82	40.5	39	34	338		9am	653	5.56	39.1	35	41	342
	10am	543	4.6	40.2	40	36	336		10am	825	7.04	38.8	38	40	339
	11am	816	7.81	39.5	53	48	336		11am	912	7.93	38.4	43	56	338
	12pm	961	8.56	39.6	52	49	336		12pm	905	8.15	37.6	47	45	352
	1pm	961	8.56	39.6	53	50	336		1pm	839	7.7	37.7	47	52	347
	2pm	486	3.96	38.4	54	48	336		2pm	705	7.01	37.8	43	53	340
	3pm	371	3.61	39.3	51	46	337		3pm	474	4.81	37.4	44	49	341
	4pm	340	3.25	38.9	49	43	337		4pm	185	2.25	36.4	39	44	342
	5pm	149	1.89	38.3	33	32	339		5pm	100	0.89	31.9	38	40	342
15/03/2021								15/04/2021							
	7am	100	2.42	40.2	31	24	318		7am	164	1.34	35.3	30	32	343
	8am	303	2.91	40.4	36	32	339		8am	478	3.89	38.9	32	41	359
	9am	556	5.49	40.1	42	40	338		9am	686	5.95	39.5	33	34	347
	10am	704	5.79	40.1	44	41	337		10am	829	6.96	39.2	38	43	343
	11am	726	6.42	39.2	50	46	337		11am	600	2.59	38.4	37	42	346
	12pm	939	7.36	39.1	53	50	337		12am	472	4.26	38.1	38	42	345
	1pm	866	7.36	39.1	53	52	337		1pm	790	7.16	38.2	42	47	344

2pm	594	5.29	39.6	49	43	335
3pm	630	5.62	38.8	51	50	336
4pm	229	2.36	39	44	40	337
5pm	109	1.16	38	41	38	339
16/03/2021						
7am	100	1.84	40	31	30	334
8am	206	1.92	40.1	33	28	339
9am	521	3.9	40	42	40	338
10am	579	5.64	39.9	46	42	337
11am	690	8.31	40	47	46	336
12pm	700	6.2	38.9	50	46	336
1pm	521	4.96	39.6	47	45	336
2pm	509	6.16	39.7	48	43	336
3pm	711	6.5	39.6	51	50	336
4pm	100	0.68	37.8	34	32	339
5pm	100	0.4	36.8	33	31	341
17/03/2021						
7am	100	0.64	37.6	27	23	335
8am	100	0.79	39.1	29	26	339
9am	247	2.27	40.7	30	28	339
10am	374	3.31	40.5	33	29	339
11am	419	3.7	40.7	37	34	338
12pm	539	4.84	39.8	43	36	337
1pm	401	3.83	39.7	42	39	338
2pm	235	2.23	39.6	37	34	339
3pm	205	2.13	39.6	36	32	338
4pm	164	1.47	39.2	35	36	339
5pm	100	0.56	37.7	32	30	339

2pm	581	6.4	37.8	43	47	351
3pm	510	5.06	37.8	43	43	347
4pm	263	3.17	36.7	42	49	347
5pm	100	0.86	32	37	44	348
16/04/2021						
7am	191	1.83	36.7	31	34	356
8am	461	3.88	38.5	35	38	350
9am	767	6.86	39	38	43	350
10am	831	7.36	39.3	42	47	353
11am	415	3.2	36.6	41	43	343
12pm	870	7.71	38.1	43	51	346
1pm	840	7.73	38.6	41	43	346
2pm	660	6.02	38.1	41	49	346
3pm	441	3.94	37.6	41	43	343
4pm	254	2.59	36.9	38	43	344
5pm	100	0.94	32.9	37	38	340
17/04/2021						
7am	100	1.01	33.5	29	31	354
8am	422	3.82	38.6	34	38	346
9am	680	5.95	38	37	37	355
10am	789	6.97	38.6	43	44	353
11am	908	8.04	38.3	44	43	345
12pm	893	8.01	37.8	51	50	344
1pm	755	7.14	37.4	44	49	350
2pm	205	2.12	35.6	43	49	356
3pm	181	2.45	36.6	41	43	355
4pm	117	1.27	36.4	36	37	345
5pm	100	0.73	38.1	36	37	352

18/03/2021						
7am	100	0.84	40.3	28	26	331
8am	264	1.88	40.5	30	29	339
9am	622	5.75	40.5	40	39	338
10am	805	7.14	40.4	45	40	337
11am	913	8.23	39.7	49	46	336
12pm	934	8.4	39.1	51	50	335
1pm	901	7.99	39.3	50	48	336
2pm	731	6.56	39.3	51	46	335
3pm	520	4.62	38.8	49	44	336
4pm	336	3.24	38.6	48	43	337
5pm	102	1.02	37.9	40	38	338
19/03/2021						
7am	100	2.41	40.2	34	32	330
8am	395	3.61	40.5	36	34	339
9am	648	5.91	40.2	43	40	338
10am	745	6.69	40	48	46	338
11am	936	8.45	38.9	54	52	336
12pm	977	8.65	38.8	55	51	336
1pm	879	7.8	38.9	58	52	335
2pm	836	7.4	38.7	56	50	336
3pm	563	5.14	39	54	52	336
4pm	349	3.26	38.8	50	48	337
5pm	101	0.93	37.6	42	40	338
20/03/2021						
7am	134	2.3	40.1	32	28	330
8am	225	2.12	39.9	36	34	339
9am	588	5.77	40.3	42	40	337

18/04/2021						
7am	104	1.05	33.9	27	28	346
8am	306	2.85	38.3	31	32	353
9am	711	6.43	39.6	32	38	357
10am	870	6.01	38.1	37	43	349
11am	837	7.54	38.9	36	43	348
12pm	899	7.62	39.3	40	46	343
1pm	325	4.29	37.7	38	40	345
2pm	729	6.56	38	44	46	351
3pm	391	4.57	38.3	37	41	355
4pm	218	2.24	36.4	38	41	352
5pm	117	1.47	35.1	37	42	359
19/04/2021						
7am	170	1.63	36.3	30	34	348
8am	285	2.38	37.6	31	36	343
9am	671	5.86	39.2	34	42	356
10am	489	4.42	37.7	37	44	344
11am	678	5.17	38.7	37	43	353
12pm	905	8.17	38.7	40	50	343
1pm	935	8.51	39.7	40	46	352
2pm	707	6.41	37.8	45	50	345
3pm	340	2.03	35.5	39	43	355
4pm	133	1.25	34.6	40	44	350
5pm	120	1.04	32.8	37	39	350
20/04/2021						
7am	164	1.57	35.8	33	34	347
8am	409	3.72	38	37	45	345
9am	630	5.49	38.4	37	34	347

	10am	563	5.19	40.5	43	42	337		10am	796	7.01	38.2	42	50	356
	11am	658	5.69	38.9	47	45	336		11am	860	7.76	37.5	46	49	341
	12pm	755	6.77	39.5	49	46	336		12pm	901	8.17	35.7	47	49	350
	1pm	929	7.93	39.2	50	48	335		1pm	852	7.73	37.3	47	50	349
	2pm	509	4.47	39.1	49	43	336		2pm	717	6.58	37.1	51	52	349
	3pm	326	2.94	39	44	40	337		3pm	520	5.1	37.2	45	53	348
	4pm	239	2.22	38.8	42	38	337		4pm	281	3.17	34	46	48	352
	5pm	100	0.98	38	36	34	339		5pm	100	0.68	29.4	40	45	357
21/03/2021								21/04/2021							
	7am	100	1.8	38.2	34	31	328		7am	101	1.05	33.9	29	30	356
	8am	248	2.3	39.8	37	35	339		8am	241	1.21	35.5	32	31	352
	9am	595	5.53	40.4	41	39	338		9am	617	2.54	37.6	37	39	357
	10am	742	6.43	39.6	46	48	337		10am	773	3.6	38.1	37	38	352
	11am	871	7.2	38.4	52	48	335		11am	870	4.3	37.9	40	49	350
	12pm	869	7.74	38.7	54	36	336		12pm	870	4.42	37.5	44	54	346
	1pm	932	8.34	38.4	60	58	335		1pm	837	4.43	37.5	42	51	354
	2pm	768	6.87	38.4	56	53	335		2pm	736	3.71	37.3	42	43	346
	3pm	606	5.32	38.5	52	50	336		3pm	534	3.71	37.3	42	46	351
	4pm	268	2.62	38.5	47	43	338		4pm	229	2.17	39.1	40	38	318
	5pm	100	0.94	37.3	43	40	338		5pm	100	0.93	38.5	25	22	318
22/03/2021								22/04/2021							
	7am	212	1.84	40.1	33	30	320		7am	150	2.6	30.8	31	36	351
	8am	287	2.65	40.4	35	31	339		8am	405	2.7	37.2	35	42	342
	9am	735	6.52	40.2	43	41	338		9am	642	2.7	38	37	37	351
	10am	828	7.36	40	46	43	337		10am	781	2.4	38.1	45	44	358
	11am	913	8.09	39.5	50	48	336		11am	863	2.8	38	42	47	347
	12pm	932	8.43	39.3	51	49	334		12pm	887	2.2	37.7	44	45	348

1pm	920	8.18	38.6	57	53	335
2pm	810	6.9	38.6	52	50	334
3pm	587	5.38	38.4	54	51	336
4pm	106	1.3	37.5	43	40	338
5pm	100	0.87	37.4	39	34	339
23/03/2021						
7am	100	0.4	38	22	20	330
8am	112	0.6	39.1	25	22	339
9am	159	1.54	40.6	26	24	339
10am	162	1.59	40.5	27	25	339
11am	366	3.57	41.2	32	30	338
12pm	324	3.15	40.8	34	31	338
1pm	444	4.25	41.1	36	32	338
2pm	374	3.5	40.2	38	33	337
3pm	224	2.11	39.8	35	33	337
4pm	212	1.99	39.8	25	22	338
5pm	137	1.43	39.5	25	20	339
24/03/2021						
7am	100	0.63	38.1	25	20	330
8am	109	0.71	38.9	28	28	336
9am	263	2.63	40.6	32	30	339
10am	349	2.83	40.5	35	32	339
11am	622	5.33	39.9	45	42	337
12pm	566	5.03	39.1	47	41	336
1pm	402	3.97	39.3	45	41	338
2pm	509	4.95	39.5	47	43	337
3pm	377	3.58	39.2	24	21	337
4pm	248	2.03	38.8	41	39	339

1pm	840	2.1	37.2	45	49	349
2pm	725	2	37.4	48	49	348
3pm	570	1.9	37.8	45	54	357
4pm	203	2.3	29.6	39	43	353
5pm	101	2.8	28.2	37	39	355
23/04/2021						
7am	103	2.9	32.5	28	29	353
8am	387	2.6	45.2	31	35	351
9am	333		37.6	34	37	342
10am	455		39.5	35	38	351
11am	586		38.5	43	48	358
12am	832		39.3	39	43	347
1pm	755		39	42	44	348
2pm	647		39.2	40	43	349
3pm	447		39.1	41	40	348
4pm	212		38.2	38	39	357
5pm	109		37.7	35	37	353
24/04/2021						
7am	101	1.09	39.3	28	29	348
8am	256	2.7	40.2	31	32	350
9am	888	7.37	41	36	39	341
10am	820	7.9	39.7	42	43	349
11am	775	7.22	40.1	49	46	347
12pm	803	7.69	417	38	43	341
1pm	575	5.18	40.5	40	41	349
2pm	596	7.52	39.1	43	43	359
3pm	380	3.44	40.2	39	44	345
4pm	241	2.43	38.8	39	38	345

5pm	100	0.9	38.3	25	22	339		5pm	154	1.61	39.6	37	42	346
25/03/2021							25/04/2021							
7am	100	1.51	39.3	32	30	334		7am	146	1.68	40	31	33	352
8am	221	1.91	39.9	35	32	337		8am	205	2.64	40.2	33	36	351
9am	504	4.13	40.4	40	38	337		9am	639	6.38	40.4	37	42	350
10am	663	5.91	40.5	42	39	337		10am	490	5.35	39.7	43	41	342
11am	757	5.22	40.1	46	41	335		11am	650	6.37	40.7	40	46	341
12pm	938	7.36	39.1	53	50	337		12pm	920	8.77	40.9	44	43	351
1pm	867	6.82	39.5	50	48	336		1pm	897	8.53	40.3	42	48	353
2pm	594	5.29	39.6	49	43	335		2pm	734	6.88	39.1	47	42	346
3pm	620	5.61	38.8	51	46	336		3pm	193	2.03	38.6	39	45	345
4pm	228	2.36	39	44	40	337		4pm	253	2.33	38.4	41	45	354
5pm	100	1.16	38	35	32	1.16		5pm	140	1.53	38.9	37	42	351
26/03/2021							26/04/2021							
7am	103	1.06	39.3	29	29	350		7am	133	1.64	39.4	34	36	353
8am	366	2.9	41.5	32	34	344		8am	349	3.64	39.7	39	44	351
9am	600	5.65	40.1	38	36	349		9am	593	5.8	39.9	38	50	342
10am	765	6.93	41.2	40	44	350		10am	755	7.28	40.5	41	43	351
11am	859	9.76	39.7	43	44	349		11am	854	7.89	39.9	46	52	358
12pm	871	7.95	39.8	46	51	344		12pm	966	8.69	38.6	49	50	347
1pm	858	8.2	41.1	46	42	356		1pm	868	7.89	40.1	47	54	348
2pm	763	7.15	40.4	45	51	348		2pm	754	6.93	39.2	53	50	349
3pm	574	5.52	39.3	45	42	351		3pm	518	5.3	38.5	45	44	348
4pm	191	1.98	38.7	41	43	349		4pm	339	3.38	39.6	46	45	357
5pm	123	1.31	38.3	36	37	346		5pm	106	1.18	38.8	41	48	353

Where SI = solar irradiance, Isc = short circuit current, Voc = open circuit voltage, Tpv = panel temperature, Tam = ambient temperature, Lat = latitude, VL = load voltage

Table C2: Rainy Weather Condition

		August – 2021								September – 2021					
Date	Time	SI	ISC	VOC	TPV	TA	Lat	Date	Time	SI	ISC	VOC	TPV	TA	Latt
01/08/2021								01/09/2021							
	7am	100	0.71	31.2	27	28	340		7am	120	1.5	40	33	33	345
	8am	160	1.6	37	27	28	345		8am	380	3.9	40.2	34	34	348
	9am	160	1.74	37.1	30	30	344		9am	619	6.18	40.5	41	42	350
	10am	366	3.66	38.7	35	33	352		10am	254	3.7	39.3	42	36	351
	11am	758	5.11	38.1	40	39	351		11am	362	3.07	40.2	42	35	345
	12noon	732	9.41	39.5	42	39	344		12pm	982	9.3	40.2	48	40	347
	1pm	378	3.12	38.5	37	38	344		1pm	612	5.5	38.5	46	38	347
	2pm	262	3.52	38.6	38	36	344		2pm	731	7.5	40.3	46	38	346
	3pm	309	3.42	38.6	37	39	345		3pm	626	2.6	40.1	44	40	352
	4pm	126	1.35	35	33	37	338		4pm	206	2.6	39.4	37	36	359
	5pm	100	0.9	35	33	36	335		5pm	100	1.2	38.7	32	33	352
02/08/2021								02/09/2021							
	7am	100	0.97	32.6	25	26	344		7am	120	1.2	40	25	26	344
	8am	299	2.66	38.7	32	35	351		8am	181	2	40.6	26	27	347
	9am	692	6.1	38.8	40	37	342		9am	228	2.4	40.2	30	27	343
	10am	103	9.25	39.9	44	49	340		10am	249	2.7	40.5	30	28	347
	11am	227	2.58	35.9	44	41	345		11am	352	3.8	40.8	34	31	342
	12noon	417	4.06	38.6	39	40	345		12noon	488	6.8	40.6	38	34	350
	1pm	850	8.42	39.1	48	40	342		1pm	322	3.64	40.9	35	33	348
	2pm	213	2.65	36.5	41	39	344		2pm	394	4.2	40.9	35	34	349
	3pm	144	4.25	38	37	36	345		3pm	426	2.8	40.2	36	37	346
	4pm	152	2.58	37.2	39	38	345		4pm	263	2.8	40.2	36	37	346
	5pm	100	1.07	33.4	35	36	348		5pm	122	1.4	39.2	33	34	354

03/08/2021							
	7am	168	1.65	36.7	30	28	346
	8am	405	2.74	37.9	37	36	340
	9am	482	4.75	38.7	40	39	341
	10am	693	6012	38.3	48	42	345
	11am	844	4.45	37.2	50	44	345
	12noon	1054	9.63	38.9	52	43	345
	1pm	950	9.19	38.5	55	47	345
	2pm	875	7.6	36.8	55	47	343
	3pm	117	5.8	38.4	51	44	344
	4pm	100	1.08	33.6	37	36	343
	5pm	100	0.89	32.2	32	33	343
04/08/2021							
	7am	100	0.63	29.6	26	25	348
	8am	186	1.86	37.3	27	26	342
	9am	286	3	38.4	33	31	347
	10am	652	5.99	38.9	42	39	346
	11am	690	7.16	39.2	43	44	346
	12noon	299	3.44	38.4	37	35	343
	1pm	352	3.9	38.7	36	35	343
	2pm	355	3.75	37.8	37.9	42	346
	3pm	349	2.85	37.7	38	36	346
	4pm	349	3.55	38.2	39	40	351
	5pm	104	1.13	33.7	32	35	352
05/08/2021							
	7am	100	0.49	28.6	25	28	346
	8am	128	1.27	35.1	27	28	342
	9am	140	1.55	36.4	28	27	343

03/09/2021							
	7am	150	1.6	40.5	30	31	345
	8am	262	3.25	40.8	32	32	346
	9am	544	4.84	40.9	38	37	349
	10am	391	4.5	40.5	37	34	343
	11am	326	3.2	39.5	40	37	345
	12noon	581	6.9	40.1	42	37	349
	1pm	381	4.4	40.1	32	33	347
	2pm	100	2.9	39.2	25	24	348
	3pm	100	3	40	29	27	350
	4pm	100	3.2	38.4	27	29	349
	5pm	100	2.9	39.2	28	29	349
04/09/2021							
	7am	100	0.9	40.5	28	29	330
	8am	191	1.9	40.7	29	30	307
	9am	316	3.25	40.3	34	31	342
	10am	407	4.6	40.3	39	32	344
	11am	261	3.4	40.5	35	32	344
	12noon	785	11.54	39.8	51	44	339
	1pm	468	10.2	38.5	50	42	340
	2pm	477	4.35	38.2	49	42	346
	3pm	332	3.5	39.5	43	39	343
	4pm	158	1.6	38.8	37	36	347
	5pm	100	2.6	37.6	31	32	346
05/09/2021							
	7am	110	1.2	39	27	27	345
	8am	212	2.1	40.7	28	27	346
	9am	302	3.56	40.7	30	31	344

	10am	309	2.83	38.1	33	32	344		10am	540	5.3	41.1	36	35	344
	11am	143	1.88	36.9	30	31	344		11am	1023	10.2	40	53	45	341
	12noon	172	1.91	37.6	27	29	348		12noon	587	6.6	39.9	48	45	339
	1pm	405	3.76	26.2	37	33	343		1pm	504	5.4	39.9	52	44	342
	2pm	318	3.85	26	45	38	345		2pm	860	7.5	39.4	51	49	347
	3pm	100	1	33.1	24	26	348		3pm	645	5.2	39.7	48	46	348
	4pm	100	1.05	34.3	25	26	348		4pm	408	3.51	39.5	44	49	350
	5pm	100	0.4	27.4	24	25	344		5pm	113	1.24	38.7	36	37	345
09/08/2021								06/09/2021							
	7am	100	0.63	30.6	24	26	307		7am	120	1.3	40	35	36	153
	8am	159	1.52	36.3	28	27	346		8am	280	5.8	40.1	36	37	343
	9am	446	4.49	39	37	34	345		9am	503	6.6	40.3	41	35	342
	10am	241	2.63	38.2	33	32	344		10am	899	8.6	40.3	43	37	341
	11am	346	3.67	39.1	33	34	344		11am	1060	9.6	39.8	50	39	342
	12noon	239	3.49	36.1	49	38	340		12noon	1114	10.58	39.5	51	46	343
	1pm	950	8.69	39.3	47	46	340		1pm	877	9.5	40.2	51	42	340
	2pm	609	7.99	39.1	47	46	340		2pm	335	7.4	38.7	53	42	348
	3pm	769	6.25	39.5	45	44	351		3pm	634	5.52	39.9	40	37	346
	4pm	166	1.75	36.8	31	31	340		4pm	366	3.56	39.9	40	37	347
	5pm	100	0.9	32.2	28	30	347		5pm	141	1.62	39.2	35	36	347
07/08/2021								07/09/2021							
	7am	100	0.46	28.2	25	26	339		7am	130	1.8	40.5	34	32	342
	8am	240	1.65	36.9	30	29	352		8am	380	3.84	40.5	35	33	346
	9am	534	8.09	41	37	37	351		9am	642	6.62	40.2	43	37	343
	10am	222	3.48	38.5	35	34	348		10am	835	7.85	39.9	47	41	342
	11am	1087	3.09	381	42	41	348		11am	997	9.2	39.7	50	46	341
	12noon	754	9.85	40.3	45	42	345		12noon	982	9	39.1	53	43	342
	1pm	278	9.5	37.2	46	42	345		1pm	912	8.8	39.1	57	45	342

	2pm	845	7.62	39.1	50	42	335		2pm	740	7.3	39.9	52	44	345
	3pm	701	6.35	38.5	47	45	335		3pm	470	4.4	39	48	42	347
	4pm	406	4.02	38.3	42	43	351		4pm	259	2.5	38.6	44	42	347
	5pm	139	1.64	35.9	37	40	348		5pm	100	0.56	36.8	34	35	344
08/08/2021								08/09/2021							
	7am	137	1.27	33.8	29	28	352		7am	100	1.2	40.8	26	26	345
	8am	193	2.02	37.2	31	32	345		8am	210	3	40.9	27	26	346
	9am	302	2.99	37.9	34	33	100		9am	541	3.1	41.2	37	33	344
	10am	593	4.87	39.3	40	39	339		10am	864	2.8	40.6	40	33	343
	11am	1078	10.41	38.4	47	49	339		11am	519	2.7	40.4	41	39	343
	12noon	808	9.7	39.1	51	47	344		12noon	810	2.6	39.4	50	43	342
	1pm	830	5.43	39.4	44	43	344		1pm	556	2.5	39.4	50	43	342
	2pm	230	2.93	37.3	46	45	337		2pm	564	2.5	39.4	44	40	346
	3pm	177	2.26	36.6	39	41	342		3pm	622	2.4	39.7	49	45	342
	4pm	186	37.8	3.65	40	42	352		4pm	346	2.4	39.4	43	41	351
	5pm	115	1.25	31.5	36	41	339		5pm	115	2.7	28.7	35	36	347
09/08/2021								09/09/2021							
	7am	100	0.81	30.3	27	28	343		7am	150	1.5	40.l	34	34	344
	8am	140	1.46	35.7	29	28	343		8am	356	3.6	40.5	35	34	344
	9am	226	2.46	37.9	32	31	353		9am	379	2.7	40.3	37	36	344
	10am	100	0.98	32.6	30	31	100		10am	860	8.7	40.4	42	39	344
	11am	318	3.48	38.9	31	32	347		11am	1046	10.2	40.2	50	43	344
	12noon	390	4.05	38.5	37	34	348		12noon	528	2.6	39.3	42	38	343
	1pm	908	9.77	36.8	51	40	348		1pm	336	6.6	39.4	50	43	342
	2pm	572	3.95	38.9	38	36	348		2pm	211	2.4	39.2	36	35	343
	3pm	100	1.28	34.6	36	33	344		3pm	340	3.2	40.3	37	35	344
	4pm	100	0.6	30.2	26	27	341		4pm	100	0.54	36.4	31	32	348
	5pm	100	0.51	27.8	28	26	341		5pm	100	0.2	37.5	30	29	334

10/08/2021							
	7am	100	0.2	25.6	21	22	348
	8am	25.6	32	27.3	21	23	344
	9am	100	0.48	28.4	22	23	345
	10am	299	3.24	39.7	22	25	352
	11am	534	5.39	39.4	37	28	100
	12noon	565	5.04	38.4	42	32	345
	1pm	281	3.57	38.7	35	35	346
	2pm	335	3.57	39.3	31	23	343
	3pm	205	2.01	37.6	28	27	344
	4pm	160	1.88	37	30	29	344
	5pm	100	1.07	33.6	30	28	347
11/082021							
	7am	100	0.48	28.5	24	25	346
	8am	100	0.89	33.2	24	25	345
	9am	100	0.75	30.8	25	26	346
	10am	280	1.88	37.2	27	26	346
	11am	392	4	38.9	34	31	345
	12noon	392	3.92	39.3	33	29	345
	1pm	692	8.44	39.8	41	37	340
	2pm	637	3.75	39.1	39	38	344
	3pm	726	3.45	39.4	39	38	343
	4pm	238	2.7	37.8	35	34	345
	5pm	155	1.44	35.3	32	34	345

10/08/2021							
	7am	100	0.9	40.8	26	28	345
	8am	186	2.9	40.9	27	29	349
	9am	457	3.4	39.8	38	39	343
	10am	334	3.5	40.1	37	38	345
	11am	466	5.6	39.3	55	42	342
	12noon	451	4.6	39.9	40	36	343
	1pm	915	7.4	38.5	56	47	343
	2pm	340	3.5	39.6	44	41	343
	3pm	149	1.5	40	31	34	347
	4pm	202	2.3	39.2	38	36	349
	5pm	100	0.7	38.2	32	31	345
11/092021							
	7am	105	0.8	39	44	28	344
	8am	356	5.1	39.6	45	39	344
	9am	694	2.6	39.7	52	42	343
	10am	875	2.6	38.9	54	43	341
	11am	778	2.4	38	56	40	342
	12noon	1084	2.3	38.6	60	43	342
	1pm	1043	2.9	38.3	60	44	343
	2pm	839	2.5	39.3	55	52	346
	3pm	131	2.7	38.7	0.36	35	347
	4pm	258	2.4	39.9	37	36	350
	5pm	100	2.8	36.7	29	31	344

12/08/2021									12/09/2021							
	7am	100	0.29	24.2	24	25	350			7am	130	1.3	40.5	28	26	345
	8am	299	2.11	37.6	30	30	342			8am	249	2.4	40.8	29	27	345
	9am	721	8.06	40.7	36	37	346			9am	486	4.7	39.1	43	36	343
	10am	732	9.05	40.1	42	44	346			10am	766	4.7	39.1	43	36	343
	11am	977	9.05	40.1	42	44	346			11am	552	11.8	39.4	56	47	341
	12noon	332	9.48	36.6	48	43	341			12noon	1141	3.6	39.1	48	43	330
	1pm	943	5.96	37.8	42	39	342			1pm	803	11.5	40.5	49	44	340
	2pm	351	3.25	37.2	38	37	346			2pm	215	2.5	37.6	47	43	344
	3pm	568	4.61	37.9	39	37	353			3pm	243	6.5	39.8	47	43	345
	4pm	503	2.06	36.8	36	37	339			4pm	374	3.5	38.7	44	45	348
	5pm	100	1.2	34.4	31	34	339			5pm	100	1	38.1	34	36	345
13/08/2021									13/09/2021							
	7am	100	0.33	27.2	26	28	346			7am	190	1.9	40.5	35	35	344
	8am	100	0.73	30.5	25	26	100			8am	486	4.9	40.8	36	35	355
	9am	101	1.17	34.4	26	25	351			9am	665	6.7	40.2	47	37	349
	10am	100	0.33	27.6	25	24	349			10am	863	8.5	39.5	49	37	341
	11am	100	1.35	36.5	25	26	347			11am	963	9.1	39.1	59	42	347
	12noon	366	37.3	38.7	36	30	340			12noon	1116	10.2	38.4	60	62	340
	1pm	100	1.56	33.5	35	30	345			1pm	923	8.3	38.4	62	53	341
	2pm	385	2.92	38.3	35	31	349			2pm	794	7.35	38.7	56	41	347
	3pm	100	0.47	28.5	28	26	349			3pm	592	5.6	37.6	52	43	342
	4pm	472	4.62	38.7	42	32	345			4pm	332	3.4	38.9	44	42	349
	5pm	106	1.62	35	34	32	345			5pm	100	1.2	38.4	35	36	347

14/08//2021								14/09/2021							
	7am	100	0.64	30.1	26	28	345		7am	250	2.5	40	32	43	34
	8am	147	1.56	36.3	30	28	346		8am	431	4.6	41	33	34	344
	9am	229	2.47	38.1	31	30	346		9am	688	6.8	40.5	42	38	344
	10am	541	5.43	39.3	40	36	341		10am	774	7.7	40.3	43	36	346
	11am	697	7.14	38.5	46	36	341		11am	584	5.6	40.2	42	40	342
	12noon	672	8.83	38.5	48	46	344		12noon	988	9.4	38.9	55	40	347
	1pm	1089	10	39.5	46	49	344		1pm	910	8.5	39.4	56	47	338
	2pm	296	3.65	37.9	40	41	343		2pm	817	7.5	38.8	54	44	347
	3pm	578	5.49	39.8	37	39	343		3pm	618	5.8	39.5	50	43	349
	4pm	237	1.72	37.3	36	39	343		4pm	361	3.4	39.2	44	40	350
	5pm	100	0.89	32.7	31	34	343		5pm	109	1.7	38.4	37	39	347
15/08/2021								15/09/2021							
	7am	100	0.45	28.2	27	26	342		7am	200	2.9	40.5	37	34	331
	8am	100	0.84	32.6	25	26	344		8am	483	4.7	40.8	38	34	332
	9am	125	1.25	35.1	27	28	345		9am	651	6.2	40.8	39	35	342
	10am	100	0.92	33.2	26	25	344		10am	432	7.8	40.1	43	36	345
	11am	145	1.49	35.8	27	28	343		11am	970	9.2	39.6	52	42	331
	12noon	366	4.09	38.7	35	31	100		12noon	1075	9.01	37.7	49	44	341
	1pm	824	7.6	38.5	50	39	343		1pm	962	9.01	39.4	55	44	341
	2pm	913	5.6	39.4	42	40	350		2pm	671	2.2	37.6	42	41	348
	3pm	557	6.25	37.6	47	45	100		3pm	387	5.6	39.2	51	43	349
	4pm	166	2.02	36.7	34	37	347		4pm	109	1.6	38.4	36	37	346
	5pm	106	0.97	32.7	31	33	351		5pm	100	0.09	29.7	26	24	342

16/08/2021							
	7am	100	0.59	29.4	26	25	343
	8am	100	0.68	30.3	25	27	347
	9am	182	1.95	37.8	26	27	344
	10am	307	2.8	39.1	29	30	350
	11am	344	3.33	38.5	34	40	345
	12noon	609	60.4	39.2	42	34	347
	1pm	442	8.17	39.7	42	40	346
	2pm	568	6.38	37.7	50	40	345
	3pm	147	1.72	36	34	33	100
	4pm	100	0.13	24.8	27	26	341
	5pm	100	0.09	29.7	26	24	342
17/08/2021							
	7am	100	0.36	27.4	22	23	342
	8am	101	1.2	26	36	25	345
	9am	250	2.58	38.1	32	27	341
	10am	822	9.25	38.7	55	41	343
	11am	544	5.23	38	44	39	343
	12noon	961	7.12	38.3	55	45	344
	1pm	257	2.44	37.1	38	35	344
	2pm	299	2.56	37.9	37	35	347
	3pm	164	1.75	36	38	33	347
	4pm	276	2.96	37.9	38	34	345
	5pm	100	1.16	31.4	31	0	346

16/09/2021							
	7am	130	1.3	40.5	32	32	344
	8am	234	3.2	40.7	33	32	349
	9am	528	4.28	40.7	39	36	346
	10am	447	4.46	40.5	39	34	350
	11am	315	3.03	39.3	40	36	348
	12noon	523	6.87	41.1	44	39	347
	1pm	432	4.23	39	31	29	343
	2pm	100	0.79	39.3	25	36	347
	3pm	100	1.46	39.8	30	28	347
	4pm	100	0.62	38.4	27	28	346
	5pm	100	0.66	38.5	29	30	343
17/09/2021							
	7am	130	1.3	40.5	28	26	345
	8am	141	1.8	40.6	29	28	307
	9am	345	3.21	40.3	36	32	348
	10am	410	4.4	40.2	40	34	348
	11am	285	3.12	40.4	36	33	342
	12noon	427	11.56	39.6	50	38	340
	1pm	419	5.5	38.3	50	42	339
	2pm	440	4.38	38.1	51	42	348
	3pm	334	3.44	39.3	44	40	345
	4pm	153	1.64	38.6	38	37	346
	5pm	100	0.54	37.5	31	32	343

18/08/2021								18/09/2021							
	7am	123	1.34	36.1	27	28	341		7am	120	1.3	40	35	36	153
	8am	395	3.54	38.6	38	39	344		8am	250	2.01	40.8	29	27	337
	9am	260	2.33	36.7	37	35	344		9am	315	3.25	41.1	31	29	337
	10am	821	7.41	39.1	47	39	340		10am	559	5.2	40.9	39	35	334
	11am	395	3.54	38.6	38	39	344		11am	1025	10.23	39.9	51	46	338
	12noon	984	8.74	37.6	58	53	345		12noon	598	603	39.8	51	44	328
	1pm	913	8.13	37.3	58	51	345		1pm	558	9.56	39.5	50	45	335
	2pm	800	7.27	32.4	58	50	343		2pm	837	7.66	39.3	53	48	334
	3pm	584	5.39	37.4	54	50	343		3pm	634	5.83	39.7	50	46	338
	4pm	340	3.38	37	47	46	344		4pm	383	3.59	39.6	45	43	338
	5pm	179	1.75	35.7	40	44	346		5pm	106	1.24	38.6	37	39	343
19/08/2021								19/09/2021							
	7am	100	0.81	31.6	26	27	345		7am	100	0.9	40.8	26	28	345
	8am	100	0.03	23.3	21	22	347		8am	293	5.5	39.9	37	36	337
	9am	100	0.07	24	21	20	345		9am	514	5.37	40.3	43	36	337
	10am	100	0.35	37.4	21	24	348		10am	514	5.57	40.3	43	36	337
	11am	100	1	33.2	22	23	346		11am	1031	9.14	39.5	51	38	334
	12noon	254	2.63	38.7	28	26	346		12noon	1173	9.14	39.5	51	38	334
	1pm	359	3.81	40.9	35	30	352		1pm	842	8.71	39.6	52	41	335
	2pm	582	5.78	40	44	37	352		2pm	751	7.7	38.6	56	44	334
	3pm	389	3.89	40.1	39	35	346		3pm	629	3.58	39.9	39	39	337
	4pm	220	2.23	39.9	35	34	346		4pm	338	3.58	39.9	41	38	338
	5pm	130	1.38	39.5	31	32	350		5pm	154	1.6	39.1	36	32	345

20/08/2021							
	7am	179	1.98	37.7	28	32	348
	8am	202	1.68	36.4	32	32	342
	9am	694	1.81	36.1	34	32	345
	10am	324	2.76	40.4	43	39	343
	11am	1057	2.76	40.4	43	39	343
	12noon	1032	9.2	37.8	59	47	341
	1pm	970	8.81	37.7	55	51	341
	2pm	840	7.52	37.4	58	48	340
	3pm	650	5.82	37.4	53	51	340
	4pm	248	2.5	36.4	44	41	338
	5pm	100	0.47	28.6	33	36	339
21/08/2021							
	7am	100	0.81	31.6	26	27	345
	8am	100	0.03	23.3	21	22	347
	9am	100	0.07	24	21	20	345
	10am	100	0.35	37.4	21	24	348
	11am	100	1	33.2	22	23	346
	12noon	254	2.63	38.7	28	26	346
	1pm	359	3.81	40.9	35	30	352
	2pm	582	5.78	40	44	37	352
	3pm	389	3.89	40.1	39	35	346
	4pm	220	2.23	39.9	35	34	346
	5pm	130	1.38	39.5	31	31	350

20/09/2021							
	7am	240	2.4	40.1	36	33	340
	8am	404	3.38	40.4	37	34	341
	9am	644	6.13	39.9	45	35	336
	10am	851	7.87	39.5	50	42	330
	11am	388	9.15	39.5	51	46	334
	12noon	992	9.34	39	56	44	332
	1pm	924	8.82	38.9	56	42	332
	2pm	732	7.16	39.1	53	45	344
	3pm	460	4.53	38.8	50	41	336
	4pm	250	2.54	38.6	45	43	339
	5pm	100	0.46	39.7	34	35	340
21/09/2021							
	7am	140	1.2	40.2	27	26	134
	8am	217	2.17	40.7	28	27	335
	9am	537	5.01	40.7	39	32	336
	10am	964	7	40.3	44	34	333
	11am	546	5.58	40	42	39	332
	12noon	824	7.54	39.6	49	40	334
	1pm	586	6.59	37.2	50	44	333
	2pm	512	5.39	39.2	46	39	331
	3pm	618	5.66	39.4	48	47	331
	4pm	344	3.35	39.4	42	40	332
	5pm	124	1.22	38.6	36	35	334

22/08/2021

7am	162	2.14	40.9	29	31	348
8am	190	1.58	39.3	33	32	349
9am	644	1.86	41.9	38	34	345
10am	873	2.49	38.7	42	38	345
11am	1033	9.82	38.9	63	48	348
12noon	1017	9.5	38.7	59	46	347
1pm	984	9.12	38.4	62	50	349
2pm	877	7.84	38.4	59	47	349
3pm	688	6.14	38.9	56	50	347
4pm	255	2.66	38.6	45	41	347
5pm	100	0.48	37	33	35	347

22/09/2021

7am	100	0.9	40.8	26	28	345
8am	217	2.17	40.7	28	27	335
9am	537	5.01	40.7	39	32	336
10am	964	7	40.3	44	34	333
11am	546	5.58	40	42	39	332
12noon	824	7.54	39.6	49	40	334
1pm	586	6.53	37.2	50	44	333
2pm	512	5.39	39.2	46	39	331
3pm	618	5.96	39.2	46	39	331
4pm	344	3.35	39.4	42	40	332
5pm	124	1.22	38.6	36	35	334

23/087/2021

7am	100	0.29	24.2	24	25	350
8am	507	4.45	40.6	39	36	330
9am	685	6.74	39.5	50	37	332
10am	881	8.2	38.9	54	39	332
11am	967	9.07	38.7	59	39	331
12noon	1090	10.34	38	66	50	328
1pm	921	8.61	35.5	60	52	330
2pm	790	7.37	38.9	57	43	333
3pm	586	5.5	38.8	53	40	337
4pm	324	3.2	38.9	46	44	338
5pm	100	1.04	38.2	35	36	337

23/309/2021

7am	100	1	40.7	27	28	330
8am	177	2.08	40.7	28	29	331
9am	382	3.35	39.3	41	40	330
10am	334	3.39	39.8	39	36	330
11am	1107	5.85	39	57	43	330
12noon	499	4.19	39.7	43	37	329
1pm	820	7.61	38.9	54	46	332
2pm	350	4.37	39.7	46	40	329
3pm	154	1.66	39.9	31	35	335
4pm	195	2.22	39.3	39	38	338
5pm	100	0.75	38.2	31	32	339

24/08/2021								24/09/2021								
	7am	123	1.34	36.1	27	28	341		7am	100	0.9	40.8	26	28	345
	8am	485	4.47	40.6	36	33	344		8am	485	2.02	38.9	48	40	333
	9am	661	6.19	40.5	41	34	335		9am	679	2.72	39.2	52	38	333
	10am	866	7.99	38.7	46	37	329		10am	904	2.87	38.6	58	47	328
	11am	974	9.15	39.3	51	42	341		11am	704	2.91	38.1	56	37	332
	12noon	1072	5.09	39.9	54	43	331		12noon	1211	3.21	38.2	67	47	328
	1pm	937	9.16	39.2	55	42	333		1pm	1017	2.63	39.4	58	44	331
	2pm	794	2.07	38.1	43	41	334		2pm	784	2.55	39.4	56	52	328
	3pm	602	5.7	39.1	50	43	334		3pm	127	2.6	38.6	35	36	337
	4pm	178	1.27	38.4	37	38	333		4pm	273	2.62	39.9	38	37	339
	5pm	100	1.23	39	32	33	353		5pm	100	0.28	36.4	29	30	338

Table C3: Harmattan Weather Condition

Nov-21								Dec-21						
Date	TIME	SI	ISC	VOC	TPV	TA	LAT	Date	Time	SI	ISC	VOC	TPV	SI
01/11/2021	7am	205	1.8	40.9	27	27	344	01/12/2021	7am	115	1.2	40	31	115
	8am	331	2.65	40.7	31	30	339		8am	363	3.26	41.3	32	363
	9am	571	4.74	40.4	42	38	339		9am	615	5.37	41.4	39	615
	10am	741	5.89	40.2	46	43	339		10am	780	7.45	41.3	43	780
	11am	814	6.87	39.5	50	42	339		11am	879	8.5	40.8	48	879
	12noon	845	7.3	39.1	57	44	338		12am	951	8.5	40.4	50	951
	1pm	772	6.75	38.9	54	47	338		1pm	754	8.29	40.3	50	754
	2pm	474	3.9	39	47	48	339		2pm	771	7.71	40	50	771
	3pm	637	5.44	38.9	52	48	337		3pm	459	4.17	39.9	45	459
	4pm	211	5.78	38.4	44	43	339		4pm	283	2.83	39.4	42	283
	5pm	100	0.54	37.2	34	35	341		5pm	100	0.41	37.2	32	100
02/11/2021														
	7am	100	0.92	40.2	25	26	320	02/12/2021	7am	115	1.2	40	31	48
	8am	351	3.21	41.5	31	29	319		8am	314	3.04	41.6	30	314
	9am	594	5.42	41.5	39	36	318		9am	588	5.64	41.5	37	588
	10am	785	7.02	41.2	43	37	318		10am	791	7.24	41.2	42	791
	11am	918	8.2	41.8	49	41	314		11am	910	8.43	40.8	47	910
	12noon	936	8.53	40.4	48	40	322		12am	649	8.53	39.8	54	649
	1pm	899	8.12	40	54	42	326		1pm	528	8.77	38.9	55	528
	2pm	757	7.01	39.7	51	40	324		2pm	580	7.36	40.2	49	580
	3pm	560	5.31	39.9	50	40	330		3pm	267	3.26	39.2	48	267
	4pm	325	3.11	39.6	44	38	327		4pm	224	2.63	39.6	41	224
	5pm	100	0.7	38.1	35	35	322		5pm	100	1.08	38.5	36	100

03/11/2021														
	7am	100	0.78	40.1	23	24	341	03/12/2021	7am	115	1.2	40	31	
	8am	353	2.82	40.5	37	34	341		8am	413	3.81	41.6	34	413
	9am	600	5.84	40.1	43	45	339		9am	625	5.98	40.4	37	625
	10am	790	6.49	40	48	43	338		10am	826	7.63	41	46	826
	11am	901	7.24	39.6	51	41	336		11am	949	8.7	40.5	50	949
	12noon	917	7.66	39.1	55	49	337		12am	948	9.8	40.2	54	948
	1pm	860	7.02	39.3	54	44	339		1pm	964	8.81	39.5	55	964
	2pm	724	6	39.1	56	44	337		2pm	866	7.89	39.1	58	866
	3pm	532	3.95	38.8	49	47	337		3pm	656	6.05	39.6	39.6	656
	4pm	261	2.24	38.8	43	42	339		4pm	386	3.77	39.7	46	386
	5pm	100	0.51	37.1	36	37	340		5pm	100	0.78	38.3	36	100
04/11/2021								04/12/2021	7am	115	1.2	40	31	
	7am	100	O.72	40.1	23	25	341		8am	381	3.58	41.2	34	381
	8am	299	2.52	40.6	42	31	316		9am	638	5.96	41.3	41	638
	9am	550	4.48	40.4	40	40	336		10am	855	7.19	40.7	47	855
	10am	753	6.22	40.1	49	41	337		11am	954	8.77	40.4	50	954
	11am	871	6.93	40.1	47	44	334		12am	1023	9.4	40.1	53	1023
	12noon	799	7.27	39.9	52	44	337		1pm	989	8.92	40	53	989
	1pm	843	6.99	39.2	53	44	334		2pm	896	8.01	39.6	54	896
	2pm	743	5.91	39.1	54	47	334		3pm	673	6.03	40	51	673
	3pm	527	4.06	39.1	49	45	335		4pm	430	4.04	39.8	46	430
	4pm	248	2.09	38.6	44	44	338		5pm	100	0.56	37.6	36	100
	5pm	100	0.53	87.2	36	38	339							
05/11/2021	7am	100	0.59	39.4	25	25	339	05/12/2021	7am	115	1.2	40	31	
	8am	263	2.24	40.5	32	31	338		8am	356	3.37	41.4	33	356
	9am	395	2.83	39.9	37	36	337		9am	606	5.68	41.1	40	606

	10am	487	5.33	39.8	46	40	336		10am	798	7.33	40.8	45	798
	11am	737	5.59	40.3	44	41	333		11am	955	8.67	40.6	49	955
	12noon	837	6.98	39.5	53	47	337		12am	962	8.92	39.8	54	962
	1pm	373	5.54	38.7	52	45	337		1pm	900	8.52	40.1	53	900
	2pm	768	5.68	37.6	44	43	336		2pm	778	7.28	39.9	52	778
	3pm	578	3.76	39.3	42	36	337		3pm	614	5.2	39.7	51	614
	4pm	237	2.09	38.6	30	34	337		4pm	374	3.64	40	43	374
	5pm	100	0.69	36.8	26	23	313		5pm	100	0.83	38.2	36	100
06/11/2021								06/12/2021	7am	115	1.2	40	31	
	7am	100	0.94	39.9	22	26	338		8am	388	3.71	41.6	32	388
	8am	369	2.71	41.2	32	29	338		9am	610	5.82	41.4	39	610
	9am	675	5.2	41.1	38	37	336		10am	780	7.1	40.8	45	780
	10am	843	6.5	40.3	46	39	336		11am	845	8.41	40.7	50	845
	11am	921	7.38	40.1	46	37	334		12am	978	8.69	39.9	53	978
	12noon	936	7.96	40	53	43	334		1pm	960	9.01	40	53	960
	1pm	527	4.06	39.1	48	43	336		2pm	763	6.5	40.1	48	763
	2pm	687	5.62	39.4	50	44	333		3pm	606	5.58	40.3	46	606
	3pm	570	4.14	39.5	47	42	336		4pm	388	3.93	40.2	43	388
	4pm	298	2.3	39.3	41	40	338		5pm	100	0.66	38.1	35	100
	5pm	100	0.56	37.5	43	34	339							
07/11/2021	7am	134	0.97	40.4	23	27	339	07/12/2021	7am	115	1.2	40	31	
	8am	447	3.46	41.1	32	31	337		8am	386	3.58	41.4	33	386
	9am	381	3.52	40.8	33	31	336		9am	652	6.07	41.6	37	652
	10am	837	6.64	40.8	34	40	337		10am	866	7.8	41.4	42	866
	11am	915	7.36	47	47	37	335		11am	977	8.95	41.5	43	977
	12noon	941	7.36	40.1	50	43	336		12am	1012	9.3	40.5	49	1012
	1pm	781	7.5	39.9	51	45	337		1pm	907	8.75	40.2	53	907
	2pm	753	6	39.9	50	42	337		2pm	995	9.54	41.2	42	995

	3pm	555	4.41	39.8	44	40	335		3pm	705	6.52	40.3	47	705
	4pm	348	2.8	39.7	41	41	341		4pm	431	3.9	40.4	42	431
	5pm	100	0.33	36.6	32	33	342		5pm	100	0.69	38.8	32	100
08/11/2021								08/12/2021	7am	115	1.2	40	31	
	7am	131	1.07	40.5	24	25	340		8am	368	3.48	42.1	29	368
	8am	379	3.03	41.3	30	29	337		9am	625	5.72	42.2	33	625
	9am	613	4.72	41.3	36	34	336		10am	829	7.64	41.8	38	829
	10am	785	6.26	41	42	35	335		11am	944	8.73	41.4	43	944
	11am	842	6.96	40.5	44	42	335		12am	997	9.16	40.8	48	997
	12noon	886	7.44	40.2	49	43	334		1pm	962	8.2	40.7	46	962
	1pm	794	6.93	40.1	48	41	335		2pm	841	7.77	40.2	48	841
	2pm	693	5.61	39.7	51	43	335		3pm	678	6.13	40.6	45	678
	3pm	505	4.23	39.8	43	42	336		4pm	393	3.94	40.4	42	393
	4pm	257	2.05	39.3	40	40	338		5pm	100	0.99	39.2	31	100
	5pm	100	0.49	37.4	33	32	340							
09/11/2021														
	7am	115	1.24	40.8	23	25	319	09/12/2021	7am	115	1.2	40	31	
	8am	404	3.71	41.5	32	33	317		8am	438	4.27	42.3	27	438
	9am	654	5.86	41.6	39	34	323		9am	636	5.63	42.1	33	636
	10am	839	7.46	41.1	43	37	321		10am	812	7.42	41.8	40	812
	11am	949	8.58	40.8	49	41	321		11am	958	8.57	41.4	45	958
	12noon	972	8.86	40.5	48	40	321		12am	989	9.04	40.9	46	989
	1pm	920	8.71	40.3	53	43	326		1pm	949	8.79	40.5	49	949
	2pm	887	7.28	40.2	50	39	323		2pm	816	7.66	40.7	47	816
	3pm	608	5.49	40.1	49	40	313		3pm	589	5.82	40.5	46	589
	4pm	349	3.28	40.1	41	37	325		4pm	372	4.09	30.3	36	372
	5pm	100	0.8	38.6	34	34	324		5pm	100	3.26	30.6	31	100

10/11/2021	7am	100	0.67	39.9	22	23	339
	8am	294	2.35	41.2	28	27	338
	9am	523	4.19	41.3	34	32	337
	10am	733	5.72	41.2	41	37	337
	11am	795	6.75	40.9	42	35	336
	12noon	777	5.51	40.6	46	36	335
	1pm	773	6.17	40.3	45	37	335
	2pm	588	5.33	40.1	45	39	337
	3pm	480	3.81	40.2	42	37	339
	4pm	252	2.11	39.7	37	35	339
	5pm	100	0.58	38	31	32	341
11/11/2021							
	7am	100	0.77	40.4	20	22	341
	8am	359	2.87	41.4	30	26	325
	9am	619	4.68	41.4	35	35	336
	10am	796	6.27	41.1	40	34	336
	11am	881	7.09	40.7	43	38	337
	12noon	912	7.46	40.3	50	39	335
	1pm	842	7	39.8	49	42	338
	2pm	733	5.76	39.8	50	39	334
	3pm	546	4.15	39.8	46	44	336
	4pm	345	3.09	37.1	38	31	334
	5pm	100	0.08	37.6	32	30	330
12/11/2021	7am	100	0.81	39.9	24	25	341
	8am	308	2.23	40.9	29	28	339
	9am	550	4.3	41.1	36	35	338

10/12/2021	7am	115	1.2	40	31	
	8am	335	3.14	42	28	335
	9am	622	5.63	42.1	34	622
	10am	824	7.58	41.8	39	824
	11am	927	8.47	41.3	44	927
	12am	968	9.04	40.7	48	968
	1pm	937	8.79	8.79	40.8	937
	2pm	844	7.83	40.4	49	844
	3pm	703	6.26	40.4	46	703
	4pm	408	3.9	40.5	43	408
	5pm	100	0.97	37.2	30	100
11/12/2021	7am	115	1.2	40	31	
	8am	305	2.96	42	26	305
	9am	536	5.38	42	33	536
	10am	798	7.41	41.8	37	798
	11am	938	8.49	41.5	43	938
	12am	997	8.97	41	46	997
	1pm	913	8.81	40.6	49	913
	2pm	830	7.59	40.7	47	830
	3pm	617	5.98	40.4	47	617
	4pm	404	3.8	40.5	41	404
	5pm	100	1.07	39.3	33	100
12/12/2021	7am	115	1.2	40	31	
	8am	328	2.96	41.9	27	328
	9am	587	5.56	42	34	587

	10am	709	5.79	41	43	38	337
	11am	793	6.75	40.7	45	38	337
	12noon	864	7.16	40.4	49	38	337
	1pm	758	7.91	40.5	47	42	338
	2pm	685	5.39	39.9	50	40	338
	3pm	461	3.71	39.6	44	40	339
	4pm	272	2.11	39.4	41	36	339
	5pm	100	0.51	37.5	32	33	340
13/11/2021							
	7am	100	1.08	40.5	24	26	339
	8am	419	3.09	41.2	33	32	340
	9am	650	5.1	41.3	36	35	339
	10am	840	6.53	40.8	44	37	340
	11am	950	7.4	40.4	45	42	339
	12noon	977	7.79	40.1	51	40	334
	1pm	927	8.51	39.9	49	43	335
	2pm	805	6.16	39.6	53	40	334
	3pm	601	4.51	39.7	47	42	335
	4pm	346	2.58	39.5	42	37	336
	5pm	100	0.6	34	34	34	338
14/11/2021							
	7am	100	0.71	39.7	25	26	339
	8am	348	2.71	41.1	32	29	338
	9am	591	4.63	41.2	37	35	336
	10am	794	6.15	40.8	44	38	334
	11am	907	7.08	40.4	45	41	333
	12noon	938	7.46	40	51	40	338
	1pm	883	7.03	39.5	51	42	335
	2pm	767	5.98	39.2	54	41	337

	10am	817	7.45	41.8	39	817
	11am	939	8.65	41.4	43	939
	12am	943	8.73	40.6	49	943
	1pm	943	8.72	40.6	49	943
	2pm	781	7.73	40.7	48	781
	3pm	631	5.65	40.5	45	631
	4pm	360	3.56	40.3	41	360
	5pm	100	1.53	39.6	34	100
13/12/2021						
	7am	115	1.2	40	31	
	8am	345	3.2	41.7	30	345
	9am	607	5.58	40.8	36	607
	10am	808	7.41	41.7	40	808
	11am	950	8.96	41	46	950
	12am	980	8.69	40	46	980
	1pm	952	8.69	40.4	49	952
	2pm	833	7.73	40.3	46	833
	3pm	697	6.17	40.5	47	697
	4pm	433	3.98	40.3	43	433
	5pm	433	3.98	40.3	43	433
14/12/2021						
	7am	115	1.2	40	31	
	8am	341	3.15	41.8	29	341
	9am	601	5.5	41.9	34	601
	10am	806	7.28	41.7	40	806
	11am	926	8.41	41.3	44	926
	12am	974	8.94	41	46	974
	1pm	947	8.75	40.8	47	947
	2pm	847	7.49	40.4	39	847

	3pm	570	4.32	39.3	49	43	335		3pm	670	5.91	40.4	44	670
	4pm	322	2.43	39	45	30	339		4pm	405	3.94	40.3	42	405
	5pm	100	0.54	37.5	35	36	341		5pm	100	1.03	38.2	34	100
15/11/2021								15/12/2021						
	7am	100	0.99	40.8	20	21	314		7am	115	1.2	40	31	
	8am	375	3.11	41.7	31	27	313		8am	369	3.44	42	29	369
	9am	617	5.6	541.7	35	32	315		9am	642	5.91	42.1	35	642
	10am	796	7.17	41.5	39	33	313		10am	865	7.68	41.6	39	865
	11am	910	8.16	41.2	37	38	318		11am	969	8.81	41.5	43	969
	12noon	926	8.46	40.5	47	39	323		12am	1004	9.16	40.7	47	1004
	1pm	869	8.09	40.2	52	41	319		1pm	955	8.92	40.5	50	955
	2pm	751	6.8	40.4	48	37	326		2pm	832	7.91	40.3	51	832
	3pm	566	4.88	40.3	47	42	310		3pm	672	602	40.1	48	672
	4pm	365	3.6	39.9	40	36	313		4pm	339	3.39	40.4	44	339
	5pm	100	0.2	39	32	30	324		5pm	100	0.95	39.2	36	100
16/11/2021		SI	ISC	VOC	TPV	TA	LAT	16/12/2021						
	7am	100	0.92	40	23	25	315		7am	115	1.2	40	31	
	8am	287	2.98	41.5	29	28	316		8am	240	2.19	41.5	26	240
	9am	544	5.07	41.5	37	34	316		9am	583	4.97	41.8	34	583
	10am	719	6.68	41.3	41	38	314		10am	750	6.78	41.2	42	750
	11am	835	7.77	40.9	46	38	319		11am	865	7.92	40.8	45	865
	12noon	843	8.13	40.9	46	37	317		12am	996	9.18	40.8	48	996
	1pm	792	7.69	40.9	50	42	318		1pm	899	8.14	40.3	50	899
	2pm	672	6.32	40.4	49	40	326		2pm	806	7.18	40.1	48	806
	3pm	450	4.51	40.1	45	39	328		3pm	624	5.57	39.7	50	624
	4pm	274	2.61	39.9	40	36	326		4pm	363	4.09	39.9	44	363
	5pm	100	0.67	38.1	31	33	322		5pm	100	0.92	38.8	36	100

17/11/2021	7am	249	1.74	40.6	29	28	338	17/12/2021	7am	115	1.2	40	31	
	8am	469	3.14	40.8	37	30	337		8am	218	1.93	41.3	27	218
	9am	664	4.72	40.5	43	36	336		9am	415	3.9	41.8	31	415
	10am	769	5.95	40.5	47	42	335		10am	624	5.7	41.5	38	624
	11am	858	5.99	39.7	52	42	337		11am	707	6.57	40.7	44	707
	12noon	831	5.82	39.3	53	49	337		12am	770	7.22	40.5	47	770
	1pm	689	4.93	39.4	53	43	335		1pm	713	7.2	40.3	48	713
	2pm	519	3.97	39.1	51	44	336		2pm	556	5.8	39.8	48	556
	3pm	313	2.2	38.8	45	36	337		3pm	476	4.82	40.1	47	476
	4pm	119	0.91	38.1	37	30	338		4pm	263	2.54	39.6	41	263
	5pm	100	0.9	38	37	30	337		5pm	105	1.15	38.8	36	105
18/11/2021	7am	354	4.22	41.2	36	30	322	18/12/2021	7am	115	1.2	40	31	
	8am	586	5.25	41.2	39	35	321		8am	189	1.72	41.1	25	189
	9am	756	6.69	40.9	46	36	308		9am	407	3.74	41.6	32	407
	10am	880	8.57	40	53	44	321		10am	608	5.75	41.7	37	608
	11am	998	9.09	39.8	56	46	320		11am	780	7.09	41.3	41	780
	12noon	869	7.36	39.6	53	42	319		12am	797	8.07	41.6	50	797
	1pm	769	6.08	39.3	49	39	318		1pm	821	7.69	40.4	49	821
	2pm	597	5.36	38.2	46	37	315		2pm	721	6.59	40.2	48	721
	3pm	345	3.67	38.6	37	32	314		3pm	530	5.04	40	45	530
	4pm	105	1.09	38.3	38	30	318		4pm	431	4.39	39.9	41	431
	5pm	100	0.9	37	37	29	317		5pm	100	1.11	38.8	35	100
19/11/2021	7am	289	1.97	40.6	32	30	338	19/12/2021	7am	115	1.2	40	31	
	8am	484	3.46	40.7	38	32	337		8am	397	3.41	41.7	31	397
	9am	776	5.55	40.4	47	39	336		9am	611	5.19	41.8	36	611
	10am	921	6.78	40	48	36	336		10am	831	5.91	41.9	39	831
	11am	963	7.01	39.8	52	40	334		11am	1003	8.81	40.8	49	1003
	12noon	942	6.88	39.3	55	48	335		12am	969	8.75	40.6	50	969
	1pm	809	6.04	38.8	56	48	334		1pm	976	8.77	40.4	51	976

	2pm	606	4.26	39	52	47	337		2pm	811	7.75	40.2	50	811
	3pm	527	3.47	38.9	48	39	337		3pm	690	6.18	40.6	47	690
	4pm	107	0.97	38.2	39	36	338		4pm	563	5.49	40.3	44	563
	5pm	100	0.8	38	38	35	337		5pm	114	1.12	39.2	34	114
20/11/2021														
	7am	294	1.76	40.7	30	28	338	20/12/2021	7am	115	1.2	40	31	
	8am	468	3.46	40.9	39	31	337		8am	190	1.68	40.9	27	190
	9am	646	4.74	40.6	44	36	336		9am	403	3.66	41.5	33	403
	10am	976	5.96	40.3	47	40	335		10am	605	5.47	41.3	40	605
	11am	858	5.96	39.8	52	42	335		11am	719	6.79	41.1	43	719
	12noon	834	5.84	39.4	53	46	337		12am	801	7.33	40.5	49	801
	1pm	686	4.93	39.4	53	44	335		1pm	820	7.49	40.7	50	820
	2pm	519	3.67	39.2	51	44	336		2pm	659	5.98	39.9	49	659
	3pm	313	2.21	38.8	46	37	337		3pm	481	4.33	40	46	481
	4pm	118	0.96	38.6	36	30	338		4pm	250	2.45	39.5	42	250
	5pm	106	0.86	37.8	37	30	337		5pm	101	1.01	38.6	36	101
21/11/2021														
	7am	100	1	40	31	29	338	21/12/2021	7am	115	1.2	40	31	
	8am	290	2.06	40.5	32	30	339		8am	242	2.21	41.1	29	242
	9am	597	4.52	40.5	44	40	336		9am	459	4.13	41.3	37	459
	10am	811	6.15	40	48	39	336		10am	692	6.11	41.2	42	692
	11am	955	7.22	39.5	55	44	335		11am	850	7.59	40.8	48	850
	12noon	1008	7.7	39.3	55	49	336		12am	891	8.06	40.3	50	891
	1pm	998	7.82	39.2	54	46	336		1pm	875	7.94	39.7	52	875
	2pm	847	6.41	38.5	58	50	335		2pm	732	6.49	39.3	56	732
	3pm	644	4.47	38.6	56	45	335		3pm	587	5.2	39.8	49	587
	4pm	385	2.94	38.9	47	34	336		4pm	343	3.05	39.6	45	343
	5pm	122	0.94	37.8	40	30	337		5pm	120	1.17	38.8	37	120

22/11/2021

7am	130	1.3	40	35	31	335
8am	363	3.26	40.7	36	32	337
9am	587	4.08	40.8	40	36	336
10am	763	5.53	40.5	46	40	335
11am	887	6.9	39.6	55	46	333
12noon	987	7.28	39.4	57	49	337
1pm	940	6.09	39.3	54	43	335
2pm	863	4.65	38.9	53	42	336
3pm	767	4.09	38.6	50	39	338
4pm	596	3.54	38.3	49	36	332
5pm	106	0.86	37.8	37	30	337

23/11/2021

7am	100	1.2	39	33	33	337
8am	250	1.64	39.8	34	30	338
9am	500	3.59	40.2	41	34	336
10am	621	4.28	40	49	36	337
11am	833	6.24	39.7	47	35	336
12noon	997	7.7	39.3	55	46	336
1pm	998	7.82	39.2	54	45	336
2pm	753	6.02	38.8	55	47	337
3pm	689	6.56	38.6	53	45	336
4pm	296	2.17	38.2	46	34	338
5pm	100	0.98	38.1	37	31	338

24/11/2021

7am	102	0.9	41	39	28	315
8am	257	2.35	41.1	30	29	316
9am	470	4.35	41.2	36	33	315
10am	671	5.97	40.9	44	39	314

22/12/2021

7am	115	1.2	40	31	
8am	240	2.16	41	29	240
9am	499	4.58	41.3	37	499
10am	726	6.37	41.2	42	726
11am	857	7.98	40.6	48	857
12am	924	8.6	40.2	51	924
1pm	890	8.39	39.5	55	890
2pm	774	7.29	39.5	54	774
3pm	631	5.75	39.4	53	631
4pm	372	3.6	39.7	46	372
5pm	100	1.39	38.8	39	100

23/12/2021

7am	115	1.2	40	31	
8am	190	1.83	40.8	29	190
9am	580	5.21	41.3	39	580
10am	795	7.33	41	43	795
11am	956	8.73	40.5	51	956
12am	1009	9.3	40.1	52	1009
1pm	974	8.99	39.8	54	974
2pm	890	7.99	39.7	56	890
3pm	696	6.36	39.5	53	696
4pm	443	4.02	39.7	49	443
5pm	118	1	38.5	39	118

24/12/2021

7am	115	1.2	40	31	
8am	340	3.28	41.2	33	340
9am	621	5.81	41.2	41	621
10am	835	7.63	40.9	46	835

11am	807	7.46	40.6	45	40	311	11am	971	8.96	40.5	51	971
12noon	859	7.73	40.2	51	44	310	12am	1024	9.44	39.8	54	1024
1pm	838	7.41	39.9	51	48	311	1pm	1003	9.2	39.8	55	1003
2pm	676	6.36	39.9	50	46	332	2pm	900	8.18	39.4	57	900
3pm	522	4.96	39.6	49	39	324	3pm	898	7.59	39.4	53	898
4pm	324	2.87	39.4	43	38	325	4pm	447	4.3	39.2	49	447
5pm	121	1.2	38.7	37	32	312	5pm	103	1.3	37.8	37	103

APPENDIX D: EXPERIMENTAL DATA FOR THE THREE WEATHER CONDITION-2022

Table D1: Dry – Windy condition

Mar-22								Apr-22							
Date	Time	SI	ISC	VOC	TPV	TA	Latt.	Date	Time	SI	ISC	VOC	TPV	TA	Lat.
	7am	120	1.11	40.1	28	26	249	01/04/2022	7am	113	1.23	40	30	28	343
01/03/2022	8am	368	3.29	40.2	36	32	338		8am	360	3.5	40.9	35	32	343
	9am	481	3.86	40.3	40	35	336		9am	636	5.78	40.6	41	38	341
	10am	621	5.3	40.3	42	37	338		10am	731	6.66	40.6	41	39	342
	11am	736	6.63	40.1	49	36	336		11am	887	7.87	40.2	47	45	342
	12am	821	7.36	39.3	57	48	335		12pm	880	7.77	39.9	45	43	339
	1pm	846	7.69	39.2	55	44	334		1pm	909	8.11	39.8	51	50	338
	2pm	643	5.62	38.8	54	46	335		2pm	898	6.58	39.6	50	48	338
	3pm	565	5.64	37.8	55	44	336		3pm	767	5.11	39.4	48	46	342
	4pm	317	2.93	36.8	49	34	338		4pm	635	4.59	39.2	39	36	338
	5pm	103	1.06	31.6	32	30	334		5pm	589	1.49	38.7	36	34	340
02/03/2022	7am	104	1.07	40.1	28	26	249	02/04/2022	7am	106	0.98	39.4	29	26	340
	8am	278	2.38	40.1	35	30	338		8am	303	1.89	39.6	34	32	342
	9am	418	3.6	40.2	40	32	336		9am	196	1.41	39.5	33	32	344
	10am	612	5.27	40.3	42	33	334		10am	299	5.71	41.8	36	34	345
	11am	763	6.36	40.1	48	36	336		11am	738	6.71	40.1	48	43	340
	12am	812	7.06	39.1	56	46	334		12pm	841	7.67	39.3	48	44	338
	1pm	836	7.63	39.2	54	43	334		1pm	818	7.66	39.1	52	49	338
	2pm	644	5.72	38.7	58	48	335		2pm	763	3.65	38.5	47	44	342
	3pm	556	5.63	38.5	54	43	335		3pm	264	2.23	39.2	39	37	341
	4pm	316	2.93	36.9	48	34	337		4pm	200	2.1.92	39	37	35	342
	5pm	102	0.96	30.6	31	30	338		5pm	100	0.87	38	36	34	338

03/03/2022	7am	100	0.5	38.5	26	24	243
	8am	249	2.04	39.4	34	30	338
	9am	493	4.3	40.7	40	32	337
	10am	694	6.01	40.1	44	36	336
	11am	826	7.11	39.4	49	36	336
	12am	882	7.66	38.7	52	43	335
	1pm	431	7.2	38.3	58	47	336
	2pm	486	7.09	38.5	56	44	336
	3pm	438	3.95	41.5	34	31	337
	4pm	149	1.21	38.2	40	33	334
	5pm	100	0.22	35.8	32	29	339
04/03/2022	7am	118	1.11	40.1	30	26	300
	8am	249	2.16	40.4	33	30	338
	9am	511	4.56	40.6	41	32	337
	10am	782	7.82	39.6	57	41	335
	11am	809	8.26	39.3	58	43	336
	12am	976	8.81	38.9	60	49	335
	1pm	949	8.66	38.6	62	50	336
	2pm	793	7.3	38.6	61	49	335
	3pm	736	6.86	38.4	57	43	336
	4pm	372	3.62	38.7	51	39	335
	5pm	122	1.39	37.9	43	32	337
05/03/2022	7am	115	1.05	38	35	31	330
	8am	220	2.06	40	35	30	336
	9am	584	5.37	40.4	42	33	337

03/04/2022	7am	103	1.02	40.1	26	24	343
	8am	369	3.5	41	34	32	342
	9am	521	5	40.8	37	36	341
	10am	367	3.24	39.2	38	34	341
	11am	922	7.83	39.9	45	43	337
	12pm	893	8.12	39.9	45	44	340
	1pm	845	7.56	39.4	47	43	336
	2pm	686	6.47	39.1	50	47	339
	3pm	535	4.92	39.4	41	38	339
	4pm	313	3.14	39.1	43	42	341
	5pm	117	1.3	38.4	38	32	340
04/04/2022							
	7am	112	1.2	40	29	28	343
	8am	384	3.48	40.9	35	34	340
	9am	535	5.11	40.8	36	34	341
	10am	739	6.56	40.3	43	30	343
	11am	879	7.9	40	37	35	339
	12pm	879	7.89	39.6	47	45	339
	1pm	862	7.83	39.1	50	48	340
	2pm	755	6.82	39.9	52	50	338
	3pm	558	5.05	39.5	45	43	341
	4pm	333	3.17	39.5	41	40	342

	10am	634	6.89	40.3	50	36	338
	11am	930	8.29	39.9	52	38	335
	12am	904	8.22	38.7	58	46	334
	1pm	904	9.37	39.6	53	42	336
	2pm	895	8.66	38.4	56	43	335
	3pm	598	5.57	38.4	56	43	335
	4pm	496	4.29	38.8	48	34	336
	5pm	100	1.16	37.6	43	33	336
06/03/2022	7am	118	1.11	40.1	30	26	300
	8am	322	2.94	38.9	40	30	337
	9am	550	5	39.5	49	32	336
	10am	678	6.29	39.3	50	38	337
	11am	956	8.62	38.9	56	40	335
	12am	986	8.86	38.9	57	43	334
	1pm	898	8. 56	38.8	56	39	336
	2pm	800	7.26	39.2	55	40	334
	3pm	726	6.55	38.7	49	37	336
	4pm	300	3	39	45	32	336
	5pm	143	4.48	38.1	42	31	337
07/03/2022	7am	100	0.5	38.5	26	24	243
	8am	286	2.57	40.1	36	30	338
	9am	581	5.07	40.4	42	31	336
	10am	648	6.26	40.4	49	34	336
	11am	903	7.81	39.9	48	36	335
	12am	927	8.33	39.1	55	38	334
	1pm	919	9.27	38.9	58	42	336
	5pm	123	1.42	38.7	39	36	334
05/04/2022							
	7am	195	1.69	40.2	31	30	342
	8am	488	4.72	40.9	36	34	341
	9am	329	3.26	40.7	35	32	341
	10am	523	5.34	40.5	40	38	342
	11am	859	7.62	39.9	45	432	339
	12pm	966	8.79	39.4	49	46	339
	1pm	966	8.89	39.4	52	50	336
	2pm	830	7.5	39.5	50	48	341
	3pm	587	5.5	39.3	48	44	339
	4pm	319	3.09	38.9	46	42	339
	5pm	100	0.84	37.6	36	32	342
06/04/2022							
	7am	162	1.49	40.4	29	24	343
	8am	366	3.62	40.5	32	34	347
	9am	612	5.62	40.3	40	38	343
	10am	416	3.7	40.4	36	34	342
	11am	412	3.91	38.7	43	42	342
	12pm	874	8.12	40.6	43	42	340
	1pm	924	9.02	40.2	42	40	340
	2pm	746	6.67	40.2	43	42	343
	3pm	536	4.88	40.2	42	40	343
	4pm	249	2.64	39.5	39	35	344

	2pm	863	7.64	39.1	53	39	336		5pm	161	1.54	39.1	34	32	342
	3pm	630	5.71	38.6	56	38	335								
	4pm	100	0.98	37.5	40	30	337	07/04/2022							
	5pm	134	1.17	37.5	42	32	336		7am	146	1.4	40.3	28	24	342
									8am	405	3.75	41	33	32	341
08/03/2022	7am	100	0.5	38.5	26	24	243		9am	536	4.53	41.1	36	34	341
	8am	148	1.31	39.7	31	30	337		10am	757	6.76	40.7	39	36	341
	9am	252	2.4	40.3	34	30	337		11am	846	7.65	40.3	44	42	335
	10am	337	3.29	40.2	39	32	336		12pm	857	7.81	39.5	45	43	342
	11am	798	7.1	39.5	51	38	335		1pm	897	8.06	39.4	49	44	342
	12am	938	8.49	39.3	53	48	336		2pm	719	6.28	39.9	46	42	337
	1pm	779	7.06	38.7	56	43	335		3pm	628	5.68	39.6	43	41	342
	2pm	726	6.34	38.5	51	38	337		4pm	244	2.33	39.7	34	31	340
	3pm	444	4.17	39.4	48	33	336		5pm	100	1.04	38.6	35	31	342
	4pm	346	3	38.1	42	30	334								
	5pm	103	1.02	37.8	40	32	337								
								08/04/2022							
09/03/2022	7am	118	1.11	40.1	30	26	300		7am	100	0.39	38.3	25	24	342
	8am	277	2.31	39.9	37	30	337		8am	100	0.49	38.7	24	22	342
	9am	480	4.23	40.1	44	31	336		9am	102	1.03	39.7	26	24	342
	10am	639	5.35	40	47	36	335		10am	449	4.29	40.8	37	34	340
	11am	797	6.97	39.3	51	38	334		11am	477	4.49	41	37	36	338
	12am	878	8.23	39.2	55	40	336		12pm	587	5.42	40.7	39	36	342
	1pm	800	7.12	39.1	57	41	334		1pm	871	7.78	40.7	45	42	340
	2pm	698	6.07	39	55	40	335		2pm	699	6.85	40.9	38	34	340
	3pm	494	4.47	39	52	41	335		3pm	484	5.46	40.6	39	34	340
	4pm	288	2.58	38.7	47	33	336		4pm	320	3.17	39.5	38	34	342
	5pm	109	1.09	37.7	40	32	337		5pm	125	1.41	38.8	39	35	341

10/03/2022	7am	100	0.5	38.5	26	24	243	09/04/2022							
	8am	319	3.01	40.5	37	30	337		7am	122	1.17	39.8	29	27	343
	9am	561	4.84	40.5	44	32	333		8am	433	5.06	40.9	38	36	341
	10am	741	6.59	40.1	47	31	336		9am	599	5.98	40.6	40	38	341
	11am	885	7.79	39.6	54	39	334		10am	787	7.26	40.6	41	39	341
	12am	901	8.07	39.3	53	38	332		11am	789	6.67	39.1	38	36	341
	1pm	809	7.81	39.1	52	37	335		12pm	1064	8.97	39.4	47	46	341
	2pm	742	6.63	38.7	53	43	334		1pm	600	5.56	39.5	44	42	339
	3pm	515	4.46	38.7	53	37	335		2pm	673	6.32	40.4	42	40	339
	4pm	288	2.68	38.8	47	35	336		3pm	654	6.26	40	46	42	338
	5pm	138	1.29	38.1	41	33	337		4pm	611	5.79	43	40	36	340
									5pm	126	1.47	39.2	37	35	341
11/03/2022															
	7am	118	1.11	40.1	30	26	300	10/04/2022							
	8am	305	2.62	40.1	37	30	337		7am	117	1.03	40	27	23	342
	9am	499	4.72	39.6	48	31	337		8am	184	1.79	40.3	30	28	342
	10am	738	6.29	39.9	46	33	336		9am	254	2.5	40.8	32	20	342
	11am	830	7.3	39.7	48	36	334		10am	349	3.52	40.6	36	33	341
	12am	889	7.82	3.94	51	37	334		11am	315	3.01	40.4	37	36	341
	1pm	864	7.59	38.7	53	39	334		12pm	316	3.22	40.4	35	32	344
	2pm	787	7.36	38.4	56	37	336		1pm	485	5.39	39.7	44	42	326
	3pm	530	4.62	38.8	52	34	335		2pm	516	5.32	40.1	43	42	324
	4pm	284	2.5	38.7	47	32	336		3pm	164	1.64	38.8	38	34	325
	5pm	189	1.77	38.2	44	29	336		4pm	139	1.6	38.6	36	34	324
									5pm	144	1.65	39.4	34	30	336

12/03/2022	7am	100	0.5	38.5	26	24	243
	8am	236	1.96	39.8	36	30	338
	9am	587	5.08	40.5	43	31	335
	10am	762	6.54	40	47	32	336
	11am	832	7.79	39.9	48	33	335
	12am	918	8.03	38.7	61	49	335
	1pm	869	7.78	38.6	56	43	334
	2pm	737	6.57	38.3	60	48	334
	3pm	586	5.19	38.8	52	43	332
	4pm	325	2.98	38.4	49	34	336
	5pm	131	1.61	37.5	44	32	336
13/03/2022	7am	131	1.37	39.8	30	31	346
	8am	481	4.66	41.1	36	32	341
	9am	585	5.48	40.5	40	38	341
	10am	779	7.02	40.2	45	42	339
	11am	877	7.95	39.6	48	44	339
	12pm	898	8.15	39	54	52	339
	1pm	203	2.49	37.9	54	52	340
	2pm	765	6.97	38.8	52	49	338
	3pm	526	3.62	36.6	55	50	339
	4pm	320	3.01	38.5	49	46	344
	5pm	124	1.38	38.1	42	40	341
14/03/2022							
	7am	130	1.18	39.6	31	29	342
	8am	249	3.07	40.5	36	34	342

11/04/2022							
	7am	136	1.22	40.4	26	24	342
	8am	256	2.5	40.6	30	28	341
	9am	574	5.32	40.7	39	36	341
	10am	669	5.92	40.2	41	39	340
	11am	839	7.6	40.2	43	40	340
	12pm	862	7.81	40.1	47	44	338
	1pm	699	7.28	40	45	42	342
	2pm	487	6.47	40.2	46	42	342
	3pm	524	4.83	39.8	42	40	340
	4pm	329	3.28	39.5	42	40	343
	5pm	121	1.17	38	34	35	342
12/04/2022							
	7am	124	1.2	40.2	26	28	342
	8am	351	3.58	41.4	31	29	342
	9am	587	4.99	41.2	37	35	341
	10am	473	4.64	40.5	37	36	340
	11am	917	7.5	40.1	46	42	340
	12pm	845	7.79	40.1	44	42	342
	1pm	900	7.78	39.9	50	48	341
	2pm	286	5.53	39.9	41	38	342
	3pm	446	4.14	39.8	41	36	340
	4pm	307	3.04	40	38	36	340
	5pm	129	1.35	39	38	36	343

	9am	467	4.61	40.6	39	38	341								
	10am	749	6.85	40.3	43	41	342	13/04/2022							
	11am	838	7.78	40.2	47	43	341		7am	119	1.18	40.1	29	26	339
	12pm	875	7.96	39.6	49	42	341		8am	329	3.22	41.1	31	29	342
	1pm	969	7.7	39.2	53	50	339		9am	599	5.2	41.2	36	30	342
	2pm	709	6.65	39.4	46	42	340		10am	636	5.79	40.6	39	36	341
	3pm	519	4.55	39.4	48	42	339		11am	829	5.79	40.6	43	40	339
	4pm	199	2.89	39.1	43	40	341		12pm	372	3.96	38.9	46	44	340
	5pm	105	1.25	38.4	38	36	341		1pm	866	5.69	39.6	47	46	342
									2pm	411	3.95	40.3	39	34	341
15/03/22									3pm	715	5.47	40	44	42	337
	7am	130	1.25	39.6	31	28	342		4pm	169	1.67	39.4	35	32	341
	8am	332	3.35	40.7	35	32	342		5pm	100	1.05	37.7	33	30	342
	9am	606	5.51	40.5	40	38	343								
	10am	777	7.09	40.1	44	41	340								
	11am	805	7.31	39.8	46	42	337	14/04/2022							
	12pm	871	7.91	39.3	51	48	341		7am	135	1.4	40.1	30	28	343
	1pm	860	7.76	38.6	54	50	341		8am	519	4.72	39	43	41	341
	2pm	738	6.58	38.7	53	50	338		9am	676	6.82	39.7	44	41	340
	3pm	552	5.07	38.7	50	49	339		10am	519	4.72	39	43	40	341
	4pm	317	3.03	38.5	49	45	344		11am	676	6.78	39.7	42	40	340
	5pm	100	1.09	37.1	43	40	342		12pm	641	6.36	39.9	44	42	338
									1pm	801	7.24	39.1	51	49	340
16/03/22									2pm	674	6.15	39.2	48	46	339
	7am	100	0.76	39.1	29	27	342		3pm	632	5.36	39.1	46	44	338
	8am	116	1.09	39.3	30	28	342		4pm	313	3.16	39	43	40	340
	9am	323	3.43	40.4	35	32	341		5pm	100	1.07	38.3	36	34	343
	10am	736	6.67	40	43	40	341								

	11am	907	8.15	39.3	49	43	341
	12pm	359	8.9	39.2	43	40	343
	1pm	861	7.73	39.2	47	43	338
	2pm	747	6.79	39.3	51	50	339
	3pm	534	4.84	39.4	46	43	341
	4pm	321	3.01	39.2	44	41	341
	5pm	104	1.21	38.3	39	36	341
17/03/22							
	7am	164	1.61	40.2	31	29	343
	8am	178	1.87	40.3	31	28	343
	9am	569	5.4	41.1	39	35	342
	10am	711	6.45	40.4	44	42	321
	11am	665	5.43	40.6	43	40	341
	12pm	689	5.78	40.4	46	43	340
	1pm	833	7.54	38.8	57	55	339
	2pm	704	6.41	38.5	52	49	339
	3pm	502	4.55	39	38	46	340
	4pm	274	2.59	39.1	43	40	340
	5pm	125	1.24	38.1	41	38	342
18/03/22							
	7am	129	1.27	39.7	32	30	322
	8am	339	3.37	40.5	36	31	320
	9am	566	5.31	40.3	42	39	320
	10am	733	6.81	39.6	49	45	320
	11am	839	7.82	39.1	52	49	327
	12pm	849	7.92	38.8	54	50	320
15/04/2022							
	7am	100	0.63	38.4	26	22	340
	8am	103	0.79	38.6	28	26	341
	9am	117	1.6	39	30	28	330
	10am	164	1.59	40.6	27	24	343
	11am	202	1.97	40.6	29	27	343
	12pm	588	5.53	39.9	44	42	336
	1pm	669	6.16	40.3	41	40	340
	2pm	676	6.16	40.3	39	36	340
	3pm	266	2.59	40.3	34	32	341
	4pm	205	2.04	40	33	30	344
	5pm	131	1.28	39.4	32	31	342
16/04/2022							
	7am	159	1.55	40.1	30	28	341
	8am	217	2.2	40.5	31	30	342
	9am	281	3.53	40.3	35	31	342
	10am	197	1.71	39.7	34	32	342
	11am	369	3.94	41	35	31	341
	12pm	605	5.79	41.1	37	34	341
	1pm	762	7.19	40.7	42	40	340
	2pm	376	3.88	40.5	39	36	342
	3pm	251	2.55	39.8	39	34	342
	4pm	212	2.3	39.6	38	34	341
	5pm	100	1.04	38.8	33	30	342

	1pm	818	7.58	38.7	55	51	324
	2pm	699	6.44	38.4	57	52	319
	3pm	511	4.85	39.1	51	48	326
	4pm	134	2.59	39.4	43	40	324
	5pm	100	1.05	37.9	41	40	329
19/03/22							
	7am	116	1.17	39.4	32	30	342
	8am	328	3.18	40.5	35	32	344
	9am	561	5.15	40.5	40	38	341
	10am	631	6.65	40.5	42	40	341
	11am	539	7.29	39.7	45	43	348
	12pm	350	3.47	39.7	41	38	343
	1pm	789	7.29	40.1	49	43	337
	2pm	708	6.47	39.6	48	42	340
	3pm	440	4.69	39.9	44	40	340
	4pm	101	0.99	38	37	36	344
	5pm	100	0.15	34.3	35	33	342
20/03/22							
	7am	177	1.73	40.2	33	30	342
	8am	393	3.78	40.2	38	34	342
	9am	588	5.36	40.1	43	41	341
	10am	742	6.81	40	45	42	340
	11am	861	7.86	39.1	52	50	341
	12pm	877	7.95	39	52	49	341

17/04/2022							
	7am	100	0.26	37.2	25	23	343
	8am	112	0.24	38.3	30	28	341
	9am	203	0.36	38.6	30	28	334
	10am	366	3.48	41.2	32	30	356
	11am	100	0.23	36.4	30	29	356
	12pm	100	0.78	39.9	23	20	356
	1pm	344	3.21	42.1	27	26	353
	2pm	180	1.84	40.9	27	23	355
	3pm	216	2.06	40.5	30	28	351
	4pm	189	1.84	40.2	31	29	355
	5pm	100	0.73	39	28	36	357
18/04/2022							
	7am	100	0.61	39.3	25	24	354
	8am	213	2.02	40.7	29	26	351
	9am	309	3.03	40.5	34	32	352
	10am	227	4.11	40.5	38	32	357
	11am	416	3.2	40	38	34	353
	12pm	836	11.46	41	46	42	359
	1pm	1127	3.8	38	49	43	353
	2pm	756	6.89	40.2	45	43	348
	3pm	370	5.17	39.8	43	42	356
	4pm	117	1.19	37.9	40	38	350
	5pm	119	1.33	39.7	36	34	353

	1pm	817	7.46	39	53	50	339
	2pm	703	6.34	39.1	51	48	338
	3pm	530	4.9	39.33	49	46	340
	4pm	305	2.92	39.2	44	42	340
	5pm	109	1.25	38.3	38	36	341
21/03/22							
	7am	155	1.53	40.2	31	29	341
	8am	369	3.45	40.8	34	32	343
	9am	588	5.43	39.7	40	29	341
	10am	755	6.79	40.2	42	40	340
	11am	846	7.68	39.8	48	46	340
	12pm	875	7.95	38.9	50	48	339
	1pm	841	7.75	39.3	54	52	323
	2pm	746	6.99	38.8	55	51	323
	3pm	537	4.48	39.3	50	49	341
	4pm	299	2.98	39	46	43	340
	5pm	123	1.24	38.2	39	36	341
22/03/22							
	7am	100	0.5	38.5	26	24	243
	8am	100	0.56	38.6	28	25	342
	9am	101	0.56	38.4	29	26	340
	10am	113	0.64	39.4	30	28	341
	11am	296	2.75	41.1	30	26	342
	12pm	204	1.97	40.5	27	24	342
	1pm	165	1.64	40.4	29	27	324

19/04/2022							
	7am	100	0.69	39.5	25	22	351
	8am	100	0.67	39.7	24	22	353
	9am	164	1.72	40.3	29	24	355
	10am	282	2.46	40.3	31	29	350
	11am	485	4.63	41.5	36	34	351
	12pm	490	4.46	41.4	37	32	351
	1pm	494	6.58	41.4	38	32	351
	2pm	689	5.55	40.8	41	36	354
	3pm	178	1.82	38.5	39	34	352
	4pm	117	1.26	38.6	39	34	357
	5pm	100	0.79	38.3	34	32	356
20/04/2022							
	7am	185	1.91	40.9	31	29	353
	8am	310	3.49	41.6	31	30	353
	9am	561	5.22	40.6	40	38	358
	10am	734	6.72	40.3	43	31	353
	11am	834	7.55	39.5	53	50	357
	12pm	854	7.76	39.4	48	46	354
	1pm	805	7.31	39.4	50	48	354
	2pm	264	2.81	38.4	43	41	354
	3pm	536	4.93	39.4	47	44	356
	4pm	318	3.01	39.3	45	43	353
	5pm	111	1.26	38.6	37	35	350
21/04/2022							
	7am	184	1.78	40.6	31	30	351

	2pm	180	1.76	40	28	24	342		8am	309	3.23	41	34	32	353
	3pm	222	2.13	40	31	29	342		9am	556	5.5	40.9	43	40	355
	4pm	211	2.01	39.3	30	28	340		10am	698	6.42	40.5	42	40	351
	5pm	150	1.5	39	28	26	340		11am	792	7.2	40.1	49	42	351
									12pm	844	7.83	40.3	47	42	353
23/03/22									1pm	801	7.19	40.1	48	46	353
	7am	100	0.53	38.2	27	23	341		2pm	720	6.41	39.6	48	44	356
	8am	142	1.38	39.7	30	38	343		3pm	519	4.81	40.1	44	40	351
	9am	258	2.48	40.4	34	32	343		4pm	334	3.12	39.8	41	40	352
	10am	296	2.87	40.5	36	34	341		5pm	165	1.76	39.4	36	33	352
	11am	933	8.66	39.6	47	45	340								
	12pm	764	4.38	38.5	50	48	339	22/04/2022							
	1pm	154	1.52	39.3	33	34	341		7am	133	1.34	39.9	29	26	351
	2pm	162	1.56	39.2	35	34	340		8am	161	1.63	40.4	28	25	356
	3pm	143	1.39	38.3	30	29	341		9am	407	4.03	41.5	34	32	355
	4pm	120	0.59	38.2	29	27	340		10am	344	2.82	40.4	34	32	352
	5pm	106	0.56	38	28	34	340		11am	430	4.04	41.3	37	35	355
									12pm	649	5.04	39.8	49	46	354
24/03/22									1pm	806	9.96	41.3	48	44	357
	7am	146	1.26	40.5	27	25	342		2pm	521	5.35	40.8	41	40	349
	8am	255	2.6	40.1	33	30	320		3pm	449	5.32	40.3	44	42	355
	9am	632	5.77	40.4	41	38	341		4pm	255	2.3	39.5	43	40	351
	10am	446	4.86	40.8	37	34	341		5pm	107	1.16	39.3	32	30	349
	11am	844	7.44	40.4	44	40	340								
	12pm	933	8.29	39.8	45	42	339	23/04/2022							
	1pm	848	7.98	39.5	47	45	338		7am	123	1.2	40.2	29	26	355
	2pm	647	6.03	39.7	45	42	338		8am	295	2.86	40.6	29	35	353
	3pm	421	4.09	39.8	43	41	344		9am	489	4.57	40.5	41	40	349

	4pm	301	2.98	39.9	40	38	341
	5pm	166	1.8	39.3	36	34	341
25/03/22							
	7am	179	1.82	40.5	30	28	343
	8am	352	3.32	40.5	32	30	342
	9am	630	5.78	40.7	40	38	341
	10am	371	3.36	40.7	36	34	339
	11am	829	7.16	40.7	43	40	340
	12pm	867	7.87	39.7	46	44	339
	1pm	846	2.75	37.8	49	46	339
	2pm	748	6.84	38.9	51	49	338
	3pm	184	1.81	39.2	37	35	342
	4pm	164	1.58	39.3	35	33	342
	5pm	160	1.59	39	29	26	341
26/03/22							
	7am	179	1.6	40.5	29	26	340
	8am	285	2.84	40.4	34	32	342
	9am	495	4.52	40.3	41	38	341
	10am	752	6.84	39.8	45	42	343
	11am	880	8.05	40	47	42	339
	12pm	936	9.38	39.6	51	43	340
	1pm	817	7.33	39.3	52	50	338
	2pm	699	6.37	39.2	46	44	342
	3pm	515	4.83	39.5	45	42	340
	4pm	255	2.63	39	43	41	341
	5pm	115	1.27	38.5	38	34	340
	10am	654	5.89	40.4	43	42	350
	11am	857	7.75	40.2	50	48	353
	12pm	863	9.39	40.2	48	46	352
	1pm	809	5.15	39.5	46	44	350
	2pm	783	7.08	39.9	49	47	351
	3pm	561	5.09	40.1	43	40	354
	4pm	169	3.41	40	41	38	348
	5pm	115	1.36	38.7	35	33	355
24/04/2022							
	7am	100	0.91	39.4	28	26	353
	8am	172	1.73	40.5	29	26	349
	9am	424	4.09	41.7	34	30	356
	10am	373	3.6	40.7	35	33	351
	11am	369	3.84	40.8	35	32	354
	12pm	334	4.89	38.8	43	40	351
	1pm	967	8.85	41.2	41	38	353
	2pm	803	7.16	40.3	44	42	349
	3pm	593	5.26	40.8	39	36	351
	4pm	312	3.08	40.2	38	36	356
	5pm	160	1.75	39.5	37	36	351
25/02/2022							
	7am	100	0.82	39.3	29	26	350
	8am	120	1.22	39.6	30	28	358
	9am	555	3.52	40.5	37	33	353
	10am	100	0.2	35.7	37	36	350
	11am	139	1.34	40.5	27	25	353

27/3/22							
	7am	144	1.45	40.2	30	28	343
	8am	254	2.64	40.5	33	30	342
	9am	637	5.87	40.5	41	39	340
	10am	759	7.02	40.4	42	41	342
	11am	870	7.96	39.6	49	46	339
	12pm	920	8.5	39.1	51	49	339
	1pm	677	6.13	39.6	46	43	339
	2pm	706	6.53	39.6	49	45	339
	3pm	581	5.31	39.6	43	42	339
	4pm	302	2.93	39.2	42	40	341
	5pm	123	1.41	38.6	38	34	343

	12pm	209	1.79	40.6	30	28	354
	1pm	159	1.52	40.3	27	25	350
	2pm	222	2.11	40.3	32	30	354
	3pm	220	2.12	40.6	31	30	356
	4pm	329	3.06	40.7	38	36	352
	5pm	108	1.3	39.4	32	30	356
25/4/2022							
	7am	170	1.91	40.9	29	26	353
	8am	209	2.09	40.8	30	24	354
	9am	583	5.44	40.7	43	40	355
	10am	678	6.34	40.7	41	39	353
	11am	871	8.39	40.7	48	44	352
	12pm	885	7.96	40.5	44	42	350
	1pm	302	8.96	40.3	49	45	349
	2pm	268	7.61	41	44	40	350
	3pm	180	1.87	37.7	46	42	352
	4pm	329	3.22	39.7	45	42	350
	5pm	100	1.03	38.5	37	35	349
27/4/2022							
	7am	112	1.28	39.9	30	28	349
	8am	262	2.4	40.6	34	32	358
	9am	539	5.31	40.5	43	42	350
	10am	254	2.54	40.3	36	33	350
	11am	451	4.89	41.1	38	36	351
	12pm	454	4.81	40	47	42	356

1pm	505	5.06	39.8	49	47	357
2pm	689	6.13	39.9	48	46	348
3pm	416	4.46	39.7	45	43	354
4pm	266	2.46	39.6	41	40	349
5pm	102	1.05	38.7	35	33	353

Table D2: Rainy weather Condition

AUGUST-2022 SEPTEMBER-2022

01/08/2022							01/09/2022						
7am	141	1.4	40.8	25	24	352	7am	100	0.55	39.2	25	23	353
8am	215	2.31	41	29	25	353	8am	296	3.5	40.6	31	29	351
9am	118	1.12	40	26	24	353	9am	626	5.52	40.9	39	36	349
10am	100	0.46	38.5	25	23	353	10am	317	3.31	40.6	36	34	350
11am	100	0.9	40.1	24	22	351	11am	639	6.1	40.8	42	40	351
12pm	213	2.45	40.9	30	28	350	12am	798	7.63	39.8	46	41	349
1pm	217	2.19	40.7	31	29	352	1pm	569	4.98	40.1	37	35	350
2pm	259	2.46	40.4	33	30	351	2pm	486	3.69	38.4	38	34	353
3pm	342	2.35	40.3	36	34	350	3pm	369	3.75	40.8	36	34	348
4pm	218	2.1	40.3	30	31	352	4pm	209	3.45	40.9	35	33	349
5pm	111	1.12	39.3	33	30	352	5pm	183	1.15	40	34	32	349

02/08/2022 02/09/2022

	7am	100	0.48	38.7	25	24	356		7am	100	0.72	39.4	26	24	349
	8am	217	2.07	41.2	28	25	354		8am	100	0.64	38.5	29	25	347
	9am	591	2.91	41.3	31	29	350		9am	161	1.59	40.4	31	29	350
	10am	1043	8.93	41.8	38	36	354		10am	436	3.56	40.6	38	37	348
	11am	235	2.31	40.7	31	29	351		11am	429	4.27	40.6	39	35	350
	12pm	729	7.04	41.4	38	36	352		12am	511	4.94	40.5	40	38	347
	1pm	1238	5.07	39.6	47	45	353		1pm	503	4.91	40.4	41	39	349
	2pm	959	9.29	40.6	42	40	351		2pm	250	2.57	39.9	37	35	350
	3pm	760	6.69	40.2	46	44	351		3pm	281	2.77	40.6	37	35	351
	4pm	120	1.2	39.2	33	30	352		4pm	101	0.98	39.1	32	31	350
	5pm	196	2.16	40.1	36	34	350		5pm	100	0.79	39	30	28	350
03/08/2022	7am	180	1.93	41.2	28	26	353	03/09/2022							
	8am	138	5.01	41.7	32	30	353		7am	100	0.89	39.2	26	24	348
	9am	504	8.77	41.9	37	35	351		8am	119	1.26	39.4	28	25	350
	10am	429	9.26	41.9	39	37	356		9am	393	3.36	39.6	30	28	352

	11am	601	7.41	40.9	39	35	353
	12am	926	8.8	39.2	48	46	351
	1pm	569	9.98	41.3	43	352	
	2pm	609	3.97	40.4	39	36	353
	3pm	807	7.52	40.7	45	42	350
	4pm	449	4.5	40.8	39	36	352
	5pm	140	1.73	39.9	34	32	351
04/08/2022							
	7am	200	2.16	41.1	30	28	353
	8am	261	2.5	41.4	31	29	353
	9am	266	5.5	40.5	35	34	351
	10am	299	7.44	40.1	41	39	352
	11am	396	3.69	40.8	37	35	350
	12am	371	3.59	40.8	36	34	350
	1pm	272	2.66	40.5	34	32	355

	10am	498	3.94	39.9	38	36	349
	11am	687	6.32	40.8	40	37	350
	12am	834	7.96	39.8	39	36	350
	1pm	963	8.39	39.1	44	41	350
	2pm	459	3.76	39.5	38	36	349
	3pm	396	2.93	39.8	30	27	350
	4pm	267	1.98	38.9	28	25	350
	5pm	100	0.89	38.3	26	25	350
04/09/2022	7am	100	0.91	39.9	26	23	350
	8am	149	1.2	39.4	32	30	349
	9am	669	6.28	40	44	42	348
	10am	815	7.54	39.5	48	46	347
	11am	927	8.6	39.1	52	50	350
	12am	876	8.68	38.9	59	50	353

	2pm	498	9.9	41.4	38	36	352		1pm	1079	10.2	39.3	56	52	350
	3pm	600	7.57	41	40	36	351		2pm	847	7.92	39.4	51	50	350
	4pm	100	0.97	39.1	30	28	353		3pm	216	1.96	38.8	43	41	351
	5pm	100	0.43	37.7	39	36	348		4pm	103	1.01	39.5	29	26	249
									5pm	100	0.89	38.3	26	24	350
05/08/2022	7am	121	1.2	40.3	27	25	348	05/09/2022							
	8am	198	1.79	40.8	29	26	353		7am	100	0.76	39.6	26	24	350
	9am	361	3.44	40.9	33	30	350		8am	104	0.96	39.8	27	23	350
	10am	820	7.59	41.3	40	38	353		9am	396	2.98	40.8	33	30	349
	11am	740	7.96	41	39	37	349		10am	709	6.29	39.5	40	37	347
	12am	1016	9.47	41.4	43	40	354		11am	1236	11	40.2	49	46	353
	1pm	1054	10.2	40.9	43	41	355		12am	849	7.45	40.9	40	35	349
	2pm	301	2.94	40.3	38	36	352		1pm	910	8.48	40.2	46	44	350
	3pm	341	3.19	40.6	36	32	350		2pm	734	6.67	40	42	39	349
	4pm	269	3.85	37	34	33	352		3pm	100	0.94	37.9	37	35	349

	5pm	100	0.74	38.5	31	29	349		4pm	473	4.3	41	37	35	352
									5pm	100	1.05	38.8	33	30	349
06/08/2022															
	7am	182	1.94	40.8	30	28	353	06/09/2022							
	8am	209	2.08	40.9	31	25	358		7am	130	1.33	40.6	26	24	351
	9am	315	3.03	40.8	34	32	358		8am	424	4.13	40.5	36	34	349
	10am	795	7.34	40.3	44	41	352		9am	651	6.04	40.6	40	38	350
	11am	293	9.78	40.4	45	42	351		10am	914	6.46	40.5	43	42	349
	12am	1025	9.42	39.6	50	46	351		11am	1019	9.58	40.1	49	46	346
	1pm	979	9.08	39.3	50	46	353		12am	912	8.33	39.4	52	50	349
	2pm	782	6.99	39.6	48	44	351		1pm	1010	9.33	39.3	51	50	351
	3pm	628	5.97	40	44	41	351		2pm	522	5.05	39.6	44	41	350
	4pm	395	3.25	40.5	38	34	349		3pm	369	3.23	39.3	42	41	349
	5pm	145	1.76	39.6	35	33	351		4pm	391	4.06	40.1	43	42	348
									5pm	149	1.42	39	35	33	350
07/08/2022															

	7am	104	1.06	39.6	31	30	352
	8am	367	3.25	40.7	34	33	354
	9am	515	4.8	41	37	35	354
	10am	118	1.41	38.9	35	31	353
	11am	100	0.98	38.9	30	28	358
	12am	926	10.28	41.8	43	40	352
	1pm	576	5.45	39.2	43	41	352
	2pm	437	4.21	40.3	41	39	355
	3pm	342	3.35	40.4	38	35	350
	4pm	311	3.22	40.2	39	36	350
	5pm	100	0.85	38.7	33	30	353
08/08/2022							
	7am	100	0.86	39.6	28	26	354
	8am	137	1.32	40.1	29	26	352
	9am	231	2.22	40.5	32	30	353
	10am	301	2.96	40.6	34	31	352

07/09/2022							
	7am	153	1.56	41	29	26	350
	8am	449	4.27	40.6	37	35	350
	9am	331	3.32	40.7	35	33	349
	10am	332	3.45	40.2	36	34	348
	11am	247	2.36	41	33	30	349
	12am	836	7.56	40.7	43	41	349
	1pm	535	5.05	40.3	42	40	349
	2pm	278	2.6	40.7	40	38	350
	3pm	165	1.64	40.7	30	29	353
	4pm	100	0.55	38.6	29	27	350
	5pm	100	0.38	38.1	26	24	350
08/09/2022							
	7am	141	1.34	40.8	25	23	350
	8am	422	3.99	41.6	33	30	351
	9am	165	1.62	39.4	34	32	352

	11am	459	4.51	40.4	40	38	350		10am	959	8.67	41.1	42	40	351
	12am	419	4.06	40.4	40	38	352		11am	1150	11.2	40.3	47	45	349
	1pm	405	3.93	40.2	38	36	351		12am	569	4.59	39.9	43	41	350
	2pm	293	2.8	39.8	40	38	352		1pm	478	3.46	40.6	40	38	349
	3pm	162	1.52	39.6	35	33	352		2pm	925	9.1	40.6	39	37	352
	4pm	156	1.53	39.5	34	33	351		3pm	169	1.09	39.9	34	32	350
	5pm	100	0.62	38.4	30	29	353		4pm	102	0.99	39.1	28	26	350
									5pm	100	0.89	38.7	26	23	350
09/08/2022	7am	100	0.67	39.5	25	24	354	09/09/2022							
	8am	429	4.17	41	35	33	351		7am	100	0.58	39.5	26	23	349
	9am	660	6.3	40.8	41	39	355		8am	184	1.73	40.8	29	27	350
	10am	794	7.32	40.3	43	40	354		9am	459	3.69	40.9	33	31	353
	11am	802	8.46	40.1	47	41	354		10am	435	3.25	40.6	40	38	350
	12am	306	3.33	387.8	43	42	350		11am	569	4.99	41.4	39	36	350

	1pm	265	2.52	38.1	46	42	348
	2pm	827	7.64	39.9	45	42	349
	3pm	639	5.93	40.3	42	40	356
	4pm	359	3.58	40.3	39	36	352
	5pm	145	1.89	39.7	38	32	353
10/08/2022							
	7am	126	1.2	40.2	29	28	352
	8am	209	1.59	40.1	30	29	353
	9am	775	7.47	41.3	39	36	354
	10am	761	2.75	39.8	38	36	358
	11am	998	3.1	39.1	43	40	353
	12am	1146	10.7	41.1	43	41	353
	1pm	843	7.86	40.6	45	42	351
	2pm	925	8.6	39.6	52	50	352
	3pm	654	6.32	40.3	45	42	352

	12am	596	5.57	40.6	45	42	349
	1pm	269	2.7	40.6	34	32	352
	2pm	646	6.44	42.4	43	41	349
	3pm	173	1.81	40	35	33	351
	4pm	257	2.29	40	36	34	350
	5pm	100	0.92	38.7	32	30	352
10/09/2022							
	7am	100	0.91	38.9	26	22	350
	8am	149	1.2	39.4	32	30	349
	9am	636	6.27	40	39	36	348
	10am	815	7.54	39.5	46	42	347
	11am	926	8.61	39.1	40	36	350
	12am	867	8.2	38.9	38	36	352
	1pm	1049	10.2	39.3	56	54	350
	2pm	863	7.82	39.3	50	49	350

	4pm	251	2.64	39.8	39	34	351		3pm	218	1.97	38.9	43	41	351
	5pm	100	0.86	38.3	34	30	350		4pm	108	1.09	39.6	28	25	349
									5pm	100	0.88	38.3	27	24	350

11/08/2022	7am	100	0.45	38.6	24	22	354	11/9/2022							
	8am	171	2.69	40.3	27	23	350		7am	100	0.56	38.2	24	20	349
	9am	160	1.4	40.2	29	26	352		8am	112	1.05	39.1	27	25	350
	10am	211	2.05	40.5	31	30	350		9am	107	0.91	39.6	26	24	352
	11am	676	6.55	41.4	40	38	353		10am	439	4.41	41	34	32	350
	12am	696	9.84	42.4	36	34	352		11am	736	6.49	40.7	38	36	350
	1pm	395	4.17	40.7	39	37	351		12am	371	3.72	40.6	37	32	350
	2pm	233	2.32	40.4	33	30	352		1pm	305	3.07	39.6	41	40	350
	3pm	263	2.36	40.1	37	33	352		2pm	431	3.79	40.6	37	35	349
	4pm	161	1.75	39.7	34	30	353		3pm	690	5.49	39.9	43	41	349
	5pm	100	0.96	38.8	34	32	352		4pm	309	2.75	39.9	36	34	349

									5pm	115	1.14	39.2	33	30	349
12/08/2022	7am	100	0.71	39.2	25	23	352	12/9/2022							
	8am	340	5.35	41.5	36	33	351		7am	151	1.62	41	27	25	352
	9am	566	6.6	41.2	38	36	350		8am	436	4.32	40.4	30	28	350
	10am	843	7.812	39.3	47	45	349		9am	578	5.67	39.7	33	31	350
	11am	998	8.59	39.2	53	50	353		10am	868	8.71	39.5	39	36	349
	12am	926	8.42	38.9	55	51	354		11am	1036	9.36	40.3	48	44	353
	1pm	913	8.47	38.9	55	52	353		12am	1131	10.6	40.3	46	43	353
	2pm	620	3.25	38.6	49	48	353		1pm	1010	9.19	39.4	52	50	348
	3pm	323	3.08	39.3	42	40	355		2pm	218	2.17	38.1	40	39	350
	4pm	417	4.08	40.4	40	38	352		3pm	579	6.21	39.9	46	4	350
	5pm	10	0.37	38	36	32	353		4pm	113	1.14	37.6	40	38	349
									5pm	136	1.35	39.3	30	29	350
13/08/2022	7am	100	0.76	39.9	24	22	356	13/09/2022							

	8am	131	1.27	40.3	25	23	351		7am	140	1.43	40.5	28	26	343
	9am	100	0.68	39.2	26	24	352		8am	429	4.15	40.2	39	37	345
	10am	384	3.76	40.9	33	30	351		9am	460	4.16	40.1	40	39	346
	11am	203	1.94	40.2	31	29	352		10am	339	3.48	40	39	35	343
	12am	200	2.1	40.6	31	30	352		11am	209	2.07	39.4	36	33	349
	1pm	365	3.49	41.3	32	30	349		12am	289	2.07	39.4	36	35	349
	2pm	624	6.04	41.5	36	33	352		1pm	198	1.83	39.3	28	26	349
	3pm	291	2.79	40.5	34	31	350		2pm	186	1.69	38.3	29	27	349
	4pm	156	1.51	40	31	29	352		3pm	110	1.8	41.5	27	22	347
	5pm	100	0.5	38.2	28	26	357		4pm	149	1.58	40.9	28	26	245
									5pm	100	0.74	39.6	25	23	349
14/08/2022															
	7am	100	0.38	38.36	24	22	352	14/09/22	7am	100	0.7	39.3	24	21	347
	8am	100	0.92	38.1	25	23	355		8am	233	2.25	40.2	28	27	246
	9am	139	1.44	40.4	27	25	354		9am	283	2.41	40.9	33	30	345
	10am	222	2.2	40.7	30	28	352		10am	312	3.03	40.7	36	34	349

11am	236	2.99	41.2	32	30	352
12am	377	3.26	41.5	39	34	355
1pm	420	4.12	41.1	36	32	351
2pm	316	3.44	40.8	34	31	350
3pm	593	5.17	40.1	38	34	353
4pm	174	1.79	39.8	32	31	349
5pm	116	1.19	39.9	30	25	353

11am	263	2.48	39.8	25	23	346
12pm	235	2.39	39.9	32	30	349
1pm	346	3.51	41.2	30	29	349
2pm	245	2.36	39.9	29	28	346
3pm	168	1.67	39.4	26	26	349
4pm	114	1.23	39.2	27	24	347
5pm	100	0.97	38.9	25	23	

15/08/2022

7am	100	0.77	39.6	25	23	353
8am	289	2.65	41.2	34	31	352
9am	355	3.34	41.2	32	30	352
10am	285	3.97	40.1	39	37	351
11am	429	8.51	41.2	40	39	354
12am	889	9.18	41.2	43	42	354

15/09/22

7am	144	1.95	39.8	28	25	349
8am	526	5.32	40.5	34	32	349
9am	243	2.26	41.5	34	32	348
10am	425	3.97	40.8	41	40	348
11am	1136	10.9	41.8	50	48	350
12pm	1236	11.48	41.2	53	50	351

	1pm	599	9.89	40.7	43	41	353
	2pm	598	6.3	41	40	38	353
	3pm	314	2.86	39.7	39	35	354
	4pm	276	3.37	40.3	38	35	354
	5pm	129	1.55	39.5	36	32	349
16/08/2022							
	7am	100	0.89	40	24	20	348
	8am	132	1.12	40.4	29	27	353
	9am	754	6.67	41.3	40	38	754
	10am	613	5.11	40.6	39	36	350
	11am	927	8.53	40.1	46	44	353
	12am	933	9.73	39.9	49	47	349
	1pm	936	8.65	39.8	47	44	352
	2pm	1002	9.18	40.7	6	43	350
	3pm	368	6.79	40.4	45	42	352

	1pm	1034	10.16	40.9	47	45	347
	2pm	331	3.59	40.7	43	40	345
	3pm	713	6.71	40.1	46	44	350
	4pm	368	3.39	41.2	37	36	349
	5pm	100	0.76	38.7	32	31	348
16/09/22							
	7am	100	0.88	39.6	25	21	350
	8am	379	3.77	39.7	34	31	349
	9am	261	2.52	40.5	35	33	350
	10am	393	3.89	40.1	40	38	346
	11am	395	3.88	40.3	40	36	348
	12pm	1052	9.96	38.6	55	51	350
	1pm	565	5.42	39.1	50	49	351
	2pm	366	3.46	40.1	40	39	347
	3pm	523	4.28	40	45	42	348

	4pm	239	2.86	39.8	38	36	352		4pm	102	0.99	38.7	38	36	346
	5pm	100	0.8	38.3	34	31	354		5pm	100	0.51	38	34	32	350
17/08/2022								17/09/22							
	7am	100	0.32	37.4	27	25	351		7am	100	0.86	39.7	25	23	350
	8am	100	0.53	36.4	26	23	357		8am	286	39.8	39.8	28	24	249
	9am	100	0.17	33.3	26	24	353		9am	368	3.69	39.9	38	36	348
	10am	223	2.08	40.9	28	25	352		10am	498	4.81	39.6	39	34	350
	11am	716	8.09	41.3	38	36	350		11am	386	3.56	38.9	33	31	350
	12am	979	9.64	41.3	43	40	349		12pm	298	2.67	39.8	29	25	348
	1pm	421	5.3	40.4	43	41	351		1pm	496	4.21	40	38	34	349
	2pm	406	3.94	40.5	38	36	350		2pm	398	3.27	39.6	36	34	350
	3pm	601	5.57	40.8	40	35	350		3pm	399	4.87	39.4	36	32	350
	4pm	358	3.06	40.4	38	33	350		4pm	196	1.94	39.7	29	23	349
	5pm	100	0.77	38.6	31	30	350		5pm	100	0.84	38.9	27	24	349
18/08/2022								18/09/22							

7am	100	0.29	37.8	26	24	354
8am	100	0.89	39.2	26	24	350
9am	243	2.42	41.4	28	26	349
10am	608	5.99	40.5	38	36	350
11am	350	3.72	40.4	36	35	351
12am	427	3.47	39.8	39	36	352
1pm	1039	9.89	42	40	38	350
2pm	385	4.36	41.2	39	35	352
3pm	335	2.4	40.5	34	32	350
4pm	349	2.51	40.6	33	30	351
5pm	100	0.76	38.6	30	28	350

7am	100	0.57	39.2	25	24	350
8am	101	0.87	39.7	28	25	349
9am	307	3.29	40.3	34	31	348
10am	345	3.69	40.2	35	33	350
11am	477	4.21	40.5	37	33	349
12pm	495	4.21	40.2	40	37	346
1pm	946	8.96	40	41	40	350
2pm	849	9.63	40	44	41	349
3pm	596	6.13	40.6	42	40	350
4pm	156	1.52	39.3	36	34	346
5pm	100	0.94	38.9	33	30	348

22/08/2022

7am	127	0.144	40.7	27	25	350
8am	413	3.88	40.6	37	35	354

22/09/22

7am	103	1.22	38.7	26	23	350
8am	424	4.12	40.3	40	37	351

9am	646	5.99	40	43	41	353
10am	802	8.55	40.3	46	42	351
11am	334	3.29	40.2	43	41	350
12am	859	7.29	41.4	48	46	354
1pm	780	8.45	39.8	48	42	351
2pm	925	8.86	40.2	48	44	351
3pm	341	2.37	38.8	43	41	353
4pm	306	3.26	38.8	38	35	353
5pm	100	0.09	34.8	27	23	350

23/8/2022

7am	108	1.2	40.4	26	23	354
8am	189	1.81	40.9	27	25	353
9am	267	3.32	40.1	31	29	354
10am	409	3.72	41.4	33	30	353
11am	315	3	40.2	37	32	355

9am	424	4.1	40.3	40	36	351
10am	242	2.41	39.5	38	36	348
11am	839	8.32	39.1	51	50	349
12pm	1032	9.79	39.4	54	51	349
1pm	955	9.11	39.2	55	50	345
2pm	351	3.44	39.9	43	41	346
3pm	169	1.77	39.2	37	35	346
4pm	108	0.95	38.8	29	25	346
5pm	100	0.59	38.6	26	25	345

23/09/22

7am	188	2.1	41.5	27	25	350
8am	337	2.25	40.1	34	33	349
9am	527	4.99	40.1	43	41	349
10am	905	8.3	38.8	55	51	349
11am	902	8.02	38.8	55	51	349

12am	759	7.16	39.9	46	42	349	12pm	769	8.77	39.8	51	48	344
1pm	221	2	40.3	32	30	351	1pm	1028	9.62	40.2	48	44	346
2pm	209	2.16	41.1	37	35	353	2pm	801	7.61	38.8	54	52	348
3pm	142	1.49	40.6	27	25	350	3pm	491	4.72	39.4	48	46	346
4pm	119	1.21	39.5	30	29	353	4pm	320	3.3	39.2	44	40	349
5pm	100	0.93	39.4	28	25	351	5pm	129	1.32	38.1	39	35	346

24/08/2022							24/09/22						
7am	100	0.75	38.3	25	23	349	7am	164	1.79	41	28	34	347
8am	173	1.38	40.6	26	24	351	8am	468	4.69	40.5	38	36	347
9am	254	2.1	41.4	28	24	352	9am	719	6.63	40.5	43	40	348
10am	377	3.85	41.3	31	30	352	10am	920	8.7	39.5	51	49	347
11am	413	4.59	41.6	36	31	352	11am	1086	9.86	39.9	55	52	349
12am	1171	10.12	41.8	38	36	351	12pm	1121	10.59	38.7	55	54	348
1pm	165	1.63	39.5	33	30	351	1pm	353	3.51	39.7	50	48	349

	2pm	373	4.32	40	38	35	353		2pm	789	7.57	39.7	49	45	348
	3pm	785	7.2	40.9	43	41	352		3pm	198	1.36	38.3	39	35	348
	4pm	520	5.96	40	36	33	354		4pm	349	3.63	39.9	40	38	351
	5pm	125	1.55	39.9	32	31	352		5pm	266	3.01	39.8	41	40	347
25/08/2022	7am	129	1.42	40.8	27	25	350	26/09/22							
	8am	443	4.17	41.1	33	30	354		7am	100	0.39	38.6	23	21	347
	9am	760	7.46	41.3	37	33	351		8am	100	0.6	39.8	28	25	346
	10am	404	3.95	40.7	37	34	352		9am	584	5.78	41.4	33	30	344
	11am	955	9.08	40.8	44	41	350		10am	315	2.91	40	37	35	347
	12am	1016	9.73	41.1	45	42	354		11am	100	0.59	38.7	25	22	346
	1pm	729	6.59	40.2	46	42	351		12pm	100	0.75	39.8	27	24	350
	2pm	357	3.31	39.9	40	35	352		1pm	102	1.03	39.9	35	32	351
	3pm	654	6.17	40.3	44	41	349		2pm	221	2.1	40.8	30	26	350
	4pm	320	3.32	40.5	37	35	354		3pm	229	2.24	40.7	31	29	349
	5pm	119	1.09	38.9	34	32	351		4pm	156	1.52	40.3	30	26	347

5pm	100	0.86	39.4	27	25	350

Table D3: Harmattan weather conditions

Nov-22								Dec-22							
Date	Time	SI	ISC	VOC	TPV	TA	Latt.	Date	Time	SI	ISC	VOC	TPV	TA	Lat.
01/11/2022	7am	169	1.76	40.6	25	22	348	01/12/2022	7am	100	0.91	43.9	22	20	349
	8am	422	4.19	43	41	40	347		8am	355	3.41	44.9	4	32	348
	9am	751	7.27	41.8	55	51	347		9am	563	5.46	44.5	41	40	346
	10am	970	8.12	41.7	56	53	348		10am	766	7.23	43.5	49	41	348
	11am	1009	9.33	41.2	56	53	346		11am	858	8.18	43.4	50	48	350
	12pm	986	8.69	41	55	52	347		12pm	912	8.76	43.3	53	50	349
	1pm	989	8.19	41	54	52	346		1pm	817	7.85	42.8	54	51	347
	2pm	729	6.72	41.4	52	50	348		2pm	707	6.97	42	50	47	349
	3pm	709	6.29	40.8	50	46	346		3pm	474	4.6	42.8	48	44	346
	4pm	227	2.04	41.2	44	41	347		4pm	170	1.68	42.1	40	38	350
	5pm	100	0.56	39.8	36	33	347		5pm	100	0.63	40.6	34	31	346
02/11/2022								02/12/2022							
	7am	195	2.3	43.7	27	25	351		7am	102	1.39	43.5	24	20	350
	8am	398	2.69	42.7	31	30	350		8am	438	3.18	43.4	37	33	348
	9am	862	7.79	42	43	41	347		9am	576	6.99	43.7	41	40	347
	10am	936	8.26	41.2	46	42	348		10am	958	8.69	42.5	50	47	348

	11am	929	8.99	41.4	58	53	348		11am	996	8.99	42.7	53	50	346
	12pm	954	9.08	40.7	60	57	349		12pm	812	8.34	41.9	52	50	348
	1pm	937	8.1	41	87	53	347		1pm	906	8.38	41.4	51	50	351
	2pm	786	6.7	41.2	53	50	346		2pm	676	6.5	41.2	48	43	349
	3pm	502	4.86	41.6	49	45	347		3pm	624	5.96	40.8	47	45	347
	4pm	262	2.45	40.35	39	36	348		4pm	315	3.13	39.9	45	42	349
	5pm	100	0.53	39.5	36	34	349		5pm	100	0.79	40.2	37	36	348
								03/12/2022							
03/11/2022									7am	159	1.8	44.6	22	20	351
	7am	100	1.39	43.5	25	23	350		8am	461	4.02	44.1	37	32	347
	8am	439	3.18	43.4	37	35	348		9am	569	5.63	44.2	39	36	341
	9am	596	7.26	43.7	40	38	347		10am	693	6.54	43.5	45	41	349
	10am	959	8.69	42.5	51	50	348		11am	726	6.76	42.9	48	45	348
	11am	998	8.98	42.7	53	50	348		12pm	818	7.79	42.9	50	48	349
	12pm	810	8.33	41.8	52	50	349		1pm	969	8.54	42.4	55	50	350
	1pm	906	8.38	41.4	51	48	351		2pm	756	6.43	42.7	53	51	347
	2pm	686	6.5	41.2	48	42	349		3pm	657	5.56	42.5	48	42	348
	3pm	624	5.69	40.8	47	43	347		4pm	209	1.58	41.6	40	36	346
	4pm	315	3.12	39.2	45	41	347		5pm	100	0.6	39.8	33	30	350
	5pm	100	0.79	40.2	37	32	348								
								04/12/2022							

04/11/2022							
	7am	161	1.86	43.3	27	25	350
	8am	398	3.64	43.2	36	34	349
	9am	674	6.34	43.1	43	41	348
	10am	808	7.77	42.4	50	48	349
	11am	923	8.84	41.7	55	53	347
	12pm	989	8.69	41.5	57	54	347
	1pm	898	7.98	40.7	52	51	346
	2pm	877	7.6	40.8	50	46	347
	3pm	529	4.72	41.5	47	43	347
	4pm	248	2.53	41.8	43	40	349
	5pm	100	0.4	39	31	28	349

7am	100	1.11	43.4	22	20	351
8am	459	3.79	43.2	38	34	348
9am	624	6.11	43.9	41	38	349
10am	840	7.69	43.7	49	45	349
11am	967	8.2	43.3	52	50	350
12pm	936	8.49	42.9	55	51	349
1pm	929	8.36	43.4	54	51	348
2pm	759	6.89	43	54	51	349
3pm	528	4.95	42.5	50	47	349
4pm	294	2.02	40.1	40	38	346
5pm	100	0.64	41	34	32	348

05/11/2022							
	7am	135	1.64	43.4	24	22	347
	8am	482	4.61	42.6	43	40	351
	9am	629	5.36	42.7	48	45	351
	10am	822	7.75	40.9	52	50	345
	11am	934	8.86	40.6	54	51	348
	12pm	919	8.7	42.2	53	51	351
	1pm	914	8.69	41.9	52	50	350
	2pm	766	7.06	41.9	48	46	349
	3pm	535	4.93	42	47	45	350

05/12/2022							
	7am	123	1.43	44.6	21	20	351
	8am	440	3.97	44.1	37	35	351
	9am	632	6.2	45.7	31	29	348
	10am	818	7.88	43.5	48	46	349
	11am	912	8.92	43.2	49	46	348
	12pm	1012	9.16	42.8	54	51	350
	1pm	969	8.66	42.3	54	51	348
	2pm	879	7.28	42	55	51	349
	3pm	589	4.79	42.4	50	46	347
	4pm	320	3.3	42.6	46	42	347

	4pm	254	2.62	41.7	41	39	348		5pm	111	0.8	39.8	38	34	353
	5pm	100	0.75	40.2	35	33	351								
								06/12/2022							
06/11/2022									7am	100	1.22	44.6	20	18	349
	7am	106	1.19	43.4	23	22	352		8am	463	4.57	44.5	36	31	350
	8am	543	5.17	43.4	40	35	349		9am	773	7.79	43.6	47	45	346
	9am	629	5.36	42.9	43	41	350		10am	968	8.52	43.6	50	48	350
	10am	916	8.55	42.4	49	45	346		11am	1020	9.43	43.2	55	51	348
	11am	1008	9.48	41.7	53	50	352		12pm	989	9.47	42.8	55	50	349
	12pm	1026	9.86	41.9	55	51	351		1pm	88.6	9.09	43.1	56	54	348
	1pm	896	8.28	41.6	53	51	350		2pm	890	7.69	42.8	54	51	349
	2pm	825	7.89	41.3	49	46	353		3pm	780	6.39	42.3	51	50	347
	3pm	543	4.92	41.1	48	45	351		4pm	222	1.3	40.2	40	39	350
	4pm	368	2.86	40.8	43	41	349		5pm	100	0.59	39.7	33	30	346
	5pm	100	0.44	39.8	33	31	351								
07/11/2022															
								07/12/2022							
	7am	272	3.07	43.9	28	25	353								
	8am	436	3.79	43.8	36	34	353		7am	112	1.5	44.7	23	21	351
	9am	761	7.13	43.1	45	42	350		8am	232	2.3	44.4	29	25	350
	10am	923	8.75	42.6	46	41	349		9am	650	6.43	43.9	46	42	346
	11am	1069	9.45	42.3	55	51	349		10am	879	8.3	43.3	50	48	349

	12pm	1069	9.61	41.8	56	53	350
	1pm	986	8.88	42.1	54	52	351
	2pm	757	7.18	42.1	49	454	349
	3pm	719	6.89	41.9	48	45	348
	4pm	325	3.18	42.2	43	41	350
	5pm	100	0.67	40.8	36	32	352
08/11/2022							
	7am	200	2.33	44.2	24	22	352
	8am	523	4.86	43.6	41	39	348
	9am	849	8.06	43.5	44	42	349
	10am	955	8.56	42.9	50	48	350
	11am	969	9.1	41.8	53	52	347
	12pm	971	9.27	42.1	58	52	350
	1pm	913	8.55	41.7	54	51	351
	2pm	899	7.89	41.7	52	50	350
	3pm	573	5.13	42	51	50	351
	4pm	263	2.66	41.8	41	39	351
	5pm	100	0.58	40.6	33	31	350

	11am	930	8.7	42.9	52	50	348
	12pm	860	7.4	42.6	52	50	346
	1pm	789	7.2	42.1	50	48	348
	2pm	760	6.12	42	53	51	350
	3pm	697	5.8	41.7	52	50	347
	4pm	198	1.7	39.9	34	31	350
	5pm	100	0.59	39.7	33	31	346
08/12/2022							
	7am	168	2.13	44.8	24	21	352
	8am	598	4.99	44.1	48	46	348
	9am	765	6.84	43.9	49	45	346
	10am	869	7.28	44	42	50	349
	11am	850	8.16	43.8	52	50	349
	12pm	896	8.54	42.7	54	51	347
	1pm	986	8.99	40.9	56	51	349
	2pm	789	6.54	42.5	56	51	350
	3pm	536	5.16	43	41	38	351
	4pm	289	1.96	40.2	43	41	348
	5pm	100	0.56	39.8	33	31	346

09/11/2022							
	7am	137	1.58	43.9	22	20	351
	8am	428	4.14	43.7	36	33	346
	9am	671	6.41	43.3	41	40	351
	10am	671	6.41	43.3	43	42	352
	11am	898	7.74	41.3	47	42	348
	12pm	915	8.68	41.9	51	50	348
	1pm	911	8.22	41.6	52	50	351
	2pm	710	6.64	41.7	50	48	352
	3pm	689	5.79	41.5	47	45	351
	4pm	224	2.16	41.2	43	41	348
	5pm	100	0.46	40.5	34	31	349
10/11/2022							
	7am	153	1.64	43.5	25	23	348
	8am	212	2.16	43.7	29	26	348
	9am	598	5.61	42.7	47	45	345
	10am	825	7.93	41.6	56	52	351
	11am	919	8.39	41.8	57	52	350
	12pm	969	8.86	41.9	55	53	351
	1pm	887	7.57	41.5	54	51	346
	2pm	682	5.49	41.6	51	50	351
	3pm	589	4.89	41.2	48	46	348

09/12/2022							
	7am	161	1.95	45	24	22	351
	8am	616	5.1	44.3	39	34	349
	9am	834	7.81	43.9	46	42	350
	10am	889	8.66	44	48	42	350
	11am	1112	9.79	42.9	55	51	349
	12pm	998	8.99	42.6	54	51	348
	1pm	899	8.6	43	53	51	347
	2pm	873	7.49	43.2	55	51	348
	3pm	750	6.49	43.6	52	50	347
	4pm	380	3.67	43.2	42	41	348
	5pm	100	0.39	39.8	33	30	346
10/12/2022							
	7am	119	1.19	44.6	23	20	352
	8am	489	4.62	44.7	37	32	351
	9am	687	5.49	44.3	44	41	348
	10am	896	7.86	48	46	42	349
	11am	979	8.67	44	51	47	350
	12pm	636	5.66	43.1	48	42	346
	1pm	609	5.36	42.9	44	41	347
	2pm	529	4.36	43.1	40	35	349

	4pm	134	1.53	40.5	40	36	347
	5pm	100	0.66	39.8	35	32	346
11/11/2022							
	7am	141	2.15	44.1	24	22	354
	8am	554	4.74	45.4	32	30	352
	9am	429	3.3	42.9	42	40	351
	10am	739	5.81	42.5	46	42	346
	11am	1005	9.27	42.4	54	52	345
	12pm	1021	10.11	42.3	52	50	348
	1pm	869	7.49	41.9	54	51	347
	2pm	733	6.07	42.5	52	50	348
	3pm	393	2.29	41.5	48	46	346
	4pm	298	2.17	41.7	36	33	346
	5pm	100	0.45	39.7	32	30	345
12/11/2022							
	7am	166	2	44.2	24	21	246
	8am	525	5.21	43.6	42	41	350
	9am	788	7.7	43.1	44	41	351
	10am	963	8.18	41.7	47	45	350
	11am	986	8.76	41.9	50	48	350

	3pm	498	3.48	42.6	42	40	350
	4pm	140	1.33	39.9	36	34	348
	5pm	100	0.49	39.7	33	30	346
11/12/2022							
	7am	100	1.12	44.5	23	20	351
	8am	109	1.29	44.6	29	25	350
	9am	386	2.76	44.6	39	36	348
	10am	493	3.56	43.9	45	41	349
	11am	459	3.44	44.1	48	42	347
	12pm	596	4.6	43.4	39	36	350
	1pm	589	4.86	43.5	43	41	349
	2pm	867	7.29	42.3	49	42	351
	3pm	396	2.6	43.5	38	34	348
	4pm	256	2.11	43	36	31	346
	5pm	100	0.6	40	32	30	346
12/12/2022							
	7am	100	1.18	44.7	25	23	351
	8am	439	4.48	45.3	31	29	351
	9am	596	5.09	44.8	39	35	349
	10am	816	7.82	44.7	41	38	349

	12pm	992	9.23	42.1	55	52	348		11am	885	8.89	44.5	45	42	351
	1pm	1009	9.89	42.2	56	53	347		12pm	768	6.52	43.5	50	48	348
	2pm	969	9.79	41.9	54	50	345		1pm	719	6.39	43.2	49	45	347
	3pm	550	4.98	42.3	46	42	348		2pm	829	7.52	43.8	51	46	350
	4pm	234	2.09	40.8	39	35	347		3pm	321	2.06	42.7	40	36	348
	5pm	100	0.6	40.2	32	31	346		4pm	219	1.28	39.9	37	34	347
									5pm	100	0.58	39.8	32	30	346
13/11/2022															
								13/12/2022							
	7am	146	1.73	44	23	20	353								
	8am	563	4.63	43	46	42	352		7am	244	2.89	45.3	25	23	349
	9am	670	6.44	42.7	48	42	351		8am	439	3.29	44.9	30	26	350
	10am	939	8.29	42.9	49	45	350		9am	486	3.35	42.1	37	34	346
	11am	996	8.89	42.8	52	50	348		10am	585	5.73	44.8	37	36	349
	12pm	990	9.69	42.6	56	53	348		11am	1011	9.98	43.2	43	41	347
	1pm	896	7.76	41.7	57	52	346		12pm	1220	12.3	43.8	46	42	350
	2pm	768	5.57	42.3	52	50	350		1pm	989	9.84	43.7	50	48	351
	3pm	596	4.66	41.8	45	43	348		2pm	798	6.83	43.6	52	50	348
	4pm	136	1.74	40.3	41	36	347		3pm	437	3.29	43	39	32	350
	5pm	100	0.71	40	37	35	346		4pm	209	1.98	40.2	38	34	347
									5pm	100	0.55	41.4	36	32	346
14/11/2022															

7am	116	1.29	43.4	24	20	350
8am	468	4.52	43.3	39	35	350
9am	636	5.65	43.2	45	41	351
10am	929	8.36	41.9	51	49	348
11am	989	8.66	42.4	53	50	350
12pm	915	8.85	42.2	50	49	348
1pm	872	8.14	41.7	56	53	347
2pm	836	7.86	40.9	52	50	346
3pm	564	4.87	41.9	47	45	348
4pm	303	3.01	42.1	43	40	349
5pm	100	0.49	39.8	32	30	346

14/12/2022

7am	107	1.09	44.5	24	22	351
8am	139	1.2	44.6	29	25	350
9am	659	5.85	44.9	37	35	349
10am	876	7.54	45.1	40	38	348
11am	898	8.67	44.8	44	42	347
12pm	978	8.57	43.7	51	49	348
1pm	783	7.22	42.3	55	50	346
2pm	786	7.13	42.7	53	52	350
3pm	596	42.4	46	41	40	347
4pm	129	1.13	41.9	36	32	347
5pm	100	0.56	39.8	33	30	346

15/11/2022

7am	192	1.98	43.5	25	23	353
8am	568	4.5	43.5	40	38	353
9am	639	5.36	42.9	48	45	350
10am	769	6.59	41.8	50	42	348
11am	698	6.49	42.8	53	51	352
12pm	789	6.79	41.8	52	50	348
1pm	928	8.08	41.6	52	50	346
2pm	863	6.96	41.8	50	48	349
3pm	459	3.75	41.3	42	40	348

15/12/2022

7am	119	1.17	44.8	24	21	351
8am	158	1.43	44.6	29	25	349
9am	736	6.3	44.7	38	36	347
10am	778	7.32	44.6	44	41	347
11am	869	8.19	43.9	50	47	349
12pm	868	7.79	43	53	50	348
1pm	897	7.99	42.5	54	51	346
2pm	736	7.16	43.2	56	52	350

	4pm	319	2.36	40.8	37	35	346		3pm	466	3.56	42.9	49	47	347
	5pm	100	0.53	40	33	30	343		4pm	216	2.09	42.6	36	33	346
									5pm	100	0.5	40	32	31	346
16/11/2022															
								16/12/2022							
	7am	153	1.84	44.1	24	21	350								
	8am	449	4.43	43.7	37	35	351		7am	100	1.07	44	19	12	351
	9am	559	4.89	43.5	46	43	350		8am	149	1.98	43.9	26	25	352
	10am	858	7.97	43	48	45	348		9am	489	4.17	44.8	26	23	352
	11am	968	9.63	42.4	49	43	348		10am	868	7.91	44.8	45	41	346
	12pm	979	9.59	42.2	52	50	349		11am	936	8.36	44.6	50	48	348
	1pm	985	8.85	41.4	55	52	348		12pm	987	8.58	43.5	54	52	347
	2pm	639	5.53	41.3	52	50	346		1pm	1013	9.46	42.9	56	54	349
	3pm	536	4.89	41	48	44	350		2pm	771	7.27	43.3	52	50	349
	4pm	306	2.19	40.6	37	35	346		3pm	683	6.29	42.8	48	46	348
	5pm	100	0.32	38.8	32	30	353		4pm	1112	1.01	40	36	34	347
									5pm	100	0.54	39.9	34	32	346

17/11/2022															
								17/12/2022							
	7am	123	1.45	43.9	22	20	351								
	8am	484	4.6	43.4	39	34	348		7am	112	1.15	44.5	23	20	350
	9am	649	5.36	42.9	43	40	348		8am	389	3.35	44.7	30	28	348
	10am	754	7.23	42.6	48	45	350		9am	486	4.56	44.3	36	32	349

	11am	882	7.1	42.6	52	50	352
	12pm	979	8.79	41.9	53	51	350
	1pm	996	8.98	42.3	55	50	348
	2pm	968	8.49	42.8	56	53	349
	3pm	490	4.6	41.7	49	45	350
	4pm	386	2.39	40.7	38	35	348
	5pm	100	0.45	39.8	33	30	346
18/11/2022							
	7am	100	1.19	43.7	21	20	353
	8am	444	4.24	43.2	40	38	347
	9am	639	5.89	43	48	41	348
	10am	823	7.89	41.6	49	42	351
	11am	949	8.76	41.5	53	50	350
	12pm	986	8.76	42.3	53	51	350
	1pm	998	8.86	41.8	57	54	348
	2pm	896	7.69	41.7	53	50	351
	3pm	500	4.71	41.3	50	46	354
	4pm	221	2.07	41.3	42	40	348
	5pm	100	0.69	40.8	34	31	346

	10am	769	7.37	44.6	43	42	349
	11am	896	8.32	43.8	46	42	346
	12pm	939	8.46	43.3	51	47	346
	1pm	986	8.86	42.9	54	52	350
	2pm	896	7.86	43.2	53	51	347
	3pm	586	4.99	43.4	48	45	348
	4pm	149	1.32	40.2	39	35	349
	5pm	100	0.59	39.8	34	31	346
18/12/2022							
	7am	109	1.12	44.3	20	18	351
	8am	337	3.15	45.3	25	23	350
	9am	787	6.85	44.9	38	36	348
	10am	896	7.8	44.5	48	46	349
	11am	937	8.28	43.3	53	50	346
	12pm	989	9.29	44.6	53	51	350
	1pm	936	8.91	43.7	55	50	347
	2pm	896	7.86	42.9	52	50	349
	3pm	689	6.19	43.6	49	45	348
	4pm	369	2.73	43.3	39	35	348
	5pm	100	0.61	40.1	35	33	346

19/11/2022

	7am	100	0.97	43.7	22	20	349
	8am	215	2.1	43.7	28	26	350
	9am	633	6.14	42.8	47	45	348
	10am	826	7.61	42.9	47	43	348
	11am	879	8.39	42.3	48	42	350
	12pm	919	8.53	41.9	53	50	351
	1pm	816	7.73	42.1	51	48	350
	2pm	786	7.41	41.6	52	50	348
	3pm	502	4.53	41.3	48	44	347
	4pm	226	2.18	42.1	37	34	350
	5pm	100	0.69	40.8	33	30	346
20/11/2022							
	7am	165	1.99	44.1	24	20	352
	8am	444	4.41	43.3	42	40	348
	9am	643	6.33	42.7	47	45	352
	10am	836	8.01	42.2	53	50	347
	11am	926	8.92	41.6	54	51	344
	12pm	939	8.99	41.5	59	55	350
	1pm	855	8.03	41.4	54	52	349
	2pm	829	7.42	41.3	50	47	348
	3pm	547	5.26	41.9	49	46	351
	4pm	251	2.45	41.2	44	40	352
	5pm	100	0.73	40.2	34	31	346

19/12/2022							
	7am	105	1.04	43.6	22	20	351
	8am	149	1.29	44.6	26	22	350
	9am	349	2.86	43.9	28	24	348
	10am	789	7.36	44.8	39	35	349
	11am	989	8.74	43.9*	46	43	350
	12pm	989	8.96	43.6	49	47	348
	1pm	896	7.8	43.3	54	51	349
	2pm	786	6.59	42.9	51	50	346
	3pm	679	5.8	43.3	49	46	347
	4pm	398	3.29	43.5	39	37	348
	5pm	105	0.56	39.9	37	35	346
20/12/22							
	7am	120	1.35	44.5	24	20	352
	8am	493	4.62	44.6	38	34	351
	9am	696	5.89	44.5	46	42	348
	10am	896	7.96	43.6	50	46	349
	11am	969	8.66	43.8	49	45	350
	12pm	647	5.59	43.3	49	43	346
	1pm	599	5.49	42.1	43	41	347
	2pm	586	4.59	43.2	42	40	349
	3pm	507	3.38	42.8	40	38	350
	4pm	149	1.39	40	35	33	348

									5pm	100	0.6	39.8	34	31	346
21/11/2022															
	7am	116	1.17	42.3	24	20	353	21/12/22							
	8am	361	3.6	43.7	35	32	355		7am	113	1.08	44.6	25	23	351
	9am	607	5.97	42.9	45	42	349		8am	112	1.09	44.8	28	25	350
	10am	755	7.27	42.4	49	43	346		9am	389	2.87	44.7	40	39	348
	11am	865	8.2	41.8	53	51	348		10am	468	3.39	44.1	44	42	349
	12pm	909	8.49	41.6	55	52	347		11am	439	3.67	44.4	49	47	347
	1pm	889	7.61	42	54	51	348		12pm	559	4.79	43.6	45	42	350
	2pm	787	6.22	41.4	52	51	350		1pm	579	4.96	43.8	48	42	349
	3pm	749	5.92	41.2	49	44	347		2pm	869	7.37	42.4	50	42	351
	4pm	369	2.36	41.3	46	42	346		3pm	249	2.55	43.4	39	36	348
	5pm	100	0.39	39.6	33	31	350		4pm	259	2.09	43.1	37	32	346
									5pm	100	0.63	39.9	34	31	346
22/11/2022															
	7am	100	1.11	42.9	25	21	351	22/12/22							
	8am	117	1.15	42.7	38	36	350		7am	100	1.16	44.6	24	22	351
	9am	137	1.42	42.1	32	30	351		8am	436	4.65	45.6	31	28	351
	10am	868	6.26	42.7	47	45	348		9am	598	5.16	44.9	38	36	349
	11am	899	7.36	41.9	39	34	348		10am	826	7.59	45	42	40	351
	12pm	699	6.32	41.9	46	42	349		11am	947	9.12	44.7	46	42	351
	1pm	787	6.89	42.3	50	48	350		12pm	759	6.86	43.8	52	50	358
	2pm	698	5.36	40.6	46	44	350		1pm	786	6.98	43.6	53	50	347
	3pm	569	4.38	40.3	41	40	348		2pm	876	7.98	44	54	51	350

	4pm	116	1.09	40.3	38	36	350		3pm	319	2.02	42.8	38	36	348
	5pm	100	0.6	40	35	33	348		4pm	128	1.24	40.1	38	35	347
									5pm	100	0.6	39.9	34	31	346

23/11/2022															
	7am	115	1.64	43.9	20	18	349	23/12/22							
	8am	220	2.16	43.3	29	26	348		7am	287	2.94	45.4	26	24	349
	9am	485	4.66	43.2	42	40	351		8am	496	3.86	44.8	31	30	350
	10am	462	5.36	42.5	47	43	346		9am	489	3.36	42.3	36	32	346
	11am	636	5.78	42.8	49	43	348		10am	583	5.55	45.2	36	33	349
	12pm	736	6.29	42.5	48	43	347		11am	1012	9.99	43.9	42	40	349
	1pm	868	7.52	42.2	55	51	350		12pm	1112	11.3	44.8	48	45	350
	2pm	786	6.69	41.6	51	48	348		1pm	998	9.88	43.8	49	47	351
	3pm	677	5.49	42.9	49	45	349		2pm	786	9.88	43.8	49	45	351
	4pm	112	0.99	39.8	34	31	350		3pm	436	3.63	43.6	40	36	350
	5pm	100	0.45	39.8	34	32	346		4pm	199	1.86	40	37	35	347
									5pm	100	0.6	41.5	33	30	346
24/11/2022								24/12/2022							
	7am	101	1.18	43.3	24	22	349		7am	107	1.09	44.8	25	21	351
	8am	198	2.09	42.9	28	26	350		8am	138	1.4	44.7	28	26	350
	9am	568	5.5	43.4	42	40	351		9am	668	5.95	45.3	38	36	349
	10am	786	6.69	42.8	46	44	348		10am	865	7.69	45.2	42	40	348
	11am	868	7.36	42.7	50	48	351		11am	916	8.86	44.9	46	42	347

	12pm	896	7.6	42.3	52	50	348		12pm	986	8.66	43.9	53	52	348
	1pm	768	6.82	42	53	50	347		1pm	789	7.3	42.7	56	51	346
	2pm	669	5.47	42.3	57	55	353		2pm	785	7.19	42.9	52	50	350
	3pm	396	2.9	41.7	37	35	346		3pm	586	5.26	42.3	48	41	347
	4pm	233	1.98	41.9	39	36	346		4pm	130	1.16	41.8	35	33	347
	5pm	100	0.49	38.9	34	31	345		5pm	100	0.65	40	38	34	346
25/11/2022								25/12/2022							
	7am	151	1.64	43.6	26	23	347		7am	113	1.16	44.7	25	24	351
	8am	226	2.09	43.3	31	30	350		8am	158	1.49	44.9	28	25	349
	9am	624	5.95	43.2	43	40	345		9am	819	6.83	44.9	39	36	349
	10am	698	6.67	42.9	48	44	348		10am	863	7.86	44.3	45	42	348
	11am	888	7.36	42.3	50	47	351		11am	886	7.86	44.3	45	42	348
	12pm	896	7.86	42.9	52	51	350		12pm	868	7.89	43.3	56	52	348
	1pm	929	8.36	42.7	55	50	350		1pm	896	8.23	43.6	55	50	346
	2pm	679	5.46	41.9	52	50	346		2pm	749	7.29	43.4	54	51	350
	3pm	412	3.36	41.6	49	42	348		3pm	469	3.66	42.6	46	43	347
	4pm	128	1.32	40.1	34	32	347		4pm	286	2.08	42.9	38	36	346
	5pm	100	0.59	39.9	35	33	346		5pm	100	0.45	39.9	33	30	346

APPENDIX E: EXPERIMENTAL DATA (PROCESSED) FOR THE THREE WEATHER CONDITIONS

Table E1: Average Irradiance for each Weather Condition

Time	Dry-Windy Condition Irradiance (W/m2)	Rainy Condition Irradiance (W/m2)	Harmattan Condition Irradiance (W/m2)	Control Irradiance (W/m2)
7am	133.07	117.28	138.85	140.14
8am	274.43	237.44	396.59	401.68
9am	468.09	382.58	629.31	645.80
10am	576.92	502.43	828.58	850.32
11am	711.22	597.02	919.09	958.92
12pm	743.42	693.72	924.09	927.40
1pm	771.84	617.81	900.82	905.20
2pm	663.46	509.55	790.52	801.00
3pm	492.33	407.64	557.02	574.00
4pm	273.43	240.41	249.07	316.00
5pm	125.77	112.76	100.30	116.25

Table E2: Average Short Circuit Current and Time of Day for each Weather Condition

Time	Dry-Windy Short Circuit Current (A)	Rainy Short Circuit Current (A)	Harmattan Short Circuit Current (A)	Control Short Circuit Current (A)
7am	1.67	1.39	1.58	1.73
8am	2.65	2.39	3.58	3.70
9am	4.43	3.65	5.80	5.96
10am	5.44	4.83	7.56	7.96
11am	6.59	5.88	8.46	8.61
12pm	6.95	6.68	8.61	9.04
1pm	7.18	5.91	8.17	8.52
2pm	6.27	4.89	7.01	7.15
3pm	5.65	3.81	4.89	6.07
4pm	4.50	2.39	2.19	5.22
5pm	1.19	1.02	0.58	3.14

Table E3: Average open circuit voltage and time of day for each weather condition

Time	Dry-Windy Open Circuit Voltage (V)	Rainy Open Circuit Voltage (V)	Harmattan Open Circuit Voltage (V)	Control Open Circuit Voltage (V)
7am	39.77	39.81	43.83	44.93
8am	40.28	40.26	43.84	44.72
9am	40.24	40.34	43.50	44.28
10am	40.13	40.44	42.93	43.50
11am	39.87	40.49	42.68	43.29
12pm	39.65	40.43	42.53	43.27
1pm	39.47	40.34	42.23	43.17
2pm	39.52	40.29	42.12	43.12
3pm	39.00	39.81	42.06	43.09
4pm	38.47	39.70	41.11	42.35
5pm	38.10	38.69	39.98	41.43

Table E4: Average Panel Temperature and Time of Day for each Weather Conditions

Time	Dry-Windy condition Panel Temperature (ºC)	Rainy condition Panel Temperature (ºC)	Harmattan condition Panel Temperature (ºC)	Control Panel Temperature (ºC)
7am	29.77	25.59	23.40	31.36
8am	33.64	30.49	35.46	37.68
9am	38.66	33.56	42.87	45.84
10am	41.15	37.50	48.14	50.52
11am	45.39	39.63	51.01	56.04
12pm	47.03	42.12	53.47	56.84
1pm	50.00	41.77	54.65	57.66
2pm	48.30	39.78	51.64	54.08
3pm	45.31	38.43	47.24	51.92
4pm	41.53	34.69	39.80	43.65
5pm	37.43	31.34	34.11	39.71

Table E5: Average Power and Time of Day for each Weather Conditions

Time	Dry-Windy Power (W)	Rainy Power (W)	Harmattan Power (W)	Control Power (W)
7am	50.05	40.75	69.17	73.38
8am	107.35	97.18	157.09	190.78
9am	174.74	146.77	252.20	270.16
10am	218.59	195.53	324.23	334.32
11am	262.42	239.68	360.93	371.01
12pm	275.45	251.36	366.25	378.29
1pm	283.35	238.74	345.26	367.01
2pm	247.35	194.34	295.41	312.00
3pm	181.44	152.99	205.65	250.01
4pm	110.45	95.18	130.22	150.55

APPENDIX F: MATLAB CODING OF THE SOLAR CELL CHARACTERISTIC EQUATION FOR GENERATION OF THE ELECTRICAL CHARACTERISTICS OF THE SOLAR MODULE

```
Load PV datasheet information
clear all
data_JKM295
 %data_JKM295P
%% PV model calculation
Gn =1000;             %Nominal irradiance [W/m^2] @ 25oC
Tn = 25 + 273.15;       %Nominal operating temperature [K]
%Increment of Rs
Rsinc = 0.001;
%% Maximum tolerable power error
tol = 0.0001; %Defines the model precision
%% Voltage points in each iteration
nv = 100; %Defines how many points are used for obtaining the IxV curve
nimax = 500000;
%used for debugging
plott = 0; %1 = Enables plotting during algorithm execution
          %0 = Disables plotting (better)
%% PROGRAM STARTS HERE
% Modeling algorithm - here we are obtaining the PV model parameters
%% Reference values of Rs and Rp
% be
Rs_max = (Vocn - Vmp)/ Imp;
Rp_min = Vmp/(Iscn-Imp) - Rs_max;
%% Initial guesses of Rp and Rs
Rs = 0;
Rp = Rp_min;
%% The model is adjusted at the nominal condition
T = Tn;
G = Gn;
k = 1.3806503e-23;   %Boltzmann [J/K]
q = 1.60217646e-19;  %Electron charge [C]
Vtn = k * Tn / q;          %Thermal junction voltage (nominal)
Vt  = k * T  / q;          %Thermal junction voltage (current temperature)
perror = Inf; %dummy value
ni = 0; %counter
a = 1; %Initial value of a
%% Iterative loop executed until Pmax,model = Pmax,experimental
while (perror>tol) && (Rp > 0) && (ni < nimax)
ni = ni + 1;
%  Temperature and irradiation effect on the current
dT = T-Tn;
Ipvn = (Rs+Rp)/Rp * Iscn;        % Nominal light-generated current
Ipv = (Ipvn + Ki*dT) *G/Gn;       % Actual light-generated current
Isc = (Iscn + Ki*dT) *G/Gn;       % Actual short-circuit current
Ion = (Ipv - Vocn/Rp)/(exp(Vocn/Vt/a/Ns)-1);
Io = Ion;
```

```
% Increments Rs
Rs  = Rs + Rsinc;
Rp_ = Rp;
% Egap = 2.72370016e-19;  % Bandgap of silício amorfo em J (=1.7 eV)
  Egap = 1.8e-19;         % Bandgap do silício cristalino em J (=1.124 eV)
a = (Kv - Vocn/Tn) / ( Ns * Vtn * ( Ki/Ipvn - 3/Tn - Egap/(k*Tn^2) ) );
% Comments:% a = 1;
Rp = Vmp*(Vmp+Imp*Rs)/(Vmp*Ipv-
Vmp*Io*exp((Vmp+Imp*Rs)/Vt/Ns/a)+Vmp*Io-Pmax_e);
% Solving the I-V equation for several (V,I) pairs
clear V
clear I
V = 0:Vocn/nv:Vocn;        % Voltage vector
I = zeros(1,size(V,2));    % Current vector

for j = 1 : size(V,2) %Calculates for all voltage values
% Solves g = I - f(I,V) = 0 with Newton-Raphson
g(j) = Ipv-Io*(exp((V(j)+I(j)*Rs)/Vt/Ns/a)-1)-(V(j)+I(j)*Rs)/Rp-I(j);
while (abs(g(j)) > 0.001)
g(j) = Ipv-Io*(exp((V(j)+I(j)*Rs)/Vt/Ns/a)-1)-(V(j)+I(j)*Rs)/Rp-I(j);
glin(j) = -Io*Rs/Vt/Ns/a*exp((V(j)+I(j)*Rs)/Vt/Ns/a)-Rs/Rp-1;
I_(j) = I(j) - g(j)/glin(j);
I(j) = I_(j);
end
end % for j = 1 : size(V,2)
if (plott)
%% Plots the I-V and P-V curves
%Current x Voltage
figure(1)
grid on
hold on
title('I-V curve - Adjusting Rs and Rp');
xlabel('V [V]');
ylabel('I [A]');
xlim([0 Vocn]);
ylim([0 Iscn]);
%% Plots I x V curve
plot(V,I,'LineWidth',2,'Color','k')
%% Plots the "remarkable points" on the I x V curve
plot([0 Vmp Vocn],[Iscn Imp 0],'o','LineWidth',2,'MarkerSize',5,'Color','k')
%% Power x Voltage
figure(2)
grid on
hold on
title('P-V curve - Adjusting peak power');
xlabel('V [V]');
ylabel('P [W]');
xlim([0 Vocn])
ylim([0 Vmp*Imp]);
```

```
end % if(plott)
%% Calculates power using the I-V equation
P = (Ipv-Io*(exp((V+I.*Rs)/Vt/Ns/a)-1)-(V+I.*Rs)/Rp).*V;
Pmax_m = max(P);
perror = (Pmax_m-Pmax_e);
if (plott)
%% Plots P x V curve
plot(V,P,'LineWidth',2,'Color','k')
%Plots the "remarkable points" on the power curve
plot([0 Vmp Vocn],[0 Vmp*Imp 0],'o','LineWidth',2,'MarkerSize',5,'Color','k')
end % if (plott)
end % while (error>tol)
if (Rp<0) Rp = Rp_
end
% PROGRAM ENDS HERE
%% Outputs
%% I-V curve
figure(3)
grid on
hold on
title('Adjusted I-V curve');
xlabel('V [V]');
ylabel('I [A]');
xlim([0 max(V)*1.1]);
ylim([0 max(I)*1.1]);
plot(V,I,'LineWidth',2,'Color','k') %
plot([0 Vmp Vocn ],[Iscn Imp 0 ],'o','LineWidth',2,'MarkerSize',5,'Color','k')
%% P-V curve
figure(4)
grid on
hold on
title('Adjusted P-V curve');
xlabel('V [V]');
ylabel('P [W]');
xlim([0 Vocn*1.1]);
ylim([0 Vmp*Imp*1.1]);
plot(V,P,'LineWidth',2,'Color','k') %
plot([0 Vmp Vocn ],[0 Pmax_e 0 ],'o','LineWidth',2,'MarkerSize',5,'Color','k')
disp(sprintf('Method 1 - complete model\n'));
disp(sprintf(' Rp_min = %f',Rp_min));
disp(sprintf('Rp = %f',Rp));
disp(sprintf('Rs_max = %f',Rs_max));
disp(sprintf('Rs = %f',Rs));
disp(sprintf('a = %f',a));
disp(sprintf('T = %f',T-273.15));
disp(sprintf('G = %f',G));
disp(sprintf('Pmax,m = %f(model)',Pmax_m));
disp(sprintf('Pmax,e = %f(experimental)',Pmax_e));
disp(sprintf('tol = %f',tol));
disp(sprintf('P_error = %f',perror));
```

```
disp(sprintf('Ipv = %f',Ipv));
disp(sprintf('Isc = %f',Isc));
disp(sprintf('Ion = %g',Ion));
disp(sprintf('\n\n'));
```

APPENDIX G: CALCULATION OF FILL FACTOR (FF), POWER OUTPUT, AND EFFICIENCY OF THE SOLAR MODULE

Estimation of Power Output and Efficiency From I-V And P-V Curves

The maximum power output for each weather condition can be located on their respective characteristic curves using a data curser on a computer MATLAB program. The fill factor (FF) is calculated first for each I-V curve representing each weather condition before proceeding to do the efficiency and the power output calculations.

Fill factor(FF)

$$=\frac{\textbf{maximum power current (Imp)} * \textbf{maximum power voltage (Vmp)}}{\textbf{short circuit current (Isc)} * \textbf{open circuit voltage (Voc)}} = \frac{\boldsymbol{Imp * Vmp}}{\boldsymbol{Isc * Voc}} \quad (\mathbf{1})$$

Module Efficiency (η) at STC$=\frac{\boldsymbol{electrical\ power\ output}}{\boldsymbol{ideal\ power\ input\ into\ the\ module}} * \boldsymbol{FF} * \mathbf{100\%}$

$$= \frac{\boldsymbol{Pout}}{\boldsymbol{Pin}} = \frac{\boldsymbol{Isc * Voc}}{\boldsymbol{Gn * Am}} * \boldsymbol{FF} * \mathbf{100\%} \quad (2)$$

Estimation of Power Output and Efficiency From I-V and P-V Curves

(Note: the maximum power output of panel at test standard conditions (STC) is 295W)

Referring to Figures 29 and Figure 30 respectively

- For the control panel (which was always kept clean)

The maximum power and voltage values were 282.8W and 34.5V

Reduction in power = $\frac{\boldsymbol{Power\ of\ panel(STC) - power\ of\ dusty\ panel}}{\boldsymbol{power\ of\ panel(STC)}} * \mathbf{100\%} =$

$\frac{\mathbf{295 - 282.8}}{\mathbf{295}} * \mathbf{100\%} = \mathbf{4\%}$

Reduction in Efficiency$=\frac{\mathbf{20.5 - 17.4}}{\mathbf{20.5}} * \mathbf{100} * = 15.12\%$

FF =

$$\frac{\textbf{maximum power current (Imp)} * \textbf{maximum power voltage (Vmp)}}{\textbf{short circuit current (Isc)} * \textbf{open circuit voltage (Voc)}}$$

$$= \frac{\boldsymbol{Imp * Vmp}}{\boldsymbol{Isc * Voc}} \quad (3)$$

$$= \frac{\mathbf{7.988 * 34.5}}{\mathbf{8.952 * 43.7}} = \frac{\mathbf{275.58}}{\mathbf{391.20}} = \mathbf{0.7044} \quad (4)$$

Module Efficiency (η) at STC$=\frac{\boldsymbol{electrical\ output\ power}}{\boldsymbol{ideal\ power\ input\ into\ the\ module}} * \boldsymbol{FF} * \mathbf{100\%}$

$$= \frac{Pout}{Pin} = \frac{Isc * Voc}{Gn * Am} * FF * 100\% = \frac{8.952 * 43.7}{1000 * 1.5822} * 0.7044 * 100 = 17.4\% \quad (5)$$

- For the Harmattan (green curve)

The maximum power output and maximum power voltage are 259.1W and 34.43V

$$FF = \frac{Imp * Vmp}{Isc * V\,oc} = \frac{7.32 * 35.4}{8.62 * 43.7} = 0.68$$

$$\eta = \frac{Pout}{Pin} = \frac{Isc*Voc}{Gn*Am} * FF * 100\% = \eta = \frac{8.62*43.7}{1000*1.5822} * 0.68 * 100\%$$

= 16.12% (6)

$$\text{Reduction in power} = \frac{295W - 259.1W}{295} * 100\%$$

= 12.17% (7)

$$\text{Reduction in Efficiency} = \frac{20.5 - 16.12}{20.5} * 100 *$$

=21.37% (8)

Under Dry- Windy conditions (red curve)

FF =maximum power voltage and the maximum power values are 34.96 V and 212W respectively from Figure1

$$\frac{Imp * Vmp}{Isc * V\,oc} = \frac{6.066*34.96}{6.91*42.83} = 0.716 \quad (9)$$

$$\eta = \frac{Pout}{Pin} = \frac{Isc*Voc}{Gn*Am} * FF * 100\% = \frac{6.91*42.83}{1000*1.5822} * 0.716 * 100 = 13.39\% \quad (10)$$

$$\text{Reduction in power} = \frac{Power\ of\ panel(STC) - power\ of\ dusty\ panel}{power\ of\ panel(STC)} * 100\%$$

$$= \frac{295 - 212}{295} * 100\% = 28.14\% \quad (11)$$

$$\text{Reduction in Efficiency } (\eta) = \frac{\eta STC - \eta dp}{\eta STC} * 100\%$$

$$= \frac{20.5 - 13.96}{20.5} * 100\% = 34.68\% \quad (12)$$

For the rainy season module (blue curve) in figures 1&2
The maximum power voltage and the maximum power output for the module are 34.52V and 185.1W respectively.

$$\text{Fill factor for module} = \frac{Imp*Vmp}{Isc*Voc}$$

$$= \frac{5.45*34.52}{6.211*42.42} = 0.714 \quad (13)$$

$$\eta = FF * \frac{Isc * Voc}{Gn*Ad} * 100\% = \frac{6.211*42.42}{1000*1.5822} * 0.714 * 100\%$$

= 11.89% (14)

$$\text{Reduction in power} = \frac{295 - 185.1}{295} * 100\%$$

= 37.25% (15)

$$\text{Reduction in Efficiency} = \frac{20.5 - 11.89}{20.5} * 100\% = 34.68\% \quad (16)$$