STUDY ON ENERGY CONSUMPTION CHARACTERISTICS OF REFRIGERATOR IN SOLAR CELL COMMUNITY

ABANG MOHD FIKRI BIN ABANG ASNAN

B092110537

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (BMKH) WITH HONOURS

2025

Faculty of Mechanical Technology and Engineering

STUDY ON ENERGY CONSUMPTION CHARACTTERISTICS OF REFRIGERATOR IN SOLAR CELL COMMUNITY

Abang Mohd Fikri Bin Abang Asnan

Bachelor of Mechanical Engineering Technology (BMKH) with Honours

2025

STUDY ON ENERGY CONSUMPTION CHARACTERISTICS OF REFRIGERATOR IN SOLAR CELL COMMUNITY

ABANG MOHD FIKRI BIN ABANG ASNAN

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (BMKH) with Honours

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **STUDY ON ENERGY CONSUMPTION CHARACTERISTICS OF REFRIGERATOR IN SOLAR CELL COMMUNITY**

SESI PENGAJIAN: **2024-2025 Semester 1**

Saya **ABANG MOHD FIKRI BIN ABANG ASNAN**

mengaku membenarkan tesis ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐	TERHAD	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	SULIT	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
√	TIDAK TERHAD	

Disahkan oleh:

Alamat Tetap:

Cop Rasmi:

DR. MUHAMMAD ZULKARNAIN
Pensyarah Kanan
Fakulti Teknologi Dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka (UTeM)

Tarikh: 15 JANUARY 2025__________

Tarikh: ___________________________

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

2025

FACULTY OF TECHNOLOGY AND MECHANICAL ENGINEERING
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BACHELOR DEGREE PROJECT
SUPERVISOR DECLARATION FORM

BACHELOR DEGREE PROJECT 1 ✅ **BACHELOR DEGREE PROJECT 2** ✅

SEMESTER .....1..... SESSION ....2024...../...2025..........

A. DETAILS OF STUDENT *(to be completed by student)*

Name : ABANG MOHD FIKRI BIN ABANG ASNAN

Program : BMKH **Matric No. :** B092110537 **Phone No. :** ____________

Title : STUDY ON ENERGY CONSUMPTION CHARACTERISTICS OF REFRIGERATOR IN SOLAR CELL COMMUNITY

B. CHECKLIST *(to be completed by student, choose only 1)*

BACHELOR DEGREE PROJECT 1 *(Please tick (/) if completed)*

Project Proposal ☐ E-log book ☐

BACHELOR DEGREE PROJECT 2 *(Please tick (/) if completed)*

Full report ✅ E-log book ✅ Technical paper ✅

Student's Signature

Date : 3/1/2025

C. CERTIFICATION BY SUPERVISOR *(to be completed by student, choose only 1)*

Comments:

Punctual and good progress performance

☑ I hereby certified that the student is completed all the documents as stated in Part B and recommended for evaluation

☐ Not recommended for evaluation

Supervisor's Signature :
And Stamp

Date : 06/01/2025

DR. MUHAMMAD ZULKARNAIN
Pensyarah Kanan
Fakulti Teknologi Dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka (UTeM)

REMINDER:
Kindly submit the completed form to the PSM (JTK) FTKM Committee

DECLARATION

I declare that this Choose an item. entitled "Study on Energy Consumption Characteristics of Refrigerator in Solar Cell Community" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : ABANG MOHD FIKRI BIN ABANG ASNAN

Date : 18/4/2024

APPROVAL

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Heating, Ventilation and Air Conditioning Engineering Technology (BMKH) with Honours.

Signature : ....

Supervisor Name : DR. MUHAMMAD ZULKARNAIN

Date : 11/06/2024

DEDICATION

I would like to dedicate this research thesis to all the Air Conditioning technicians whom job to give the comfort for all human comfort through temperature adjust and also gives fresh air to us. I would also like to thank Dr Muhammad Zulkarnain on the guiding on the unlimited guidance throughout the research thesis duration and all the time he spends on guiding me. My parents whom provide me mental support and funding for this research thesis. Finally, my fellow friends that help me and gave their opinion on improving this project.

ABSTRACT

In an era of growing environmental awareness and green energy acceptance, solar-powered homes have emerged as models of sustainable lifestyle. Refrigerators, among the many solar-powered appliances, are essential pillars of modern living, preserving perishable commodities. Understanding the varied energy consumption features of refrigerators in these areas is critical for minimizing energy usage and supporting sustainability efforts. This work conducts an extensive investigation to uncover the numerous characteristics of energy consumption patterns displayed by refrigerator in solar cell communities. This study aims to shed light on the complex dynamics governing refrigerator operation in solar-powered environments using a rigorously built research approach that combines statistical analysis of data with qualitative insights. Concurrently, qualitative data are collected using a multidimensional strategy that includes surveys, interviews, and focused group discussions with homeowners and community stakeholders. These qualitative observations give vital context for tenants' actions, attitudes toward conserving energy, and the issues they face while monitoring refrigerator consumption in solar-powered homes. The study's goal is to gain a better understanding of the intricate relationship among individuals and utilization of energy in solar cell communities by investigating the social and cultural, economic, and technological factors that influence energy consumption patterns. The combination of quantitative and qualitative findings promises to provide an in-depth comprehension of refrigerator functionality within solar cell communities, informing methods for improving energy efficiency and promoting sustainability. Furthermore, the study's findings have major implications for policy development, advancements in technology, and community involvement programs targeted at improving sustainable in solar energy communities. The project intends to contribute to the larger goal of developing resilient, environmentally friendly communities powered by renewable energy sources by identifying opportunities for energy savings, improving appliance design, and raising user awareness. Furthermore, the study emphasizes the significance of neighborhood involvement and education in creating a culture of environmentally friendly energy practices. The project aims to create capacity and foster a sense of ownership among people through specific outreach programs, educational seminars, and collaborative activities with local stakeholders, ultimately nurturing a driven by communities' approach to sustainability. In conclusion, this study is an important step in comprehending and maximizing the energy consumption characteristics of refrigerator in solar cell communities. By combining thorough quantitative research with sensitive qualitative observations, the study provides a comprehensive understanding of the complex dynamics of energy consumption in various situations.

ABSTRAK

Dalam era kesedaran alam sekitar yang semakin meningkat dan penerimaan tenaga hijau, rumah berkuasa solar telah muncul sebagai model gaya hidup mampan. Peti sejuk, antara banyak peralatan berkuasa solar, adalah tiang penting dalam kehidupan moden, memelihara komoditi mudah rosak. Memahami ciri penggunaan tenaga yang berbeza bagi peti sejuk di kawasan ini adalah penting untuk meminimumkan penggunaan tenaga dan menyokong usaha kemampanan. Kerja ini menjalankan penyiasatan yang meluas untuk mendedahkan pelbagai ciri corak penggunaan tenaga yang dipaparkan oleh peti sejuk dalam komuniti sel suria. Kajian ini bertujuan untuk memberi penerangan tentang dinamik kompleks yang mengawal operasi peti sejuk dalam persekitaran berkuasa solar menggunakan pendekatan penyelidikan yang dibina dengan teliti yang menggabungkan analisis statistik data dengan pandangan kualitatif. Pada masa yang sama, data kualitatif dikumpul menggunakan strategi multidimensi yang merangkumi tinjauan, temu bual dan perbincangan kumpulan berfokus dengan pemilik rumah dan pihak berkepentingan komuniti. Pemerhatian kualitatif ini memberikan konteks penting untuk tindakan penyewa, sikap terhadap penjimatan tenaga, dan isu yang mereka hadapi semasa memantau penggunaan peti sejuk di rumah berkuasa solar. Matlamat kajian adalah untuk mendapatkan pemahaman yang lebih baik tentang hubungan rumit di kalangan individu dan penggunaan tenaga dalam komuniti sel suria dengan menyiasat faktor sosial dan budaya, ekonomi dan teknologi yang mempengaruhi corak penggunaan tenaga. Gabungan penemuan kuantitatif dan kualitatif menjanjikan untuk memberikan pemahaman yang mendalam tentang fungsi peti sejuk dalam komuniti sel solar, memaklumkan kaedah untuk meningkatkan kecekapan tenaga dan menggalakkan kemampanan. Tambahan pula, penemuan kajian mempunyai implikasi besar untuk pembangunan dasar, kemajuan dalam teknologi, dan program penglibatan komuniti yang disasarkan untuk meningkatkan kelestarian dalam komuniti tenaga suria. Projek ini berhasrat untuk menyumbang kepada matlamat yang lebih besar untuk membangunkan komuniti yang berdaya tahan, mesra alam yang dikuasakan oleh sumber tenaga boleh diperbaharui dengan mengenal pasti peluang untuk penjimatan tenaga, menambah baik reka bentuk perkakas dan meningkatkan kesedaran pengguna. Tambahan pula, kajian ini menekankan kepentingan penglibatan dan pendidikan kejiranan dalam mewujudkan budaya amalan tenaga mesra alam. Projek ini bertujuan untuk mewujudkan kapasiti dan memupuk rasa pemilikan di kalangan orang ramai melalui program jangkauan khusus, seminar pendidikan, dan aktiviti kerjasama dengan pihak berkepentingan tempatan, akhirnya memupuk pendekatan yang didorong oleh komuniti terhadap kemampanan. Kesimpulannya, kajian ini merupakan langkah penting dalam memahami dan memaksimumkan ciri penggunaan tenaga peti sejuk dalam komuniti sel solar. Dengan menggabungkan penyelidikan kuantitatif yang teliti dengan pemerhatian kualitatif yang sensitif, kajian ini memberikan pemahaman yang komprehensif tentang dinamik kompleks penggunaan tenaga dalam pelbagai situasi.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for the financial assistance.

My utmost appreciation goes to my main supervisor, Dr. Muhammad Zulkarnain, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey.

Last but not least, from the bottom of my heart a gratitude to my Family whom always pray for my success. My friends whom also guide and teach me throughout the journey, my love ones whom always support me mentally. And to all that had been involve in this roller coaster ride of life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

PV	-	Photovoltaic
MV/LV	-	Medium Voltage and Low Voltage
COP	-	Coefficient of Performance
NEM	-	Net Energy Metering
SEB	-	Sarawak Energy Berhad
AC	-	Alternating Current
DC	-	Direct Current
CCP	-	Common Connection Point
HH1	-	Household 1
HH2	-	Household 2
ADL	-	Average Daily Loads

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, economic expansion has culminated to an abundance of resource exploitation, and the petroleum reserve is depleted. It will run out in less than 50 years, triggering a so-called energy crisis. Overexploitation has also resulted in an increasingly major global warming problem. Many advanced countries throughout the world are leading the way in fostering the study and development of renewable energy sources as wind, solar, and biomass. (Mungwe, 2024)

Furthermore, the unique world of solar energy communities is a patchwork of residential settings that includes suburban developments, metropolitan neighborhoods, and rural landscape. This is the place where sustainable living meets technical innovation. These settlements are microcosms of a future powered by renewable energy sources because they are yet little-studied aspect of everyday life. Researchers has conducted hourly simulation and performance of solar electron-vapor compression refrigeration system in the year 2011. Understanding refrigeration’s energy consumption characteristics in the larger setting of solar cell communities is crucial for optimizing energy usage and encouraging sustainability, even though refrigeration is necessary for food preservation and comfort. (Aldhshan, 2021).

The incorporation of solar electricity has become a critical element in reducing the harmful effects of energy use in the current conversation about clean energy and sustainable living. It is becoming more and more important to comprehend the shifting patterns of solar energy usage in particular contexts as nations throughout the world progressively choose solar energy solutions. To indicate that continuously operating solar-powered aqua ammonia absorption system with refrigerant storage is the most suitable alternative design for and uninterrupted supply of cooling effect. (Mungwee, 2024)

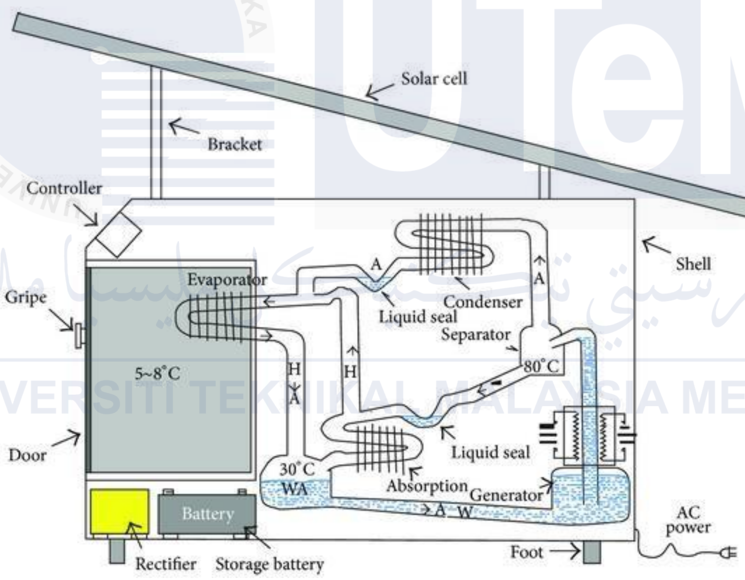


Figure 1.1 Experimental Equipment of Absorption Refrigerator (Mungwe, 2024)

Finally, this research thesis investigates the energy consumption characteristics of refrigerators in solar cell communities, specifically how solar energy integration affects appliances usage. By deciphering the complexity of refrigerator energy efficiency and promoting eco-friendly practices in solar-powered communities. Researchers propose optimization solar absorption refrigerator. One of the most promising schemes is the utilization of an absorption refrigeration cycle with solar energy serving as the source of heat to operate the generator. (Mungwe et al., 2024)

1.2 Problem Statement

Regarding lack of information on characteristics of refrigeration in solar cell community, it is critical due to the growing importance of renewable energy in climate change mitigation and compelling need to optimize energy consumption. Refrigerators, as vital household appliances, consume a large amount of energy, especially in solar-powered areas. Understanding how solar energy dynamics affect refrigerator usage is critical to increasing energy efficiency and promoting sustainability. This research thesis intends to bridge this knowledge vacuum by providing insights that legislators, energy providers, and residents can use to maximize energy saving while minimizing environmental effect in solar cell communities.

The installation of solar panels for refrigeration systems incurs large upfront expenditures, which include the purchase of solar panels, inverters, batteries, and installation fees. Many communities, particularly those in developing or low-income areas, may lack access to the financial resources or finance methods required to meet these charges. As a result, the use of powered by solar energy refrigeration system may be limited, impending efforts to shift to sustainable energy solutions and enhance access to dependable refrigeration services in these communities.

1.3 Research Objective

This research focus on the understanding on how energy consumption and its characteristics of refrigerator in solar cell community. Specifically, the objective are as follows:

a) To study energy consumption characteristics of refrigerator in solar cell community.

b) To determine solar power characteristic in refrigeration system of a residential household.

1.4 Scope of Research

The scope of this research are as follows:

- Standard Package sizes ranging between 3 kWp to 20 kWp (Depend on consumers).
- Black Frame Modul
- The area research on **Kuching Sarawak** with altitude 1.65499, 110.200615.
- Photovoltaic Meter (PV)
- Standard 1.7m X 1.0m.
- Weight of solar panel is approximately 15kg each.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Reviewing the journals for gaining information is the development and improving solar cell communities represent a possible frontier in sustainable energy, utilizing solar power to lessen dependency on traditional electrical sources. In these areas, knowing the energy consumption habits of home devices, particularly refrigerators, is critical. Refrigerators are vital for keeping food fresh and comfortable, but their energy use has an impact on overall sustainability. This literature analysis examines existing studies to identify the elements that influence refrigerator energy use in solar energy communities. Its goal is to guide methods for reducing energy usage, improving system efficiency, and encouraging sustainable living practices in these communities by synthesizing information. Net Energy Metering (NEM) stands as a beneficial agreement between solar energy providers and utility companies, fostering a symbiotic relationship that yields advantages for both sides. According to the Solar Energy Industries Association (SEIA), NEM enables surplus electricity generated from solar panels to be fed back into the grid, effectively causing the meter to run in reverse and accruing credits for solar energy producers. Conversely, during periods of low or no solar generation, such as at night or on cloudy days, users rely on the grid as per usual. This mechanism ensures equity and stimulates the uptake of renewable energy by empowering consumers to offset their electricity expenses with excess energy produced. Consequently, NEM emerges as a pivotal policy instrument in accelerating the adoption of solar energy. (Zublie, 2023)

2.2 Energy Consumption Characteristics of Refrigerators

The energy produced by solar PV and the consumption electricity by refrigerator of a household typically around 300 to 700 watts of electricity. To determine how much of electricity consumes of a refrigerator of a certain household, Homeowners need consider the energy consumption rate and how much they have to pay the electricity company monthly pricing. Installing solar PV does not meant fully independent in generating self-electricity. Homeowners still have to pay for the electricity but having a solar PV system for a house would contribute less price for electricity bill. Energy consumption is measured in kilowatt-hours(kWh) which represents the amount of usage electricity over time. (Borikar, 2021)

Figure 1.2 Example of Residential Using Solar PV (Malaysia, n.d.)

2.2.1 Energy Consumption Patterns

Energy consumption patterns encompass our usage and timing of energy utilization, evident in our daily routines, where energy expenditure typically surges during morning preparations and evening activities like cooking and entertainment. These patterns fluctuate due to various factors such as weather conditions, time of day, and geographical location. In the context of solar cells, their energy consumption aligns closely with sunlight availability. Solar cells generate more electricity when exposed to bright sunlight and less during cloudy or nighttime conditions, resulting in a daily cycle of energy production peaking during daylight hours and diminishing at night. However, efficiency in converting sunlight into electricity significantly influences this pattern, with higher efficiency cells ensuring a more consistent energy output. Additionally, the utilization of solar power aligns with our varying energy needs, which typically peak during mornings and evenings. Energy storage technologies, such as batteries, are essential for smoothing out these fluctuations by storing excess energy produced during sunny periods for later use when sunlight is scarce. Recognizing these consumption patterns is crucial for designing efficient solar energy systems, maximizing their effectiveness, and fully tapping into the potential of renewable energy. Now, let's analyze how a refrigerator's energy usage fits into this solar-powered system. (Perera, 2024). There is a few examples of energy consumption pattern below.

Figure 2.1 Example of a household using Solar PV (Borikar, 2021)

Solar Panel Generation: Solar panels utilize sunlight to produce electricity using the photovoltaic phenomenon. The quantity of electricity produced is influenced by variables such as the dimensions and efficacy of the panels, their installation angle, and the sunlight's intensity. (Lee and Jang, 2023)

Battery Storage: In many solar panel systems, excess electricity generated during the day is stored in batteries for use during periods of low sunlight or at night. This stored energy ensures continuous power supply to the refrigerator even when sunlight is not available. (Qiu, 2022)

Direct Consumption: In daylight hours, solar panels directly power the refrigerator, cutting down on or eliminating the necessity for electricity from the grid. This leads to substantial reductions in electricity bills and less reliance on non-renewable energy sources. (García-López, 2023)

Net Metering: Net metering enables homeowners in certain areas to contribute surplus solar-generated electricity to the grid, potentially earning them credits or payments from utility providers, thereby aiding in reducing the expenses associated with powering appliances like refrigerators. (D, 2023)

Load Management: Load management involves using efficient energy management systems to optimize energy usage. For example, one can schedule the operation of a refrigerator during periods of peak solar production to make the most of solar energy. (Noor Waleed, 2023)

Backup Power: To guarantee uninterrupted operation of the refrigerator during extended periods of limited sunlight or equipment malfunctions, alternative power sources like batteries or access to the grid can be utilized. (net, 2023)

In general, a refrigerator running on a solar panel system primarily utilizes solar energy during the day, with support from battery storage or grid connections for continuous functionality. This arrangement provides economic advantages by cutting electricity expenses and decreasing greenhouse gas emissions linked to conventional fossil fuel-powered electricity generation. (D, 2023)

2.3 Energy Efficiency

Solar-powered refrigeration provides an environmentally friendly alternative to standard grid-powered system. However, optimizing efficiency is critical to ensuring that your system captures enough energy from the sun to operates effectively. (Gorina, 2024) Here's a breakdown of what current research says concerning energy-efficient refrigeration solutions for solar-powered applications:

2.3.1 General Strategies

- High-Efficiency Refrigeration System

High-efficiency refrigeration system are intended to reduce energy usage while yet providing efficient cooling or freezing capabilities. These are systems use a variety of technologies and design ideas to achieve more energy efficiency than standard refrigeration system. (Gorina, 2024)

- Thermal Energy Storage

Thermal energy storage (TES) is an innovation that keeps thermal energy by cooling or heating a storage medium as the energy is plentiful or cheap, and then discharges that stored energy when it is required for cooling, heating, or power generation, allowing for greater energy flexibility and improving overall system efficiency. (Gorina, 2024)

2.3.2 Specific Technologies

- Vapor Compression with DC Inverters

Vapor compression with DC inverters is a refrigeration and air conditioning technology in which a compressor's velocity is modified using a direct current (DC) inverter to match the cooling load, improving energy efficiency by reducing wasted energy caused by frequent cycling on and off. (Gorina, 2024)

- Solid-State Cooling (Thermoelectric Cooling)

Solid-state cooling, also known as thermoelectric cooling, uses the Peltier effect, in which a current of electricity is passed through two different types of semiconductors to create a temperature difference, allowing heat transfer without the use of refrigerants or moving parts. It is commonly used in smaller-scale cooling applications such as portable coolers and electronic devices. (Gorina, 2024)

- Absorption Cooling

Absorption cooling or immersion conditioning is a refrigeration system that uses heat rather than energy to cool by absorbing and releasing a refrigerant gas. (Gorina, 2024)

- Evaporating Cooling

Evaporative cooling is a natural process in which water evaporates into the air, absorbing heat and cooling the surrounding environment. It is commonly used in systems in which heated air flows over water-soaked pads or through water-moistened surfaces, resulting in cooler air being discharged into the space. (Gorina, 2024)

2.4 Solar Refrigeration System

Solar refrigeration system is a refrigerator that uses the sun's energy, either through solar panels or heat collectors, to cool food. There are two primary types of solar refrigeration systems. (Tarawneh, 2024)

2.4.1 Photovoltaic (PV) systems

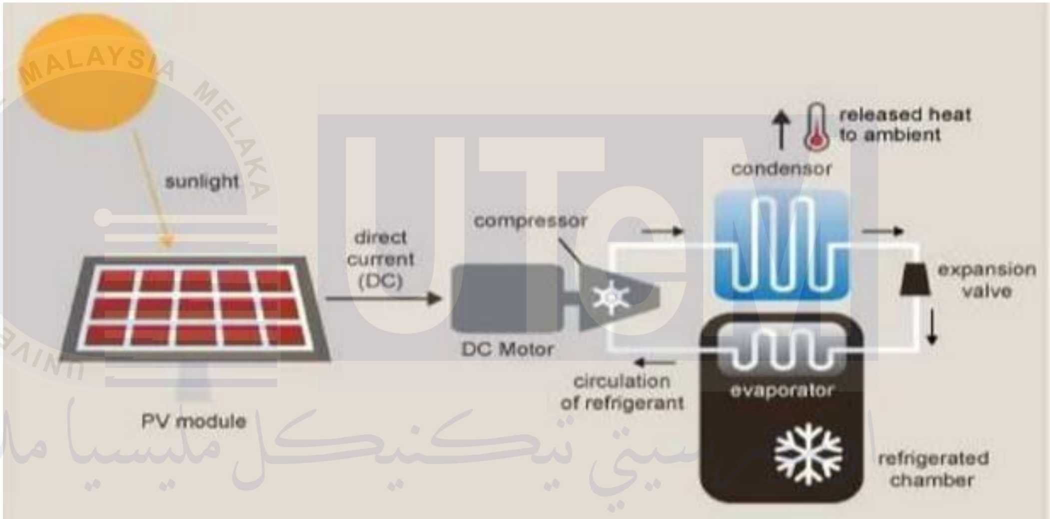


Figure 2.2 PV Solar Refrigerating System (Tarawneh, 2024)

These systems employ solar panels to turn sunlight into electricity. The electricity then powers a standard compressor, similar to those found in refrigerator, but with a DC motor rather of an AC motor. These systems often use energy for use at night or on overcast days. (Tarawneh, 2024)

2.4.2 Solar Thermal Refrigeration System

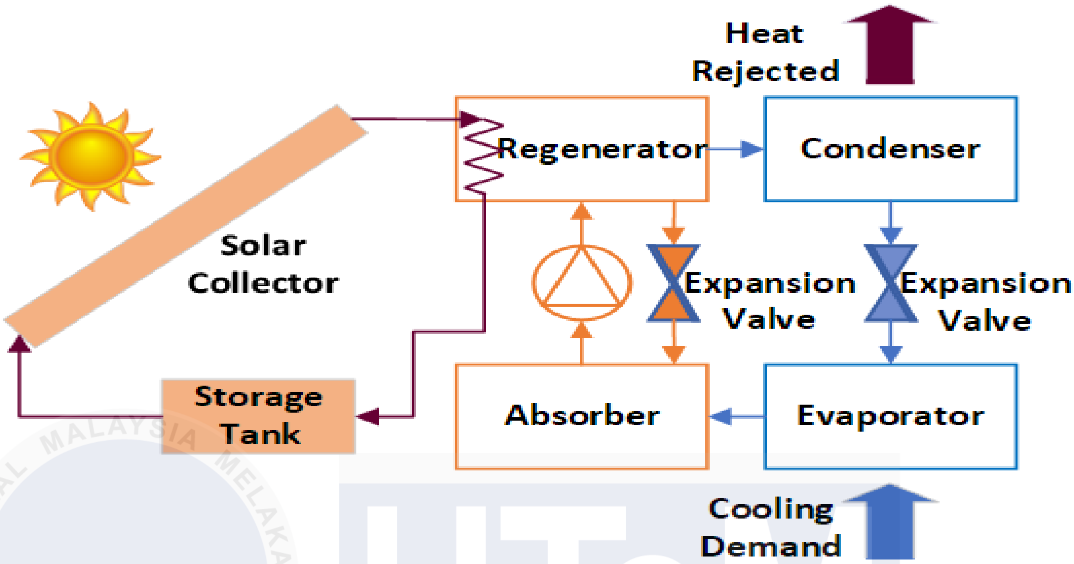


Figure 2.3 Solar Refrigeration System Process (Ali, 2022)

Solar thermal refrigeration systems are a unique technology that uses the warmth of the sun directly to keep your food chilled, eliminating the need for power. Consider an array of panels acting as sun sponges that are absorbing heat. This heat is then transferred through a liquid solution, similar to a hot water-antifreeze mixture, to the system's heart, the absorption refrigerator. The heat causes a chemical reaction, which provides the chilly atmosphere within your refrigerator. This reliance on solar heat rather than electricity allows for a potentially simpler design while also harnessing the potential of renewable energy. However, keep in consideration that these systems might have more moving parts in the refrigerator than solar panel-powered systems, resulting in additional maintenance. (Ali, 2022)

2.5 Refrigeration Technologies

Refrigeration technology is concerned with the transfer of heat energy from lower to higher temperatures. Increasingly, known and occasionally unfamiliar approaches are being used to exploit high temperature heat for a variety of purposes, primarily space and water heating. (Lee and Jang, 2023). There are two main types of refrigeration systems:

2.5.1 Vapor-Compression Refrigeration

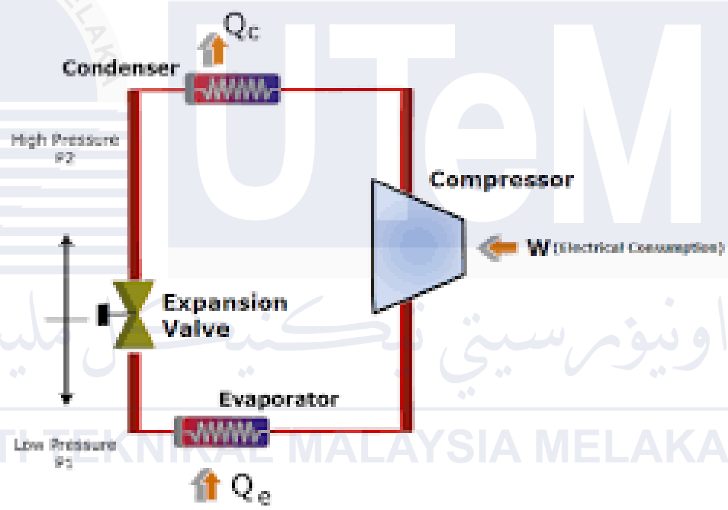


Figure 2.4 Vapor compression Refrigeration Cycle Loop. (Araner, 2021)

This is the most popular form of refrigeration system, found in refrigerators, freezers, and air conditioning units. It operates by compressing a refrigerant gas, increasing the temperature and pressure. The hot, high-pressure gas then passes into a condenser, where it is cooled with air or water. As the gas cools, it condenses to a liquid. The liquid refrigerant then passes through an expansion valve, lowering its pressure. This leads to the air conditioning fluid to evaporate and absorb heat from its surroundings. The chilled refrigerant then passes through an evaporator, absorbing heat from the space being cooled. The refrigerant is subsequently returned to the compressor, and the process repeats. (Araner, 2021)

2.5.2 Absorption Refrigeration

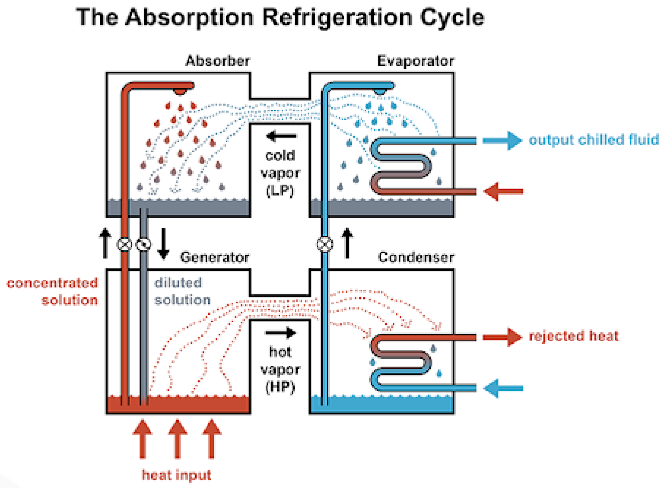


Figure 2.5 Absorption Refrigeration Cycle. (Overbey, 2021)

The heat from the heat source forces the refrigerant out of the absorbent material. The refrigerant vapor then passes into a condenser, where it cools and condenses into a liquid. The liquid refrigerant then passes through an expansion valve, lowering its pressure. This causes the refrigerant to evaporate and absorb heat from its surroundings. The chilled refrigerant then passes through an evaporator, absorbing heat from the space being cooled. The refrigerant vapor is subsequently absorbed by the absorbent substance, and the cycle continues. (Overbey, 2021)

From the humble beginnings of keeping food fresh to the comfort of air-conditioned homes, refrigeration technology has transformed how we live. The basic theory of heat transfer underpins all refrigeration processes, but the inventiveness lies in the various approaches used. Most systems rely on vapor compression, which uses a closed loop to remove heat, whereas absorption refrigeration uses a heat source to cool. The future seems promising, with revolutionary technology such as solar-powered and magnetic refrigeration providing sustainable and efficient solutions. As we continue to investigate the science of heat transmission, refrigeration technology will definitely advance, ensuring a cooler and more comfortable future.

2.6 Performance Metrics

Performance Metrics for Refrigerators in solar cell communities strive for energy independence, yet refrigerators are a major consumer of electricity. When measuring refrigerator performance in this context, criteria that take into account energy consumption and food preservation must be prioritized. (Zhang, 2021)

a) Coefficient of Performance (COP)

The Coefficient of Performance, or COP, is a measure of HVAC system efficiency based on heat production. Every system requires some type of energy input to function, but not all systems can make the most use of the supplied energy to produce more output. COP is an objective way for measuring and comparing various HVAC systems. Hence, COP matters in order to discover the coefficient value. Divide the energy output by the energy input. The higher the COP, the more efficient your system is. An HVAC system with a COP of at least one generates more energy than is necessary to operate it. (Costa, 2023)

$$K = Q_H / W_{in}$$

$$K = Q_C / W_{in}$$

$$K_R = Q_2 / (Q_1 - Q_2)$$

Table 2.1 Three scenarios with different sizing and energy sharing configurations (Zhang, 2021)

Scenarios	Explanation	System Type	Priority of Power Exchange	Sharing type
Scenario 1	Individual sizing	Distributed battery system	Building → Own Battery → Community → Grid	Sharing Surplus
Scenario 2	Group sizing	Centralized battery system	Building → Community → Centralized battery → Grid	Surplus sharing & Storage sharing
Scenario 3	Hierarchical sizing	Distributed battery system	Building → Community → Own battery → Centralized battery → Grid	Surplus sharing & Storage sharing

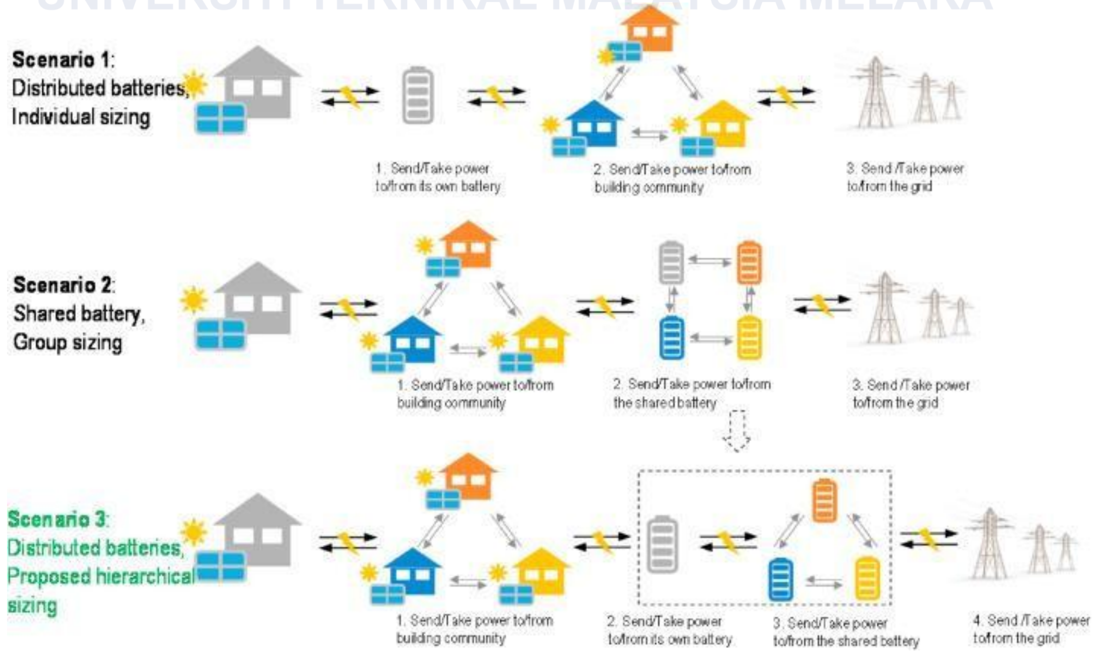


Figure 2.6 Different operation strategies and design approaches of battery system in solar power shared building community. (Zhang, 2021)

1. **Scenario 1 (Individual sizing):** Each building has its own batteries. The building's surplus PV power generation (in comparison to electricity use) will be stored first in its own battery. After the battery is fully charged, the leftover surplus power will be transferred to the building community to meet the electrical requirements of other buildings with poor power production. (Zhang, 2021)
2. **Scenario 2 (Group sizing):** The community's buildings share a centralized battery. In a centralized battery scenario, surplus power from one building is initially used to cover the power needs of buildings with insufficient PV power generation. After accounting for the enormous power supply and large power needs within the building community, the remaining excess or insufficient power will be stored in/taken from the centralized battery. (Zhang, 2021)
3. **Scenario 3 (Proposed hierarchical sizing):** Based on the centralized battery design and energy sharing operation logic, this study presents the following operating scenario for distributed battery design with surplus and storage sharing enabled. Surplus power from one building will be used to meet the power needs of buildings with insufficient PV power generation. (Zhang, 2021)

b) Temperature Stability

Temperature stability is defined as a system, component, or material's ability to maintain constant performance characteristics and qualities throughout a wide temperature range. It denotes the extent to which a system/device or substance can withstand changes or alterations in its behavior, functionality, or physical properties when subjected to temperature fluctuations. A high level of temperature stability suggests that the system or material performs or behaves consistently across a large temperature range, whereas low temperature stability indicates that the system or material is more prone to temperature-induced changes. A high degree of thermal stability is always preferred. (RF, 2023)

c) Cooling Capacity

Cooling capacity refers to the quantity of heat that the system can remove from the chilled room over time. It equals the change in the specific enthalpy of the refrigerant in the evaporator induced by the refrigeration load multiplied by the refrigerant's mass flow rate. (RF, 2023)

2.7 Energy Storage

Solar panels produce electricity throughout the day, but refrigerators must operate at night or during overcast weather. Energy storage fills the gap by collecting excess solar energy during peak production periods and releasing it when sunshine is unavailable. Its primary components are a solar collector unit, an absorption chiller (ACH), and an absorption energy storage (AES) unit. The solar collector unit is made up of a parabolic trough collector (PTC) field, working fluid, and a pump. The pump pumps the operating fluid from the PTC to the ACH, providing the necessary thermal energy to power the integrated absorption system. (Ibrahim, 2021)

2.8 Control and Optimization

Refrigerator performance in solar cell communities demands a fine balance between keeping food fresh and conserving electricity. Control theory comes into play by keeping the internal temperature within a safe level. Sensors monitor the temperature, a controller (thermostat) compares it to a fixed point, and cooling components such as compressors and fans change according to the difference. This is when optimization takes over. Optimization algorithms can fine-tune the control system by taking into account parameters such as ambient temperature, door openings, and even solar power generation. This could include timing defrost cycles during peak solar power times or lowering chilling intensity to save energy while maintaining an acceptable temperature range for food storage. In essence, control theory serves as the foundation for maintaining correct temperature, while optimization builds upon it to create the greatest energy-efficient operation possible. (Razi, 2023)

2.9 Policy and Regulatory Frameworks

Policy and regulatory frameworks play an important role in encouraging the adoption of solar cell communities and efficient refrigerators within them. These frameworks can foster a climate that fosters investment, ensures product quality, and protects customer interests. (Qlatunde, 2024) Here's a breakdown of key aspects:

- Supporting Policy Frameworks

To encourage the use of solar cell communities and efficient refrigerators, a supportive policy framework is required. Financial incentives like rebates, tax credits, and low-interest loans can help these communities purchase solar power systems and energy-efficient refrigerators. Furthermore, net metering regulations enable communities to sell extra solar power back to the grid, which offsets their electricity expenses. Building rules that require minimum energy efficiency criteria for refrigerators may encourage manufacturers to create more sustainable models. Finally, investment in research and development of improved refrigeration technologies specifically tailored for solar-powered applications lays the framework for future solutions that are even more efficient. These combined policy initiatives form a strong framework that promotes the creation and success of solar cell communities. (Qlatunde, 2024)

- Regulatory Frameworks

A robust regulatory framework is critical for solar cell communities. Refrigerators must comply with electrical and fire safety regulations. Energy efficiency labels enable communities to select models that match their solar generation. Finally, systematic performance testing enables fair comparisons of refrigerators, ensuring that communities select the most efficient alternative for their needs. These rules encourage safety, consumer knowledge, and, eventually, the success of these communities. (Qlatunde, 2024)

2.10 Future Directions

Solar cell communities and refrigerators are set for a bright future. New materials offer significantly lower energy consumption. Smart grids might enable fridges to react to real-time solar power, while internet connections would allow for distant monitoring and optimization. Off-grid refrigeration technology is a major upgrade in distant locations. As production grows, prices should fall, making these clever refrigerators more accessible. Supportive policies will be critical to widespread adoption. By embracing these improvements, solar cell communities can reach a sustainable future through efficient, environmentally friendly refrigeration. (Zahedi, 2024)

2.11 Summary

Critical energy production by numerous powerplant and energy consumption by common household from this new era has affected our earth, as a result we are looking on a global warming from our energy consumption and mainly affecting climate change. By diving into multiple studies such as Solar photovoltaic power sharing based design optimization of distributed energy storage systems for performance improvements by Xingxing Zhang. Accurate determination of Solar PV and Net Energy Metering (NEM) in distribution networks would be useful for improving the economic efficiency of electric power systems. The problem is, analyzing accurate and detail energy consumption by a certain community for system wide such as refrigerator in a specific household and large distribution network typically requires extensive network and load data and rigorous calculation effort also in terms of electricity bill. Hence, NEM areoften used in various newly design real estate as a more technological advancement towards energy consume by refrigeration system estimation approach. The goal often time sought for utilities is that, the method is effective, practically viable, require minimal resources, and yet, capable to produce reasonably accurate electricity bills. Until today, due to these problems, there is no universal and commonly agreed method for energy consumption of refrigerator system in solar cell community. (Zhang, 2021)

From literature, a method of using a set of optional tracking meter as a benchmark model for estimating electricity based of 2 types of scenarios as review in the literature. However, to date, there is no evidence of published work in establishing energy consumption characteristic of refrigerator in solar cell community for the Malaysian distribution network. In addition, most of these research works uses load flow simulation to analyze the characteristic of energy consumption and extrapolate the results for the larger network community.

However, this approach is only applicable for refrigerator system by using solar PV and bill estimation and could not be used for accurately estimating complete system wide for a specific household as a level of each feeder in the network. In addition, none of existing research specifically explain for energy consumption towards refrigerator to estimate system wide network in solar cell community. Therefore, this thesis shall attempt to initiate the establishment a set of energy consumption characteristic of refrigerator in solar cell community which can potentially serve as platform for numerous analysis such as for studying localized technological impacts of emerging technologies.

As for conclusion, in addressing the above-mentioned issue, there is a research opportunity to investigate, explore and develop new, integrated and efficient methodology and techniques for the energy consumption characteristic in solar cell community (Zhang, 2021). The model is aimed towards efficiency and reasonable accuracy. This is the main focus of this thesis. The following Chapter 3 shall discuss the proposed method and data collection in detail.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, this study focuses at the energy consumption characteristics of refrigerators in a solar cell community. The process includes several important steps that assure accurate and comprehensive data gathering, analysis, and interpretation. First, the community's solar power system is evaluated to determine its capacity, energy output, and storage capacities. This includes precise measurements of solar radiation, panel efficiency, battery storage capacity, and the community's total energy demand. (Zhang, 2021)

In addition, this thesis is located at a specific area which is allocated in Kuching, Sarawak. Therefore, the electrical production is managed by the Sarawak Energy Ber had (SEB) company. NEM has a specific work flow process from the company to the consumers, By installing rooftop solar PV system, the property or household will harness solar energy to generate electricity. This power will help to save money on electricity bill. The solar PV system is directly connected to SEB's Distribution Grid, and all energy generated is exported to SEB. With NEM, the power exported helps to reduce consumers monthly electricity bills at a one-to-one tariff rate to SEB.

Moreover, the acquired data is then rigorously evaluated to detect consumption patterns and abnormalities. Advanced statistical approaches, such as regression analysis and time-series analysis, are used to correlate refrigerator energy consumption with environmental conditions and user behavior. Furthermore, the impact of solar energy supply on refrigerator efficiency is assessed by contrasting times of high solar generation and low solar input. This dual approach not only shows the operational efficiency of solar-powered freezers, but it also identifies potential areas for community-wide energy management improvements. The findings are intended to provide actionable insights for optimizing energy use and improving the sustainability of solar-powered residential areas.

3.2 Research Flowchart

The overall activities in this study shows in Figure 3.1 Research Flowchart for PSM where it covers the whole research from beginning to end to complete this thesis. Each description can be found in table of content where every subtopic from the beginning to end of this research about study on energy consumption characteristic of refrigerator in solar cell community.

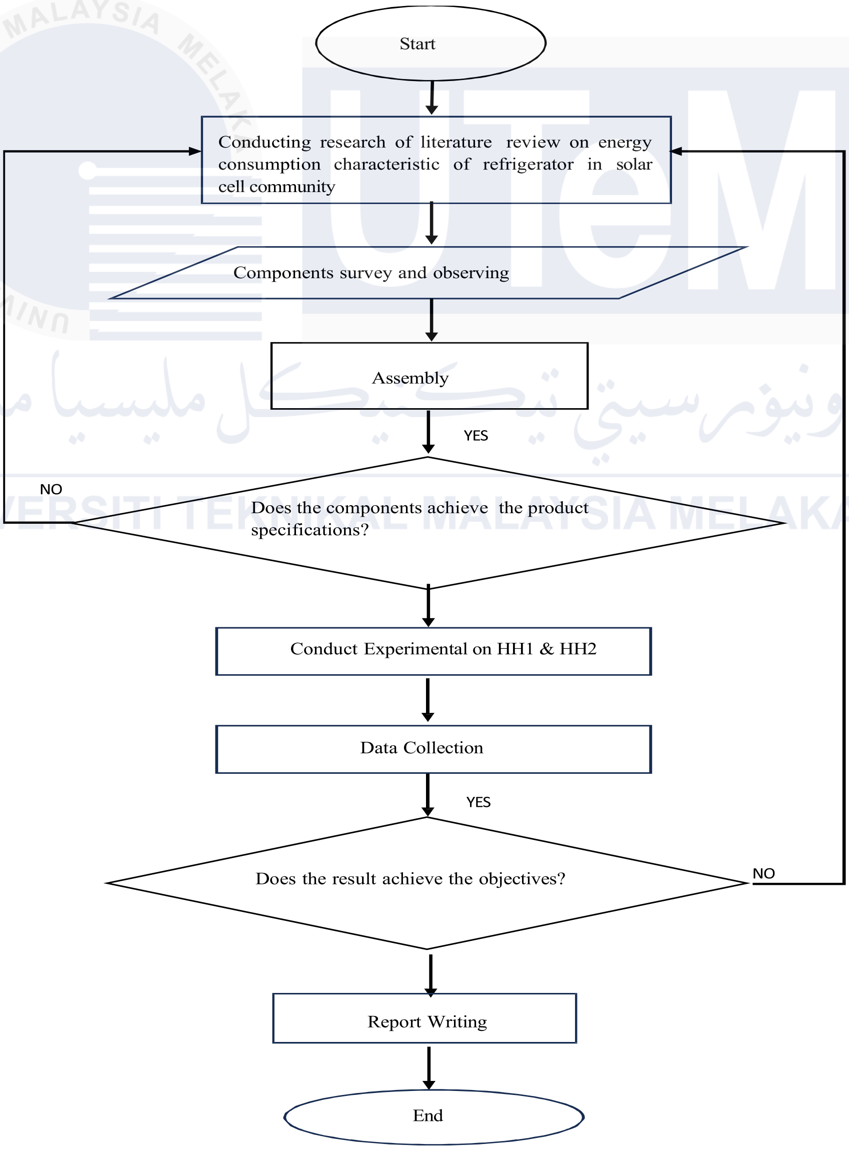


Figure 3.1 Research Flowchart for PSM

3.3 PSM Gantt Chart

Gantt Chart as shown in Figure 3.2 are very important to record the time consuming to produce this research through the whole time by looking and deciding the topic and writing the method for this research to proven the research of energy consumption characteristic of refrigerator in solar cell community from time to time.

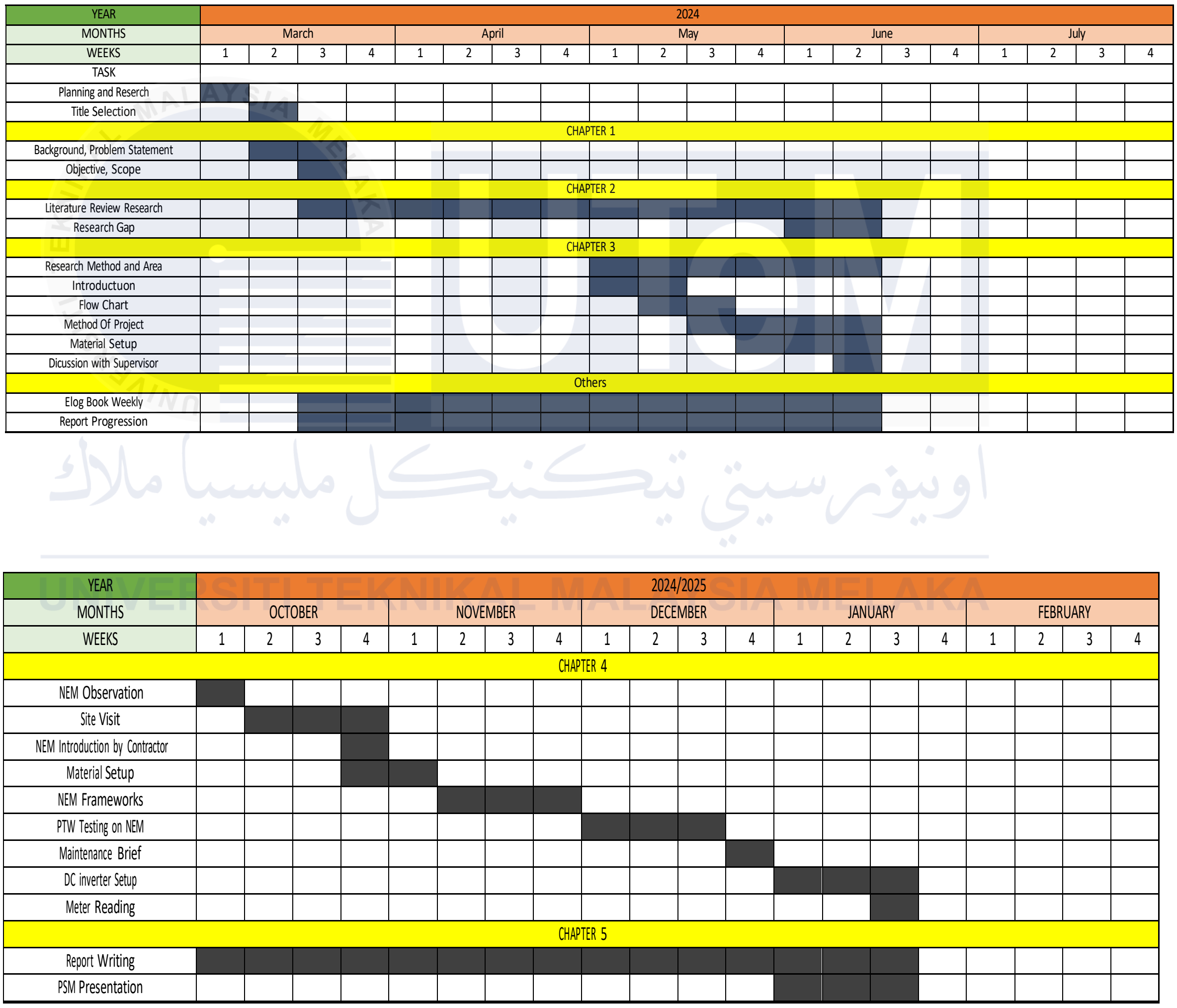


Figure 3.2 Gantt Chart

3.4 Proposed Methodology

The flow for methodology is shown as above in Figure 3.3 proposed methodology flowchart where the electrical production to be produced by the solar panel from sun then flows toward each component until the objective of this method are achieve in this experiment.

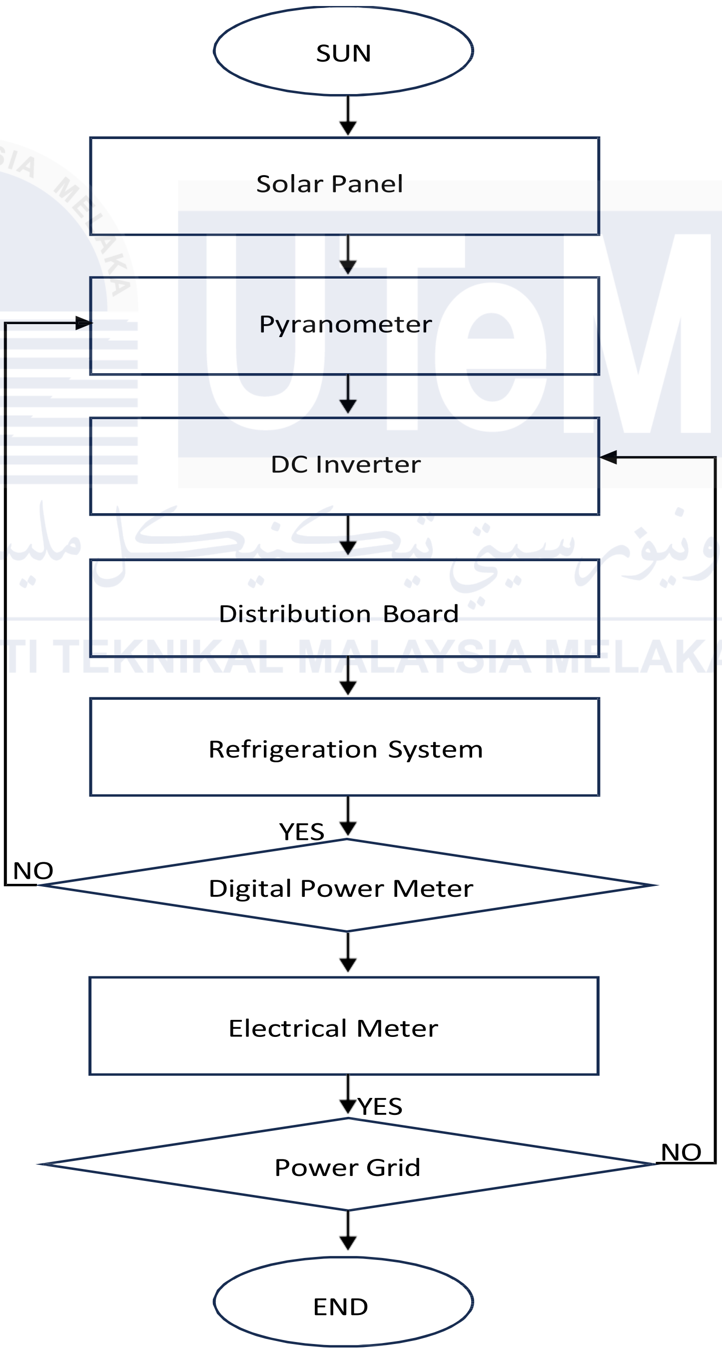


Figure 3.3 Proposed Methodology Flowchart

3.5 Method of Solar PV on Refrigerator

By looking at Figure 3.4 is a direct feed NEM approach method towards a community whom are using Solar PV as a system to provide electricity at their houses where it is dedicated energy meter (PV Meter) are installed to measure the energy exported from the photovoltaic (PV) system to the Sarawak Energy system. The PV meter as mentioned is the electrical meter in the Flow chart Methodology above is placed as close as feasible to the Sarawak Energy Meter, with a maximum distance of one meter. After receiving the supply energy produced by the PV, it then delivers towards the Distribution Board which then flow inside the inverter to provide electricity. After going through the process, any extra power demand by homeowners where the Solar PV generation generates electricity, the backup supply will then be provided by Power Grid itself. The Electrical Meter will be connected to the grid system through the existing meter cut-out and neutral link known as the Common Connection Point (CCP). This is the whole process cycle from the energy production to the usage of utilities the supply and backup back to the Power Grid.

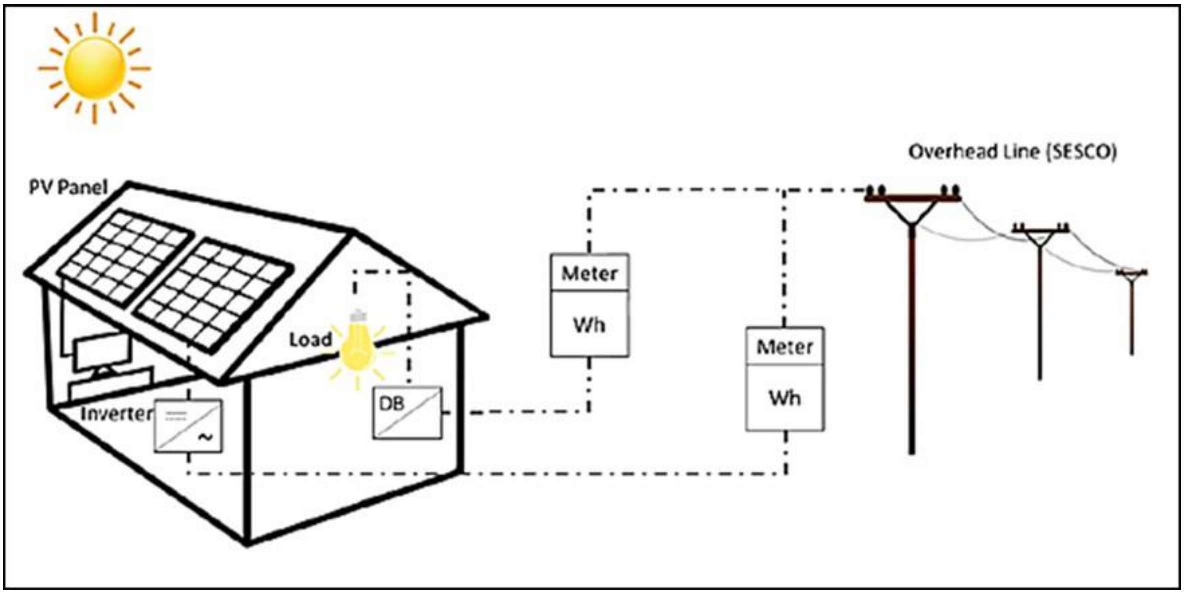


Figure 3.4 Direct Feed NEM Approach

3.6 Material Requirement

A Net Energy Metering (NEM) system enables homeowners to transmit excess solar energy back to the grid while receiving credit on their utility bills. To build a NEM system, NEM needs a variety of materials and parts. These are list of key materials needed: -

a) **Solar Panels**

- Solar panels, which come in conventional capacities ranging from 3 kW to 20 kW, are normally 1.7 meters by 1.0 meters in size.

b) **Mounting Bracket**

- Mounting brackets are critical components of solar PV systems, meant to secure the rails to the roof or ground, assuring stability and endurance. These brackets offer a strong basis for the solar panels, allowing them to resist a variety of weather situations.

c) **DC Inverter**

- String inverter efficiently converts the combined AC output of a series of solar panels into usable DC electricity for residential applications.

d) **Electrical Components**

- DC Disconnect Switch
- AC Disconnect Switch
- Electrical Conduit and Fittings
- Wiring (DC and AC)
- Combiner Box
- Grounding Equipment (Grounding Rods, Lugs, and Wire)

e) **Safety Equipment**

- Surge Protection Devices
- Fuses and Circuit Breakers
- Safety Labels and Signage

f) **Battery Storage**

- Battery Inverter DC type.
- Grid-connected solar systems typical size requires 1-3 lithium-ion batteries with 10 kWh of useful capacity or more to enable cost savings through load shifting.

3.7 Solar Panel Setup

The procedure begins with solar panels installed on rooftops or in open areas with direct sunshine. These panels are made up of photovoltaic (PV) cells, which convert solar energy into direct current (DC) electricity. The system contains a battery storage unit to store excess energy for usage during non-sunny times.

3.7.1 Solar PV Setup Procedure

Solar panels are mounted on a sunny roof to collect electricity. This DC electricity is then transformed to usable AC power via an inverter in your home. A battery can be added to store extra energy for nighttime or cloudy days, but your system is also connected to the grid via a net meter. This meter monitors electricity flow, credits you for surplus power generation, and allows you to draw from the grid.

1. Select a position with exposed the Solar PV to sunlight by minimal shadow.
2. Installed the Solar PV on the mounting bracket which have been manufactured.
    - Roof-Mounted: This type of installation is commonly used in residential settings and is mounted directly to the roof.
    - With a 30° angle of solar inclined, the Solar PV must be installed based on the sunlight hits it peak and consume enough light array.
    - Must not place the Solar PV on flat surface to avoid any debris or animal stain, facing the PV on flat surface will potentially reduce the Solar PV process to consume enough Light Ray from the sun which is why common energy company installed Solar PV with a proper manufactured mounting bracket.

3. Secure the solar panel in an inclined position facing the sun.
    - Observed sunlight direction on roof top position to install mounted to make sure full secure and also observing potential issue in the future.
    - Assemble the solar panel using nuts and bolts.
4. Connect the panel to a charge controller or inverter and record the data using a data gathering system in table form.
    - Inverter Connection: Connect the panels to an inverter, which transforms the panels' DC (direct current) to AC (alternating current) for home usage.
    - Record electrical potential consumption in voltage,
5. Connect to the Electrical Panel
    - Grid-Tied Systems: Connect the inverter to your home's electrical panel, making sure it has a net meter to monitor energy supplied back into the grid.
6. Monitor the NEM system towards supplying electricity for the house.
    - Set up a monitoring system to track energy production and consumption. Many modern inverters include monitoring capabilities.

3.8 Power Measurement on Electrical Meter (kW)

These are the requirement for data collection to build up the comparison between a residence using NEM and normal electrical supply from Power Grid based on table form will be needed in this experiment. The following procedure explains the steps by step to complete the role of having NEM system in a community as given: -

I. Create a table which contain the time based on hours.

- Table 3.1 presented the example data table to collect the result based on hours per day.

II. Record the reading on electrical consumption each 4 hours per day by using the Electrical Power Meter.

III. Compared cost of electricity bills between community using NEM system and normal electrical supply from Power Grid at the end of the month to prove using NEM may reduce electricity bills.

IV. Provide figure from comparison of bills at the end of the month.

V. Plot the electrical energy consumption produced by Solar PV from 2 different scenarios data in graph.

- The data plotted inside the graph are between Time (h) and Power (W).

VI. Create a graph for 2 different scenarios between NEM system and Direct supply from Power Grid of residences.

a) Energy Consumption using NEM

Table 3.1 shows the data example energy consumption using NEM will be stated in Result in Chapter 4 where the voltage will be different between 2 scenarios. As mention in research scope, the range for a specific household are 3 kW to 20 kW standard. For information, homeowners can increase the voltage standard by demanding more Solar PV towards NEM system at their house as per requirement inside contractor quotations. The time mention in table below is the requirement to collect the data for this experimental setup.

Table 3.1 Energy Consumption using NEM

Time (h)	**Power (W)**
7 a.m-10 a.m.	**3 kW to 20 kW**
1 p.m-4 p.m.	**3 kW to 20 kW**
5 p.m-8 p.m.	**3 kW to 20 kW**
9 p.m-12 a.m.	**3 kW to 20 kW**

b) Specification of Main Component

Table 3.2 shows the specification of main component given are the standard model for Malaysia market model which are commonly found and use by consumer. By referring (Zhang, 2021), a standard house should have 5 – 6 Solar PV depend on consumers' demand.

Table 3.2 is a Specification of Main Component

Equipment	**Model**	**Specifications**	**Quantity**
Solar panel	GA 100	P_p = 100W, V_p = 17.5V, I_p = 5.7A	8
Solar charge controller	SR 12L	I = 12A, V = 24V	1
Inverter	GAINV 150	P = 150W, V = 24V	1

3.9 Equipment and Materials

Solar Array absorbed Energy from Sun as shown in Figure 3.5 which is shown on solar cells within the panels are made of semiconductor materials such as silicon, which absorb photons from sunlight, activating electrons and generating an electric current. This information is required to highlight the example of Light Array on Solar PV as example of the Solar Process.

Figure 3.5 Solar Array absorbed Energy from Sun

Pyranometer as shown in Figure 3.6 is used in a solar panel system to measure solar irradiance or sunlight intensity In methodology, it is very important to show the location to installed this device where the idea is to installed it near the Solar PV and exposed on sunlight.

Figure 3.6 Pyranometer

The DC inverter as shown in Figure 3.7 is an essential part of a Net Energy Metering (NEM) system, acting as the vital link between your solar panels and your home's electrical system. This DC Inverter is located at outdoor where the setup of wiring went directly to the battery storage.

Figure 3.7 DC Inverter

Residual Current Devices (RCDs) or Ground Fault Circuit Interrupters (GFCIs) to prevent electric shocks. Figure 3.8 shows the standard distribution board. This information is vital for the experimental setup as Distribution Board is one of the main components to control the residence electric.

Figure 3.8 Distribution Board

Figure 3.9 is an example of split unit of a resident with NEM system. After the distribution board distributes electricity throughout the house, the Split Unit uses the energy generated by the solar panels to preserve food and to provide comfort.

Figure 3.9 Example of Split Unit of a resident with NEM system

Figure 3.10 shows the digital power meter in a home with a solar panel system are required for monitoring and regulating energy usage and output. Digital panel reading gets the data from the pyranometer then delivers directly to the interface. The idea is to delivers the information for homeowners to get the information on electricity consumption.

Figure 3.10 Digital Power Meter

Figure 3.11 shows electrical meter monitors power use in both directions, electrical energy consumed from the grid when solar production is insufficient, and excess energy created by solar panels that is fed back into the system. This capacity enables households to better monitor their energy usage and participate in demand response programs, in which utilities offer incentives to cut consumption during peak periods.

Figure 3.11 Electrical Meter

Figure 3.12 shows an example of Power Grid role is a backup power during the NEM system are down under maintenance or the Panels could not produce any electrical power which depends on the weather or night time, During the night when NEM and Solar Panels could not produce electricity the supply from the grid system will supply back to the house as backup power aside from the battery storage.

Figure 3.12 Power Grid

Figure 3.13 shows the fully setup NEM System through animated design which connected through power grid line also generated electricity independently flowing through each components in the household.

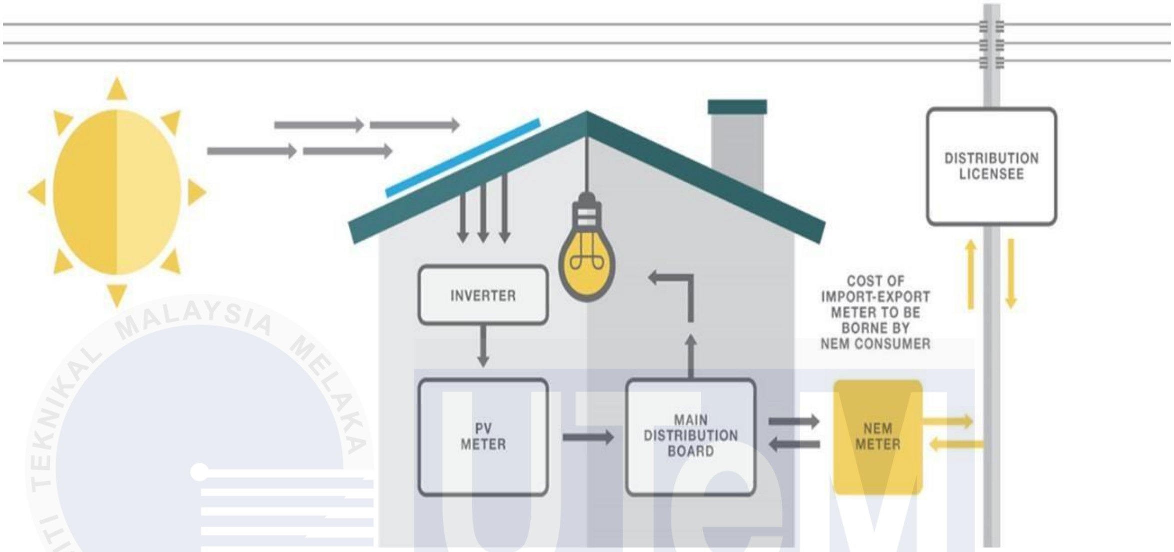


Figure 3.13 Fully Setup NEM System

3.10 Development Maintenance Activities Standard

Maintenance actions for Net Energy Metering (NEM) systems are directed by industry standards to maintain maximum performance and safety. These operations often include routine inspection and cleaning of solar panels to enhance efficiency and detect potential problems such as dirt collection, shadowing, or damage. Electrical connections should be checked on a regular basis to ensure that they are secure and corrosion-free. The performance of the inverter, which converts DC to AC power, should be monitored to guarantee proper operation. Furthermore, safety inspections, such as ensuring correct grounding and that all safety devices are operating, are required. Maintenance also includes monitoring the system's operation using the NEM meter to detect any inconsistencies in energy generation and export. These requirements are crucial to prolonging the longevity.

3.11 Limitation of Proposed Methodology

a) Unexpected Failures

Even if you have a comprehensive preventative maintenance policy in place, unexpected equipment failures or breakdowns may occur. Routine inspections may not reveal all concerns, and even with regular maintenance, unexpected circumstances or component failures can still arise.

b) Complexity and Technical Expertise

Because of their complicated needs, certain equipment may necessitate the use of specific technical knowledge and expertise. This could include requesting assistance from outside service providers or guaranteeing access to experienced staff. Organizations that lack in-house expertise or have difficulty accessing external resources may struggle to acquire and keep the essential skills and knowledge for proper maintenance duties.

3.12 Summary

Net Energy Metering has one of the highest demands of energy production by consumers in the last 5 years a shown by researchers and therefore it is proven to be one of the best green technologies in energy production. Due to the high demand by consumer, NEM installation is getting higher at price where most electrical companies are racing towards investing in these projects. The method proposed of solar PV to generate electricity for the refrigerator in a community is also depend of the house size and some consumers can also demand to install more solar PV for them to have more electrical supply in their home. Moreover, a normal double story house should have 5-6 solar PV on roof install for the NEM system in their livings, but some consumers as mention can have more if required. A house with this system should can generate 3-20 kW for one unit of solar panel. Based on the research scope, the location of the household demanded for 8 Solar PV which total up to 160 kW total power supply per hour.

CHAPTER 4

PRELIMINARY RESULTS

4.0 Introduction

In this chapter, our goal is to achieve 3 to 20 kW per solar PV of electricity supply produced by the NEM system. On the other hand, the aim of this chapter also wants proven based on our observation of NEM system, it is relevant for a community to install solar power generation to fulfill the desire usage of electricity towards refrigeration in their house. Regarding on the matter, the characteristic of refrigerator is a crucial matter to focuses on due to the maintenance of NEM system and also the consumption of electricity by the refrigerator itself.

Furthermore, the require time to observe this setup is time consuming based on electricity bills at the end of the month and also the meter reading for the solar panels to generate electricity per day. Besides that, the factor also must be focuses also towards the condition on maintenance for solar panels and the weather also plays a big role on solar PV technologies. As for awareness, NEM will soon be one of the highest energy productions to supply human needs in the upcoming future. This technology will help the younger generation about climate change and also motivates them to produce more new innovation towards green technology and clean energy.

4.1 Result and Discussion

Two household (HH1 and HH2) has been selected as the research ground for data and result to secure the findings and also limitation for solar PV to provide electricity. In this case, HH1 has installed NEM system in their livings meanwhile HH2 is a standard house.

Figure 4.1 shows the daily solar irradiation (in orange) begins at zero in the early morning, peaks around midday, and then drops into the evening. The temperature (in red) rises in the morning, peaks somewhat after the irradiation peak, usually in the early afternoon, and then drops in the evening.

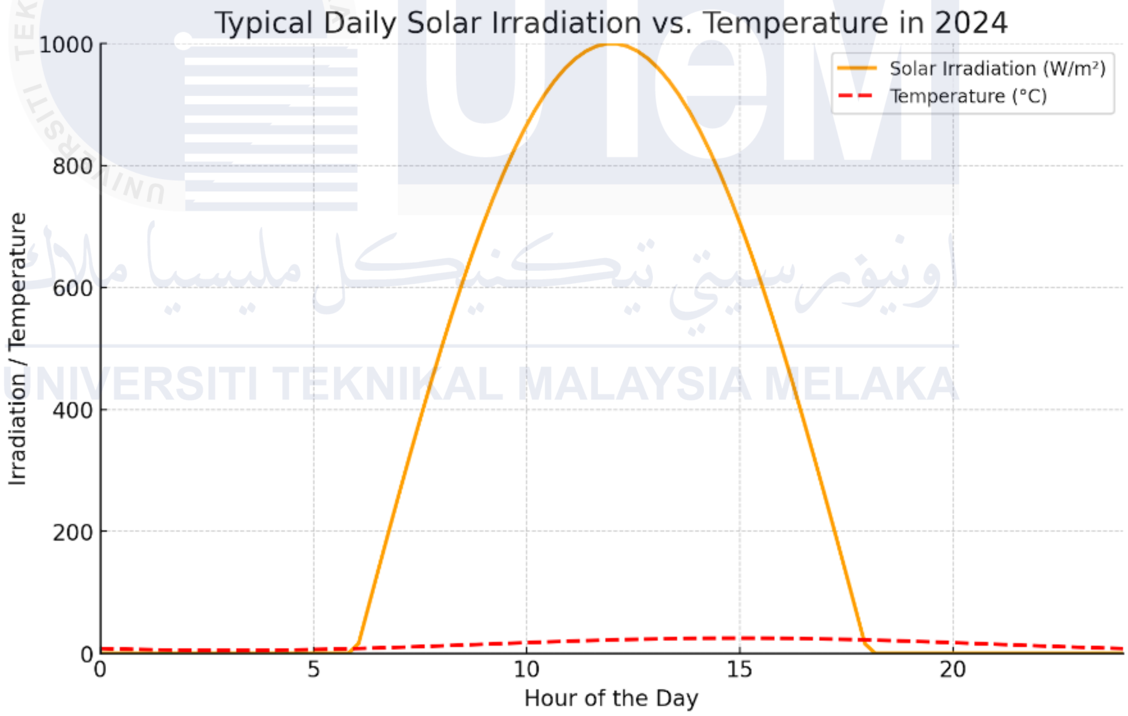


Figure 4.1 Daily Solar Irradiations (W/m²) versus Temperature (◦C) at selected location

4.2 Household 1

HH1 electrical consumption are most peak during day time where consumer used electricity to run their daily life. The data were recorded every 4 hours and the electricity usage depend on the consumer demand based on daily routine. HH1 are installed with NEM system to generate the electrical energy as counted based on Table 4.1 daily output and variation data. As 30 kWh per day divided by 6 intervals of 4 hours (24 hours total) gives:

$$30 \text{ kWh} \div 6 = 5 \text{ kWh per 4 hours}$$

Table 4.1 HH1 Net Energy Metering System Daily Output and Variation Data

Time (h)	Power (kW)
00.00 – 04.00	**2 kWh**
04.00 – 08.00	**6 kWh**
08.00 – 12.00	**13.6 kWh**
12.00 – 16.00	**16.5 kWh**
16.00 – 20.00	**13.4 kWh**
20.00 – 24.00	**4 kWh**

On average, 5 kWh would be consuming every 4 hours however Energy consumption is not constant and frequently varies throughout the day, with peak periods in the morning and evening.

4.3 Household 2

Table 4.2 shows Household 2 (HH2) observation are more direct approach regarding on the standard power flow supply directly from the grid as the electrical power supply by SEB. Meanwhile, HH2 has 5 occupants consume by whole house daily.

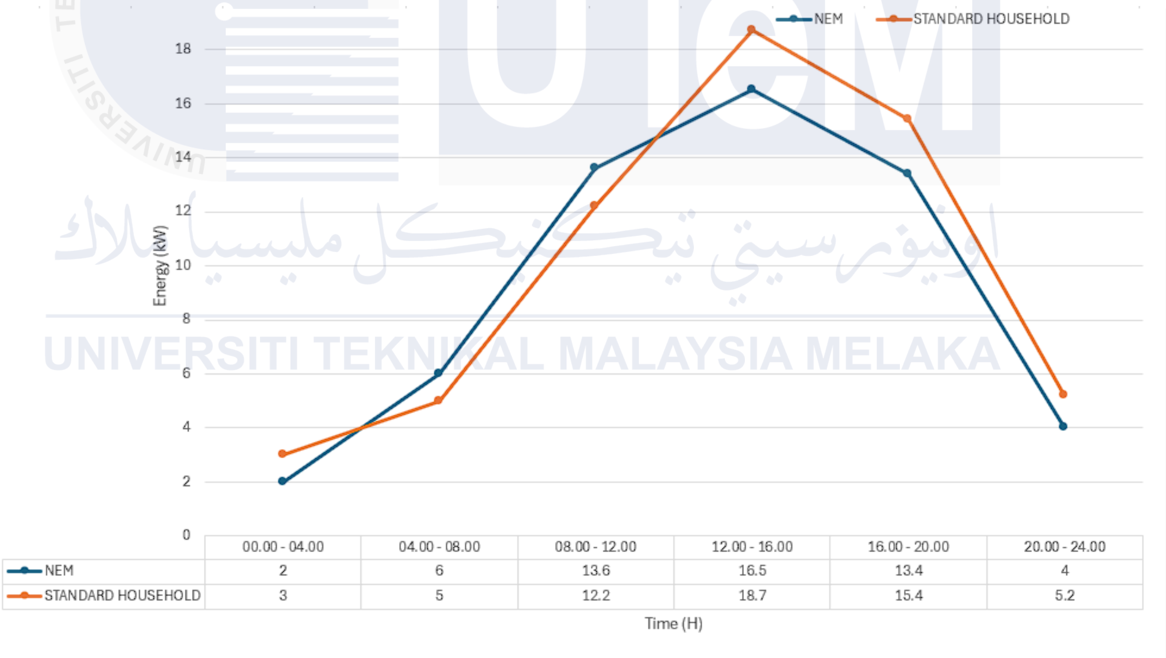
Table 4.2 HH2 Standard Household Output and Variation Data

Time (h)	**Power (kW)**
00.00 – 04.00	**3 kWh**
04.00 – 08.00	**5 kWh**
08.00 – 12.00	**12.2 kWh**
12.00 – 16.00	**18.7 kWh**
16.00 – 20.00	**15.4 kWh**
20.00 – 24.00	**5.2 kWh**

Based on the HH2 data recorded, the exact value of electrical consumption cannot be easily defined as HH2 has different routine each day by looking at the scenario on guest attending at the HH2. Variation of data based on Table 4.2 Standard Household Output and Variation Data are proven slightly higher demand on electrical consumption compare to HH1 which has lesser occupants and also minimum guest visiting.

4.4 Energy Consumption Between HH1 and HH2

Figure 4.2 shows the result based on graph plotting towards the different between HH1 using NEM system and HH2 using direct supply from Sarawak Energy Berhad (SEB). The amount on each 4 hours are the exact estimated value which is most likely not consistent energy usage. The current HH1 occupants stated that using NEM system has been helpful on the electricity compare to HH2 occupants which monthly bills is common as same as the community. The graph shows the Energy (kW) against Time (h) which gives the obvious amount of energy consumption to both households. Conclusion, these data was recorded on two separate days within each 4 hours in 24 hours.



	00.00 - 04.00	04.00 - 08.00	08.00 - 12.00	12.00 - 16.00	16.00 - 20.00	20.00 - 24.00
NEM	2	6	13.6	16.5	13.4	4
STANDARD HOUSEHOLD	3	5	12.2	18.7	15.4	5.2

Figure 4.2 Energy Demand of Different Household Over Time

4.5 Household Daily Input

Table 4.3 shows the households daily input are mostly common connected load in most residence used in their household, as a result, the typical loads are the usual input which make both result of input value almost the same amount but the electrical bills are the one separating both of HH1 and HH2 consumption.

Table 4.3 Households Daily Input

	Household 1 (HH1)	**Household 2 (HH2)**
Connected Load	*4 Split AC Unit (1.8kW each), 7 Lighting (3W), 3 Mobile Phones Charger (20W), 1 Refrigerator (0.15kW)*	*4 Split Units (1.8 kW each), 10 Lighting (3W), 3 Mobile Phone Charger (20 kW), 1 PC (10 W), 1 Refrigerator (0.15kW)*
Daily Loads	*7.431 kW/day*	*7.45 kW/day*
Average Daily Load	*18.29 kWh/day*	*18.35 kWh/day*

Table 4.3 presents the average daily input calculation most likely cumulative as most of the load are standard usage of daily routine on electricity where the value is almost the same compare to each household. The result also shows the comparison between both household their daily loads.

4.5.1 Household Daily Loads Calculation

Table 4.4 compares the Daily Loads for Household 1 (HH1) and Household 2 (HH2) based on the power ratings of their appliances. The Daily Load represents the total power consumption of all appliances in a household, typically measured in kW (kilowatts).

Table 4.4 HH1 and HH2 Daily Loads

Household 1 (HH1)	Household 2 (HH2)
1 Refrigerator = 0.15 kW *4 Split Units × 1.8 kW each = 7.2 kW* *7 Lighting × 3W=21W = 0.021 kW* *3 Mobile Phones Charger (20W) = 60W = 0.06kW* ***Total Amount Daily Load = 7.431kW***	*1 Refrigerator = 0.15 kW* *4 Split Unit × 1.8 kW = 7.2 kW* *10 Lighting × 3W = 0.03kW* *3 Mobile Phone Charger = 0.06kW* *1 PC × 10W = 0.01 kW* ***Total Daily Load = 7.45 kW***

4.5.2 Household Average Daily Load Calculation

Table 4.5 presents the Average Daily Load (ADL) for two households, HH1 and HH2, based on the power consumption of various household appliances. The Average Daily Load is the total amount of electrical energy a household uses per day, measured in kWh/day (kilowatt-hours per day).

Table 4.5 HH1 and HH2 Average Daily Load

Household 1 (HH1)	Household 2 (HH2)
Refrigeration *– 0.15kW × 24 hours = 3.6kWh* ***AC Split Unit*** *– 1.8kW × 8 hours = 14.4kWh* ***Lighting –*** *0.021kW × 5 hours = 0.105kWh* ***Mobile Phone Charger*** *– 0.06kW × 3 hours = 0.18kWh* ***Total Average Daily Load = 18.29kWh/day***	***Refrigeration*** *– 0.15kW × 24 hours = 3.6kWh* ***AC Split Unit*** *– 1.8kW × 8 hours = 14.4kWh* ***Lighting*** *– 0.03kW × 5 hours = 0.15kWh* ***Mobile Phone Charger*** *– 0.06kW × 3 hours = 0.18kWh* ***PC –*** *0.01 × 2 hours = 0.02kWh* ***Total Average Daily Load = 18.35kWh/day***

4.6 Maintenance on HH1 NEM System

Maintaining a double-story house with a Net Energy Metering (NEM) solar system of 3 to 20 kW begins with cleaning the solar panels every few months to eliminate dust and debris, as dirty panels diminish efficiency. It's also important to check for any shadowing from nearby items and make sure the inverter is transferring energy correctly. If you have a battery storage system, keep it cool and dry, check for leaks, and clean the connections to prevent corrosion.

Once a year, have a professional inspect the complete system, including the wiring, grounding, and circuit breakers. Monitoring your system's performance with an app can also help you detect any decreases early. Taking these procedures guarantees that your NEM system functions efficiently, saves energy, and extends its longevity.

4.7 Technical Challenges and System Limitations

Figure 4.3 shows Battery Bank on NEM Sire Location, during site visit and observing NEM System for data recording, there are several challenges with the Net Energy Metering (NEM) system that might impair its efficiency, reliability, and integration with household and grid infrastructure. One major difficulty is the inverter capacity restriction. Inverters transform DC energy from solar panels into AC electricity for use in the home, and an undersized inverter might limit the system's peak power output, particularly during periods of high solar production. This occurs in "clipping," in which surplus generated energy is not used, lowering total efficiency.

Figure 4.3 Battery Bank on NEM Site Location

Figure 4.4 shows Net Energy Metering (NEM) Battery Bank Precaution Label is important to know the challenges during this whole process, battery storage restrictions are also important in NEM systems, especially for residences that rely on solar power at night or during outages. Batteries can be expensive, and even high-quality batteries can degrade over time, resulting in lower storage capacity and efficiency. Due to the low storage capacity of many batteries, extra solar energy may not always be saved for later use, diminishing the financial benefits of NEM. Another drawback is grid dependency, as well as integration issues.

Figure 4.4 NEM Battery Bank Precaution Label

4.8 Electrical Bill Both Household

Figure 4.5 shows household electricity bills based on current month charges and the exact amount on Ringgit Malaysia also include Tax which is 8% under Tax Act 2018. The amount of payment is RM 246.25 rounded value for HH1.

CURRENT MONTH CHARGES	AMOUNT RM	Tax%	Tax RM	TOTAL RM
Electricity Charges(600 kWh)	183.00	0% - ST*	0.00	183.00
Electricity Charges	58.56	8% - ST*	4.68	63.24
Service Tax under Service Tax Act 2018			4.68	246.24
			Rounded	**246.25**

Figure 4.5 HH1 Electrical Bill

Figure 4.6 shows the electrical bill for household which are not using a NEM System. Based on the current month charges and the amount of payment is significantly higher including tax. The rounded value is RM 362.95 for household 2 (HH2).

CURRENT MONTH CHARGES	AMOUNT RM	Tax%	Tax RM	TOTAL RM
Electricity Charges(600 kWh)	186.00	0% - ST*	0.00	186.00
Electricity Charges	109.12	6% - ST*	6.55	115.67
Electricity Charges	56.73	8% - ST*	4.54	61.27
Service Tax under Service Tax Act 2018			11.09	362.94
			Rounded	**362.95**

Figure 4.6 HH2 Electrical Bill

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The investigation into the energy consumption features of refrigeration systems in communities based on sun cells has yielded important information on the energy requirements of solar-powered residential refrigerators. According to the results, the refrigerators in Household 1 (HH1) and Household 2 (HH2) exhibit varying patterns of energy consumption throughout the day, with the highest power consumption taking place between 12:00 and 16:00. This corresponds with the peak daytime hours when solar power generation is most abundant. In terms of energy usage, both homes show comparable patterns, with lower usage at night (00:00–04:00) and in the early morning (04:00–08:00). In order to maintain refrigeration system operation even during periods of low solar generation, these findings highlight the need of comprehending the diurnal changes in energy consumption and the necessity of efficient energy storage options in solar-powered communities.

When HH1 and HH2 power consumption data are compared, it is clear that HH2 uses more energy overall and at all times, with a significant surge between 12:00 and 16:00 (18.7 kWh for HH2 vs. 16.5 kWh for HH1). The size and effectiveness of the refrigerators, the number of people using them, and the frequency and duration of refrigerator door openings—all of which have a direct impact on cooling demands—are some of the factors that contribute to this variation in consumption. Furthermore, as refrigerators may have to work harder to maintain ideal temperatures during hotter times of the day, external environmental factors like temperature and humidity may also have an impact on energy consumption. The noteworthy results reveal that although the energy usage patterns of the two houses are comparable, HH2's higher energy consumption may be the result of a larger or less effective refrigeration equipment, or it may be higher because of the necessity to store food. These findings demonstrate how home behavior, appliance features, and solar power generation interact intricately to determine energy use in communities that rely on solar power.

5.2 Recommendation

The study's conclusions suggest that solar cell communities concentrate on maximizing refrigeration systems' energy efficiency by taking into account variables including appliance size, insulation quality, and the usage of energy-efficient models. Furthermore, as solar power generation is most abundant during the noon hours, homes should be urged to adopt energy management practices including minimizing refrigerator door openings and lowering peak load demand during this time. A steady energy supply for refrigeration system during times of low solar availability, especially in the early morning and at night, would be ensured by investing in energy storage devices, such as batteries, which would also aid in storing excess solar power during peak generating times. Finally, more studies on how home habits and environmental factors affect energy use may help develop more efficient energy-saving measures that are unique to each community's circumstances.

REFERENCES

[1] Aldhshan, S.R.S. et al., 2021. Energy Consumption and Spatial Assessment of Renewable Energy Penetration and Building Energy Efficiency in Malaysia: A Review. Sustainability, 13(16), p.9244.

[2] Ali, M.T., 2022, Solar Cooling Overview [Online]. Available at: https://www.thermopedia.com/content/10199/ [Accessed: 11 May 2024].

[3] Araner, 2021, The Vapor Compression Refrigeration Cycle, Step By Step [Online]. Available at: https://www.araner.com/blog/vapor-compression-refrigeration-cycle.

[4] Borikar, S.A. et al., 2021. A case study on experimental and statistical analysis of energy consumption of domestic refrigerator. Case Studies in Thermal Engineering, 28, p.101636.

[5] Costa, V.A.F., 2023, On the best coefficient of performance and specific heating or cooling power combination for adsorption refrigerators and heat pumpsSur la meilleure combinaison du coefficient de performance et de la puissance spécifique de chauffage ou de refroidissement pour les réfrigérateurs et pompes à chaleur à adsorption [Online]. Available at: https://www.sciencedirect.com/science/article/pii/S0140700723001032.

[6] D, T., 2023, The Power of Net Metering: How Solar Energy Users Can Save Money and Reduce Carbon Footprint [Online]. Available at: https://www.linkedin.com/pulse/power-net-metering-how-solar-energy-users-can-save-money-dimitrov [Accessed: 21 April 2024].

[7] García-López, M., Montano, B. and Melgarejo, J., 2023. Household energy consumption and the financial feasibility of self-consumption through photovoltaic panels in Spain. Energy Efficiency, 16(6).

[8] Gorina, L., Korneeva, E., Kovaleva, O. and Wadim Strielkowski, 2024. Energy-saving technologies and energy efficiency in the post-COVID era. Sustainable development.

[9] Ibrahim, N.I., Al-Sulaiman, F.A. and Rehman, S., 2021, Economic analysis of a novel solar-assisted air conditioning system with integral absorption energy storage [Online]. Available at:

https://www.sciencedirect.com/science/article/abs/pii/S0959652621001384.

[10] Lee, S.-H. and Jang, Y.-C., 2023. Analysis for End-of-Life Solar Panel Generations by Renewable Energy Supply towards Carbon Neutrality in South Korea. Energies, 16(24), pp.8039–8039.

[11] Lu, Y., Hao, N., Li, X. and Alshahrani, M.Y., 2024. AI-enabled sports-system peer-to-peer energy exchange network for remote areas in the digital economy. Heliyon, 10(16), p.e35890. Available at: https://pubmed.ncbi.nlm.nih.gov/39262953/.

[12] Malaysia, P.S.C. in, Solar Energy Company for Commercial & Solar Farm in Malaysia - Plus Xnergy [Online]. Available at: https://www.plusxnergy.com/solutions/energy-generation/solar-for-home/.

[13] Mungwe, J.N. et al., 2024. Technical Evaluation of Photovoltaic Systems in the Bamenda Municipality of the North West Region of Cameroon. NaN, 2024(NaN), pp.1–14. Available at: https://www.citedrive.com/en/discovery/technical-evaluation-of-photovoltaic-systems-in-the-bamenda-municipality-of-the-north-west-region-of-cameroon/ [Accessed: 14 April 2024].

[14] net, G., 2023, Solar Backup Systems: Understanding The Basics | Gadgetronix [Online]. Available at: https://gadgetronix.net/solar-backup-systems-understanding-the-basics/ [Accessed: 21 April 2024].

[15] Noor Waleed, Rakan Khalil Antar and Abdullah, A.A., 2023. Solar power load energy management system – A review. AIP conference proceedings, 2862(1). Available at: https://pubs.aip.org/aip/acp/article-abstract/2862/1/020017/2930070/Solar-power-load-energy-management-system-A-review?redirectedFrom=fulltext [Accessed: 21 April 2024].

[16] Overbey, D., 2021, The Absorption Refrigeration Cycle | Building Enclosure [Online]. Available at: https://www.buildingenclosureonline.com/blogs/14-the-be-blog/post/90447-the-absorption-refrigeration-cycle.

[17] Perera, J., 2024, The Role of Energy Storage in Enhancing the Performance of Solar PV Systems [Online]. Available at: https://www.linkedin.com/pulse/role-energy-storage-enhancing-performance-

solar-pv-systems-perera-flb2c#:~:text=By%20storing%20excess%20energy%20during [Accessed: 21 April 2024].

[18] Qiu, Y. (Lucy) et al., 2022. Heterogeneous changes in electricity consumption patterns of residential distributed solar consumers due to battery storage adoption. iScience, 25(6), p.104352.

[19] Qlatunde, Tosin.M., Okwandu, Azubuike.C. and Akande, Dorcas.O., 2024, Reviewing the impact of energy-efficient appliances on household consumption [Online]. Available at: https://www.researchgate.net/publication/380207530_Reviewing_the_impact_of_energy-efficient_appliances_on_household_consumption.

[20] Razi, A., Safdar, A. and Irfan, R., 2023. Optical Optimization of Tandem Solar Cells: A Systematic Review for Enhanced Power Conversion. Nanomaterials (Basel, Switzerland), 13(23), p.2985. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10708336/ [Accessed: 5 March 2024].

[21] RF, E., 2023, What Is Temperature Stability? - Everything RF [Online]. Available at: https://www.everythingrf.com/community/what-is-temperature-stability#:~:text=Temperature%20stability%20refers%20to%20the.

[22] Tarawneh, M., Shahed AL-Shorman and Ahmad Bani Yaseen, 2024. Exploring refrigeration system performance with solar-powered mechanical porous sub-cooling. Journal of thermal analysis and calorimetry.

[23] Zahedi, R. et al., 2024. Potentiometry of wind, solar and geothermal energy resources and their future perspectives in Iran. Environment, development and sustainability.

[24] Zhang, X., Lovati, M. and Sun, Y., 2021, Solar-photovoltaic-power-sharing-based design optimization of distributed energy storage systems for performance improvements [Online]. Available at: https://www.sciencedirect.com/science/article/pii/S0360544221001808#abs0010.

[25] Zublie, M.F.M., Hasanuzzaman, Md. and Rahim, N.A., 2023. Modeling, Energy Performance and Economic Analysis of Rooftop Solar Photovoltaic System for Net Energy Metering Scheme in Malaysia.Energies,16(2),p.723.

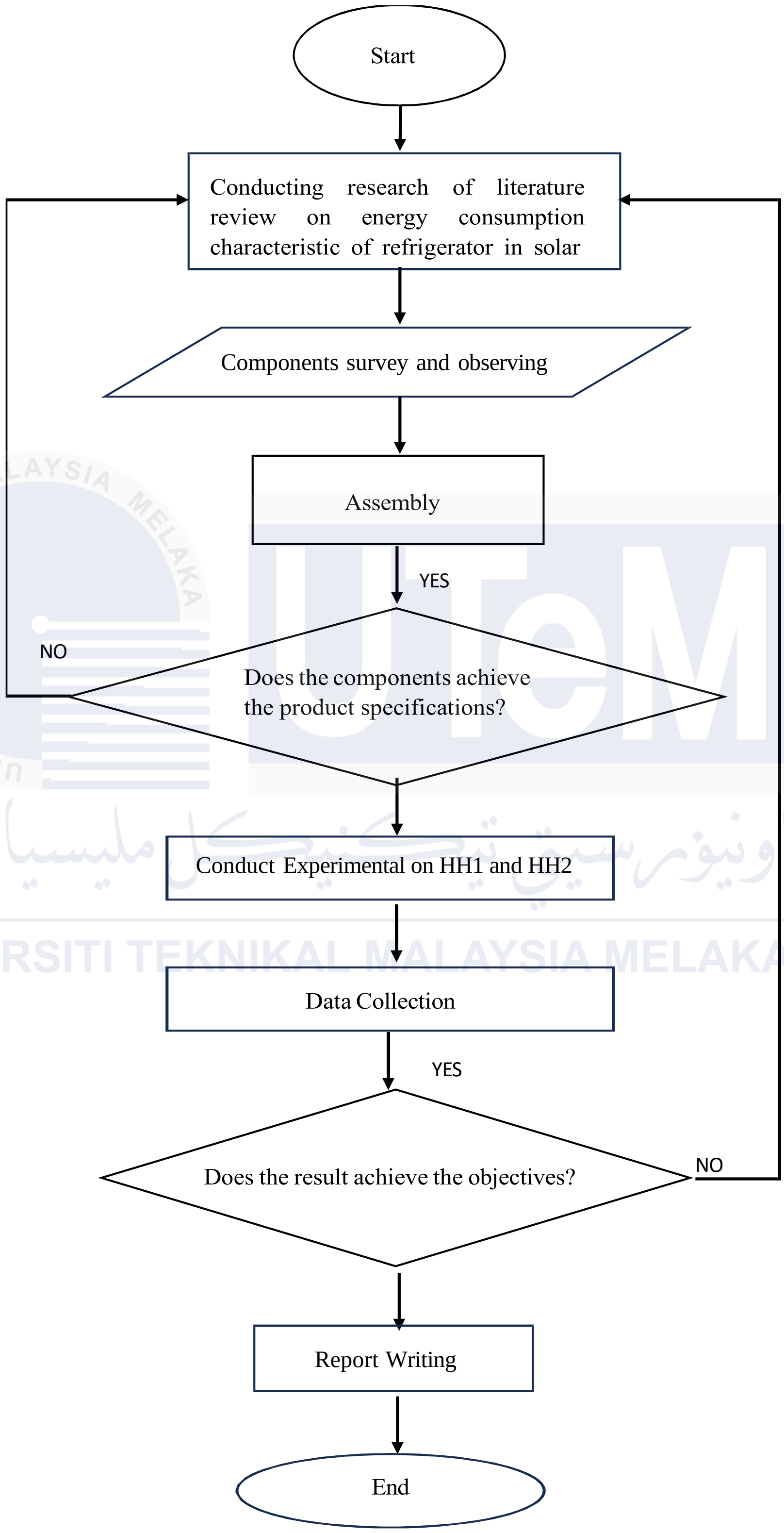
APPENDICES

APPENDIX A List of Gantt Chart weekly PSM progress

YEAR	2024																			
MONTHS	March				April				May				June				July			
WEEKS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TASK																				
Planning and Reserch	■																			
Title Selection		■																		
CHAPTER 1																				
Background, Problem Statement		■	■																	
Objective, Scope			■																	
CHAPTER 2																				
Literature Review Research			■	■	■	■	■	■	■	■	■	■	■	■						
Research Gap													■	■						
CHAPTER 3																				
Research Method and Area									■	■	■	■	■	■						
Introductuon									■	■										
Flow Chart										■	■									
Method Of Project											■	■	■	■						
Material Setup												■	■	■						
Dicussion with Supervisor														■						
Others																				
Elog Book Weekly			■	■	■	■	■	■	■	■	■	■	■	■						
Report Progression			■	■	■	■	■	■	■	■	■	■	■	■						

YEAR	2024/2025																			
MONTHS	OCTOBER				NOVEMBER				DECEMBER				JANUARY				FEBRUARY			
WEEKS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
CHAPTER 4																				
NEM Observation	■																			
Site Visit		■	■	■																
NEM Introduction by Contractor				■																
Material Setup				■	■															
NEM Frameworks						■	■	■												
PTW Testing on NEM									■	■	■									
Maintenance Brief												■								
DC inverter Setup													■	■	■					
Meter Reading															■					
CHAPTER 5																				
Report Writing	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
PSM Presentation													■	■	■					

APPENDIX B Research Flowchart for PSM



APPENDIX C Proposed Methodology