`

# OPTIMIZATION OF ENERGY SAVING STRATEGIES IN R410A RESIDENTIAL AIR-CONDITIONING (RAC), OPERATED USING R32


**AHMAD HAFFIS BIN ABDUL RAHIM**

**B092010393**


**BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (REFRIGERATION SYSTEM AND AIR CONDITIONING) WITH HONOURS**

**2025**

`

# Faculty of Mechanical Technology and Engineering

# OPTIMIZATION OF ENERGY SAVING STRATEGIES IN R410A RESIDENTIAL AIR-CONDITIONING (RAC), OPERATED USING R32



**AHMAD HAFFIS BIN ABDUL RAHIM**

**Bachelor of Mechanical Engineering Technology (Refrigeration System and Air Conditioning) with Honours**

**2025**

`

# OPTIMIZATION OF ENERGY SAVING STRATEGIES IN R410A RESIDENTIAL AIR-CONDITIONING (RAC), OPERATED USING R32

**AHMAD HAFFIS BIN ABDUL RAHIM**



**A thesis submitted**
**in fulfillment of the requirements for the degree of**
**Bachelor of Mechanical Engineering Technology (Refrigeration System and Air Conditioning) 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: **Optimization of Energy Saving Strategies in R410A Residential Air Conditioning (RAC), Operated Using R32**

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

Saya **Ahmad Haffis Bin Abdul Rahim**

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:

TS. DR. MOHD. FARID BIN ISMAIL
Pensyarah
Jabatan Teknologi Kejuruteraan Mekanikal
Fakulti Teknologi dan Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

Tarikh: 10 January 2025

Tarikh: 10 January 2025

** 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.

`

## DECLARATION

I declare that this Choose an item. entitled " Optimization of Energy Saving Strategies in R410A Residential Air Conditioning (RAC), Operated Using R32" 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 | : | AHMAD HAFFIS BIN ABDUL RAHIM |
| Date | : | 9 JANUARY 2025 |

`

**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 Mechanical Engineering Technology (Refrigeration System and Air Conditioning) with Honours.

Signature : ..........................................................

Supervisor Name : DR MOHD FARID BIN ISMAIL

Date : 31 JANUARY 2025

`

**DEDICATION**

I dedicated this report first and foremost to Almighty, ALLAH S.W.T for his guidance and blessings. Special dedication to my beloved parents. In addition, dedication should be compulsory granted to my supervisor for their continuous knowledge.

`

## ABSTRACT

This study investigates the optimization of energy-saving strategies in residential air conditioning systems utilizing R410A refrigerant, operated with R32 as an alternative. With increasing concerns regarding environmental impact and energy consumption, finding efficient solutions becomes imperative. The research explores various approaches, including system design modifications, operational adjustments, and technology integration, to enhance energy efficiency while maintaining optimal cooling performance. Through a combination of theoretical modeling, simulation studies, and empirical data analysis, this research identifies key factors influencing energy consumption in residential air conditioning systems and proposes innovative strategies for optimization. Furthermore, the study incorporates a comprehensive test rig and thermal control room setup to conduct real-world experiments. This infrastructure facilitates the evaluation of proposed energy-saving strategies under controlled conditions, allowing for accurate measurement and validation of performance metrics. The integration of a test rig and thermal control room enhances the reliability and applicability of the research findings, ensuring their relevance to practical implementation in residential air conditioning systems. Overall, the findings of this research contribute to advancing sustainable cooling technologies, offering practical insights for policymakers, manufacturers, and heating, ventilation and air conditioning professionals to mitigate environmental impact and promote energy conservation in residential air conditioning applications.

# ABSTRAK

Kajian ini mengkaji kaedah untuk mengoptimumkan strategi penjimatan tenaga dalam sistem penghawa dingin kediaman yang menggunakan bahan pendingin R410A, dikendalikan dengan R32 sebagai alternatif. Dengan peningkatan kebimbangan mengenai kesan alam sekitar dan penggunaan tenaga, mencari penyelesaian yang cekap menjadi penting. Penyelidikan meneroka pelbagai pendekatan, termasuk pengubahsuaian reka bentuk sistem, pelarasan operasi, dan penyepaduan teknologi, untuk meningkatkan kecekapan tenaga sambil mengekalkan prestasi penyejukan yang optimum. Melalui gabungan pemodelan teori, kajian simulasi dan analisis data empirikal, penyelidikan ini mengenal pasti faktor utama yang mempengaruhi penggunaan tenaga dalam sistem penghawa dingin kediaman dan mencadangkan strategi inovatif untuk pengoptimuman. Tambahan pula, kajian ini menggabungkan pelantar ujian komprehensif dan persediaan bilik kawalan haba untuk menjalankan eksperimen dunia sebenar. Infrastruktur ini memudahkan penilaian strategi penjimatan tenaga yang dicadangkan di bawah keadaan terkawal, membolehkan pengukuran tepat dan pengesahan metrik prestasi. Penyepaduan pelantar ujian dan bilik kawalan haba meningkatkan kebolehpercayaan dan kebolehgunaan penemuan penyelidikan, memastikan kaitannya dengan pelaksanaan praktikal dalam sistem penghawa dingin kediaman. Secara keseluruhannya, penemuan penyelidikan ini menyumbang kepada kemajuan teknologi penyejukan lestari, menawarkan pandangan praktikal untuk penggubal dasar, pengilang dan profesional pemanasan, pengudaraan dan penyaman udara untuk mengurangkan kesan alam sekitar dan menggalakkan pemuliharaan tenaga dalam aplikasi penyaman udara kediaman.

## ACKNOWLEDGEMENTS


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

First and foremost, I want to express my thanks and praise to Allah, the Almighty, who is also my Creator and Sustainer, for everything that has been provided for me from the dawn of time. I express my gratitude to Universiti Teknikal Malaysia Melaka (UTeM) for granting access to the research platform. Also appreciated for the financial support is the Malaysian Ministry of Higher Education (MOHE).

My deepest gratitude belongs to my primary supervisor, TS. DR. Mohd Farid Bin Ismail of the Universiti Teknikal Malaysia, Melaka (UTeM) Faculty of Mechanical Technology and Engineering, for all his guidance, advice, and motivation. His endless patience in mentoring and sharing priceless knowledge will always be appreciated. I would especially like to express my gratitude to TS. Muhammad Fairuz Bin Abu Bakar, Muhammad Ajmal, and Abdur Rahim, my fellow friends, for all their support and assistance.

Finally, but no less, I want to express my sincere thanks to my parents for their continuous love, support, and prayers. Finally, I would like to express my gratitude to the person or people that helped, encouraged, and supported me when I started my studies.

# TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| HVAC | - | Heating, Ventilation and Air-Conditioning |
| RTU | - | Roof Top Units |
| ACSU | - | Air-Conditioning Split Unit |
| CO2 | - | Carbon Dioxide |
| kWh | - | kilowatt hours |
| CFC | - | Chlorofluorocarbons |
| HFC | - | Hydrofluorocarbons |
| HC | - | Hydrocarbons |
| HCFC | - | Hydrochlorofluorocarbons |
| HFO | - | Hydrofluoroolefins |
| GWP | - | Global Warming Potential |
| ODP | - | Ozone Depleting Potential |
| RAC | - | Residential Air Conditioning |
| IoT | - | Internet of Things |
| TCR | - | Temperature Control Room |
| COP | - | Coefficient of Performance |
| EER | - | Energy Efficiency Ratio |
| VCRS | - | Vapor Compression Refrigerant System |
| Cond IN | - | Condenser Inlet |
| Cond OUT | - | Condenser Outlet |
| Cold OUT | - | Air blown by blower |
| Evap IN | - | Evaporator Inlet |
| Crit Temp | - | Critical Temperature |

`

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Energy is essential to the expansion of the economy, the advancement of society, and the survival of humankind. It is necessary for all physical activity and is the ability to perform activity. Energy is essential for operating enterprises, supplying fuel for vehicles, and lighting homes. It is an essential component of many industrial processes, such as those in manufacturing, services, and agriculture. For example, the World Bank emphasises that economic activities like irrigation, mechanised farming, and agro processing which are essential for enhancing food security and local incomes require access to electricity. World Bank, 2020). The increasing need for energy is closely linked to advances in economic growth, innovations in technology, and improved living standards. The energy consumption rises in relation to the development of economies, industries, and people. The International Energy Agency (IEA) projects that by 2050, the world's energy consumption will have increased by almost 50%, mostly due to the rapid economic expansion of developing nations (IEA, 2021).

Energy consumption varies significantly across different sectors, each with its own unique demand patterns and sources of energy. The primary sectors include industrial, transportation, residential, commercial, and agriculture. For industrial sector, Key industries with high energy consumption include the production of chemicals, iron and steel, cement, and aluminium. For example, smelting and clinker production in the manufacturing of steel and cement use a lot of energy. The energy sources used by the industrial sector are variable. While coal and natural gas are used for heating and chemical reactions, electricity is necessary for operating machines and other equipment. Additionally, petroleum products like fuel oil and diesel are utilised, especially in sectors of the economy without access to natural gas (EIA,2021). The transportation sector is critical for the movement of goods and people and is one of the largest consumers of energy globally. The industry is heavily dependent on goods based on petroleum. Most cars run on petrol or diesel, but aviation fuel is required for aircraft. Petroleum continues to be the most widely used energy source, despite efforts to diversify (DOE, 2021). Residential and commercial sector's energy most used are electricity. Electricity powers lighting, appliances, and air conditioning, while natural gas is commonly used for heating and cooking. Although the agricultural sector consumes less energy compared to other sectors, it is vital for food production and has specific energy needs. The primary energy sources in agriculture are diesel and electricity. Diesel is used for operating tractors and other machinery, while electricity is essential for irrigation and processing (USDA, 2021). Each sector has distinct energy consumption patterns, driven by specific needs and energy sources. The industrial and transportation sectors are the largest consumers, with a notable reliance on fossil fuels. The residential and commercial sectors follow, with significant electricity use, while the agricultural sector, though smaller in consumption, is increasingly integrating renewable energy sources.

Energy is used by HVAC (Heating, Ventilation, and Air Conditioning) systems to heat, cool, and ventilate buildings. The size of the building, the surrounding temperature, the effectiveness of the HVAC system, and the thermostat's setting all effect the quantity of energy they consume. The HVAC industry is a significant consumer of energy across various sectors, including residential, commercial, and industrial applications. Different HVAC systems use energy in diverse ways, depending on their design, efficiency, and operational requirements. Energy use and expenses can be decreased with routine maintenance and energy-saving techniques. Roof top units (RTU) commonly used in commercial buildings, RTUs are self-contained units installed on the roof. They handle both heating and cooling needs. The energy consumption of RTUs is significant due to the need to condition large volumes of air. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) notes that HVAC systems can account for 40-50% of the total energy use in commercial buildings. Besides, Chilled Water System are systems use chilled water produced by a central chiller to cool the air in a building. They are typically used in large commercial and industrial buildings. The energy efficiency of these systems depends on the performance of the chiller and the distribution pumps. According to the Environmental Protection Agency (EPA), optimizing chiller operations can save up to 20-50% of energy used for cooling in large buildings. On the other hand, Residential Air Conditioning (RAC) also consume large energy. These are the most common HVAC systems in residential buildings. They consist of an outdoor unit and an indoor unit. The energy consumption of split systems primarily comes from the compressor in the outdoor unit and the blower fan in the indoor unit. According to the U.S. Department of Energy (DOE), residential HVAC systems account for about 6% of total energy use in the United States.

Refrigerants are compounds that are used in cooling systems, including freezers, refrigerators, and air conditioners. They absorb and release heat to accomplish cooling as they go through a transition from liquid to gas and back again. Because of safety and environmental concerns, the types of refrigerants utilised have changed significantly throughout time. Refrigerants have evolved from natural substances like ammonia and CO2, which were initially used despite their toxicity and pressure issues, to chlorofluorocarbons (CFCs) such as R-12 that were phased out due to their ozone-depleting effects under the Montreal Protocol. They were replaced by hydrochlorofluorocarbons (HCFCs) such as R-22 and hydrofluorocarbons (HFCs) which is R-32, which, while better for the ozone but have high global warming potentials. Presently, hydrofluoroolefins (HFOs) are emerging as environmentally friendly alternatives due to their low global warming potential such as R-1234yf. Focusing to the future, there is a renewed focus on natural refrigerants like ammonia, CO2, and hydrocarbons and advanced HFO blends driven by regulatory actions like the Kigali Amendment, aiming to reduce environmental impact and enhance sustainability in refrigeration technologies (UNEP, 2016).

Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) are both classes of refrigerants that have been widely used in various cooling and refrigeration applications. While they share some similarities, there are key differences between them, particularly in terms of their impact on energy savings and efficiency. Because of their historical efficiency in terms of thermal performance, CFCs such as R-12 were well-liked during their time. By today's standards, the CFC-designed systems might not be as energy-efficient. Older systems using CFCs often lack the advanced energy-saving technologies available today, resulting in lower overall efficiency (ASHRAE,2020). Energy-saving technologies including variable speed drives, advanced control systems, and improved heat exchanger designs are increasingly frequently seen in newer HCFC systems. HCFC systems are easier to retrofit with modern, eco-friendly refrigerants compared to CFC systems, which are often near the end of their lifespan and less efficient (DOE,2021). Based on current timeline, R-410A refrigerant has become a commonly used in residential or commercial sectors. R-410A offers a high energy efficiency which is leading to energy savings, but R-32 may offer slightly better performance due to its lower boiling point and higher latent heat of vaporization (IIR,2020). R-32 stands out for its better environmental performance with a significantly lower GWP compared to R-410A (ASHRAE, 2020). R-32 is classified as slightly flammable, which can pose safety concerns. However, advancements in technology and safety standards have made its use increasingly viable, especially in smaller systems and well-ventilated areas.

## 1.2 Problem Statement

The phase-out of traditional refrigerants due to their high Global Warming Potential (GWP) and ozone-depleting potential (ODP) has driven research into environmentally friendly alternatives. R32 is a refrigerant with a lower GWP compared to R410A and a negligible ODP, making it an attractive alternative for residential air conditioning (RAC). However, optimizing the energy consumption of systems using R32 is necessary to ensure its feasibility and effectiveness for the market. In Malaysia, most households currently use R410A-based air conditioners, and it seems they do not want to change the system to the newer ones. While R410A has been beneficial, R32 offers a lower environmental impact, aligning with global efforts to reduce greenhouse gas emissions. In addition, R32 refrigerant is a single chemical based while R410A was a multiple blend chemical which is making their properties different.

R32 refrigerant split units are currently being widely produced by many companies. However, a comparison of energy savings between R32 and R410A refrigerants in the same system remains important. While the thermodynamic properties of both refrigerants are similar, R32 offers specific advantages, such as higher cooling capacity and better thermal conductivity, which may ensure superior performance. Therefore, conducting this research to collect data, analyze energy efficiency, and validate these claims is essential.

## 1.3 Research Objective

The main aim of this research is to collect data from actual HVAC system and try to optimize the existed systems. Specifically, the objectives are as follows:

a) The development of the test-rig of R32 refrigerant in a temperature control room.

b) The analysis of optimization of energy saving in residential air conditioning (RAC) using R32 in R410A system.

## 1.4 Scope of Research

Analyzing the RAC system's energy savings was the primary objective of the current study. A pair of objectives were created for the study framework. The following various scopes are assigned to each of the study's objectives to achieve its objectives:

i. This performance study used a R410A 1 horsepower split unit

ii. The indoor unit of the RAC will be hung on a custom test rig made from aluminum profile

iii. Temperature control room size 140 square feet will be used to place the test rig.

iv. Between 33 and 37 degrees Celsius will be controlled for ambient temperatures.

v. The experiment will be conducted on energy savings strategies and power consumption.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview Of Energy

Energy is fundamental to almost every aspect of modern life, playing a important role in economic development, environmental sustainability, and overall human well-being. Energy is an essential factor that drives economic expansion by facilitating transportation, industry, and services. Nations having large and accessible energy resources typically have more stable economies. The International Energy Agency (IEA) states that the development of industry and the generation of jobs depend on having access to reliable energy, both of which are necessary for economic progress (EIA,2020). Access to energy significantly improves living standards by powering homes, providing clean water, enabling healthcare services, and facilitating education. Many of the Sustainable Development Goals (SDGs), such as reducing poverty, promoting good health, and providing high-quality education, depend on having access to energy, according to the United Nations (UN, 2023).

Technological advancement is driven by energy innovations, which also open new business and employment opportunities. Our ability to create and use energy is changing because of developments in energy storage, smart grids, and renewable technologies. Pollution and greenhouse gas emissions are two major effects of energy production and use on the environment. Addressing climate change and safeguarding ecosystems require a shift to clean and renewable energy sources. Energy is key to modern society's growth and operation. It stimulates economic growth, raises living standards, backs technical innovation, encourages environmental sustainability, strengthens national security, makes transportation possible, and guarantees food security. It is essential to concentrate on sustainable and effective energy solutions to properly satisfy current and potential demands as the world's population grows and the demand for energy rises.

### 2.1.1 Requirement and Importance Of Energy

Every year, the world's energy consumption rises because of population expansion and economic advancement. Between 1990 and 2020, the world population expanded by 47.67%, which resulted in a large increase in global energy consumption of 69.22% . Over the past three decades, energy use in European countries has stayed constant, whereas energy consumption in Asian countries has increased the greatest. However, because of the global economic recovery that occurred between 2020 and 2021, global energy consumption increased by 5% overall following the COVID-19 pandemic. According to ExxonMobil, global energy consumption would increase by more than 15% between 2021 and 2050. 70% of the world's energy consumption is provided by the power producing industry, particularly in developing nations. Additionally, the transportation industry will have a 30% increase in the world's energy requirement (Mohan, M.2021).



After the COVID-19 pandemic, there was an increase in the demand for energy worldwide in 2021. Fossil fuels, which comprise 38% of petroleum, 23% of coal, and 20% of natural gas, were the most widely used energy sources. Between 2020 and 2021, the emissions of carbon dioxide (CO2) increased by 5.3% because of these fossil fuels. This may result in a climatic crisis and other serious environmental effects on the well-being and life conditions of people and animals. However, the energy sector has faced the challenge of exceeding the energy production issues while using appropriate resources for generating energy and cutting CO2 emissions. This is due to the rapidly growing global energy demand and environmental concerns. To achieve global carbon reduction and a sustainable energy supply, alternative energy sources are thus desperately needed in the global energy system (Mohan, M.2021).

According to the Department of Political Science, Yale University, USA, it is expected that the world's oil production will peak before 1990. Given the growing awareness of the social and environmental issues related to coal mining and burning, the United States' abundant coal resources seem to be a mixed blessing. Because of the severe safety and environmental risks involved, nuclear power is now more expensive than it was ten years ago. Since the world's energy supplies are so unfairly divided, there is a very real risk of violent international conflict if energy costs continue to climb over the next ten years. Therefore, it should be helpful to summarize what is known about the supply and demand for energy around the world and to think about some implications for energy research and development both domestically and internationally (Russett, 1979).

### 2.1.2 Limitation Of Energy

Energy is divided into renewable energy and non-renewable energy, because of that, there is a limitation of using this energy without any precautions. The worldwide usage of fossil fuels exceeds the rate at which they are produced, and they are not renewable. This has given rise to worries about the upcoming "peak oil" and ultimate depletion of these resources. Dependency on limited resources makes nations without domestic resources economically and strategically fragile (Bazilian, M & Onyeii, l. 2012).

Carbon dioxide (CO2) and other greenhouse gases are released in huge quantities during the burning of fossil fuels, which contributes to climate change and global warming. Furthermore, the extraction and processing of fossil fuels may result in damage to habitat, loss of biodiversity, and contamination of the air and water. The effects of these environmental changes on agriculture, water supplies, human health, and the stability of entire ecosystems are severe (Sovacool, et al., 2021). This is the reason why fossil fuels should be limited by time.

One common suggestion for a sustainable energy source is the use of nuclear technology, either entirely or in combination. Nuclear power is indeed one of the main mitigation technologies that is currently commercially viable, according to the Intergovernmental Panel on Climate Change (IPCC). The persistent misconception that nuclear energy is a "emission free" source of energy and is frequently reported as having "0 emissions" in tables comparing energy sources is widespread in the media and even in peer-reviewed literature (Pearce, J. 2012).

This is because nuclear energy does not produce carbon dioxide (CO2) as a byproduct during the electricity generation process, unlike fossil fuels. The Nuclear Energy Institute reports that there are 104 nuclear reactors in the U.S. that provide electricity "while emitting no carbon dioxide". When considering the nuclear fuel life cycle, these ideas are regrettably naive, CO2 emissions are a result of every kilowatt-hour of nuclear energy, with the precise amount depending on location and several technical considerations. As an example, some studies have indicated that nuclear power plants can even release almost the same amount of CO2 per unit of electricity as a natural gas power station, depending on the source and quality of the ore, milling, mining, and transporting of uranium (Pearce, J. 2012).

Fossil fuels are the main source of electricity in Malaysia. In 2009, fossil fuels like coal, oil, and natural gas produced nearly 94.5% of the world's electricity. Hydroelectric power produced the remaining amount. It appears that fossil fuels account for the majority of energy generation. In the fourteen years between 1995 and 2009, Malaysia's power generation increased by over 154%. Fig. 2.1 shows the Malaysia generation mix of electricity for year 1995, 2003 and 2009 (Shafie et al., 2012).

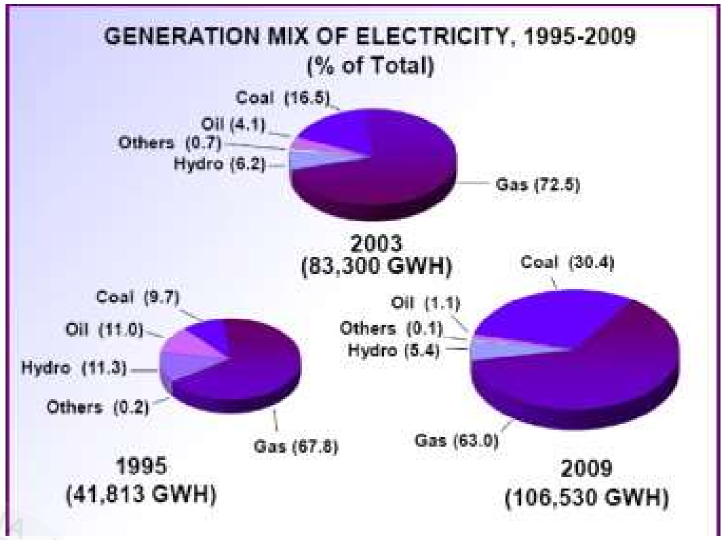



Figure 2.1; Generation of mix electricity, 1995-2009 (Shafie et al., 2012).

Gas and electricity were the primary energy sources used in the industrial sector. Malaysia's electricity energy sector is predicted to develop, with demand for power estimated to rise from 91,539 GWh in 2007 to 108,732 GWh in 2011. With the rapid economic development, Malaysia needs more and more resources to support the industrial development and to enhance the productivity of capital, labor and other factors to production. Although Malaysia is well-known for having significant petroleum resources, its share in the global market is quite minimal. Compared to Saudi Arabia (260 billion barrels), Iran (138 billion barrels), and Iraq (115 billion barrels), Malaysia has relatively little oil reserves (approximately 5.5 billion barrels). For natural gas, Malaysia has 88 trillion cubic feet (tcf) of reserves, which is significantly less than those of Qatar (900 tcf), Iran (1046 tcf), and Russia (1680 tcf). Countries will compete over the remaining stocks of fossil fuels as they deplete and get more costly. We should currently explore other energy sources, especially renewable ones (Shafie et al., 2012).

### 2.1.3 Future Of Energy

The role of renewable energy resources in the overall primary energy supply is growing. Currently, 15% of the world's primary energy comes from renewable resources. The majority of this comes from hydropower (3%), bioenergy (10%), and other renewable energy sources (2%), like wind and photovoltaic (PV). According to integrated assessment models (IAMs) and scenarios by the World Energy Outlook, renewable energy sources might provide 20–30% of the world's primary energy by 2040. Additionally, research indicates that it may be possible to transition to a fully renewable energy system by 2050 (Gernaat et al., 2021).

Future climate change may affect renewable energy resources, as they are climate dependent. To quantify this effect on important renewables, we here employ integrated assessment models and the climate. Eight technologies are evaluated in terms of their future potential and costs across two warming scenarios: hydropower, first-generation and lignocellulosic bioenergy, concentrated solar power, onshore and offshore wind energy, and utility-scale and rooftop photovoltaic. Next, the cost-supply curves that are produced are used to calculate the effects on the energy system. Though this depends on the degree of CO2 fertilization, the biggest effect under a baseline warming scenario is an increase in the availability of bioenergy. Impacts on wind and hydropower are unpredictable, with rises and decreases in different areas, and no effect on solar energy. These effects are less in a future mitigation scenario, but because the mitigation scenario depends more heavily on renewable energy sources, the energy system reaction is comparable to the baseline scenario (Gernaat et al., 2021).

## 2.2 Energy Consumed by Sector

In the industrial sector, energy is the primary means of powering machinery and producing goods. Industries employ harmful forms of energy. In the majority of industries, fuel and electricity. The main fuels used in the industrial sector are kerosene, diesel, petrol and gas. Kerosene is a fuel used by very few companies. Petrol usage has grown quickly in response to the industrial sector's rising energy needs. Petrol is utilized in the food industry sector around twice every ten years (Saidur et al., 2007).

### 2.2.1 Transportation and Industrial Sector

The term "transportation energy use" describes the total amount of energy used for the manufacturing, running, and dismantling of all infrastructure and vehicles within the transportation industry. This adds to the overall final consumption of a sector, which is an indicator of all the energy the sector is using. Energy can be used in transportation in a variety of ways; primarily, it is used to power cars and other vehicles through the burning of fuel, but it is also used in the manufacturing of the vehicles as well as in the construction of highways, airports, seaports, and pipelines (World Energy Balance, 2017).

The wise use of industrial energy is what enables industries to harvest resources and manufacture commodities. While both are companies, industrial energy usage is different from industrial energy use in that the former refers to the production of commodities, typically from raw materials, while the latter involves engaging in commerce. Energy can be used by enterprises in a variety of ways; the metal, paper, and pulp, chemical, and food industries utilize a significant amount of it (World Energy Balance, 2017).

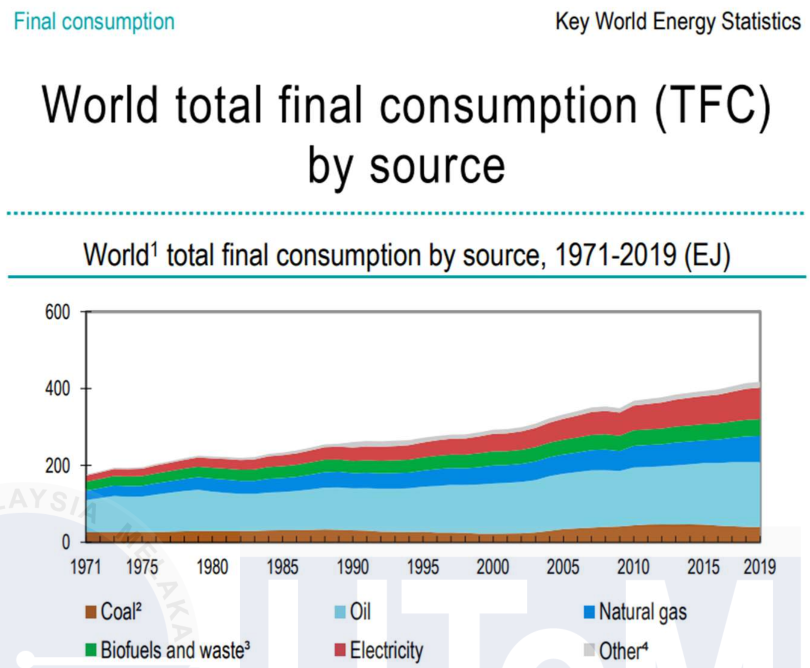



Figure 2.2: World’s Total Final Energy Consumption by Source, 1971-2019, (IEA, 2019)

### 2.2.2 Residential and Commercial Sector

Several reputable sources have conducted comprehensive studies of the world's energy use in the residential and commercial sectors. The International Energy Agency (IEA) estimates that in 2022, the buildings sector which includes both residential and commercial structures will be responsible for around 34% of global final energy consumption. With a consistent yearly growth rate of almost 1% during the previous ten years, this sector accounts for a significant portion of the world's energy consumption. The demand for energy services like space cooling, which grew by more than 3% from the previous year, is the factor that drives this expansion (UNEP, 2023).

Particularly in the residential sector, energy consumption for appliances, lighting, heating, and cooling is high. Energy efficiency is being worked on, but challenges including high upfront expenses and low public awareness prevent progress. In order to lower energy consumption and related emissions in this industry, investments in energy efficiency technology and techniques are considered essential (Belaid et al., 2023).

The amount of energy used worldwide is also greatly influenced by commercial buildings, which include public buildings, retail establishments, and workplaces. Usually, they utilized energy for lighting, heating, cooling, and running different appliances. Commercial building energy consumption patterns are impacted by a number of variables, including building size, occupancy, and energy system type. To lessen its influence on the environment, the commercial sector plans to focus on increasing energy efficiency and switching to renewable energy sources, much like the residential sector does (UNEP, 2023).

## 2.3 HVAC System Energy's Usage

Heating, Ventilation, and Air Conditioning (HVAC) systems account for a significant portion of energy consumption in buildings. Globally, HVAC systems are estimated to consume about 40% of total building energy usage. This energy consumption is largely due to the need for heating, cooling, and ventilation to maintain indoor air quality and thermal comfort (IEA,2021).

The demand for energy has increased because of the faster rate of population expansion. According to estimates from the International Energy Agency (IEA) in 2013, buildings are now the third-largest energy consumers worldwide. In most buildings, lights, electrical equipment, and HVAC systems use the most energy. Numerous studies demonstrate that indoor climate control accounts for half of the building's energy use. The design of the building, modifications to occupant comfort standards, building management and maintenance, and HVAC system design all have a significant impact on the rise in building energy consumption. Comfort of the occupants and energy usage should be considered in the design of all those elements (Nasruddin et al., 2019).

### 2.3.1 Residential and Commercial HVAC System

In the residential sector, HVAC systems contribute significantly to overall energy usage. For instance, space cooling saw a notable increase in demand of over 3% in 2022, while space heating energy consumption decreased by 4% due to milder winters in some regions, like Europe. In total, buildings (residential and commercial) consume around 30-34% of global energy, with HVAC systems being a substantial part of this consumption (IEA, 2023).

The building industry, which uses the most electricity, has a significant potential to contribute to energy consumption reduction. Commercial buildings use more energy (per unit area) than other types of buildings because of their functional and operational features. In these buildings, one of the main energy consumers is the HVAC system (heating, ventilation, and air conditioning), especially in harsh climates. HVAC systems are regarded as an essential component of buildings in hot climates since they are necessary for the buildings to function and to maintain a certain level of indoor environmental quality. It is evident from the average breakdown of commercial building energy consumption per year that HVAC systems use the most energy (Fasiuddin & Budaiwi, 2011).

### 2.3.2 Optimizating HVAC System Operations

Modern HVAC techniques and technology are being used to improve energy efficiency. Demand-controlled ventilation, inverter controls, and the usage of variable speed fans are a few of them. These steps can cut rooftop packaged air conditioner energy usage by roughly 17%. Additionally, combining HVAC systems with renewable energy sources, such solar thermal systems, can drastically cut carbon emissions and dependency on conventional energy sources. Efforts to improve HVAC energy efficiency are also driven by regulatory changes and the adoption of new refrigerants with lower global warming potential. This transition is critical to reducing the environmental impact of HVAC systems (Department of Climate Change, Energy, the Environment and Water, 2023).

The HVAC sector generally employs innovative technology as part of its efforts to combat climate change and promote sustainability. The industry has been able to enhance current building operations and lower energy usage and related carbon emissions thanks to this crucial step. Technology is being used in building control methods, time schedule optimization, temperature adjustments for the boiler and chiller, and nighttime free cooling. One example of this is the usage of Internet of Things (IoT) sensors. One way to automate HVAC services and offer the ideal quantity of heating, cooling, and ventilation when and where it is actually needed—that is, when the building or room is occupied is by connecting Internet of Things sensors with building management systems. This gets rid of the requirement for HVAC systems to operate continuously at 100%, which is how buildings are typically operated. These technological developments can aid in a 50% reduction in energy usage and a more efficient balance of building operations (Alex Bax, 2022).



Building energy consumption from HVAC systems can be reduced by making plans far in advance of both the system's purchase and the building's construction. When designing a low-energy building, consideration must be given not only to the HVAC system's efficiency but also to the various combinations of materials and their thermal properties, including wall thickness, wall material, window width, window material, and window blind kinds. These elements influence the structures' life cycle costs as well as their energy demands and consumptions (Hazlina Selamat, 2020).

## 2.4 Refrigerants and Their Impact

Refrigerants are used by many contemporary appliances, including water heaters, air conditioners, heat pumps, and freezers, to transport heat from sources to sinks. Substances or combinations used in heat cycles that undergo a phase shift from gas to liquid and vice versa are known as refrigerants. Refrigerant cylinders are colour coded to prevent unintentional mixing of refrigerants within the system. The refrigerant categorization system was standardised by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). Refrigerants are typically identified using a letter (R-stands for refrigerant) followed by a number (Vuppaladadiyam et al., 2022).

Most of the refrigerants that are commonly used belong to any of the following five categories: (i) chlorofluorocarbons (CFCs), (ii) hydrochlorofluorocarbons (HCFCs), (iii) hydrofluorocarbons (HFCs), (iv) natural refrigerants and (v) refrigerant blends (zeotropic blends and azeotropic blends). Though advancements in technology and economy have contributed to the increased awareness of refrigeration systems worldwide, the emissions from these systems have the potential to negatively impact the environment by increasing the Earth's surface temperature and reducing ozone levels. Continuous efforts are being made by the regulation agencies in ruling out the harmful refrigerants and replacing them with environmentally benign alternative refrigerants (Vuppaladadiyam et al., 2022).



### 2.4.1 Types of Refrigerants

The majority of early refrigerants were used in industrial systems because they were dangerous or flammable at the start of the 20th century. Ammonia is toxic and flammable, but it is difficult to ignite, and is commonly employed in ice-making plants. Dangerous sulphur dioxide or flammable and hazardous methyl chloride were utilised in smaller systems. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), commonly referred to as "freons," are a class of halogenated chemicals that were developed in response to the need for safer refrigerants that could be used in both residential and commercial settings. In the 1990s, a comparable class of compounds known as hydrofluorocarbons (HFCs) were introduced to the market as alternatives. The global warming potential (GWP), a measurement of a gas's climate impact in relation to carbon dioxide (CO2), indicates that although the HFCs lack chlorine and so have no ozone depletion potential (ODP), they nevertheless maintain the heat-trapping properties of the CFCs and HCFCs (McLinden et al., 2020). Figure below shows the example of refrigerants based on their elements.

Table 2.1 The refrigerants based on their elements (Admin, 2021)

| **Type** | **Name** | **Chemical Name** | **Formula** | **A. Life** | **GWP** | **ODP** |
|---|---|---|---|---|---|---|
| CFC | R-12 | Dichlorodifluoromethane | $CCI_2F_2$ | 100 | 10200 | 1 |
| HCFC | R-22 | Chlorodifluoromethane | $CHCIF_2$ | 12 | 1760 | 1.05 |
| HFC | R-32 | Difluoromethane | $CH_2F_2$ | 4.9 | 677 | 0 |
| HFC | R-134a | 1,1,2,2- Tetrafluoroethene | $C_2H_2F_4$ | 9.6 | 1120 | 0 |
| HFC | R-407a | R-32/125/134a (20+2/40+2/40+2) | | 18 | 2107 | 0 |
| HFC | R-407C | R-32/125/134a (23+2/25+2/52+2) | | 15 | 1704 | 0 |
| HFC | R-410a | R-32/125 (50+1.5, -1.5/50+1.5, -0.5) | | 17 | 2088 | 0 |
| HC | R-290 | Propane | $C_3H_8$ | 12 | 3 | 0 |
| HC | R-600a | Isobutane | $C_4H_{10}$ | 12 | 3 | 0 |
| | R-717 | Ammonia | $NH_3$ | 0 | 0 | 0 |
| | R-718 | Water / Steam | $H_20$ | 0 | 0 | 0 |



### 2.4.2 Environmental effects of refrigerants

The release of synthetic chemicals into the atmosphere has resulted in ODP, which is the first significant environmental impact on the refrigeration-based sectors. Because the chlorine atoms in the refrigerants are stable enough to reach the stratosphere, they can cause the destruction of the stratospheric ozone layer, which shields the earth's surface from direct ultraviolet radiation. Between 10 and 50 km above the earth's surface, the stratosphere contains 90% of the ozone that is present there. The first phase out schedule for the harmful refrigerants formulated by the Montreal protocol (1987) and was made stringent during the follow-up international meetings (Paul et al., 2013).

The absorption of infrared radiation from the earth, which raises the planet's surface temperature globally, is the second main environmental impact, or global warming potential (GWP). The majority of the sun's radiation, which enters the planet at 5800 K and 1360 W/m2, travels through the atmosphere before returning to space in excess of 30% of the time. The earth is heated by solar radiation that has a spectral peak in the infrared wavelength region, heating it roughly to the temperature of a black substance. The absorption of this infrared light by greenhouse gases, such as halogenated refrigerants, prevents it from passing through the atmosphere. Consequently, the temperature of the atmosphere rises, a phenomenon known as global warming. Worldwide commitments to cut greenhouse gas emissions were made voluntarily when the Kyoto Protocol was being formulated. In comparison to refrigerants based on chlorine, HFC refrigerants have comparatively large values of both atmospheric lifetime and GWP (Paul et al., 2013).



### 2.4.3 Future of refrigerants

Advances in technology, stricter regulations, and growing environmental concerns are going to have a big impact on refrigerants in the future. The worldwide community has agreed to phase out high global warming potential (GWP) refrigerants, especially hydrofluorocarbons (HFCs), by over 80% over the course of the next three decades, via accords such as the Kigali Amendment to the Montreal Protocol. Natural refrigerants like ammonia, carbon dioxide, and hydrocarbons which are preferred for their low greenhouse gas footprint and low ozone depletion potential (ODP) are becoming more and more popular as a result of this change (US EPA, 2014).

Through developments in compressor technology, heat exchanger design, and overall system integration, technological innovations are also improving the energy efficiency of refrigeration systems, lowering operating costs and having a positive environmental impact. Stricter regulations are being implemented by governments and international organisations. One such regulation is the F-Gas Regulation of the European Union, which seeks to considerably cut F-gas emissions by 2030. It is anticipated that continued efforts in chemical engineering and materials science will produce new, ecologically friendly refrigerants, demonstrating the importance of continual research and innovation. When taken as a whole, these patterns show a clear shift towards environmentally friendly refrigerant options, spurred by legislative changes and the pressing need to combat global warming (Gao et al., 2018).

Hydrofluoroolefins (HFOs) are the primary form of refrigerant that has the potential to become the next widely used refrigerant type since they have a lower global warming potential and don't destroy the ozone layer. Its global warming potential is just four times higher than that of conventional carbon dioxide, but it is nearly 300 times lower than that of some HFCs. Numerous automakers in the United States have now shifted to using HFOs in their vehicles after the European Union outlawed some HFCs and began to transition to HFOs. There are also a number of natural refrigerants that, while they might not be as effective as some, have little to no potential to cause global warming and don't include chlorine, which destroys ozone. For instance, natural refrigerants like carbon dioxide, ammonia, and propane are suitable substitutes for a range of other refrigerants, including the well-known HFC blend R404A (The Future Of Refrigerants, 2020).

Hydrofluorocarbon refrigerants such as Difluoromethane or well-known as R32 is actually a good refrigerant. (Rohit Patil et al., 2020) studied all known and currently used refrigerants, as well as those that are outdated, were thoroughly analysed using several high-quality international journals and research publications. All currently used refrigerants were

`

compared to the pure refrigerants of the next generation. Following a thorough analysis of each refrigerant's thermophysical characteristics, it was determined that laboratory tests involving comparisons of R134a, R410a, and R32 were necessary. Following trial, every point was taken into account while putting the strategy into action to ensure its success. R32 must be used as an alternative to other refrigerants in the RAC industry because the research findings showed that it performed significantly better in terms of heat transfer and pressure drop than any other refrigerant.

### 2.5 Residential Air Conditioning (RAC) Experiments

For researchers to assess how effectively various refrigerants function thermally, especially in reaction to changes in refrigerant charge and ambient factors, the refrigeration and air conditioning (RAC) experiment is required. Research has indicated that the choice of refrigerant has a significant impact on energy consumption, environmental sustainability, and system efficiency (ASHRAE, 2019). This experiment compares R32 with R410A in order to evaluate their suitability for use in air conditioning systems, with an emphasis on energy efficiency, cooling capacity, and condenser temperature fluctuations. With a lower Global Warming Potential (GWP) of 675 than R410A's 2088 GWP, research indicates that R32 provides a more environmentally friendly option (UNEP, 2022). Its modest flammability (A2L rating) calls for further safety precautions, albeit (ISO 817:2014). In order to facilitate the shift to more sustainable and energy-efficient refrigerants, this study attempts to present empirical evidence.

#### 2.5.1 Temperature Control Room

When doing an experiment that consists of harmful or non-environmental products, the experiment should be done in a controlled room. This may prevent the harmful products expose to environment and it is convienient to control the parameters. According to (Mahyuddin % Awbi, 2010), although classroom surroundings are the main focus of this research, the section that will be presented here is primarily based on experimental tests that were carried out in a full-scale test chamber with various ventilation techniques under transitory situations. This chamber is divided into two sections: the working space, measuring 2.78 × 2.78 × 2.3 m (ceiling height), and the environment control room, which houses the air conditioning equipment. The environment control room's air conditioning is supplied by an air handling device, which has a compressor outside the chamber and can heat the compartment to 35 °C or cool it to -5 °C. A cooling coil, fan, and heater regulate the heating and cooling. To get the appropriate temperature in the room, a PID temperature controller is utilised.

Another experiment conducted by (Azmi et al., 2024) "Tribological and residential air conditioning performance using SiO2-TiO2/PVE nanolubricant". Inside a temperature control room (TCR) constructed in accordance with ISO5151:2010 standard was the residential air conditioning (RAC) test equipment installed. There are two distinct regions that make up the TCR: the interior area and the outdoor area. Each section had an air handling device attached to it to regulate the environment as specified by the standard. Multiple air conditioning units were used to maintain a regulated temperature of 296 K for the TCR in the laboratory.

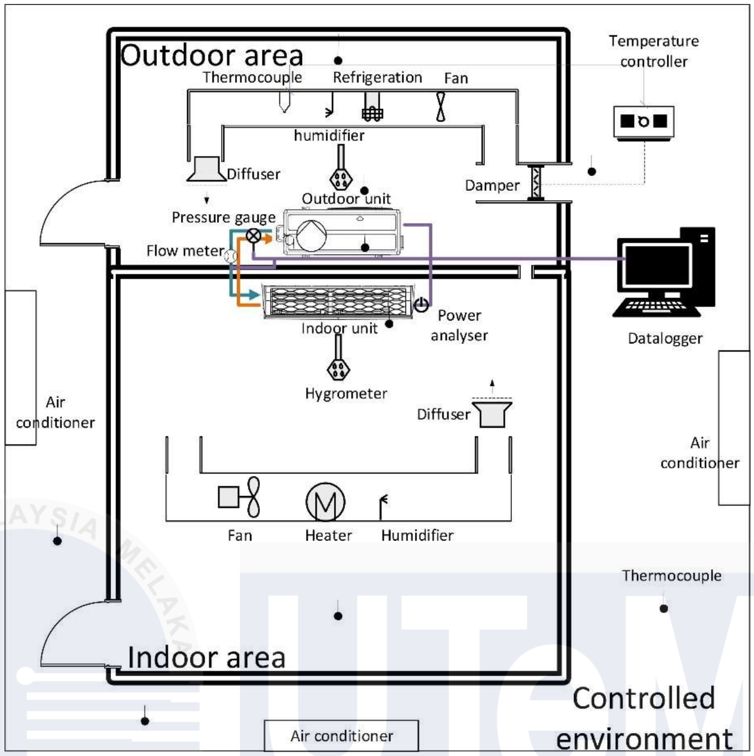



Figure 2.4: The test rig setup in environment control room by (Azmi et al., 2024).

### 2.5.2 Safety Precautions For Flammable Refrigerants Handling

Because of safety concerns, flammable hydrocarbon refrigerants have not been used in standard air conditioning applications for the past few decades. It has been determined that hydrocarbon refrigerants, like R290, are safe, colourless, and odourless refrigerants with superior thermos-physical qualities. However, because of its flammability, it was disregarded after the invention of CFC and HCFC. Hydrocarbon refrigerant has excellent energy performance and emission control, but it is quite flammable. To take into account its flammability features, compatibility with materials and equipment, and relevant regulations for its safe usage and handling, risk and safety analysis is required. Risk assessment of flammable natural refrigerant application in air conditioning systems (Anonymous, 2022).

Choudhari and Sapali (2017) claim that R290's flammability is a serious worry. But keep in mind that when it comes into contact with air, it does not spontaneously catch fire. The proper ratio of 1% to 10% of refrigerant to air must be released, and there must be an ignition source with an energy larger than 2.5 x 10-4kJ or a surface temperature greater than 440°C in order for any incidents to occur. R290 can be used safely if a few safety measures are taken. The key principles of a safer use of flammable refrigerants are charge minimization, seal tight systems, and adequate ventilation. A number of organisations and groups are collaborating to create new safety guidelines for the use of combustible refrigerants. The majority of current rules reject R290 since, for approximately 50 years, safe refrigerants like CFCs and HCFCs were an option. In the near future, these limitations are anticipated to be loosened due to the requirement for environmentally and energy-friendly refrigerant.

Recent research on Safety Considerations (DCCEEW, 2022) claim that The Commonwealth Ozone Protection and Synthetic Greenhouse Gas Management Regulations of 1995 prohibit the handling of natural refrigerants, including hydrocarbons, from the need for a refrigerant handling permit. However, a valid refrigerant handling licence is required for anyone handling fluorocarbon refrigerants, such as halocarbons, hydrochlorofluorocarbons (HCFCs), HFCs, and CFCs but without permission or a licence from the appropriate government, using hydrocarbon refrigerants to maintain or repair air conditioning systems may be illegal in various states and territories.

## 2.6 Energy Saving Strategies of Split Unit

Saving energy is important for split units since it lowers greenhouse gas emissions, lowers power costs, and has a smaller environmental effect. In addition, it saves maintenance costs, increases the unit's lifespan, and guarantees that energy efficiency laws are followed. Furthermore, energy-efficient appliances frequently provide better comfort and performance.

An experiment by (Nethaji & Mohideen, 2017) shown they cooled a compressor shell using a refrigerator's defrost drips to enhance a compressor's performance. The experiment's findings showed that, in comparison to the original refrigerator, the compressor shell temperature was lowered by about 6.5%, and that energy savings and COP improvements were 10.3% and 9.7%, respectively. Wang et al (2010) tested the performance of household air conditioners using R134a, R407C, R410a, and R425a as refrigerants and added NiFe2O4 nanoparticles to the naphthene-based oil B32. The outcomes of the experiment showed that substituting a nanolubricant for the polyol-ester oil VG32 lubricant resulted in a 6% increase in the energy efficiency ratio (EER).

A high heat-transfer performance refrigerant not only improves the evaporator's heat exchange efficiency but also lowers the temperature of the refrigeration oil, reduces compressor friction loss, and raises the motor's winding temperature, all of which extend the compressor's service life and operational efficiency. Furthermore, certain carefully engineered cooling systems and designs can also accomplish the intended cooling effect on the compressor (Chan & Teng, 2018).

### 2.6.1 Factors Affects The Energy Savings



Vakiloroaya et al (2014) states that a HVAC system's energy consumption is determined by its performance and operating parameters as well as the building's thermodynamic behaviour and the nature of the heating and cooling demands. Because of the way buildings behave, the HVAC systems' actual load is typically lower than their intended load during operation hours. Therefore, effective demand control for heating and cooling is one of the most important aspects in reducing HVAC energy consumption in a particular building.

Recent research on Critical Factors That Impact Your Air Conditioning Efficiency Rescue Rooter (n.d) claims that the thermostat's temperature set point is another factor that affects how efficient the air conditioner is. The air conditioner has to use more energy for every degree that the outside and inside temperatures diverge in order to maintain a substantial temperature differential between the cooling space and the outside environment.

The HVAC system's performance is greatly affected by its size. Bigger air conditioners have the power to quickly cool or heat a house. Smaller units, however, can find it difficult to meet the temperature needs. Not to mention that it will cycle off due to the huge related air conditioning system, consuming a lot of electricity in the process. The air conditioning system's efficiency is further decreased by poor insulation. Heat can go from the inside to the outside of your house due to it, which raises the temperature and makes the air conditioner work harder to reach the right cooling temperature (Robert & Robert, 2022).

### 2.6.2 Advancement Technology in Energy Savings

Split unit air conditioner technological developments are a big step towards increased energy savings and environmental responsibility. The environmental effects and running expenses of air conditioning are being reduced by innovations including energy recovery systems, smart systems, eco-friendly refrigerants, enhanced filtration, and inverter technologies. These technologies have the potential to produce even more effective, affordable, and long-lasting climate control solutions in the future as they develop further.



The compressor's revolutions are changed by the inverter air conditioner to easily adjust capacity. The capacity of the inverter air conditioner may be adjusted based on the load: at low frequencies, it produces low capacity with low revolutions, and at high frequencies, it produces high capacity with high revolutions. The system is intended to manage the anticipated peak demand, not this fluctuating load, and the non-inverter functions at constant capacity (Almogbel et al., 2020).

Yoon et al. (2018) conducted a study on the performance of inverter and non-inverter air conditioners in Riyadh and Seoul. This investigation was conducted in a properly calibrated, airtight style test room with a certain size and a constant 26.0 °C air conditioning temperature setting (outside side: temperature; indoor side: heat flow controlled). In Saudi Arabia, the cooling season is nine months, while in Korea it is four. The findings show that even in the hot temperature of Saudi Arabia, inverter air conditioners are more energy efficient than non-inverter air conditioners. In the months of March through November in Riyadh, energy savings of 18.3% to 47.1% were noted for inverter-type systems; in contrast, during the months of June through September in Seoul, energy savings ranged from 36.3% to 51.7%.

Another technology that helps to increase the energy savings in HVAC system is timer control. An experiment was conducted by (Sha et al., 2008) in UMP's lecture halls and lab shows that setting up the timer control could cut down on energy waste by roughly 4%, or RM 5881.92, annually. The estimated return on investment is 3.2 years. The goal of developing a new intelligent control system for energy conservation is to reduce the energy consumption of the air conditioning system in the lecture hall and laboratories by 10%.

Henry et al., (2015) says that to investigate the effects of different frequencies between 15 and 50 Hz on the variable speed compressors (VSC) application, a number of experiments were carried out. The temperature and speed are influenced by the energy consumption and cooling capacity of the system, which is dependent on the motor's frequency. Split unit air conditioning systems that use VSC offer greater energy savings and improved energy efficiency. Better thermal comfort will result in increased system efficiency from the inverter-driven compressor motor operating at a higher frequency at higher thermal loads and vice versa. Compared to the existing thermostat controller, Fuzzy logic controller (FLC) offers better control and bigger energy savings.

## 2.7 Summary

Energy is critical for economic development, environmental sustainability, and overall human well-being, driving growth and improving living standards. Global energy consumption has significantly increased due to population growth and economic development, with a considerable reliance on fossil fuels. Between 1990 and 2020, the world population expanded by 47.67%, leading to a 69.22% increase in global energy consumption. This trend is expected to continue, with predictions suggesting a further 15% increase by 2050. The extensive use of fossil fuels, which constitute 38% of petroleum, 23% of coal, and 20% of natural gas, has resulted in a 5.3% increase in carbon dioxide emissions between 2020 and 2021, contributing to climate change and environmental degradation. This highlights the urgent need for a shift towards clean and renewable energy sources to mitigate these issues.

Energy consumption varies across sectors, with the industrial and transportation sectors being major consumers. The industrial sector relies heavily on fossil fuels for powering machinery and producing goods, while the transportation sector's energy use is expected to increase by 30%. In residential and commercial sectors, energy consumption for appliances, lighting, heating, and cooling is high, driven by a consistent yearly growth rate of about 1%.



Efforts to improve energy efficiency and adopt renewable energy sources are crucial for reducing consumption and emissions in these sectors. HVAC systems, which account for about 40% of building energy usage, play a significant role in energy consumption. Innovations such as demand-controlled ventilation, inverter controls, and the use of variable speed fans can significantly enhance HVAC energy efficiency. Additionally, integrating HVAC systems with renewable energy sources like solar thermal systems can reduce carbon emissions and dependency on conventional energy sources.

Refrigerants used in cooling systems pose significant environmental risks, including ozone depletion and global warming. Historically, refrigerants like chlorofluorocarbons

(CFCs) and hydrochlorofluorocarbons (HCFCs) have been phased out due to their high ozone depletion potential (ODP). The transition to hydrofluorocarbons (HFCs) offered a temporary solution, but these still contribute to global warming. Future refrigerants are expected to focus on environmentally friendly alternatives, such as hydrofluoroolefins (HFOs) and natural refrigerants like ammonia, carbon dioxide, and hydrocarbons, which have lower global warming potential (GWP) and ODP. Advances in technology and stricter regulations, such as the Kigali Amendment to the Montreal Protocol, are driving this transition towards sustainable refrigerant options.

Energy-saving strategies for split unit air conditioners include the use of inverter technology, smart systems, and proper maintenance, which can significantly reduce energy consumption, operational costs, and environmental impact. For instance, inverter air conditioners can adjust their capacity based on load, providing low capacity at low frequencies and high capacity at high frequencies, resulting in greater energy efficiency. Studies have shown that inverter systems can achieve energy savings of 18.3% to 47.1% in hot climates like Saudi Arabia, and 36.3% to 51.7% in temperate climates like South Korea. Additionally, technologies such as demand-controlled ventilation and the integration of IoT sensors with building management systems can optimize HVAC operations, leading to a 50% reduction in energy usage.

Overall, energy plays a vital role in modern society, supporting economic growth, improving living standards, and driving technological advancements. However, current practices pose significant challenges, including environmental degradation and resource depletion. Therefore, it is essential to transition to sustainable and efficient energy systems, focusing on renewable energy sources, innovative technologies, and improved energy efficiency to meet future demands and mitigate the adverse effects of climate change.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

Several refrigerants were employed in residential air conditioning (RAC) systems throughout the experimental phase of this study to see how they affected system performance. To accomplish this goal, a test rig was created to produce outcomes that closely mirrored genuine RAC usage and real-world circumstances. To precisely replicate the system's operating conditions, a control room was added to the RAC system test rig. The original working fluid was used to test the RAC system upon installation. The confirmation test was carried out by comparing the experimental results with the information supplied by the manufacturer of the RAC system. If the manufacturer's data and the trial findings differed by less than 5%, the RAC system was replaced with R32 refrigerant.

The outcome of the experiment was designed to collect preliminary data for the R32 working fluid. The purpose of the first test was to find the ideal R32 refrigerant charge. After gathering baseline data, the experiment on refrigerant performance was carried out. Various refrigerants were introduced into the system at varying ambient temperatures. To assess how a new refrigerant will affect the RAC system, performance criteria were used. When the charge is judged satisfactory, the experiment is concluded by gathering data and comparing it to the baseline data until it satisfies the necessary requirements. Figure 3.1 presents a synopsis of the research process.

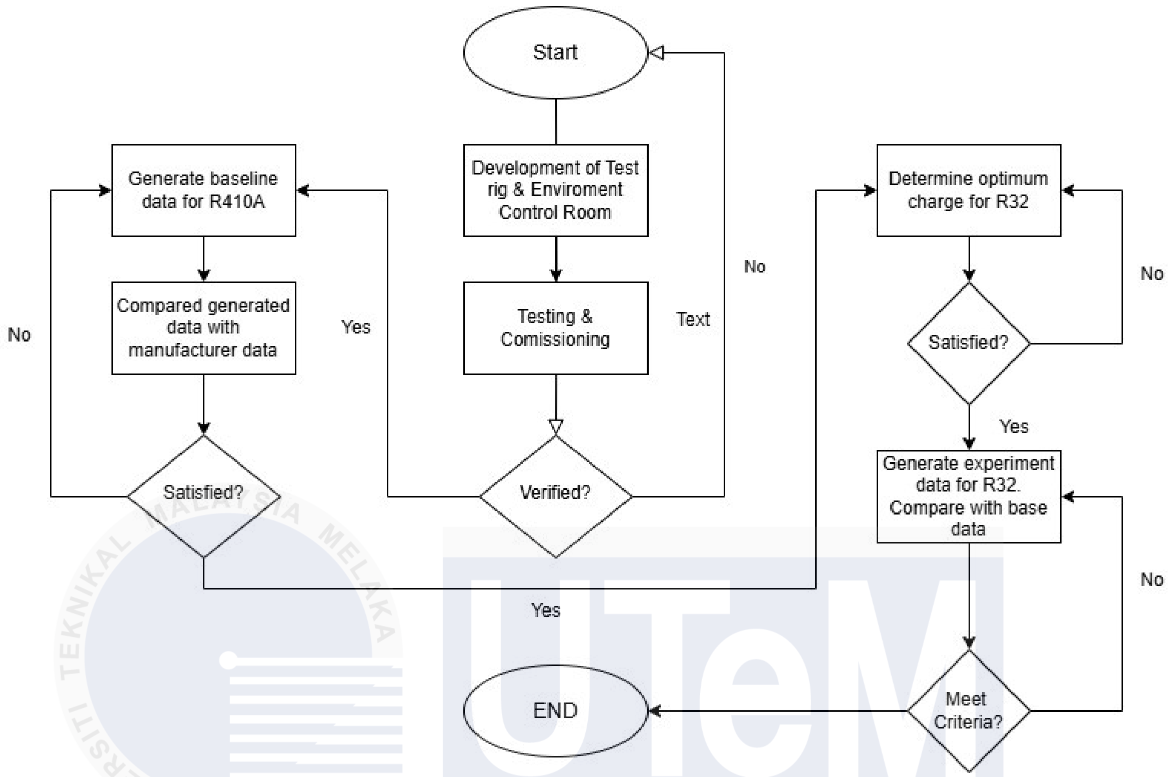



Figure 3.1: Flowchart process for the research

## 3.2 Experimental Setup

The research flow that was previously discussed usually shows the RAC experimental setup. For the test rig, an indoor and outdoor unit were mounted back-to-back on a specially made split-type RAC hanger. With a cooling capability of 9,000 BTU/hour, the RAC was fitted according with the manufacturer's advice as stated in the FTKF25CV1MF Service Manual. The RAC is equipped with a rolling piston rotary compressor. Wearing personal protection equipment and the proper tools were necessary for the installation process. It included installing insulation, condensate water pipes, insulation, and electrical wire connections. Copper lines measuring 0.25 inches for the liquid side and 0.37 inches for the gas side joined the indoor and outdoor units. The standard power input and current for the indoor unit were 819 Watt and 3.22 A, respectively. Located in a temperature control room was the RAC test rig. The indoor and exterior regions are the two separate portions that make up the environment control room. The indoor unit's air temperature was adjusted to 27 degrees Celsius. Table 3.1 provides an overview of the tools and equipment applied in this investigation. The placement of sensors and how they are connected to the data collection device are depicted in the schematic diagram in Figure 3.2.

Table 3.1 Overview of the tools and equipment applied in this research

| EQUIPMENT | DESCRIPTION |
|---|---|
| Indoor unit | Evaporator, blower fan, electronic control board. |
| Outdoor unit | Rolling piston rotary compressor, condenser, condenser fan, capillary tube, discharge valve, suction valve, flow meter sensor head. |
| Thermocouple Hub | Pico datalogger: 8 channels of thermocouples per unit, connected to PC by USB interface. |
| Pressure gauge | Testo 2-way manifold to measure discharge and suction pressure; Data Collection via Bluetooth and software. |
| Power Analyzer | 3-phase power analyzer from Prova (6830A) used to measure power. |
| Flowmeter | Sensor head, controller and display, clamp to measure liquid refrigerant. |
| Refrigeration scale | Digital weigh scale with automatic controller to charge refrigerant into RAC system accurately. |
| Vacuum pump | Single stage vacuum pump (VALUE model VE115N) 2C F; used to evacuate air and moisture from the RAC system up to 150 microns |
| Humidity Meter | Monitoring instantaneous humidity in the indoor and oudoor area |
| Datalogger | Personal computer connected to the Pico datalogger (16 channel), Power analyzer and additional data display. |

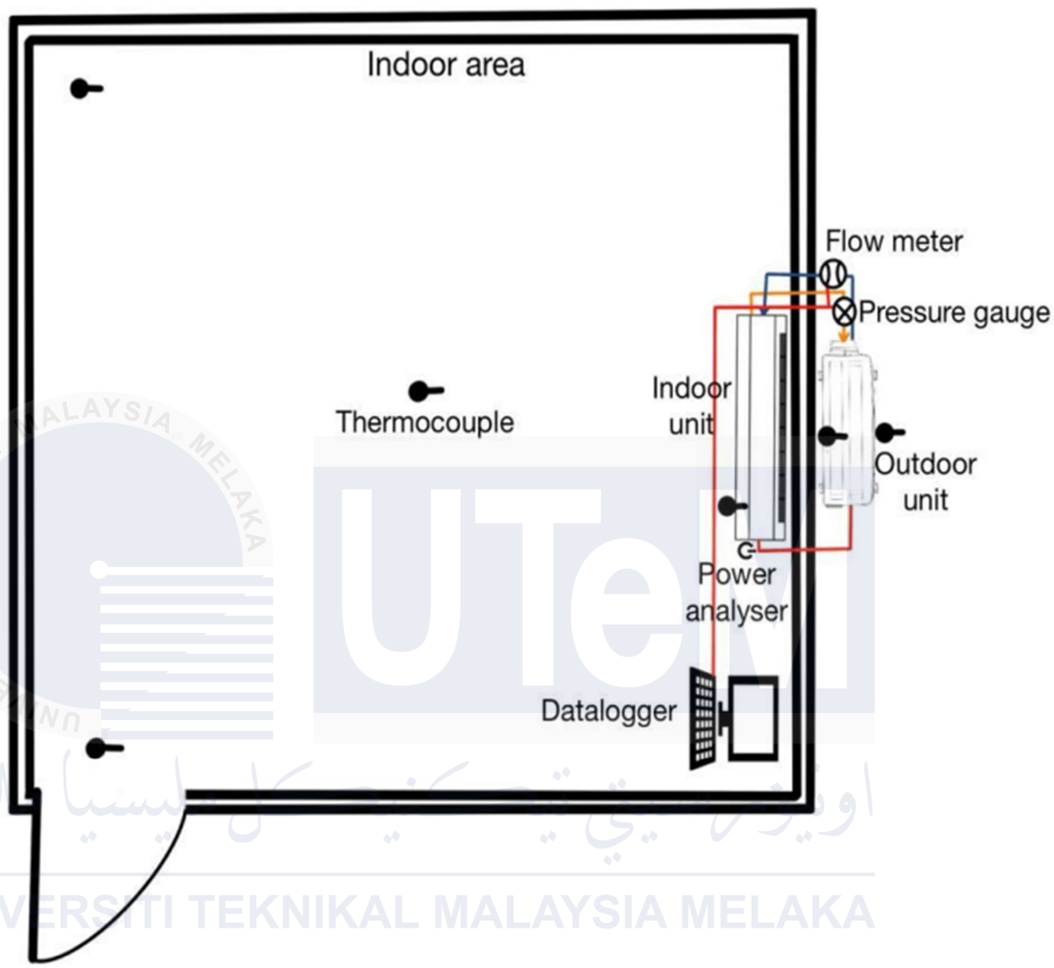





Figure 3.2 Schematic diagram of RAC test rig

Figure 3.3 shows the concept of TCR. Where the exact placement of indoor and outdoor unit of the air-conditioner. This concept is drawn by using a modelling software which is Revit 2025.

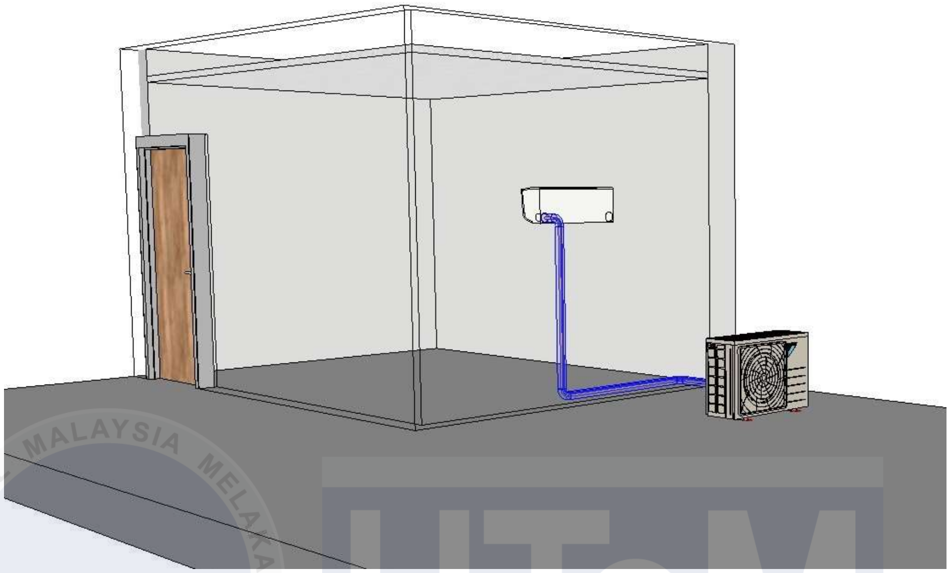


Figure 3.3 Concept Design of the TCR

## 3.3 RAC Experimental Procedure

Upon the final steps of the experimental set-up installation, we carefully inspected and tested each piece of equipment, both separately and as a whole. To stop any possible current leakage, every electrical connection needed to be carefully inspected. The refrigerant circuit underwent a leakage test, which involved inspecting all copper joints and manifold connections. After that, a vacuum pump was used to evacuate the piping system to remove any surplus gas and moisture. For a duration of 12 hours, the system was placed under vacuum to confirm that the refrigerant leakage test produced a satisfactory result. The next step involves adding 225 g of R32 refrigerant to the RAC system.

R32 refrigerant was used to calculate the ideal refrigerant charge prior to the experiment. R32 refrigerant was added to the RAC system in increments of 25 g, ranging from 225 g to 375 g. The indoor area's air temperature stayed steady at 27 °C (Standards-Malaysia, 2014). The RAC was run continuously for an hour to bring it to a stable state.

For the first hour, data was gathered every two minutes to confirm the steady-state condition. Thirty minutes of data collection were done after the steady state was achieved. Using specialized software and a data logger, temperatures, energy efficiency, and pressure rates were tracked and recorded in real time. Two seconds was the constant time interval used to record the data. To combine and interpret experimental data from many equipment, Microsoft Excel was used. To guarantee the consistency of the collected results, the data gathering procedure was carried out several times. For the ultimate experimental outcomes, the mean value for every parameter was computed.

After calculating the ideal refrigerant charge, the experiment proceeded with the use of R32 refrigerant. The air temperature inside the indoor area remained constant at 27 °C, even as the outdoor temperature fluctuated between 31 and 39 °C. The RAC was operated continuously for one hour until it reached a stable condition before the data collection period, which lasted for 30 minutes. Once the data collection was finished, the refrigerant was safely recovered, and the lubricant was collected using a specialized refrigerant handling machine. The refrigerant handling machine consists of five primary components. The components consist of a compressor, an external tank, a cooling system, a set pressure gauge, and a control system.

The experiment with the RAC system was carried out in a previous chapter in order to investigate the cooling capacity and energy efficiency of the R32 drop-in process into RAC. We just changed the energy efficiency and cooling capacity of the drop-in R32 for this experiment. The regulated parameters and the factory default settings were taken into consideration for optimizing the performance of the RAC system employed in this experiment. The instruments and sensors that oversaw gathering data from the RAC system were kept at the location that was indicated in the preceding section. The experiment's output was this set of data.

After the data collection process was completed, the data was analyzed. In the section that follows, the measured parameters used in this experiment's data gathering activity were described. We will examine the analytical strategy applied to the experimental data in the section that follows.

### 3.3 Ambient Temperature Control Chamber

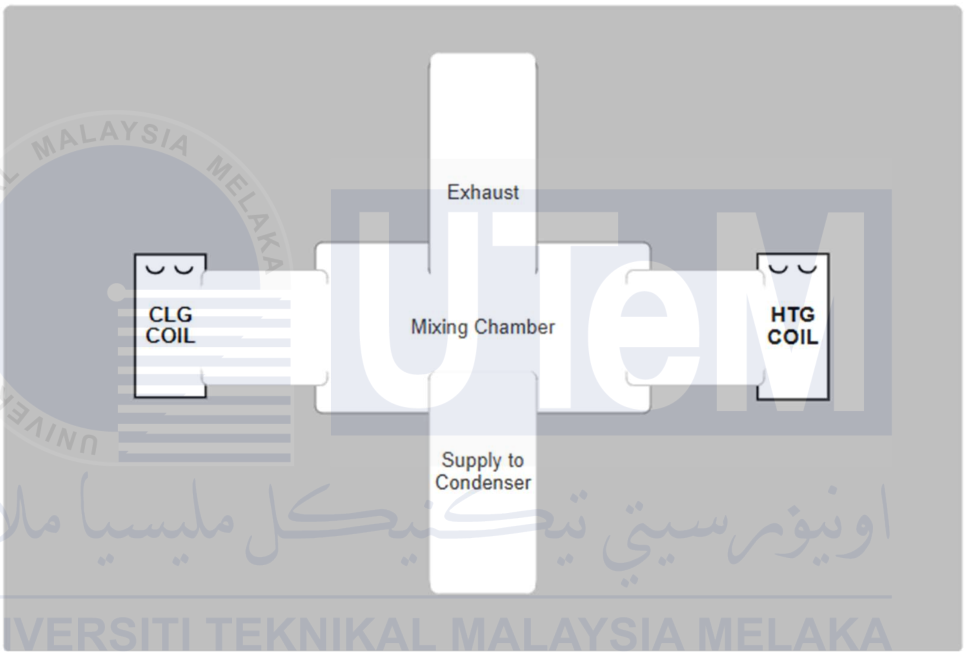





Figure 3.4 Schematic Diagram of Ambient Temperature Control Chamber

By referring to Figure 3.4 above, this is an innovative design which is proposed to control the ambient temperature around the condenser or the outdoor unit of the RAC system. This method consists of a cooling coil, a heating coil, a chamber and an exhaust outlet. The cooling coil is another residential air-conditioning system that will be installed. The source of the heat comes from a heater with 3 kWh power. The body of the chamber is made from acrylic sheets 10 mm thickness which are more durable and have a strong structure. Exhaust outlet's function is to balance the heat among both coils by releasing it to the surrounding. The target of the ambience temperature is about 37 degrees Celsius which is currently a normal day temperature. By controlling the ambience temperature, the data that will be collected are strong enough and have equivalent parameters to be compared with each other. Therefore, there should be no difference conditions between the R410A and R32 data.

## 3.5 Conclusion

This study tested various refrigerants in an air conditioning split-unit (ACSU) system to see how they affect performance. A special test rig was set up to closely mimic real-world conditions. First, the ACSU was tested with its original refrigerant. The results matched the manufacturer's data by within 5%, providing a reliable baseline. Next, the R32 refrigerant was tested to find the ideal charge amount. After this, the system's performance with R32 was measured at different temperatures. The results showed that R32 could effectively replace the original refrigerant without losing efficiency or stability. This research provides useful data for using R32 in RAC systems, supporting its potential real-world use.

The research set up for testing refrigerants in a split-type room air conditioner (RAC) was meticulously designed to replicate real-world conditions. An indoor and outdoor unit with a 9,000 BTU/hour cooling capacity were mounted on a specialized hanger as per the manufacturer's guidelines. The RAC used a rolling piston rotary compressor, and proper safety measures were observed during installation. Key components included insulation, condensate water pipes, electrical connections, and copper lines (0.25 inches for the liquid side and 0.37 inches for the gas side) between the units. The indoor unit operated at 819 Watts and 3.22 A. The test rig was housed in a temperature-controlled room, with the indoor temperature set to 27 degrees Celsius. This setup ensures accurate reflection of the RAC system's performance under different conditions, providing a reliable basis for evaluating various refrigerants, including R290.

The experimental setup for testing the R32 refrigerant in a split-type room air conditioner (RAC) involved meticulous inspection, leakage testing, and evacuation of the refrigerant circuit. After ensuring no leaks, 225 g of R32 was added incrementally. The system was stabilized, and data was collected to determine the optimal refrigerant charge. Throughout the experiment, the indoor temperature was maintained at 27°C while the outdoor temperature varied. Key performance metrics, including temperatures, energy efficiency, and pressure rates, were tracked in real time using specialized software and recorded every two seconds. The data was repeatedly collected and analyzed to ensure consistency and accuracy. Ultimately, the experiment provided valuable insights into the cooling capacity and energy efficiency of the RAC system using R32 refrigerant.

`

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

This chapter presents the results and analysis on the development of the test rig and the temperature control room and observing the power consumption and energy efficiency in R410A RAC operated using R32. The objective of the experiment is to identify a refrigerant substitute for R410A. The replacement is picked mostly to locate a more efficient RAC system, but also to make sure it meets with the properties. This technology will become available to everyone rather than limited to those with the improved RAC system. To conduct the experiment, first the TCR is developed, and the test rig is installed. Next, the system is operated using an R410A split unit at its optimal charge, and the data is gathered and stored as baseline data. After that, the system's refrigerant is recovered, and a vacuum is used to clean it. R32 refrigerant is then added to the system. The data from the baseline data and the data from the experiment are being compared. The properties table of R32 and R410A are shown in Table 4.1.

Table 4.1 Properties for Refrigerants Used (EVAP-COND NIST, 2016)

| **Properties/Refrigerants** | **R32** | **R410A** |
|---|---|---|
| Chemical/Blend Name | Difluoromethane | Suva 9100, Puron |
| Class | Hydrofluorocarbon | Hydrofluorocarbon |
| CAS Number | 75-10-5 | - |
| Oil | POE | POE |
| Critical Temperature (Degree Celsius) | 78.11 | 71.34 |
| Critical Pressure (psi) | 838.6 | 710.83 |
| Boiling Point (Degree Celsius) | -51.65 | -51.44 |
| Safety Group | A2L | A1 |
| Global Warming Potential (GWP) | 675 | 2088 |



According to the refrigerant properties in Table 4.1, it shows that R32's GWP value is almost three times less compared to R32 and since the critical pressure of R32 is higher than R410A, it can enable better heat transfers efficiency and cooling effectiveness besides focusing on saving strategies. This can be a good alternative to replace refrigerant R410A.

## 4.2 Temperature Control Room Development

To conduct this experiment, the study needs to be performed in a temperature control room (TCR) to get accurate results. Therefore, the development was following the system capabilities to avoid system overwork or oversized. These requirements are essential in order to generate the exact data. Figure 4.2 below shows the flow of TCR development.


Figure 4.2 Temperature Control Room Development

The roof structure is built from wood, it is used to place the asbestos ceiling.

4*2 feet Asbestos ceiling install to complete the interior.

Wiring for lamps and test-rig are being performed before finishing.

When the walls and ceilings finished, the gap between those boards was sealed by plaster cement to prevent air leakage.



Figure 4.2 Continued

`

For finishing, white paint was applied to the exterior and interior walls and ceilings to prevent heat absorption.

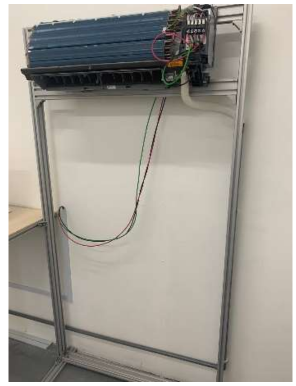
The complete of temperature control room development.

Figure 4.2 Continued

## 4.3 Test-rig Development and Air-Conditioner Installation

After the temperature control room's development finished, the test-rig of R32 ACSU system began to be started. The material used for the test-rig is an aluminum profile which has a very strong structure and anti-corrosion. The installation also started at this phase by referring to the actual way according to the manufacturer's advice as stated in the FTKF25CV1MF Service Manual. The steps for test-rig development are shown below in figure 3.6.

The structure of the test-rig is built from aluminum profiles which is a strong material. This test-rig consists of indoor unit placement and a table for datalogger



The indoor unit is suspended at a height of 3 meters to make it easier to reach for any upcoming ideas.

To complete the installation, copper pipes which in size of ¼ inch and 3/8 inch are used. The copper pipes also be insulated by an insulator to prevent heat losses.

This is the whole set-up for outdoor unit.

Figure 4.3 Test-rig Development and Air Conditioner Installation

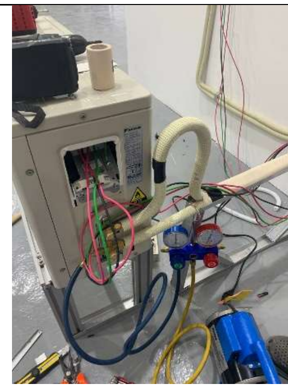
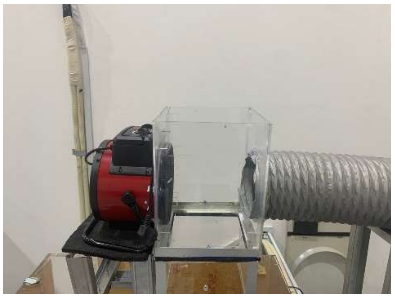
| | |
|---|---|
|  |  |
| The reason why the ¼ inch copper pipes being installed like U-shape is to prevent from oil in the system flows through the evaporator which can cause clogging, and the evaporator will not work at maximum capability. | Lastly, before beginning to run the system, the copper pipes and indoor unit should be vacuumed to avoid contaminants or air inside the system. |

Figure 4.3 Continued



### 4.4 Ambient Temperature Control Chamber Development

To complete the setup for the experiment, an ambient temperature control chamber was developed. This innovative product is an owned design and not available in any market. For heating coil, an air-conditioner was used to supply cool air. For heating coil, a 3-kW heater is used to supply hot air and both hot and cool air will be mixed with fresh air in the control chamber. This concept allows the ambient temperature to be controlled by mixing the right amount of cool and hot air. This chamber provided equal conditions for both refrigerants that are being tested. Figure 4.4 below shows the development and design of the control chamber.



A heater with a blower is sealed to the acrylic sheet to ensure no losses.

1hp air conditioner is supported by a custom-made flexible round duct to direct the cool air towards the chamber.

The setup for outdoor side

The whole mixing chamber covers all the sizes of the condenser

Figure 4.4 Ambient Temperature Control Chamber Development

## 4.5 Experimental Data Analysis

Two categories of analysis were used to classify the experimental analysis used in this investigation. The original investigation was limited to analyzing the vapor compression refrigerants system (VCRS) cycle's efficiency. Three processes make up the VCRS cycle: two isobaric heat exchange processes, continuous enthalpy expansion, and isentropic compression. Important parameters, such as the enthalpy for compressor suction ($h_1$), enthalpy for compressor discharge ($h_2$), and enthalpy for evaporator inlet ($h_6$), were determined by gathering pressure and temperature data. By calculating the compressor effort ($W_{in}$), COP, and refrigerant effect ($q_{in}$), the performance of the VCRS cycle was assessed.

The performance of the RAC system was the focus of the experiment's second study. To determine the RAC system's cooling capacity ($q_c$), total power consumption ($P_{sys}$), and energy efficiency ratio (EER), we collected data from the flowmeter and power analyzer in addition to the original analysis. Both kinds of analysis techniques were applied to evaluate the effect of R32 refrigerant on the RAC system's and the VCRS cycle's performance.



The efficiency of the VCRS cycle and RAC system can be determined by the COP and EER, as shown in Equation 4.5.1 and 4.5.2, respectively.

$$COP = \left(\frac{q_{in}}{W_{in}}\right) \quad 4.5.1$$

$$EER = \left(\frac{\dot{q}_c}{P_{sys}}\right) \quad 4.5.2$$

where $P_{sys}$ is the total power consumption used by the ACSU system.

## 4.6 Compressor Output and Running Ampere Comparison

The graph 4.6.1 shows the relationship between refrigerant charge and compressor outlet temperature for R32 and R410A. It is evident that the compressor outlet temperature decreases as the refrigerant charge increases for both refrigerants. However, the rate of temperature reduction is more pronounced for R32 compared to R410A. For R32, the outlet temperature exceeds its critical temperature (~78.1°C) at lower refrigerant charges, such as 300 to 400 grams. Beyond 450 grams, the outlet temperature drops below the critical temperature, reaching approximately 60°C at 550 grams, indicating the system is under working pressure.

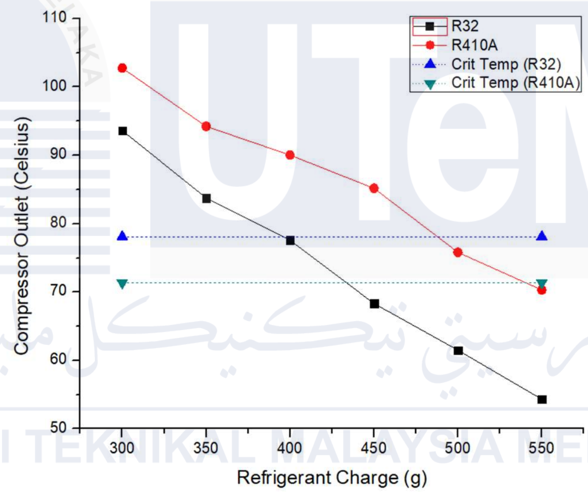



Figure 4.6.1 Compressor Outlet Temperature VS Refrigerant Charge

In contrast, R410A operates above its critical temperature (~72.5°C) at all charges until became normal when it reaches 550 grams where the outlet temperature is around 71°C. This suggests that R410A may need more charges compared to R32. Based on the data, R32 demonstrates better performance, particularly in the refrigerant charge range of 400 to 500 grams, where the system remains within acceptable thermal limits. R410A, on the other hand, shows limitations in maintaining efficient operation within the observed charge levels, making R32 the more suitable replacement's refrigerant for this system.

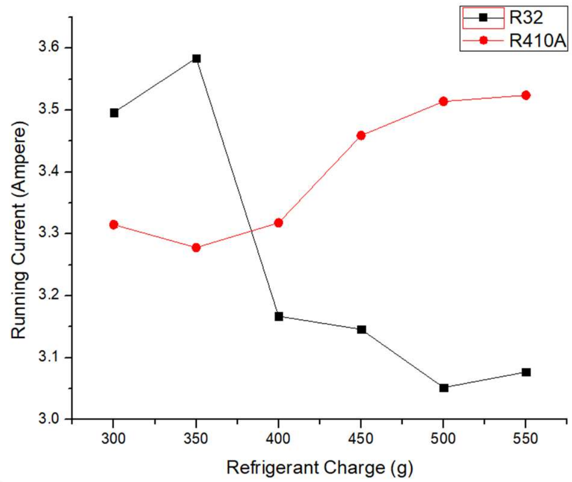



Figure 4.6.2 Refrigerant Charge VS Running Ampere

The graph above illustrates the relationship between refrigerant charge and running ampere for R32 and R410A. For R32, the running ampere begins at approximately 3.5 A at 300 grams, increases slightly to around 3.6 A at 350 grams, and then drops sharply to 3.1 A at 400 grams. Beyond this point, the running ampere stabilizes, remaining close to 3.1 A up to 550 grams. In contrast, R410A shows a steady increase in running ampere, starting at around 3.3 A for 300 grams and gradually rising to 3.5 A at 550 grams.

When comparing the two refrigerants, R32 demonstrates greater efficiency at higher refrigerant charges, with a significant drop and stabilization in running ampere beyond 400 grams. This trend suggests that R32 operates more efficiently under these conditions. Meanwhile, R410A shows consistent but increasing running ampere as the charge increases, indicating higher energy requirements and less efficiency compared to R32. Overall, R32 proves to be the more energy-efficient refrigerant, particularly at higher refrigerant charges, aligning with its superior performance observed in compressor outlet temperature analysis.

## 4.7 Cooling Effectiveness and Heat Transfer Efficiency

By referring to Figure 4.7.1, for R32, the "Evap IN" temperature increases steadily with higher refrigerant charges, indicating that the heat transfer efficiency at the evaporator inlet improves as more refrigerant is added. However, the "Cold OUT" temperature, which represents the air blown by the blower, initially decreases, reaching its lowest point at around 350g. This suggests that cooling effectiveness improves up to this point, as the colder air indicates efficient heat absorption by the refrigerant.

For Figure 4.7.2, for R410A, the "Evap IN" temperature increases steadily at first, peaking at around 450g before starting to decline. This trend indicates that heat transfer efficiency improves initially with increasing refrigerant charge but begins to decline beyond a certain threshold, likely due to oversaturation of the refrigerant and reduced heat exchange efficiency. The graphs demonstrate that R32 achieves peak cooling effectiveness and optimal heat transfer efficiency at a lower refrigerant charge compared to R410A. For R32, the "Cold OUT" temperature reaches its minimum, indicating maximum cooling effectiveness, at around 350g. Beyond this point, the cooling performance begins to decline due to overcharging, suggesting that 350g is close to the ideal refrigerant charge for R32.



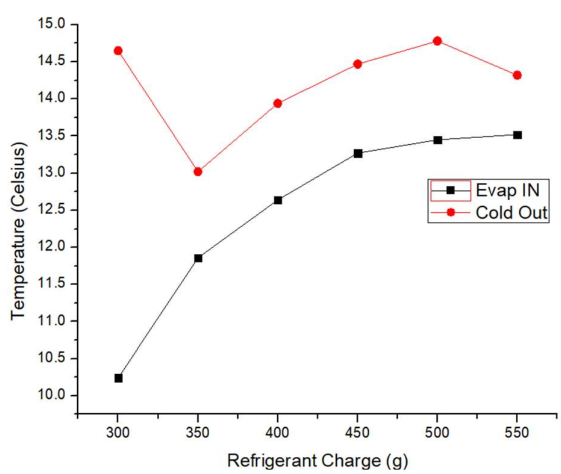



Figure 4.7.1 Refrigerant Charge vs Evaporator Inlet and Cold Air Outlet Temperature (R32)

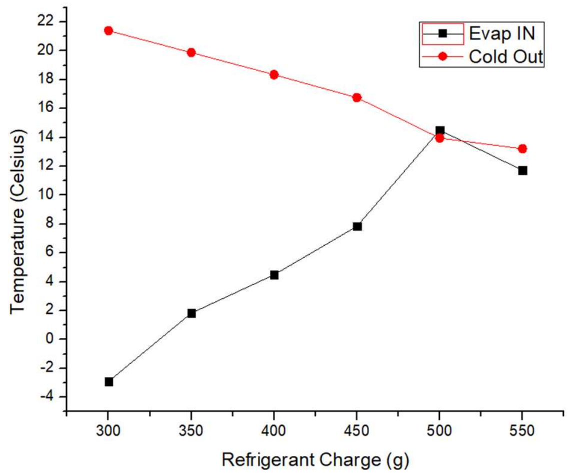



Figure 4.7.2 Refrigerant Charge vs Evaporator Inlet and Cold Air Outlet Temperature (R410A)

In contrast, R410A shows a steady improvement in cooling effectiveness as the refrigerant charge increases, with no clear signs of overcharging effects until around 450g or higher. This suggests that R410A requires a higher refrigerant charge to achieve similar cooling performance. Furthermore, the peak heat transfer efficiency for R32, as indicated by the steadily rising "Evap IN" temperature, is achieved at a lower charge compared to R410A, which peaks at around 450g before slightly decreasing. These trends indicate that R32 is more effective at achieving optimal cooling and heat transfer with less refrigerant, making it a more efficient option in terms of charge quantity compared to R410A (Alhendal et al., 2020).

## 4.8 Condenser Performance Comparison

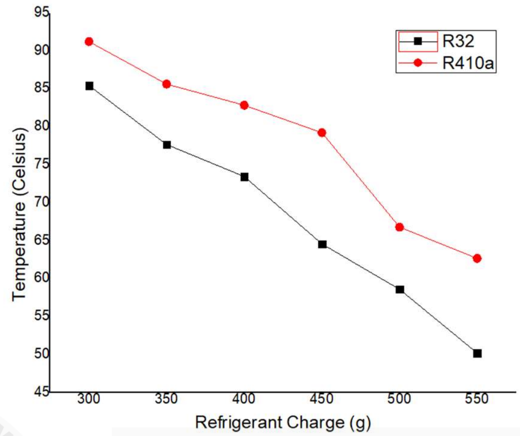



Figure 4.8.1 Refrigerant Charge vs Condenser Inlet Temperature

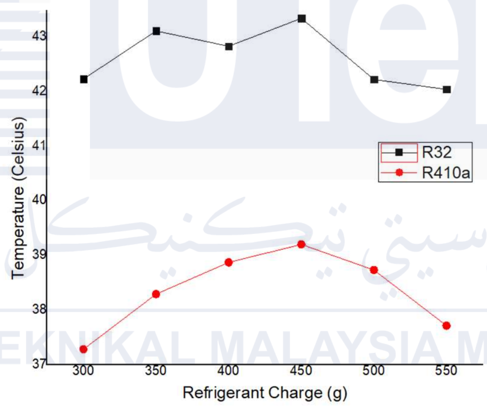



Figure 4.8.2 Refrigerant Charge vs Condenser Outlet

The analysis of the condenser inlet temperature in Figure 4.8.1 shows a clear decreasing trend as the refrigerant charge increases for both R32 and R410A. However, R410A consistently exhibits higher inlet temperatures compared to R32 across all charge levels. This suggests that R410A retains more heat before entering the condenser, which may indicate a higher discharge temperature from the compressor. The greater temperature drop in R32 implies that it rejects heat more efficiently before reaching the condenser, potentially leading to improved overall system performance. This characteristic could mean lower energy consumption for R32, as the compressor may not need to work as hard to maintain system pressures and temperatures.

Figure 4.8.2 represents condenser outlet temperature graph reveals a different trend. While R32 maintains a relatively stable temperature of around 42–43°C, R410A follows a parabolic pattern, initially increasing from approximately 37.5°C to a peak at around 450g refrigerant charge before declining at higher charge levels. The stable temperature of R32 at the condenser outlet suggests a more consistent heat rejection process, which may contribute to better thermal efficiency. On the other hand, R410A's fluctuating outlet temperature indicates that its heat transfer characteristics vary more significantly with charge levels. This could be due to differences in refrigerant properties, such as latent heat of vaporization and specific heat capacity, affecting the condensation process.

When comparing the two refrigerants, R32 appears to have a more efficient heat rejection process. Its lower condenser inlet temperature and stable outlet temperature imply that it might be better suited for maintaining optimal operating conditions without excessive refrigerant charge dependency. Additionally, the lower inlet temperature for R32 could mean that the compressor operates under less thermal stress, potentially reducing energy consumption and increasing system lifespan. Conversely, R410A's higher inlet temperature suggests that the compressor must work harder to compress the refrigerant, leading to higher power consumption.

From a practical perspective, the findings support the potential replacement of R410A with R32 in existing systems, given that R32 demonstrates lower condenser inlet temperatures and stable outlet temperatures. However, additional factors such as oil compatibility, pressure levels, and long-term durability must be considered before making a definitive switch. The study highlights the importance of refrigerant selection in optimizing energy efficiency, and R32 presents promising characteristics that warrant further investigation in real-world applications.

## 4.9 Energy Parameter Evaluation and Comparison

In determining whether the system meets the objective or not, this parameter becomes very important when it involves energy consumption. Energy efficiency is particularly important when deciding which unit to purchase. Not only does a more efficient unit mean cheaper energy bills; it's also better for the planet, using less energy to produce its heating or cooling output (Daikin, 2020).

### 4.9.1 Power Consumption

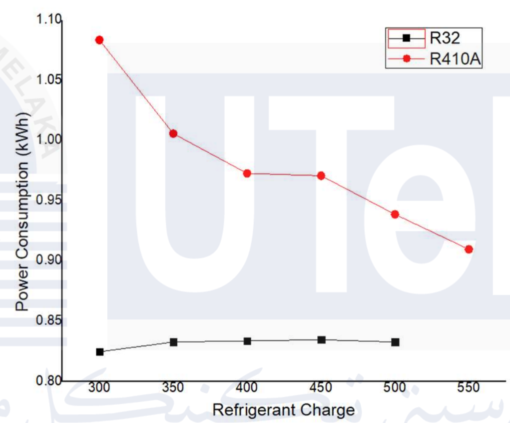



Figure 4.9.1 Refrigerant Charge vs Power Consumption



Graph 4.9.1 illustrates the power consumption (kWh) of R32 and R410A refrigerants across varying refrigerant charge levels, ranging from 300 g to 550 g. It is evident that R32 consistently consumes less power than R410A at all charge levels, demonstrating superior energy efficiency. The power consumption of R32 remains relatively stable, fluctuating slightly around 0.85 kWh, regardless of the charge level. In contrast, R410A shows a decreasing trend in power consumption, starting at approximately 1.1 kWh at 300 g and declining to about 0.9 kWh at 550 g, indicating that higher refrigerant charges improve its efficiency.

R32's operational stability is demonstrated by its consistent power consumption across all charge levels, which also indicates that systems utilizing R32 are less affected to changes in refrigerant charge. However, R410A's performance is heavily dependent on reaching the ideal refrigerant charge because any changes could lead to increased power consumption and decreased system efficiency.

Overall, R32's lower and stable power consumption makes it a more energy-efficient and environmentally friendly option compared to R410A. These characteristics suggest that R32 is better suited for applications where energy efficiency, cost-effectiveness, and operational stability are prioritized, further supporting its adoption as a sustainable refrigerant.

### 4.9.2 Coefficient of Performance

The graph 4.9.2 defines the Coefficient of Performance (COP) of R32 and R410A refrigerants across various refrigerant charge levels, ranging from 300 g to 550 g. The COP is an indicator of the efficiency of the refrigeration cycle, with higher values reflecting better performance. This statement aligns with (Cengel & Boles, 2015) which stated that the Coefficient of Performance (COP) is a measure of a system's efficiency, defined as the ratio of useful heating or cooling provided to the work required. A higher COP value signifies greater efficiency, as more thermal output is achieved for a given input of energy.



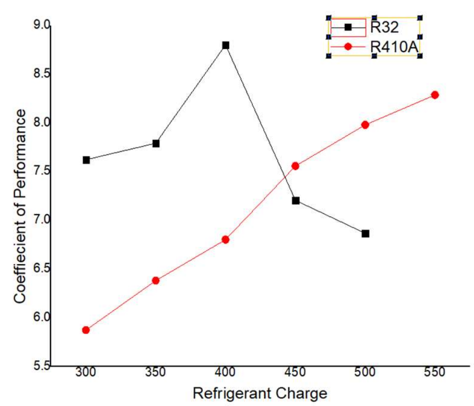



Figure 4.9.2 Refrigerant Charge vs Coefficient of Performance (COP)

For R32, the COP initially increases slightly from 7.625 at 300 g to approximately 8.803 at 400 g, reaching a peak at this charge level. However, as the refrigerant charge increases

`

beyond 400 g, the COP declines sharply, dropping to about 7.0 at 500 g and further decreasing to 6.5 at 550 g. This trend indicates that R32 achieves its optimal performance at around 400 g, with diminishing efficiency as the charge moves away from this value. In contrast, the COP for R410A exhibits a steady increase across the entire range of refrigerant charge. Starting at approximately 5.87 at 300 g, the COP rises gradually to 7.5 at 450 g and continues to improve, reaching 8.5 at 550 g. This consistent increase suggests that R410A performs better at higher refrigerant charges and does not exhibit a distinct peak efficiency within the tested range.

The comparison highlights that R32 provides superior performance at lower refrigerant charges, particularly around 400 g, where it achieves its maximum COP. However, R410A demonstrates a steady improvement in efficiency with increasing charge levels, surpassing R32 at higher refrigerant charges. These findings indicate that the selection of refrigerant should depend on the specific operating conditions and the targeted charge level for the refrigeration system. R32 is more suitable for systems operating at lower refrigerant charges, while R410A performs better at higher charges (Xu et al., 2013).



### 4.9.3 Energy Efficiency Ratio

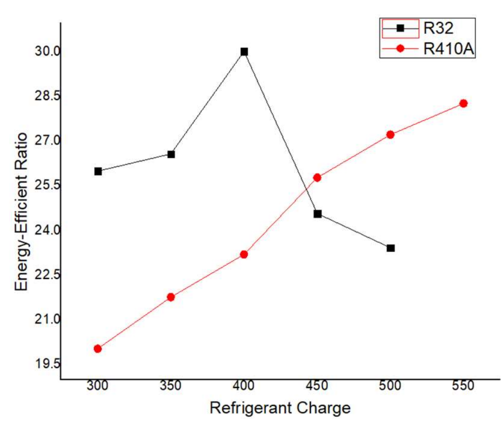



Figure 4.9.3 Refrigerant Charge vs Energy Efficiency Ratio (EER)

The graph illustrates the Energy Efficiency Ratio (EER) of R32 and R410A refrigerants across a range of refrigerant charges from 300 g to 550 g. The EER measures the cooling efficiency of the refrigeration system, with higher values indicating better performance.

For R32, the EER starts at approximately 25.5 at 300 g and remains relatively stable until 350 g. At 400 g, the EER peaks sharply at around 30.0, indicating optimal performance at this charge level. However, beyond 400 g, the EER declines significantly, dropping to approximately 24.0 at 450 g and further decreasing to around 21.0 at 550 g. This trend suggests that R32's energy efficiency is highly sensitive to the refrigerant charge, with a distinct peak efficiency at 400 g.

In contrast, the EER of R410A shows a steady and consistent increase throughout the range of refrigerant charges. Starting at around 20.0 at 300 g, the EER rises gradually to approximately 24.0 at 450 g and continues improving, reaching about 28.5 at 550 g. This indicates that R410A becomes increasingly efficient as the refrigerant charge increases, without exhibiting a clear peak within the tested range.



The comparison reveals that R32 achieves efficiency at lower refrigerant charges, particularly around its peak at 400 g. In contrast, R410A demonstrates a steady improvement in EER as the refrigerant charge increases, with no distinct peak. These findings indicate that even in R410A system, R32 performs more efficiently at optimal charge levels, whereas R410A shows consistent efficiency gains with increasing refrigerant charge. This highlights the importance of carefully optimizing refrigerant charge to achieve the best performance (Panato et al., 2022).

## 4.10 Summary

The comparative analysis between R32 and R410A refrigerants in the same system reveals significant insights into their performance based on several key parameters. The compressor outlet temperature indicates that R32 operates at lower temperatures compared to R410A across all refrigerant charges, which can potentially enhance the reliability and longevity of the compressor. In terms of power consumption, R32 consistently shows lower power usage compared to R410A, making it a more energy-efficient choice for the tested system.

The coefficient of performance (COP) and energy efficiency ratio (EER) further support R32's advantages, as it exhibits higher COP and EER values at optimal charge levels, particularly around 400 g. This reflects R32's great thermodynamic performance and efficiency at moderate refrigerant charges. Conversely, R410A demonstrates a steady increase in COP and EER as the refrigerant charge rises, suggesting that it performs better under higher refrigerant charges.

Additionally, the system running current (in amperes) reinforces R32's efficiency, as it generally exhibits lower current draw compared to R410A. This lower electrical demand further enhances its appeal for energy-conscious applications.

In conclusion, R32 proves to be more efficient and thermodynamically favourable at optimal charge levels, characterized by lower compressor outlet temperatures, reduced power consumption, and higher efficiency metrics (COP and EER). On the other hand, R410A shows steady performance improvements with increasing refrigerant charge. The findings shows that R32 can be used as alternative refrigerant in R410A system to replace R410A, not only because of the GWP effect but also because R32 still can achieve energy savings for the system.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Introduction

The study's overall conclusions are provided in this chapter. These include of the RAC evaluations, test-rig development, ambient temperature control chamber development, TCR development, and RAC system optimisation. To demonstrate that every study objective has been accomplished, interesting findings from each have been provided. Some suggestions for further research are included at the end of this chapter.

## 5.2 Conclusions

The current study was separated into two main objectives. First objective concentrated on the development of test-rig in a temperature control room to make sure that the second objective can be achieved without any interruption and inequality parameters. The second objective was the analysis of optimization of energy saving in residential air conditioning (RAC) using R32 in R410A system. The parameters that involved in this study are compressors temperature output, running ampere, coefficient of performance (COP), power consumption and energy efficiency ratio (EER). When evaluating the RAC, R32 refrigerant shows great performance on compressors output temperature at low refrigerant charge compared to R410A. Along with the compressors output temperature, running ampere and power consumption also reduced when R32 refrigerant take over the system. It also increased the COP of the system, when COP and power consumption reduced, automatically the EER increased. The optimum charge for R32 was determined which is 400g and for R410A is 550g. The charge of R32 was more less compared to R410A about 27%. This highlighted significant advantage for R32 in terms of environmental impact. The lower refrigerant charge requirement directly correlates with a reduced environmental footprint. R32's substantially lower GWP underscores its potential as an environmentally friendly refrigerant option, aligning with global efforts to mitigate climate change.

## 5.3 Recommendations for Future Work

As mentioned earlier, the present research successfully achieved its objectives. However, as there is always opportunity for improvement, new researchers will always find new areas to explore. Future projects are suggested to include the following:

i. This study focused on R32 refrigerant which is still considered as harmful substance to the environment. It is recommended that future research for the RAC system use much lower GWP impact refrigerants such as natural refrigerants which is hydrocarbons. Hydrocarbons are particularly promising for small-scale applications, as they exhibit excellent thermodynamic properties, high energy efficiency, and compatibility with existing systems, though safety measures for flammability must be addressed.

ii. The current RAC performance evaluations were demonstrating the energy-saving potential and feasibility of using R32 as a replacement for R410A in the same system. Further studies are needed to assess the long-term effects on system components and system lifespan. This includes investigating material compatibility, wear and tear, and overall durability when operating with R32. Encouraging such follow-up research will provide a more comprehensive understanding of the trade-offs involved in making the switch.

REFERENCES


A.Yatim, Risk assessment of flammable natural refrigerant application in air conditioning systems. (2022, December 7). IEEE Conference Publication | IEEE Xplore. https://ieeexplore.ieee.org/abstract/document/9989964?casa_token=orBe7lqLngcAAAAA:ME-0HeNSx92o7_PCQMEYptclmkZPlmc24SW4qqKe4wp241t61VozVTUQJZc60guGU8uy8da2dE0

Admin. (2021, March 17). Primary and secondary refrigerants: Energypurse. https://www.energypurse.com/primary-and-secondary-refrigerants/

Alex Bax, (2022). Hvacinformed.com. https://www.hvacinformed.com/insights/hvac-industry-addressing-climate-change-sustainability-co-1570804656-ga-co-1581682229-ga-co-1592321964-ga-co-1598629327-ga-off.1601288089.html

Alhendal, Y., Gomaa, A., Bedair, G., & Kalendar, A. (2020). Thermal Performance Analysis of Low-GWP Refrigerants in Automotive Air-Conditioning System. Advances in Materials Science and Engineering, 2020, 1–14. https://doi.org/10.1155/2020/7967812

Almogbel, A., Alkasmoul, F., Aldawsari, Z., Alsulami, J., & Alsuwailem, A. (2020). Comparison of energy consumption between non-inverter and inverter-type air conditioner in Saudi Arabia. Energy Transitions, 4(2), 191–197. https://doi.org/10.1007/s41825-020-00033-y

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2020). ASHRAE Handbook—HVAC Systems and Equipment. (Accessed on 10 April 2024)

ASHRAE. (2020). ASHRAE Position Document on Natural Refrigerants - ASHRAE. (Accessed on 24 May 2024)

ASHRAE. (2020). Refrigerant Management. (Accessed on 15 May 2024)

Azmi, W., Ismail, M., Zawawi, N., Mamat, R., & Safril, S. (2024). Tribological and residential air conditioning performance using SiO2-TiO2/PVE nanolubricant. International Journal of Refrigeration. https://doi.org/10.1016/j.ijrefrig.2024.01.002

`


Bazilian, M., & Onyeji, I. (2012). Fossil fuel subsidy removal and inadequate public power supply: Implications for businesses. Energy Policy, 45, 1–5. https://doi.org/10.1016/j.enpol.2012.02.057

Belaid, F., Sanin, M., & Lazaric, N. (2023). Editorial: Energy efficiency and residential energy consumption: current challenges, policies, and emerging trends. Frontiers in Energy Research, 11. https://doi.org/10.3389/fenrg.2023.1218527

Bolaji, Bukola. (2020). Theoretical assessment of new low global warming potential refrigerant mixtures as eco-friendly alternatives in domestic refrigeration systems. Scientific African. 10. e00632. 10.1016/j.sciaf.2020.e 00632.

Buildings - Energy System - IEA. (n.d.). IEA. https://www.iea.org/energy-system/buildings (Accessed on 2 June 2024)

Cengel, Y. A., & Boles, M. A. (2015). *Thermodynamics: An Engineering Approach.* McGraw-Hill Education. (Accessed on 5 January 2025)

Chen, W., Mo, H., & Teng, T. (2018). Performance improvement of a split air conditioner by using an energy saving device. Energy and Buildings, 174, 380–387. https://doi.org/10.1016/j.enbuild.2018.06.055

Choudhari, C., & Sapali, S. (2017). Performance investigation of natural refrigerant R290 as a substitute to R22 in refrigeration systems. Energy Procedia, 109, 346–352. https://doi.org/10.1016/j.egypro.2017.03.084

Ciconkov, R. (2018). Refrigerants: There is still no vision for sustainable solutions. International Journal of Refrigeration, 86, 441–448. https://doi.org/10.1016/j.ijrefrig.2017.12.006

Clean energy is boosting economic growth – Analysis. (2024, April 18). IEA. https://www.iea.org/commentaries/clean-energy-is-boosting-economic-growth (Accessed on 24 May 2024)

Department of Climate Change, Energy, the Environment and Water| energy.gov.au. (2023, December 20). Energy.gov.au. https://www.energy.gov.au/business/equipment-guides/hvac (Accessed on 4 June 2024)

Environmental Protection Agency (EPA). (2017). Energy Efficiency Opportunities in the HVAC Systems. Retrieved from EPA HVAC Efficiency. (Accessed on 10 April 2024)

Fasiuddin, M., & Budaiwi, I. (2011). HVAC system strategies for energy conservation in commercial buildings in Saudi Arabia. Energy and Buildings, 43(12), 3457–3466. https://doi.org/10.1016/j.enbuild.2011.09.004

Gao, B., et al. (2018). Recent Research Progress of Low GWP Refrigerants: A Review. International Journal of Refrigeration, 93, 70-85. doi: 10.1016/j.ijrefrig.2018.05.008.

Gernaat, D. E. H. J., de Boer, H. S., Daioglou, V., Yalew, S. G., Müller, C., & van Vuuren, D. P. (2021). Climate change impacts on renewable energy supply. Nature Climate Change, 11(2), 119–125. doi:10.1038/s41558-020-00949-9

Global Status Report for Buildings and construction. (n.d.). UNEP - UN Environment Programme. https://www.unep.org/resources/report/global-status-report-buildings-and-construction (Accessed on 2 June 2024)

Hazlina Selamat, Mohamad Fadzli Haniff,1, Zainon Mat Sharif, Seyed Mohammad Attaran, Fadhilah Mohd Sakri&, and Muhammad Al'Hapis Bin Abdul Razak. Review on HVAC System Optimization Towards Energy Saving Building Operation. International Energy Journal. (n.d.). http://www.rericjournal.ait.ac.th/index.php/reric

Henry N., Member, IAENG, Afiq A. Dahlan, Affandi M. Nasib, Azhar A. Aziz, Member, IAENG and Sumeru. Performance of a Variable Speed of the Split Unit Air Conditioning System using Fuzzy Logic Controller: Proceedings of the International Multiconference of Engineers and Computer Scientists 2015 Vol I, IMECS 2015, March 18 - 20, 2015, Hong Kong.

High stakes and high seas - United Nations Development Programme | UNDP. (n.d.). Exposure. Retrieved June 11, 2024, from https://stories.undp.org/high-stakes-and-high-seas?gad_source=1&gclid=CjwKCAjw65-zBhBkEiwAjrqRMLVzwDkalr1sxzoUtVtrZYLlQ9vdrHKZJYDrYrQP235mswEjBythIRoCNYUQAvD_BwE (Accessed on 24 May 2024)

IEA (2021), Key World Energy Statistics 2021, IEA, Paris https://www.iea.org/reports/key-world-energy-statistics-2021, Licence: CC BY 4.0 (Accessed on 1 June 2024)

International Energy Agency (IEA). (2021). World Energy Outlook 2021. Retrieved from IEA website. (Accessed on 31 March 2024)

International Institute of Refrigeration (IIR). (2020). The Evolution of Refrigerants. (Accessed on 7 May 2024)

International Institute of Refrigeration (IIR). (2020). The Role of Natural Refrigerants in Climate Change Mitigation - IIR. (Accessed on 24 May 2024)

Johannes van Es. NLR - Netherlands Aerospace Centre. (2019, December 19). Taking thermal control to new heights - NLR. Royal Netherlands Aerospace Centre. https://www.nlr.org/article/taking-thermal-control-to-new-heights/

Kaoru. (2022, November 18). Types of refrigerant - W-refrigerant. W-refrigerant. https://w-refrigerant.com/en/latest__lecture/types-of-refrigerant/

Mahyuddin, N., & Awbi, H. (2010). The spatial distribution of carbon dioxide in an environmental test chamber. Building and Environment, 45(9), 1993–2001. https://doi.org/10.1016/j.buildenv.2010.02.001

McLinden, M. O., Seeton, C. J., & Pearson, A. (2020). New refrigerants and system configurations for vapor-compression refrigeration. Science, 370(6518), 791–796. https://doi.org/10.1126/science.abe3692

Mohan, M. (2021). Perovskite Photovoltaics. In Elsevier eBooks (pp. 447–480). https://doi.org/10.1016/b978-0-12-812915-9.00014-9

Nasruddin, N., Sholahudin, N., Satrio, P., Mahlia, T. M. I., Giannetti, N., & Saito, K. (2019). Optimization of HVAC system energy consumption in a building using artificial neural network and multi-objective genetic algorithm. Sustainable Energy Technologies and Assessments, 35, 48–57. https://doi.org/10.1016/j.seta.2019.06.002

Nethaji, N., & Mohideen, S. T. (2017). Energy conservation in domestic refrigerators by cooling compressor shell – A case study. Case Studies in Thermal Engineering, 10, 382–387. https://doi.org/10.1016/j.csite.2017.08.002

Panato, V. H., Marcucci Pico, D. F., & Bandarra Filho, E. P. (2022). Experimental evaluation of R32, R452B and R454B as alternative refrigerants for R410A in a refrigeration system. International Journal of Refrigeration, 135, 221–230. https://doi.org/10.1016/j.ijrefrig.2021.12.003

Paul, S., Sarkar, A., & Mandal, B. (2013). ENVIRONMENTAL IMPACTS OF HALOGENATED REFRIGERANTS AND THEIR ALTERNATIVES: RECENT

DEVELOPMENTS. International Journal of Emerging Technology and Advanced Engineering, 3, 2250–2459. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=dc2903ecf35984b5803c47fc893da89bd5283a8b

Pearce, J. M. (2012). Limitations of nuclear power as a sustainable energy source. Sustainability, 4(6), 1173–1187. https://doi.org/10.3390/su4061173

Qiu, S., Lei, T., Wu, J., & Bi, S. (2021). Energy demand and supply planning of China through 2060. Energy, 234, 121193. doi: 10.1016/j.energy.2021.121193 10.1016/j.energy.2021.121193

Rescue Rooter. 6 Critical Factors That Impact Your Air Conditioning Efficiency. (n.d.). Www.ars.com. https://www.ars.com/blog/air-conditioning-efficiency-factors#:~:text=The%20short%20answer%20is%20there (Accessed on 10 June 2024)

Robert, & Robert. (2022, June 27). What are the factors affecting the performance of your air conditioner? EZeletric. https://www.ezeletric.com/factors-affecting-your-ac-performance/?trk=article-ssr-frontend-pulse_little-text-block

Russett, B. (1979). World energy demand and world security. Policy Sciences, 11(2), 187–202. https://doi.org/10.1007/bf00139829.

Safety considerations when using flammable refrigerants - DCCEEW. (2022). Dcceew.gov.au. https://www.dcceew.gov.au/environment/protection/ozone/rac/safety-considerations (Accessed on 10 June 2024)

Saidur, Rahman and Hasanuzzaman, M. and Sattar, M.A. and Masjuki, Haji Hassan and Badruddin, I.A. and Mohiuddin, A.K.M. (2007) An analysis of energy use, energy intensity and emissions at the industrial sector of Malaysia. International Journal of Mechanical and Materials Engineering, 2 (1). pp. 84-92. ISSN 1823-0334.

Sha, Mo & Saad, N. & Rahman, S. & Abas, Mohammad Fadhil & Hanafi, A. & Yusuf, Mr. (2008). The Effect of Using Timer to the Split Unit Air-conditioning Control in UMP's Lecture Halls and Labs.

Shafie, S., Mahlia, T., Masjuki, H., & Andriyana, A. (2011). Current energy usage and sustainable energy in Malaysia: A review. Renewable & Sustainable Energy Reviews, 15(9), 4370–4377. https://doi.org/10.1016/j.rser.2011.07.113

`

Sovacool, B. K., Griffiths, S., Kim, J., & Bazilian, M. (2021). Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical systems and policy options for reducing synthetic greenhouse gas emissions. Renewable & Sustainable Energy Reviews, 141, 110759. https://doi.org/10.1016/j.rser.2021.110759

The Future of Refrigerants. (2020, July 13). Sustainable Investment Group. https://sigearth.com/the-future-of-refrigerants/

U.S. Department of Agriculture (USDA). (2021). Energy Use and Efficiency in Agriculture. (Accessed on 2 April 2024)

U.S. Department of Energy (DOE). (2021). Energy Efficiency in Residential and Commercial Refrigeration. (Accessed on 15 May 2024)

U.S. Department of Energy (DOE). (2021). Transportation Energy Data Book. (Accessed on 2 April 2024)

U.S. Department of Energy (DOE). (n.d.). Energy Saver Guide: Tips on Saving Money and Energy at Home. Retrieved from DOE Energy Saver. (Accessed on 20 April 2024)

U.S. Energy Information Administration (EIA). (2021). Annual Energy Outlook. (Accessed on 2 April 2024)

U.S. Environmental Protection Agency (EPA). (2021). Phaseout of Class II Ozone-Depleting Substances. (Accessed on 28 April 2024)



United Nations Environment Programme (UNEP). (2016). Kigali Amendment to the Montreal Protocol. (Accessed on 7 May 2024)

US EPA, O. (2014, November 4). Regulations, Proposed Rules and Final rules determined by EPA. Www.epa.gov. https://www.epa.gov/snap/regulations-proposed-rules-and-final-rules-determined-epa

Vakiloroaya, V., Samali, B., Fakhar, A., & Pishghadam, K. (2014). A review of different strategies for HVAC energy saving. Energy Conversion and Management, 77, 738–754. https://doi.org/10.1016/j.enconman.2013.10.023

Vuppaladadiyam, A. K., Antunes, E., Vuppaladadiyam, S. S. V., Baig, Z. T., Subiantoro, A., Lei, G., Leu, S., Sarmah, A. K., & Duan, H. (2022c). Progress in the development and use of refrigerants and unintended environmental consequences. Science of the Total Environment, 823, 153670. https://doi.org/10.1016/j.scitotenv.2022.153670

Wang, R., Wu, Q., & Wu, Y. (2010). Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants. Energy and Buildings, 42(11), 2111–2117. https://doi.org/10.1016/j.enbuild.2010.06.023

What is meant by the terms COP and EER? (n.d.). Www.daikin.co.uk. https://www.daikin.co.uk/en_gb/faq/what-is-meant-by-the-terms-cop-and-eer-.html. (Accessed on 5 January 2025)

World Bank. (2020). The Role of Energy in Economic Growth. Retrieved from World Bank website. (Accessed on 29 March 2024)

World energy balances. (2017). [Dataset]. https://doi.org/10.1787/data-00512-en

Xu, X., Hwang, Y., & Radermacher, R. (2013). Performance comparison of R410A and R32 in vapor injection cycles. International Journal of Refrigeration, 36(3), 892–903. https://doi.org/10.1016/j.ijrefrig.2012.12.010

Yoon, M., Lim, J., Qahtani, T., Nam, Y.: Experimental study on comparison of energy consumption between constant and variable speed air-conditioners in two different climates. In: Proceedings of the 9th Asian Conference on Refrigeration and Air-conditioning (2018)

APPENDIX B Gantt Chart

| ACTIVITY | | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | WEEKS 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PSM 1 | Title Selection | 1 | 1 | 1 | 1 | ■ | | | | | | | | | | | | | |
| | Planning and Research | 2 | 2 | 2 | 2 | | ■ | ■ | | | | | | | | | | | |
| | **CHAPTER 1** | | | | | | | | | | | | | | | | | | |
| | Background, Problem Statement | 3 | 2 | 3 | 3 | | | ■ | ■ | ■ | | | | | | | | | |
| | Objective, Scope | 3 | 3 | 3 | 3 | | | ■ | ■ | ■ | | | | | | | | | |
| | **CHAPTER 2** | | | | | | | | | | | | | | | | | | |
| | Literature Review | 3 | 6 | 3 | 10 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | |
| | Research Gap | 10 | 2 | 11 | 2 | | | | | | | | | | | ■ | ■ | | |
| | **CHAPTER 3** | | | | | | | | | | | | | | | | | | |
| | Introduction | 4 | 1 | 4 | 2 | | | | ■ | ■ | | | | | | | | | |
| | Research Flow | 5 | 2 | 5 | 2 | | | | | ■ | ■ | | | | | | | | |
| | Flow Chart | 5 | 2 | 5 | 3 | | | | | ■ | ■ | ■ | | | | | | | |
| | Metarial Selection | 7 | 2 | 7 | 3 | | | | | | | ■ | ■ | ■ | | | | | |
| | Research method and Area | 7 | 3 | 8 | 4 | | | | | | | | ■ | ■ | ■ | ■ | | | |
| | Equipment | 7 | 3 | 9 | 5 | | | | | | | | | ■ | ■ | ■ | ■ | ■ | |
| | **Others** | | | | | | | | | | | | | | | | | | |
| | Elog Book Weekly | 1 | 12 | 1 | 13 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| | Report Progression | 1 | 12 | 1 | 13 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| PSM 2 | **CHAPTER 4** | | | | | | | | | | | | | | | | | | |
| | Development and Testing | 2 | 8 | 2 | 9 | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| | Results and Data | 7 | 3 | 8 | 4 | | | | | | | | ■ | ■ | ■ | ■ | | | |
| | **CHAPTER 5** | | | | | | | | | | | | | | | | | | |
| | Conclusion | 10 | 2 | 11 | 3 | | | | | | | | | | | ■ | ■ | ■ | |
| | Recommendations | 10 | 2 | 11 | 3 | | | | | | | | | | | ■ | ■ | ■ | |
| | **Others** | | | | | | | | | | | | | | | | | | |
| | Elog Book Weekly | 1 | 12 | 1 | 13 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| | Report Progression | 1 | 12 | 1 | 13 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |

## APPENDIX C Example of Raw Data

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 541 | 2021-03-2 | 13.57 | 80.59 | 75.72 | 41.47 | 42.1 | 11.96 | 11.09 | 11.9 | 26.93 | 12.64 |
| 542 | 2021-03-2 | 13.57 | 80.58 | 75.71 | 41.41 | 42.07 | 11.97 | 11.1 | 11.94 | 26.59 | 12.64 |
| 543 | 2021-03-2 | 13.57 | 80.59 | 75.71 | 41.4 | 42.05 | 11.97 | 11.1 | 11.93 | 26.51 | 12.63 |
| 544 | 2021-03-2 | 13.58 | 80.59 | 75.71 | 41.42 | 42.04 | 11.98 | 11.11 | 11.96 | 26.48 | 12.63 |
| 545 | 2021-03-2 | 13.6 | 80.6 | 75.71 | 41.44 | 42.05 | 11.99 | 11.12 | 11.91 | 26.45 | 12.62 |
| 546 | 2021-03-2 | 13.6 | 80.59 | 75.7 | 41.47 | 42.05 | 11.98 | 11.11 | 11.8 | 26.71 | 12.62 |
| 547 | 2021-03-2 | 13.6 | 80.59 | 75.7 | 41.48 | 42.06 | 11.97 | 11.1 | 11.4 | 26.58 | 12.6 |
| 548 | 2021-03-2 | 13.6 | 80.58 | 75.7 | 41.42 | 42.07 | 11.96 | 11.09 | 11.51 | 26.52 | 12.6 |
| 549 | 2021-03-2 | 13.59 | 80.58 | 75.69 | 41.37 | 42.03 | 11.95 | 11.08 | 11.65 | 26.77 | 12.61 |
| 550 | 2021-03-2 | 13.58 | 80.57 | 75.69 | 41.38 | 42 | 11.95 | 11.07 | 11.8 | 26.74 | 12.6 |
| 551 | 2021-03-2 | 13.58 | 80.58 | 75.69 | 41.43 | 42.01 | 11.95 | 11.08 | 11.86 | 26.78 | 12.59 |
| 552 | 2021-03-2 | 13.57 | 80.58 | 75.69 | 41.44 | 42.03 | 11.96 | 11.09 | 11.74 | 26.83 | 12.58 |
| 553 | 2021-03-2 | 13.57 | 80.58 | 75.68 | 41.38 | 42.02 | 11.96 | 11.1 | 11.65 | 26.8 | 12.58 |
| 554 | 2021-03-2 | 13.57 | 80.58 | 75.69 | 41.29 | 41.99 | 11.96 | 11.1 | 11.7 | 26.77 | 12.59 |
| 555 | 2021-03-2 | 13.57 | 80.58 | 75.69 | 41.25 | 41.94 | 11.95 | 11.08 | 11.79 | 26.71 | 12.6 |
| 556 | 2021-03-2 | 13.56 | 80.58 | 75.69 | 41.25 | 41.9 | 11.95 | 11.08 | 11.46 | 26.62 | 12.59 |
| 557 | 2021-03-2 | 13.55 | 80.57 | 75.68 | 41.3 | 41.9 | 11.94 | 11.07 | 11.39 | 26.52 | 12.57 |
| 558 | 2021-03-2 | 13.55 | 80.58 | 75.68 | 41.38 | 41.93 | 11.94 | 11.07 | 11.05 | 26.56 | 12.55 |
| 559 | 2021-03-2 | 13.54 | 80.58 | 75.68 | 41.41 | 41.97 | 11.94 | 11.08 | 10.9 | 26.72 | 12.58 |
| 560 | 2021-03-2 | 13.54 | 80.58 | 75.69 | 41.4 | 41.99 | 11.94 | 11.07 | 10.92 | 26.6 | 12.55 |
| 561 | 2021-03-2 | 13.54 | 80.58 | 75.69 | 41.36 | 41.99 | 11.91 | 11.04 | 11.08 | 26.66 | 12.54 |
| 562 | 2021-03-2 | 13.53 | 80.57 | 75.68 | 41.28 | 41.95 | 11.89 | 11.01 | 11.3 | 26.62 | 12.52 |
| 563 | 2021-03-2 | 13.52 | 80.56 | 75.68 | 41.26 | 41.91 | 11.9 | 11.02 | 11.51 | 26.59 | 12.54 |
| 564 | 2021-03-2 | 13.51 | 80.57 | 75.68 | 41.3 | 41.9 | 11.89 | 11.02 | 11.64 | 26.52 | 12.53 |
| 565 | 2021-03-2 | 13.51 | 80.57 | 75.68 | 41.3 | 41.91 | 11.88 | 11.02 | 11.7 | 26.17 | 12.49 |
| 566 | 2021-03-2 | 13.51 | 80.58 | 75.68 | 41.34 | 41.92 | 11.89 | 11.03 | 11.78 | 26.3 | 12.5 |
| 567 | 2021-03-2 | 13.5 | 80.59 | 75.7 | 41.39 | 41.94 | 11.91 | 11.05 | 11.71 | 26.56 | 12.51 |
| 568 | 2021-03-2 | 13.49 | 80.58 | 75.69 | 41.35 | 41.95 | 11.92 | 11.06 | 11.12 | 26.69 | 12.52 |
| 569 | 2021-03-2 | 13.48 | 80.58 | 75.69 | 41.37 | 41.96 | 11.93 | 11.07 | 11.2 | 26.91 | 12.54 |