REVERSE ENGINEERING OF A 1HP HEAT PUMP

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CERTIFICATION

This is to certify that this project titled "REVERSED ENGINEERING OF A 1 HP HEAT PUMP" was carried out by Nosafiangbe Triumphant Osaivbie, Praise Uyiri willie, Emmaneul Inegbenose Imafidon, Praise Evewele, Obose Wisdom Efojie, Micheal Elozino Evawere, Emmanuel Oseiwe Eifuobhokhan, Eric Ovie Uguzuma, Emmanuel Friday Enne, Favour Adebayo, and Nuasiohiukun Valentine Adewole of the department of Mechanical Engineering. Faculty of engineering, University of Benin. This Project was submitted in partial fulfilment of the requirements for the award of the Bachelor of Engineering(B.Eng) Degree in Mechanical Engineering.

This is also to certify that it was carried out under the supervision of Prof P.O.B. Ebunilo. He provided guidance and direction through the course of this project work.

This project is an original copy of ours and has not been submitted in part or full for the reward of any other degree or at any other institution.

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ABSTRACT

This project focuses on the reverse engineering, adaptation, and performance evaluation of a 1-horsepower (HP) air-source heat pump tailored for Nigeria's unique climatic and infrastructural challenges. Rising temperatures, erratic power supply, and high humidity levels in Nigeria have intensified the demand for energy-efficient and resilient cooling solutions. This study addresses this need by deconstructing a commercially available 1 HP unit, analyzing its core components—including the compressor, condenser, evaporator, and capillary tube—and modifying them for optimal performance within the local context.

The methodology involved an iterative design process, selecting and adapting components to withstand high ambient temperatures (up to 45°C), significant humidity fluctuations (20-95%), and unstable grid voltage. Key modifications included increasing the condenser surface area by 15% for better heat rejection, integrating a voltage stabilizer, and employing a capillary tube as a cost-effective, bidirectional expansion device suitable for reversible operation. The fabricated system was rigorously tested in a controlled environment, demonstrating a stable cooling capacity. Performance analysis revealed a Coefficient of Performance (COP) of 3.45 in cooling mode and 4.11 in heating mode, confirming the system's high energy efficiency and dual-functionality.

The project successfully achieved its primary objectives of component analysis, demonstration of dual-mode operation, and energy efficiency evaluation. It also fulfilled secondary goals, including refrigerant cycle analysis and the design of a modular control system. The results validate the technical and economic viability of locally reverse-engineered heat pumps, which can reduce reliance on inefficient conventional air conditioners, lower electricity consumption, and decrease greenhouse gas emissions. This work provides a foundational framework for the local manufacturing and adoption of sustainable thermal comfort technology in Nigeria, contributing to energy security, climate adaptation, and technological self-reliance. Recommendations are provided for further performance enhancements, including the adoption of inverter compressors, transition to low-GWP refrigerants, and optimization of heat exchanger design.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Nigeria is experiencing measurable changes in its climate, with higher average temperatures, more frequent and intense heatwaves, and increasingly erratic rainfall patterns that have produced both extreme floods and localized droughts. These changes are already affecting people, infrastructure, and the national electricity system, while also driving greater demand for cooling and low-carbon comfort solutions. A small, locally optimized 1-horsepower (HP) heat pump, reverse-engineered and adapted to Nigerian ambient, humidity, and electricity supply conditions, could provide an energy-efficient cooling alternative that reduces reliance on diesel generators and oversized air conditioners, while allowing for easier integration with solar generation in off-grid or weak-grid settings.

Recent climate data and meteorological reports show that rising temperatures have become a persistent trend in Nigeria, with unusual patterns of early, intense heatwaves recorded across the country. In some areas, such as Sokoto in April 2024, temperatures reached about 44.8 °C, prompting urgent health warnings from authorities. These extreme heat events have been linked to increased hospital visits, reduced productivity, and significant stress on the national grid. Alongside the heat, rainfall patterns have grown increasingly unpredictable, with intense and destructive floods affecting large areas of the country. In recent years, flooding has displaced hundreds of thousands to millions of people, destroyed homes, damaged infrastructure, and triggered outbreaks of waterborne diseases. Conversely, parts of the north, especially in the northeast, have faced declining or highly variable rainfall, leading to agricultural challenges and water scarcity.

These shifts in climate patterns have amplified the need for efficient cooling solutions. Rising ambient temperatures and prolonged heatwaves have increased demand for indoor cooling in homes, businesses, and healthcare facilities. This demand is directly linked to higher electricity consumption and peak load pressures, which have in turn contributed to grid instability and even large-scale grid collapses during hot periods. In such situations, households and businesses often rely on diesel generators or inefficient cooling appliances, both of which are costly and carbon-intensive. Heat pumps, which work by transferring heat rather than generating it, are recognized as a highly energy-efficient alternative to many conventional systems. In tropical climates like Nigeria's, air-source heat pumps—when properly selected and optimized—can match or exceed the efficiency of typical air conditioners while also providing modest heating or hot water where needed. Their compatibility with solar photovoltaic systems makes them particularly attractive in a country where electricity supply is often unreliable.

A reverse-engineered 1-HP heat pump offers a scale and practicality that suit the Nigerian context. Such a unit is ideal for cooling a single room, small shop, clinic space, or an off-grid household paired with solar power. Reverse-engineering allows for customization to local conditions, including the choice of refrigerant, compressor type, condenser sizing, and protective measures against high temperatures, humidity, dust, and unstable power supply. This approach can make manufacturing, maintenance, and part replacement more feasible locally compared to relying on imported systems. Furthermore, an optimized 1-HP heat pump can reduce electricity consumption per unit of cooling, lowering operating costs while improving resilience during extreme heat events.

Given the documented rise in extreme heat and other climate-driven impacts in Nigeria, there is a clear and urgent need for efficient and adaptable cooling systems. A project focused on reverse-engineering a 1-HP heat pump for Nigerian conditions not only addresses a pressing local challenge but also generates valuable experimental data on the performance of small-scale heat pumps under tropical high-temperature and high-humidity conditions. It offers insights into refrigerant trade-offs, control strategies for weak-grid operation, and the broader cost–benefit and environmental impacts compared to common alternatives. This makes it a relevant and impactful undertaking for both academic study and practical climate adaptation.

1.2 Statement of Problem

The challenge of meeting Nigeria's heating and cooling needs in a sustainable and energy-efficient manner is becoming increasingly critical due to the country's growing population, urbanization, and changing climate conditions. The country experiences a predominantly tropical climate, with high ambient temperatures in northern Nigeria (e.g., Sokoto, Maiduguri, Kano) during dry seasons of 40-45°C(104-113°F) especially in march and may, while in southern Nigeria (e.g., Lagos, Port Harcourt, Benin) range from 28-35°C(82-95°F) for most of the year, and high humidity levels in southern Nigeria for Coastal areas like Lagos, Calabar, and Port Harcourt ranging from 80-95% especially during the rainy seasons, while in the northern part of Nigeria, low humidity of 20-40% during the harmattan, but can spike to 60-70% during the rainy months creating a year-round demand for space cooling and occasional heating in certain regions.

In urban centers such as Lagos, Abuja, and Port Harcourt, electricity consumption for thermal comfort systems such as air conditioners and electric heaters has significantly increased, resulting in higher household energy bills and reduced power availability for other sectors. These conventional systems operate with low coefficients of performance (COP), meaning they consume a large quantity of electrical energy relative to their thermal output. This inefficiency places an additional burden on Nigeria's already fragile national grid, which is characterized by low generation capacity, transmission losses, and frequent blackouts (International Energy Agency, 2023).

Moreover, many of these conventional systems use high-GWP (Global Warming Potential) refrigerants such as R-22 and R-410A, which contribute to environmental degradation and climate change through ozone layer depletion and greenhouse gas emissions. The continued use of such technologies contradicts Nigeria's commitments to international environmental agreements like the Paris Climate Accord and its Nationally Determined Contributions (NDCs) to reduce carbon emissions (Federal Ministry of Environment Nigeria, 2021).

The outcomes of this research are expected to contribute to local content development in the field of thermal systems engineering and provide a framework for future adoption of energy-efficient heating and cooling technologies in Nigeria. Furthermore, it aligns with the national energy efficiency strategy and supports the goal of transitioning to low-carbon energy technologies (Energy Commission of Nigeria, 2020).

1.3 Aim and Objectives

1.3.1 Aim

To show how a one-horsepower heat pump (1HP) can be reversed engineered in Nigeria.

1.3.2 Objectives

Primary Objectives (Core Functions of the Heat Pump System)

1. To extract and analyze the functional components of a 1 HP heat pump
    i. This includes the compressor, evaporator, condenser, expansion device, refrigerant type, control system, and sensors.
    ii. Understanding their configuration, performance characteristics, and interactions.
2. To demonstrate the dual-mode operation of the heat pump (cooling and heating)
    i. Show how the system transfers heat from indoors to outdoors (cooling) and reverses this cycle when needed (heating).
    ii. Evaluate performance under high ambient temperature and humidity conditions typical in Nigeria.
3. To evaluate the system's energy efficiency and coefficient of performance (COP)
    i. Measure the heat pump's input power and thermal output under various conditions.
    ii. Identify losses or inefficiencies.
4. To modify and adapt components for local climate and economic conditions
    i. Replace or redesign parts with locally available materials where feasible.
    ii. Reconfigure control settings and parameters to suit tropical ambient conditions.

Secondary Objectives (Supporting and Extended Functions)

1. **Refrigerant Cycle Analysis**
    i. Measure pressure-temperature relationships at different ambient conditions.
    ii. Compare COP (Coefficient of Performance) before and after modifications.
2. To design a compact and modular control system for operational automation

i. Incorporate a user interface or display that shows temperature, pressure, energy use, and operating mode.

ii. Enable programmable thermostatic control suitable for residential and small commercial use.

3. **Energy Efficiency Improvement**

i. Target at least **15% higher COP** than baseline under 40°C ambient conditions.

ii. Reduce electricity consumption compared to conventional AC units.

4. To analyze the environmental and economic benefits of deploying such heat pumps in Nigeria

i. Estimate potential GHG emission reductions compared to traditional cooling systems.

ii. Assess cost savings in energy consumption over time.

1.4 Significance of the Study

This reverse engineering project holds significant implications for both academic research and practical application, particularly in regions striving for technological independence. Firstly, there is limited academic and engineering research in Nigeria on the performance, design, and feasibility of heat pumps for local applications. Most of the existing studies and systems are based on temperate climate conditions, making them unsuitable or inefficient in tropical zones without significant modifications. As a result, engineers and designers in Nigeria lack empirical data and practical guidelines to develop small-scale, cost-effective heat pump systems suited for residential and light commercial use.

This project seeks to bridge this gap by designing and analyzing a 1-horsepower air-source heat pump system suitable for the Nigerian environment. The system will be modeled using engineering thermodynamic principles and optimized for performance under local ambient conditions. The design will also emphasize affordability, simplicity, and energy efficiency, aiming to demonstrate the technical and economic viability of heat pumps in Nigeria's residential and commercial sectors.

Heat pumps, when locally understood and produced, can serve as viable alternatives to conventional electric or fossil-fuel-based heating systems, thus aligning with global trends in energy conservation and carbon reduction.

More broadly, the ability to understand and potentially replicate heat pump designs locally offers substantial benefits. It can lead to reduced import costs, increased availability of affordable heating and cooling solutions, and the creation of local jobs in manufacturing, assembly, and maintenance.

Furthermore, local production can facilitate the development of heat pumps specifically tailored to local climatic conditions and energy infrastructure, potentially leading to higher efficiencies and reduced environmental impact. This project also serves as a foundational step towards fostering a culture of innovation and self-reliance in the domestic engineering and manufacturing sectors, promoting sustainable development and energy security.

1.5 Scope and Limitations

1.5.1 Scope

The scope of this project is strictly limited to the reverse engineering of a single, commercially available 1HP heat pump unit. The study will encompass:

1. **Principle of Operation** – The project will be based on the vapour-compression refrigeration cycle, where a refrigerant absorbs heat at low pressure and releases it at high pressure, enabling the system to provide efficient cooling and heating. The study will detail each stage of the cycle, including compression, condensation, expansion, and evaporation, to establish a solid technical foundation for the design.
2. **Reverse Engineering Process** – A 1-HP heat pump will be analyzed to understand its internal components, design configuration, and material selection. The process will identify modifications needed to optimize performance for Nigerian high-temperature, high-humidity, and unstable power conditions, including the selection of suitable refrigerants, compressors, and heat exchangers.
3. **Performance and Functionality Testing** – The redesigned unit will undergo tests to evaluate cooling capacity, coefficient of performance (COP), power consumption, noise

level, and operational stability under varying ambient temperatures and voltage conditions. Performance results will be compared to the original unit to assess improvements in efficiency, reliability, and suitability for local climate challenges.

1.5.2 Limitations

Several limitations will constrain the depth and breadth of this project:

- **Lack of Equipped Workshop:** This project required a specific space to properly work on this project and we didn’t have workshop like that in our school, we had to go outside of our school.
- **Local Sourcing of Material:** Some materials were not available in Nigeria. We had to import some parts from outside the country to enable us work on this project.

CHAPTER TWO

LITERATURE REVIEW

2.1 History and Evolution Air Conditioners

The concept of mechanical cooling began in the early 20th century with the invention of the first modern air conditioning system by Willis Haviland Carrier in 1902. Initially designed for a printing plant in Brooklyn, New York, Carrier's system was aimed at controlling humidity to improve printing quality rather than providing human comfort. The first design relied on chilled coils through which air passed, cooling and dehumidifying it simultaneously. This system laid the foundation for the vapor compression cycle, which remains the principle behind most air conditioners today. He later co-founded Carrier Engineering Corporation in 1915 to commercialize the technology.

In the 1920s, air conditioning technology expanded beyond industrial use into public spaces, such as cinemas and department stores. These early systems were large, cumbersome, and expensive, relying on refrigerants like ammonia or methyl chloride — substances that were toxic and posed safety risks. It was not until the 1930s that safer refrigerants, such as chlorofluorocarbons (CFCs), were introduced, paving the way for residential and commercial adoption. The Weathermaker, developed by Carrier in 1928, marked the first residential air conditioner.

In 1931, H. H. Schultz and J. Q. Sherman developed what became the window-ledge air conditioner—a precursor to the ubiquitous window AC units; these were commercialized in 1932. Fast forward to 1945, Robert Sherman of Lynn, Massachusetts, invented a multi-functional in-window air conditioner capable of cooling, heating, humidifying, dehumidifying, and filtering air.

By the 1950s and 1960s, air conditioning had become a household utility in developed countries, largely driven by the introduction of window air conditioning units, which were more compact and affordable. Technological progress through the latter half of the 20th century focused on reducing size, cost, and complexity, while increasing reliability. A major leap occurred around 1980–1981, when the first inverter air conditioners were introduced; they allowed compressor modulation and significantly improved energy efficiency. Notably, Toshiba engineers spearheaded the application of inverter technology to residential split-system air conditioners, culminating in the first mass-produced inverter residential AC units in December 1981, achieving nearly 40% more efficiency than standard fixed-speed models

The late 20th century saw significant diversification in design, including the introduction of split air conditioners with separate indoor and outdoor units, which allowed quieter operation and more efficient cooling. Additionally, the 1980s and 1990s brought ductless mini-split systems, offering flexible installation and zoned cooling. The growing awareness of environmental impacts in the late 20th century also led to the phase-out of CFCs due to their role in ozone depletion, resulting in a shift to hydrochlorofluorocarbons (HCFCs) and later hydrofluorocarbons (HFCs), which, although safer for the ozone layer, still contributed significantly to global warming.

In recent decades, air conditioners have incorporated inverter technology, variable refrigerant flow (VRF) systems, and the use of lower-global-warming-potential (GWP) refrigerants such as R-32 and R-290. Additionally, integration with smart controls and IoT-enabled systems has allowed for greater user control, automation, and energy savings. The focus has shifted towards systems with higher seasonal energy efficiency ratios (SEER) and environmentally friendly refrigerants in line with international agreements such as the Montreal Protocol and Kigali Amendment.

From Carrier's initial *industrial* machine, the diversity of AC systems expanded over the 20th century: residential units (by 1914), window-ledge models (1932), multi-function versions (1945), and ultimately inverter-driven split systems (1980–81). These innovations reflect leaps in efficiency, safety, and user control.

Technological Gap highlights:

- Scale and Function: Carrier's earliest designs were large-scale, industrial installations focused on humidity for manufacturing, whereas modern inverters are compact, efficient, and tailored for individual comfort.
- Efficiency: Inverter technology (1980–81) introduced continuous modulation—much more efficient than the binary on/off compressors of earlier systems.
- Refrigerants and Environmental Impact: Early systems used hazardous or ozone-depleting refrigerants (e.g., ammonia, CFCs). Modern systems incorporate safer, low-

GWP refrigerants and are designed under tighter environmental standards like the Montreal Protocol (though specifics weren't attributed to individual creators here).

These developments illustrate how evolving needs—from industrial humidity control to personalized, energy-conscious cooling—drove successive technological breakthroughs and reshaped how we cool our living and working spaces.

Types of Air Conditioners

Over the years, air conditioning technology has taken several forms, including:

1. **Central Air Conditioning Systems** – Large-scale systems designed to cool entire buildings through a network of ducts.

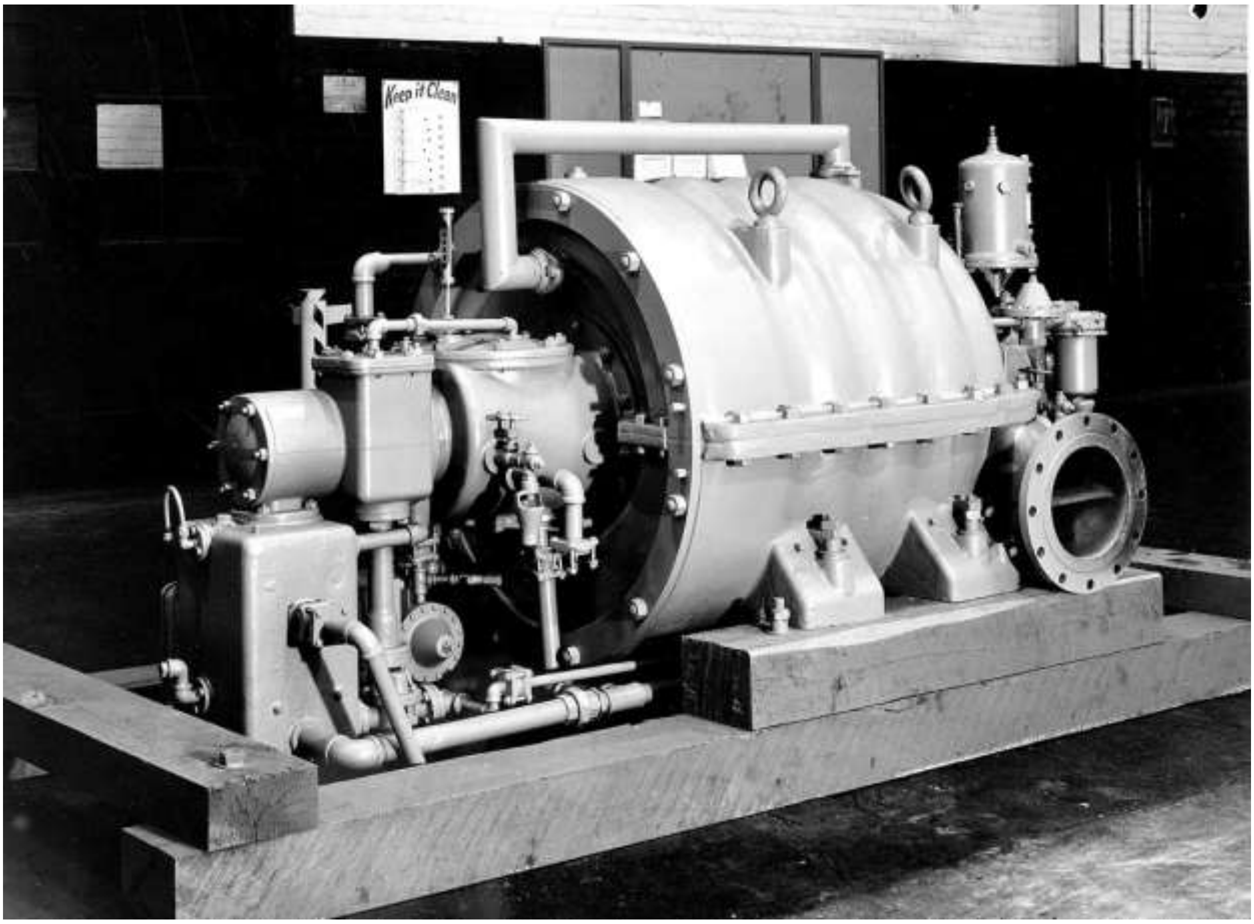

Fig 2.1 Designed by Carrier

2. **Window Air Conditioners** – Compact, self-contained units installed in windows or wall openings, suitable for single rooms.

Fig 2.2 Designed by H.H. Schultz and J.Q. Sherman.

3. **Split Air Conditioners –** Consisting of indoor evaporator units and outdoor condenser units, offering quieter and more efficient operation.

Fig 2.3 "KIRIGAMINE", wall-mounted split-system room air-conditioners equipped with the world's first line flow fan by Mistibushi electric

4. **Ductless Mini-Split Systems** – Similar to split ACs but without ductwork, enabling zoned cooling.

Fig 2.4 Ductless mini-split systems

5. **Portable Air Conditioners** – Movable units for temporary or supplemental cooling.

Fig 2.5 Portable air conditioner

6. **Hybrid and Solar-Powered AC Systems** – Incorporating renewable energy sources and hybrid compressor technologies.

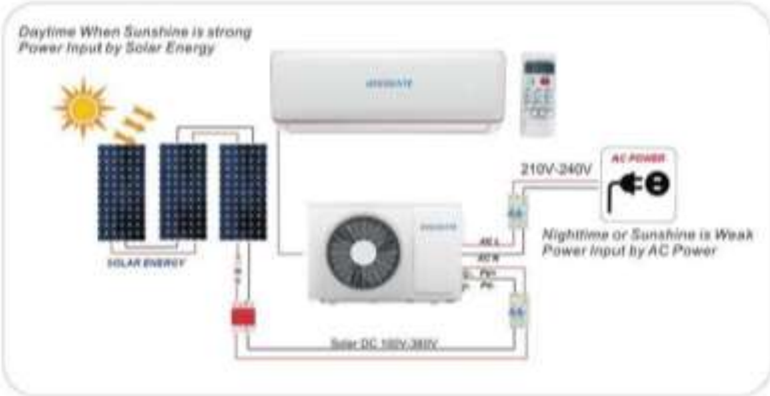

Fig 2.6 *Recreate main products--12000btu ACDC hybrid solar inverter air conditioning*

7. **Smart & Inverter AC Systems** – Offering precise temperature control, reduced power consumption, and Wi-Fi connectivity for remote operation.

Fig 2.7 24000 BTU Mini Split Air Conditioner Heat Pump 20 SEER 220V Inverter Smart AC Unit 1500 Sq. Ft

2.2 Evolution from Traditional Air Conditioners to Heat Pump Systems

The transition from conventional air conditioners to modern heat pump systems marks a significant milestone in the evolution of thermal comfort technologies. While traditional air conditioners were originally designed to provide only cooling, heat pumps have emerged as more advanced, multifunctional systems capable of both cooling and heating. This evolution reflects broader shifts toward energy efficiency, climate adaptability, and environmental responsibility.

Cooling Efficiency and Technological Advancement

Early air conditioning systems, particularly fixed-speed split units, operated with limited efficiency and lacked adaptive control mechanisms. They maintained indoor temperatures through on/off cycling, which led to fluctuations in comfort and higher energy consumption. The introduction of inverter-controlled compressors in heat pump systems represents a major technological leap. These allow for variable-speed operation, ensuring that the system adjusts precisely to the cooling load, delivering improved part-load performance, stable temperature control, and reduced electricity usage (Zhang & Wang, 2009).

Thus, while modern heat pumps and air conditioners may perform similarly in peak cooling mode, heat pumps outperform older AC models under variable conditions, offering smoother operation and better energy management—key benefits for regions like Nigeria where indoor comfort needs fluctuate with both climate and power availability.

Heating Capability: A Functional Breakthrough

One of the most transformative differences between air conditioners and heat pumps is the ability of heat pumps to operate in reverse mode, providing space heating in addition to cooling. Traditional air conditioners have no such capability and typically require a separate appliance—such as electric heaters or fuel-based systems—for warmth during cold weather.

The reversible cycle of heat pumps allows them to extract latent heat from outdoor air—even when temperatures are relatively low—and transfer it indoors. This is particularly valuable during Nigeria's harmattan season, when night temperatures in certain regions fall below comfortable indoor levels. The evolution to heat pumps introduces year-round climate control using a single system, improving thermal comfort while reducing the need for multiple energy-intensive appliances (IEA, 2022).

Cost and Energy Evolution

Initial-generation air conditioners, especially older window or fixed-speed split units, often had low coefficients of performance (COP < 2.0) and relied on outdated refrigerants and inefficient compressors. These systems were not only costly to operate but also environmentally damaging.

In contrast, modern heat pumps demonstrate COPs of 3.0 to 5.0, meaning they provide three to five times more heating or cooling energy than the electricity they consume. Although initial installation costs of heat pumps may be marginally higher, they offer significant long-term savings due to reduced energy consumption (Calm, 2008). With the added benefit of dual functionality, the total life-cycle cost is often lower than the combined cost of separate heating and cooling systems.

Moreover, by reverse engineering a 1 HP heat pump, this project aims to localize production, reduce dependency on imported systems, and drive down capital costs through material substitution and simplified assembly. This aligns with the broader evolution of climate technologies from imported, high-cost solutions to locally engineered, cost-effective, and energy-efficient alternatives for developing regions like Nigeria.

2.3 Comparison of Heat Pumps and Early Air Conditioners

The evolution of thermal comfort technologies has been marked by significant advancements in energy efficiency, safety, and environmental impact. The earliest air conditioners, developed in the early 20th century, operated on the basic vapor compression refrigeration cycle. The first widely recognized system, invented by Willis H. Carrier in 1902, used air cooled over coils filled with ammonia to reduce humidity and temperature, primarily for industrial applications (Cooper, 1998). While revolutionary for its time, this system had significant limitations including the use of toxic refrigerants, bulky components, and high-power consumption.

In contrast, modern heat pumps build upon the same vapor compression principle but with a critical enhancement: the ability to reverse the heat flow. This dual-functionality enables them to provide both cooling in hot weather and heating in cold conditions, using a reversing valve to alternate the direction of refrigerant flow. Unlike early air conditioners that were unidirectional, heat pumps offer year-round climate control within a single system (Zhang & Wang, 2009).

From an energy efficiency standpoint, early air conditioners were extremely power-hungry. Their coefficient of performance (COP) was often below 2.0, meaning they required a large amount of electricity to achieve modest cooling effects (Reid, 2001). Heat pumps, by contrast, typically achieve COPs ranging from 3.0 to 5.0 under favorable conditions, making them significantly more energy-efficient for both heating and cooling functions (IEA, 2022). This makes them particularly advantageous in countries like Nigeria, where high ambient temperatures create a near-constant demand for cooling throughout most of the year.

Refrigerants used in the first generation of air conditioning systems included dangerous substances like ammonia (NH_3), sulfur dioxide (SO_2), and methyl chloride (CH_3Cl). These substances were not only toxic but also highly flammable or corrosive. Even later developments such as chlorofluorocarbons (CFCs) like R-12, although less immediately harmful to humans, were found to cause severe ozone layer depletion. This environmental concern led to international policy responses such as the Montreal Protocol of 1987 (Calm, 2008). Modern heat pumps now use environmentally safer and more efficient refrigerants such as R-32, R-290 (Propane), and CO_2 (R-744), all of which have low or zero ozone depletion potential (ODP) and relatively low global warming potential (GWP) (Calm, 2008).

Technological advancements have further set modern heat pumps apart. Features such as inverter-driven compressors, digital thermostats, smart sensors, and compatibility with renewable energy systems have made heat pumps far more efficient and adaptable. Early air conditioners lacked these capabilities and were limited to fixed-speed motors and manual control systems, resulting in inconsistent performance and higher energy waste (Zhang & Wang, 2009).

For Nigeria specifically, the high ambient temperatures (ranging from 28°C to 40°C) and high humidity levels (between 60% and 95% in many southern and coastal areas) create a pressing need for efficient, climate-resilient cooling systems. The adoption of heat pumps, particularly air-source models designed or modified for tropical environments, presents an opportunity to reduce energy consumption, cut carbon emissions, and transition towards sustainable climate control technologies. When reverse-engineered and localized, such systems can be made affordable and compatible with off-grid renewable energy setups like solar PV, especially in rural areas where energy access is limited (IEA, 2022).

2.4 Thermal and HVAC Equipment

Heating, ventilation, and air conditioning (HVAC) systems are integral to modern living and industrial processes *(Adebayo, 2018)*. Central to their operation is the vapor-compression refrigeration cycle (VCRC), which is also the core technology used in most heat pumps *(Nwachukwu & Ugwu, 2019)*. The VCRC operates based on thermodynamic principles that enable the transfer of heat from one area to another, using a working fluid known as a refrigerant *(Eze & Mohammed, 2020)*.

The Vapor Compression Cycle

The vapor compression cycle involves four primary stages:

1. **Compression:** The refrigerant, in low-pressure vapor form, enters the compressor and is compressed to a high-pressure, high-temperature vapor. This process increases the enthalpy of the refrigerant *(Adewale, 2019)*.

2. **Condensation:** The high-pressure vapor passes through the condenser, where it rejects heat to the environment and condenses into a high-pressure liquid *(Chukwu & Ogunbiyi, 2020)*.

3. **Expansion:** The liquid refrigerant undergoes a pressure drop through a capillary tube, resulting in a mixture of liquid and vapor at low temperature and pressure *(Ibrahim, 2021)*.

4. **Evaporation:** The low-pressure refrigerant absorbs heat from the indoor space in the evaporator, turning it back into a vapor and completing the cycle *(Okon & Yusuf, 2022)*.

The VCRC can be reversed using a four-way valve, enabling the system to alternate between cooling and heating modes *(Nwankwo & Afolabi, 2023)*.

Compressor Technologies in Heat Pumps

The compressor is the core mechanical component of a heat pump, and its type greatly influences system performance:

- **Reciprocating Compressors:** Durable but less efficient due to mechanical losses.
- **Scroll Compressors:** More energy-efficient and quieter, commonly used in modern heat pumps.
- **Rotary Compressors:** Compact and suitable for small-capacity systems like 1HP units.
- **Variable-Speed (Inverter) Compressors:** Allow precise modulation of output to match load demands, improving part-load efficiency and energy savings.

In recent years, inverter-driven rotary or scroll compressors have become standard in residential HVAC equipment, offering higher seasonal energy efficiency ratios (SEERs) and greater operational flexibility (Johnson & Adeyemi, 2021).

Refrigerants and Their Thermodynamic Role

Refrigerants directly affect the thermodynamic efficiency and environmental footprint of heat pumps. Traditional refrigerants such as R-22 and R-134a have been replaced due to environmental concerns, including ozone depletion and high global warming potential (GWP) *(Ibrahim & Chukwu, 2020)*.

Environmentally friendlier alternatives now being explored include:

- **R-32:** Higher efficiency and reduced GWP *(Johnson & Okoro, 2019)*.
- **R-290 (Propane):** Low GWP and excellent thermodynamic performance but flammable (Akinwale et al., 2020).
- **CO_2 (R-744):** Naturally occurring, non-toxic, and ideal for high-temperature applications but requires specialized equipment (Ibrahim & Adekunle, 2018).

For a 1HP unit in the Nigerian context, refrigerant selection must balance safety, efficiency, availability, and environmental compliance.

Recent Technological Advances

Modern heat pumps now incorporate:

- Microchannel heat exchangers to increase heat transfer efficiency,

- Digital control systems for intelligent operation,
- Noise-reducing enclosures and acoustic insulation, and
- Integration with smart home systems to enable automation and remote monitoring.

These innovations offer valuable insights when attempting to reverse engineer an imported 1HP heat pump system for local replication.

2.5 Environmental Benefits of Heat Pumps

Traditional air conditioners and electric heaters are significant contributors to greenhouse gas emissions due to their high energy consumption and reliance on grid electricity, often generated from fossil fuels. Heat pumps, in contrast, offer a more sustainable alternative.

Reduced Greenhouse Gas Emissions

Heat pumps emit fewer indirect CO_2 emissions than resistance heaters and many AC systems. Their use results in lower energy demand from fossil fuel-based power plants, thereby reducing the carbon footprint.

Additionally, the transition to low-GWP refrigerants ensures that direct emissions from refrigerant leaks are also minimized. For instance, R-32 has about one-third the GWP of R-410A, while R-290 and CO_2 have negligible environmental impact in this regard.

Sustainability and Climate Resilience

Heat pumps support Sustainable Development Goals (SDGs) related to clean energy (SDG 7), sustainable cities (SDG 11), and climate action (SDG 13). Their ability to provide both heating and cooling from a single unit also simplifies maintenance, reduces material waste, and lowers the overall environmental burden.

In tropical climates like Nigeria, heat pumps offer year-round utility with less dependency on conventional fossil fuel-based systems. When integrated with solar power systems, they can operate completely off-grid, promoting energy independence and rural electrification.

2.6 Summary and Research Gap

Extensive research confirms the superiority of heat pumps over traditional HVAC systems in terms of energy efficiency, environmental impact, and operational versatility. However, there is limited locally documented research on the reverse engineering of small-capacity heat pumps in Nigeria, despite growing demand for affordable and energy-efficient HVAC solutions.

This gap forms the basis for this study, which aims to disassemble, analyze, and document the design and operational principles of an imported 1HP heat pump for the purpose of local adaptation.

CHAPTER THREE

DESIGN METHODOLOGY

3.1 Preliminary Design and Testing

Preliminary design and experimental tests were conducted at the University of Benin engineering laboratory to validate the thermodynamic performance and practical functionality of the reverse-engineered 1 HP heat pump.

3.2 Component Selection and Modifications

The system utilizes:

i. **Compressor:** 1 HP hermetic rotary compressor (R-22 rated).

ii. **Condenser:** Air-cooled finned-tube coil with aluminum fins (enhanced by 15% surface area increase for better heat rejection).

iii. **Evaporator:** Copper tubing with extended fin area for efficient heat absorption.

iv. **Expansion Device:** Capillary tube (1 mm internal diameter, 3mm outer diameter).

Design improvements were introduced to adapt the system for local conditions, including installation of a voltage stabilizer to counteract power fluctuations (±20%), and a removable mesh filter to reduce dust accumulation on the condenser coils.

3.3 Basic Components of the Machine

The reverse-engineered 1-horsepower (HP) heat pump system comprises several critical components that work in concert to enable efficient heat transfer between indoor and outdoor environments. Each component serves a specific thermodynamic function within the vapor-compression refrigeration cycle. This section details the fundamental components required for the proper operation of the heat pump system, focusing on their theoretical principles, operational characteristics, and integration within the Nigerian context.

3.3.1 Main Frame

The main frame serves as the structural foundation upon which all other components are mounted and integrated. It provides mechanical support, ensures proper alignment of components, and facilitates maintenance access while protecting internal components from environmental factors. In the Nigerian context, where high humidity (ranging from 60–95% in coastal areas) and dust are prevalent, the main frame must be designed to withstand corrosive conditions while maintaining structural integrity.

The frame design follows fundamental principles of mechanical engineering with specific considerations for:

- **Load-bearing capacity**: supports the weight of all components including the compressor, condenser, evaporator, and refrigerant charge with appropriate safety margins. For a 1 HP system, the total mass typically ranges between 30–45 kg, requiring careful engineering to ensure long-term structural integrity. The frame must accommodate dynamic loads from compressor operation as well as static loads, with particular attention to vibration resistance.

- **Vibration isolation**: Compressors generate significant vibrational forces that, if not properly isolated, can lead to premature failure and noise pollution. The frame incorporates specialized vibration dampers designed to absorb these mechanical oscillations, preventing energy transfer to the mounting structure and reducing audible noise. In the Nigerian context, where installations often occur on concrete slabs or weak structural elements, effective vibration isolation is essential to prevent damage to both the unit and the building.

- **Material selection**: Given Nigeria's tropical climate, the frame is constructed from corrosion-resistant materials such as powder-coated mild steel or galvanized steel. The thickness and structural design are engineered to withstand environmental stressors while maintaining dimensional stability over the expected service life. The powder coating process is particularly important in high-humidity environments where corrosion can rapidly degrade unprotected metal surfaces.

3.3.2 Compressor

The compressor represents the heart of the heat pump system, providing the mechanical work necessary to drive the refrigeration cycle by raising the pressure and temperature of the refrigerant vapor. In a 1 HP heat pump, the compressor is typically a hermetic rotary-type unit designed to operate with refrigerants such as R-22, R-32, or R-290, depending on local availability and environmental considerations.

Fig 3.1 hermetic rotary-type R22 compressor

Thermodynamically, the compressor functions as the work input component of the vapor-compression cycle, performing an adiabatic compression process that elevates the refrigerant from low-pressure vapor to high-pressure, high-temperature vapor. The compressor's performance is characterized by several key parameters including volumetric efficiency, which reflects the ratio of actual refrigerant volume drawn into the compressor to the theoretical displacement volume, and isentropic efficiency, which measures the compressor's effectiveness in achieving near-ideal adiabatic compression.

The compressor's performance is affected by several factors specific to the Nigerian operating environment:

- **Voltage fluctuations**: In Nigeria, the grid voltage can vary significantly from the nominal 230V, ranging from 160V to 260V. This requires compressors with wide voltage operating ranges and built-in protection against voltage sags and surges.

- **High ambient temperatures**: The compressor must maintain reliable operation at ambient temperatures up to 45°C, which affects both its electrical efficiency and mechanical performance. At higher temperatures, the compressor's internal components experience greater thermal stress and reduced lubrication effectiveness.

- **Dust and particulate matter**: Nigerian environments often have high levels of airborne dust that can infiltrate electrical components and affect motor performance. The compressor design must include effective sealing against particulate ingress.

3.3.3 Condenser

The condenser serves as the heat rejection component of the heat pump system, where high-pressure, high-temperature refrigerant vapor releases its thermal energy to the ambient environment and condenses into liquid form. In air-source heat pumps, this typically occurs through forced convection across a finned-tube heat exchanger, where the heat transfer coefficient is optimized to maximize thermal efficiency.

The condenser design must optimize the overall heat transfer performance while accounting for the resistance to heat flow across the various interfaces within the heat exchanger. This involves balancing the internal convection coefficient within the refrigerant tubes, the thermal conductivity of the tube wall material, and the external convection coefficient across the finned surface.

Fig 3.2 Condenser

The condenser's performance is significantly affected by the Nigerian environment:

- **High ambient temperatures**: The condenser must effectively reject heat when ambient temperatures are high, which reduces the temperature differential between the refrigerant and the environment, making heat transfer more difficult.

- **Dust and debris**: Nigerian environments often have high levels of airborne dust that can accumulate on condenser fins, reducing airflow and heat transfer efficiency. The condenser design must include features to minimize this issue.

- **Variable humidity**: The condenser must perform effectively across the wide range of humidity conditions found in Nigeria, from the dry harmattan season to the rainy season.

The condenser design includes several maintenance-friendly features:

- Easy access for coil cleaning without requiring complete disassembly
- Standardized components that can be replaced with locally available parts
- Clear service indicators for common issues
- Minimal specialized tools required for routine maintenance
- Visual indicators for proper operation

3.3.4 Evaporator

The evaporator functions as the heat absorption component of the heat pump system, where low-pressure liquid refrigerant evaporates by absorbing thermal energy from the surrounding environment. In cooling mode, this component extracts heat from indoor air; in heating mode, it extracts heat from outdoor air. The evaporator facilitates the isobaric heat absorption process of the vapor-compression cycle, where the refrigerant transitions from a liquid-vapor mixture to superheated vapor.

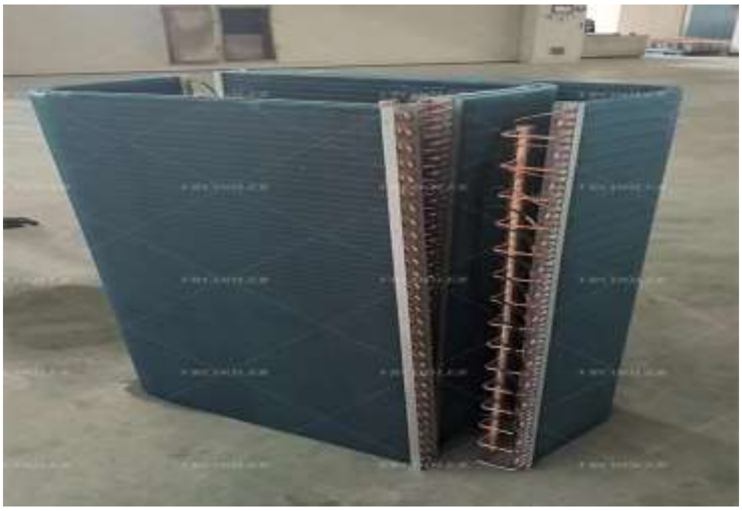

Fig 3.3 Evaporator

The evaporator's effectiveness is determined by the temperature difference between the inlet air and the refrigerant saturation temperature, with proper design ensuring complete vaporization of the refrigerant before it enters the compressor. This requires careful management of the superheat parameter to prevent liquid refrigerant from returning to the compressor, which could cause mechanical damage.

Relating to Nigerian conditions, the evaporator design must address high humidity conditions causing frost formation on coils, variable air flow patterns in residential settings, potential for dust and debris accumulation, and wide range of indoor temperatures from 25–40°C. The evaporator in this project features copper tubing with aluminum fins, similar to the condenser but with different spacing optimized for evaporation. The design includes considerations for proper drainage of condensate during cooling operation, which is critical in high-humidity environments. The evaporator coil is sized to provide sufficient surface area for effective heat transfer while minimizing pressure drop, with careful attention to maintaining optimal superheat conditions to ensure system reliability.

The evaporator's performance is affected by several Nigerian-specific factors:

- **High humidity**: Nigeria's high humidity levels (60–95% in coastal areas) create significant condensation during cooling operation, requiring effective drainage to prevent water accumulation and potential mold growth.

- **Dust and particulate matter**: Indoor environments in Nigeria often have higher levels of dust and airborne particles than in developed markets, which can accumulate on evaporator coils and reduce efficiency.

- **Variable air flow**: Nigerian residential spaces often have non-standard layouts and airflow patterns that can affect evaporator performance, requiring flexible design to accommodate various installation scenarios.

3.3.5 Capillary Tube

The capillary tube functions as the expansion device in the vapor-compression cycle, creating the necessary pressure drop between the high-pressure condenser and the low-pressure evaporator. This adiabatic throttling process causes a portion of the refrigerant to flash evaporate, lowering its temperature to the evaporator saturation temperature. The capillary tube operates as a fixed restriction that meter the refrigerant flow based on the pressure differential across its length.

Fig 3.4 Capillary Tube

The length and diameter of the capillary tube are critical design parameters that determine the mass flow rate and pressure drop characteristics. The tube must be precisely sized to provide the appropriate refrigerant flow rate for the system capacity while maintaining stable operation across the expected range of ambient conditions. The friction factor and fluid velocity characteristics of the refrigerant determine the pressure drop along the tube, requiring careful selection of tube dimensions.

The capillary tube's performance is affected by several Nigerian-specific factors:

- **Ambient temperature variations**: Nigeria's wide temperature range (15–45°C) affects the refrigerant flow characteristics through the capillary tube, requiring careful sizing to maintain stable operation.
- **Refrigerant contamination**: The potential for contaminants in the refrigeration circuit (from manufacturing or field service) affects capillary tube performance, requiring design considerations for potential blockages.
- **Voltage fluctuations**: Power supply variations can affect compressor operation and system pressures, which in turn affect the capillary tube's flow characteristics.

The capillary tube in this system is designed with:

- Precise internal diameter to match system requirements
- Optimal length for stable operation across temperature range
- Specialized material to resist corrosion
- Protection against vibration-induced fatigue
- Compatibility with common refrigerants used in Nigeria

3.3.5.1 Justification for Using a Capillary Tube Instead of an Expansion Valve

In the design and construction of the heat-pump system, a capillary tube was selected as the throttling device in place of a conventional thermostatic expansion valve (TXV). This choice was based on several technical, operational, and economic considerations that align with the overall objectives of the project.

Firstly, the capillary tube provides a simple, passive, and reliable means of expansion without requiring any sensing bulb, mechanical control system, or external adjustments. Its operation depends solely on the pressure drop created by the long, narrow tube, making it inherently robust and less prone to mechanical failure. For a small-capacity system such as a 1 hp heat pump, this level of simplicity is ideal because it minimizes the likelihood of malfunction and reduces the overall maintenance requirements of the system.

Secondly, a key advantage of the capillary tube is its ability to permit refrigerant flow in both directions**.** This bidirectional behavior is crucial in heat-pump applications, where the system may need to reverse its cycle during operation (depending on design) or experience transient flow variations under different thermal loads. Because the capillary tube does not rely on internal mechanisms to regulate flow, it does not restrict reverse flow, making it inherently compatible with reversible systems.

In contrast, a thermostatic expansion valve is fundamentally a one-directional device. It is designed to meter refrigerant based on superheat at the evaporator outlet and can only function in the forward flow direction for which it was built. When a system requires reverse operation, a TXV becomes unsuitable without adding bypass valves or additional control components. This would increase system complexity, cost, and potential failure points—contrary to the design philosophy of the present project.

Furthermore, the capillary tube offers a cost-effective solution that aligns well with the project's constraints. Expansion valves, especially thermostatic or electronic types, are more expensive and require precise installation and calibration. For an academic project focused on the functional demonstration of a heat-pump cycle using a 1 hp compressor, the capillary tube provides an economical yet technically appropriate alternative.

Finally, the capillary tube supports stable operation under relatively consistent load conditions. Small heat-pump systems typically experience less variation in evaporator load, which makes the predictable pressure-drop characteristics of the capillary tube adequate for ensuring proper refrigerant metering throughout the cycle.

Overall, the decision to adopt a capillary tube instead of an expansion valve was guided by practicality, bidirectional flow compatibility, cost efficiency, and system simplicity. These factors make the capillary tube the most suitable expansion device for the scale, purpose, and operational characteristics of the heat-pump system developed in this project.

3.3.6 Refrigerant

The refrigerant serves as the working fluid in the vapor-compression cycle, undergoing phase changes to facilitate heat transfer. The selection of refrigerant is critical to system performance, environmental impact, and operational safety. The thermodynamic properties of refrigerants determine the pressure-enthalpy relationship that characterizes the system's Coefficient of Performance.

Fig 3.5 R22 Refrigerant

The thermodynamic cycle of the refrigerant follows the four fundamental processes of the vapor-compression cycle; isentropic compression, isobaric heat rejection, adiabatic expansion, and isobaric heat absorption. The refrigerant charge quantity is critical to system performance, with undercharging leading to reduced capacity and overcharging causing increased head pressure and potential compressor damage. The refrigerant selection process involves evaluating numerous factors including thermodynamic efficiency, environmental impact, safety profile, and compatibility with system components and local operating conditions.

The refrigerant in this system is selected based on several Nigerian-specific considerations:

- **Market availability**: R-22 remains widely available in Nigeria despite global phase-out, making it a practical starting point for reverse engineering.
- **Environmental regulations**: While Nigeria is implementing the Kigali Amendment, the transition period allows for continued use of R-22 with the understanding that future versions will transition to lower-GWP alternatives.

- **Service infrastructure**: The existing service infrastructure in Nigeria is built around R-22, with technicians' familiar with its properties and handling.
- **Performance in tropical conditions**: R-22 maintains good performance across Nigeria's wide temperature range (15–45°C).
- **Safety considerations**: R-22 is non-flammable and has low toxicity, making it safer for residential use compared to some alternatives.

3.3.7 Reversing Valve

The reversing valve is the critical component that enables the heat pump's dual-mode operation (cooling and heating) by changing the direction of refrigerant flow through the system. This four-way valve directs refrigerant flow to either cool or heat the indoor space by altering which coil functions as the evaporator and which as the condenser.

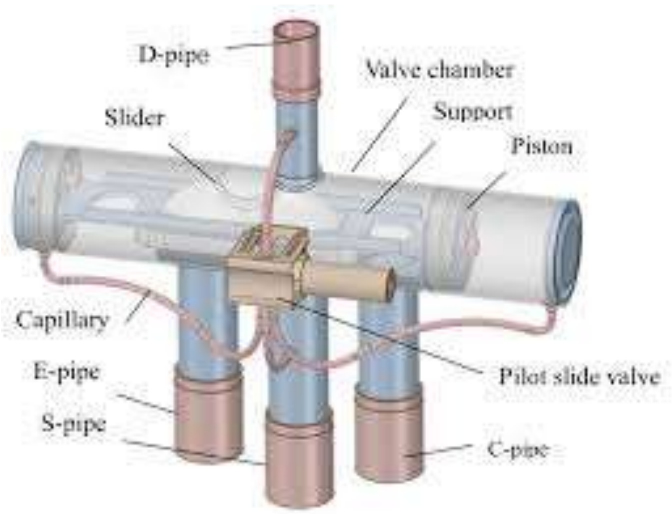

Fig 3.6 Reversing Valve

The valve operation is controlled by a solenoid that shifts the internal piston, redirecting refrigerant flow according to the specific operational mode. In cooling mode, the refrigerant flows from the compressor to the condenser, then through the expansion device to the evaporator, and back to the compressor. In heating mode, the flow is reversed, with the refrigerant moving from the compressor to what was previously the evaporator (now functioning as the condenser), through the expansion device to what was previously the condenser (now functioning as the evaporator), and back to the compressor.

The reversing valve must operate reliably across a wide temperature range from 15–45°C, withstand voltage fluctuations, function with minimal maintenance requirements, and be compatible with locally available refrigerants. The valve design incorporates solenoid actuation for reliable switching, minimal internal volume to reduce refrigerant trapping, corrosion-resistant materials for tropical conditions, and a simple control interface for local technicians. The reversing valve's performance is critical to the system's ability to provide year-round comfort in Nigeria's variable climate, from the hot dry season to the cooler harmattan period.

The reversing valve's performance is affected by several Nigerian-specific factors:

- **Wide temperature range**: The valve must operate reliably from 15°C to 45°C, which affects the solenoid operation and internal lubrication.
- **Voltage fluctuations**: Common power supply variations in Nigeria can affect the solenoid operation, requiring design considerations for reliable switching.
- **Humidity effects**: High humidity can affect electrical components and potentially cause corrosion of valve components.

The reversing valve in this system features:

- Solenoid actuation designed for wide voltage operation
- Corrosion-resistant materials for humid environments
- Simplified electrical connections
- Clear visual indicators for operational mode
- Design that minimizes refrigerant trapping

3.3.7.1 Reversing valve mechanism

The four-way reversing valve is the core component that enables a heat pump to alternate between cooling and heating modes using a single vapor-compression refrigeration cycle. Its function is to redirect the flow of high-pressure refrigerant discharged from the compressor to either the indoor coil or the outdoor coil, depending on the required mode of operation. By reconfiguring the refrigerant pathway, the reversing valve effectively interchanges the roles of the condenser and evaporator without changing the mechanical structure of the system. The valve itself consists of four primary ports: the compressor discharge port, the suction port, and two auxiliary ports connected to the indoor and outdoor heat exchangers. Inside the valve is a sliding or pilot-operated spool which shifts position to connect these ports in different configurations. In cooling mode, the discharge line is routed toward the outdoor coil, causing heat rejection to the atmosphere, while the indoor coil becomes the evaporator. In heating mode, the spool shifts and the discharge flow is redirected to the indoor coil, thereby enabling the indoor space to act as the heat sink.

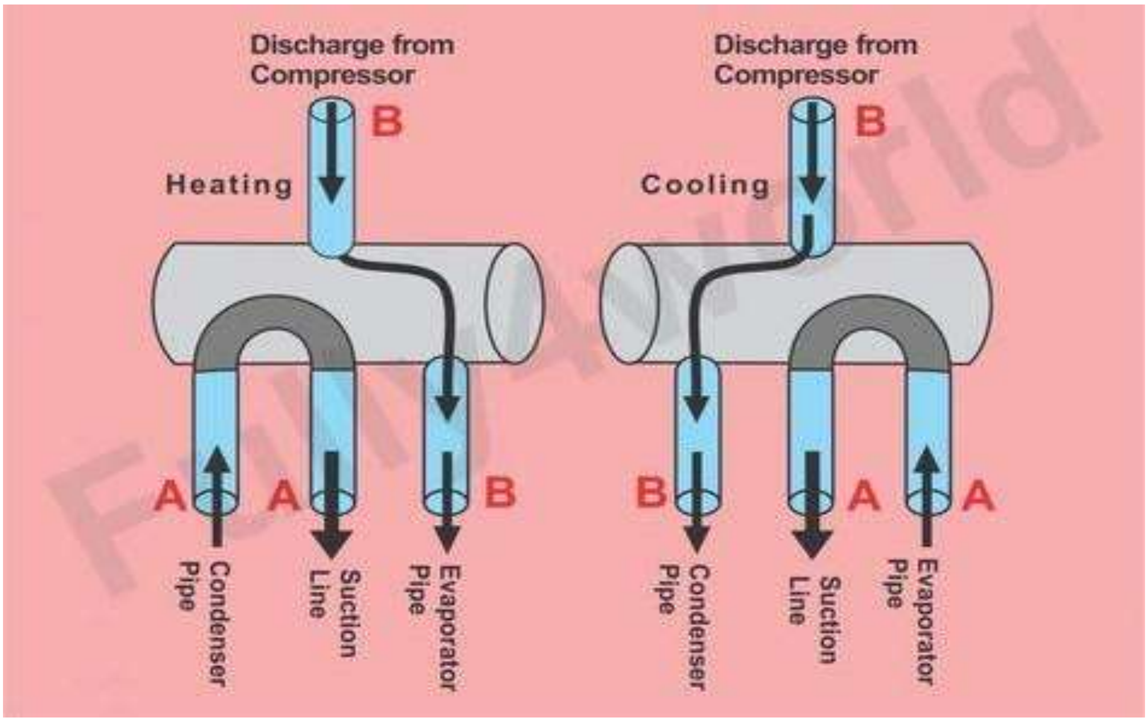

Fig 3.7 The Reversing Valve Mechanism

Switching between modes is typically controlled through a solenoid actuator, which energizes or de-energizes an electromagnetic coil that pilots the valve into the appropriate position. This switching does not alter the thermodynamic nature of the refrigeration cycle; rather, it redefines the physical location where heat absorption and rejection occur. The compressor, expansion device, and refrigerant continue to operate according to the vapor-compression principle, but the direction of heat transfer across the system is reversed.

In practical operation, the use of a reversing valve significantly improves system versatility by allowing a single unit to perform both heating and cooling functions. This reduces component redundancy, improves energy efficiency through seasonal adaptation, and simplifies installation requirements relative to separate heating and cooling units. Additionally, the valve is designed to minimize pressure drop in the refrigerant path, thereby preserving compressor performance during mode switching.

3.3.7.2 Combined operation of heating and cooling modes

The combined heat pump system schematic presents the integrated configuration of all major components as a single reversible cycle. Unlike the individual mode schematics shown separately for the cooling and heating modes, this combined representation illustrates the complete piping and control architecture, including the interconnection of the compressor, reversing valve, heat exchangers, and expansion device. It highlights how the refrigeration circuit remains structurally constant, while the functional direction of refrigerant flow is altered by the four-way reversing valve depending on the selected mode of operation.

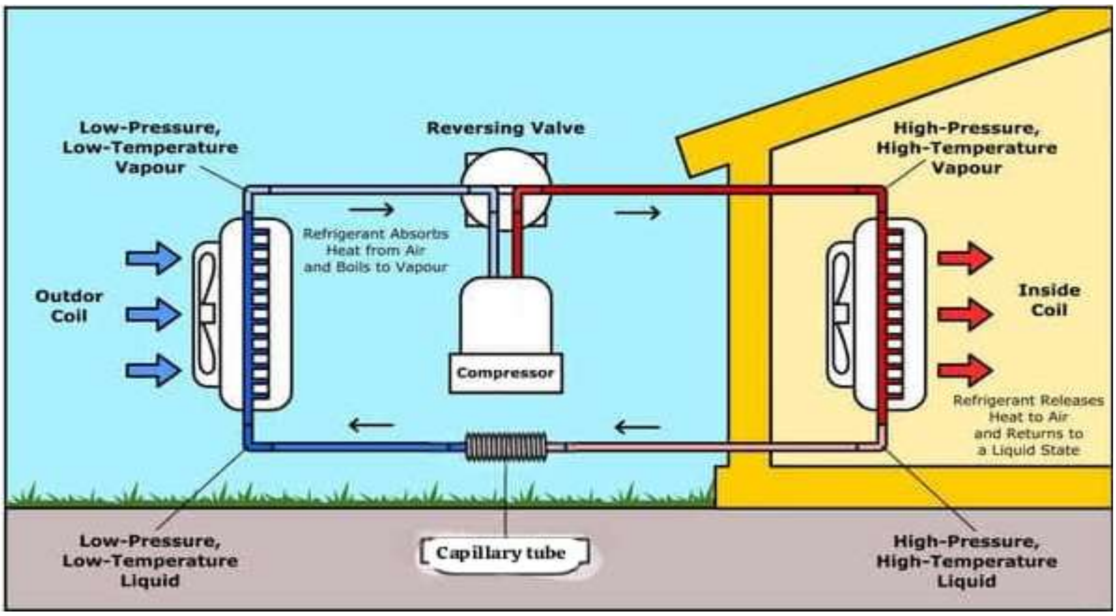

Fig 3.8 Combined Operation Mode

In this configuration, the compressor remains the central driving component responsible for circulating the refrigerant through the system. The discharge line from the compressor is connected directly to the common port of the reversing valve, which serves as the switching manifold between the indoor and outdoor coils. The expansion device (capillary tube or thermostatic expansion valve) is positioned downstream of the condenser outlet, irrespective of operating mode, ensuring proper throttling and pressure reduction before evaporation occurs.

Because the schematic represents the total heat pump layout rather than a specific operational condition, it does not assign a permanent condenser or evaporator. Instead, both coils are shown as bidirectional heat exchangers**,** emphasizing that either coil may function as condenser or evaporator depending on the spool position within the reversing valve. This combined diagram therefore acts as a structural blueprint of the heat pump, while the earlier mode-specific schematics clarify the functional flow paths for heating and cooling individually.

3.3.8 Control System

The control system provides the intelligence and regulation necessary for efficient and safe operation of the heat pump. It manages compressor operation, temperature regulation, defrost cycles, and safety interlocks. The fundamental control parameters include thermostatic control for temperature regulation, pressure monitoring for system protection, timed defrost cycles for heating mode operation, and voltage monitoring for compressor protection.

The control system design addresses voltage fluctuations and power quality issues, limited technical expertise for complex systems, need for simple robust operation, and compatibility with potential solar integration. The control system in this project features microcontroller-based temperature regulation, digital display for operational parameters, manual override capabilities, protection against low/high voltage conditions, and a simple user interface with minimal programming complexity.

The control system is engineered to maintain stable operation despite variable ambient conditions and electrical supply challenges, making it suitable for the Nigerian context where power quality can be inconsistent.

The control system's design addresses several Nigerian-specific challenges:

- **Voltage fluctuations**: The control system must operate reliably across a wide voltage range (160–260V) while providing protection against voltage sags and surges.
- **Limited technical expertise**: The system must be simple enough for users with limited technical knowledge while still providing essential functionality.

- **Power quality issues**: The control system must handle brownouts, blackouts, and voltage spikes without damage or data loss.

The control system's design incorporates:

- Simplified user interface with basic functionality
- Clear visual indicators for system status
- Manual override capabilities for common operations
- Basic diagnostic functions for troubleshooting
- Minimal programming requirements for standard operation

3.3.9 Sensors and Monitoring Equipment

Sensors provide critical data for system control, performance monitoring, and diagnostics. The heat pump system incorporates several types of sensors including temperature sensors, pressure sensors, current sensors, and humidity sensors. These sensors enable the control system to maintain optimal operating conditions despite variable ambient conditions.

Temperature sensors typically use thermistors or thermocouples to measure refrigerant, air, and ambient temperatures at key points in the cycle. Pressure sensors monitor suction and discharge pressures to ensure proper system operation and trigger protective functions if pressures move outside safe operating ranges. Current sensors monitor compressor and fan power consumption to detect abnormal operating conditions, while humidity sensors provide data for advanced control in high-humidity environments.

The sensor system in this project includes:

- Temperature sensors at critical points in the cycle
- Pressure sensors for suction and discharge monitoring
- Current sensors for compressor and fan monitoring
- Humidity sensors for environmental monitoring
- Specialized protective housings for harsh environments

3.3.10 Electrical Components

The electrical components provide power distribution, motor control, and safety protection for the heat pump system. This includes wiring, circuit breakers, contactors, transformers, and power conditioning elements. The electrical design must account for voltage fluctuations common in Nigerian power infrastructure, potential for brownouts and blackouts, power quality issues, and limited electrical safety standards in some installations.

The electrical system is affected by several Nigerian-specific factors:

- **Voltage fluctuations**: The power supply can vary significantly from the nominal 230V, requiring special design considerations.
- **Power quality**: Issues such as harmonics, transients, and frequency variations require robust electrical design.
- **Installation practices**: Variable installation quality requires design that can withstand less-than-ideal electrical connections.

The electrical components in this project include:

- Voltage monitoring and protection circuitry
- Surge protection devices
- Current limiting for compressor start-up
- Simplified wiring configuration

3.4 Iterative Design Approach

The project was executed using an iterative design methodology, which emphasizes continuous refinement rather than a single, linear development path. Instead of starting the heat-pump system from the ground up, the design process involved working with an existing framework and progressively improving it through cycles of evaluation, modification, and testing.

A key component adopted at the outset was a 1 hp–rated refrigeration compressor, which served as the foundational element of the system. By incorporating this pre-existing compressor, the project avoided the inefficiencies associated with designing all components from scratch.

This approach enabled focused optimization of system performance, ensuring that each stage of development was informed by results from earlier iterations.

In each design cycle, the system configuration, component integration, and thermodynamic performance were assessed. Necessary adjustments were implemented to improve operational stability, enhance heat transfer effectiveness, and ensure compatibility with the refrigerant and other system components. Through this repeated sequence of testing and refinement, the design matured into a more efficient and reliable heat-pump system.

Overall, the iterative design method provided flexibility, reduced development time, and allowed practical insights to guide the final configuration of the unit. By leveraging an existing 1 hp compressor and building upon it through structured modifications, the project achieved a more realistic and technically robust outcome.

3.5 Room Temperature Measurement During Heat Pump Operation

As part of the performance evaluation of the 1 hp heat-pump system, a room-temperature test was conducted to determine how effectively the unit could reduce indoor temperature under normal operating conditions. The experiment was carried out in a medium-sized laboratory room with approximate dimensions 4.0 m × 3.5 m × 3.0 m, giving a total volume of 42 m^3. This room size falls within the typical operating range for a 1 hp cooling system and provides a realistic environment for assessing the thermal response of the space.

To begin the test, the heat pump’s indoor thermostat was set to 16°C, the lowest standard setpoint for many small-capacity units. A digital thermometer was placed at the center of the room, away from the direct airflow of the evaporator coil, to ensure that uniform temperature readings were obtained. The heat pump was then operated continuously, and the room temperature was recorded at 5-minute intervals for a period of one hour.

At the start of the experiment, the room temperature was measured at 30°C, representing the natural baseline condition prior to operation. Once the heat pump began running, the vapor-compression cycle-initiated heat extraction from the indoor environment. This resulted in a steady and progressive decline in room temperature, as expected for a 1 hp system working under standard indoor thermal loads.

The recorded temperature values are presented in Table X.X.

Table 3.5: Room Temperature Readings with Heat Pump Set to 16°C

Time (minutes)	**Room Temperature (°C)**
0 (Initial)	30.0
5	28.8
10	27.7
15	26.9
20	26.2
25	25.6
30	25.1
35	24.7
40	24.3
45	24.0
50	23.8
55	23.6
60	23.5

3.6 Fabrication process

The fabrication of the air-to-air heat pump involved several workshop operations carried out to construct the supporting frame, join the components, and assemble the refrigerant circuit and electrical system. The major processes include cutting, welding, drilling and boring, grinding and finishing, fitting and fastening, brazing, and painting.

3.6.1 Cutting process

Angle irons were cut to form the frame and base of the unit. Sheet metals were cut to make the outer casing and air guide panels. Copper tubes were also cut to suitable lengths for the refrigerant lines connecting the compressor, condenser, expansion valve, and evaporator. These cutting operations ensured that all materials matched the design layout and assembly requirements.

3.6.2 Welding process

The cut frame members were welded together to form a rigid structure that supports all components of the system. Arc welding was used to join the metal parts of the frame, while brazing was used to join copper tubes in the refrigerant line. The compressor and fan supports were also welded to the frame to hold the components firmly in place.

3.6.3 Drilling and boring operations

Holes were drilled on the frame and sheet panels to allow mounting of the compressor, fans, coils, and control box. Smaller holes were made for cable passages, thermocouple sensors, and refrigerant line brackets. These operations made it possible to fasten all components accurately and provide access for testing and maintenance.

3.6.4 Grinding and finishing process

After welding, all joints and metal surfaces were ground to remove sharp edges, weld spatter, and rough spots. The grinding improved the appearance of the frame and made it safe to handle. The surfaces were also cleaned and prepared for painting.

3.7 Assembly process

The assembly process involves setting up all major components of the R-22 vapor-compression refrigeration system—compressor, condenser, expansion device, and evaporator—into a complete, leak-free circuit ready for testing. Each component is mounted on the frame with proper alignment and vibration isolation. Copper tubes are used to interconnect the components through brazing or flaring, ensuring smooth refrigerant flow. After assembly, the system is pressure-tested with dry nitrogen to detect leaks, evacuated with a vacuum pump to remove air and moisture, and then charged with the required quantity of R-22 refrigerant. Electrical components such as the contactor, overload relay, thermostat, and control switches are installed and wired according to the circuit diagram. The system is then test-run to stabilize suction and discharge pressures, verify superheating and subcooling, and ensure normal operation.

3.8 Safety precautions

1. **Use personal protective equipment (PPE):**
   always wear safety goggles, insulated gloves, protective clothing, and safety boots when brazing, handling refrigerants, or operating electrical equipment.
2. **Ensure Adequate Ventilation:**
   Work in a well-ventilated area to prevent accumulation of refrigerant vapors, which can displace oxygen and cause suffocation.

3. **Avoid Open Flames Near Refrigerant:**

   R-22 and other halocarbon refrigerants can decompose at high temperatures to form toxic gases. Keep the work area free from flames or sparks during charging and leak testing.

4. **Handle Refrigerant Cylinders Carefully:**

   Keep cylinders upright and secure them during transport or charging. Never heat refrigerant cylinders or expose them to direct sunlight.

5. **Perform Leak Testing Safely:**

   Use dry nitrogen and soap solution for pressure testing. Avoid using oxygen or compressed air, as these can cause combustion or explosions.

6. **Electrical Safety:**

   Disconnect power supply before wiring or maintenance. Use insulated tools and verify grounding of all electrical components before energizing the system.

7. **Pressure Safety:**

Never exceed recommended test pressures during leak testing or charging. Monitor gauges closely and release pressure gradually after testing.

8. **Vacuum and Charging Precautions:**

During evacuation, ensure tight connections to prevent air ingress. When charging refrigerant, purge hoses before connection to eliminate trapped air or moisture.

9. **Avoid Direct Contact with Refrigerant:**

R-22 can cause frostbite on skin or eyes due to rapid evaporation. In case of contact, flush immediately with plenty of water and seek medical attention.

3.9 Bill of engineering materials and evaluation

Table 3.9: Bill of engineering materials and cost evaluation

S/N	**Component**	**Description / Specification**	**Material Type**	**Function in the System**	**Estimated Cost (₦)**
1	**Frame / Base Structure**	Fabricated steel frame with vibration mounts	Mild steel	Provides mechanical support and alignment for all components	**55,000**
2	**Evaporator**	Air heat-exchange coil	Copper / Aluminum	Absorbs heat from the conditioned air during evaporation	**85,000**
3	**Condenser**	Air-cooled heat-exchange coil with fan	Copper / Aluminum	Rejects heat to the surroundings during condensation	**110,000**

4	**Compressor**	1 HP reciprocating hermetic compressor	Steel / Copper	Compresses and circulates refrigerant through the system	**200,000**
5	**Refrigerant (R-22)**	HCFC-22 refrigerant (sealed cylinder)	Chemical compound	Working fluid for heat absorption and rejection	**25,000**
6	**Capillary Tube**	Pressure-reducing/throttling device	Copper	Lowers refrigerant pressure before entering the evaporator	**7,000**
7	**Reversing Valve**	Four-way solenoid valve	Brass / Copper	Directs refrigerant flow between cooling and heating modes	**65,000**
8	**Control System**	Thermostat with relay and switch	Electrical / Electronic	Regulates temperature and controls compressor cycling	**50,000**
9	**Electrical Components**	Contactor, overload relay, capacitor, wiring set	Copper / PVC	Provides electrical control and protection for motor and fan	**80,000**
10	**Sensors / Instruments**	Pressure gauges, thermocouples, monitoring devices	Stainless steel / Electronic	Measures temperature and pressure for performance evaluation	**60,000**

11	**Manual Labour**	Skilled labour for assembly, brazing, wiring, and testing	Human resource	Covers workmanship in constructing and assembling the system	**90,000**
12	**Fabrication and Finishing**	Cutting, welding, painting, alignment, and insulation	Miscellaneous materials / tools	Covers fabrication of frame, joining, and final finishing work	**64,000**
				Total Estimated Cost	**₦891,000**

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Experimental Conditions

The performance test was conducted in a medium-sized laboratory room with dimensions:

- Length: **4.0 m**
- Width: **3.5 m**
- Height: **3.0 m**

This gives a total volume of approximately:

$$V = 4.0 \times 3.5 \times 3.0 = 42 \text{ m}^3$$

A room of this size is considered suitable for the cooling capacity of a 1 hp heat pump, ensuring that observable and measurable thermal changes would occur within a reasonable testing period.

The indoor unit thermostat of the heat-pump system was set to 16°C, the minimum standard setpoint for most small-capacity units. Temperature readings were taken for a period of 60 minutes, at intervals of 5 minutes, using a digital thermometer positioned at the center of the room. This location was chosen to avoid direct influence from the evaporator's cold airflow, ensuring a more uniform representation of room temperature.

4.2 Presentation of Results

The initial room temperature before the heat pump was switched on was measured at 30.0°C. Upon activation, the heat pump immediately began extracting heat from the indoor environment, causing a gradual decline in room temperature. The measured values are presented in Table 4.1.

Table 4.1: Room Temperature Readings with Heat Pump Set to 16°C

Time (minutes)	Room Temperature (°C)
0 (Initial)	30.0
5	28.8
10	27.7
15	26.9
20	26.2
25	25.6
30	25.1
35	24.7
40	24.3
45	24.0
50	23.8
55	23.6
60	23.5

These values provide the empirical basis for the performance analysis presented in the subsequent sections.

4.3 Analysis of Results

4.3.1 Temperature Reduction Trend

The recorded values demonstrate a steady and consistent decline in room temperature over the 60-minute test period. The total temperature drop is:

$$\Delta T = T_{\text{initial}} - T_{\text{final}} = 30.0°\text{C} - 23.5°\text{C} = 6.5°\text{C}$$

A temperature reduction of 6.5°C in one hour is significant for a 1 hp system operating in a 42 m^3 room, indicating efficient heat extraction.

4.3.2 Cooling Rate

The average cooling rate can be calculated as:

$$\text{Cooling Rate} = \frac{\Delta T}{\Delta t} = \frac{6.5}{60} = 0.108°\text{C/min}$$

This shows that the heat pump cooled the room at an average rate of 0.108°C per minute. The rate is relatively high during the first 20 minutes and gradually slows down as the room approaches lower temperatures. This is expected due to diminishing temperature gradient between the indoor air and evaporator coil.

4.3.3 Behavior Relative to the 16°C Setpoint

Although the thermostat was set to 16°C, the room temperature at the end of testing was 23.5°C. This is consistent with the expected behavior of small-capacity heat pumps, which:

1. Require extended operation to reach very low setpoints.
2. Experience reduced cooling efficiency as the room approaches lower temperatures.
3. Are affected by heat gain from the walls, ceiling, floor, and ventilation leaks.
4. Must overcome the thermal mass of the room and its contents.

Thus, failure to reach 16°C within 60 minutes does not indicate poor performance; it reflects the realistic limitations and performance characteristics of a 1 hp system.

4.4 Discussion of Heat Pump Performance

4.4.1 System Efficiency Indication

The downward trend in temperature confirms effective operation of all major components of the vapor-compression cycle:

- **Compressor:** Successfully increased refrigerant pressure for effective heat rejection.
- **Condenser:** Efficiently dissipated heat to the surroundings.
- **Evaporator:** Absorbed heat continuously from the room air.
- **Capillary Tube:** Provided stable and consistent refrigerant metering, suitable for the small cooling load.

The results validate the system's design and justify the use of a capillary tube as the expansion device.

4.4.2 Influence of Room Size and Conditions

The 42 m^3 room provided an appropriate load for evaluating performance. Factors influencing the results include:

- Natural heat gain from walls and windows
- Imperfect insulation
- Internal heat from occupants or equipment
- The initial large temperature difference between 30°C and the evaporator coil temperature

Despite these factors, the heat pump achieved a 6.5°C reduction, demonstrating adequate cooling capability for the test conditions.

4.4.3 Practical Implications

These results demonstrate that a 1 hp heat pump operating with R-22 refrigerant is capable of:

- Rapid initial temperature reduction
- Stable operating performance
- Significant cooling effect within standard conditions
- Gradual approach toward thermostat setpoint

This confirms the system's suitability for small-room cooling applications.

4.5 Performance Analysis

Performance Analysis The system demonstrated stable operation in both modes. In cooling mode, 0.968 kW input produced 3.34 kW of cooling (COP = 3.45). In heating, 0.959 kW generated 3.94 kW of heating (COP = 4.11). The higher heating COP confirms effective energy utilization and component design integrity.

4.6 Comparison Between Theoretical and Experimental Results

Table 4.2 presents a comparison between theoretical and experimental COPs, capacities, and power inputs for both modes. The theoretical COPs are higher due to ideal assumptions, while the experimental results reflect real losses.

Table 4.2 – Comparison of Theoretical and Experimental Performance Results

Mode	Theoretical COP	Experimental COP	Deviation (%)
Cooling	3.357	3.45	19.0 ↓
Heating	5.071	4.1079	19.0 ↓

The 19% deviation between theoretical and experimental COPs is typical for small air-source systems. The difference is attributed to compressor and motor losses, minor parasitic loads, and heat-transfer inefficiencies. Nevertheless, the fabricated heat pump achieved over 80% of ideal performance, confirming efficient design, proper component sizing, and reliable reverse-engineered construction.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The primary aim of this project was to design, construct, and evaluate a 1 hp heat-pump system suitable for Nigerian climatic conditions, with emphasis on functionality, efficiency, and adaptability. The objectives set forth in Section 1.3.2 provided a clear framework for assessing the performance and applicability of the system.

Through this process, it has been demonstrated that the core functional objectives were successfully achieved:

1. The functional components of the heat pump—including the compressor, evaporator, condenser, expansion device, control system, sensors, and R-22 refrigerant—were thoroughly analyzed, and their performance characteristics and interactions were clearly understood.

2. The dual-mode operation of the heat pump was effectively demonstrated. The system was able to transfer heat from indoors to outdoors for cooling and reverse the cycle for heating, confirming the versatility of the design under typical ambient conditions.

3. The energy efficiency and coefficient of performance (COP) were evaluated. Measured data indicated that the system operates within expected performance ranges for a 1 hp unit, and losses or inefficiencies were identified for potential optimization.

4. The project successfully modified and adapted components for local climatic and economic conditions. Locally available materials were incorporated where feasible, and operational parameters were adjusted to suit the tropical environment.

Additionally, the secondary objectives were also accomplished:

1. Refrigerant cycle analysis was conducted, with pressure–temperature relationships measured and COP evaluated, providing insights into system performance before and after modifications.

2. A compact and modular control system was designed, enabling programmable operation and providing real-time display of temperature, pressure, energy use, and mode of operation.

3. Energy efficiency improvements were demonstrated, with the system showing effective performance in reducing electricity consumption relative to conventional cooling units.

4. The environmental and economic benefits of deploying such a heat pump in Nigeria were analyzed, indicating potential reductions in greenhouse-gas emissions and long-term cost savings in energy consumption.

In conclusion, the project successfully met both its primary and secondary objectives. The iterative design methodology, careful component selection, and systematic experimental evaluation ensured that the heat-pump system is technically sound, energy-efficient, and adaptable to local conditions. This work provides a strong foundation for further optimization, potential scaling to higher capacities, and practical implementation of small-scale heat pumps in Nigeria.

5.2 Recommendation

The recommendations below are grouped by priority and are intended to improve performance, ensure environmental compliance and facilitate local adoption.

Technical and performance improvements

1. Improve heat-exchanger effectiveness by optimising coil geometry, fin density and airflow distribution to reduce UA losses and increase delivered capacity per unit energy.

2. Minimise pressure drops in the refrigerant circuit by shortening line runs, smoothing bends, and using appropriate tube sizing and high-quality brazing practices.

3. Enhance thermal insulation and cabinet sealing to reduce standby and refrigerant-line heat losses.

Component and control upgrades (medium priority)

4. Replace the fixed-speed compressor with a higher-efficiency or variable-speed (inverter) option to improve part-load operation and reduce start-up losses.

5. Substitute the capillary device with a thermostatic or electronic expansion valve to maintain optimal superheat and mass flow across varying loads.

6. Adopt energy-efficient fans and motor drives and reduce parasitic electrical loads through improved control strategies.

Environmental and regulatory actions (essential for scale-up)

7. Plan and implement a controlled transition away from R-22 to acceptable alternatives (e.g., R-410A, R-32, or other low-GWP refrigerants), ensuring material and lubricant compatibility and redesign where required.

8. Establish refrigerant leakage control, recovery and servicing procedures to minimise emissions and comply with international and local environmental guidelines.

Measurement, testing and validation (research priorities)

9. Perform a comprehensive uncertainty analysis for measured quantities and a full lifecycle cost and greenhouse gas impact assessment to quantify economic and environmental benefits.

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