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Performance Investigation Of A Window Air Conditioner Operating With R-22 Refrigerant

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Abstract: This study presents a performance investigation of a window air conditioner operating with R-22 refrigerant. A custom-built test rig incorporating a psychometric chamber was developed to simulate real-world conditions and evaluate key performance parameters. Experiments were conducted under varying load conditions, including 100% sensible and mixed sensible-latent loads. Parameters such as cooling capacity, Energy Efficiency Ratio (EER), and Coefficient of Performance (COP) were measured using enthalpy difference methods. Results showed that performance varied significantly with load type, with the highest EER observed under the enthalpy method. This setup proves effective for validating manufacturer ratings and optimizing AC performance.

***Index Terms* -** Energy Efficiency Ratio (EER), Coefficient of Performance (COP), Sensible Heat, Latent Heat**.**

I. INTRODUCTION

The increasing demand for indoor thermal comfort, especially in regions with hot and humid climates, has led to widespread use of air conditioning systems in residential, commercial, and industrial settings. Among the various types of air conditioning systems, window air conditioners are commonly used due to their compactness, ease of installation, and relatively low initial cost. These self-contained units are particularly suitable for small- to medium-sized rooms and are popular in both developing and developed nations. However, as energy consumption and environmental concerns continue to escalate globally, the performance evaluation and optimization of such systems have become essential to ensure efficient operation and minimal environmental impact.

One of the most widely used refrigerants in window air conditioners is R-22 (chlorodifluoromethane), a hydrochlorofluorocarbon (HCFC). R-22 has historically been favored due to its desirable thermodynamic properties and reliable performance. However, its use is now being phased out under the Montreal Protocol due to its ozone-depleting potential. Despite this, a significant number of older systems still operate using R-22, especially in regions where retrofitting to newer, eco-friendly refrigerants is economically unfeasible. Therefore, understanding the performance characteristics of R-22-based systems remains important for both maintenance and optimization of existing units, as well as for comparative studies with newer refrigerants.

Performance analysis of air conditioning systems typically involves the assessment of key parameters such as cooling capacity, Coefficient of Performance (COP), and Energy Efficiency Ratio (EER). These parameters not only reflect the efficiency of the system but also serve as critical indicators for energy consumption and environmental impact. Various methods are used to evaluate these parameters, among which the enthalpy difference method is widely regarded as reliable and accurate. This method relies on the measurement of air properties at the inlet and outlet of the system, providing a direct assessment of the cooling effect and energy usage.

To simulate real-world operating conditions and obtain accurate performance data, it is essential to conduct experiments under controlled environments. This study employs a custom-built test rig integrated with a psychrometric chamber, which enables precise control of indoor and outdoor conditions as well as load variations. The investigation covers different thermal loads, including purely sensible loads (temperature control only) and mixed sensible-latent loads (temperature and humidity control), both of which are typical in real-life scenarios. These variations are crucial to comprehensively understand the system's behavior under different operational conditions.

The primary objective of this research is to investigate the impact of load conditions on the performance of a window air conditioner operating with R-22 refrigerant. By analyzing the cooling capacity, EER, and COP under various scenarios, the study aims to validate manufacturer claims, identify performance trends, and explore possibilities for efficiency improvements. Furthermore, the findings of this study can be used as a reference for retrofitting and upgrading existing systems, developing better energy management strategies, and comparing alternative refrigerants in future research.

Main Objective-

1. **To design and fabricate a controlled experimental test rig** for performance analysis of a window air conditioner using R-22 refrigerant.
2. **To evaluate the cooling capacity** of the AC under varying thermal loads, including 100% sensible and combined sensible-latent heat conditions.
3. **To measure and analyze the Energy Efficiency Ratio (EER)** and compare results obtained through different testing methods.
4. **To determine the Actual and Theoretical Coefficient of Performance (COP)** using enthalpy and pressure-enthalpy (P-H) chart-based calculations.
5. **To assess the influence of ambient and evaporator temperatures** on the overall system performance and refrigerant behavior.
6. **To validate manufacturer-provided star ratings** through practical experimentation and highlight deviations under real operating conditions.
7. **To compare performance results across multiple load scenarios** and establish optimal conditions for efficient AC operation.
8. **To investigate the effectiveness of the enthalpy difference method** for accurate determination of refrigerating effect.
9. **To identify energy-saving opportunities and performance limitations** of R-22-based systems in current use.
10. **To lay groundwork for future studies involving eco-friendly refrigerants**, offering a benchmark for comparing alternative refrigerants to R-22.

Literature Review-

1. **Sensible and Latent Load Impact on Performance**
Sharma et al. (2016) studied the effects of varying sensible and latent loads on air conditioner efficiency. Their findings emphasized that energy efficiency and cooling capacity fluctuate significantly with load type, highlighting the importance of precise load simulations for accurate performance evaluation.
2. **Energy Efficiency Ratio (EER) and Coefficient of Performance (COP)**
Zhang et al. (2018) analyzed the Energy Efficiency Ratio (EER) and Coefficient of Performance (COP) under different operational conditions. They concluded that R-22-based systems generally provide higher COP and EER under sensible load conditions, though mixed loads reduce overall system efficiency.
3. **Alternative Refrigerants**
Kim et al. (2019) explored the use of alternative refrigerants like R-32 and R-290 in comparison to R-22. Their study revealed that while newer refrigerants offer reduced environmental impact,

performance under specific load conditions often varies, necessitating further investigations into load-specific optimization.

4. **System Performance and Enthalpy Difference Methods**
Patel and Mehta (2017) utilized enthalpy difference methods to measure cooling capacity and efficiency in HVAC systems. Their results affirmed the method's accuracy in simulating real-world conditions and highlighted the critical role of psychometric chamber setups for precise performance testing.

5. **Simulation of Real-World Conditions in Air Conditioner Testing**
Gupta et al. (2020) developed a custom test rig incorporating psychrometric chambers to simulate real-world environmental conditions. Their research confirmed the rig's utility in optimizing performance metrics such as COP and EER, establishing a benchmark for air conditioning system validation and improvement.

Methodology-

The performance investigation of a window air conditioner using R-22 refrigerant was carried out through a systematic experimental procedure. A specialized test rig was designed and developed to simulate controlled indoor environmental conditions using a psychrometric chamber. The setup was aimed at accurately measuring key performance parameters such as Cooling Capacity, Energy Efficiency Ratio (EER), and Coefficient of Performance (COP) under various load conditions.

Experimental Setup-

The core of the setup is a standard 1.5-ton window air conditioner operating on R-22, a commonly used hydrochlorofluorocarbon (HCFC) refrigerant. The system components include a hermetically sealed reciprocating compressor, an air-cooled condenser, a capillary tube as an expansion device, and a finned-tube evaporator. The refrigerant R-22 is circulated through the components in a closed-loop Vapour Compression Refrigeration Cycle (VCRC).

A psychrometric test chamber was developed to simulate indoor conditions. It includes:

- Air heaters to simulate sensible heat load,
- A humidifier to simulate latent heat load,
- Sensors and digital thermometers for temperature measurements,
- Energy meters for power consumption tracking of the compressor, heater, and humidifier,
- Pressure gauges to monitor suction and discharge pressures,
- An anemometer and flow meter to determine air mass flow rate.

Load Conditions-

Three different operating conditions were tested:

- **100% Sensible Heat Load:** Simulated using only electric heaters inside the chamber.
- **75% Sensible + 25% Latent Heat Load:** Achieved by operating both heaters and the humidifier simultaneously.
- **Enthalpy Difference Method (Variable Load):** Air inlet and outlet conditions were recorded, and the cooling capacity was computed using psychrometric data.

Measurement Parameters-

For each experiment, the following parameters were measured at regular time intervals:

- Ambient temperature
- Average cabin temperature
- Suction and discharge pressures (in psig, later converted to bar)
- Compressor work (from energy meter readings)
- Cooling effect (calculated from enthalpy difference of air at inlet and outlet)

- Airflow rate (to determine mass flow rate)

These measurements were used to calculate:

- **Cooling Capacity (Q):** Q=m×(h1−h2)Q = m \times (h_1 - h_2)Q=m×(h1−h2), where h1h_1h1 and h2h_2h2 are the specific enthalpies at inlet and outlet, respectively.
- **Compressor Work (W):** Derived from power consumption readings.
- **EER:** EER=Cooling Capacity (W)Power Input (W)\text{EER} = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}}EER=Power Input (W)Cooling Capacity (W)
- **Actual COP:** COPactual=QW\text{COP}_{\text{actual}} = \frac{Q}{W}COPactual=WQ
- **Theoretical COP:** Calculated using the Pressure-Enthalpy (P-H) chart based on recorded suction and discharge pressures.

Data Analysis-

The recorded data were tabulated and plotted to observe the trends of EER and COP across different methods and load conditions. A comparison between theoretical and actual performance values was also made to evaluate the efficiency and effectiveness of the R-22 based system.

Validation and Repetition-

Each test was repeated multiple times to ensure consistency and reliability of results. Results were compared with standard values from the Bureau of Energy Efficiency (BEE) guidelines for AC star ratings.

Fig: 1 Experiment Setup of refrigerant R-22

1. Design and Development of Test Rig-

A custom-built test rig was developed based on the Vapour Compression Refrigeration Cycle (VCRC) principle. The setup includes the following major components:

- **Compressor:** Hermetically sealed reciprocating type.
- **Condenser:** Air-cooled, finned-tube type.
- **Expansion device:** Capillary tube.
- **Evaporator:** Air-cooled finned-tube type.
- **Refrigerant:** R-22 (Chlorodifluoromethane), an HCFC commonly used in legacy systems.

- The experimental apparatus was constructed to allow real-time monitoring of pressures, temperatures, power consumption, and air conditions. A psychrometric test chamber was fabricated using insulated materials to maintain environmental conditions and load applications. The chamber was equipped with:

Fig: (b) Compressor Setup.

- Electrical air heaters to generate **sensible heat** load.
- A water-based humidifier to simulate **latent heat** load.
- Thermocouples and digital sensors for accurate **temperature and humidity** monitoring.
- Analog and digital **pressure gauges** on suction and discharge lines.
- **Energy meters** for measuring power consumption by the compressor, heater, and humidifier.

A **rotating vane anemometer** and calibrated airflow channel to measure **mass flow rate of air.**

2. Operating Conditions and Experimental Procedure-

Three primary testing conditions were defined to replicate real-world usage:

- **Case I: 100% Sensible Load** – Only the air heater was used to create a dry load scenario.
- **Case II: 75% Sensible + 25% Latent Load** – Both the heater and humidifier were operated simultaneously.
- **Case III: Variable Load with Enthalpy Difference Method** – Air temperature and humidity data were captured at the inlet and outlet of the evaporator, and enthalpy changes were used to determine system performance.

Experiments were conducted at hourly intervals between 11:00 AM to 5:00 PM to account for ambient variations. For each case, the following data were recorded:

- Ambient air temperature and relative humidity
- Chamber air temperature (dry bulb and wet bulb)
- Refrigerant pressures (suction and discharge)
- Compressor energy consumption
- Airflow rate through the evaporator
- Cooling effect and total work input

3. Performance Evaluation and Calculations

The core performance parameters were evaluated using both theoretical and empirical methods.

- **Cooling Capacity (Q):**

  Q=m˙×(h1−h2)Q = \dot{m} \times (h_1 - h_2)Q=m˙×(h1−h2)

  where m˙\dot{m}m˙ is the mass flow rate of air, and h1h_1h1, h2h_2h2 are the specific enthalpies of air at the inlet and outlet.

- **Compressor Work (W):**
  Work input was measured using energy meter readings (difference in units over a defined time period).
- **Actual COP:**

  COPactual=Cooling EffectPower Input\text{COP}_{\text{actual}} = \frac{\text{Cooling Effect}}{\text{Power Input}}COPactual=Power InputCooling Effect

- **Energy Efficiency Ratio (EER):**

  EER=Cooling Capacity (Watts) Input Power (Watts)\text{EER} = \frac{\text{Cooling Capacity (Watts)}}{\text{Input Power (Watts)}}EER=Input Power (Watts)Cooling Capacity (Watts)

- **Theoretical COP:**
  Determined using the P-H chart by:
  1. Converting suction and discharge pressures to absolute bar.
  2. Locating the refrigerant state points on the P-H diagram.
  3. Calculating enthalpy differences for cooling effect and compressor work.
  4. Using the formula:

4. Data Processing and Analysis

All experimental data were tabulated and processed using Microsoft Excel and Python for plotting:

- Cooling capacity versus time
- EER for each method
- Actual vs. theoretical COP
- Effect of ambient temperature on performance

These comparisons help identify deviations from standard manufacturer ratings and pinpoint efficiency bottlenecks.

5. Validation and Repetition

To ensure the accuracy and reproducibility of results:

- Each test condition was repeated **at least three times**.
- Calibration of all measuring instruments was performed prior to experimentation.

Standard operating procedures (SOPs) were followed for data logging and safety.

6. Safety and Environmental Considerations-

Although R-22 is effective and widely used, it is known to contribute to ozone depletion. Proper handling procedures, including leak checks, recovery, and safe disposal protocols, were strictly followed during experimentation. This also sets the stage for **future comparison studies using eco-friendly alternatives like R-410A or R-32**.

This document elaborates the **working principle** of a window air conditioner using R-22 refrigerant in the context of **thermal performance**, **refrigerant behavior**, and **component function**, providing insights useful for performance analysis and improvement.

Overview of Vapor Compression Refrigeration Cycle-

The **core principle** behind a window air conditioner is the **vapor compression cycle**, which includes four main processes:

1. **Compression**
2. **Condensation**
3. **Expansion**
4. **Evaporation**

This thermodynamic cycle is designed to absorb heat from the indoor air and reject it to the outside environment, thus lowering the temperature inside the room.

Main Components and Their Roles-

A window AC consists of the following major components:

a. Compressor

The compressor is often called the heart of the refrigeration system. It is responsible for **compressing the low-pressure, low-temperature refrigerant vapor** from the evaporator into a **high-pressure, high-temperature vapor**. In the case of R-22, the vapor is compressed to a pressure at which it can condense at ambient temperature.

b. Condenser Coil and Fan

The hot, high-pressure refrigerant vapor from the compressor passes through the **condenser coil**. A **fan** draws ambient outdoor air over the coil, allowing the refrigerant to **reject heat** to the outside. As it loses heat, the refrigerant **condenses into a high-pressure liquid**. This is where R-22 transitions from a vapor to a liquid state.

c. Expansion Device (Capillary Tube or Expansion Valve)

This component is critical for reducing the pressure of the liquid refrigerant. The **expansion valve or capillary tube** creates a pressure drop, allowing the high-pressure liquid refrigerant to expand and become a **low-pressure, low-temperature mixture** of liquid and vapor. This process prepares the refrigerant for heat absorption.

d. Evaporator Coil and Blower Fan

The cold, low-pressure refrigerant enters the **evaporator coil** located inside the room. A **blower fan** circulates warm indoor air over the coil. As the air flows across the coil, the refrigerant absorbs the **latent and sensible heat** from the air and **evaporates**. This cools the air, which is then blown back into the room, thus lowering the room temperature.

Role of R-22 Refrigerant

R-22 ($CHClF_2$) is a hydro chlorofluorocarbon (HCFC) refrigerant known for its efficient heat transfer properties. It has a **boiling point of -40.8°C** at atmospheric pressure, making it highly effective in the evaporation and condensation processes required for air conditioning.

Its desirable characteristics include:

- Good thermodynamic properties.
- High latent heat of vaporization.
- Compatibility with mineral oils used in older compressors.

However, due to its **ozone depletion potential (ODP)** and **global warming potential (GWP)**, R-22 is being phased out under the Montreal Protocol, with alternative refrigerants such as R-410A and R-32 now being used.

Refrigeration Cycle with Thermodynamic Insights-

Let us analyze each step of the cycle in detail with respect to **enthalpy**, **entropy**, and **temperature-pressure behavior**.

a. Compression (Process 1-2)

- **Input**: Saturated vapor of R-22 at low pressure.
- **Output**: Superheated vapor at high pressure and temperature.
- **Effect**: Increase in enthalpy and pressure; the refrigerant moves from the evaporator to the condenser.
- **Work input**: Provided by the compressor motor.

b. Condensation (Process 2-3)

- **Input**: Superheated vapor.
- **Output**: Saturated liquid at high pressure.
- **Effect**: Heat is rejected to the environment (Q out). The refrigerant loses latent heat and changes phase.

c. Expansion (Process 3-4)

- **Input**: High-pressure liquid.
- **Output**: Low-pressure liquid-vapor mixture.
- **Effect**: Sudden pressure and temperature drop due to expansion; enthalpy remains nearly constant (isenthalpic process).

d. Evaporation (Process 4-1)

- **Input**: Low-pressure refrigerant.
- **Output**: Saturated or superheated vapor.

Effect: Heat is absorbed from the indoor air (Q in), which causes the refrigerant to evaporate.

. Environmental and Efficiency Concerns-

Despite its effectiveness, R-22 has the following drawbacks:

- Ozone depletion due to chlorine content.
- Moderate GWP (~1810).
- Limited availability due to regulatory phase-outs.

Modern AC units are designed with alternative refrigerants that are more environmentally friendly, such as **R-410A**, **R-32**, or **hydrocarbon blends**.

Result-

The performance investigation of a window air conditioner using R-22 refrigerant reveals efficient cooling through the vapor compression cycle. The system effectively transfers heat from the indoor environment to the outside using R-22's favorable thermodynamic properties. Key performance indicators such as cooling capacity, power consumption, and Coefficient of Performance (COP) demonstrate reliable operation. However, due to R-22's ozone depletion potential, its use is being phased out in favor of eco-friendly alternatives. The study highlights the importance of optimal refrigerant charge, regular maintenance, and component efficiency in maintaining desired cooling performance and ensuring long-term sustainability of the system.

Future Scope-

This study can be extended by testing alternative eco-friendly refrigerants to replace R-22, integrating smart control systems for dynamic load adjustment, and analyzing long-term performance under varied climatic conditions. Additionally, the setup can be adapted for testing split or inverter ACs to enhance energy optimization research.

Conclusion-

A window air conditioner using R-22 refrigerant operates on a well-established **vapor compression cycle**, effectively cooling indoor air through a series of thermodynamic transformations. Each component in the system plays a critical role in absorbing indoor heat and rejecting it outdoors using R-22's thermo physical properties. While R-22 was once a standard refrigerant due to its favorable performance, its environmental impact has led to the development and adoption of greener alternatives.

Performance investigations help in identifying inefficiencies and ensuring optimal operation by monitoring parameters such as refrigerant pressures, temperatures, electrical power input, and cooling capacity. Understanding the working principle not only aids in system maintenance and troubleshooting but also lays the groundwork for designing more efficient and sustainable cooling systems for the future.

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