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# Dehumidification of Heat Pump Air Conditioning System Using Ecofriendly Refrigrent

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**Abstract:**
An extensive performance analysis of a heat pump air conditioning system for cooling applications is included in this research. The purpose of the research is to assess the system's overall performance, energy consumption, and efficiency under various operating scenarios. The study makes use of a variety of experimental measurements. An overview of the heat pump air conditioning system's parts and operation is given at the outset of the examination. Key factors like the outside temperature, the flow rate of refrigerant, the power consumption of the compressor, and the differences in temperature between the inside and outside are monitored in the experimental setup. Cooling modes are taken into account while collecting these measurements throughout a range of operational circumstances. For HVAC engineers, researchers, and policymakers, the heat pump air conditioning system performance study provided in this paper is an invaluable resource. The knowledge gathered from this research helps with continuous attempts to enhance the functionality and design of heat pump systems for use in heating and cooling, promoting energy efficiency and sustainability in the built environment.

**Keywords:** Heat pump; Dehumidifier; Air Conditioning; Eco-friendly refrigerants

## INTRODUCTION

As temperatures rise and humidity changes, the need for effective air conditioning systems has grown. Many traditional air conditioners use chemicals called hydrofluorocarbons (HFCs), which can harm the environment and contribute to climate change. To address this issue, the HVAC industry is moving towards eco-friendly refrigerants that are better for our planet. Heat pump air conditioning systems are versatile because they can cool in the summer and heat in the winter. However, managing indoor humidity is essential for comfort and health, as too much moisture can lead to problems like mold and damage to buildings.

Dehumidification is a crucial part of how these systems work. By using eco-friendly refrigerants and advanced technology, we can improve energy efficiency while reducing environmental impact. This introduction looks at how we can effectively control humidity in heat pump systems while being kind to the environment, leading to better and more sustainable air conditioning solutions.

## LITERATURE REVIEW

**Byrne** [1] focused on the heat pump for simultaneous heating and cooling (HPS) carries out space heating, space cooling and hot water production for small office and residential buildings. It works under heating, cooling and simultaneous modes to produce hot and chilled water according to the thermal demand of the building. A sub cooler connected to a water tank is placed after the condenser to recover some energy by sub cooling of the refrigerant during a heating mode. The water loop at a higher temperature than ambient air is used subsequently as a source fora water evaporator. Average winter performance is improved compared to a standard reversible heat pump (HP). The air evaporator is defrosted by a two-phase thermosphere without stopping the heat production. Annual simulations of the HPS coupled to a hotel are run in order to evaluate annual performance and energy consumption of the system. The results are compared to the one sofa standard reversible HP. Depending on the scenario, savings in electric energy consumption and annual performance improvement can reach respectively 55% and 19%.

**Shin** [2] proposed a refrigerating machine for domestic use constitutes part of the test bench. It is designed to operate in an ambient temperature between 16 ◦C and 38 ◦C. The unit does not function properly outside of this temperature range. If the device is exposed to at high temperature for a long time, the temperature in the refrigerator will rise above4◦C. Temperature and refrigerator cooling rate depend on the location, the door opening frequency and the ambient temperature of the room where the appliance is located. To become a heat pump for simultaneous cooling and desalination, the small refrigerator has been modified in order to make a coupling with a membrane distillation cell. The original static condenser was replaced by a tube-in-tube coaxial ex changer to transfer the condensation heat to water loop. Three pressure taps (Shredder valves) at the suction, compressor discharge, and condenser outlet were installed on the refrigeration circuit. The electrical power indicated on the nameplate of the device is 60 W. The refrigerant used is isobutane (R600a) which is a natural fluid with low environmental impact but highly flammable. The high flammability is acceptable for this device because of the refrigerant charge (mass)under the regulatory limit. Given the performance of R290 in simulation for air conditioning and freshwater production, the choice of a hydrocarbon seemed relevant for the experimental study. Isobutane happens to be the cheapest refrigerator ant on the market.

**Diaby** [3] introduced a System configuration, membrane selection, operating conditions, and control strategies play crucial roles in optimizing performance and ensuring reliable 13 operation. The compatibility between the air conditioning and AGMD units, including temperature and pressure requirements, should be carefully considered in the design process. The coupling of an AGMD unit to an air conditioner for desalination purposes offers promising solution to address water scarcity challenges. It allows for the efficient utilization of waste heat, provides high-quality freshwater, and offers a combined water and cooling solution. Continued research and development, along with advancements in system design and control strategies, will further enhance the feasibility and adoption of this coupling design for sustainable and efficient water desalination.

## 4. METHODOLOGY

### 4.1 System Design and Operation

The objective of this system is to create a sustainable, energy-efficient air conditioning solution capable of both cooling and dehumidification using an eco-friendly refrigerant, specifically R-290 (propane). The system is designed to extract moisture from indoor air effectively while maintaining a comfortable temperature, minimizing power consumption, and reducing environmental impact. The system integrates a heat pump cycle with an additional dehumidification module, supported by advanced sensors and control algorithms.

**4.1.1 System Overview**

The heat pump air conditioning system consists of several core components: a compressor, condenser, expansion valve, and evaporator. Additionally, for dehumidification purposes, a crystal-based dehumidifier (using calcium chloride) is incorporated to further reduce moisture levels in the conditioned air. This integrated setup is designed to provide efficient thermal control and air quality enhancement.

A programmable controller with temperature and humidity sensors is employed to automate operations and ensure optimal performance under varying environmental conditions.

**4.1.2 Design Objectives**

The design aims to fulfill the following functions:

1. Cooling of indoor air by extracting heat using the vapor compression refrigeration cycle.
2. Dehumidification by two methods:
1. Moisture removal during the air's condensation on the evaporator coil.
2. Use of a passive crystal dehumidifier to absorb residual moisture.
3. Environmental sustainability through the use of R-290, which has a Global Warming Potential (GWP) of 3 and zero Ozone Depletion Potential (ODP)
4. Energy efficiency by employing optimized cycle design, component selection, and operational parameters.

**4.1.3 System Layout**

The core layout consists of the following:

**Indoor Unit:** Contains the evaporator coil and blower fan. Humid air is pulled in, cooled, and moisture is condensed out.

**Outdoor Unit:** Houses the compressor and condenser. It expels heat absorbed from indoor air.

**Expansion Valve:** Reduces the pressure and temperature of the refrigerant before it enters the evaporator.

**Refrigerant Lines:** Carry R-290 between components.

**Crystal Dehumidifier Unit:** Positioned within the return air stream to absorb excess moisture.

**Digital Thermo-Hygrometer:** Monitors temperature and humidity continuously.

**Control Panel:** Features programmable logic to automate system operations, including temperature and humidity thresholds.

**4.1.4 Working Operation**

The operation of the system is based on the reverse Carnot cycle used in heat pump systems. The steps are as follows:

1. **Air Intake**: Warm, humid air from the room is drawn into the indoor unit.
2. **Evaporation**: The low-pressure R-290 refrigerant in the evaporator absorbs heat from the indoor air, cooling it. During this process, water vapor in the air condenses on the cold evaporator coils.
3. **Moisture Removal:** Condensed water is collected and drained. This accounts for primary dehumidification.
4. **Compression:** The refrigerant vapor is compressed in the compressor, raising its temperature and pressure.
5. **Condensation:** High-pressure refrigerant releases heat to the environment in the condenser and turns into a liquid.
6. **Expansion:** The refrigerant passes through an expansion valve, lowering its pressure and temperature before returning to the evaporator.
7. **Supplementary Dehumidification:** Air leaving the evaporator passes through the crystal

dehumidifier ($CaCl_2$), which passively absorbs any residual moisture.

8. **Air Recirculation:** The cooled and dried air is sent back into the room, improving comfort levels.

**4.1.5 Refrigerant Selection**

R-290 (propane) is chosen for the following reasons:

**Environmental Safety**: Zero ODP and extremely low GWP.

**Thermodynamic Efficiency**: Excellent heat transfer properties and compatibility with system components.

**Operational Range:** Suitable for both low and high ambient temperatures.

**Drawback Management:** Though flammable, the system design includes leak detection, ventilation, and safety shutoffs to mitigate risk.

**4.1.6 Humidity and Temperature Monitoring**

The system includes a digital thermo-hygrometer to continuously monitor:

Room Temperature (°C)

Relative Humidity (%RH)

Based on sensor feedback, the controller adjusts the compressor's speed and operation time. If humidity remains high after evaporator-based dehumidification, the passive dehumidifier helps reach desired humidity levels.

**4.1.7 Energy Control Features**

To enhance energy efficiency:

A variable speed compressor modulates cooling capacity.

Smart algorithms adjust system operation based on real-time humidity and temperature feedback.

A dimmer-based energy control circuit optimizes fan speed and airflow rate, reducing power consumption during partial load conditions.

**4.1.8 Safety and Automation**

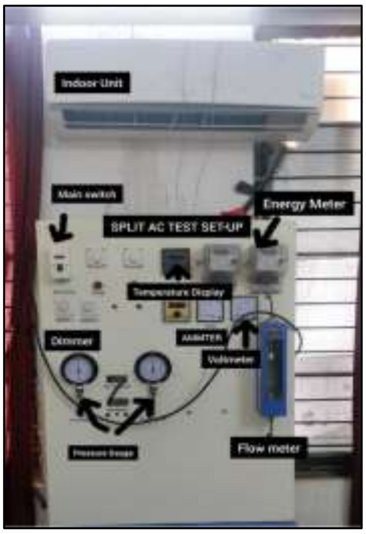
**Leak Sensors:** Positioned near the refrigerant lines to detect R-290 leakage.

**Overload Protection:** Prevents compressor damage.

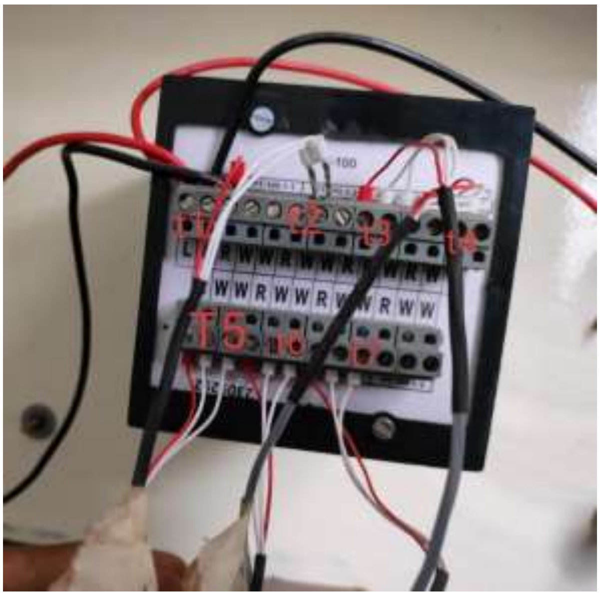
**User Interface**: Allows manual override and real-time data display.

**Auto Restart Function:** Ensures continuity after power failure.

**EXPERIMENTAL SETUP**




**Test Setup**



**Temperature Sensors**

**Results :**


**Before Dehumidification**


**After Dehumidification**

**Calculation:**
**Before Installing Dehumidifier**

| **Outdoor conditioning** | **Indoor Conditioning** |
|---|---|
| DBT=46 | DBT=21 |
| WBT=37 | WBT=16 |

**Condenser Temperature**=53 **Condenser Pressure**=23.71 **Evaporator Temperature**=21 **Evaporator Pressure**=12.2
**Pressure Ratio**=Pc/pe
=23.71/12.20
=1.94
**Density of Air** =1/0.848
=1.18 kg/$m^3$
**Area of Rectangular Duct**=Length *Width
=2.75 * 0.95
=2.16 $ft^2$
**Velocity of Air= 3.7 m/s**
=531.49 ft/min
**Volume of Air Flow** =Area of Duct *Velocity of Air
= 2.16 * 531.49
=1387.18 kg/$m^3$
**Volume Flow Rate** =1387.18/2115.8
**Entering of Enthalpy from Pressure** = 46 &37
**= 125**
**Humidity** =61%
**Mass Flow rate** = vol. Flow Rate of Air/Specific Volume of Air
=0.65/0.848
=076 kg/sec
**Enthalpy Difference** =76-41
=35
Cooling capacity = Mass*Enthalpy Difference
=0.76 *35
=26.6KW
**Power Consumption** = No. of Blinks *3600 / EC * Time
= 75*3600 /1500*60
=3KW
COP= Cooling Capacity/ Power Consumption
= 26.6/3
= 8.86
**After Installation of Dehumidifier:**

| **Outdoor** | **Indoor** |
|---|---|
| DBT=40 | DBT=21 |
| WBT=31 | WBT=15 |

**Condenser Temperature**=41 **Condenser pressure** =17.51 **Evaporator Temperature**=21 **Evaporator**

**Pressure**=12.20
**Pressure Ratio** = PC/PE
=17.51/12.2
= 1.43
**Specific Volume Air** =0.845
Density =1/0.845
=1.8 kg/m3
**Cubic fit per unit** = Area of duct*Velocity of air
**Area of rectangular duct** =length*width
=2.75*0.95
=2.61ft$^2$
**Velocity of air** =3.7m/s
=531.5 Feet/min
**Volume flow rate** =Area of duct*Velocity of air
=2.61*531.5
=1387. 4 m3/s
**Volume per fit** = 1387.4/2118.8
= 0.63
**Mass flow rate** =0.6/0.8
= 0.76 Kg/s
**Enthalpy difference** = 55-40
= 15
Cooling Capacity = Mass flow rate*Enthalpy Difference
= 0.76 * 50
= 11.5 KW
**Power consumption** = No. of blinks*3600/Ec*time
=59*3600/1500*60
=2.2 KW
**COP** = Colling capacity /Power consumption
=10.5/2.2
=4.87

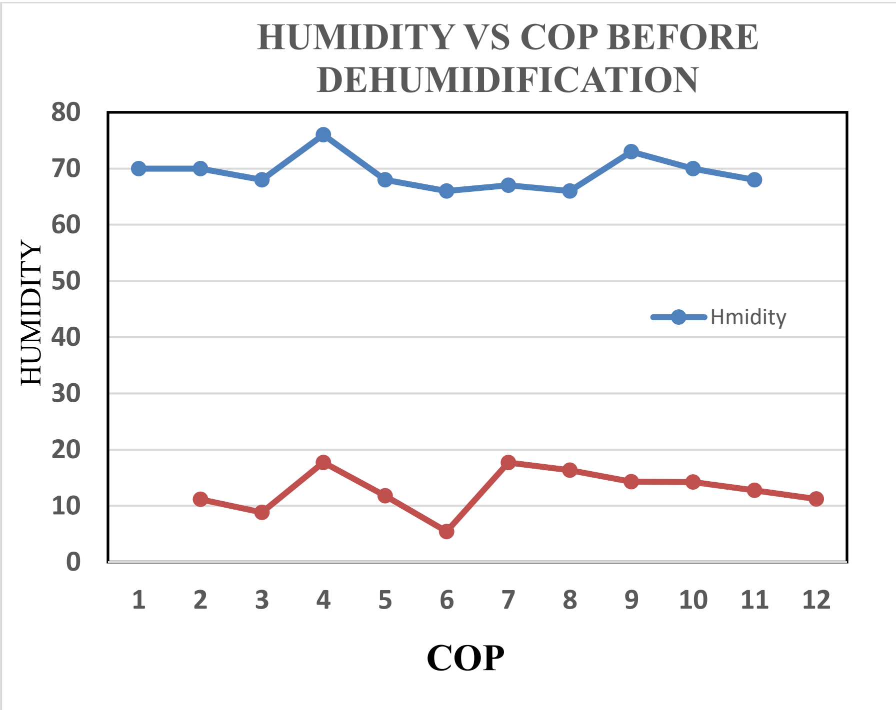
**Table : System Performance Parameters Before and After the Installation of The Dehumidifier**

| Parameter | Before Dehumidification | After Dehumidification |
|---|---|---|
| Dry Bulb Temperature (Indoor) | 21°C | 21°C |
| Wet Bulb Temperature (Indoor) | 16°C | 15°C |
| Dry Bulb Temperature (Outdoor) | 46°C | 40°C |
| Wet Bulb Temperature (Outdoor) | 37°C | 31°C |
| Condenser Temperature | 53°C | 41°C |

| | | |
|---|---|---|
| Condenser Pressure | 23.71 bar | 17.51 bar |
| Evaporator Temperature | 21°C | 21°C |
| Evaporator Pressure | 12.20 bar | 12.20 bar |
| Pressure Ratio | 1.94 | 1.43 |
| Specific Volume of Air | 0.848 m³/kg | 0.845 m³/kg |
| Air Density | 1.18 kg/m³ | 1.8 kg/m³ |
| Volume Flow Rate | 1387.18 ft³/min | 1387.40 ft³/min |
| Mass Flow Rate | 0.76 kg/s | 0.76 kg/s |
| Enthalpy Difference | 35 kJ/kg | 15 kJ/kg |
| Cooling Capacity | 26.6 kW | 11.5 kW |
| Power Consumption | 3.0 kW | 2.2 kW |
| COP | 8.86 | 4.87 |

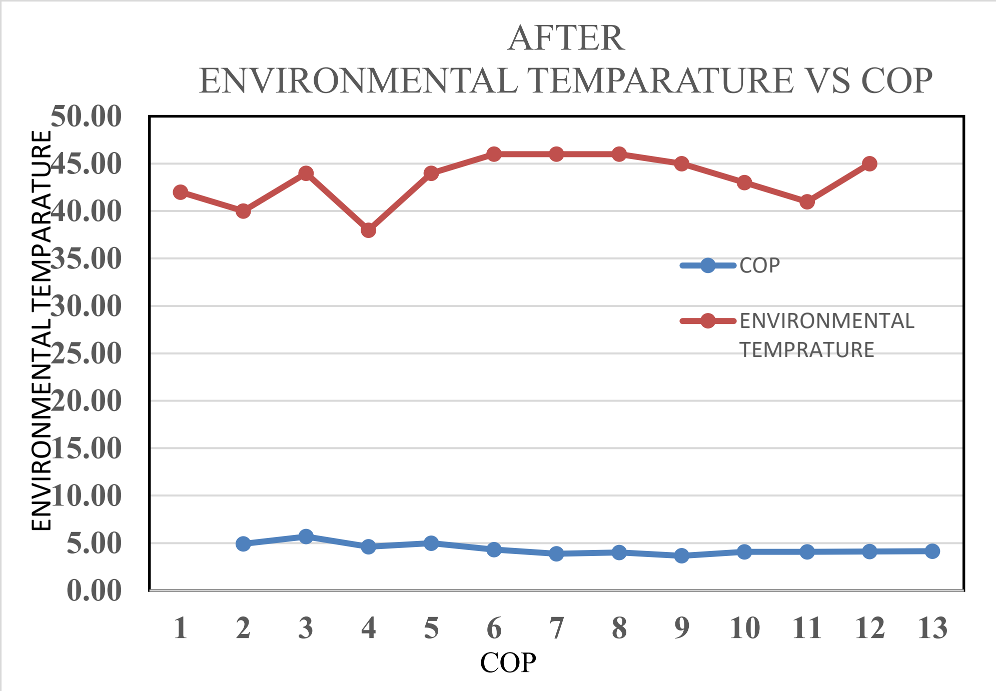
**Calculations Graph:**

Humidity Vs Cop Before Dehumidification:



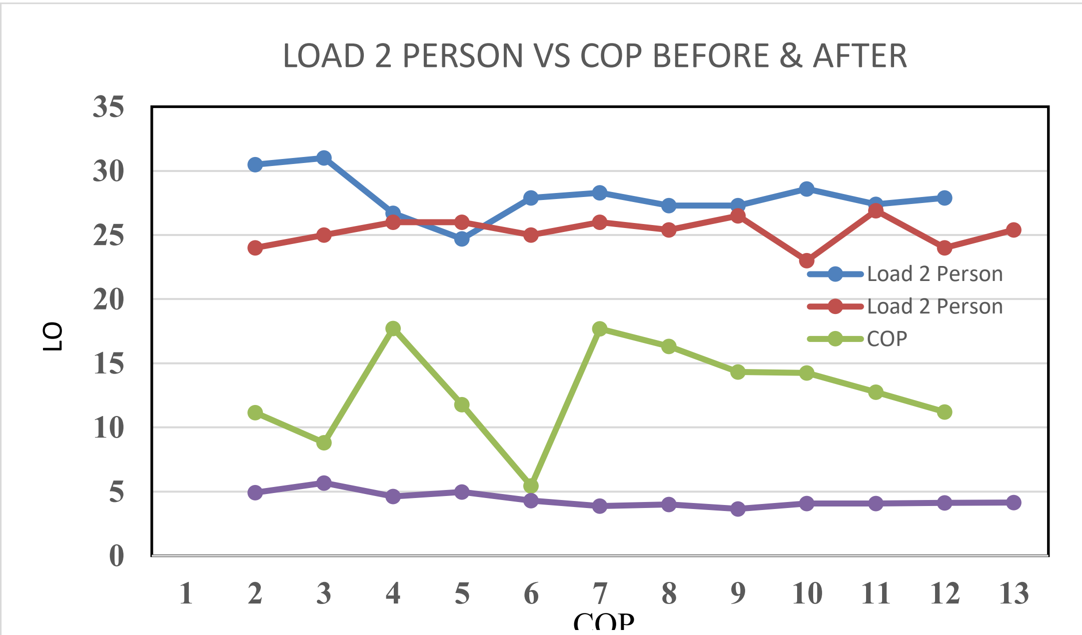

- The graph compares humidity levels with COP (Coefficient of Performance) before dehumidification.
- The blue line represents humidity, and the orange line shows COP.Humidity levels are high, mostly staying between 65% and 72%.
- COP values show noticeable fluctuations, ranging from about 8 to 20. There's no clear pattern or stability in the COP, indicating system inconsistency.
- Spikes and dips in COP suggest poor efficiency under high humidity conditions. The overall trend shows that high humidity affects cooling performance negatively.

After Environmental Temperature Vs Cop:




- The graph shows how environmental temperature and COP (Coefficient of Performance) vary after dehumidification.
- The orange line represents environmental temperature, while the blue line shows the COP values.
- Environmental temperature remains relatively high and stable, ranging between 35°C and 45°C.
- COP values are much lower, staying consistently around 4 to 5 across all data points.
- There are minor fluctuations in both lines but no drastic changes.

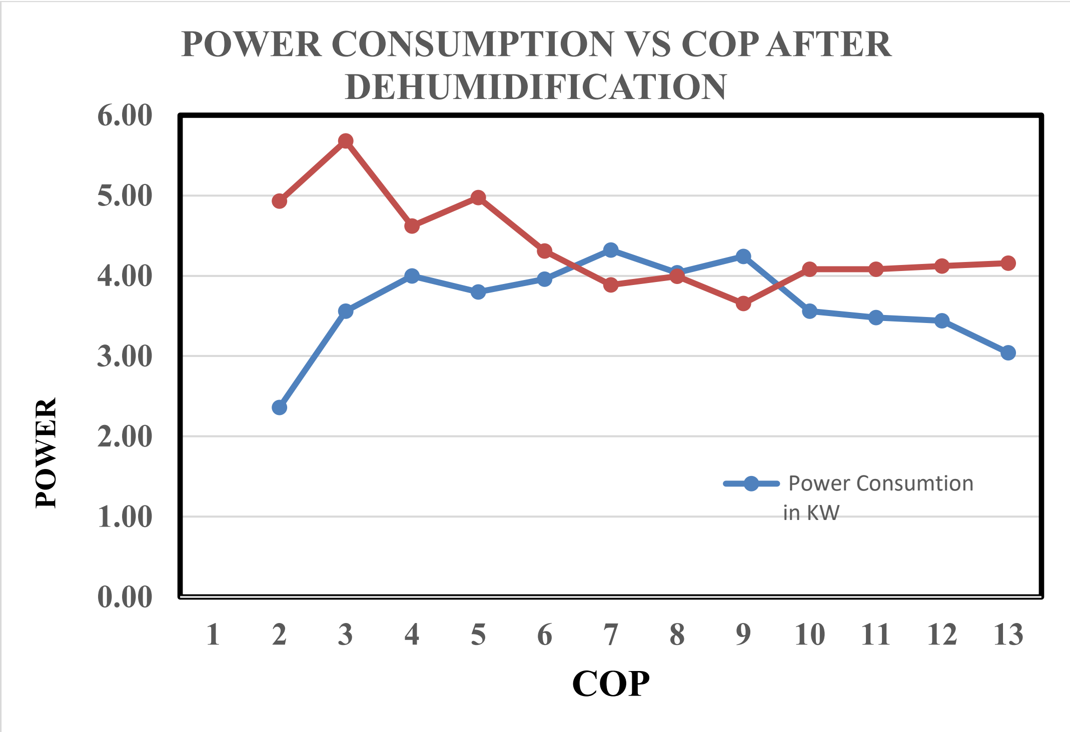
Load 2 & 4 Person vs COP Before Dehumidification:




- The graph compares cooling loads for 2-person and 4-person occupancy with COP before dehumidification.

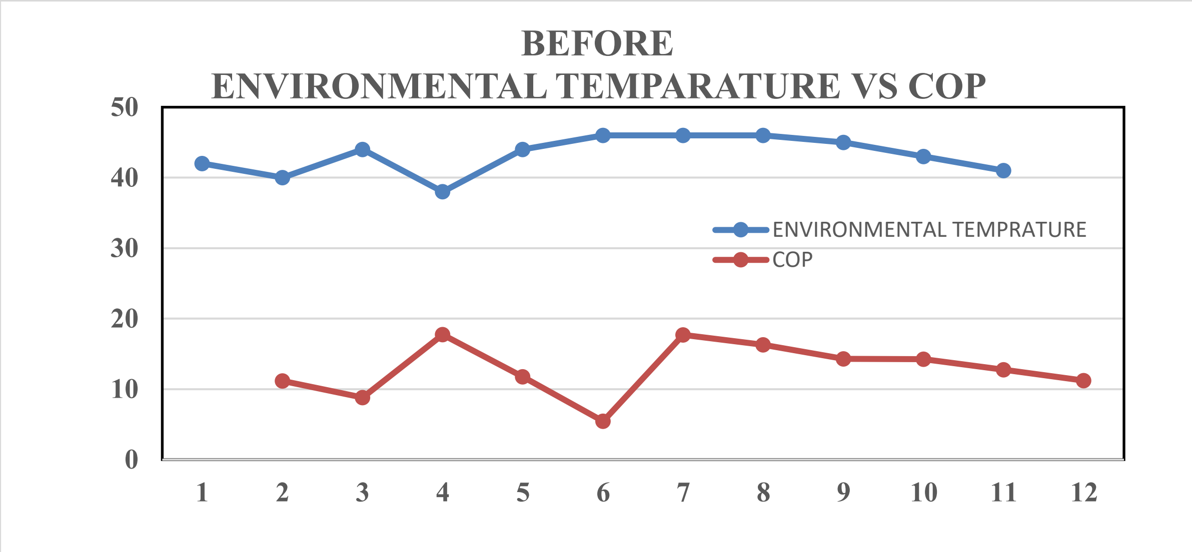
- Both load curves (blue for 2-person, orange for 4-person) follow a similar downward trend with minor fluctuations.
- Load values are higher for 2-person scenarios compared to 4-person, possibly due to varying cooling patterns.
- The COP (gray line) shows significant variation, dropping and rising sharply across the timeline.
- The lowest COP appears around the 6th point, showing system inefficiency at that stage.
- Higher cooling loads slightly correlate with reduced COP, indicating strain on the system.
- COP is not stable, reflecting performance issues in handling different occupancy loads.
- Overall, the system's efficiency decreases slightly with increased load and fluctuating COP before dehumidification.

Power Consumption vs COP After Dehumidification:



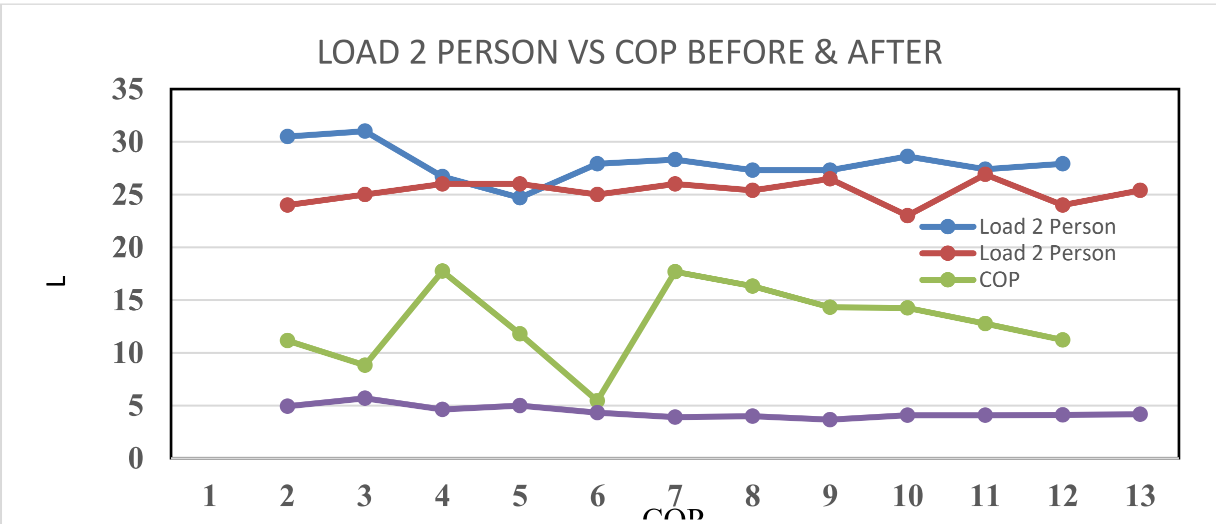

- The graph compares power consumption and COP after dehumidification.
- Power consumption initially increases slightly and then stabilizes between 3.5 to 4.5 kW.
- COP starts around 5.2, drops slightly, and then levels off around 4.1 to 4.3.
- The trend shows improved consistency in both power use and COP compared to pre-dehumidification.
- Despite a slight rise in energy use, system efficiency remains more stable.
- There are no extreme fluctuations in COP, suggesting smoother operation.
- The consistent COP values indicate the system is operating efficiently.
- Overall, dehumidification leads to better performance and controlled energy usage

Before Environmental Temperature vs COP:




- The graph compares Environmental Temperature and Coefficient of Performance (COP) before dehumidification.
- Environmental temperature is shown in blue, and COP is shown in orange.
- The temperature fluctuates between 38°C and 47°C across the 12 COP points.
- COP values vary between 6 and 18, with noticeable ups and downs.
- Temperature shows minor fluctuations and remains relatively high throughout.
- COP has more drastic changes, especially between COP values 3 to 7.
- Both variables do not follow the same trend, indicating limited correlation.
- The system appears to maintain stable environmental temperatures despite varying COP.
- Let me know if you'd like a description for a similar graph labeled "After Dehumidification" or help editing the document.

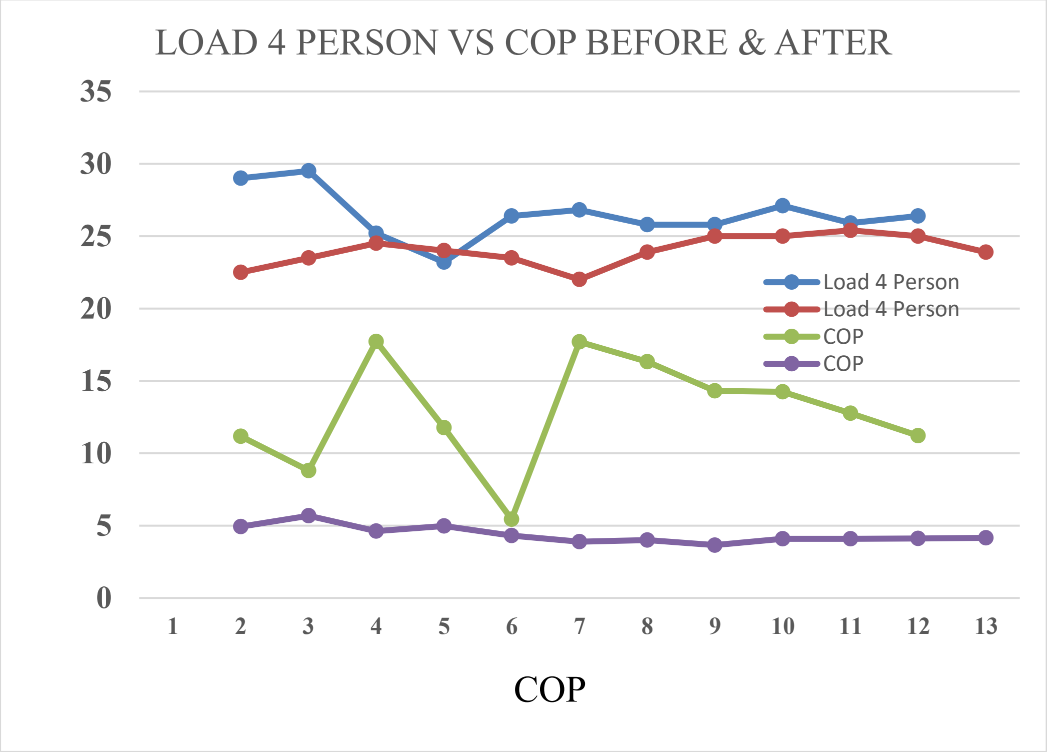
Load 2 Person vs COP Before & After:




- The graph compares the load and COP for two-person scenarios before and after dehumidification.
- Blue and orange lines represent load before and after dehumidification, respectively.
- Grey and yellow lines show COP values before and after dehumidification.

- Before dehumidification, the load fluctuates more compared to after.
- After dehumidification, load values become more stable and consistent.
- COP values before dehumidification (grey) vary widely, indicating instability.
- COP values after dehumidification (yellow) remain almost flat, showing better uniformity.
- Overall, dehumidification improves COP consistency and reduces variation in load.

Load 4 Person Vs Cop Before & After:




- The graph compares the load for 4 persons and COP (Coefficient of Performance) before and after a certain change.
- The x-axis represents different COP data points (from 1 to 13), and the y-axis shows the load values.
- The blue line shows the load before the change, and the orange line shows the load after.
- Both blue and orange lines stay relatively stable, with some fluctuations around 25–30 units.
- The grey line represents COP before the change and varies significantly, peaking around point 4 and 7.
- The yellow line shows COP after the change and remains consistently low and steady, around 4–5 units.
- This indicates that COP was stabilized after the change, possibly due to system improvements.
- Overall, load performance remained steady, while COP became more controlled and predictable after intervention.

**RESULT:**

The following table provides a detailed comparison of system performance parameters before and after the installation of the dehumidifier. This comparison highlights the impact on cooling capacity, energy efficiency, and humidity control.

**CONCLUSION:**

Dehumidification in heat pump air conditioning systems using eco-friendly refrigerants is a step toward more sustainable HVAC practices. By reducing environmental impacts through low-GWP refrigerants, improving energy efficiency, and maintaining effective humidity control, this approach balances comfort with ecological responsibility. The continued development and adoption of these technologies are crucial for creating environmentally- conscious cooling solutions.

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