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Experimental and Performance Analysis of R-32 and R290 Heat Pump Driven Air Conditioning System

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Abstract

A thorough performance analysis of a heat pump air conditioning system for both heating and cooling applications is presented in this research. The purpose of the study is to assess the system's overall performance, energy usage, and efficiency under various operating circumstances. The study makes use of a variety of experimental measurements. An outline of the heat pump air conditioning system's parts and operation is given at the start of the analysis. Important factors including compressor power usage, ambient temperature, refrigerant flow rate, and indoor/outdoor temperature differentials are all monitored during the experimental setting. These measurements, which take into account both heating and cooling modes, are gathered under varied working conditions. For HVAC engineers, researchers, and policymakers, the performance analysis of the heat pump air conditioning system provided in this paper is an invaluable resource. The insights gained from this study contribute to the on-going efforts to improve the design and operation of heat pump systems for heating and cooling applications, fostering sustainability and energy conservation in the built environment.

Keywords: Air-conditioning, Heat-Pump, HVAC, R290, R32.

Introduction

The growing emphasis on environmental sustainability and energy efficiency in the HVAC (Heating, Ventilation, and Air Conditioning) industry has spurred significant interest in the performance of various refrigerants. Among these, R-32 and R-290 have emerged as prominent candidates due to their distinct properties and potential environmental benefits. This project delves into the performance analysis of heat pump and air conditioning systems using R-32 refrigerant, providing a theoretical comparison with R-290 refrigerant to highlight their respective advantages and limitations. In many developed nations, commercial and residential buildings contribute significantly to energy consumption and greenhouse gas emissions, with estimates suggesting they account for approximately 40% of total energy use and 25% of emissions. As a result, the building sector presents a major opportunity for reducing energy consumption and environmental impact. To address this, construction companies are increasingly focusing on developing environmentally sustainable building solutions. One of the key areas of improvement is the thermal performance of buildings, which has seen continuous advancements. However, the growing demand for enhanced comfort in these spaces also leads to higher energy consumption, presenting a challenge in balancing energy efficiency with occupant satisfaction. This study evaluates the thermodynamic performance of R-32 and R-290, highlighting their efficiency and cooling capacities in air conditioning systems (1). The performance evaluation of R-32 and R-290 refrigerants in air conditioning systems on comparative analysis of the energy efficiency of R-32 and R-290 in heat pump applications (2). The energy efficiencies of R-32 and R-290 in heat pump systems, emphasizing potential energy savings and performance improvements (3). This research investigates the thermodynamic properties and performance metrics of R-32 and R-290 in residential air conditioning units (4), which also inspected on Environmental impact assessment of R-32 and R-290 refrigerants in heat pump systems. The study assesses the environmental impacts of R-32 and R-290, focusing on their global warming

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potentials and ecological footprints in heat pump systems (5). Author assessed on Experimental study on the performance of R-32 and R-290 refrigerants in heat pumps. This experimental study measures and compares the performance of heat pumps using R-32 and R-290, providing empirical data on their efficiencies and also viewed on Comparative study of R-32 and R-290 refrigerants in split air conditioners (6). The paper presents a comparative analysis of the performance and energy consumption of split air conditioners using R-32 and R-290 and appraised on Evaluation of energy performance and safety aspects of R-32 and R-290 refrigerants (7). This study evaluates the energy performance and safety considerations of using R-32 and R-290 refrigerants in HVAC system (8). The research conducts a life cycle assessment to compare the environmental impacts of R-32 and R-290 refrigerants throughout their operational lifetimes in heat pumps (9). Performance comparison of R-32 and R-290 in variable-speed heat pumps in variable-speed heat pump systems, focusing on efficiency and operational stability (10). Analysis of the thermodynamic efficiency of R-32 and R-290 refrigerants in air conditioning systems. The study analyses the thermodynamic efficiencies of R-32 and R-290, highlighting their potential for improving air conditioning system performance (11). Comparative environmental analysis of R-32 and R-290 refrigerants and provides a comparative environmental analysis of R-32 and R-290, examining their impacts on greenhouse gas emissions and energy efficiency (12). Energy efficiency and environmental impact of R-32 and R-290 refrigerants and the research evaluates the energy efficiency and environmental impacts of R-32 and R-290, presenting data on their suitability for sustainable HVAC applications (13). Experimental analysis of the performance of R-32 and R-290 in heat pump water heaters. This experimental study analyses the performance of heat pump water heaters using R-32 and R-290, comparing their heating efficiencies and operational characteristics (14). Demonstrated the safety and performance of R-32 and R-290 refrigerants in heat pump systems and examines the safety and performance of R-32 and R-290 refrigerants, focusing on their application in heat pump systems (15). The performance of R-32 and R-290 refrigerants in household air conditioners and provides an experimental investigation into the performance of household air conditioners using R-32 and R-290 refrigerants. Park and Kim reviewed on Thermodynamic analysis of R-32 and R-290 refrigerants for heat pump applications. The research conducts a thermodynamic analysis of R-32 and R-290, assessing their efficiencies and suitability for heat pump applications (16). By utilizing comparative study on the environmental and economic performance of R-32 and R-290 which compares the environmental and economic performance of R-32 and R-290, evaluating their impacts on sustainability and cost-effectiveness (17). Performance evaluation of R-32 and R-290 in air conditioning systems for hot climates. The study evaluates the performance of air conditioning systems using R-32 and R-290 in hot climates, focusing on cooling efficiency and energy consumption (18). Experimental and performance comparison of R-32 and R-290 refrigerants in variable-speed air conditioners. This experimental study compares the performance of variable-speed air conditioners using R-32 and R-290 refrigerants, highlighting efficiency gains and operational benefits (19). Followed up on Analysis of the environmental impact of using R-32 and R-290 refrigerants in heat pump systems. The research analyses the environmental impact of using R-32 and R-290 in heat pump systems, focusing on their contributions to global warming and energy efficiency (20-21).

Methodology

The experimental setup and manufacturing process play a crucial role in the development and evaluation of heat pump systems for cooling and heating purposes. This section provides an introduction to the experimental setup and manufacturing considerations involved in the design and production of such systems. It outlines the key components, techniques, and procedures utilized to create and test heat pumps capable of providing heating and cooling.

Description of the System

- Utilizing R-32 and R-290 as refrigerants design and construct an air conditioning system like Compressor, condenser, expansion valve, evaporator, and heat exchangers are essential parts.

- Install the mass flow, temperature, and pressure sensors that are required for data collection.
- Heat pumps designed for heating and cooling typically consist of several key components that work together to provide both heating and cooling capabilities.
- Measure key performance indicators like Cooling capacity ($\dot{Q}c$), Heating capacity ($\dot{Q}h$), Coefficient of Performance (COP), Energy consumption (Wc), Discharge and suction pressures, Evaporator and condenser temperatures.
- Operate the system under varied ambient conditions (temperature, humidity, and load variations).
- Error Analysis for instrument Uncertainty Analysis Estimate errors from sensor specifications (±0.5°C for temperature, ±1% for pressure transducers, etc.)
- Use uncertainty propagation formula for derived parameters

$$Uy = \text{Square Root of } [\left(\frac{\sigma y}{\sigma x1} Ux1\right) + \left(\frac{\sigma y}{\sigma x2} Ux2\right)] + \cdots \quad [1]$$

This equation represents the propagation of uncertainty Uy based on the partial derivatives of a function y with respect to variables x1, x2, ... each multiplied by their respective uncertainties Ux1, Ux2, ...

Operation of a Heat Pump

A heat pump is a flexible HVAC system that can both heat and cool indoor spaces by moving heat between the inside and outside environments. It operates through a refrigeration cycle, where the direction of refrigerant flow is reversed depending on whether heating or cooling is needed, allowing it to regulate the temperature effectively. This system efficiently manages energy by transferring heat rather than generating it, making it an economical and eco-friendly option for year-round comfort.

Operation of a Heat Pump in Cooling Mode:

Heat Absorption (Evaporator): In cooling mode, the evaporator and condenser switch roles. The evaporator coil is positioned indoors, where it absorbs heat from the air inside the building. As the refrigerant passes through the evaporator, it evaporates, drawing heat from the indoor environment.

Compression (Compressor): The refrigerant, now in a low-pressure gas form, moves to the compressor, which increases both its pressure and temperature by compressing it.

Heat Release (Condenser): The high-pressure, high-temperature gas is then directed to the condenser coil located outside the building. Here, the refrigerant releases the heat it absorbed indoors into the outdoor air, cooling down and condensing back into a liquid form.

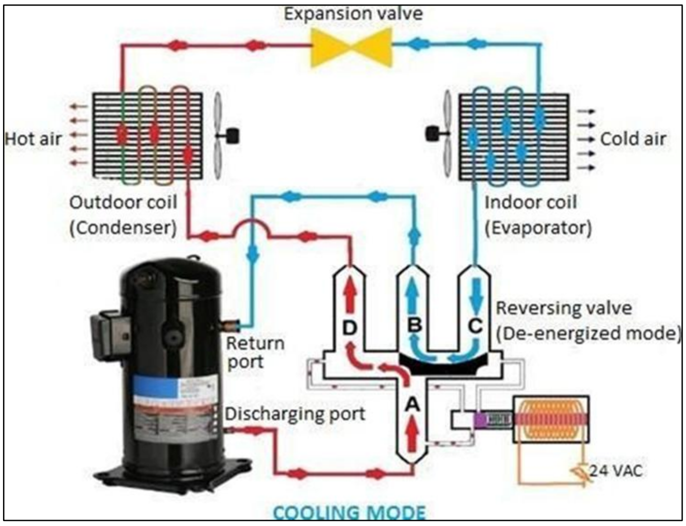

Figure 1: Cooling Mode (22)

The heat pump functions similarly to a typical air conditioner in cooling mode in Figure 1. In this setup, the outside coil acts as the condenser, releasing the heat to the outside world, while the indoor coil acts as the evaporator, removing heat from the indoor air. Similar to a conventional air-conditioning system, this configuration enables the heat pump to efficiently chill the interior space (22).

Operation of a Heat Pump in Heating Mode: The refrigerant leaves the compressor and passes via the reversing valve in Figure 2, where it is redirected to the indoor coil while the heat pump is in heating mode. In this instance, the indoor coil serves as the condenser because the refrigerant always goes through it after exiting the compressor. In this case, the refrigerant warms the occupied space by releasing heat into the interior air. Before going to the outdoor coil, where it collects heat from the air, water, or earth, the refrigerant passes via an expansion mechanism after passing through the indoor coil. The cycle then resumes when the refrigerant enters the compressor again. In this mode, the outdoor coil collects low-temperature heat from the surrounding environment, while the indoor coil delivers higher temperature heat to the indoor space, providing effective heating (23-24).

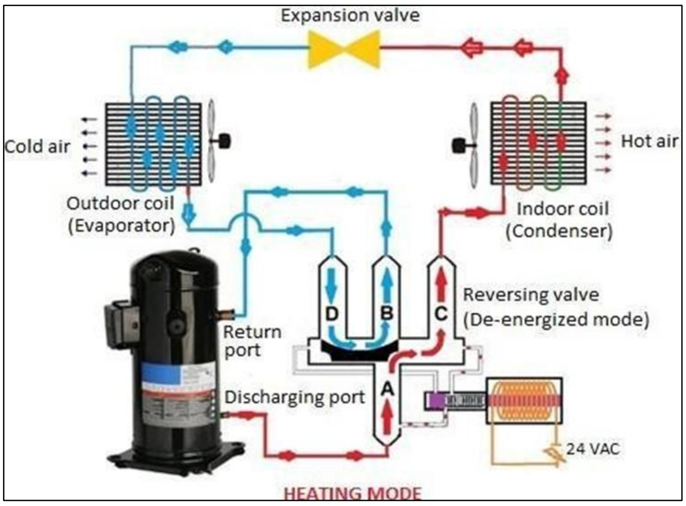

Figure 2: Heating Mode (22)

Experimentation on Experimental Setup

The experimentation on the experimental setup of heat pump driven air conditioning system which is shown in the Figure 3, using R290 (propane) and of R32 (difluoromethane) as a refrigerant in various temperature conditions (T1 to T7) for heating and cooling applications depend on several factors, including the system design, operating conditions, and specific application. A general overview of when using R290 and R32, considering different temperature ranges (T1 to T7) and suction and discharge pressures (P1, P2). Where, T1- inlet temperature of Compressor (suction), T2- outlet temperature of compressor (Discharge),T3- Temperature of condenser at middle, T4- outlet temperature of condenser, T5- outlet temperature of capillary tube, T6- Environment temperature,T7- Outlet temperature of Evaporator. Meanwhile we have also taken the reading from P1-P7 according to the temperature from T1-T7.

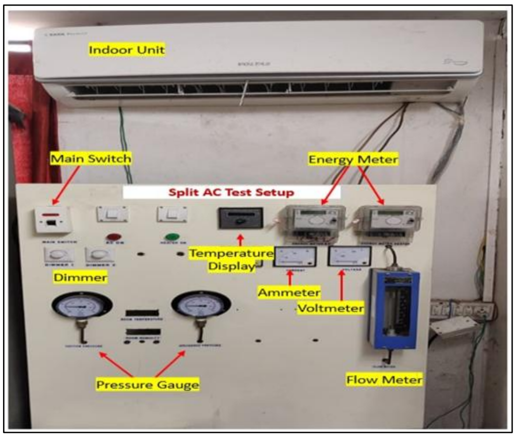

Figure 3: Experimental Setup of Heat Pump Driven Air Conditioning System

Process to Conduct the Experiment on the Experimental Setup for Heating and Cooling

As per the process of experimentation in the one room having 200 ft2 areas perform the experiment taking the reading T1-T7 using PT100 thermocouple and pressure using pressure gauge for heating and cooling application using R32 and R290 refrigerant. The details reading are taken and shown in the Table 1.

Heating and Cooling with Examples: Here are a few observation tables for heat pumps used for heating and cooling purposes, including the calculation of the Coefficient of Performance (COP).The details reading of heat pump driven air conditioning system for heating application using R32 is given in the Table 1.

Here are a few observation tables for heat pumps used for heating and cooling purposes, including the calculation of the Coefficient of Performance (COP). The details reading of heat pump driven air conditioning system for heating application using R290 as a refrigerant is given in the Table 2. We have taken the observation table for cooling purpose for R32 and R290 same as we have taken for heating purpose which is shown in the above observation table.

Table 1: Inlet and Outlet Temperature and Pressure of Components (Heating)

R 32 Readings										
SR. NO.	**T1 (°C)**	**T2 (°C)**	**T3 (°C)**	**T4 (°C)**	**T5 (°C)**	**T6 (°C)**	**T7 (°C)**	**Blink In 10Sec**	**Velocity of air m/s**	**Humidity**
1	37	59	16	14	8	17	29	7.4	1.3	41%
2	39	79	17	18	10	18	28	6.7	1.4	36%
3	42	85	19	22	9	19	30	7.5	1.3	40%
4	48	96	20	23	12	18	30	7.5	1.4	41%
5	46	104	22	20	16	15	28	8	1.3	37%
6	39	75	24	26	11	20	32	7.4	1.4	45%
7	41	95	21	21	13	21	33	7.1	1.2	47%
8	44	102	18	25	14	16	28	7.1	1.3	37%
9	40	100	24	17	10	19	32	7.9	1.5	45%
10	45	105	20	19	15	22	33	8	1.4	47%

Table 2: Inlet and Outlet Temperature and Pressure of Components (Heating)

R 290 Readings										
SR. NO.	**T1 (°C)**	**T2 (°C)**	**T3 (°C)**	**T4 (°C)**	**T5 (°C)**	**T6 (°C)**	**T7 (°C)**	**Blink In 10Sec**	**Velocity of air m/s**	**Humidity**
1	36	49	16	15	8	17	28	7	1.4	36%
2	38	51	18	17	10	18	23	8	1.4	37%
3	42	55	20	19	12	19	31	8	1.5	39%
4	48	75	22	21	14	18	33	6.3	1.5	38%
5	31	85	24	23	16	15	32	7	1.5	40%
6	39	72	17	25	18	20	32	7.2	1.5	38%
7	39	77	20	22	15	21	19	7.5	1.5	38%
8	38	82	19	16	9	16	32	6	1.3	36%
9	40	57	21	18	11	19	31	8	1.5	41%
10	45	68	23	20	13	22	34	8	1.6	38%

Results and Discussion

Heating and Cooling Capacity Test and Calculations for Heat Pump for Heating and Cooling Purposes for Finding the COP of the System

Calculation for Finding the Coefficient of Performance for Heating Purpose Using R32 and R290 Refrigerant in the Heat Pump Air Conditioning System:

Condenser Temperature(°C) = 40°C
Condenser Pressure(Psi)= 23.76 bar
Evaporator Temperature(°C) = 3°C
Evaporator Pressure(Psi) = 7.8 bar
Indoor temperature
DBT = 32°C, WBT = 23°C
Outdoor Temperature
DBT = 20°C, WBT = 12°C
Specific Volume of Air = 0.884 m^3/kg
Density Of Air= 1 / Specific Volume of air
1/0.884 = 1.13 kg/m^3
Area of Duct=
Length*Width =2.75 * 0.95 = 2.61 ft^2
Cubic Fit Per Minute =
Velocity * Area
275.6*2.61
CFM = 719.31 ft^3/min
Volume Flow Rate =
CFM / 2118.88
719.31/2118.88
0.34 m^3/sec
Mass Flow Rate =
Volume flow Rate / Specific Volume of Air
0.34/0.889 = 0.40 kg/sec
Entering Air Enthalpy = 33.94 KJ/Kg
Leaving Air Enthalpy = 64.12
Enthalpy Difference = 30.18
Heating Capacity in KW =
Mass Flow Rate * Enthalpy Difference= 0.40*30.18
= 12.072 KW
Power Consumption = no. of Blinks * 3600 / EC * Time
= 7.4*3600 / 1500*10
= 1.776 KW
COP of System = Heating Capacity in KW / Input Power in KW
COP =12.072/1.776 =6.70

Calculation for Finding the Coefficient of Performance for Cooling Purpose Using R32 and R290 Refrigerant in the Heat Pump Air Conditioning System:

Condenser Temperature (°C) = 53°C
Condenser Pressure (bar) = 23.71
Evaporator Temperature (°C) = 22°C
Evaporator Pressure (bar) = 14.5
Indoor temperature = DBT = 22°C, WBT = 16°C
Outdoor Temperature = DBT = 36°C, WBT = 25°C
Specific Volume of Air = 0.848 m^3/kg
Density of Air= 1/Specific Volume = 1/0.848 = 1.18 kg/m^3

Area of Duct = length*width = 2.75 ft * 0.95 ft
=2.61 ft^2
Velocity of Air = 1.5 = 295.276 feet/min
Cubic Feet per Min. = Velocity * Area
295.276 * 2.61 =
CFM = 770 ft^3/min
Volume Flow Rate = CFM / 2118.88 = 770/2118.88 = 0.360 m^3/sec
Mass Flow Rate = Volume flow Rate / Specific Volume of Air
= 0.36/0.848 = 0.43 kg/sec
Entering Air Enthalpy = 69.71
Leaving Air Enthalpy = 44
Enthalpy Difference = 25.02
Cooling Capacity in KW =
Mass Flow Rate * Enthalpy Difference = 25.02 * 0.43= 10.8 KW
Power Consumption = no. of Blinks * 3600 / EC * Time
7.4*3600 / 1500*10 = 1.776 KW
COP of System =
Cooling Capacity in KW / Input Power in KW
10.8/ 1.7 = 5.6

The performance of a 1.5-ton air conditioning system has been experimentally assessed using R32 and R290, as can be seen from the calculations above. The split air conditioning system was tested experimentally by keeping the indoor and outdoor air temperatures at ISO5151 standards, which are 27 °DBT, 19 °WBT indoors and 34 °DBT, 24 °WBT outdoors, respectively. Additionally, the suction and discharge pressures are measured under global test conditions, which include the condenser temperature at 54.5°C and the evaporator temperature at 16°C.

Comparison between R290 and R32 for Heating in Heat Pump Air Conditioning System

Table 3 shows the Performance of COP of heat pump air conditioning system for heating application using R32 and R290 as a refrigerant. As environment temperature increases a slight increase in power consumption having minor change in COP of R-290 and R-32 which is shown in Figure 4. When we kept environment temperature constant for the same parameters for R32 and R290 Refrigerant, we found that R290 having higher COP than R290. As graph between COP of R-32 & R-290, COP of R- 290 is better than R32. In this it shows that in same power consumption for the same constant parameters for R32 and R290 refrigerant for the heat pump air conditioning system, we found the higher COP for R290 which is shown in Figure 5.

Table 3: Environmental Temp. Vs COP of R290 and R32

Sr. No.	Environment Temp.	Heating Capacity(R32)	Heating Capacity(R290)	COP of R32	Cop of R290
1	17	10.56	8.6319	5.9	6.0
2	18	9.65	10.99	6.0	5.7
3	19	11.59	12.3	6.4	6.4
4	18	11.749	9.82	6.5	6.5
5	15	12.67	11.69	6	6.8
6	20	12.072	11.86	6.7	6.9
7	21	11.72	12.6	6.8	6.9
8	16	11.814	11.11	6.9	7.7
9	19	14.1105	13.6	7.0	7.0
10	22	16.15	16.41	7.4	7.4

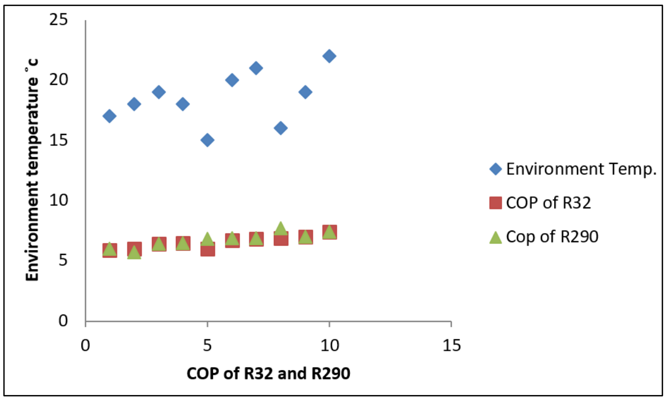

Figure 4: Environmental Temp. Vs COP of R290 and R32

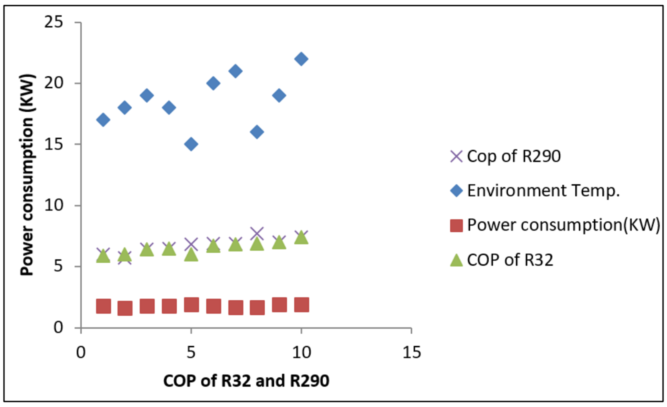

Figure 5: Power consumption Vs COP of R290 and R290

Comparison between R290 and R32 for Cooling in Heat Pump Air Conditioning System

Table 4 shows the Performance) COP) of heat pump air conditioning system for cooling application using R32 and R290 as a refrigerant.

As environment temperature increases a slight increase in power consumption having minor change in COP of R-290 and R-32 and in which COP of R290 is Greater than R32 based on the same parameters for both refrigerant in the heat pump air conditioning system for which is shown in Figure 6.

Table 4: Environmental Temp. Vs COP of R290 and R32

Sr. No.	Environment Temp.	Cooling Capacity(R32)	Cooling Capacity(R290)	COP of R32	Cop of R290
1	30	10.4	11.22	5.85	5.8
2	33	10.8	8.51	5.6	5.7
3	32	9.76	10.31	5.49	5.42
4	34	8.78	9.48	4.95	5
5	35	9.89	11.02	5.52	5.74
6	31	7.29	9.95	6.02	6.02
7	35	11.58	8.62	6.2	4.23
8	36	10.36	9.43	5.81	5.17
9	38	9.51	13.42	5.15	5.98
10	39	9.18	8.87	5.17	5.43

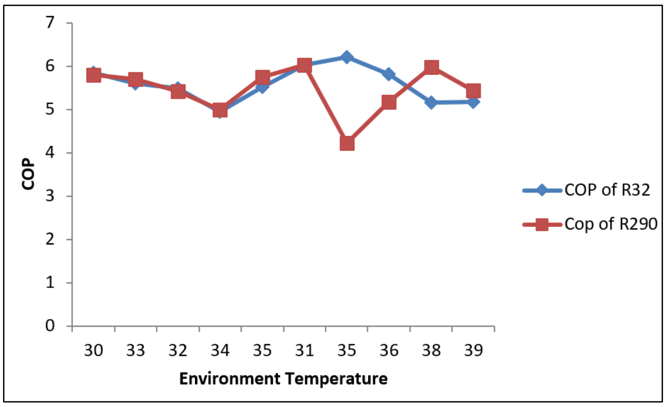

Figure 6: Environmental Temp. Vs COP of R290 and R32

Conclusion

In conclusion, the selection between R32 and R290 refrigerants for heating and cooling applications hinges on factors like temperature conditions, system design, and safety precautions. R290 is favored for its higher heating capacity and can excel in low-temperature heating scenarios (T1 to T3), but demands careful system design and stringent safety measures due to its flammability.

R32, on the other hand, is commonly used for cooling applications, especially in high-temperature conditions (T4 to T7), while specific operating parameters vary with system design and load requirements. Both refrigerants necessitate safety as a top priority due to their flammable nature, and regulatory compliance is vital.

Heat pump systems designed for simultaneous heating and cooling purposes offer several advantages and opportunities for efficient and sustainable indoor climate control. These systems utilize the heat transfer process to provide both heating and cooling functions, leading to energy savings, year-round comfort, and reduced environmental impact.

By leveraging advancements in control strategies, integration with renewable energy sources, and smart grid technologies, the future scope for simultaneous heating and cooling systems looks promising. Improvements in system design, components, and data analytic can further enhance their performance and optimize energy consumption.

While there are limitations to consider, such as temperature differentials, capacity constraints, and installation complexity, these can be addressed through proper system design, sizing, and professional consultation.

Overall, simultaneous heating and cooling systems present a viable and sustainable solution for indoor climate control, contributing to energy efficiency, comfort, and environmental responsibility.

Abbreviations

COP: Coefficient of performance, DBT: Dry Bulb Temperature, EER: Energy efficiency ratio, HVAC: Heavy Ventilation and air conditioning, R290: Propane, R32: Difluoromethane, WBT: Wet Bulb Temperature.

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Author Contributions

Subhash Kumarhave: Done the research and performed the experiment, P J Bansod: Helped to write the research paper in the terms of guidance, Akhya Kumar Behera: Helped to write the research paper in the terms of guidance.

Conflict of Interest

We have no conflicts of interest to disclose, all authors declare that they have no conflicts of interest.

Ethics Approval

All the Tables and figures are self-made, those data have taken from the research paper is properly cited and required ethics approval is taken.

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