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Comparative Study of R32 and R410A in Heat Pump in Residential Applications

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Abstract

Split air conditioning (AC) systems are the predominant choice for both commercial and residential applications. The primary refrigerant used in modern split AC systems is R410A, a hydrofluorocarbon (HFC) with a high global warming potential (GWP) of 2088. Additionally, due to its zeotropic nature, R410A cannot be recharged into a system with a leak, leading to increased maintenance costs. This research examines the feasibility of replacing R410A with R32 in split AC systems. R32 is selected due to its significantly lower GWP of 675 and higher latent heat of evaporation at a constant temperature. The study evaluates cooling capacity, energy consumption at different ambient temperatures, heating capacity, and the seasonal energy efficiency ratio (SEER) in the Egyptian market before and after retrofitting. The experimental process involved conceptualization, installation, data collection, and quantitative analysis. Results showed a 6% increase in cooling capacity at 35°C and a 9% increase at 43°C, with improved capacity retention at high ambient temperatures post-retrofit. Additionally, SEER improved by 15% after switching to R32. These findings confirm that converting an R410A-based system to R32 is both viable and effective.

1. Introduction

Recently, Urbanization, rising disposable income, and climate change have all contributed to a sharp growth in demand for air conditioning (AC) systems and refrigerators in homes and businesses [1]. The split air conditioning has emerged as the most popular option among HVAC technologies because of its effectiveness, adaptability, and simplicity of installation, for both heating and cooling requirements. The hydrofluorocarbon (HFC) refrigerant R410A has been the industry standard for contemporary air conditioning systems due to its zero-ozone depletion potential (ODP) and excellent energy efficiency [2]. Finding alternate solutions is necessary, though, as regulatory pressure to phase out high-GWP refrigerants has increased due to worries about its Global Warming Potential (GWP) of 2088 [2]. A low-GWP refrigerant called R32 has surfaced as a possible R410A substitute as part of the global transition to greener refrigerants. R32 is a desirable alternative for lessening the environmental impact of HVAC systems because of its much lower GWP of 675, which is almost one-third that of R410A [3]. R32 has a high latent heat of evaporation in addition to a lower GWP, which enhances heat exchange and energy consumption efficiency in a variety of environmental circumstances [4].

Recent studies have placed a great deal of emphasis on the effects of refrigerant on the environment, especially in relation to their GWP. Higher GWP levels indicate greater long-term environmental harm. GWP is a measure of a refrigerant's ability to contribute to global warming. There have been attempts to phase out R410A in favor of alternatives like R32 because of its GWP of 2088, which has been questioned for its role in climate change. R32 is a superior choice for lowering the carbon footprint of air conditioning systems because its GWP of 675 is much lower than that of R410A. Table 1 lists the basic properties for R32 and R410A [4]. The P-h diagrams of R32 and R410A are contrasted in figure 1. The latent heat of R32 is higher than that of R410A since it is readily apparent that the enthalpy difference between the saturation vapor and liquid lines of R32 is always greater than that of R410A. Because R32's isentropic line slope is likewise lower than R410A's, at the same pressure lift condition, R32's compressor electrical consumption per unit of mass flow rate is usually higher than R410A's.

Table.1 A comparison for basic property between R32 and R410A [4].

Property	R32	R410A
Molecular weight [g/mol]	52	72.6
Composition	Pure fluid	R32/R125 (50/50wt.%)
Critical temperature [ºC]	78.1	72.1
Critical pressure [MPa]	5.78	4.93
Critical density [kg/m^3]	424.1	489
GWP	675	2088
Normal boiling point [ºC]	-51.7	-51.5

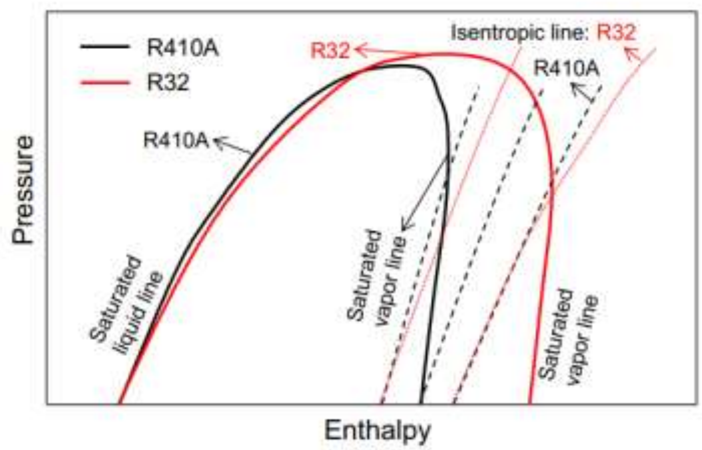


Fig.1; The P-h diagram for both R32 and R410A.

In Egypt's air conditioning (AC) market, R32 refrigerant has not been widely adopted. According to the "Cool Up Cooling Sector Status Report Egypt 2022," R32 and other natural refrigerants have not yet made a commercial appearance in Egypt [5]. The report ascribes this to problems with high operating pressures linked to specific natural refrigerants, as well as safety concerns about flammability and toxicity. In the Gulf Cooperation Council (GCC) region, which consists of nations including Saudi Arabia, the United Arab Emirates, Qatar, Kuwait, Oman, and Bahrain, Daikin debuted R32-based inverter air conditioning systems in 2015. Compared to conventional refrigerants, these systems provided high energy efficiency and a lower impact on global warming. Nevertheless, no precise information about the retrofitting or adoption rates of R32 systems in Egypt is currently available.

Compared to R410A, R32, a single-component refrigerant, has a number of benefits. R32 is more environmentally friendly due to its reduced GWP, which is one of its main advantages. Additionally, R32 has improved thermodynamic qualities, such as a higher latent heat of vaporization, which enhances system efficiency and performance. According to research, R32 systems can use up to 10% less energy than R410A systems, especially in hotter climates [6]. According to Tian et al. [6], switching from R410A to R32 air conditioning systems improved cooling performance by 7–9% in high-temperature environments, which are typical in the Middle East and some parts of Asia. In a similar vein, Lopez et al. [7] verified that R32 systems outperformed R410A in terms of Coefficients of Performance (COP), resulting in lower energy usage for the same heating or cooling output.

There were more studies focused on the pressure drop, heat transfer coefficient and two phase flow using R32 and R410A [8], [9], [10], [11], [12].Daisuke et al. [13]explored the pressure drop and condensation heat transfer performance used R134A, R32, R12134zw(E) and R410A. The heat exchanger was horizontal multiport tube. They concluded that the reduction in hydraulic diameter lead to an increase of frictional pressure drop. Song et al. [14]compared the performance of R290 and R32 as substitute refrigerants for R22 and R410A in a compact split home air conditioner equipped with a 5 mm finned tube heat exchanger. The findings showed that when compared to R22 and R410A, both R32 and R290 offer greater COP values in the cooling and heating modes.

Kabeel et al. [15] compared the performance of a vapor compression system to refrigerate a cold room using R134A and R1234ze. They concluded that R1234ze uses less power and has a higher COP than R134A in all situations. The cooling capability of R1234ze is roughly 2–13% less than that of R134a. Qiqi et al. [16] investigated experimentally and numerically R32/R92 mixture instead of R134a in air conditioner. According to experimental results, the heating and cooling capacities of R32/R290 are boosted by 14.0% to 23.7% while the refrigerant charge is decreased by 30.0% to 35.0%. Bachir et al. [17]examined R410A and R32 on the chiller performance theoretically. A simulation tool is used to compare the efficiency of the entire refrigeration unit running at full load and at seasonal efficiency in accordance with the European standard EN 14825. It was shown that R32 had a 5.7% greater cooling capacity than R410A. When employing the identical heat exchangers, the COP was about the same for both refrigerants, but the SEER for R32, as defined by EN 14825, is 2 to 3% higher.

Recent research focused on using different refrigerants as an alternative to R410, searching for a new refrigerant with lower GWP. Many research studies utilize R32 as a substitute to R410A due to its lower GWP. With an emphasis on the Egyptian market, which is known for its high ambient temperatures, this study examines the viability and provide guideline of converting current split air conditioning systems from R410A to R32. The purpose of the study is to evaluate R32's performance both before and after retrofitting in terms of energy consumption, cooling and heating capacity, and the Seasonal Energy Efficiency Ratio (SEER). The results will be used to assess if R32 can offer a more affordable and environmentally friendly substitute for R410A without sacrificing system functionality.

2. Experimental Method

This study presents a comparative analysis of the performance of two refrigerants, R410A and R32, in a split-type air conditioning system with a cooling capacity of 24,000 BTU/hr, manufactured by ELARABY under the Sharp brand. The results indicate that the system operating with R32 achieves a slightly higher coefficient of performance (COP) than the one using R410A. Furthermore, R32 demonstrates a greater refrigeration effect and lower compressor energy consumption compared to R410A. These findings suggest that R32 is a viable retrofit alternative to R410A, offering improved energy efficiency and reduced power consumption.

To systematically assess the performance of split air conditioning systems under varying environmental conditions, an air enthalpy method calorimeter laboratory was utilized. This approach highlights the necessity of evaluating air conditioning systems under dynamic and realistic operating conditions to ensure precise performance assessments. The laboratory setup facilitates the measurement of critical parameters, including temperature, pressure, and electrical performance, which are essential for determining cooling and heating capacities as well as overall system efficiency.

Designed to replicate actual working conditions, the air enthalpy method calorimeter laboratory provides a reliable and comprehensive platform for performance testing. It supports the evaluation of various air conditioning system types, including split-type, window-type, free-standing, ceiling cassette, and ducted units. All testing procedures comply with internationally recognized standards, ensuring the accuracy and comparability of the results with industry benchmarks. The standards adhered to in this study include **ISO 5151/2017** [18], **EN 14825** [19], **EN 14511** [20], **ISO16358** [21], **ES3795/2023** [22]. By following these standardized protocols, this study ensures a rigorous and consistent evaluation of air conditioning system performance, contributing to a more accurate assessment of energy efficiency and system effectiveness.

2.1 Test Chamber Setup

The test chamber regulates air temperature and humidity through a balanced adjustment mechanism. This process involves continuous operation of the refrigeration system for cooling and dehumidification. The dry bulb and wet bulb temperature control meters modulate the power output of the heater and humidifier, respectively, to regulate the heat and moisture introduced into the air. This approach ensures precise control over the desired air temperature and humidity levels within the chamber.

The experimental setup consists of two calorimeter test chambers: an indoor chamber and an outdoor chamber, separated by an insulated partition. The partition features opening where the non-ducted, single-packaged air conditioning equipment are installed. **Figure 1** provides a side view of the testing chambers. Each test chamber is equipped with reconditioning units, to maintain the required airflow and prescribed environmental conditions. These reconditioning systems ensure that the experimental parameters remain stable and consistent throughout the testing process.

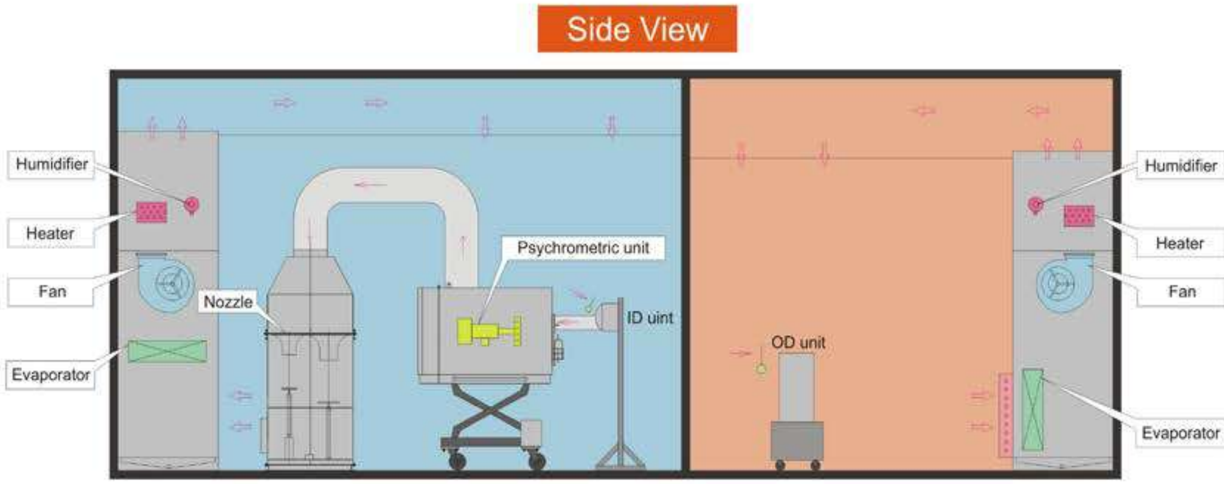


Fig.1: The Side View of Calorimeters rooms

2.2 Test Principle:

The evaluation of refrigerating capacity is based on the air enthalpy difference method, where thermal energy exchange is assessed on the indoor side of the system. The refrigerating capacity is determined using the following equation:

$$\Phi_c = \frac{q_{ml}(h_{a1} - h_{a2})}{V_n'(1 + W_n)} + q_0$$

(1) Where, Φc and q_{ml} denote the total refrigerating capacity (W) and the airflow rate of the air conditioning system (m^3/s), respectively. Also, h_{a1}, and h_{a2} represent the enthalpy values of air at the inlet and outlet, respectively (J/kg (dry)). Vn′ and Wn are the humid volume(m^3/kg) and the air humidity (kg/kg (dry)) at the test point, respectively, and q0 is a heat loss in the air volume device. Similarly, the heating capacity of a heat pump under steady-state conditions is evaluated using the air enthalpy difference approach, focusing on the indoor side conditions. The heating capacity is as follows:

$$\Phi_{hi} = \frac{q_{ml} C_{pa}(t_{a2} - t_{a1})}{V_n'(1 + W_n)} + q_0$$

(2) Where, Φ_{hi} and C_{pa} represent the heating capacity of the heat pump in the indoor space (W) and the specific heat capacity of air (J/kg.K (dry)), respectively, and t_{a1} and t_{a2} are the inlet and the outlet temperature of the air conditioner, respectivelly at the indoor space (°C). By implementing this methodology, the study ensures a reliable and standardized evaluation of the air conditioning system's performance under controlled environmental conditions.

2.3 Test Procedures:

The procedures are going through three main stations: preparing, testing and data collection. Before each test, the test chamber is prepared by setting the desired indoor and outdoor temperature and humidity levels. This ensures that the environmental conditions are consistent for each test. After that, the air conditioner is installed in the indoor chamber and connected to the outdoor chamber, simulating a real-world setup. The air conditioner is then turned on, and its performance is monitored over a predetermined period. Then, the performance of the air conditioner is assessed by measuring key parameters such as thermocouples temperature, air volume, total power consumption, Capacity and Coefficient of Performance (COP). These measurements are taken at regular intervals to ensure accurate data collection.

2.4 Working Conditions:

The Tests are done according to ISO5151:2017/AMD2020. After conducting the AC unit and waiting 35 minutes until the room temperatures became stable, the unit was run for 1 hour and start taking the data after another 35 minutes.

3. Results and Discussion:

All tests were carried out for heat pump system using R410A refrigerant and R32 refrigerant. The first test was conducted using R410A refrigerant. The second test was carried out using R32 at different ambient temperatures in summer 35, 43 and 46 °C respectively and 7 °C for winter.

Table 1; test setup cooling and heating ambient temperature according to (ISO5151:2017).

	Cooling			**Heating**	
	Test 1 at T_O=35 °C	**Test 2 at T_O =43 °C**	**Test 3 at T_O= 46 °C**	**Test 1 at T_O= 7 °C**	**Defrost Heating Test 2**
(Indoor) Inlet D.B	27°C	32°C	29°C	20°C	20°C
Inlet W. B	19°C	23°C	19°C	15°C	15°C
(Outdoor) Inlet D. B	35°C	43°C	46°C	7°C	2°C
Inlet W. B	24°C	26°C	24°C	6°C	1°C

Table 2: Test results for heat pump system using R410A and R32.

Refrigerant Type	R410A					R32				
Test Type	Cooling Capacity @35 °C	Cooling Capacity @43 °C	Cooling Capacity @46 °C	Heating Capacity @ 7 °C	Defrost Heating Capacity	Cooling Capacity @35 °C	Cooling Capacity @43 °C	Cooling Capacity @ 46 °C	Heating Capacity @ 7 °C	Defrost Heating Capacity
Refrigerant Volume (gm)	1609					1265				
Cooling Capacity (W)	6590.7	6167.52	5976	7681.9	5989.78	7003.9	6697.67	6249	7652.3	5635.86
Source total input (W)	2129.6	2616.1	2644	2354.6	2189.2	2008	2521.4	2595.4	2152.1	1946.8
COP (W/W)	3.09	2.36	2.26	3.26	2.74	3.49	2.66	2.40	3.56	2.89
EVA IN. T (°C)	9.8	11	-	33.1	27.3	9.8	10.9	-	32.1	25.3
COND OUT T (°C)	39.7	48.1	-	2.7	-2	37.7	47.3	-	5.8	0.8
Suction pipe (°C)	10.9	12.4	-	0.7	2.1	9.8	8.4	-	0.3	7.1
Discharge pipe (°C)	76.8	89.6	-	82.7	87.2	88.6	100.2	-	98.4	86.9
Suction pressure (kPa)	940	952	-	796	664	980	988	-	799	633
Discharge pressure (kPa)	2832	3402	-	3395	3152	2953	3527	-	3197	2729
Evaporating temp (°C)	5.2	5.7	-	-0.1	-5.6	5.96	6.23	-	-0.55	-7.59
Condensing temp (°C)	46.5	54.5	-	54.4	51.1	47.34	55.09	-	50.76	44
SH (°C)	5.7	6.7	-	0.8	3.5	3.8	2.2	-	0.9	0.5
SC (°C)	6.8	6.4	-	21.3	23.8	9.6	7.8	-	18.7	18.7
SEER	15.7					18				
Rank	S5					S7				

The testing for each refrigerant was carried out at the same time. Data was recorded after the steady state system, which was estimated to be 10 minutes after the operation of the system. These measurements were taken at regular intervals to ensure accurate data collection. The test data obtained as an example as shown in Table 2. Based on the output data from the experimental study that has been obtained, refrigeration effect, cooling capacity and system coefficient of performance (COP) are calculated for each experiment.

3.1 Effect of using R32 on the cooling capacity

Figure 2 illustrates the heating and cooling capacity for 24000 Btu/h heat pump using R410A and R 32 at different ambient conditions. In summer, it’s clear to see that cooling capacity decreases with increasing the outdoor temperature for both refrigerants due to decreasing the cooling effect of the heat pump. R32 has higher cooling capacity than R410A for different ambient temperatures owing to the high latent heat of R32 is than the R410A. Cooling capacity decreased by 10% for R410A and R32 at the maximum outdoor condition which represent the extreme weather for heat pump. Meanwhile, R32 has 6 % higher cooling capacity on average than R410A attributed to enthalpy difference between the saturation vapor and liquid lines of R32 which is greater than R410A in Ph charts. In contrast, in winter the heating capacity of R32 is less than R410A by 0.3% at 7 ^{o}C outdoor temperature and the same in the Defrost heating capacity by 6.3%.

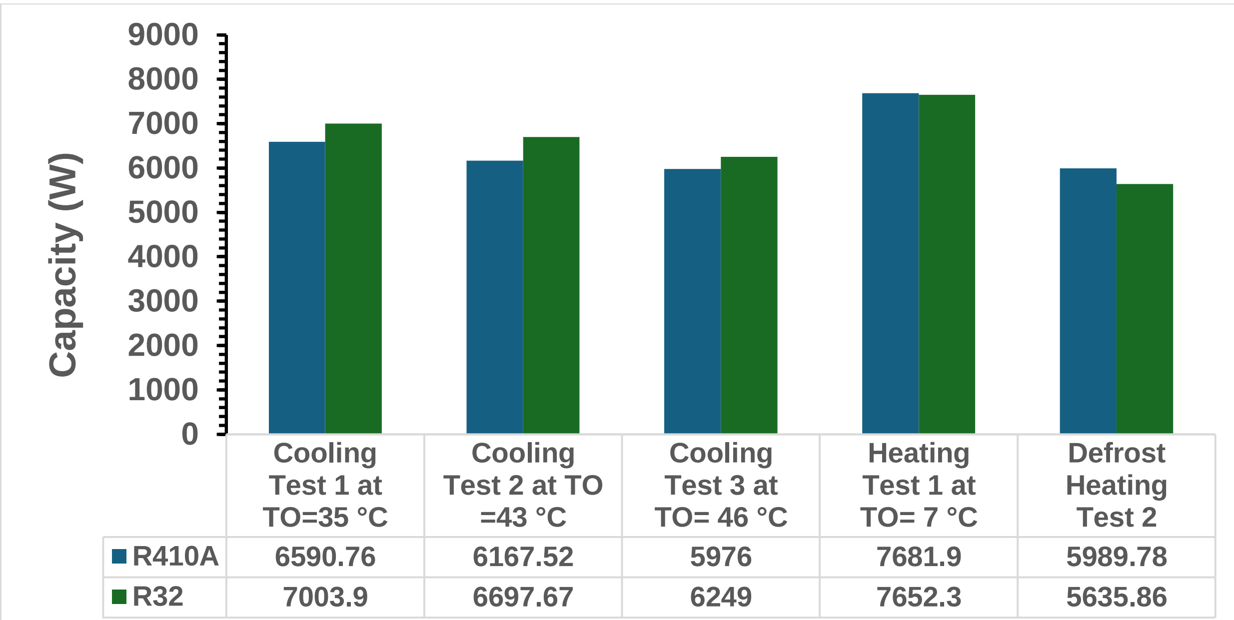


Fig. 2: The effect of different ambient temperatures on the cooling capacity for R410A and R32.

Figure 3 demonstrates the reduction of cooling capacity due to increasing of outdoor conditions for heat pump using R410A and R32. Overall, with the increase of the outdoor temperature, the cooling capacity decreased. According to ISO5151:2017/AMD2020, heat pump using R410A achieves 100% of the required cooling capacity of the unit. However, R32 records 6% cooling capacity higher than R410A. 10 % and 5.2 % reduction of cooling capacity in R410A and R32 Respectively due to lift up the cycle in the Ph Chart, which decreases the cooling effect of the cycle.

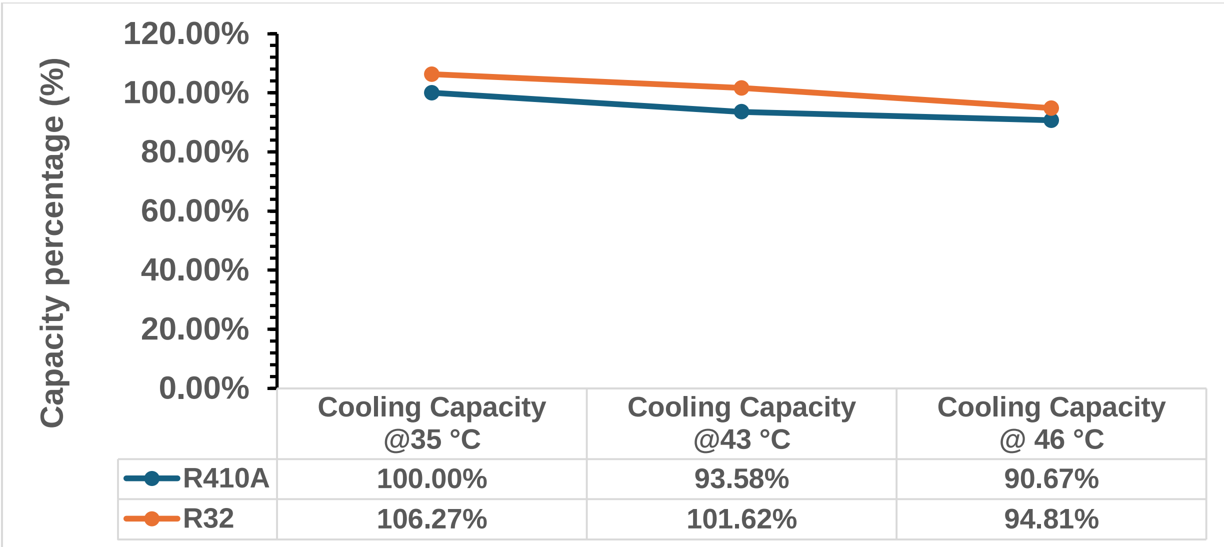


Fig. 3: The effect of different outdoor temperatures on the cooling capacity reduction for R410A and R32.

3.2 The effect of using R32 on the Power consumption of heat pump's compressor

Figure 4 shows the compressor power input of the heat pumps using R410A and R32. Power consumption of heat pumps increased with increasing the outdoor ambient temperature. Input power for heat pumps using R32 is less around 8 % than that used R410A attributed to the 13 % higher liquid and vapor densities of R410A compared to those of R32. Similarly, in winter the power input for the compressor using R32 is less by 9% than R410A owing to the decreasing of evaporation temperature of the condenser to 20 ^{O}C and condensation temperature to 7 ^{O}C. At defrost heating capacity at 2°C R410A also has a higher Power Consumption than R32 by around 12.5%.

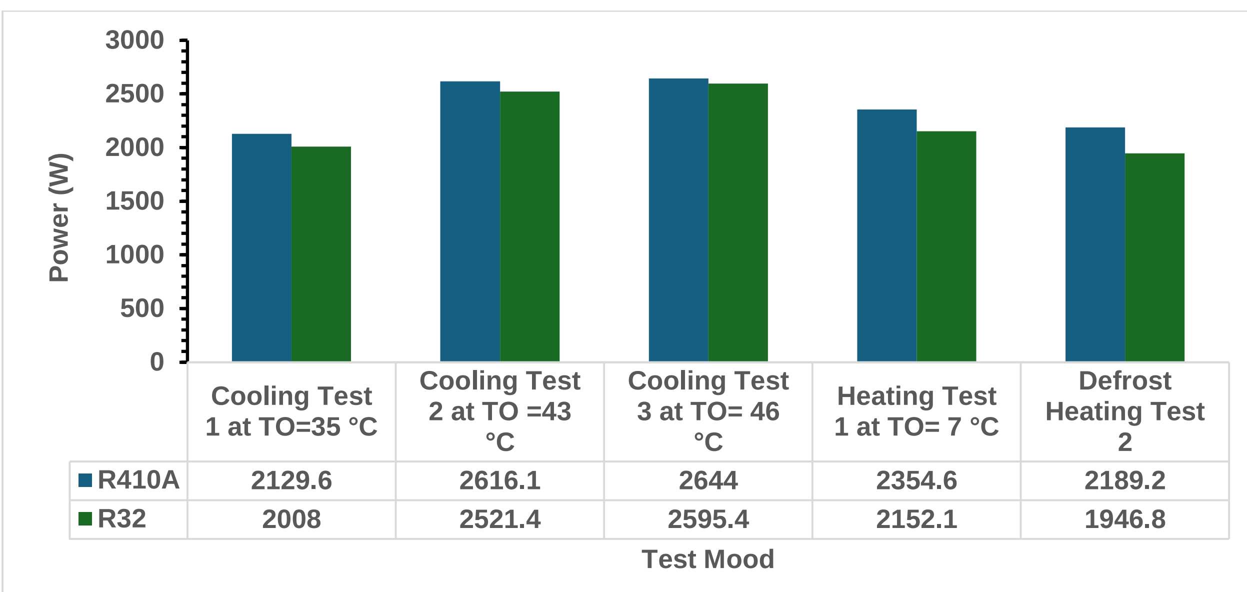
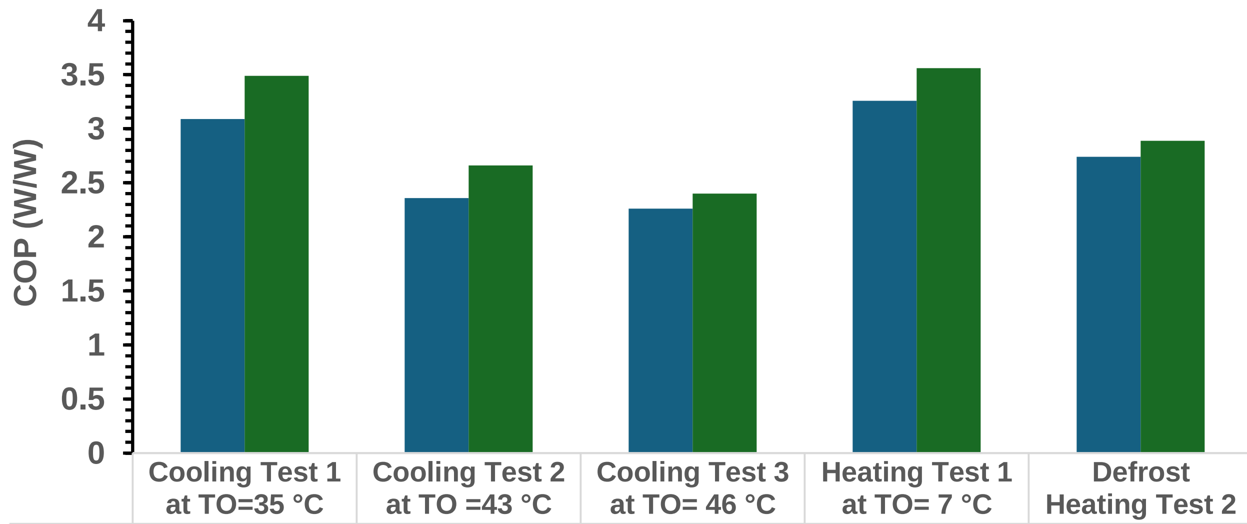


Fig.4 heat pumps' compressor power inputs using R410A and R32.

3.3 The effect of using R32 on the coefficient of Performance

Figure 5 shows the coefficient of performance of using R410A and R32 in heat pumps. The Coefficient of Performance (COP) are measures of a heat pump or heating and cooling solution's efficiency. They indicate a ratio of useful heating or cooling produced by the unit against the energy it consumes at a given operating point. With the increase of the external outdoor temperature, the cooling COP of the heat pump reduced gradually. The maximum COP for R32 and R 410A at 35 ^{O}C ambient temperature was 3.49 and 3.09 respectively, which was 33 % higher than that for maximum ambient temperature. Because the Capacity of R32 is higher than R410A in average 5.1% in all experiments at different outdoor temperatures, while the input power 9% lower. Therefore, R32 has a much better COP than R410A.



	Cooling Test 1 at TO=35 °C	Cooling Test 2 at TO =43 °C	Cooling Test 3 at TO= 46 °C	Heating Test 1 at TO= 7 °C	Defrost Heating Test 2
R410A	3.09	2.36	2.26	3.26	2.74
R32	3.49	2.66	2.40	3.56	2.89

Fig. 5 effect of using R410A and R32 on heat pumps performance.

3.4 The effect of using R32 on the Seasonal Energy Efficiency Ratio

The Seasonal Energy Efficiency Ratio (SEER) is the ratio of the total cooling of the heat pump to the total electrical energy input during the same period of varying weather conditions. The SEER of R32 is 14.3 % higher than that of R410A, indicating superior energy efficiency due to higher cooling effect of R32 than R 410A. Furthermore, the lower density of R32 and its charge quantity is 21% lower than that of R410A led to decreasing the input power of the compressor. According to the Egyptian standard ES 3795/2023, R32 is classified under the S7 rank, which represents the highest level of efficiency. In contrast, R410A falls under the S5 rank, reflecting its comparatively lower efficiency. This distinction underscores R32's advantage in terms of energy savings and environmental sustainability.

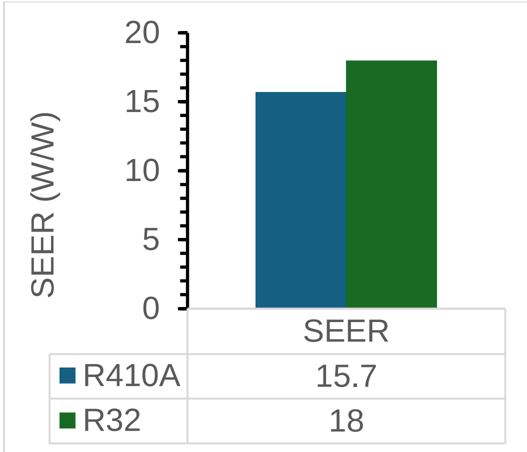


Fig. 6 The Seasonal Energy Efficiency Ratio for heat pumps using R410A and R32.

3.5 P-h diagram for heat pump using R32 and R410A

Table 3 provides a systematic comparison of the operational parameters of R410A and R32 refrigerants, explaining their efficiency and performance under various temperature settings. At 35°C, R410A shows specific pressure and enthalpy values that differ from those of R32 at 6°C, highlighting the performance characteristics of each refrigerant. The following graph demonstrates variations in thermodynamic properties, facilitating in the selection of appropriate refrigerants for certain applications.

Table 3: Comprehensive comparison between R410A and R32 at the two outside temperatures of 35 and 43 degrees

		R410A		R32	
		COOL RATED 35	**COOL MAX 43**	**COOL RATED 35**	**COOL MAX 43**
Capacity total	W	6590.76	6167.52	7003.9	6697.67
TOTAL INPUT	W	2129.6	2616.1	2008	2521.4
EVA IN	degC	9.8	11	9.8	10.9
Cond Out TOTAL	degC	39.7	48.1	37.7	47.3
Suction pipe	degC	10.9	12.4	9.8	8.4
Discharge pipe	degC	76.8	89.6	88.6	100.2
DIS .Pressure	Kpa-abs	2832	3402	2953	3527
SUC. Pressure	Kpa-abs	940	952	980	988
Condensating Temp	degC	46.5	54.5	47.34	55.09
Evaporating Temp	degC	5.2	5.7	5.96	6.23
SH	degC	5.7	6.7	3.8	2.2
SC	degC	6.8	6.4	9.6	7.8

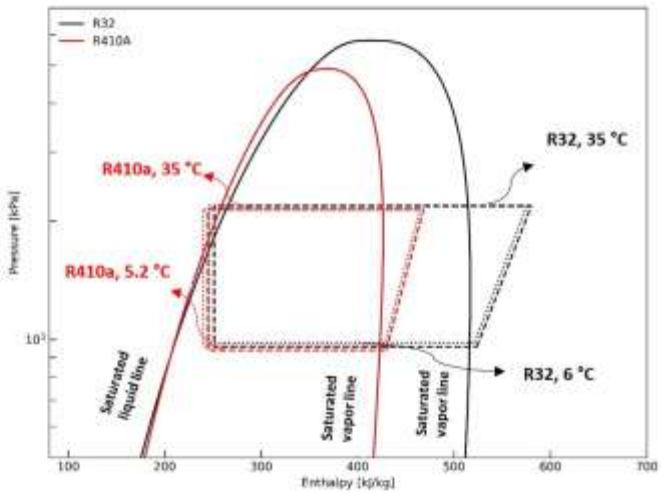


Fig. 7: Comparative analysis of single-stage cycles for R32 and R410A in the p-h diagram

R32 indicates a cooling capacity around 6.27% more than R410A at 35°C. Similarly, as shown in Figure 7 and demonstrated in Table 3, R32's cooling capacity at 43°C exceeds R410A by around 8%; at 46°C, it is greater by roughly 4.6%. At 35°C cooling capacity, R410A has a 6.1% greater power consumption than R32; the difference increases with temperature.

Conclusions

From the experimental study it can be concluded that the Refrigerants R410A and R32 were tested on a split air conditioning system of capacity 24000 BTU/hr according to ISO 5151 standard. Using R32 instead for R410A decreases the charge quantity by 21% lower than utilize R410A which contributes to a lower environmental impact. In addition, decreased charge requirement reduces the overall refrigerant emissions, enhancing sustainability and making R32 a more environmentally friendly alternative compared to R410A. At standard global temperature R32 offers 6 % increase in cooling capacity higher than R410A. in contrast, the cooling capacity reduced by 5 % and 10 % for R32 and R410A respectively at maximum outdoor temperatures. Using R32 have highly impact on increasing the COP and SEER of the split air conditioning system by 12.9 and 14.3 % respectively

Nomenclature

AC	Air conditioning	CSPF	Cooling seasonal power factor
EER	Energy efficiency ratio	CSTL	Cooling seasonal total load
SEER	Seasonal energy efficiency ratio	CSEC	Cooling seasonal energy consumption
Q_{tot}	Total cooling capacity	W_{in}	Input power
Q_s	Sensible cooling capacity	ϕ_{tci}	total cooling capacity, indoor-side
Q_l	Latent cooling capacity	ϕ_{hi}	total heating capacity, indoor-side
L	Latent heat		
$m^{\cdot}$	Mass flow rate		

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