J Ther Eng, Vol. 11, No. 1, pp. 40−48, January, 2025

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000902

Research Article

Exploring low-GWP refrigerants for enhanced domestic refrigerator performance: A comprehensive investigation

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ARTICLE INFO

Article history
Received: 24 July 2023
Revised: 12 February 2024
Accepted: 14 February 2024

Keywords:
Domestic Refrigerator; HFC-134a; HFC 1234yf; R152a

ABSTRACT

Our present investigation mainly focus on to identify the most appropriate refrigerants from various groups for replacing HFC-134a in a household refrigerator. The study involved conducting experiments using refrigerants from three different groups: Hydrofluoroolefin (HFO), Hydrofluorocarbon (HFC), and Hydrocarbon (HC). Among the tested refrigerants, R152a from the HFC group and HFC 1234yf from the HFO group showed the most potential. Compared to HFC-134a, both R152a and HFC 1234yf shows a reduction in refrigerating effect by approximately 4-7% and less power consumption in the compressor by around 5-7%.In conclusion, for replacing HFC-134a in a domestic refrigerator without needing alterations to the existing refrigeration system, two recommendable refrigerants are R152a and HFC 1234yf. These refrigerants are considered eco-friendly with zero ozone depletion potential (ODP) and low global warming potential (GWP) values.

Cite this article as: Shaik MH, Kolla S, Sairam YNV. Exploring low-GWP refrigerants for enhanced domestic refrigerator performance: A comprehensive investigation. J Ther Eng 2025;11(1):40−48.

INTRODUCTION

The vital function of the ozone layer is to safeguard the environment by absorbing ultraviolet radiation emitted by the sun. Depletion of the ozone layer carries severe repercussions, directly affecting both human health and agriculture. Conditions like skin cancer and cataracts have been associated with the diminishing ozone shield, while there exists a potential threat to agricultural crops. In the 1970s, scientists identified the issue of ozone layer depletion. This phenomenon involves a significant and rapid reduction in the Earth's stratospheric ozone, estimated at approximately 4% per decade on a global scale [1]. The artificial "ozone hole" observed in the Polar Regions was satisfactorily explained by the Molina-Rowland hypothesis [2]. According to this hypothesis, halocarbon refrigerants are carried to the lower stratosphere, where they catalyze the depletion of ozone [3]. By the scientific community's advice, the Montreal protocol came into force on January 1, 1989. According to the Montreal Protocol, priority was placed on reducing the use of substances with high Ozone Depletion Potential (ODP). The primary focus was on addressing agents that contribute to ozone layer depletion. All countries around the world have ratified the agreement,

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University Press, İstanbul, Turkey

setting specific targets to reduce the use of CFCs and Hydro-chloro-fluoro-carbons (HCFCs), as one mole of CFC can destroy 100,000 ozone molecules [4]. The initial goal was to cut CFCs and halogens to 80% of their 1986 levels by 1994, with a further reduction to 50% by 1999. The complete phase-out of CFCs, carbon tetrachloride, and halogens was extended to 2010, while the deadline for eliminating methyl chloroform and methyl bromide was pushed to 2015. The total phase-out of HCFCs is set for 2040.

India currently relies on HC-based refrigerants like R134a, R22, and R717 for refrigeration and air conditioning. Since 2002, CFC refrigerants have been banned in new systems. Refrigerant choice is driven by cost, availability of refrigerants like R717 and R134a being cheaper. However, certain HC and HFC blends like R410a, R407, and R404a are not produced locally and must be imported, increasing costs and potentially hindering the growth of the refrigeration industry in India.

In the past, the replacement of refrigerant R12 in domestic refrigerators involved considering the use of refrigerant R134a from the HFC (Hydrofluorocarbon) group, which was believed to be a more suitable substitute. However, it has been noticed that R134a contributes significantly to global warming due to the presence of fluorine in its atomic structure. As a result, R134a is a good choice used for reduction of ozone layer depletion with a significant impact on climate change. The emission of greenhouse gases has unpredictable effects on the Earth's thermal balance, leading to an increase in ambient temperatures. Moreover, HFC refrigerants exhibit a high GWP when compared to CO_2. For instance, releasing 1 kg of Hydrofluorocarbon gas into the atmosphere can cause adverse conditions 1000 to 3000 times greater than releasing 1 kg of CO2. This underscores the urgency of addressing the use of such refrigerants and adopting more environmental friendly alternatives. Upon careful analysis of refrigerants across different groups, it has been determined that the following alternatives can be used as substitutes for HFC-134a.

- HFO - HFC 1234yf
- HFC- 152a (Difluoroethane)
- HC - Propane (R290), Iso-butane (R600a).

Among hydrofluoroolefins (HFOs), those derived from the three-carbon compound propylene have boiling points that make them ideal for refrigerants, leading to significant development in this area. As fluorine atoms replace hydrogen atoms on propene, the flammability of the compound decreases. For example, HFO-1234yf is notably difficult to ignite, and its flame is unstable, making it easily extinguishable. This refrigerant is now widely used in new automotive air-conditioning systems and is expected to become nearly universal in the EU, United States, India, and Japan in the near future. However, R-152a has a higher discharge temperature, which can affect the motor coil and the properties of lubricating oil within a compressor. So care should be taken while using R-152a in domestic refrigeration system. R290, R600a does not show any significant chemical effects on the compressor and other components of refrigeration system [24]. R134a and other identified refrigerants important properties are depicted in Table 1.

P. Saji Raveendran (2022) [7] studied and reported the performance of R1234yf/R134a in a home refrigerator through mathematical simulation. The result indicates that up to 10% of R134a can now remain below 150, the GWP of the mixture. The R1234yf blend COPs are lower than R134a and approximately 8% and 3% higher than R1234yf. The R1234yf blend is good replacement for R134a in domestic refrigeration system. In his 2016 review article, Adrián Mota-Babiloni et al. [8] presented an analysis of the thermophysical properties, compatibility, heat transfer, pressure drop characteristics, and vapor compression system performance of R1234ze(E).They distinguished between studies that investigated the use of pure R1234ze(E) and blends involving this refrigerant. The findings of the study indicate that pure R1234ze(E) is a viable choice primarily for new HVACR systems. However, when R1234ze(E) is used in combination with other refrigerants, the resulting global warming potential (GWP) is significantly reduced, while still maintaining efficiency parameters at levels that enable its substitution for R134a, R404A, or R410A in existing systems with minimal modifications.

Bolaji et al. [9-11] conducted an analysis of household refrigerator performance using refrigerants R12, R32, and

Table 1. Properties of Different Refrigerants [6]

Characteristics	R134a	HFC 1234yf	R152a	R290	R600a
Safety group	A1	A2L	A2	A3	A3
Toxicity	NO	NO	NO	NO	NO
Critical temperature (0C)	101.01	94.7	113.3	96.8	135
Boiling point (0C)	- 26.1	-29	-24.02	-42.1	-11.67
Liquid density at 298 K (kg/m^3)	1206.7	1092	899.85	492.6	550.84
Vapor density at 298 K (kg/m^3)	32.35	37.94	18.387	20.53	9.087
ODP	0	0	0	0	0
GWP	1430	4	120	20	20

R152a as potential replacements for R134a. The study revealed that the coefficient of performance (COP) was 4.7% higher with HFC-152a compared to HFC-134a, while it was 8.5% lower with R32 in comparison to HFC-134a. Overall, the performance of the home refrigerator was found to be superior when using refrigerant R152a in comparison to HFC-134a and R32, indicating it to be a preferable alternative in household refrigerators instead of R134a. Bryson et.al [12] experimented with refrigerant R152a, using an open-type compressor equipped with adjustable speed and a throttle valve. The results showed that R152a increased the cooling effect by 3% and also improved the COP by 10% compared to R134a.

Thermodynamic analysis was conducted by Mohammad Hasheer et.al. [13] Using Hydrofluoroolefins group refrigerants, namely HFO1234yf, HFO1234ze (E) and a combination of them such as R450A, R513A and HFC134a in a Vapour compression refrigeration (VCR) system. Based on the results, it was understood that power consumption remains the same with all those refrigerants against HFC134a. However, the refrigerant HFO1234ze(E) has a negligible change in refrigeration effect. Karber et al. [14] also performed experiments with HFC-134a and with the same refrigerants from HFO group. The experimental results revealed that, as compared with HFC-134a the power consumption was higher with refrigerant HFO-1234yf and lower with refrigerant HFO-1234ze (E). However, the obtained cooling capacity was less with HFO-1234ze (E) when compared with the remaining two refrigerants. Using a parallel flow condenser of microchannel type, Zhao et al. (2012) examined the performance of an automobile A/C system with refrigerants HFO-1234yf and R134a using a micro channel type parallel flow condenser [15]. The mass charge of HFC 1234yf has been diminished by roughly 5%, contrasted with HFC-134a. The refrigerating capacity was reduced by 12.4% and COP was increased by 9% when compared with HFC-134a due to different thermophysical properties of refrigerant HFO-1234yf.

Farooq et al. (2020) [16] conducted a theoretical analysis on HFO refrigerant R-1234ze and found that its refrigeration effect dropped by only 14.6% compared to R-134a at a 12-bar condenser pressure, the smallest decrease among the refrigerants studied. The COP for R-1234ze(Z) also showed minimal reduction, just 5.1% less than R-134a at a 9-bar condenser pressure and 4.7% less at a 1.9-bar evaporator pressure, while other refrigerants experienced more significant drops at higher condenser pressures.

Theoretical analysis was carried out on domestic refrigerator by Mohan raj (2013) [17] to study the energy efficiency with refrigerant R430A in view of replacing HFC-134a.The performance was assessed at different condensing temperatures with an extensive range of temperatures between -300C and 00C for the evaporator. At all operating temperatures R430A showed 2.6 to 7.5% higher COP than that of R134a, with a lower power utilization approximately 1-9%. It was concluded that R430a was environmentally friendly refrigerant and energy efficient when compared to R134a.

Daviran et al. (2017) [18] found that HFC 1234yf gave higher energy efficiency in an air-conditioning plant than HFC-134a. Kashif Nawaz et al. (2017) [19] conducted an investigation with refrigerants HFC 1234yf , and HFO-1234ze(E), and compared the COP of these two refrigerants with HFC-134a. It was concluded that they can be used directly in heat pump applications without any modifications. A hypothetical study was carried out by various authors using low GWP refrigerants with the aim of replacing HFC-134a in a refrigerator [20]. It was observed that the performance was improved by providing a liquid suction heat exchanger (LSHX), hence concluded that two refrigerants R152a and HFC 1234yf could be used as better substitutes for R134a in a household refrigerator.

Meng et al. [21] studied the air-cooling system of an automobile using HFC-134a and a blend of HFC and HFO refrigerants (HFC-1234yf/R134a in an 89:11 mass ratio). The new blend was found to have 5-15% lower COP in heating mode and 5-10% lower in cooling mode. Hasheer et.al (2019) [22] conducted a theoretical investigation with various refrigerant mixtures in a VCR system, showing that a 50:50 mix of R152A and HFO-1234ze (E) could replace HFC-134a without requiring changes to the compressor. Shaik et al. [23] conducted an exergy analysis with different refrigerants in the VCR system to replace R134a. From that theoretical investigation, it was observed that the refrigerants R152a and HFC 1234yf could be successfully used in place of R134a in a domestic refrigerator. A. Shaayan et al. [25] analyzed the synthesis mechanism, morphology, and magnetic properties of pure barium ferrite. They found that its single-domain nature increased coercivity by creating a barrier against domain wall movement. Hasheer et al. [26] conducted a theoretical analysis of refrigerants R1234yf, R152a, and HFC/HFO mixtures, such as ARM42 (8.5/14/77.5 by mass) and ARM42a (7/11/82 by mass), as replacements for HFC-134a in domestic refrigerators. Among the three, ARM42 had the lowest cooling capacity, while ARM42a's performance was nearly identical to R134a.Despite such extensive investigations on the domestic refrigerator, a literature review reveals the following:

i. The usage of refrigerants from the HFO group was not tried
ii. The usage of a combination of the refrigerants from two or three groups was also not tried.
iii. Not much experiment work was carried out on the refrigerator using LSHX.

The novelty of the present work is focused on the study of the properties of refrigerants from various groups which are having low GWP and zero ODP values or that are nearer to R134a in the perspective of replacement to R134a with them followed by performance evaluation of a domestic refrigerator has been carried out experimentally with and without use of LSHX.

EXPERIMENTAL STUDY

In the first phase, tests were conducted on a domestic refrigerator with conventional HFC group refrigerant R134a at two different condenser temperatures by varying evaporator temperature. Various performance parameters like cooling effect, work input and COP were evaluated. In the next phase of research work, two refrigerants R290 and R600a from the HC group, a refrigerant R152a from the HFC group and a refrigerant HFC 1234yf from HFO group were selected and the tests were conducted at the same conditions. The performance parameters were evaluated and plots were drawn.

Filling of a Refrigerant

The entire system was cleaned and flushed with N2 gas before charging with refrigerants so that it is free from impurities and air. The vacuum is maintained at 0.1 millibars. The gas cylinders of refrigerant were immersed in ice bath at low temperature. This action avoids the build-up of pressure during the charging process. Because R600a has a lower vapor pressure when compared with R290, the refrigerator should be filled with R600a first with the required quantity and then R290 should be filled. The density of HC refrigerant mixtures was inferior to that of refrigerant HFC-134a. Due to their low density, the quantity of charge required is low compared to HFC-134a. The central idea of this research is to select suitable refrigerants from different groups and their combinations if possible, to substitute for the R134a in a household refrigeration system.

Experimental Setup

The test facility attached to the 190-liter capacity household refrigerator for doing experiments is depicted in Figure 1a. and 1b depicts the schematic layout of experimental study. The investigation setup consists of a hermetically sealed compressor of the reciprocating type, an air-cooled condenser with wire mesh, a capillary tube expansion valve, along an evaporator. The whole system is designed to operate on a single stage with refrigerant R134a and different refrigerants. The experiments in this study were conducted in a laboratory using a vapor compression system, as shown in Figure 1a. The system includes a fixed-speed reciprocating compressor and finned tube heat exchangers serving as the evaporator and condenser coils. A capillary expansion valve was used as the expansion device for both R134a and HFC-1234yf refrigerants. All tests took place in environmental chambers, equipped with instruments to measure refrigerant parameters. The pressure and temperature at various points in the system were recorded using four thermocouple sensors and two piezoelectric pressure gauges. The thermodynamic properties of the refrigerants were calculated using REFPROP software.

The compressor is provided with ports to admit and remove the refrigerant during service. First, moisture has to be removed from the system with the help of a service port. Then, the air, water, impurities, and other materials that may affect the system's performance were removed by flushing with nitrogen. Finally, by vacuums pump, the system is evacuated and charged with the refrigerant using charging system to a pressure of 30 mm of Hg. Two pressure gauges were installed. The compressor has a capacity of 4.2 cm^3 operated with a power supply of 50Hz. Refrigerant R134a was used with this system, and Polyolester oil of 350 ml used as lubricating oil. The same lubricating oil was used while tested with different refrigerants based on computability information provided in the literature. Experiments were conducted from the obtained data, various performance parameters of the household refrigerator were calculated. Table 2 gives the information about the specifications of the refrigerator. The most promising refrigerants used in this experimental work, along with operating conditions, are presented in Table 3:

Table 2. Technical specifications of domestic refrigerator test unit

Refrigerant type	R134a
Voltage	220-240V
Frequency	50Hz
Current rating	1.1 A
Storage Volume	190L
Displacement	4.2cc
Capillary tube length	3.35m

Table 3. Refrigerants used in the experimentation with operating conditions

Refrigerant		LSHX	Te(°C)	TC (°C)
R134a			-10	
R152a	R290	With and	0	
R600a		Without	10	32.5 & 40
HFC-1234yf		LSHX	15	

The Pressure vs. Enthalpy diagram of the VCR cycle, including pressure losses, is shown in Figure 2. In this analysis, the compressor takes in the refrigerant as a superheated vapor, compresses it to a higher pressure, and then directs it to the condenser. Pressure losses occur within the condenser, and by the end, the refrigerant is in a liquid state. The refrigerant then flows to the expansion valve, where the pressure is reduced, and finally moves to the evaporator. The refrigerant enters the compressor again as superheated vapor. Pressure losses occur in the suction line (evaporator line) to the compressor and the discharge line from the condenser.

Experiments were repeated using different refrigerants from various groups and with R134a and experimental data were obtained, like pressure and temperatures from the measurement devices installed in the experimental setup.

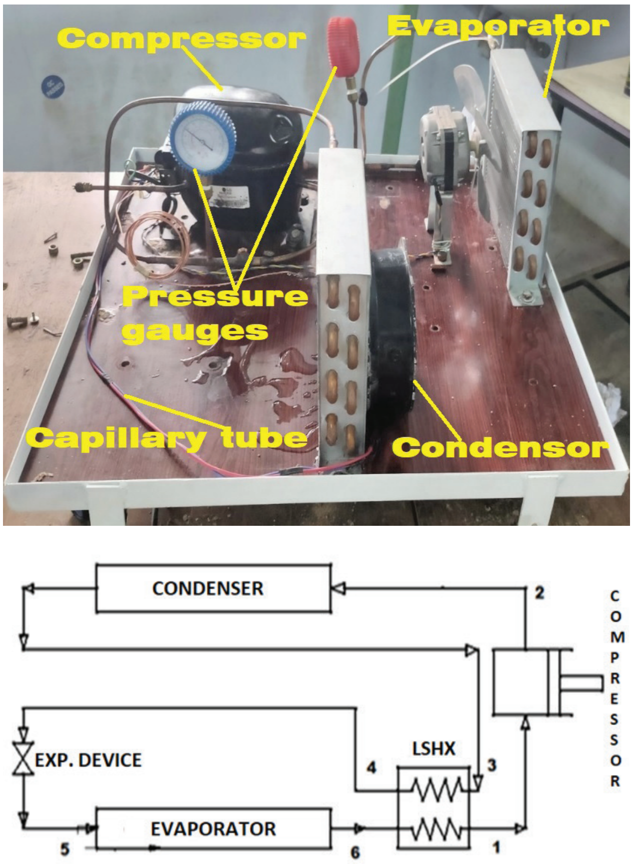

Figure 1. a) Refrigerator Test Rig, b) Schematic diagram.

From the measured variables data, enthalpy values at different salient points of the cycle were obtained from ASHRAE tables, which were inbuilt functions of REFPROP software.

Evaporator temperature ranges from -10^{0}C to 10 ^{0}C as provided by the manufacturer of compressor suitable for refrigerant R134a in domestic refrigeration applications. This temperature variation in the evaporator is obtained by regulating the quantity of air-operated through the blower. Sub-cooling of 3^{0}C to 8^{0}C is provided at the end of the condenser, and 5^{0}C to 12^{0}C of superheating was provided at the exit of the evaporator by controlling the capillary tube. The data is taken after equilibrium is arrived i.e., after 15 minutes. At the equlibrium conditions, the temperature and pressure variation allowed were 0.2^{0}C and 0.05 MPa, respectively. Moderate pressures are obtained for evaporator and condenser, between inlet and outlet and hence their temperatures are calculated. The performance parameters of a refrigerator and their calculations are shown as follows:

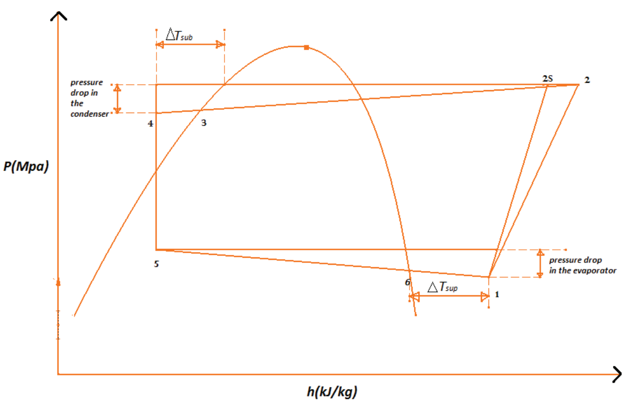

Figure 2. Pressure-enthalpy diagram.

Superheating at the evaporator is provided by

$$SH_{ev} = T_{ev,0} - T_{ev,sat} \tag{1}$$

Sub-cooling at the condenser is given by

$$SC_{cond} = T_{k,sat} - T_{k.0} \tag{2}$$

The Cooling capacity with LSHX is given by

$$\dot{Q}_c = \dot{m}_r Q_r = \dot{m}_r (h_6 - h_5) \ kW \tag{3}$$

The Cooling capacity without LSHX is given by

$$\dot{Q}_c = \dot{m}_r Q_r = \dot{m}_r (h_1 - h_5) \ kW \tag{4}$$

The Power consumption of a compressor can be calculated from

$$W_{comp} = \dot{m}_r (h_2 - h_1) \ kW \tag{5}$$

The mass flow rate of refrigerant can be calculated from [26]

$$m_r = RPM \times Vs \times \rho 1 \times \eta_{vol}/60 \tag{6}$$

The thermal effectiveness (ε_{lshx}) is given by

$$\varepsilon_{LSHX} = \left(\frac{(T_{ihx,o} - T_{ihx.i}) at \ ip}{(T_{ihx,o} - T_{ihx,i}) at \ hp} \right) \tag{7}$$

where $T_{ihx,o}$ means Temperature at internal heat exchanger at output

$T_{ihx,I}$ means Temperature at internal heat exchanger at input in both high pressure(hp) and low pressure(lp)

The refrigerator COP is given by

$$COP = \frac{cooling \ capacity}{Compressor \ power \ consumption} \tag{8}$$

$$COP = \frac{\dot{m}_r (h_6 - h_5)}{\dot{m}_r (h_2 - h_1)} = \frac{(h_6 - h_5)}{(h_2 - h_1)} \tag{9}$$

RESULTS AND DISCUSSION

An experimental investigation was conducted on the test setup developed in the lab. First, experiments were conducted with conventional refrigerant HFC-134a to have baseline data at two different condenser temperatures of 32.5 ^{0}C and 40 ^{0}C with changing evaporator temperatures from -10^{0}C to 10^{0}C. Next, experiments were repeated with all the refrigerants including LSHX, and without LSHX in the system. Based on the results plots were drawn for various performance parameters and discussed as follows:

Influence of Evaporator Temperature on Cooling Capacity

The variation of cooling capacity with evaporator temperature for different low GWP refrigerants with LSHX and without LSHX is shown in Figures 3 and 4, respectively. In both the cases, at a condenser temperature of 32.5°C and 40°C, it was found that the cooling capacities of R152a, HFO-1234yf and R600a were lower than those of R134a by around 5-7%, 5-8% and 40-43%. Similarly cooling capacity of R290 was more than R134a by about 35%. However, with the help of a liquid suction heat exchanger, there was an improvement in the cooling capacity.

Effect of Evaporator Temperature on Compressor Power Consumption

Figures 5 and 6 illustrate the variation in compressor power consumption with evaporator temperature for different low-GWP refrigerants, both with and without LSHX. For both cases, the average compressor power consumption of refrigerants R600a, R152a, and HFC-1234yf was approximately 35%, 7%, and 6% lower than that of R134a, respectively, at condenser temperatures of 32.5°C and 40°C. However, refrigerant R290 consumed about 52% more power than R134a at these temperatures. The plots also show that with LSHX, compressor power consumption

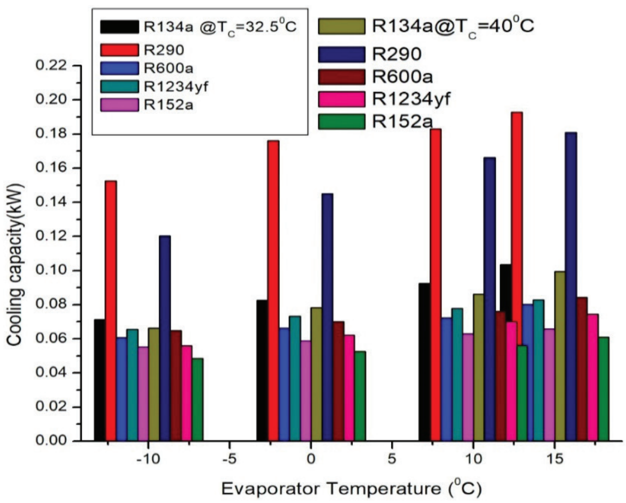

Figure 3. Cooling capacity vs. Evaporator temperature with LSHX.

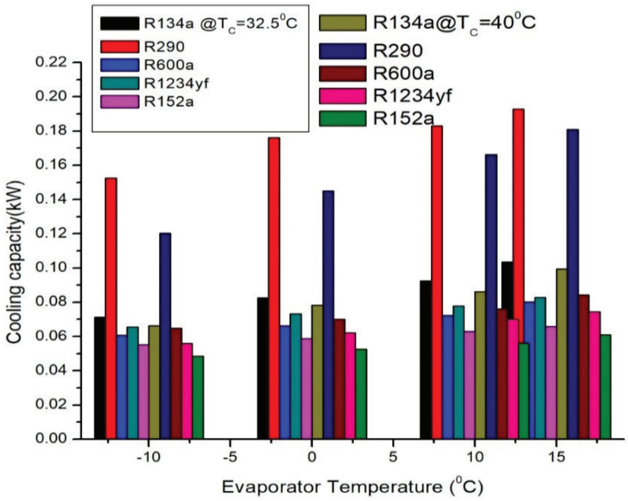

Figure 4. Cooling capacity vs. Evaporator temperature without LSHX.

increases by around 55% for all tested refrigerants compared to without it. While both the refrigerating effect and the work done increase with LSHX, the cooling effect is more pronounced than the rise in compressor power consumption. This increase in power usage is due to the higher refrigerant mass flow rate as the evaporator temperature rises.

Influence of Evaporator Temperature on COP

The variation of COP with evaporator temperature for different low GWP refrigerants with and without LSHX is portrayed in Figures 7 and 8, respectively. In both cases, at condenser temperature 32.50C, it was evident that the refrigerants both HFC 1234yf and R152 exhibits equal COP almost with R134a. However, refrigerant R290 showed COP more by 2-9%, and R600a showed COP less by 5-8% than R134a. The COP alteration among R152a and R134a and between HFC 1234yf and R134a increases with an

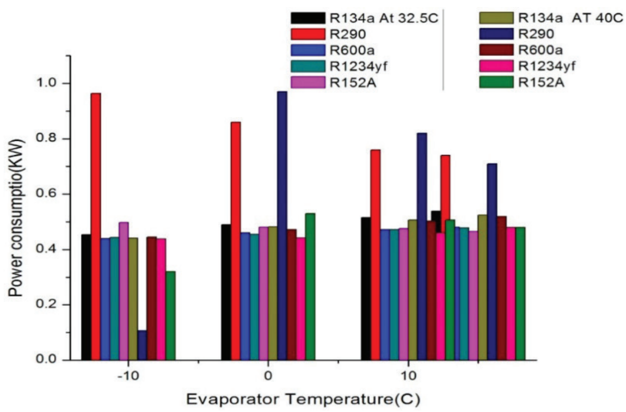

Figure 5. Compressor power consumption vs. Evaporator temperature with LSHX.

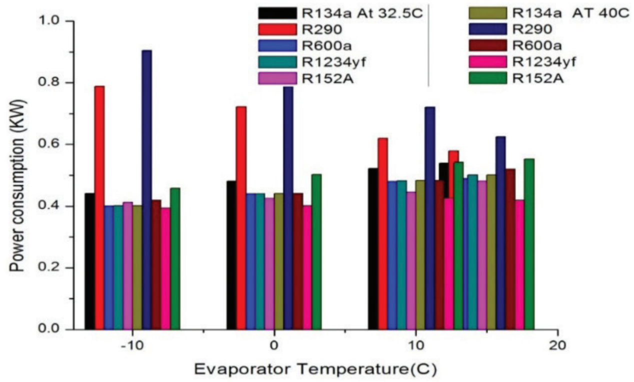

Figure 6. Compressor power consumption vs. Evaporator temperature without LSHX.

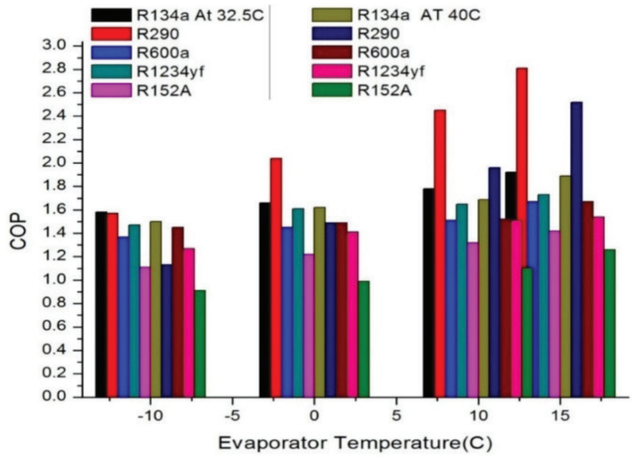

Figure 7. COP vs. Evaporator temperature with LSHX.

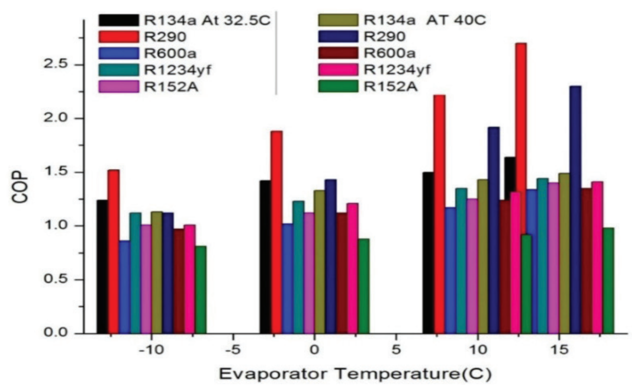

Figure 8. COP vs. Evaporator temperature without LSHX.

increase in condenser temperature because better COP can be expected with R152a and HFC 1234yf when compared with R290.

Percentage of Error Bars

The percentage variation of COP concerning Evaporator temperature for different refrigerants tested at condenser

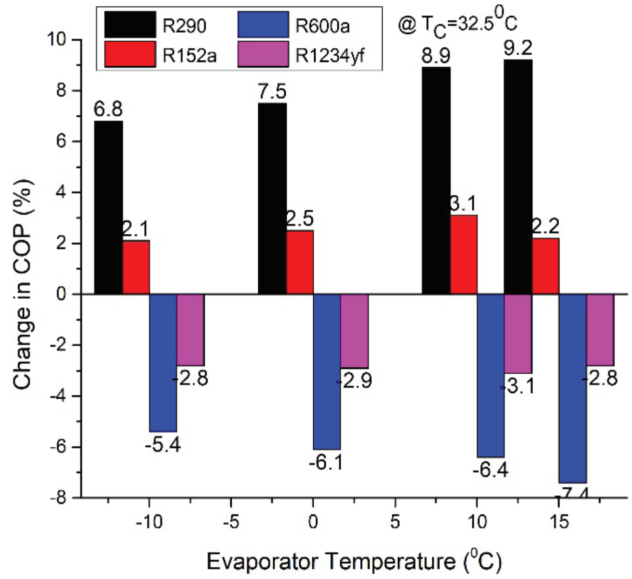

Figure 9. Change in COP (%) vs. Evaporator temperature (Tc= 32.5⁰C).

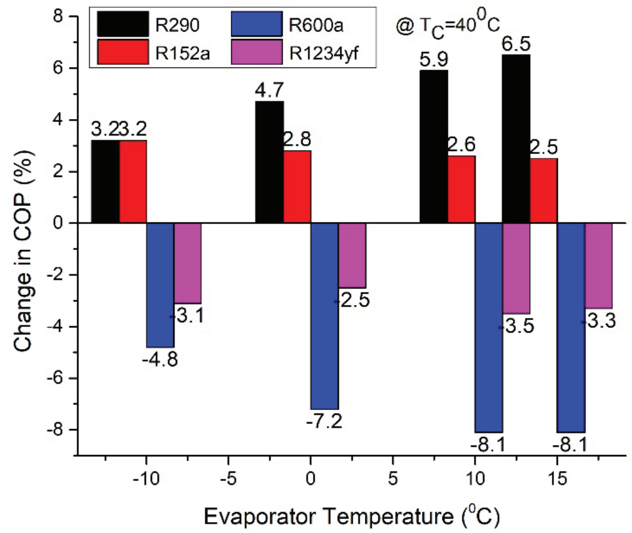

Figure 10. Change in COP (%) vs. Evaporator Temperature (Tc= 40⁰C).

temperature 32.5⁰C and 40 ⁰C is shown in Figures 9 and 10, respectively, in the form of Error bars. It can be observed that irrespective of the evaporator temperature, HC-290 or HFC-152a in place of HFC-134a improves the COP of the refrigeration facility.

For refrigerant R152a, the enhancement level ranges between 1.0% and 4.6%, whereas for R290, the increment records strike between 3.2% and 9.2%. However, it is coming to know that the improvement in COP is marginal at high-pressure ratios. In the case of refrigerants HC-600a and HFO-1234yf, the results revealed that there is a clear decline in COP when these refrigerants are used. The most significant reduction is disclosed by spending HC-600a with 9.2%. However, COP yields a decremental value when compared with HFC-134a with these refrigerants altogether.

CONCLUSION

The main aim of this research work is to select the most suitable refrigerants to replace R134a. It is coming to know that the main performance characteristics which should be considered for selection were found to be energy consumption of the compressor, refrigerating effect, COP, compressor discharge temperature etc., which are mainly depends upon condenser and evaporator temperatures. From the various experiments conducted, the following conclusions arrived from this research work.

- ➢ The experimental study revealed that evaporator temperature is the primary influence parameter that affects refrigerating effect and COP.
- ➢ For a given evaporator temperature, the refrigerating effect of the refrigerants R152a and HFC 1234yf was reduced by 5-7%, compared with R134a.
- ➢ The power consumed by the compressor with the refrigerants HFC-152a and HFO-1234yf was lower than that of HFC-134a by approximately 6-7% depending on the evaporator temperatures, due to higher latent heat of vaporization.
- ➢ The power consumption by the compressor increases with an increase in both evaporator and compressor temperatures.
- ➢ There is an improvement in the performance of a domestic refrigerator with the help of LSHX. However, the power consumption increased by using the LSHX.
- ➢ The COP of alternative refrigerants HFC-152a, HFO-1234yf showed small difference in value with HFC-134a.
- ➢ When the condenser temperature increases, the difference of COP value between the refrigerants R152a & R134a and HFC 1234yf & R134a was increased.

As a summary, it is concluded that the refrigerant R152a from the HFC group and refrigerant HFC 1234yf from the HFO group are the best refrigerants that can act as direct substitutes in place of HFC group refrigerant R134a in a domestic refrigerator without any modifications required to the prevailing system.

NOMENCLATURE

Qvol	Volumetric cooling capacity (kW/m^3)
Qc	Cooling capacity /Refrigeration effect (kW)
h	Specific enthalpy (kJ/kg)
m	Mass flow rate (kg/s)
v	Specific volume (m3/kg)
Vs	Swept volume of the Compressor (m^3/rev)
W	Energy required for Compressor (kW)
η	Efficiency (%)
ρ	density (kg/m^3)

Subscripts

1, 2, 3,4,5,6	state points
Comp	compressor
isen	isentropic
R	refrigerant
vol	volumetric

Acronym

CFC	Chlorofluorocarbon
HCFC	Hydro chlorofluorocarbon
HFO	Hydro-fluoroolefin
HC	Hydrocarbon
HFC	Hydrofluorocarbon
RPM	Revolutions per minute
A/C	Air conditioning
COP	Coefficient of performance
GWP	Global warming potential
LSHX	Liquid –suction heat exchanger
COP	Coefficient of performance
GWP	Global warming potential

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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