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Assessing Energy Performance and Environmental Impact of Low GWP Vapor Compression Chilled Water Systems

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Highlights:

- Comparative study of energy performance for a vapor compression chilled water using a new low GWP refrigerant (R1234ze), HFC refrigerants (R134a, R407C, and R410A), and the conventional HCFC22 refrigerant.
- Analyze the environmental impact of the different tested refrigerants and select the one with the lowest annual TEWI among them.

Abstract: The global concern regarding the environmental repercussions of refrigerants has escalated due to their adverse effects. These substances deplete the ozone layer and intensify the greenhouse effect. International agreements such as the Montreal and Kyoto Protocols and COP21 have imposed restrictions on refrigerants with high global warming potential (GWP) to address these issues. This study aims to explore the feasibility, energy efficiency, and environmental impact of utilizing the HFO (hydrofluoric-olefin) refrigerant R1234ze as a substitute for HFCs (hydrofluoric-carbon) (R134a, R407C, and R410A) and HCFCs (R22) in air-cooled vapor compression refrigeration and air conditioning systems. To determine their effectiveness, we evaluate the energy performance of various refrigerant operating cycles across a wide range of ambient and evaporating temperatures. Additionally, we conduct environmental impact analyses based on the total equivalent warming impact (TEWI) parameter calculated for commercially available chillers that utilize the fluids mentioned above. Our findings indicate that vapor compression chilled water systems employing R1234ze exhibit the highest performance coefficient and the lowest annual TEWI.

Keywords: vapor compression; refrigeration; refrigerants; environment impact; HFO

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1. Introduction

Air-cooled vapor compression chilled water systems (VCCW) are employed for comfort cooling in several facilities. The produced chilled water is provided to the cooling coil of the air handling unit [1,2]. These vapor compression refrigeration systems use refrigerants. Fluorocarbon refrigerants were first developed in 1930. The first CFC, R12 (CF_2Cl_2), was commercialized in 1931. The first HCFC, R22 (CHF_2Cl), entered the market in 1934. The first azeotropic mixture, R502, composed of R22 and R115, appeared in 1961. Installations (both industrial and commercial) dedicated to air conditioning still operate with the vapor compression cycle, with considerable energy consumption and a certain effect on the environment. For example, the vapor compression chiller in an office building consumes about 50% of the total energy absorbed by the air conditioning system [3].

Many works in the literature talk about vapor compression chilled water. Romero et al. [3] developed a model to accurately predict a vapor compression chiller's dynamic chilled water temperature response and adequately control the compressor speed. The model features several black box model structures to predict chilled water temperature. The results obtained by comparing the models' prediction and the experimental values show that the analyzed linear black box models are suitable for describing the behavior of the process and for predicting the dynamic response of chilled water. Lijuan et al. [4] introduced an absorption-compression refrigeration system consisting of a compression refrigeration subsystem utilizing R22 and an absorption refrigeration subsystem with Li–Br. The model of this integrated refrigeration system is based on the fundamental principles of energy and mass balance, ensuring that the mass flow rates in both the experimental and theoretical simulations of the refrigeration system are identical. The results obtained from the model demonstrate significant improvements over traditional systems. At a generation temperature of 80 °C, a cooling water temperature of 34 °C, and a chilled water temperature of 10 °C, the system achieves a coefficient of performance (COP) that is 2.56 times higher and a cooling capacity 1.9 times greater than conventional systems.

J. Ma et al. [5] performed an exergy analysis of a vapor compression refrigeration system operating under standard cooling conditions. The objective was to evaluate the thermodynamic variables of the system's main components. The analysis encompassed a range of commonly used refrigerants such as R12, R22, R134a, R152a, and R410A, as well as new-generation low global warming potential (GWP) refrigerants including R32, R1234yf, R1234ze(E), and two natural refrigerants: R600a and R744 (CO2). The analysis results indicated that R600a exhibited the best performance, followed by R152a, R1234ze(E), and R1234yf, regarding coefficient of performance (COP), total exergy destruction, and exergy efficiency. They focused on identifying technical challenges associated with applying model order reduction methods to the vapor compression cycle (VCC) and proposed corresponding solution approaches. They discussed different methodologies for stabilizing the system and highlighted the numerical efficiency of reduced-order models as part of their investigation.

Z. Li et al. [6] investigated and analyzed the thermodynamic relationship between subcooling power and increased cooling capacity. The study's authors paid particular attention to the concept of RICOSP (Ratio of the Rise in the Cooling Output to the Subcooling Power). This ratio is defined as the increase in cooling power divided by the subcooling power. As highlighted by Z. Li et al. [6], it is essential to note that the subcooling power cannot be entirely converted into increased cooling power due to factors such as compressor speed, inlet temperature, and water flow for cooling and chilled water. These factors remain the same for systems with and without subcooling. In a separate study by Grauberger et al. [7], who investigated the organic Rankine vapor compression cooling cycle utilizing the low global warming potential (GWP) refrigerant R1234ze(E), a thermal coefficient of performance (COP) of 0.56 was achieved. This COP was obtained for a pipe temperature of residual heat of 91°C and an outlet chilled water temperature of 7 °C.

Botticella et al. [8] conducted a comparative analysis of several Low-GWP refrigerants, such as R32, R290, R1234yf, R1234ze, XL41, and XL55, as potential alternatives to commonly used refrigerants (R410A, R407C, R134a). The comparison was based on criteria of energy performance (COP) and life cycle climate performance (LCCP). Yao et al. [9] studied the dynamic behavior of a vapor compression liquid chiller using R-134a to gain insight into the dynamic performance of a refrigeration system under transient conditions and to optimize the system. Finally, Mota–Babiloni et al. [10] focused on evaluating the energy performance of R1234yf and R1234ze(E) in a vapor compression system as a replacement for R134a. Two categories of simulations were analyzed (with and without an internal heat exchanger). The results of this study showed that the use of an internal heat exchanger reduced the differences in COP for both replacements.

Mendoza–Miranda et al. [11] conducted a comparative study using R1234yf, R1234ze(E), and R450A as substitutes for R134a. The results indicated a decrease in cooling capacity with R1234yf, R450A, and R1234ze(E) compared to R134a, and the COP of the replacement refrigerants was lower than that obtained with R134a. Mishra et al. [12] considered five alternative refrigerants (R32, R447A, R447B, R452B, and R454B) for an exergy analysis to find an alternative to the high global warming potential refrigerant R410A. The results focused more on R447A, a potential alternative to replace R410A in air conditioners. R447A exhibited a high COP, low exergy destruction, and superior exergetic efficiency at a condenser temperature of 60 °C compared to R410A. Cavallini et al. [13] evaluated the condensation circuit performance based on the refrigerants used and heat exchange efficiency in the circuit.

The refrigerants, such as CFCs, HCFCs, and HFCs, are potent greenhouse gases causing global warming. They have been included in the Kyoto Protocol (1997). Several authors have carried out work on the environmental impacts of refrigerants, especially Harnisch et al. [14] have evaluated the emissions contribution of halogenated greenhouse gases to climate change. They have discussed the estimated and projected halogen compound emissions in 1996, 2010, and 2020. Wu et al. [15] have studied the environmental impact of food transport refrigeration systems using the carbon footprint concept to evaluate their global warming impact. The developed model can be applied to mobile air-conditioning and other systems.

Zhao et al. [16] have used the life cycle carbon footprint method to evaluate the environmental impact of room air-conditioner refrigerants. Md.A. Islam et al. [17] have set up a mathematical model to analyze the energy performance and environmental impacts of refrigerants such as R12, R22, R134a, R152a, and R410A; new generation Low-GWP refrigerants R32, R1234yf, and R1234ze(E); and two natural refrigerants R600a and R744 (CO_2). The results indicate that the refrigeration system that uses R600a has the lowest amount of TEWI compared to other systems. On the other hand, the CO_2 system showed the highest amount of TEWI. The authors asserted that CO_2 could be considered a potential future refrigerant for its low emissions, affordability, availability, non-toxicity, non-flammability, and system compactness when nuclear/renewable sources power VCRS (Vapor Compression Refrigeration System). The VCRS model developed by Henrique de Paula et al. [18,19] showed, after TEWI analysis, the high environmental performance of R290 for an evaporation temperature of −3 °C and a gas condensation/cooling temperature of 45 °C. The authors claim that the system with R290 also exhibits higher exergy efficiency for the same thermodynamic conditions. According to Vuppaladadiyam et al. [20], theoretically, an ideal refrigerant should possess characteristics such as low global warming potential (GWP), non-toxic, non-flammable, and ozone depletion potential (ODP) null. Moreover, the refrigerants should also have excellent thermodynamic and thermophysical properties. Most of the commonly used refrigerants in air conditioning and refrigeration systems, such as R134a, R410A are going to be phased out, according to EU Regulation No 517/2014, because of their extensive utilization and their high GWP values [21,22].

Low-GWP refrigerants have been increasingly demanded in recent years due to the climate change that the planet is facing. Many works in the literature have used low-GWP refrigerants to improve energy performance or reduce the risk of toxicity and danger when using high-GWP refrigerants. HFO substances are proposed as alternative refrigerants. HFOs are synthetic fluids with a carbon–carbon double bond. They feature very low GWP values (under 10), non-toxicity, and low flammability. R1234yf was the first used in mobile air conditioning systems to replace R134a [23–25]. R1234ze is proposed in systems of medium-temperature applications [26]. R1243zf is still being studied [23].

Gonzalez et al. [27] estimated the atmospheric lifetime of R1243zf and its radiative efficiency to determine the GWP of this species. Mota–Babiloniet al. [28,29] have collected the most relevant research about R1234ze, pure or blended. Baomin Dai et al. [30] conducted a study investigating the thermodynamic performance of a heat pump water heater system that utilizes mixtures of carbon dioxide and low global warming potential (GWP) active fluids. The researchers in the study focused on conducting a detailed analysis of the effects of discharge pressure, component ratio, hot water outlet temperature, and chilled water inlet temperature on the coefficient of performance (COP) of the heat pump. The primary objective was to gain insights into how these factors impact the overall efficiency of the heat pump system. By studying the variations in discharge pressure, component ratio, hot water outlet temperature, and chilled water inlet temperature, the researchers aimed to understand their individual and combined effects on the COP of the heat pump. This analysis helps in identifying the key factors that significantly influence the performance and efficiency of the heat pump system, providing valuable information for system design and optimization. The CO_2/R41 and CO_2/R32 mixtures gave better results, regarding the COP and the operating pressure, compared to the case of a pure CO2 cycle. Mota–Babiloni et al. [29] and Mota–Babiloni et al. [31] claim that R454C and R455A may be the most viable low GWP options for directly replacing R404A due to their similar characteristics. The authors conducted experimental comparisons between R404A, R454C, and R455A using a specialized experimental device. This device used an internal heat exchanger, and the experiments were conducted at condensation temperatures that simulated operating conditions typically found in hot countries. The objective was to evaluate and compare the performance of these refrigerants under such conditions.

In their study, Henrique de Paula et al. [18] developed a steady-state model of a vapor compression refrigeration system (VCRS) that aimed to produce 1200 L of chilled water at 5 °C for an indirect expansion air conditioning system (IEACS) and 600 L of hot water at 40 °C for bathing purposes. The primary objective of their work was to design a VCRS with a compact structure. Additionally, they compared the environmental, energy, and exergy performances of refrigerants R290, R1234yf, and R744 with R134a. The results of the study indicated that the refrigerant charge required in the systems utilizing R744, R1234yf, and R134a was 102.4%, 126.9%, and 114.2% higher, respectively, compared to the system that utilized R290, for an evaporation temperature of −3 °C. This finding highlights the significant variations in refrigerant charge among the different refrigerants tested in the study. The study shed light on the potential implications of refrigerant selection on system design and performance.

Bo Shen et al. [32] evaluated refrigerants with lower global warming potentials as potential replacements for R-134a. The refrigerants considered in their analysis were R-1234yf, R-1234ze, R-290, R-513A, and R-450A. The primary objective was to assess the performance of these refrigerants in terms of the uniform energy factor (UEF). The study's results demonstrated that R-1234ze exhibited the best performance among the refrigerants, achieving a UEF value of 4.27. The UEF values for the other refrigerants (R-134a, R-290, R-1234yf, R-450A, and R-513A) ranged between 4.4 and 4.53. These findings highlight the superior performance of R-1234ze in terms of energy efficiency compared to the other refrigerants analyzed in the study.

Henrique de Paula et al. [19] presented a mathematical model of a vapor compression refrigeration system with low cooling capacity. The aim was to design an energy-efficient and cost-effective system that could operate with the most suitable environmentally friendly refrigerant. The focus was explicitly on R290, R600a, and R1234yf refrigerants. The authors conducted the environmental analysis using the Total Equivalent Warming Impact (TEWI) as the basis for evaluating the overall environmental impact of the system. Additionally, they performed thermo-economic analysis using the Coefficient of Performance (COP) and exergy efficiency (η exergy) to assess the system's performance and cost-effectiveness, respectively. Utilizing these different metrics, the study aimed to identify the most suitable ecological refrigerant that balances environmental impact, energy efficiency (COP), and exergy efficiency (η exergy) in the low cooling capacity vapor compression refrigeration system.

Mahmoudian et al. [33] improved the operation of a prototype ejector cooler using R1233zd(E). The choice of R1233zd(E) is due to its non-flammable, low GWP, and favorable thermodynamic properties, namely "dry expansion" and moderate generator pressure. According to the authors, R1233zd(E) is similar to R245fa (fluid previously used in the prototype) in terms of saturation pressure curve. Shaker Al-Sayyab et al. [34] conducted a comparative analysis of three low global warming potential (GWP) refrigerants, namely R513A, R516A, and R1234yf, intending to evaluate their potential as replacements for the hydrofluorocarbon (HFC) R134a. The analysis used a test bench under steady-state conditions. The study's results indicated that, in the heating mode, R513A exhibited the highest heating capacity, with an average increase of 3% compared to the other refrigerants. On the other hand, R516A showed the lowest heating capacity results. Regarding coefficient of performance (COP), R513A demonstrated comparable performance to that of R134a, particularly at higher evaporation temperatures. These findings suggest that R513A has the potential to be a suitable replacement refrigerant for R134a in heating applications, as it exhibited improved heating capacity and comparable COP values. The study highlights the importance of evaluating and comparing different low-GWP refrigerants as viable alternatives to HFCs for specific applications.

The low ozone depletion potential refrigerants, HCFCs, such as R22, have excellent refrigerant properties compared to R11 and R12, which help the transition away from CFCs. However, these components still contain ozone-destroying chlorine. Referring to the terms of the Montreal Protocol [28], the phase-out schedule of this type of refrigerant is shown in Figures 1 and 2.

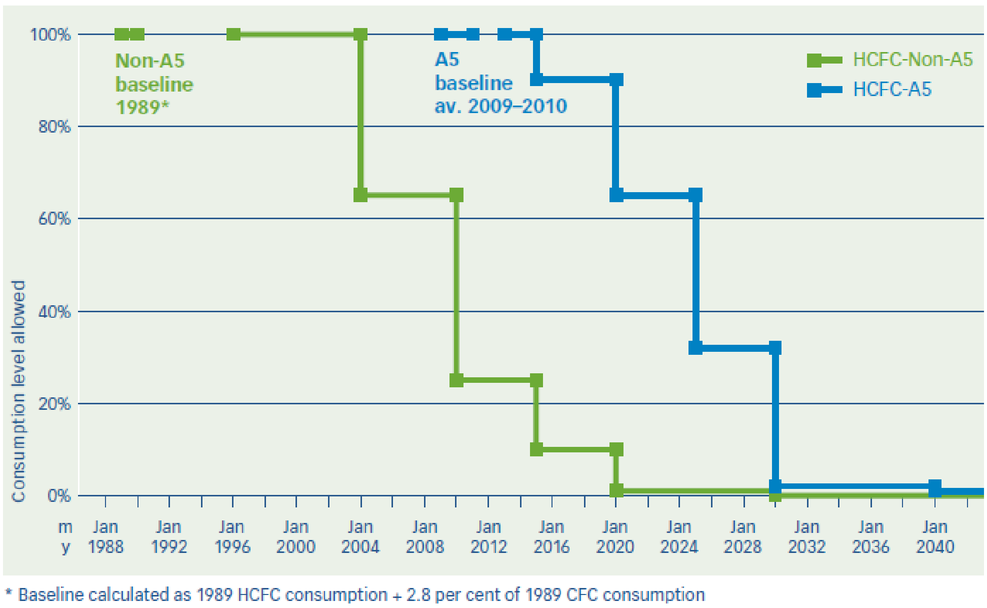

Figure 1. HCFCs consumption, reduction schedule [35].

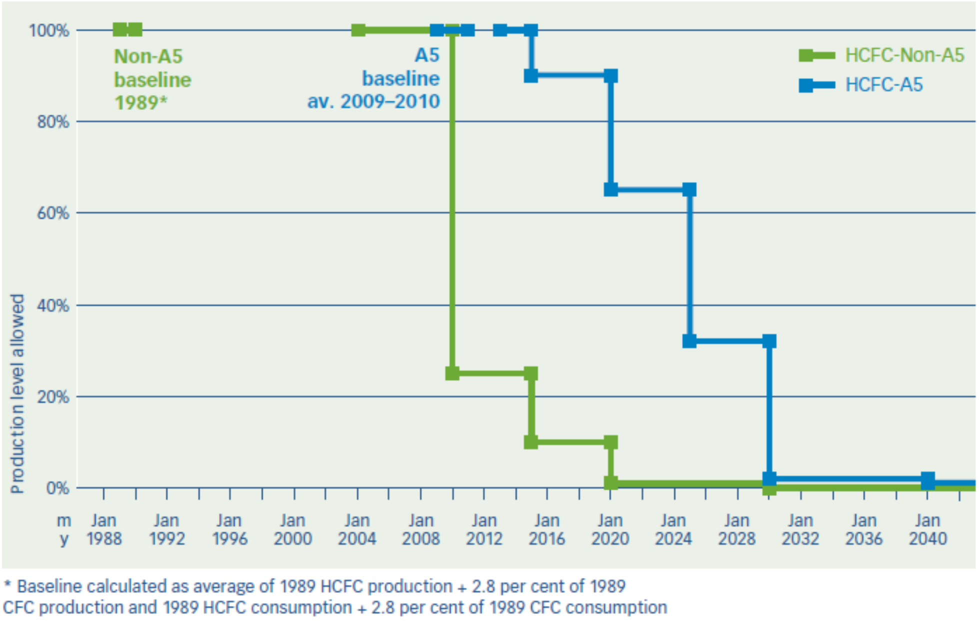

Figure 2. HCFCs production reduction schedule [35].

Developed countries had to freeze the consumption of HCFCs in 1996. They must reduce consumption by 90% by 2015 and phase out the chemicals by 2030, while developing countries must freeze HCFC consumption in 2016 and phase it out by 2040 [36]. Alternatives refrigerants with zero ozone-depleting potential (HFCs) are now used, such as R134a and HFC mixtures (R410A, R407C, R404A, . . .).

In the present work, the specific objectives and main original contributions are as follows:

i. Comparative study of energy performance for a vapor compression chilled water using a new low GWP refrigerant (R1234ze), HFC refrigerants (R134a, R407C, and R410A), and the conventional HCFC22 refrigerant.
ii. Analyze the environmental impact of the different tested refrigerants and select the one with the lowest annual TEWI among them.

2. Refrigerant Properties

The selection of refrigerants for a given application is assessed by four fundamental factors: safety, environmental impact, energy efficiency, and cost-effectiveness [37]. A refrigerant must be safe to use throughout the entire lifecycle of the unit. Possible hazards such as toxicity or flammability characteristics must be evaluated for each refrigerant. Safety classification is based on the standard ANSI/ASHRAE 34 [38]. The safety characteristics of the studied refrigerants are presented in Table 1.

Table 1. Environmental and safety properties of refrigerants.

Refrigerant	ODP	GWP	Safety Class
R22	0.055	1500	A1
R134a	0	1370	A1
R407C	0	1700	A1
R410A	0	2100	A1
R1234ze	0	7	A2

A core consideration in refrigerant choice is its environmental impact. This impact includes the refrigerant's ODP (ozone depletion potential) and its GWP (global warming potential). The ODP indicates the intensity of ozone layer destruction by various refrigerants based on the ODP of R11 as a standard. The GWP represents the degree of contribution to global warming of different greenhouse gases based on CO_2 as a reference. Table 1 summarizes the environmental impact of the used refrigerants. R1234ze presents the lowest value of GWP. Additionally, R134a, R407C, and R410A are non-ozone-depleting mixtures of HFC refrigerants. R410A is an azeotrope blend comprising two equal portions of refrigerants, R32 and R125. R407C is a zeotropic ternary mixture. It comprises R32, R125, and R134a refrigerants with ratios of 23%, 25%, and 52%, respectively. Figure 3 presents the saturation pressure of the different refrigerants vs. the temperature. The operating pressures of R1234ze are the lowest, and those of the R410A are the highest. Compared to R22, the operating pressures of R410A refrigerant are higher by more than 50%. Therefore, high-pressure compressors, thicker-walled tubing, and components must withstand these high pressures.

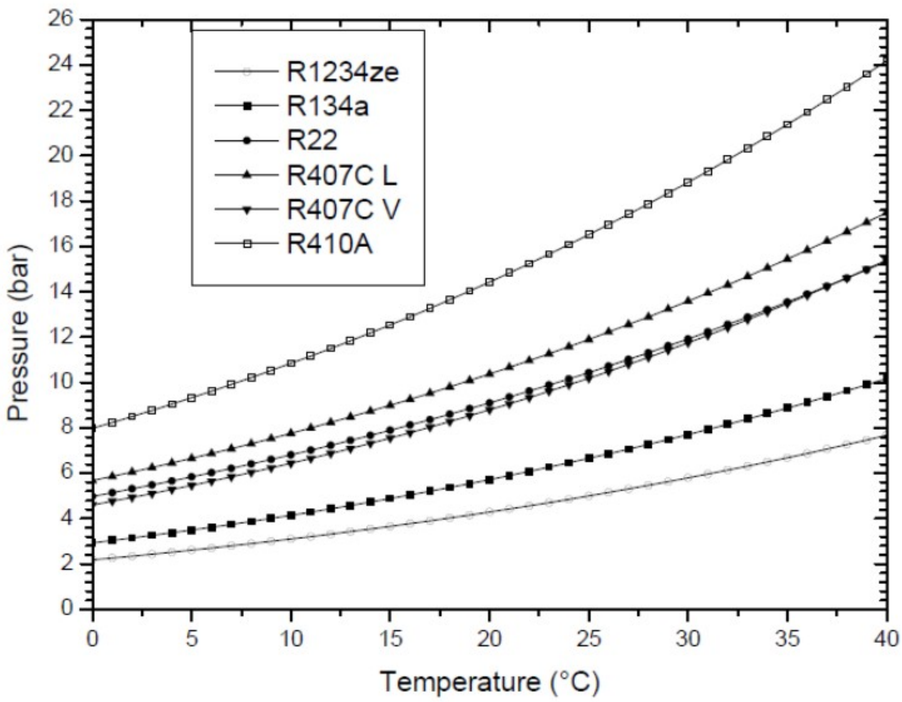

Figure 3. Saturation pressure vs. temperature.

The variation of the enthalpy of vaporization, h_{fg}, is presented in Figure 4. R410A presents the highest h_{fg} for low temperatures. As a result, R410A permits using less coil, a smaller displacement compressor, and fewer refrigerants, keeping the system efficiencies comparable to the current R22 unit. The variation of the h_{fg} of the R407C is similar to R22.

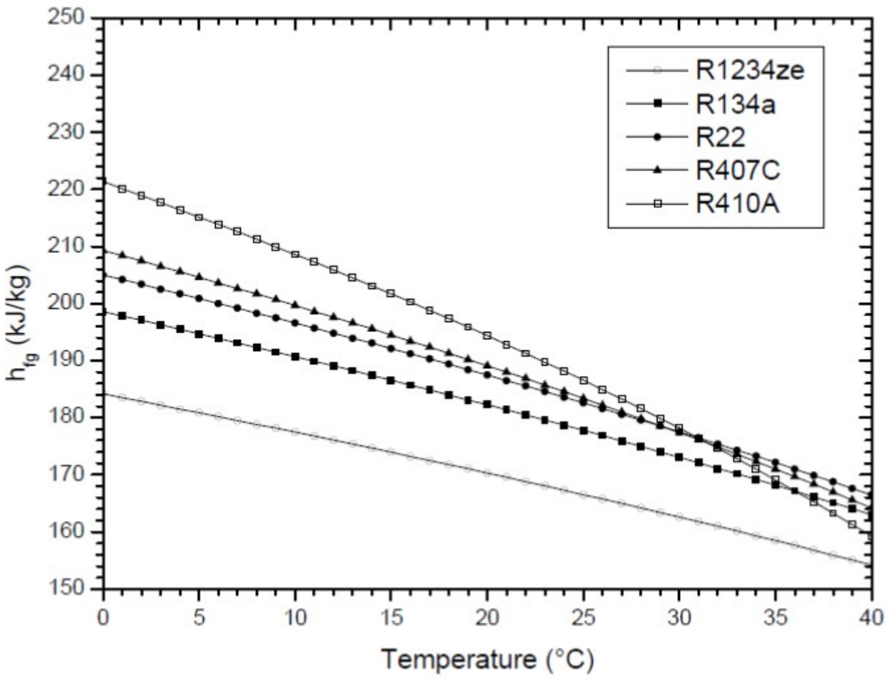

Figure 4. h_{fg} vs. temperature.

3. Energy Performance Comparison

The basic vapor compression refrigeration chilled water unit is shown in Figure 5. It consists of two separate circuits: refrigerant and water circuits. The refrigerant consists of four main components: a water-evaporator, compressor, air-cooled condenser, and expansion valve. This refrigeration system is widely used as air conditioning for residential applications and hotel rooms.

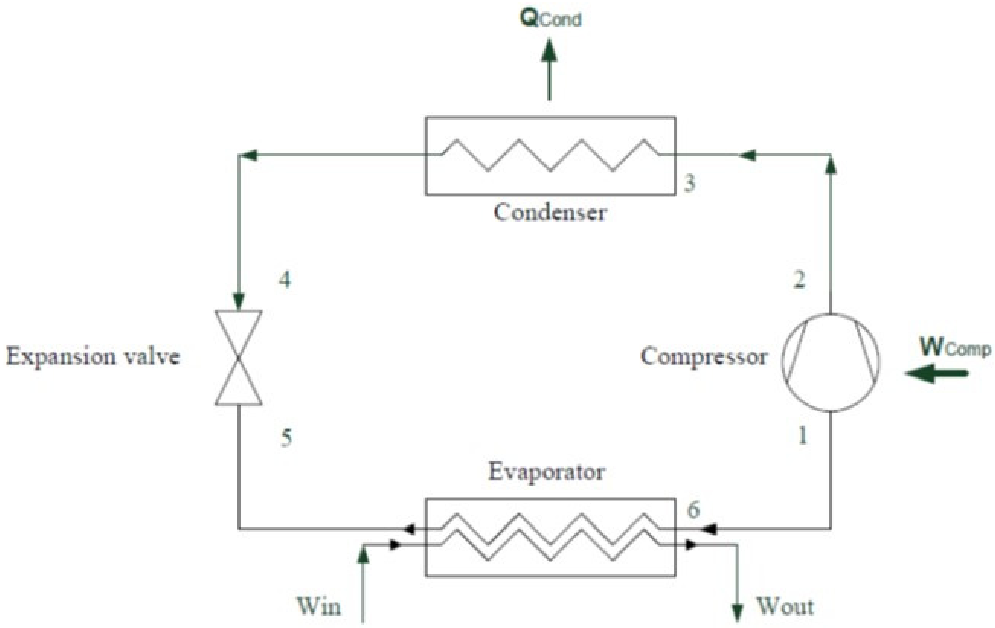

Figure 5. Schematic representation of the VCCW And refrigerant cycle 1–6.

Mass and energy balances are employed for each system component to determine the different rates of heat exchanged and the unit's energy efficiency. Each component can be considered a control volume in a constant flux process [39].

A general mass balance can be expressed in rate form as follows:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

Energy balance can be written as:

$$\dot{E}_{in} = \dot{E}_{out} \tag{2}$$

Neglecting kinetic and potential energy changes, the energy balance can be written as:

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m}h = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \dot{m}h \tag{3}$$

where $\dot{Q}$ is the rate of heat transfer between the control volume and its vicinity, $\dot{W}$ is the work rate, and h is the specific enthalpy.

Energy analyses of the overall VCRCW and its components follow:

- Compressor

$$\dot{W}_{comp} + \dot{m}h_1 = \dot{m}h_2 \tag{4}$$

- Discharge line

$$\dot{m}h_2 = \dot{m}h_3 + \dot{Q}_{dis} \tag{5}$$

- Condenser

$$\dot{m}h_3 = \dot{m}h_4 + \dot{Q}_{cond} \tag{6}$$

- Expansion valve

$$\dot{m}h_4 = \dot{m}h_5 \tag{7}$$

- Evaporator

$$\dot{m}h_5 + \dot{Q}_{evap} = \dot{m}h_6 \tag{8}$$

- Suction line

$$\dot{m}h_6 + \dot{Q}_{suc} = \dot{m}h_1 \tag{9}$$

The energetic efficiency of the VCCW (Vapor Compression Chilled Water) is the ratio of the cooling capacity $\dot{Q}_{evap}$ to the work rate necessary for the compressor $\dot{W}_{comp}$ and can be written as:

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} \tag{10}$$

Based on previous equations, a computational model is developed for the system's energy analysis using Engineering equation solver software [40]. The input data assumed for the computation are as follows:

- The environment temperature is 35 °C, and the chilled water regime is 7/12 °C (outlet/inlet).
- The temperature difference between the environment and condensation is fixed at 15 °C
- The degree of subcooling of liquid refrigerant is 5 °C
- The temperature between evaporation and the water outlet is fixed at 5 °C
- The degree of superheating of vapor leaving the evaporator is 5 °C

- The degree of de-superheating in the discharge line is 10 °C
- The degree of superheating in the suction line is 5 °C
- The isentropic efficiency of the compressor is 75%
- Pressure losses are neglected

Figure 6 compares the COP of the unit using the studied refrigerants. The COPs of the system with refrigerants R22, R134a, R407C, R410A, and R1234ze are 3.344, 3.347, 3.225, 3.035, and 3.354, respectively. The cycle operating with the R1234ze had the highest COP, followed by the R134a, R22, R407C, and R410A. The comparison between the energy efficiency of all refrigerants with the R22 is shown in Figure 7.

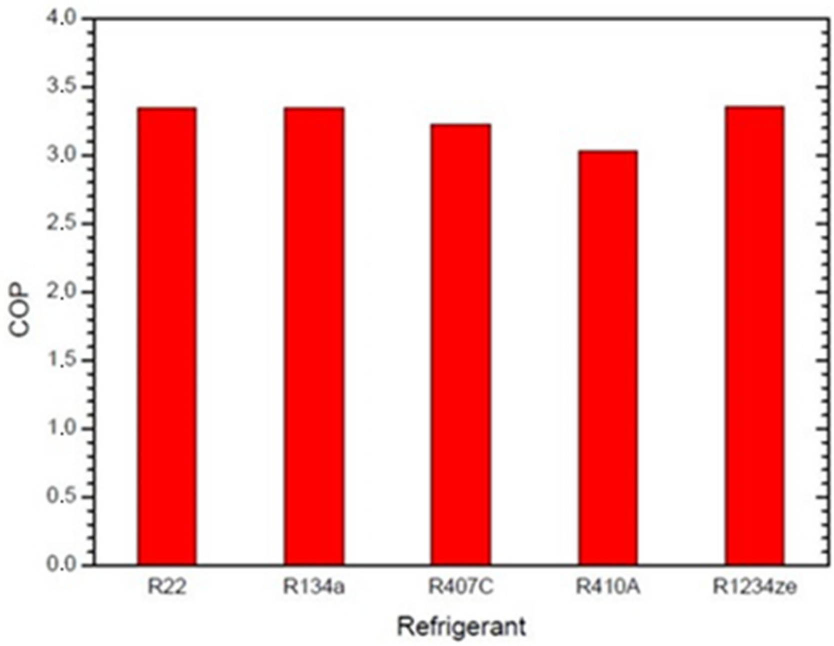

Figure 6. COP for different refrigerants.

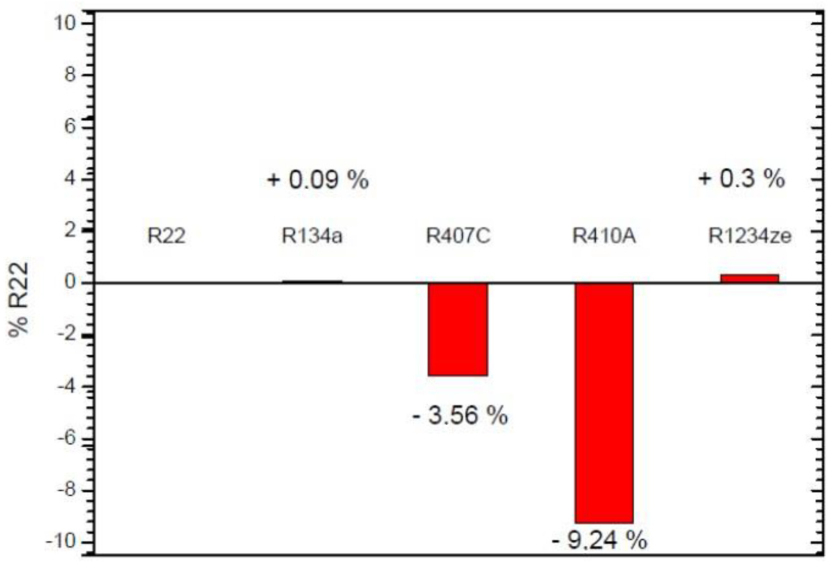

Figure 7. COP variation compared to R22 refrigerant (%).

Compared to the R22 cycle, the COP of the R1234ze and the R134a cycles exceeded by 0.3% and 0.09%, respectively. The influence of the evaporating temperature and ambient temperature on the COP reached for different fluids are presented in Figures 8 and 9, respectively.

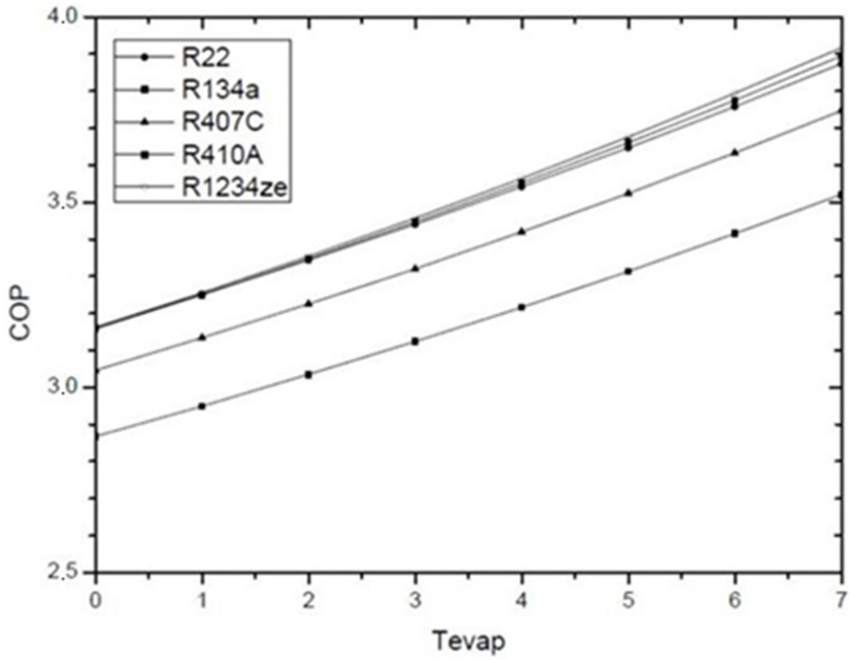

Figure 8. COP vs. evaporating temperature.

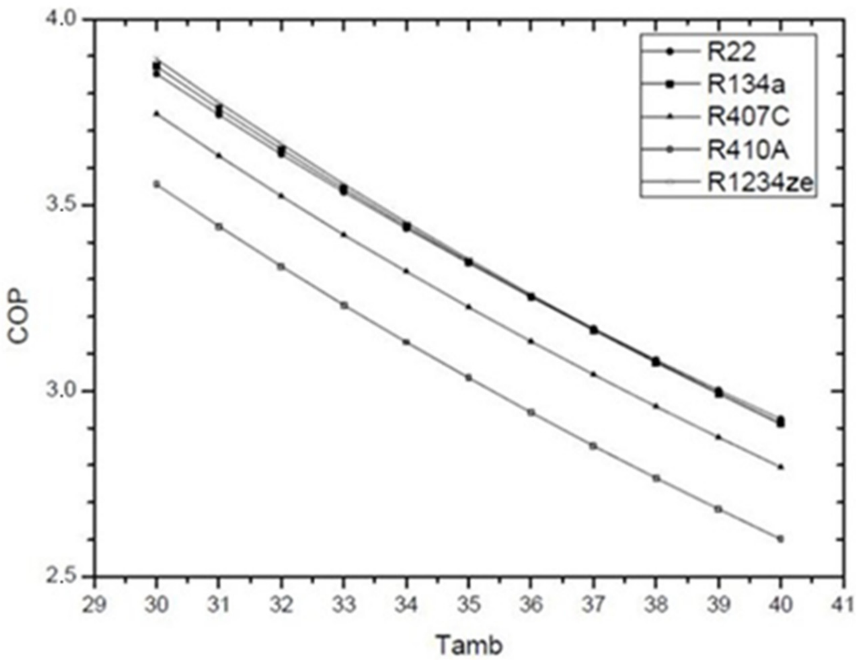

Figure 9. COP vs. ambient temperatures.

For all studied refrigerants, the COP decreases with the ambient temperature increase. It increases with the increasing value of evaporating temperature. Once the ambient temperature rises, the high-pressure value increases, which causes an increase in $\dot{W}_{comp}$. The augmentation of the evaporating temperature is accompanied by an increase in the low-pressure value, which decreases compressor work. The system's energy efficiency trends using R1234ze, R22, and R134a are nearly the same values.

Figures 10 and 11 depict the variation of energy performance compared to the R22 refrigerant as a function of the ambient and evaporating temperatures. This parameter increases with the evaporating temperature and decreases with the ambient temperature increase for all the fluids. The R407C and R410A cycles present the lowest performances regardless of evaporating and ambient temperatures. For the considered values of the evaporating temperatures, the COP of the R134a and R1234ze compared to the R22 cycle varied from −0.13% to 0.54% and from 0 to 1.11%, respectively.

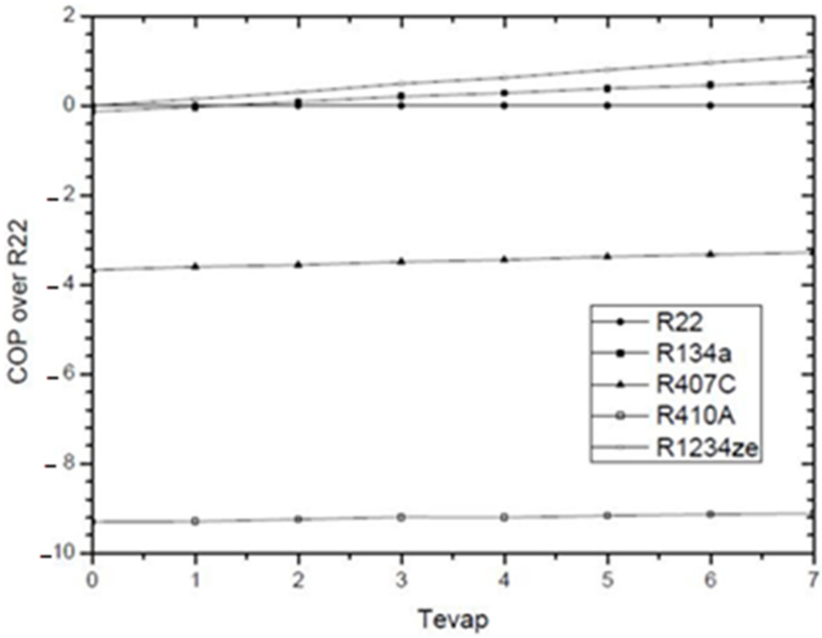

Figure 10. COP compared to R22 (%) vs. evaporating temperature.

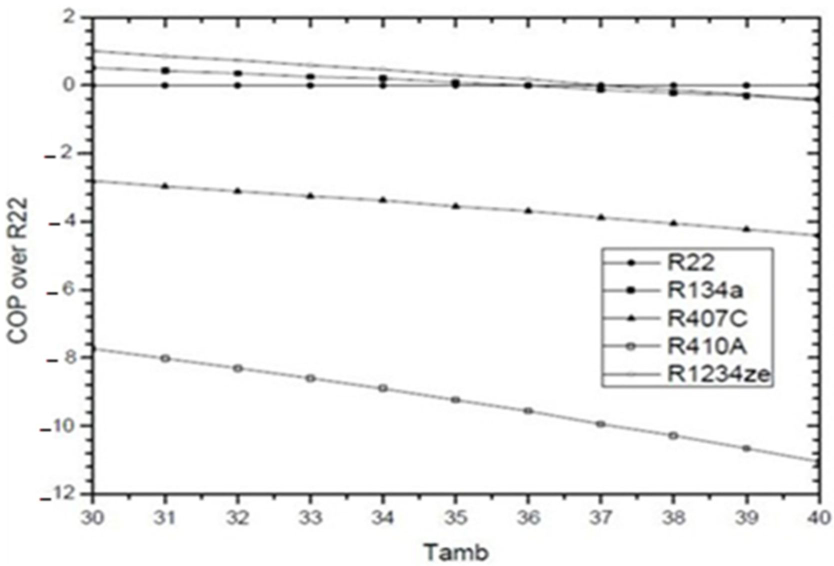

Figure 11. COP compared to R22 (%) vs. ambient temperature.

The augmentation of the ambient temperature causes COP variation compared to R22 from 0.52 to −0.41% and from 1.1% to −0.44% for R134a and R1234ze, respectively. This energy analysis proved that R1234ze shows the best energy performance among the considered working fluids compared to R22.

4. Environment Impact Comparison

The compared refrigerants are the null ODP: R134a, R407C, R410A, and R1234ze. The environmental impact comparison of using different refrigerants is based on the total equivalent warming impact (TEWI) presented in Figure 12.

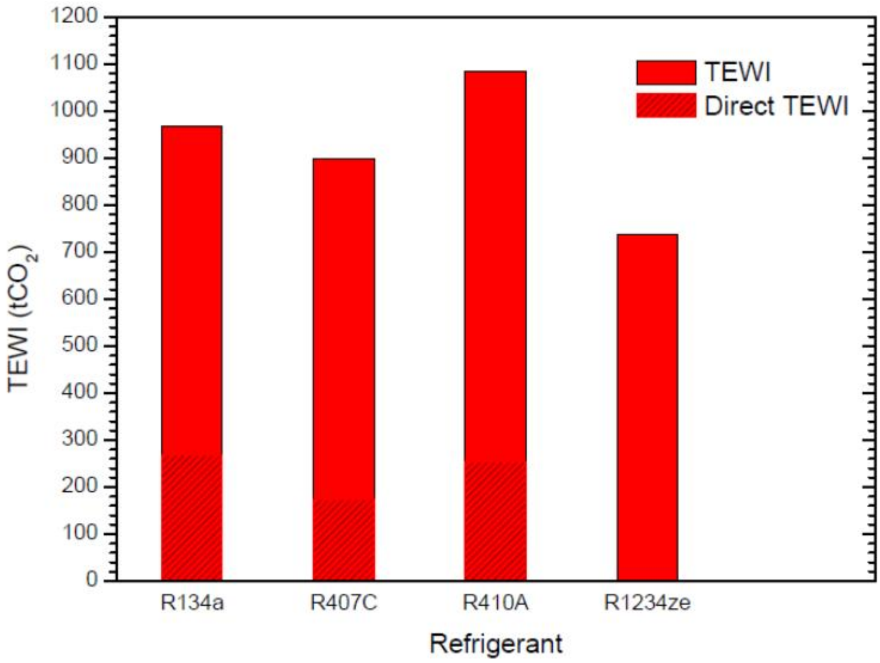

Figure 12. TEWI values for the different refrigerants.

It accounts for the GWP impact of the unit based on the total associated emissions of greenhouse gases during operation and disposition of the operating fluids at the end of the lifetime of the refrigeration system [41,42].

TEWI considers the direct and indirect emissions produced by the energy used in the functioning of the refrigeration unit.

The TEWI value is given by:

$$\mathbf{TEWI} = (\boldsymbol{GWP} \times \boldsymbol{m} \times \boldsymbol{L_{annual}} \times \boldsymbol{n}) + \boldsymbol{GWP} \times \boldsymbol{m} \times \left(1 - \propto_{\boldsymbol{recovery}}\right) + (\boldsymbol{E_{annual}} \times \boldsymbol{\beta} \times \boldsymbol{n}) \quad (11)$$

5. Validation of the Results

We used comparable studies in the literature to validate this model since no results are available for the specific conditions and configurations. Therefore, comparisons were made by referring to the trends of specific parameters. The works of Mota–Babiloni et al. [10] and Mendoza et al. [11] compare adequately with the present study. Figure 13 compares the evolution of COP with the evaporator temperature from the previous works.

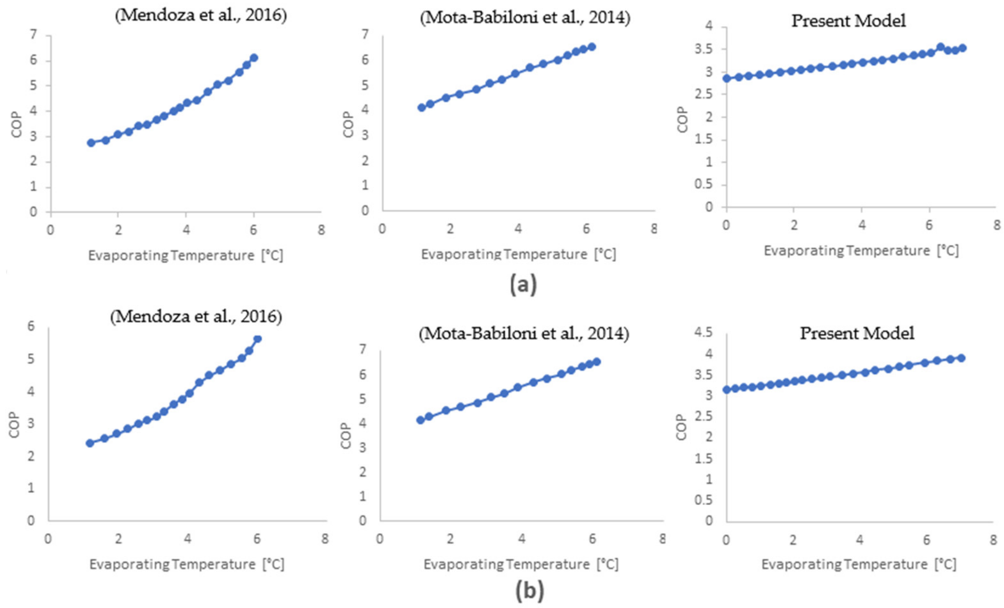

Figure 13. Comparison between the models found in the literature and the present model: (**a**) 134a and (**b**) 1234ze [10,11].

Figure 13 shows that the two studies in the literature exhibit a significant similarity with the present model for the R134a and R1234ze refrigerants. This indicates that the current model is reliable and can be used to assess the performance of other refrigerants.

6. Conclusions

This work presents an energy performance and environmental impact comparative study between the low GWP refrigerant R1234ze, HFCs (R134a, R407C, and R410A), and HCFC22, used in conventional air-cooled vapor compression chilled water systems. A simplified thermodynamic model was developed to evaluate the energy performance for different refrigerant cycles for these investigations.

The parametric study illustrates the impact of the ambient and evaporating temperature on the coefficient of performance. It shows that the R1234ze cycle has the highest energy performance. A comparative study of TEWI values for the different refrigerants used the standardized method developed by AIRAH (Australian Institute of Refrigeration, Air Conditioning, and Heating). We used the parameters of commercialized air-cooled vapor compression chillers with an average cooling capacity of 240kW operating with the studied refrigerants. The HFO refrigerant R1234ze is a good substitute for R22, R134a, R410A, and R407C in air-cooled vapor compression chillers.

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List of Abbreviations and Symbols

Latin letters

Symbol	Signification	Unit
COP	coefficient of performance	
$\dot{E}$	rate of energy	W
P	pressure	kPa
T	temperature	°C
h	specific enthalpy	
$\dot{Q}$	rate of heat transfer	W
$\dot{W}$	rate of work	W
Abbreviations		
W	water	
comp	compressor	
cond	condenser	
evap	evaporator	
in	inlet	
out	outlet	

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