An Evaluation of R448A as R404A low GWP Alternative in a Supermarket Refrigeration Application

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Abstract: In this paper we compare the efficacy of a supermarket refrigeration system using R404A and R488 (a mixture of Hydrofluorocarbons (HFC) and Hydro-Fluoro-Olefin (HFO)) in tropical climate of Mauritius. More specifically, the Total Equivalent Warming Impact (TEWI) model of the refrigeration system working on various refrigerants is used to assess the Coefficient of Performance (COP), leaks in the refrigeration circuit and equivalent CO_2 emitted. It is demonstrated that the COP for R448 is 20% higher for low temperature application under the same working circumstances and refrigeration power. It is also demonstrated that the TEWI for R448A is 16% lesser. Therefore, based on these findings, R448A is a very effective short-term replacement for R404A refrigerant in the commercial refrigeration field in Mauritius, both from an environment and energy perspective. Additionally, it can be used in place of R404A without any system modification. R448A is currently not widely accessible on the market and is a relatively more expensive refrigerant.

Keywords: Alternative refrigerants, Hydrofluorocarbons (HFC), Hydro-Fluoro-Olefin (HFO), Total Equivalent Warming Impact (TEWI)

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1. Introduction

In RAC applications worldwide, Hydrofluorocarbons (HFC) are presently the refrigerant most frequently used, and same applied to Mauritius. However, the fact that they contribute to global warming raises a significant environmental issue. Hydrofluorocarbons (HFC) will soon be phased out as a result of the Kigali amendment to the Montreal Protocol, which call for the use of environmentally favourable refrigerants.

The climate in Mauritius is mild and temperate all year long, with only a small amount of seasonal weather variation. The warmest months are January and February, with daytime high temperatures averaging 29 °C [1]. In winter, the typical relative humidity is about 60%, and in summer, it reaches 95% in coastal areas [1]. Because of this, demand for air conditioning and refrigeration is strong all year long. The RAC market rapidly accepted synthetic refrigerants like HCFCs and CFCs when they were created in the late 1920s because of their excellent thermodynamic properties, high level of stability, lack of toxicity, and lack of flammability.

However, Molina and Rowland [2] demonstrated in 1974 that Hydrochlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) were substances that deplete the ozone layer and were primarily to blame for destruction of ozone in the stratosphere. This increased global knowledge of the threats that these chemicals pose to our atmosphere. The Montreal Protocol entered into effect on 1st January, 1989, with a goal of decreasing ozone depleting substances and their use in refrigeration and air conditioning applications [3]. As a result of the Protocol of Montreal, a new class of refrigerant called Hydro Fluoro Carbon (HFC) was created in the mid-1990s to take the place of CFCs and HCFCs. HFCs are safe for the ozone barrier because they don't contain chlorine atoms. Because of this, they quickly became well-liked in the RAC industry and are now extensively used to replace HCFCs. However, all HFCs are greenhouse gases with extremely high Global Warming Potentials (GWPs) despite having negligible Ozone Depletion Potential (ODP). HFCs are therefore not suitable replacements because of their high GWP value [4–7]. On the other hand, R448A has a relatively lower GWP of 1273 and is considered a short-term substitute of HFCs and has been employed in the commercial refrigeration field in Europe.

Therefore, this paper aims to assess R448A's performance in Mauritius' tropical environment. To be more exact, we compare the performance of R404A to R448A in a commercial refrigeration application. The system COP, refrigerant leaks, and CO_2 equivalent emission are among the performance indicators. The Total Equivalent Warming Impact (TEWI) model is used to evaluate success.

2. Background

HFCs are being phased out in accordance with EU laws, the Protocol of Kyoto, and most recently the Kigali Amendment to the Protocol of Montreal because they are environmentally risky substances. The potential substitute refrigerants that have been found to replace HFCs are covered in this section. It would be necessary for substitutes that ultimately replace halogenated refrigerants to have zero ozone depleting potential and a low Global Warming Potential. Further advantages include low level toxicity, cheap cost, being chemically stable, and having good thermal characteristics. HFCs and HCFCs can be effectively replaced by natural compounds such as CO_2, HC and NH_3.

2.1 Hydrocarbon Refrigerant (HCs)

As early as 1866, hydrocarbons were used as a coolant. The 1920s saw the widespread availability of iso-butane, ethane and propane as good substances to use in refrigeration machines [8]. However, the compounds on hand at the time were not refined and had a large number of impurities. The pressure-temperature connection was therefore unsatisfactory. But in the middle of the 1990s, HCs returned to the picture due to synthetic refrigerants' detrimental effects on the environment [6, 9]. HCs have been widely utilized in air conditioning equipment, limited capacity commercial refrigeration, and domestic refrigeration, all of which use less than 150 g of refrigerant [10]. As a result, HCs are increasingly being used in household refrigeration and small commercial machinery.

2.2 Ammonia (R717)

Very good thermodynamic characteristics make ammonia an effective refrigerant that has been for more than a century in a variety of industrial uses [11]. The preparation and storage of food are its primary uses. In commercial uses for supermarkets, ammonia has been used in confined systems [12]. The use of liquid chillers with indirect cooling for air conditioning applications has also been effective [10]. NH3 has a GWP and ODP of 0. In addition to having a low price, it has a potent pungent scent that makes it simple to detect even at low concentrations. However, NH3 is toxic, has high discharge temperatures and is incompatible with traditional copper tubing used in refrigeration circuits. In concentrations between 16 and 28%, it is also mildly flammable. If safety precautions are taken and technicians are properly trained, ammonia has a chance of seeing much broader use. A new interest in ammonia applications is emerging in the RAC industry, particularly in Northern Europe [13].

2.3 CO_2 (R-744)

CO_2 was employed as a refrigerant since at least the middle of the eighteenth century. Due to its eco-friendly characteristics, CO_2 has been successfully used in a variety of refrigeration uses today [10]. Some of its benefits include being non-toxic and non-flammable, having a high volumetric cooling capacity, being less sensitive to pressure dips, being less expensive, having a small suction line diameter, and not being corrosive [12]. High pressures over 125 bars, a low critical temperature of 310 °C, and the need for extra equipment to decrease standstill pressures are some drawbacks.

2.4 HFOs

Unsaturated HFCs known as Hydro-Fluoro-Olefins (HFOs) are regarded as the fourth wave of fluorine containing gases. This group of refrigerants which are synthetically made are mildly flammable, have zero ODP and a minimal GWP [15, 16].

3. Methodology and Presentation of Results

In order to protect its identity, we have chosen a hypermarket for this research and will refer to it as hypermarket *X*. There are numerous Hypermarket *X* locations across Mauritius. As a result, it runs a number of cold chambers with positive and negative temperatures to store food. This research compared the effectiveness of the cold rooms' refrigeration systems using R404A and R448A.

This case study's goal is to use the TEWI model to examine efficiency, leaks in the circuit, and CO_2 emanations of a refrigeration system. The findings obtained will then be used to make recommendations.

In this research, an existing R404A-using refrigeration system was retrofitted with R448A, and testing was conducted over a 12-month period. Data loggers were placed to track the amount of energy used, the system's operating temperatures and pressure, as well as the overall temperature of the office space. In addition, two years' worth of maintenance data sheets were examined to look for leakage rates and other equipment-related actions. Coolpack Version 1.5 and Pack Calculation Pro were used for TEWI calculation and thermodynamic examination of R404A and R448A within the refrigeration system.

3.1. Equipment Description

The hypermarket make use of a centralized HFC DX arrangement as refrigeration equipment for producing medium and low temperatures in the cooling cabinets and cold rooms. The operating temperatures are : −0 °C to 10 °C for beverage and fresh food preservation and −20 °C for frozen food. The arrangement is depicted in Fig. 1.

Fig. 1. R404A refrigeration system.

The schematic circuit is shown in Fig. 2. The arrangement consists of 3 standby compressors in parallel with the main compressor linked to a speed controller. The circuit includes a subcooler, placed between the low temperature and the medium temperature system, which improves the system efficiency. Yang and Zhang [16] claims that using sub-cooling can provide up to 27% savings on energy consumption in R404A systems. Dedicated sub-cooling can be used to increase system effectiveness and cooling capability [17, 18].

Semi-hermetic reciprocating Bitzer compressors, type 4GE-23Y-40P, are used to ensure high operational efficiencies and reliable performance. The 50 Hz motor runs at 1450 rpm circulating with the refrigerant in the circuit. Oil separators are installed in the compressor discharge line. A variable speed controller modulates the compressor speed of the first compressor depending on the power demand. The power demand is more during business hours and less at night. As demand increase more compressors will be switched on to provide the required pressure to maintain the required temperature in the refrigeration cabinets. This results in reduced energy consumption and higher system efficiency during off-peak hours.

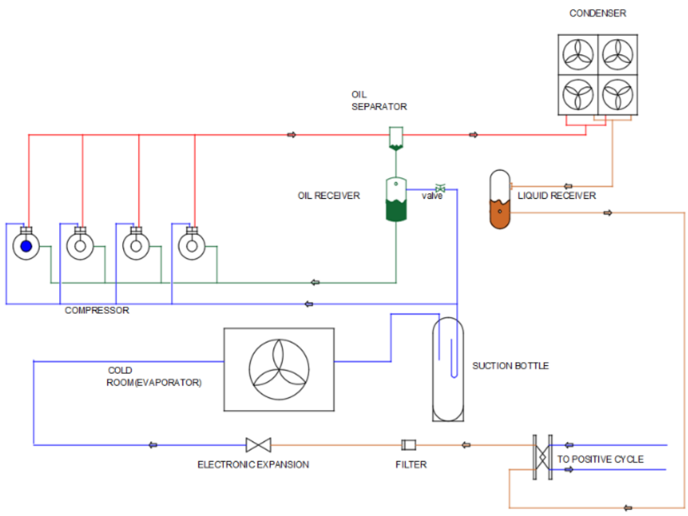

Fig. 2. System drawing for the R404A Refrigeration System, simplified.

3.2. Refrigerant Circuit

Copper lines are used exclusively in the construction of the refrigeration circuit. The cooling circuit is illustrated in Fig. 2. The fans' blades are constructed from a composite substance for corrosion resistance and sound absorption. Cross movement is avoided by the placement of the fans. The 3-phase motors used in the cooling fans offer greater performance and efficiency.

3.3. Ambient Temperature

Fig. 3 shows the prevailing temperatures that occurred during the research. Fig. 3 depicts the temperature variation during the study time, which ranged from 15 °C to 33 °C.

3.4 Working Parameters

Table 1 below provides an overview of both systems' operational characteristics.

Making use of the above data, the refrigeration cycle for R404A and R448A were drawn using the Coolpack refrigeration program.

The two systems' COP and energy usage were approximated by means of the above-mentioned software.

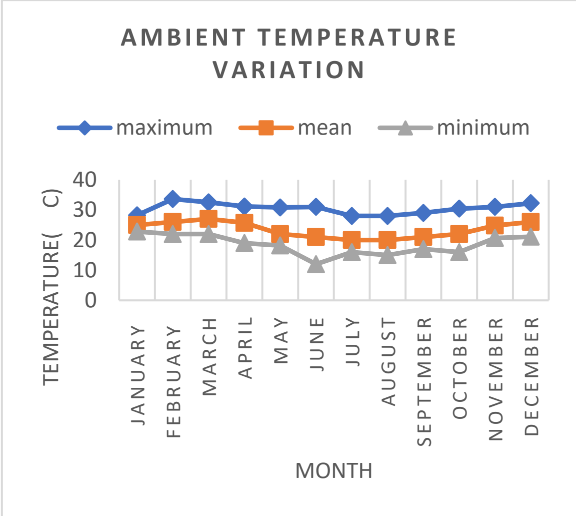

Fig. 3. Ambient temperature variation.

Table 1. System characteristics for refrigeration system

Working Parameter	Value
Evaporation temperature	−11 °C
Condensation temperature	30 °C
Degree of Superheat	10 K
Cooling Capacity	50 kW (medium cooling mode)
Sub cooling	

3.5. Energy Usage as Calculated by the Pack Pro Analyzer Program

The variation in compressor work was compared by varying the condensation temperature ranging from 30 °C to 40 °C (adding 10 °C to ambient temperature). The results are detailed in Fig. 4. From the graph, we can see that compressor work increases with an increase in condensation temperature. It shows that R404A requires more capacity than R448A. An increase in compressor capacity decreases the COP.

The average power consumption per month for the refrigeration system is given in Fig. 5. These values have been cumulated to calculate the total energy consumption for the year.

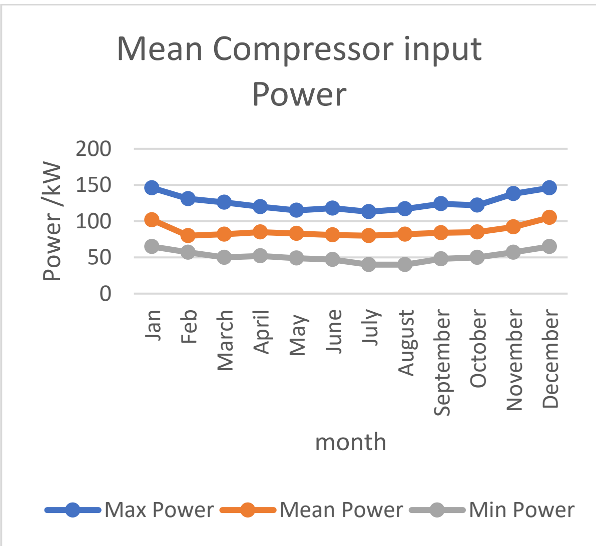

Fig. 4. Energy use per month for R404A and R408A devices.

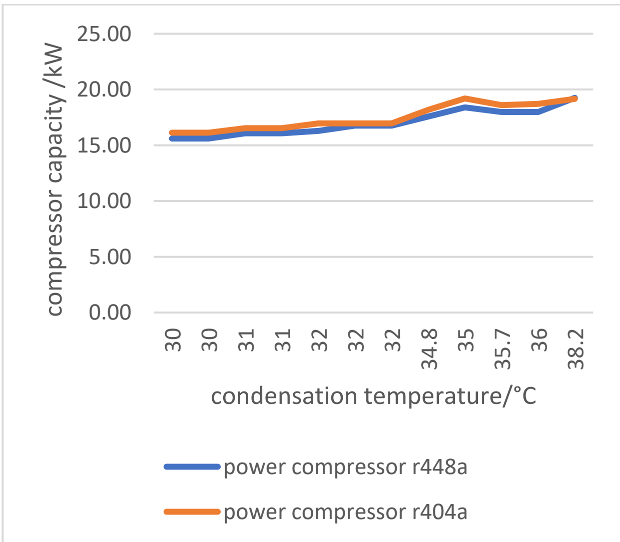

Fig. 5. Effect of condensation on compressor work.

3.6. Calculation of COP for R404A and R448A

The comparison of the mean COP over a one-year period is given in Fig. 6. The results show a better COP for R448A compared to R404A. This represents a 20% increase when retrofitting the system from R404A to R448A. Higher COP means a better energy efficiency and consumption. This is shown in Figs. 6 and 7.

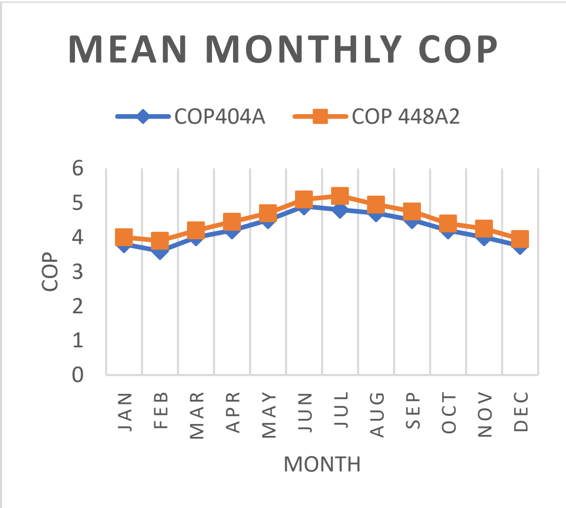

Fig. 6. Monthly COP for R404A and R408A systems.

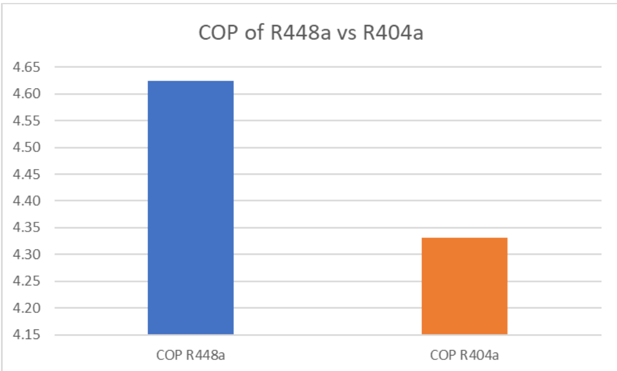

Fig. 7. Mean yearly COP for R448A and R404A

3.7. Computation of the Total Equivalent Warming Impact

This part calculates the CO_2 emanations equvalent for the hypermarket *X* equipment. The low and medium temperature machine has a total charge of 450 kg and employs nine compressors in total. This matches the refrigerant charge used by Karampour and Sawalha [14] for a medium-temperature and low-temperature system.

To determine the TEWI for the refrigerants R488a and R404A, Eq. (1), [15] was used.

$$\text{TEWI} = (\text{GWP} \times m \times \text{Lannual} \times n) + \text{GWP} \times m \times (1-\alpha) + (\text{Eannual} \times \beta \times n) \quad (1)$$

$$\text{Direct emissions} = (\text{GWP} \times m \times \text{Lannual} \times n) + \text{GWP} \times m \times (1-\alpha) \quad (2)$$

$$\text{Indirect emissions} = (\text{Eannual} \times \beta \times n) \quad (3)$$

Using the above methodology, the TEWI for both systems were computed using the following parameters:
Mean life duration of equipment: Twenty years.

Mass of refrigerant for R404A/R448A: 450 kg
Leak rate of equipment: 15%
Recuperation factor: 90%
Emission factor for Mauritius: 0.9548

From Figs. 8 and 9 we can deduce that the TEWI of the refrigeration system when operating on R448A is lower by 1576 tons Eq. CO_2. This means that the R448A systems will emit 1576 tons of CO_2 less than when the system is running on R404A. This represents a 16% decrease in CO_2 emissions. The direct emissions of for the R448A is also significantly less due to a lower much lower GWP value.

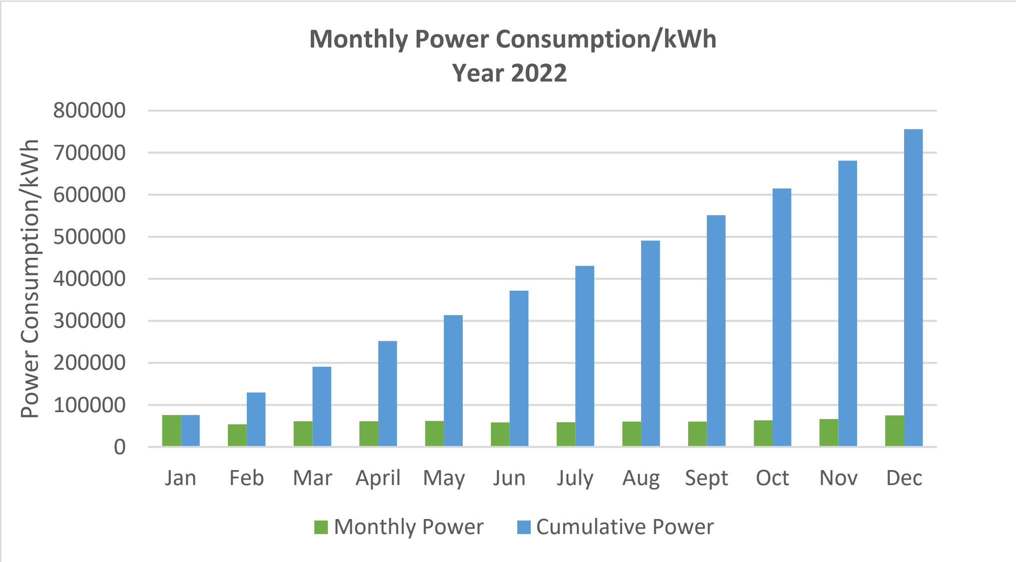

Fig. 8. Monthly cumulative power consumption.

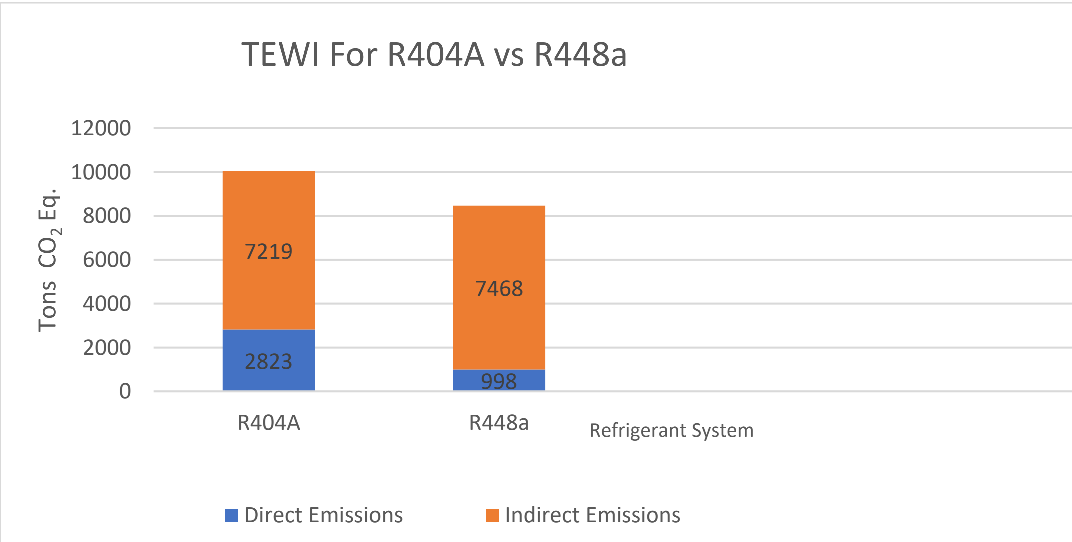

Fig. 9. TEWI for R404A and R448A commercial refrigeration systems.

4. Conclusion

This research compared the effectiveness of a refrigeration system using R404A and R448A. The findings demonstrate that, under equivalent working circumstances, R448A has a higher COP and a lower TEWI. The COP was 20% higher for the medium refrigeration system and 6.9% higher for the low temperature system. The TEWI for the R448A system was lower by 16%. From an environmental point of view, R448A can therefore be considered a better alternative for R404A system in commercial applications in the short term. However, the price of R448A is three times that of R404A and is also not readily available on the local market for the time being.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualisation, R. K Dreepaul; Methodology, B.S Bhujun; software, K Busawon; validation, R.K Dreepaul; formal analysis, R.K Dreepaul; investigation, B.S Bhujun; resources, R.K Dreepaul; data curation, K.Busawon; writing original draft, R.K Dreepaul; writing- review and editing, B.S Bhujun; Supervision, K.Busawon; Project administration, R.K Dreepaul; funding acquisition, R.K Dreepaul. All authors had approved the final version.

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