An Evaluation of R32 for the US HVAC&R Market

May, 2016

Executive Summary

This paper investigates the merits of R32 as an alternative refrigerant with the capability of reducing the global warming impact of refrigerants currently used in the HVAC&R industry. A summary of advantages and disadvantages is provided. Simulation results summarize the theoretical potential of R32 to improve energy efficiency and life cycle climate performance of HVAC&R systems. Overall, R32 is found to be a balanced replacement refrigerant with significantly reduced global warming potential (GWP) when compared with current refrigerants. R32 has the potential to improve system energy efficiency, but some concerns over system design and mild refrigerant flammability remain.

Introduction

Historically, the HVAC&R industry has been required to provide technical adaptations in order to address environmental concerns over refrigerants' potential to deplete the ozone and/or warm the planet. These adaptations continue to take place today with rising concerns over the global warming potential (GWP) of current refrigerants and the desire to minimize the impact that HVAC&R applications have on the environment and economy. Following the phase out of ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), many current HVAC&R systems use hydrofluorocarbons (HFCs), such as R134a and R410A, which made up about 2% of total greenhouse gas (GHG) emissions in the United States in 2011 (the equivalent of 129 Tg of CO_2). The US Environmental Protection Agency (EPA) projects that national HFC emissions will increase by 64% by 2020 and 139% in 2030 (compared to 2011 levels)[1]. The EPA's Significant New Alternatives Policy (SNAP) seeks to enable the implementation of low-GWP alternative refrigerants and many in the industry are working diligently to identify suitable alternative refrigerants from a vast selection of fluids and mixtures.

R32 Background

R32, or difluoromethane / HFC-32, is an HFC refrigerant that has been in use for over two decades, most often in blends with other refrigerants. R32 has zero ozone depletion potential, a 100-year GWP of 675 and is slightly flammable (A2L classification). Both R410A and R407A, relatively common current refrigerants, are composed of non-flammable mixtures of refrigerants that include R32. Because R32 has a much lower GWP than these mixtures, it is being evaluated for use as a pure fluid in HVAC&R applications despite past concerns over flammability. Millions of air conditioning units using R32 as a refrigerant have already been sold throughout Asia, New Zealand, Australia, and Europe.

Refrigerant Comparison Analysis

The selection of alternative refrigerants requires consideration of multiple characteristics, most notably: thermodynamic performance, Ozone Depletion Potential (ODP), GWP, flammability, and toxicity. Table 1 shows a qualitative summary of the major refrigerant categories and their main advantages and disadvantages. Figure 1 shows an illustration of various refrigerant options plotted on axes indicating their GWP and approximate COP (calculated through simulation); the colors indicate flammability risks and the sizes indicate the required compressor displacement volume. Table 2 provides a quantitative comparison of several relevant refrigerants' properties. It is clear from this table that the similar properties of R32 and DR55 allow for their potential use as drop-in replacements for R410A. R290 and R1234ze(E) may have favorable properties as drop-in replacements of R134a.

[1] U.S. EPA/OAP (United States Environmental Protection Agency, Office of Atmospheric Programs). 2013. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2011.* EPA 430-R-13-001. Washington, DC. April.

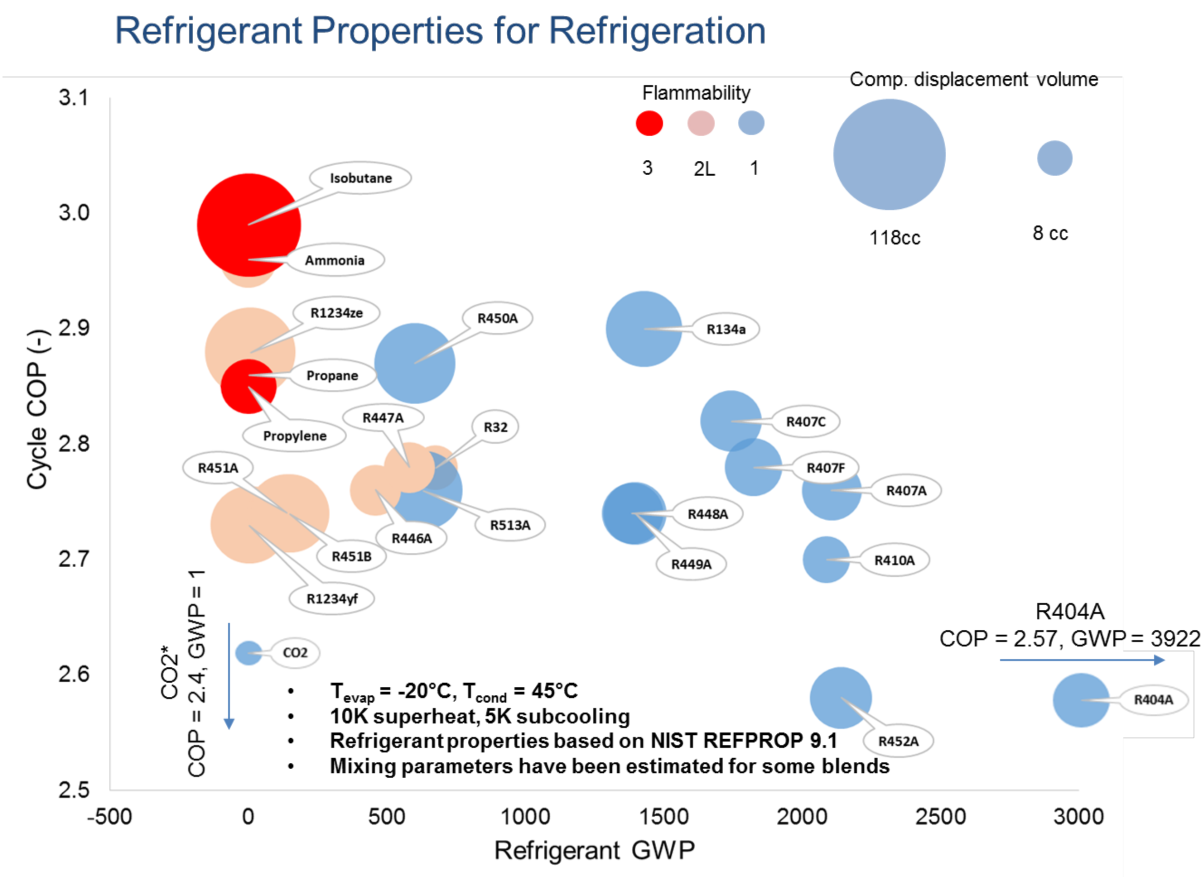


Figure 1: Refrigerant comparison (refrigeration application)

Table 1: Summary of synthetic and natural refrigerants

Synthetic Refrigerants	Natural Refrigerants
Low GWP HFCs (R32, R152a, R161) - Good efficiencies - 0 ODP, low GWP - Lower (A2) or mild (A2L) flammability	CO_2 (R744) - Low efficiency at high temperatures - 0 ODP, 1 GWP - Non-flammable, negligible toxicity (A1)
HFOs (R1234yf, R1234ze(E)) - Good efficiencies - 0 ODP, very low GWP - Mildly flammable	Ammonia (R717) - Excellent thermophysical properties - 0 ODP, 0 GWP - Moderately flammable, toxic (B2)
Fluoroiodocarbons - Very low ODP and GWP - Toxic and reactive - Potential flammability reducer in HFO blends	Hydrocarbons (R290, R600a, etc.) - Good efficiencies - 0 ODP, low GWP - Highly flammable (A3)

Table 2: Example refrigerant properties

Refrigerant	P_{cond} @45°C [MPa]	P_{evap} @4.4°C [MPa]	P_{suc} @5°C superheat	ODP	GWP
R410A	2.73	0.92	34.11	0	2090
R134a	1.16	0.34	16.38	0	1430
R32	2.79	0.94	24.57	0	675
DR55	2.45	0.83	26.63	0	698
R290	1.53	0.54	11.47	0	3
R1234ze(E)	0.88	0.25	13.34	0	6

Applications

Various applications of vapor compression cycles demand a range of refrigerants with thermophysical properties that are suitable for the applicable conditions. The optimal refrigerant for a heat pumping or air conditioning application may not be the same as a refrigerant used for very low temperature refrigeration. Several key refrigerants are compared in Figures 2 and 3 by plotting their theoretical performance (COP normalized against that of R410A) under different operating conditions with the following assumptions: 70% compressor efficiency, 5K subcooling and 10K superheat. Results are shown for air conditioning, heat pumping, and low temperature refrigeration applications with assumed saturation temperatures listed. For air conditioning and heat pumping applications, all of the listed alternative refrigerants show promise to provide improved efficiency and reduced GWP when compared with R410A, one of the most common current refrigerants. Under these conditions the COP of R32 is 1% higher than R410A in air conditioning; under operating conditions with 0K subcooling and superheat, the improvement is roughly 6%.

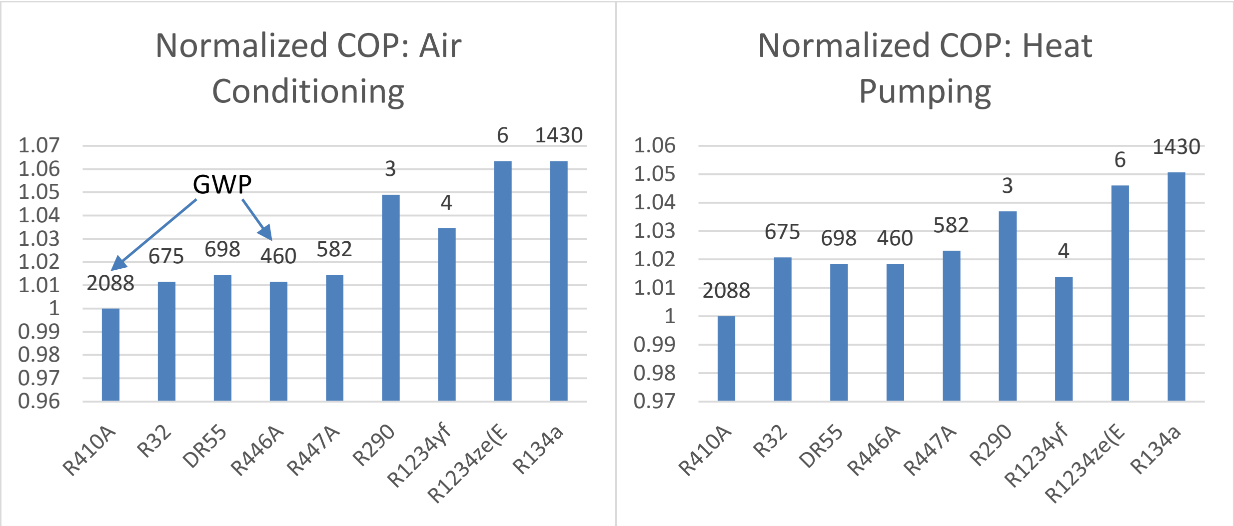


Figure 2: Refrigerant performance comparison: air conditioning (left) 0°C evaporating temperature and 45°C condensing temperature; and heat pumping (right) -1.1°C and 43°C. Data labels are GWP values

For air conditioning applications, the potential drop-in replacements for R410A, including R32, DR55, R446A and R447A all offer equivalent performance in capacity and COP to the baseline and reductions in GWP of 67-78%. In the refrigeration application, several alternatives to R404A show the potential to offer performance improvements with significantly reduced GWPs.

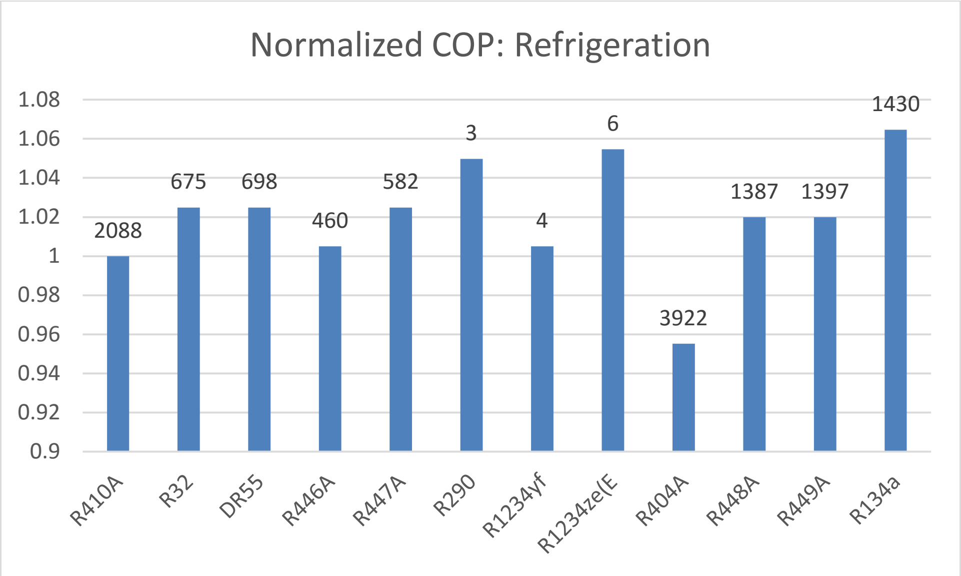


Figure 3: Refrigerant performance comparison: refrigeration, -20°C evaporating temperature, 45°C condensing temperature

Advantages of R32

The performance increases and GWP reductions outlined above represent a major advantage to the implementation of R32 in several HVAC&R applications. R32 has been implemented in air conditioning systems throughout Asia in recent years. Beyond these strengths, there are several pragmatic benefits to the adoption of R32.

Manufacturers currently face near-limitless choices of alternative refrigerants by developing customized refrigerant mixtures. However, the implementation of such an approach would be nearly impossible if service technicians and installers are required to acquire and mix dozens of different refrigerant blends. R32 is a pure fluid that is not new to the industry; since it is used as a constituent of many common refrigerants, its availability is far greater than customized and exotic blends. Because it is a pure fluid, R32 has no issues of fractionation, where concentrations of constituent components may vary throughout the system.

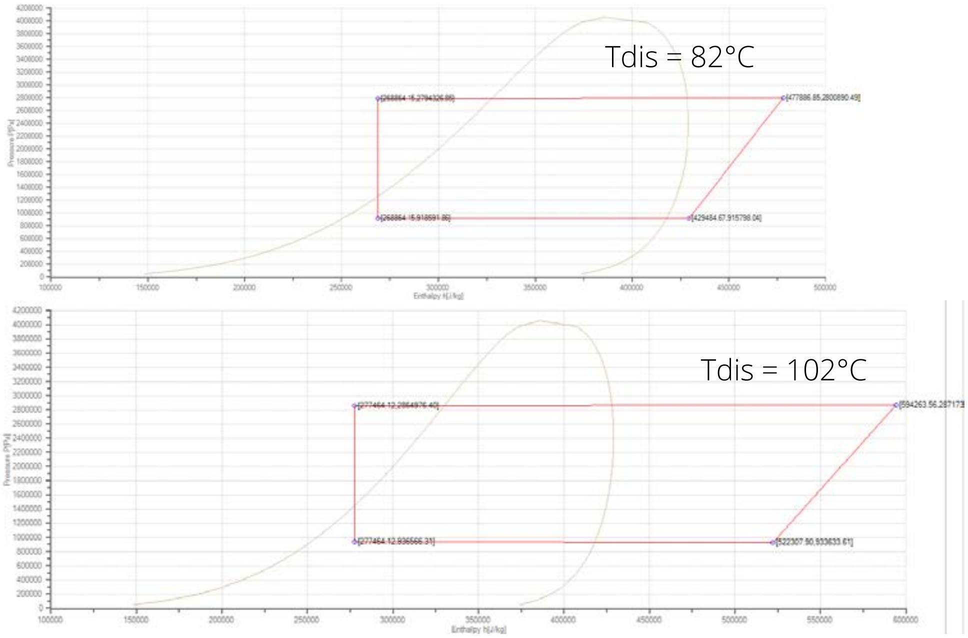
R32 has been demonstrated as a drop-in replacement for R410A in heat pumping and air conditioning systems. Similar thermophysical properties allow it to operate with compressors designed for R410A with similar operating pressures. Several case studies have been conducted using R32 as a drop-in replacement for R410A; results have varied from essentially equivalent performance[2,3] to claims of up more than 6% improvement in COP[4,5] in heat pumping and air conditioning applications.

R32 Concerns and Limitations

R32 is classified as an "A2L" refrigerant; the "A" group signifies that the refrigerant is not known to be toxic at concentrations less than or equal to 400 ppm and the "2L" status indicates that the refrigerant is only mildly flammable, with a burning velocity less than 10 cm/s. This flammability concern has been cited as a barrier to its adoption in the US. Recently, the EPA classified R32 and several other mildly flammable refrigerants as acceptable, but permitted their use only in new, self-contained equipment with limitations on the refrigerant charge[6].

The thermodynamic properties of R32 can result in high discharge temperatures. When compared to an equivalent R410A cycle, R32 can have discharge temperatures on the order of 20°C higher (Figure 4). This can have consequences for the performance and reliability of the compressor and additional steps must be taken in the system and compressor design to minimize the discharge temperature.

Figure 4: Example air conditioning cycle with 5K superheat: R410A (top) and R32 (bottom)



It is also worthy to note that while the GWP of R32 is 68% lower than R410A, each kg of refrigerant is equivalent to 675 kg of CO_2. Other alternative refrigerants including HFOs and natural

[2] Wuesthoff, E. 2015. *System Drop-in Test of Refrigerant R-32 in Single Packaged Vertical Heat Pump (SPVH).*AHRI AREP Program
[3] Pham, H. 2012. *R32 and HFOs as Low-GWP Refrigerants for Air Conditioning*. International Refrigeration and Air Conditioning Conference at Purdue.
[4] Kamioka, Y. 2014. *System Drop-in Test of R410A Alternative Refrigerant R32*. Daikin Industries. Published AHRI AREP Program
[5] Schultz, K. et al. *System Soft-optimization Tests of Refrigerant R-32, DR-5A, and DR-55 in a R-410A 4-ton Unitary Rooftop Heat Pump-Cooling Mode Performance*. Ingersoll Rand. AHRI AREP Program.
[6] US EPA. 2015. 40 CFD Part 82. Vol. 80 No. 69.

refrigerants can have GWP values that are two orders of magnitude lower. As the industry moves to reduce the environmental impact of refrigerants, the GWP of R32 may be considered too high by some parties seeking refrigerants with even lower GWP values.

Impacts

Replacing R410A with R32 can have a substantial impact on direct emissions. Assuming typical leakage rates, an R32 system will emit only 33% as much CO_2-equivalent direct emissions as the equivalent R410A system over its lifetime[7]. This value may be even lower in reality because systems using R32 will have a lower refrigerant charge than R410A systems. In the scenario where an R32 system can be constructed with 5% higher efficiency than an equivalent R410A system, Figure 5 illustrates the life cycle climate performance (LCCP) of both configurations; the R32 system can reduce lifetime emissions by 7-22% depending on location.

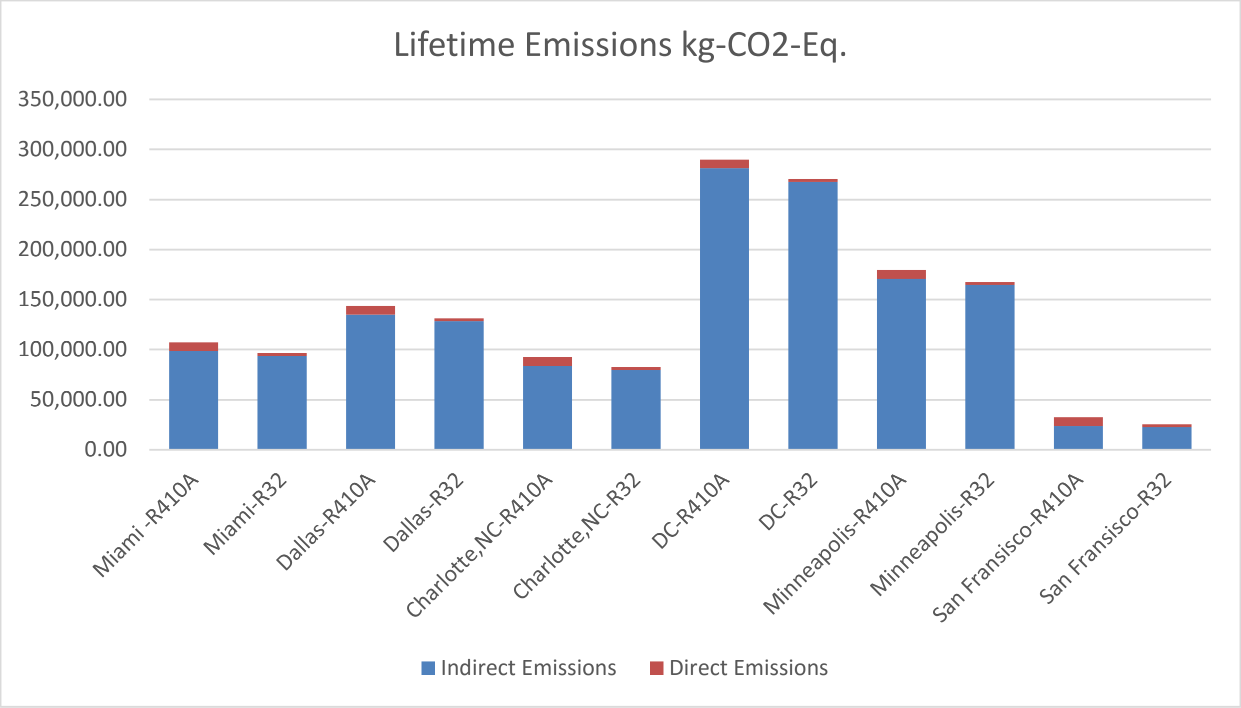


Figure 5: LCCP estimates of R410A and R32 cycles

In 2009, nearly 70 million homes (over 60%) in the US had central air conditioning systems and only 13% of all homes did not have any type of air conditioning equipment[8]. Table 3 summarizes some relevant projections on the energy consumption associated with HVAC&R applications in the US. A total of 5,280.5 trillion BTUs of energy will be consumed by these main HVAC&R

[7] Oak Ridge National Laboratory. 2016. Life Cycle Climate Performance – Residential Heat Pump. http://lccp.umd.edu/ornllccp/

[8] EIA. 2009. Residential Energy Consumption Survey. Washington DC, USA.

applications in 2020, as outlined in Table 3. For every 1% of energy savings a new refrigerant can provide, a total of 52.8 trillion BTUs (15.5 million MWh) of energy can be saved annually, which is the equivalent of 43% of the solar energy generated in the US in 2015. To consider another perspective, the median natural gas electricity generator in the US has a capacity of roughly 80 MW with a capacity factor of 0.85[9], therefore this savings could eliminate the equivalent of approximately 26 natural gas generators per 1% of efficiency improvement. The projected levelized cost of electricity (LCOE) for conventional natural gas power projected for 2020 is 75.2 $/MWh[10], therefore for each percentage improvement in HVAC efficiency, $1.2 billion dollars in new power generation costs could be avoided. If R32 can offer 5% greater efficiency than current systems, $6 billion could be avoided; therefore if even a small fraction of systems can be replaced with R32, substantial cost savings will be possible.

Table 3: Major HVAC&R energy projections

Application	2020 Projected [TBTU][11]
Residential AC	2,363.3
Residential Heat Pumping	157.7
Commercial AC	1,596.9
Commercial Heat Pumping	170.6
Commercial Refrigeration	992
Total:	5,280.5 TBTU

Summary

As the HVAC&R industry seeks to implement refrigerants with reduced environmental impacts, a near-limitless selection of working fluids is available, each with its own advantages and disadvantages. R32 is a well-established refrigerant used as a component in several common refrigerant blends and used as a pure fluid in some HVAC&R applications throughout Asia. Because of this, distribution of R32 for manufacturing and maintenance would be more straightforward than distribution of a new refrigerant blend. R32 has a considerably lower global warming potential (GWP) than many of the refrigerants in use today; its GWP is 68% lower than R410A. Additionally, some evidence has been presented to suggest that R32 HVAC systems can operate more efficiently than their R410A counterparts and a transition could have a substantial impact on the energy market and environment. Concerns over the flammability of the refrigerant should be considered by manufacturers and regulators and are often addressed by limitations on refrigerant charge. While there are many promising alternative refrigerants available, and more being developed now, R32 has the potential to reduce direct and indirect emissions of

[9] EIA. 2015. Form EIA-860 Detailed Data. Washington DC, USA.
[10] EIA. 2015. Annual Energy Outlook. Washington DC, USA.
[11] ibid.

HVAC&R systems, thus reducing the environmental impact and operating costs of heating and cooling.