Low Global Warming Potential (GWP) Alternative Refrigerants Evaluation Program (Low-GWP AREP)

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ABSTRACT

In response to environmental concerns raised by the use of high global warming potential (GWP) refrigerants, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) launched an industry-wide cooperative research program, AHRI Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP), to identify and evaluate promising alternative refrigerants for major product categories. These categories include air conditioners, heat pumps, chillers, water heaters, ice makers and refrigeration equipment. This paper provides an overview of the program, including the program's scope and procedure. A series of alternative refrigerant candidates being evaluated in the program will be introduced. The refrigerant candidates' thermodynamic cycle calculation and real testing results for various applications are presented up to the current status of the program.

1. INTRODUCTION

The Montreal Protocol calls for a complete phase-out of hydrochlorofluorocarbons (HCFCs) in developed countries effective 1 January 2030, and in developing countries by 1 January 2040. In the U.S., a ban on the sale and distribution of pre-charged equipment containing HCFC-22 has been in effect since 1 January 2010. Several candidate refrigerants have been identified as replacements for HCFCs. However, many of these replacements are hydrofluorocarbons (e.g., HFC-410A, HFC-134a, etc.) and have come under closer scrutiny due to global warming concerns. In response to these concerns, chemical producers and equipment manufacturers have stepped up efforts to develop low global warming potential (GWP) refrigerants and more efficient products. Several candidate refrigerants have already demonstrated low global warming potential. However, the performance of air conditioning and refrigeration systems using these candidates needs to be evaluated to ensure acceptable system capacity and efficiency.

AHRI launched the Low-GWP AREP in March 2011. The objective of the program is to identify and evaluate promising alternative refrigerants to high-GWP refrigerants for major product categories, and to provide common sets of quality data for the industry to use. The products covered in the program include air conditioners, heat pumps, chillers, water heaters, ice makers, and refrigeration equipment. The intent of the Low-GWP AREP Program is to help industry select the most promising refrigerants, avoid duplicative work, understand technical challenges and identify the research needed to use these refrigerants. The program will not prioritize these alternatives; rather, it will identify potential refrigerant replacements for high GWP refrigerants, and present the performance of these replacements in a consistent and standard manner.

The program primarily consists of a series of laboratory testing, including compressor calorimeter tests, drop-in tests, and soft-optimization tests. However, the program also includes a literature review of existing work related to performance testing of refrigerants to identify any gaps.

2. LOW-GWP ALTERNATIVE REFRIGERANT CANDIDATES

Forty low-GWP refrigerants were identified by a group of industry experts as potential alternative candidates. Thirty-eight of them have been selected for testing. Table 1 summarizes these candidates, their ASHRAE safety group classifications and baseline refrigerants that they intend to replace (in no particular ranking order). These refrigerants represent what industry currently feels have great potential to replace R-22 (or its HFC equivalent), R-134a, R-404A and R-410A. Some candidates in Table 1 are still in the development stage, and their compositions are currently confidential. Chemical producers will disclose these compositions to AHRI by November 2012.

Table 1: Alternative refrigerants for testing and evaluation

Baseline Refrigerants	**Alternative Refrigerant Candidates Classifications according to ASHRAE Standard 34**			**Others**
	A1	**A2L**	**A3**	
R-134a	AC5X, ARM-41a, D4Y, N-13a, N-13b, Opteon™XP10	AC5, R-1234yf, R-1234ze(E), ARM-42a	R-290+R-600a (40%+60%), R-600a	
R-404A	ARM-32a, N-40a, N-40b, DR-33	ARM-31a, ARM-30a, D2Y-65, L-40, R-32, R-32+R-134a (50%+50%), DR-7	R-290	R-744
R-410A		R-32, ARM-70a, D2Y-60, DR-5, HPR1A L-41a, L-41b, R-32+R-134a (95%+5%), R-32+R-152a (95%+5%)		R-744
R-22/R-407C	ARM-32a, LTR4X, N-20	D52Y, L-20, LTR6A	R-290	R-1270, R-717

The Low-GWP AREP also includes natural refrigerants, i.e. R-744 and R-717, as shown in Table 1. R-744 is an A1 refrigerant according to ASHRAE Standard 34. The sole reason for listing R-744 in the “Others” category of Table 1 is due to the fact that this refrigerant requires intensive system re-design, and is not suitable for either drop-in tests or soft-optimized tests for conventional systems. The program includes an effort to review existing work related to performance testing of these natural refrigerants, and to identify any gaps. The program will only accept test proposals on these refrigerants that fill known gaps on comparisons to other alternative refrigerants, since there have been a lot of experimental studies on natural refrigerants such as R-744.

An optional second round of selection later in the program will consider additional refrigerant candidates. The nominations process may be reopened in November 2012.

2.1 Global Warming Potential (GWP) Values

In the Low-GWP AREP, neither an upper numerical limit on refrigerants' GWP values nor the safety classifications are limitations to nominating refrigerants, as long as a candidate refrigerant has a significant reduction in its GWP relative to the refrigerant it is intended to replace. The GWP values of these candidates and their safety classifications are illustrated in Figure 1 [ASHRAE Standard 34, 2010]. The GWP values may be actual or estimated using 100 year integration time horizon and data from IPCC AR4 [IPCC AR4, 2007].

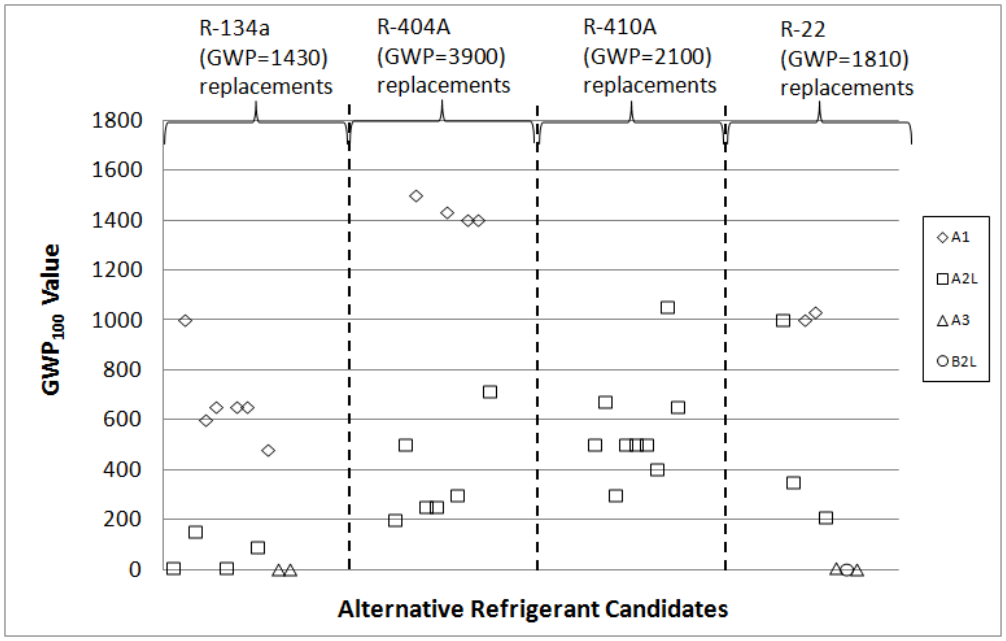

Figure 1: Overview of the candidates' GWP values (GWP values shown are approximate values.)

The figure indicates that candidates having relatively low GWP values are classified as either lower flammability (A2L), or higher flammability (A3). The non-flammable candidates (A1) have relatively higher GWP values compared to A2L and A3 candidates. No (A2) candidates were proposed for AREP. For R-410A replacements, all candidates are classified as A2L.

2.2 Results of Theoretical Cycle Analyses

The alternative refrigerant candidates listed in Table 1 cover the following possible applications:

- air-conditioning
- heat pump for conditioning air
- heat pump for heating water
- refrigeration (high-, mid-, and low-temperature)
- refrigeration (secondary-coolant)
- chiller (screw or scroll compressor)
- chiller (centrifugal compressor)

The candidates' theoretical thermodynamic cycle analyses have been carried out under typical operating conditions for the above applications. Table 2 summarizes these conditions. The analyses are based on the following assumptions:

- Compressor isentropic efficiency is a fixed value of 70%.
- Zero suction line pressure losses. Heat gain from ambient to raise vapor temperature to compressor suction superheat conditions.
- Cooling volumetric capacity is determined using density at compressor suction, and the enthalpy difference between evaporator inlet and evaporator outlet.

Table 2: Thermodynamic cycle calculation conditions

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5
Mean Evaporator Temperature, °F (°C)	40 (4)	45 (7)	20 (-7)	0 (-18)	-25 (-32)
Mean Condenser Temperature, °F (°C)	100 (38)	130 (54)	110 (43)	110 (43)	105 (41)
Evaporator Outlet Superheat, °F (K)	10 (6)	10 (6)	10 (6)	10 (6)	10 (6)
Compressor Suction Superheat, °F (K)	10 (6)	20 (11)	20 (11)	10 (6)	40 (22)
Subcooling, °F (K)	10 (6)	15 (8)	0 (0)	0 (0)	0 (0)

The candidates' relative performance to their baseline refrigerants are illustrated in Figure 2 to Figure 5.

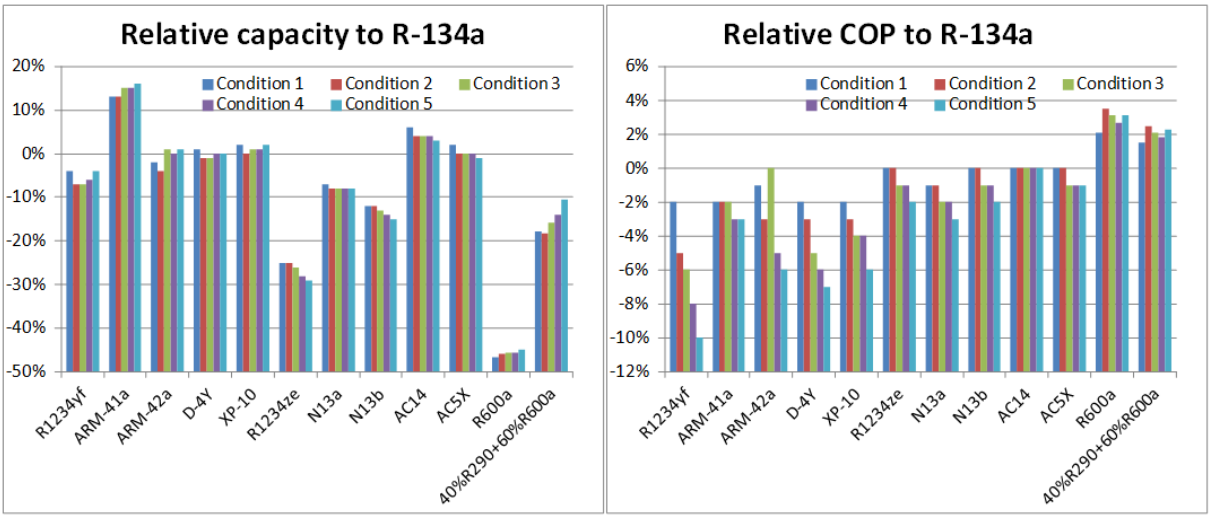

Figure 2: R-134a replacement candidates' relative performance to the baseline

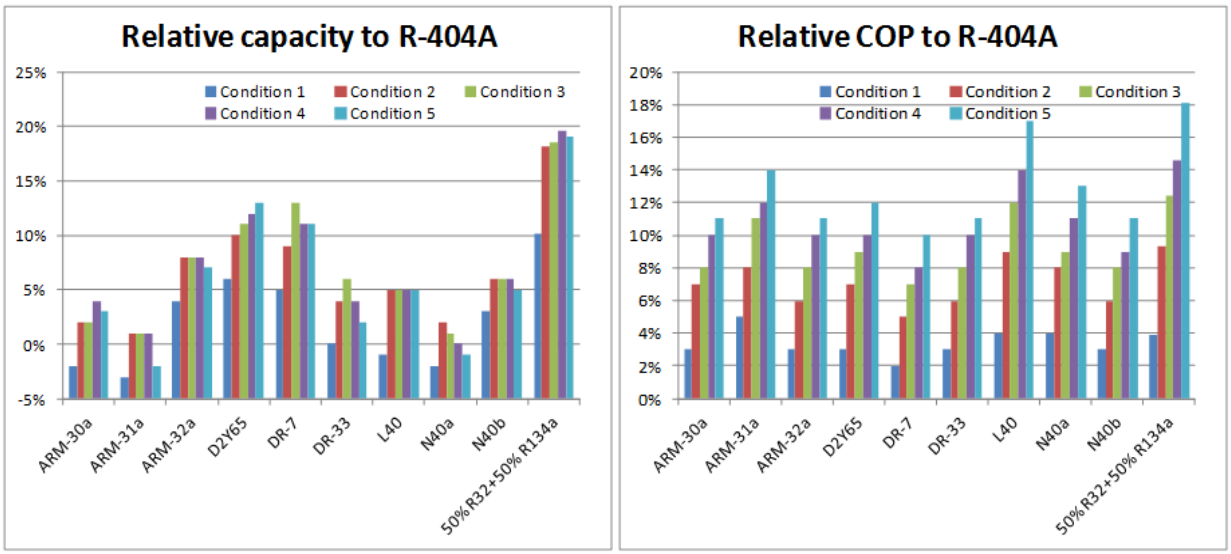

Figure 3: R-404A replacement candidates' relative performance to the baseline

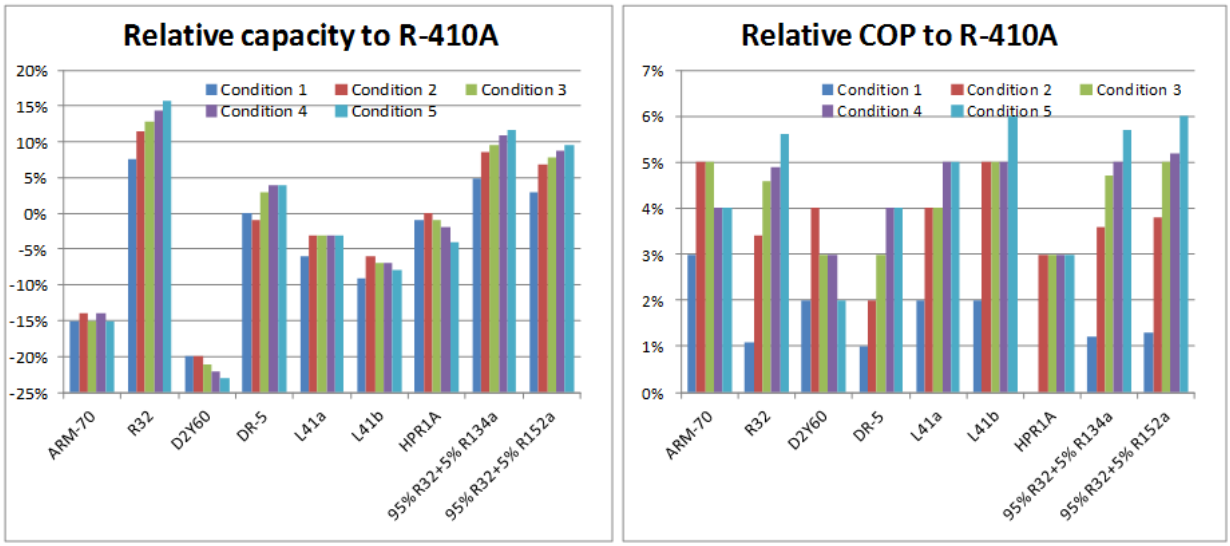

Figure 4: R-410A replacement candidates' relative performance to the baseline

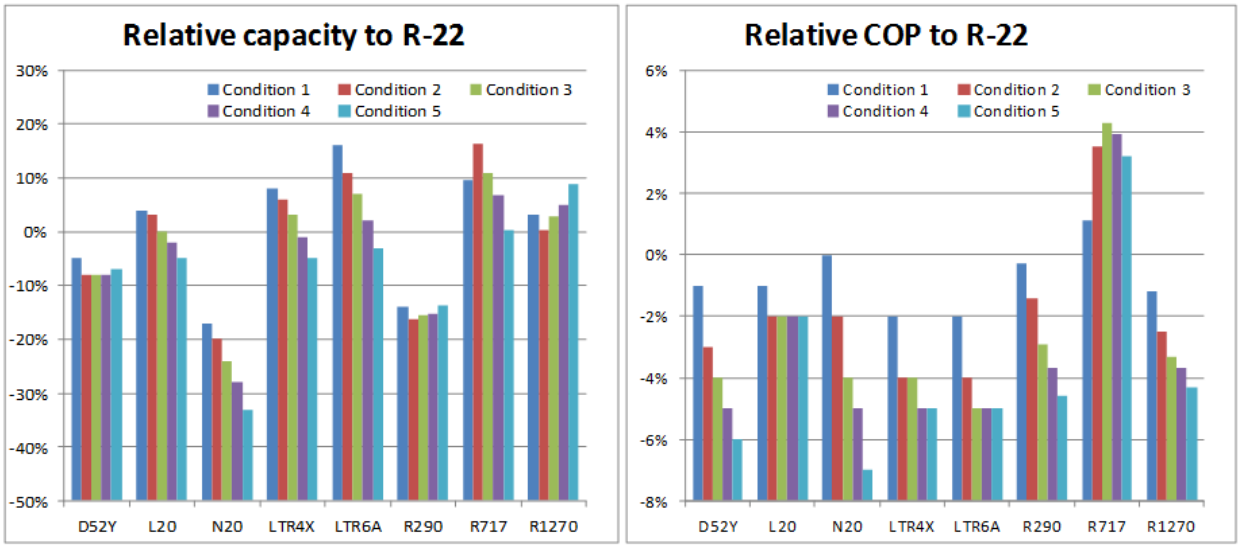

Figure 5: R-22/R-407C replacement candidates' relative performance to the baseline

3. TESTING REQUIREMENTS

The tests being undertaken at the current stage can be placed into three categories: compressor calorimeter tests, drop-in system tests, and soft-optimized system tests. Measuring the heat transfer coefficients of the alternative refrigerants will be scheduled in a later stage of the program.

One challenge faced in performing these tests is creating a standard testing environment so that results from one test site may be reasonably compared to results from a different test site. Thus, the Low-GWP AREP testing shall follow protocols and applicable standards specified in the subsections below.

3.1 Compressor Calorimeter Testing

For positive displacement compressors, tests are conducted in accordance with ASHRAE Standard 23-2010. Testing

companies in Europe can alternatively use EN 13771 as the testing standard, in which case the suction temperature tolerance must be in accordance with ASHRAE Standard 23.

3.2 Drop-in Testing

The drop-in tests are conducted with the alternative refrigerants placed in representative existing systems using baseline refrigerants with only minor modifications, if any, made to the equipment. The tests are run by following the latest industry-wide accepted standards specified by AHRI. Table 3 lists simplified examples for typical equipment and their test requirements. The detailed information is listed in the Low-GWP AREP Participants Handbook.

Table 3: Specified standards to be used in the Low-GWP AREP

Equipment type	Standards for Method of Testing	Standards for Performance Rating
Unitary Air-Conditioners and Heat Pumps (air-source)	ASHRAE Standard 37	AHRI Standard 210/240
Water Source Heat Pumps	ASHRAE Standard 37	ISO Standard 13256
Chillers (centrifugal, rotary screw, and reciprocating)	ASHRAE Standard 37	AHRI Standard 550/590
Ice Makers	ASHRAE Standard 29	AHRI Standard 810
Commercial Refrigerators	ASHRAE Standard 72	AHRI Standard 1200/1201
Ductless VRF	AHRI Standard 1230	AHRI Standard 1230

3.3 Soft-optimization Testing

Soft-optimized tests are performed using well understood R-22 and/or its HFC alternatives, R-134a, R-404A or R-410A systems as a baseline. These systems are modified for the alternative refrigerants using standard productionline components. In addition, the heat transfer area of the soft-optimized system's evaporator and condenser may be changed, provided that the sum of the total area remains the same as the baseline system. Manufacturers conducting tests may change components to get optimized performance, but are required to provide enough information to show these changes. The tests are conducted in accordance with the specified test standards in Table 3.

4. TESTING RESULTS

Test reports are not currently available to the public as the testing just started in late February 2012. However, AHRI expects that the results will be updated and presented during the conference.

5. CONCLUSIONS

The AHRI Low-GWP AREP is an ongoing effort to identify potential refrigerant replacements for high GWP refrigerants. It evaluates and presents their performance in a consistent and standard manner. Thirty-eight alternative refrigerant candidates are evaluated. Compared to the baseline refrigerants to be replaced, the candidates have significant lower GWP values. The program testing has started for some alternatives and will be on-going for the next few months. Results of the testing program will be released to the public at the end of 2012.

6. REFERENCES

American Society of Heating Refrigerating, and Air Conditioning Engineers, Standard 34, *Designation and Safety Classification of Refrigerants,* ASHRAE, Atlanta, GA, 2010.

Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: The Scientific Basis — Contribution of Working Group I to the IPCC Fourth Assessment Report*, World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), IPCC Secretariat, Geneva Switzerland, 2007

ACKNOWLEDGEMENT

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