PARTICIPANTS' HANDBOOK:

AHRI LOW-GWP ALTERNATIVE REFRIGERANTS EVALUATION PROGRAM (LOW-GWP AREP)

April 17, 2015

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NOTICES

The Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP) is an ongoing research effort managed by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). This handbook reflects the current status of this research effort. However, the information contained in this handbook may be supplemented or become outdated as the Low-GWP AREP effort progresses. It is anticipated that this handbook will be updated and revisions will be released as appropriate.

Some of the chemicals being tested under the Low-GWP AREP program may be toxic, flammable or otherwise hazardous. Companies producing, handling, testing, or using these chemicals should take all appropriate safety precautions.

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This document is a revised edition of the AHRI Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP) Participants' Handbook. It supersedes the previous versions.

EXECUTIVE SUMMARY

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 in 2011 to identify and evaluate promising alternative refrigerants for major product categories. These include air conditioners, heat pumps, chillers, heat pump water heaters, ice makers, and refrigeration equipment. The program, referred to as the Low-GWP Alternative Refrigerants Evaluation Program, or Low-GWP AREP, is strongly desired by the industry to assess the research needs, accelerate industry's response to environmental challenges raised by the use of high GWP refrigerants, and avoid duplicative work. The first round of testing within the program is complete. Thirty-eight refrigerant candidates were tested. AHRI is extending the program to a second-round of testing, or Phase II testing. Phase II testing will include newly developed candidates that were not tested in the first round testing. Phase II also includes refrigerant performance testing under high ambient conditions for various equipment.

The program consists of compressor calorimeter testing, system drop-in testing, soft-optimized system testing, and heat transfer testing. All tests other than heat transfer coefficient measurements are expected to be performed at participating companies' laboratories, using their own resources, at their own expense.

The Low-GWP AREP program is managed by a technical committee reporting to the AHRI Executive Committee. The AHRI Research Department administers the Low-GWP AREP program, coordinates and disseminates information and reports among the participating companies and the public.

Representatives of interested organizations should read this handbook to assess how they can best participate in the program, and should contact AHRI's Research Department for further information. Questions should be directed to:

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INTRODUCTION

This document has been prepared by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), a trade organization representing manufacturers of air-conditioning, heating, and refrigeration systems and components, to inform individuals and organizations of the research being undertaken through AHRI's Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP). This handbook will assist those interested in learning about the research program, contributing to the program, or obtaining the research results.

BACKGROUND

The Montreal Protocol calls for the 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.

An industry-wide cooperative program on Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP) is strongly desired by the industry to assess the research needs, accelerate industry's response to environmental challenges raised by the use of high GWP refrigerants, and avoid duplicative work. AHRI successfully managed the original R-22 AREP in the 1990s, and is again taking the lead in coordinating and managing this industry-driven research effort, along with industry experts from our member companies.

The Low-GWP AREP was launched in 2011, and first round testing is complete. Thirty-eight refrigerant candidates were tested. During this period, new candidates have been developed. Therefore, AHRI is extending the program to a second-round of testing, or Phase II testing. Phase II testing will include newly developed candidates that were not tested in the first round testing. Phase II also includes refrigerant performance testing under high ambient conditions for various equipment.

OBJECTIVES

The objective of the Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP) is to identify and evaluate promising alternatives to the high-GWP HFC refrigerants for major AHRI product categories including air-conditioners, heat pumps, dehumidifiers, chillers, heat pump water heaters, ice makers, and refrigeration equipment, and to provide common sets of quality data for the industry to use. The specific goals are as follows:

- Identify promising alternatives to high GWP HFCs for major AHRI product categories;
- Establish testing protocols for evaluating the candidate replacements;
- Conduct tests using the candidate refrigerants; and,
- Review and release the information collected and the results of tests.

The intent of the Low-GWP AREP Program is to help industry identify the most promising refrigerants, understand technical challenges and determine the research needed to use these refrigerants. The program will not prioritize these alternatives; rather, it will identify potential refrigerant replacements for high GWP HFC refrigerants, and present performance of these replacements in a consistent and standard manner.

ORGANIZATION OF THE PROGRAM

Low-GWP AREP is an effort undertaken by AHRI, its member companies and participating test entities. The AHRI Low-GWP AREP Technical Committee oversees the research that is done by the many "Participating Companies", U.S. and international organizations who have committed to performing research tasks under this program and sharing their results with the public.

The Technical Committee is composed of voting members representing AHRI member companies. The number of members may vary over the duration of the program but is no more than twenty (20). A list of these corporations and their representatives is included as Appendix A to this handbook (current members as of the revision date for this edition). Mr. Phillip Johnson, Engineering Director of Daikin Applied, serves as Chairman of the Technical Committee. Mr. Ken Hickman, Consultant of Johnson Controls, Inc., serves as Deputy Chairman of the Technical Committee. The Technical Committee is responsible for developing detailed test protocols prior to the start of the program, prioritizing tasks if refrigerant samples have limited availability, and ensuring quality of the results to be published. If the Technical Committee approves the results for publication, the refrigerant provider or the testing participant will have no veto power over the publication of the results. Additionally, AHRI will establish informal advisory groups as necessary to advise the Technical Committee on matters regarding specific elements of the testing program.

Participating companies will perform various types of tests with the alternative refrigerants selected by the Technical Committee.

The AHRI Research Department administers the Low-GWP AREP program, coordinates and disseminates information and reports among the participating companies and the public.

PARTICIPATING IN THE PROGRAM

Representatives of interested organizations should read this handbook to assess how they can best participate in the program, and should contact AHRI's Research Department for further information. Questions should be directed to:

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EVALUATION PROGRAM OVERVIEW

A group of refrigerants (and blends of refrigerants) has been identified as candidate alternative refrigerants for R-123, R-134a, R-404A, R-410A, and R-22 or its HFC alternatives. They are described in the "Alternative Refrigerants" section.

Participating members are expected to perform tests with at least one candidate refrigerant compared to a baseline. The tests being undertaken can be placed into four categories: compressor calorimeter tests, drop-in system tests, soft-optimized system tests, and heat transfer tests (to be conducted in a later stage).

The purpose of the compressor calorimeter tests is to measure the performance of the compressor as operated with the alternative refrigerants. More details about these tests, including testing protocols, are given below in the "Compressor Calorimeter Tests" section.

Also included in the Low-GWP AREP are system "drop-in" tests. These are tests conducted with the alternative refrigerants placed in representative existing systems, with only minor modifications, if any, made to the equipment. The performance of these refrigerants will be evaluated relative to the appropriate baseline such as R-22 or alternatives, R-123, R-134a, R-404A or R-410A, and the results will be reported.

A further step in the Low-GWP AREP effort is to design, build and test complete systems with the alternative refrigerants. Some adjusting of the system and its components may be performed in an attempt to "soft-optimize" the system. Thorough development and fine-tuning of optimized systems will be left up to individual companies, and will not be a part of the program.

The purpose of the heat transfer tests is to measure the heat transfer characteristics of the alternative refrigerants. Measuring the heat transfer coefficients of the alternative refrigerants will be scheduled in a later stage of the program. Ideally, it would start after the completion of compressor calorimeter testing and soft-optimized system testing. In such a sequence, some less promising refrigerant candidates may drop out.

Work other than testing, such as collection of related literature and computer simulations of a system operating at standard conditions for candidate fluids, may also be performed by participating companies as part of the Low-GWP AREP effort.

The final step will be to gather, organize, and publish the results. One outcome of this program will be published test reports approved by the Technical Committee. Approved test reports will be available to all companies conducting tests for the program two months before being made available to the public. The test reports will be available to the public through the Air-Conditioning, Heating and Refrigeration Institute, as well as from other sources.

AHRI expects that companies interested in testing alternative refrigerant candidates will submit their testing schedule and plan by the end of March 2014, and the Technical Committee will review the plans and notify the companies selected to perform the testing by the end of May 2014. It is anticipated that these companies may start testing as early as July 2014.

ALTERNATIVE REFRIGERANTS

Candidate Fluids

Selection of refrigerant candidates consists of two rounds. Refrigerants proposed by refrigerant manufacturers were considered in the initial round of nominations at the beginning of the program. The second round of selection considers additional refrigerant candidates. Neither an upper numerical limit on refrigerants' GWP values nor the safety classifications are limitations to nominating refrigerants, as long as a candidate low-GWP refrigerant has a significant reduction in its GWP relative to the refrigerant it is intended to replace.

In the initial round of selection, the Technical Committee identified and recommended forty refrigerants (and refrigerant blends) shown in Table 1 (in no particular ranking order) as potential candidates for evaluation under the Low-GWP AREP effort. Thirty-eight of them were actually tested according to test entities' interest in testing them.

The nominations process for Phase II testing was reopened in late 2013, and additional candidate refrigerants were added. The newly added refrigerants are shown in Table 2 (in no particular ranking order).

Some candidates covered in the first round testing will also be available for testing in Phase II if there is interest by test entities. These candidates are listed in Table 3 (in no particular ranking order).

The nominated candidates represent the fluids that industry currently feels have potential to replace R-123, R-22 (or its HFC equivalents), R-134a, R-404A or R-410A. The detailed information about these refrigerants is listed in Appendices B and C.

Table 1: Alternative Refrigerants for Testing and Evaluation in the First Round Nomination[1, 2]

Baseline Refrigerants	Alternative Refrigerant Candidates Classifications according to ASHRAE Standard 34			Others[3]
	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 [4]
R-410A		R-32, ARM-70a, D2Y-60, DR-5, HPR1D L-41a, L-41b, R-32+R-134a (95%+5%), R-32+R-152a (95%+5%)		R-744 [4]
R-22/R-407C	ARM-32a, LTR4X, N-20[4]	D52Y, L-20, LTR6A	R-290	R-1270, R-717

Notes:

1. Some refrigerants' composition information in the table was confidential at the beginning of the program. The individual testing companies were required to sign Non-Disclosure Agreement (NDA) with corresponding refrigerant suppliers in such a case, and must return the samples to the refrigerant suppliers upon the completion of testing unless otherwise required by the refrigerant suppliers. Refrigerant suppliers disclosed the composition(s) of their tested refrigerant(s) to the Low-GWP AREP Technical Committee in November 2012.
2. Some refrigerants in the table are available for testing in Phase II if there is interest by test entities. These candidates are listed in Table 3

3. The Low-GWP AREP TC invites submission of existing test results on the refrigerants listed in this category. Test proposals will be accepted if filling known gaps in comparisons to other alternative refrigerants.
4. No test companies proposed to test these candidates identified with superscript "4" in first round testing.

Table 2: Alternative Refrigerants for Phase II Testing and Evaluation[1]

Baseline Refrigerants	Alternative Refrigerant Candidates Classifications according to ASHRAE Standard 34		
	A1	A2L	A2
R-134a	BRB36		
R-404A	ARM-32b, ARM-35, D42Yb, D42Yz, DR-34 (R-452A), N-40c (R-448A), R-442A, R-449B[2]	ARM-20a, ARM-20b, HDR110	ARM-25a
R-410A		ARM-71a, DR-5A (R-454B)[2], DR-55, HPR2A L-41-1 (R-446A) L-41-2 (R-447A)	
R-22/R-407C	ARM-32c, D542HT, DR-91, DR-93, N-20b, R-442A, R-449B[2]	ARM-20b DR-3, L-20a (R-444B)	
R-123	ARC-1, R1233zd(E)	LPR1A	

Notes:

1. Applicable ASHRAE designations are listed in parentheses. Some refrigerants' composition information in the table may be confidential. The individual testing companies are required to sign a Non-Disclosure Agreement (NDA) with corresponding refrigerant suppliers in such a case, and must return the samples to the refrigerant suppliers upon the completion of testing unless otherwise required by the refrigerant suppliers. Refrigerant suppliers will disclose the composition(s) of their tested refrigerant(s) to the public in May 2015.
2. Pending ASHRAE's final approval and addendum publication.

Table 3: Alternative Refrigerants included in first round testing, but also available for Phase II further Testing and Evaluation[1]

Baseline Refrigerants	Alternative Refrigerant Candidates Classifications according to ASHRAE Standard 34		
	A1	A2L	A3
R-134a	AC5X, D4Y, N-13b, Opteon™XP10 (R-513A)	AC5 (R-444A) ARM-42a, R-1234yf, R-1234ze(E)	
R-404A	DR-33 (R-449A)	D2Y-65, DR-7 (R-454A)[2], L-40	
R-410A		R-32 D2Y-60, HPR1D	
R-22/R-407C	LTR4X N-20	D52Y, LTR6A	

Notes:
1. Applicable ASHRAE designations are listed in parentheses.
2. Pending ASHRAE's final approval and addendum publication

Thermodynamic property data needed for the Low-GWP AREP tests will be provided by the refrigerant supplier. The data format requirements are shown below in order of preference (most desirable is listed first):

1. Using REFPROP computer software program available from the National Institute of Standards and Technology (NIST), provide fluid file(s) and/or a mixture file (file type .FLD and .MIX).

2. If the refrigerant composition is confidential and covered by a Non-Disclosure Agreement, then provide thermodynamic property data as either:
    a. Coefficients for a series of curve fits, including definition of all empirical equation formats
    b. Tabular data with sufficiently small intervals of temperature or pressure

Definitions

Some of the alternative refrigerants are zeotropic blends, for which certain commonly used terms cannot be easily defined. The Technical Committee has agreed to use the following definitions during the Low-GWP AREP system performance testing of zeotropic blends:

- The evaporator temperature is the mean of the suction pressure dew point temperature and the evaporator inlet temperature.
- The condenser temperature is the mean of the discharge pressure dew point temperature and the discharge pressure bubble point temperature.

- The degree of superheat is the difference between the superheated vapor temperature and the suction pressure dew point temperature.
- The degree of subcooling is the difference between the subcooled liquid temperature and the discharge pressure bubble point temperature.

Schematics illustrating these definitions are shown in Appendix D.

COMPRESSOR CALORIMETER TESTS

Purpose

Compressor calorimeter tests are designed to provide an understanding of how well a given compressor works using a given refrigerant. Testing companies are expected to perform compressor calorimeter tests using the alternative refrigerants. Results are reported relative to R-22, R-123, R-134a, R-404A or R-410A.

Equipment

Different types of compressors are included in the testing program: positive displacement compressors (including those of the reciprocating, scroll, screw, and rotary types) and centrifugal compressors.

Testing Standards and Reporting

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 compressor calorimeter testing shall follow applicable standards. For positive displacement compressors, the testing shall be in accordance with ASHRAE Standard 23-2010. Testing companies in Europe may alternatively use EN 13771 as the testing standard in which case it must be clearly stated in the reports. If testing companies use EN 13771, the suction temperature tolerance shall be in accordance with ASHRAE Standard 23. Any test methods defined in both standards is acceptable (i.e. either calorimeter methods or flow meter methods are acceptable.). For tests on centrifugal compressors, the most recent American Society of Mechanical Engineers (ASME) Performance Test Code PTC-10 applies.

Individual companies may determine for themselves how many data points to measure during the compressor calorimeter tests. The test conditions for commercial refrigeration applications and air-conditioning applications are defined in the Table 4) and Table 5 respectively (each table has two unit systems labeled as IP and SI respectively.).

There may be a concern that, for zeotropic blends, the composition of the refrigerant being compressed may be different than the bulk composition of the refrigerant in the calorimeter. This could occur due to preferential evaporation of one of the components of the blend. Thus, refrigerant manufacturers need to provide their anticipated relative performance difference between low-GWP refrigerants and their baseline refrigerants to testing companies. If the testing companies

observe their testing results are out of the range provided by the refrigerant manufacturer (±10%), then testing companies need to discuss with refrigerant manufacturers. The testing companies and refrigerant manufacturers will mutually decide whether refrigerant samples will be taken from the system liquid line (while operating) after testing is completed and sent to the refrigerant manufacturer for analysis, or analyzed on-site. A preliminary check of the composition could be done on-site at the testing company facility at the time of test, by taking a sample while at target operating conditions, then bringing the sample to equilibrium with ambient temperature conditions (or a controlled temperature bath) and checking the relation of the sample's pressure versus saturation temperature. More precise composition measurements can be made by sending samples to the refrigerant manufacturer for analysis. For all confidential zeotropic blends, a refrigerant sample will always be taken after completion of testing and sent to the refrigerant manufacturer to confirm composition. Refrigerant manufacturers are to provide containers for these samples. If any refrigerant sample is found to contain incorrect composition of the zeotropic blend then previous tests must be discarded and new tests performed.

If at any point when testing a zeotropic refrigerant a leak is observed in the refrigeration system previous tests will be discarded and testing will be stopped until the leak is repaired. Once the leak is repaired a new charge of refrigerant will be installed in the system and all required tests performed from this point. Compressor performance testing with a low-GWP zeotropic blend cannot be performed on a test calorimeter or system which utilizes a "flooded evaporator" as flooded evaporators have a propensity to allow preferential evaporation of the components in the refrigerant blend.

Additionally, in order to obtain results that indicate how a refrigerant would perform in a compressor optimized for that refrigerant, the compressor calorimeter data shall be adjusted to account for different compressor speeds and motor efficiencies. Both raw and adjusted data shall be provided in the test reports. Uncertainty analysis shall be conducted, and all data for which the accuracy of the adjustments is suspect shall be flagged.

All compressor tests are performed at a refrigerant's dew point temperature for suction and discharge pressure conditions, per AHRI Standard 540 requirements. This does not have an impact on comparing compressor performance between two or more refrigerants that do not exhibit temperature glide. However, when refrigerants exhibit temperature glide, it is important to note that actual systems operate closer to the mid-point condition. When comparing compressor performance of one refrigerant with glide to another refrigerant without glide, or comparing two refrigerants with significantly different glides, comparison at pressures corresponding to the mid-point of the temperature glide rather than the dew point will yield results that are more representative of actual operation in a system.

Table 4.IP: Test Conditions for Compressors and Compressor Units for Commercial Refrigeration Applications[1,2,3]

Suction Dew Point Temperature	Discharge Dew Point Temperature [4]		Return Gas Temperature	Superheat	Subcooling
	Standard	High			
°F	°F	°F	°F	°F	°F
45	130	135	65	20	15
20	120	130	40	20	0
			60	40	
			65 [5]	45	
-10	120	125	10	20	0
			30	40	
			65 [5]	75	
-25	105	125	-5	20	0
			15	40	
			65 [5]	90	
-40	105	125	-20	20	0
			0	40	
			65 [5]	105	

NOTES:

1. This table applies to all compressor types.
2. Table values are the target operating conditions.
3. Allowable ambient temperature range surrounding compressors during performance evaluation testing shall be 70°F to 95°F. Ambient temperature surrounding the compressor during baseline refrigerant testing versus new candidate refrigerant testing shall be within ±7°F. If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
4. Two values of discharge dew point temperature are provided. The column labeled "standard" contains required operating condition test points corresponding to typical applications with outdoor ambient of 95°F. The column labeled "high" contains additional operating condition test points to be conducted at the option of the participating testing company, and correspond to typical applications with higher outdoor ambient of 115°F. Testing of these conditions is strongly encouraged.
5. Test at this value of return gas temperature if attainable.

Table 4.SI: Test Conditions for Compressors and Compressor Units for Commercial Refrigeration Applications[1,2,3]

Suction Dew Point Temperature	Discharge Dew Point Temperature [4]		Return Gas Temperature	Superheat	Subcooling
	Standard	High			
°C	°C	°C	°C	°C	°C
7.2	54.4	57.2	18.3	11.1	8.3
-6.7	48.9	54.4	4.4	11.1	0.0
			15.6	22.2	
			18.3 [5]	25.0	
-23.3	48.9	51.7	-12.2	11.1	0.0
			-1.1	22.2	
			18.3 [5]	41.7	
-31.7	40.6	51.7	-20.6	11.1	0.0
			-9.4	22.2	
			18.3 [5]	50.0	
-40.0	40.6	51.7	-28.9	11.1	0.0
			-17.8	22.2	
			18.3 [5]	58.3	

NOTES:

1. This table applies to all compressor types.
2. Table values are the target operating conditions.
3. Allowable ambient temperature range surrounding compressors during performance evaluation testing shall be 21°C to 35°C. Ambient temperature surrounding the compressor during baseline refrigerant testing versus new candidate refrigerant testing shall be within ±4K. If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
4. Two values of discharge dew point temperature are provided. The column labeled "standard" contains required operating condition test points corresponding to typical applications with outdoor ambient of 95°F [35.0°C]. The column labeled "high" contains additional operating condition test points to be conducted at the option of the participating testing company, and correspond to typical applications with higher outdoor ambient of 115°F [46.1°C]. Testing of these conditions is strongly encouraged.
5. Test at this value of return gas temperature if attainable.

Table 5.IP: Test Conditions for Compressors and Compressor Units Used In Air Conditioners and Heat Pumps [1,2,4,5]

Rating Test Point	Intended Use	Suction Dew Point Temperature	Discharge Dew Point Temperature	Return Gas Temperature	Capacity Setting (Note 3)
		˚F	˚F	˚F	
A	Air Source (Cooling)	45	130 (standard)[6] 135 (high ambient)[6]	65	MAX.
B	Air Source (Cooling)	45	115	65	MAX.
C	Air Source (Cooling & Heating)	45	100	65	MIN.
D	Air Source (Heating)	30	110	50	MAX.
E	Air Source (Heating)	5	95	25	MAX.
F	Air Source (Cooling)	45	80	65	MIN.
G	Air Source (Heating)	35	90	55	MIN.
H	Water Source (Cooling & Heating)	45	120	65	MAX. & MIN.

NOTE:
1) Allowable ambient temperature range surrounding compressors during performance evaluation testing is to be 70˚F to 95˚F. Ambient temperature surrounding the compressor during baseline testing and low-GWP refrigerants testing is to be within ±7˚F in all cases.
2) If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
3) The maximum and minimum capacity setting is the highest and lowest displacement capacity obtainable by the compressor or compressor unit.
4) 15°F degrees of subcooling
5) Table values are the target operating conditions.
6) Two discharge dew point temperatures are applied to rating point A. 130°F is the standard rating condition, and 135°F is the added high ambient condition.

Table 5.SI: Test Conditions for Compressors and Compressor Units Used In Air Conditioners and Heat Pumps[1,2,4,5]

Rating Test Point	Intended Use	Suction Dew Point Temperature	Discharge Dew Point Temperature	Return Gas Temperature	Capacity Setting (Note 3)
		˚C	˚C	˚C	
A	Air Source (Cooling)	7.2	54.4 (standard)[6] 57.2 (high ambient)[6]	18	MAX.
B	Air Source (Cooling)	7.2	46.1	18	MAX.
C	Air Source (Cooling & Heating)	7.2	37.8	18	MIN.
D	Air Source (Heating)	-1.1	43.3	10	MAX.
E	Air Source (Heating)	-15	35	3.9	MAX.
F	Air Source (Cooling)	7.2	27	18	MIN.
G	Air Source (Heating)	1.7	32	13	MIN.
H	Water Source (Cooling & Heating)	7.2	48.9	18	MAX. & MIN.

NOTE:
1) Allowable ambient temperature range surrounding compressors during performance evaluation testing is to be 21.1˚C to 35˚C. Ambient temperature surrounding the compressor during baseline testing and low-GWP refrigerants testing is to be within ±3.9˚C in all cases.
2) If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
3) The maximum and minimum capacity setting is the highest and lowest displacement capacity obtainable by the compressor or compressor unit.
4) 8.3K degrees of subcooling
5) Table values are the target operating conditions.
6) Two discharge dew point temperatures are applied to rating point A. 54.4°C is the standard rating condition, and 57.4°C is the added high ambient condition.

Performance maps for the baseline and alternative refrigerants shall be created from data obtained during the calorimeter tests and shall be provided with the test results. The polynomial equation that shall be used to represent the tabular data is a third degree equation of ten coefficients in the form of:

$$X = C1 + C2 \cdot (S) + C3 \cdot D + C4 \cdot (S^2) + C5 \cdot (S \cdot D) + C6 \cdot (D^2) + C7 \cdot (S^3) + C8 \cdot (D \cdot S^2) + C9 \cdot (S \cdot D^2) + C10 \cdot (D^3)$$

where:
C = Equation coefficient, represents compressor performance
S = Suction dew point temperature, °F [°C]
D = Discharge dew point temperature, °F [°C]
X = compressor performance (mass flow rate, capacity, power and COP)

The mass flow rate, capacity (useful capacity at evaporator based on 10˚F superheat), power input, and coefficient of performance (COP) shall be included on the performance map. Also, a performance map of the COP ratio (alternative refrigerant relative to baseline) shall be provided. These performance results should be reported over temperature ranges specified in Table 6 (the table has two unit systems labeled as IP and SI respectively.).

Testing companies may propose different discharge dew point temperature ranges to the Technical Committee for approval if it is difficult to test due to laboratories' limitations.

The baseline refrigerant (R-22, R-123, R134a, R-404A or R-410A), shall be tested, if possible, in the same compressor at the same operating conditions. It is recognized, however, that due to the different properties of some of the alternative refrigerants as compared with the baseline refrigerant, circumstances may justify altering the compressor or using a different compressor altogether. The test report shall detail any such changes and why they were made.

AHRI has provided a sample report format (see Appendix E) to be used as a guide for providing compressor calorimeter test results. This report format gives more details as to the type of data required. Authors should also refer to Appendix I for the checklist that the TC uses to review and approve the AREP test reports. The test reports should meet the requirements defined in the checklist.

Table 6.IP: Compressor Calorimeter Performance Map Reporting Conditions

Application	Suction Dew Point Temperature (Note 2)	Discharge Dew Point Temperature (Note 2)	Superheat
	˚F	˚F	˚F
Air-conditioning (including heat pump)	-10 to 55 in 5˚F increments	70 to 150 in 10˚F increments	20
High temperature (water coolers and walk-in coolers, for example)	20 to 50 in 5˚F increments	70 to 150 in 10˚F increments	20 ˚F superheat 40˚F superheat, and 65˚F return gas if attainable (see Note 3).
Medium temperature (displace cases, for example)	-10 to 35 in 5˚F increments	70 to 150 in 10˚F increments	
Low temperature (freezer cases, for example)	-40 to 10 in 5˚F increments	70 to 150 in 10˚F increments	

Note:
1. Allowable ambient temperature range surrounding compressors during performance evaluation testing to be 70˚F to 95˚F. Ambient temperature surrounding the compressor during baseline testing and low-GWP refrigerants testing to be within ±7˚F in all cases. If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
2. The tabular data shall be reported at the above conditions for the compressor application usage intended. The extreme ends of the tabular data may be omitted and not reported due to limits of acceptable operation of the compressor as determined by the manufacturer.
3. Two sets of superheating (20˚F and 40˚F) shall be applied to all tests. If attainable, 65˚F return gas shall also be tested, and performance maps shall be generated.

Table 6.SI: Compressor Calorimeter Performance Map Reporting Conditions

Application	Suction Dew Point Temperature (Note 2)	Discharge Dew Point Temperature (Note 2)	Superheat
	˚C	˚C	˚C
Air-conditioning (including heat pump)	-23 to 13 in 3˚C increments	21 to 65 in 5.6˚C increments	11.1
High temperature (water coolers and walk-in coolers, for example)	-7 to 10 in 3˚C increments	21 to 65 in 5.6˚C increments	11.1 ˚C superheat, 22.2 ˚C superheat, and 18.3˚C return gas if attainable.
Medium temperature (displace cases, for example)	-23 to 1 in 3˚C increments	21 to 65 in 5.6˚C increments	
Low temperature (freezer cases, for example)	-40 to -12 in 3˚C increments	21 to 65 in 5.6˚C increments	

Note:
1. Allowable ambient temperature range surrounding compressors during performance evaluation testing to be 21.1˚C to 35˚C. Ambient temperature surrounding the compressor during baseline testing and low-GWP refrigerants testing to be within ±3.9˚C in all cases. If airflow across the compressor is used to determine ratings, it shall be specified by the compressor manufacturer.
2. The tabular data shall be reported at the above conditions for the compressor application usage intended. The extreme ends of the tabular data may be omitted and not reported due to limits of acceptable operation of the compressor as determined by the manufacturer.
3. Two sets of superheating (11.1˚C and 22.2˚C) shall be applied to all tests. If attainable, 18.3˚C return gas shall also be tested, and performance maps shall be generated.

DROP-IN TEST

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. Minor modifications may include:

1. Adjustment of refrigerant charge quantity (by mass, the charge quantity may be different from the baseline refrigerant). It is strongly preferred to perform some type of charge optimization for each candidate refrigerant. The specific target for optimization may be selected by the testing company, but must be described and documented in the test report. Possible optimization targets are listed below (combinations of the following are also allowed):
    a. Match subcooling of baseline system (particularly if the expansion device is non-adjustable)
    b. Maximum full load capacity
    c. Maximum full load efficiency (COP)
    d. Maximum weighted part load metric or seasonal efficiency metric (weighted average of multiple COP values from different operating conditions)
2. Adjustment of expansion device (if adjustable). The specific target for adjustment may be selected by the testing company, but must be described and documented in the test report. One example is to maintain same superheat as the baseline system (either compressor suction or evaporator outlet).
    a. In the case of adjustable thermal expansion valves, an adjustment of the valve set point but not modifying internal components and not replacing the valve.
    b. In the case of electronic expansion valve, either modification of the control logic or manual operation of valve position to account for differences in the saturation properties of the candidate refrigerant.
3. Adjustment of compressor speed to modify compressor flow rate, either mass flow or volumetric flow (if baseline equipment is variable speed capable).

The tests are run under AHRI standard rating conditions for the equipment used (see Appendix G). Participating companies are strongly encouraged to perform additional tests at high ambient operating conditions, appropriately selected according to the equipment type (see Appendix G). The performance of these refrigerants will be evaluated relative to R-22, R-123, R-134a, R-404A or R-410A, and the results will be reported.

Some alternative refrigerants may not necessarily warrant drop-in tests for some applications if significantly negative results could be expected based on existing information or previous work. The Technical Committee will decide whether a drop-in test would be appropriate for a certain alternative refrigerant and its application(s) once the list of candidate refrigerants is finalized.

Refrigerant manufacturers need to provide their anticipated relative performance difference between low-GWP refrigerants and their baseline refrigerants to testing companies. If the testing companies observe their testing results are out of the range provided by the refrigerant manufacturer (±10%), then testing companies need to discuss with refrigerant manufacturers. The testing companies and refrigerant manufacturers will mutually decide whether refrigerant samples will be taken from the system liquid line (while operating) after testing is completed and sent to

the refrigerant manufacturer for analysis, or analyzed on-site. A preliminary check of the composition could be done on-site at the testing company facility at the time of test, by taking a sample while at target operating conditions, then bringing the sample to equilibrium with ambient temperature conditions (or a controlled temperature bath) and checking the relation of the sample's pressure versus saturation temperature. More precise composition measurements can be made by sending samples to the refrigerant manufacturer for analysis. For all confidential zeotropic blends, a refrigerant sample will always be taken after completion of testing and sent to the refrigerant manufacturer to confirm composition. Refrigerant manufacturers are to provide containers for these samples. If any refrigerant sample is found to contain incorrect composition of the zeotropic blend then previous tests must be discarded and new tests performed.

If at any point when testing a zeotropic refrigerant a leak is observed in the refrigeration system, previous tests will be discarded and testing will be stopped until the leak is repaired. Once the leak is repaired a new charge of refrigerant will be installed in the system and all required tests performed from this point.

AHRI has provided a sample report format and data form (see Appendix F) to be used as a guide for providing drop-in test results. Authors should also refer to Appendix I for the checklist that the TC uses to review and approve the AREP test reports. The test reports should meet the requirements defined in the checklist.

SOFT-OPTIMIZED SYSTEM TESTS

Purpose

To better understand the potential performance of the alternative refrigerants, full systems may be designed, built and tested. Using results from earlier parts of the program, participating companies may soft-optimize the new systems for the particular refrigerants. Thorough development and fine-tuning of optimized systems will be left up to individual companies, and will not be a part of the program.

Equipment

Soft-optimized tests shall be performed using well-understood R-22, R-123, R-134a, R404A or R-410A systems as a baseline. These systems shall be modified for the alternative refrigerants using standard production-line components. Tests using the baseline refrigerant in the soft-optimized systems are allowed but not required, provided that data on the performance of the baseline system with the baseline refrigerant is reported.

Manufacturers conducting tests may change components to get optimized performance, but are required to provide enough information to show these changes. In general, testing companies need to propose their testing plans and provide a detailed list of planned changes for soft-optimized testing, and the Technical Committee will decide whether the plan allows a fair comparison and the results are appropriate to be published. Following are examples that may be changed, if deemed appropriate, to soft-optimize the system for the particular alternative refrigerant:

- compressor displacement and/or motor size;
- flow control;
- heat transfer circuiting;
- use of a liquid-line/suction-line heat exchanger;
- amount of refrigerant charge;
- use of a variable speed compressor motor;
- diameter / size of the tubing to adapt to the refrigerant volume flow and pressure drop
- size of accumulators; and
- lubricant.

In addition, the heat transfer area of the soft-optimized system's evaporator and condenser may be changed, provided that the sum total area remains the same as the baseline system.

Testing Standards and Reporting

System tests shall be conducted using the most recent version of appropriate AHRI and ASHRAE Standards (see Appendix G), at one or more standard rating conditions. Testing companies shall report all required data per the applicable standards. Participating companies are strongly encouraged to perform additional tests at high ambient operating conditions, appropriately selected according to the equipment type (see Appendix G), provided that comparison data is presented for both baseline performance and soft-optimized test results.

Refrigerant manufacturers need to provide their anticipated relative performance difference between low-GWP refrigerants and their baseline refrigerants to testing companies. If the testing companies observe their testing results are out of the range provided by the refrigerant manufacturer (±10%), then testing companies need to discuss with refrigerant manufacturers. The testing companies and refrigerant manufacturers will mutually decide whether refrigerant samples will be taken from the system liquid line (while operating) after testing is completed and sent to the refrigerant manufacturer for analysis, or analyzed on-site. A preliminary check of the composition could be done on-site at the testing company facility at the time of test, by taking a sample while at target operating conditions, then bringing the sample to equilibrium with ambient temperature conditions (or a controlled temperature bath) and checking the relation of the sample's pressure versus saturation temperature. More precise composition measurements can be made by sending samples to the refrigerant manufacturer for analysis. For all confidential zeotropic blends, a refrigerant sample will always be taken after completion of testing and sent to the refrigerant manufacturer to confirm composition. Refrigerant manufacturers are to provide containers for these samples. If any refrigerant sample is found to contain incorrect composition of the zeotropic blend then previous tests must be discarded and new tests performed.

If at any point when testing a zeotropic refrigerant a leak is observed in the refrigeration system, previous tests will be discarded and testing will be stopped until the leak is repaired. Once the leak is repaired a new charge of refrigerant will be installed in the system and all required tests performed from this point.

The following data should be included in soft-optimized system test reports where applicable:

- efficiency values: EER, SEER, COP, HSPF and C_D (for unitary equipment); COP (for chillers);
- power input;
- capacity: total and sensible;
- refrigerant temperatures: compressor suction and discharge, condenser entering and leaving, expansion device inlet, subcooling at expansion device, evaporator entering and leaving, and evaporator superheating, intermediate measurement within evaporator and condenser coils are desirable for blends;
- refrigerant pressures: compressor suction and discharge, expansion device inlet, and evaporator outlet;
- vapor injection;
- liquid injection;
- mass flow rate;
- total refrigerant charge; and
- refrigerant composition at inlet (for blends) if necessary, analysis to be done by refrigerant manufacturers if restricted by NDA.

AHRI has provided a sample report format and data form (see Appendix H) to be used as a guide for providing soft-optimized system test results. Authors should also refer to Appendix I for the checklist that the TC uses to review and approve the AREP test reports. The test reports should meet the requirements defined in the checklist.

HEAT TRANSFER TESTS

Purpose

The heat transfer properties of the refrigerant can have a major impact on the efficiency of air-conditioning and refrigeration systems. Evaporative and condensing heat transfer coefficient data for the alternative refrigerants are required to provide inputs to engineering simulation models and will be used by participating companies in developing and testing air-conditioning, heat pump, and refrigeration equipment employing the alternative refrigerants.

Measuring the heat transfer coefficients of the alternative refrigerants will be scheduled in a later stage of the program. Ideally, it will start after the completion of compressor calorimeter testing and soft-optimized system testing. In such a sequence, some less promising refrigerant candidates may drop out.

Tests to be Performed

Heat transfer coefficients for boiling (evaporation) and condensation are desired for the refrigerants being evaluated. Thus, four areas of testing are required:

1. Evaporator, refrigerant inside tube (EIT)
2. Evaporator, refrigerant outside tube (EDT)
3. Condenser, refrigerant inside tube (CIT)
4. Condenser, refrigerant outside tube (COT)

In addition to the tests with pure refrigerant, heat transfer testing for some refrigerants with lubricants added will be performed. The percentage of lubricants charged will be determined in a later stage.

WORKS OTHER THAN TESTING

Although the core of the program is testing work, and computer modeling is not included in the program, the test data from the program will allow the industry members to calibrate their simulation tools. These who can do simulations are encouraged to use the testing results from the program to do their own simulations and publish their results separately.

A review team will be formed to select and compile existing works of good quality related to performance testing of low-GWP refrigerants, and to identify any gaps. The review team invites submission of existing test results on natural refrigerants and comparisons to other alternative refrigerants.

LOW-GWP AREP RESULTS

The results from this program will be available through several channels. It is expected that the results will be released upon acceptance by the Low-GWP AREP Technical Committee. It is required that test companies send test results directly to the Technical Committee without refrigerant suppliers' pre-approval. Approved test reports will be made available to all test companies two months before being made available to the public. In addition to test results, AHRI will publish the composition(s) of new Phase II refrigerants selected for tests in May 2015.

In consideration of participation in the AHRI Low-GWP AREP program, test companies grant to AHRI a perpetual, non-exclusive and irrevocable license to publish test reports on AHRI's website or other electronic and printed media. Such license shall include the right to publish, reproduce, reprint, and translate the reports, in whole or in part, in connection with the program or in any other manner in AHRI's sole discretion.

Intermediate results will also be reported in technical literature, as well as at conferences, symposia and other meetings. All results from testing conducted through the program must be reviewed and approved by the Technical Committee before anyone can publish them. Testing companies in the program must get the Technical Committee's permission to publish their results outside the program. Subsequent publication for the same content does not require the Technical Committee's approval.

Companies, individuals and organizations performing work in the area of low-GWP alternative refrigerants who wish to contribute their results to Low-GWP AREP are strongly encouraged to contact AHRI. Contributions of data and inquiries regarding the Low-GWP AREP effort should be directed to:

Mr. Karim Amrane,
Vice President, Regulatory and Research, AHRI
Phone: (703) 600-0307, E-mail: KAmrane@ahrinet.org

APPENDIX A: MEMBERS OF THE LOW-GWP AREP TECHNICAL COMMITTEE

Arkema Inc.…..Mr. Laurent Abbas
Bitzer North America.....Mr. Joe Sanchez
Carrier Corporation.....Mr. Larry Burns
CPI Fluid Engineering .....Mr. Joe Karnaz
Daikin Applied Americas Inc. ..... Mr. Phillip Johnson (Chairman)
Danfoss .....Ms. Alice Riemer
E. I. du Pont de Nemours & Co. .....Ms. Barbara H. Minor
Emerson Climate Technologies .....Mr. Rajan Rajendran
Hill Phoenix. .....Mr. Scott Martin
Honeywell International, Inc. .....Mr. Mark Spatz
Hussmann Corporation. ..... Mr. Paul Laurentius
Ingersoll Rand.....Mr. Steve Kujak
Johnson Controls, Inc.....Mr. Kenneth E. Hickman (Deputy Chairman)
Lennox Industries, Inc. .....Mr. Robert B. Uselton
Manitowoc Ice Inc. .....Mr. Bill Olson
Mexichem Fluor, Inc. .....Mr. Sean Cunningham
National Refrigerants, Inc.....Mr. Robert Yost
Tecumseh Products Co.. .....Mr. Cassio Maule

APPENDIX B: INFORMATION ON ALTERNATIVE REFRIGERANT CANDIDATES IN THE FIRST ROUND TESTING

The alternative refrigerant candidates listed in Table 1 of this document were provided by six chemical producers:

- Arkema Inc.
- Daikin Industries, Ltd.
- E. I. du Pont de Nemours & Co.
- Honeywell International, Inc.
- Mexichem Fluor, Inc.
- National Refrigerants, Inc.

These candidates cover the following possible applications:

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

Some candidates' compositions were confidential at the beginning of the program. The individual testing companies were required to sign a Non-Disclosure Agreement (NDA) with corresponding refrigerant suppliers in such a case. As the program progressed, all those refrigerants compositions were made publically available. The composition information is listed in the Table below. New candidates in Phase II may be confidential and require NDAs prior to testing. The candidates' thermodynamic cycle calculation is provided in this section compared to their baseline refrigerants. For candidates requiring NDAs, only listed were temperature glides and relative performance to baselines. The candidates' information in this section is based on the following assumptions:

- Compressor isentropic efficiency is 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.
- GWP values may be actual or estimated using 100 year integration time horizon and data from IPCC AR4. For candidates whose GWP values (single component) or components' GWP values (blends) are not listed in the IPCC AR4, their GWP values are from the UNEP 2010 RTOC Assessment Report.

Refrigerant Composition Information

Temporary Designation	ASHRAE Designation	Composition	(Mass%)
AC5	R-444A	R-32/R-152a/R-1234ze(E)	(12/5/83)
AC5X		R-32/R-134a/R-1234ze(E)	(7/40/53)
ARM-30a		R-32/R-1234yf	(29/71)
ARM-31a		R-32/R-134a/R-1234yf	(28/21/51)
ARM-32a		R-32/R-125/R-134a/R-1234yf	(25/30/25/20)
ARM-41a		R-32/R-134a/R-1234yf	(6/63/31)
ARM-42a		R-134a/R-152a/R-1234yf	(7/11/82)
ARM-70a		R-32/R-134a/R-1234yf	(50/10/40)
D2Y-60		R-32/R-1234yf	(40/60)
D2Y-65		R-32/R-1234yf	(35/65)
D4Y		R-134a/R-1234yf	(40/60)
D52Y		R-32/R-125/R-1234yf	(15/25/60)
DR-33	R-449A	R-32/R-125/R-134a/R-1234yf	(24/25/26/25)
DR-5		R-32/R-1234yf	(72.5/27.5)
DR-7	R-454A [1]	R-32/R-1234yf	(36/64)
HPR1D		R-32/R-744/R-1234ze(E)	(60/6/34)
L-20		R-32/R-152a/R-1234ze(E)	(45/20/35)
L-40		R-32/R-152a/R-1234yf/R-1234ze(E)	(40/10/20/30)
L-41a		R-32/R-1234yf/R-1234ze(E)	(73/15/12)
L-41b		R-32/R-1234ze(E)	(73/27)
LTR4X		R-32/R-125/R-134a/R-1234ze(E)	(28/25/16/31)
LTR6A		R-32/R-744/R-1234ze(E)	(30/7/63)
N-13a		R-134a/R-1234yf/R-1234ze(E)	(42/18/40)
N-13b	R-450A	R-134a/R-1234ze(E)	(42/58)
N-20		R-32/R-125/R-134a/R-1234yf/R-1234ze(E)	(12.5/12.5/31.5/13.5/30)
N-40a		R-32/R-125/R-134a/R-1234yf/R-1234ze(E)	(25/25/21/9/20)
N-40b		R-32/R-125/R-134a/R-1234yf	(25/25/20/30)
R-1234yf		R-1234yf	(100)
R-1234ze(E)		R-1234ze(E)	(100)
R-1270		R-1270	(100)
R-290		R-290	(100)
R-290/R-600a		R-290/R-600a	(40/60)
R-32		R-32	(100)
R-32/R-134a		R-32/R-134a	(50/50)
R-32/R-134a		R-32/R-134a	(95/5)
R-32/R-152a		R-32/R-152a	(95/5)
R-600a		R-600a	(100)
R-717		R-717	(100)
R-744		R-744	(100)
XP-10	R-513A	R-134a/R-1234yf	(44/56)

1. Pending ASHRAE's final approval and addendum publication.

B.1: R-134a Replacements

B.1.1: Candidates provided by Arkema Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	149
		Pressure Ratio ( )	2.8	3.9	4.9	7.7	13.5
		Compressor Discharge Superheat (°F)	32.4	48.4	55.4	56.5	107.0
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	72.3	69.9	41.8	26.0	13.8
		Cooling Efficiency (COP)	5.13	3.32	2.76	2.10	1.48
Candidate Refrigerant	R1234yf	Suction Pressure (psia)	52	57	36	24	13
		Discharge Pressure (psia)	138	207	158	158	148
		Pressure Ratio ( )	2.7	3.6	4.4	6.6	11.4
		Compressor Discharge Superheat (°F)	20.3	31.9	36.5	33.0	75.0
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	68.9	64.7	39.1	24.4	13.2
		Cooling Efficiency (COP)	5.01	3.18	2.61	1.95	1.35
		GWP_{100}	4				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	4.0%	3.6%	9.1%	14.3%	18.2%
		Discharge Pressure (%)	-0.7%	-2.8%	-1.9%	-1.9%	-0.7%
		Pressure Ratio (%)	-4.5%	-6.2%	-10.0%	-14.1%	-16.0%
		Capacity (%)	-4.7%	-7.4%	-6.5%	-6.2%	-4.3%
		Efficiency (%)	-2.3%	-4.2%	-5.4%	-7.1%	-8.8%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	149
		Pressure Ratio ( )	2.8	3.9	4.9	7.7	13.5
		Compressor Discharge Superheat (°F)	32.4	48.4	55.4	56.5	107.0
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	72.3	69.9	41.8	26.0	13.8
		Cooling Efficiency (COP)	5.13	3.32	2.76	2.10	1.48
Candidate Refrigerant	ARM-41a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	4	3	3	3	2
		Condenser Temperature Glide (°F)	5	5	5	5	5
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	< 1000				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	20%	18%	21%	24%	27%
		Discharge Pressure (%)	16%	14%	15%	15%	16%
		Pressure Ratio (%)	-4%	-4%	-5%	-7%	-9%
		Capacity (%)	13%	13%	15%	15%	16%
		Efficiency (%)	-2%	-2%	-2%	-3%	-3%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	149
		Pressure Ratio ( )	2.8	3.9	4.9	7.7	13.5
		Compressor Discharge Superheat (°F)	32.4	48.4	55.4	56.5	107.0
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	72.3	69.9	41.8	26.0	13.8
		Cooling Efficiency (COP)	5.13	3.32	2.76	2.10	1.48
Candidate Refrigerant	ARM-42a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	< 150				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	6%	6%	12%	14%	18%
		Discharge Pressure (%)	0%	-2%	-1%	-1%	0%
		Pressure Ratio (%)	-6%	-7%	-11%	-13%	-15%
		Capacity (%)	-2%	-4%	1%	0%	1%
		Efficiency (%)	-1%	-3%	0%	-5%	-6%

B.1.2: Candidates provided by Daikin Industries, Ltd.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	1234yf	Suction Pressure (psia)	53.1	58.1	36.3	23.9	13.3
		Discharge Pressure (psia)	139.6	209.8	160.7	160.7	149.9
		Pressure Ratio ( )	2.6	3.6	4.4	6.7	11.3
		Compressor Discharge Superheat (°F)	17.3	27.6	31.5	26.4	66.4
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	67.8	61.6	37.3	23.8	12.0
		Cooling Efficiency (COP)	5.02	3.17	2.59	1.94	1.33
		GWP_{100}	4				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	7%	6%	10%	13%	18%
		Discharge Pressure (%)	1%	-2%	0%	0%	0%
		Pressure Ratio (%)	-6%	-7%	-9%	-12%	-15%
		Capacity (%)	-4%	-7%	-7%	-6%	-5%
		Efficiency (%)	-2%	-5%	-6%	-8%	-10%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	D4Y	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	<600				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	9%	8%	11%	13%	16%
		Discharge Pressure (%)	5%	3%	4%	4%	4%
		Pressure Ratio (%)	-4%	-5%	-6%	-8%	-10%
		Capacity (%)	1%	-1%	-1%	0%	0%
		Efficiency (%)	-2%	-3%	-5%	-6%	-7%

B.1.3: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	150
		Pressure Ratio ( )	2.8	3.9	4.9	7.7	13.6
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.8	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	DuPont Opteon™ XP10	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	600-650				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	8%	7%	12%	14%	18%
		Discharge Pressure (%)	4%	3%	4%	4%	4%
		Pressure Ratio (%)	-3%	-4%	-7%	-9%	-12%
		Capacity (%)	2%	0%	1%	1%	2%
		Efficiency (%)	-2%	-3%	-4%	-4%	-6%

B.1.4: Candidates provided by Honeywell International

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	150
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32	47	55	56	106
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	71	67	40	25	13
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.1	1.5
Candidate Refrigerant	R1234yf	Suction Pressure (psia)	53	58	36	24	13
		Discharge Pressure (psia)	140	210	161	161	150
		Pressure Ratio ( )	2.6	3.6	4.4	6.7	11.2
		Compressor Discharge Superheat (°F)	17	27	31	27	66
		Evaporator Temperature Glide (°F)	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)	68	62	37	24	12
		Cooling Efficiency (COP)	5.0	3.2	2.6	1.9	1.3
		GWP_{100}	4				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	7%	6%	10%	13%	18%
		Discharge Pressure (%)	1%	-2%	0%	0%	0%
		Pressure Ratio (%)	-6%	-7%	-9%	-12%	-15%
		Capacity (%)	-4%	-7%	-7%	-6%	-4%
		Efficiency (%)	-2%	-5%	-6%	-8%	-10%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	150
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32	47	55	56	106
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	71	67	40	25	13
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.1	1.5
Candidate Refrigerant	R1234ze(E)	Suction Pressure (psia)	37	41	24	15	8
		Discharge Pressure (psia)	105	162	122	122	113
		Pressure Ratio ( )	2.8	4.0	5.0	7.9	13.8
		Compressor Discharge Superheat (°F)	22	33	39	36	81
		Evaporator Temperature Glide (°F)	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)	53	50	29	18	9
		Cooling Efficiency (COP)	5.2	3.3	2.8	2.1	1.4
		GWP_{100}	6				
		ASHRAE Safety Class	A2L				A2L
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-26%	-26%	-26%	-27%	-28%
		Discharge Pressure (%)	-25%	-24%	-24%	-24%	-25%
		Pressure Ratio (%)	2%	2%	3%	3%	4%
		Capacity (%)	-25%	-25%	-26%	-28%	-29%
		Efficiency (%)	0%	0%	-1%	-1%	-2%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	150
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32	47	55	56	106
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	71	67	40	25	13
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.1	1.5
Candidate Refrigerant	N-13a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	1	1	1	1	1
		Condenser Temperature Glide (°F)	1	1	1	1	1
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	550-650				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-4%	-4%	-4%	-3%	-3%
		Discharge Pressure (%)	-5%	-6%	-6%	-6%	-5%
		Pressure Ratio (%)	-1%	-1%	-2%	-2%	-3%
		Capacity (%)	-7%	-8%	-8%	-8%	-8%
		Efficiency (%)	-1%	-1%	-2%	-2%	-3%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	50	55	33	21	11
		Discharge Pressure (psia)	139	213	161	161	150
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32	47	55	56	106
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	71	67	40	25	13
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.1	1.5
Candidate Refrigerant	N-13b	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	1	1	1	1	1
		Condenser Temperature Glide (°F)	1	1	1	1	1
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	550-650				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-12%	-12%	-12%	-12%	-13%
		Discharge Pressure (%)	-11%	-11%	-11%	-11%	-11%
		Pressure Ratio (%)	0%	1%	1%	1%	1%
		Capacity (%)	-12%	-12%	-13%	-14%	-15%
		Efficiency (%)	0%	0%	-1%	-1%	-2%

B.1.5: Candidates provided by Mexichem Fluor, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	Mexichem AC5	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	12	10	9	8	7
		Condenser Temperature Glide (°F)	16	14	15	15	16
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	90				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	5%	3%	3%	2%	2%
		Discharge Pressure (%)	6%	5%	6%	6%	6%
		Pressure Ratio (%)	1%	2%	3%	3%	4%
		Capacity (%)	6%	4%	4%	4%	3%
		Efficiency (%)	0%	0%	0%	0%	0%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	Mexichem AC5X	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	7	6	5	4	4
		Condenser Temperature Glide (°F)	9	8	9	9	9
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	480				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	1%	0%	0%	0%	0%
		Discharge Pressure (%)	2%	1%	2%	2%	2%
		Pressure Ratio (%)	1%	1%	2%	2%	2%
		Capacity (%)	2%	0%	0%	0%	-1%
		Efficiency (%)	0%	0%	-1%	-1%	-1%

B.1.6: Candidates provided by National Refrigerants, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	R600a	Suction Pressure (psia)	26.6	29.2	17.9	11.5	6.3
		Discharge Pressure (psia)	72.6	110.6	84.0	84.0	78.2
		Pressure Ratio ( )	2.7	3.8	4.7	7.3	12.5
		Compressor Discharge Superheat (°F)	19.3	28.2	35.1	32.3	75.4
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	37.8	36.0	21.6	13.8	6.9
		Cooling Efficiency (COP)	5.24	3.43	2.85	2.16	1.52
		GWP100	4				
		ASHRAE Safety Class	A3				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-46.6%	-46.7%	-46.1%	-45.5%	-44.6%
		Discharge Pressure (%)	-47.7%	-48.2%	-47.8%	-47.8%	-47.8%
		Pressure Ratio (%)	-2.1%	-2.8%	-3.2%	-4.3%	-5.7%
		Capacity (%)	-46.6%	-46.0%	-45.8%	-45.6%	-44.9%
		Efficiency (%)	2.1%	3.5%	3.1%	2.7%	3.1%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	70.7	66.6	39.9	25.4	12.6
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48
Candidate Refrigerant	40% R290 + 60% R600a	Suction Pressure (psia)	43.0	46.4	29.0	19.0	10.6
		Discharge Pressure (psia)	112.7	167.3	129.2	129.2	120.7
		Pressure Ratio ( )	2.6	3.6	4.5	6.8	11.4
		Compressor Discharge Superheat (°F)	24.9	36.3	43.8	43.1	88.7
		Evaporator Temperature Glide (°F)	11.2	9.8	9.3	8.7	8.2
		Condenser Temperature Glide (°F)	12.4	11.4	12.1	12.1	12.3
		Volumetric Capacity (Btu/ft³)	58.2	54.5	33.6	21.9	11.3
		Cooling Efficiency (COP)	5.22	3.40	2.82	2.14	1.51
		GWP100	4				
		ASHRAE Safety Class	A3				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-13.6%	-15.3%	-12.6%	-10.3%	-6.6%
		Discharge Pressure (%)	-18.8%	-21.6%	-19.8%	-19.8%	-19.3%
		Pressure Ratio (%)	-6.0%	-7.5%	-8.2%	-10.6%	-13.6%
		Capacity (%)	-17.7%	-18.2%	-15.9%	-14.0%	-10.5%
		Efficiency (%)	1.5%	2.5%	2.1%	1.8%	2.3%

B.2: R-404A Replacements

B.2.1: Candidates provided by Arkema Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	370	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)	29.8	45.9	49.7	48.2	90.7
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.7	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	119.0	107.0	66.4	42.5	24.4
		Cooling Efficiency (COP)	4.77	2.89	2.38	1.78	1.24
Candidate Refrigerant	ARM-30a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	11	10	10	9	8
		Condenser Temperature Glide (°F)	13	11	12	12	12
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	< 200				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-10%	-10%	-11%	-15%	-18%
		Discharge Pressure (%)	-6%	-6%	-6%	-6%	-6%
		Pressure Ratio (%)	4%	4%	6%	10%	14%
		Capacity (%)	-2%	2%	2%	4%	3%
		Efficiency (%)	3%	7%	8%	10%	11%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	370	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)	29.8	45.9	49.7	48.2	90.7
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.7	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	119.0	107.0	66.4	42.5	24.4
		Cooling Efficiency (COP)	4.77	2.89	2.38	1.78	1.24
Candidate Refrigerant	ARM-31a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	10	9	8	7	7
		Condenser Temperature Glide (°F)	11	10	11	11	11
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	< 500				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-13%	-14%	-14%	-19%	-21%
		Discharge Pressure (%)	-9%	-9%	-9%	-9%	-9%
		Pressure Ratio (%)	4%	6%	6%	12%	15%
		Capacity (%)	-3%	1%	1%	1%	-2%
		Efficiency (%)	5%	8%	11%	12%	14%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	370	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)	29.8	45.9	49.7	48.2	90.7
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.7	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	119.0	107.0	66.4	42.5	24.4
		Cooling Efficiency (COP)	4.77	2.89	2.38	1.78	1.24
Candidate Refrigerant	ARM-32a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	8	7	7	6	6
		Condenser Temperature Glide (°F)	8	7	8	8	8
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	~1500				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-6%	-6%	-7%	-10%	-14%
		Discharge Pressure (%)	-1%	-1%	-1%	-1%	-1%
		Pressure Ratio (%)	5%	5%	7%	11%	15%
		Capacity (%)	4%	8%	8%	8%	7%
		Efficiency (%)	3%	6%	8%	10%	11%

B.2.2: Candidates provided by Daikin Industries, Ltd.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.6	27.6
		Discharge Pressure (psia)	250.4	369.3	286.1	286.1	267.8
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25
Candidate Refrigerant	D2Y-65	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	11	10	9	9	8
		Condenser Temperature Glide (°F)	11	10	11	11	11
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	<250				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-2%	-3%	-4%	-5%	-7%
		Discharge Pressure (%)	0%	0%	0%	0%	0%
		Pressure Ratio (%)	2%	3%	5%	6%	7%
		Capacity (%)	6%	10%	11%	12%	13%
		Efficiency (%)	3%	7%	9%	10%	12%

B.2.3: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	110	71	48	28
		Discharge Pressure (psia)	252	371	288	288	269
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0.7	0.6	0.6	0.6	0.6
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	115.8	101.1	61.4	41.5	22.1
		Cooling Efficiency (COP)	4.76	2.88	2.37	1.78	1.24
Candidate Refrigerant	DuPont DR-7	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	11	10	9	9	8
		Condenser Temperature Glide (°F)	11	10	11	11	11
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	200-250				
		Est ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-2%	-3%	-4%	-6%	-7%
		Discharge Pressure (%)	1%	1%	1%	1%	1%
		Pressure Ratio (%)	3%	4%	5%	7%	9%
		Capacity (%)	5%	9%	13%	11%	11%
		Efficiency (%)	2%	5%	7%	8%	10%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	110	71	48	28
		Discharge Pressure (psia)	252	371	288	288	269
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0.7	0.6	0.6	0.6	0.6
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	115.8	101.1	61.4	41.5	22.1
		Cooling Efficiency (COP)	4.76	2.88	2.37	1.78	1.24
Candidate Refrigerant	DuPont DR-33	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	8	7	7	6	6
		Condenser Temperature Glide (°F)	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	1370-1430				
		Est ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-10%	-10%	-13%	-15%	-18%
		Discharge Pressure (%)	-6%	-4%	-5%	-5%	-5%
		Pressure Ratio (%)	5%	6%	9%	11%	15%
		Capacity (%)	0%	4%	6%	4%	2%
		Efficiency (%)	3%	6%	8%	10%	11%

B.2.4: Candidates provided by Honeywell International

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	369	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7
		Compressor Discharge Superheat (°F)	28	42	47	45	89
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	116	101	63	42	22
		Cooling Efficiency (COP)	4.8	2.9	2.4	1.8	1.3
Candidate Refrigeant	L-40	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	11	10	10	10	10
		Condenser Temperature Glide (°F)	12	10	11	11	12
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	200-300				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-14%	-14%	-17%	-19%	-22%
		Discharge Pressure (%)	-9%	-8%	-9%	-9%	-9%
		Pressure Ratio (%)	6%	7%	10%	13%	16%
		Capacity (%)	-1%	5%	5%	5%	5%
		Efficiency (%)	4%	9%	12%	14%	17%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	369	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7
		Compressor Discharge Superheat (°F)	28	42	47	45	89
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	116	101	63	42	22
		Cooling Efficiency (COP)	4.8	2.9	2.4	1.8	1.3
Candidate Refrigerant	N-40a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	10	9	9	9	8
		Condenser Temperature Glide (°F)	11	9	10	10	10
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	1300-1400				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-14%	-14%	-17%	-19%	-23%
		Discharge Pressure (%)	-8%	-7%	-8%	-8%	-8%
		Pressure Ratio (%)	6%	8%	11%	14%	19%
		Capacity (%)	-2%	2%	1%	0%	-1%
		Efficiency (%)	4%	8%	9%	11%	13%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	101	109	70	48	28
		Discharge Pressure (psia)	250	369	286	286	268
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7
		Compressor Discharge Superheat (°F)	28	42	47	45	89
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	116	101	63	42	22
		Cooling Efficiency (COP)	4.8	2.9	2.4	1.8	1.3
Candidate Refrigerant	N-40b	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	8	7	6	6	6
		Condenser Temperature Glide (°F)	8	7	8	8	8
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	1300-1400				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-7%	-7%	-9%	-11%	-13%
		Discharge Pressure (%)	-3%	-2%	-3%	-3%	-3%
		Pressure Ratio (%)	4%	5%	7%	9%	12%
		Capacity (%)	3%	6%	6%	6%	5%
		Efficiency (%)	3%	6%	8%	9%	11%

B.2.5: Candidates provided by National Refrigerants

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.7	27.6
		Discharge Pressure (psia)	250.4	369.3	286.1	286.1	267.8
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25
Candidate Refrigerant	50% R32 + 50% R134a	Suction Pressure (psia)	95.3	103.5	64.6	42.5	23.7
		Discharge Pressure (psia)	251.0	376.3	288.6	288.6	269.3
		Pressure Ratio ( )	2.6	3.6	4.5	6.8	11.4
		Compressor Discharge Superheat (°F)	59.6	86.1	99.7	112.4	182.4
		Evaporator Temperature Glide (°F)	8.7	7.9	7.9	7.8	7.8
		Condenser Temperature Glide (°F)	8.5	7.3	8.2	8.2	8.3
		Volumetric Capacity (Btu/ft³)	127.5	119.6	75.2	50.2	26.3
		Cooling Efficiency (COP)	4.99	3.19	2.71	2.08	1.48
		GWP100	715				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-5.4%	-5.4%	-8.3%	-10.9%	-14.3%
		Discharge Pressure (%)	0.2%	1.9%	0.8%	0.8%	0.5%
		Pressure Ratio (%)	5.9%	7.8%	9.9%	13.1%	17.4%
		Capacity (%)	10.2%	18.1%	18.5%	19.6%	19.0%
		Efficiency (%)	3.9%	9.3%	12.4%	14.6%	18.1%

B.3: R-410A Replacements

B.3.1: Candidates provided by Arkema Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133	145	93	63	37
		Discharge Pressure (psia)	333	493	381	381	356
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.6
		Compressor Discharge Superheat (°F)	57.5	83.2	92.4	101.3	160.9
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.1	0.1	0.1
		Volumetric Capacity (Btu/ft³)	164.0	153.0	97.1	64.0	37.6
		Cooling Efficiency (COP)	4.76	2.92	2.48	1.90	1.35
Candidate Refrigerant	ARM-70a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	7	6	6	6	6
		Condenser Temperature Glide (°F)	7	6	7	7	7
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	< 500				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-18%	-19%	-19%	-21%	-22%
		Discharge Pressure (%)	-17%	-17%	-17%	-17%	-17%
		Pressure Ratio (%)	1%	2%	3%	5%	6%
		Capacity (%)	-15%	-14%	-15%	-14%	-15%
		Efficiency (%)	3%	5%	5%	4%	4%

B.3.2: Candidates provided by Daikin Industries, Ltd.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.0	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	R32	Suction Pressure (psia)	135.6	147.7	94.7	63.9	37.0
		Discharge Pressure (psia)	340.4	504.2	389.6	389.6	364.3
		Pressure Ratio ( )	2.5	3.4	4.1	6.1	9.8
		Compressor Discharge Superheat (°F)	79.3	115.4	134.6	157.2	246.9
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	173.2	162.8	105.8	73.5	40.1
		Cooling Efficiency (COP)	4.87	3.08	2.65	2.05	1.45
		GWP_{100}	675				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	1.8%	1.9%	1.7%	1.5%	1.4%
		Discharge Pressure (%)	2.3%	2.5%	2.4%	2.4%	2.3%
		Pressure Ratio (%)	0.5%	0.6%	0.7%	0.8%	0.9%
		Capacity (%)	7.6%	11.5%	12.8%	14.4%	15.7%
		Efficiency (%)	1.1%	3.4%	4.6%	4.9%	5.6%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.0	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	D2Y-60	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	9	9	8	8	8
		Condenser Temperature Glide (°F)	10	8	9	9	9
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	<300				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-22%	-23%	-23%	-24%	-25%
		Discharge Pressure (%)	-21%	-21%	-21%	-21%	-21%
		Pressure Ratio (%)	2%	2%	3%	4%	5%
		Capacity (%)	-20%	-20%	-21%	-22%	-23%
		Efficiency (%)	2%	4%	3%	3%	2%

B.3.3: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	132	144	93	63	37
		Discharge Pressure (psia)	329	485	376	376	352
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.5
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	0.2	0.2	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.3	0.3	0.3	0.3	0.3
		Volumetric Capacity (Btu/ft³)	157.6	147.0	91.2	62.1	34.1
		Cooling Efficiency (COP)	4.77	2.93	2.49	1.90	1.36
Candidate Refrigerant	DuPont DR-5	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	2	2	1	1	1
		Condenser Temperature Glide (°F)	2	2	2	2	2
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	450-500				
		Est ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-3%	-3%	-3%	-3%	-5%
		Discharge Pressure (%)	-3%	-3%	-3%	-3%	-3%
		Pressure Ratio (%)	0%	1%	1%	1%	3%
		Capacity (%)	0%	-1%	3%	4%	4%
		Efficiency (%)	1%	2%	3%	4%	4%

B.3.4: Candidates provided by Honeywell International

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133	145	93	63	36
		Discharge Pressure (psia)	333	492	381	381	356
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	52	76	87	95	160
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161	146	94	64	35
		Cooling Efficiency (COP)	4.8	3.0	2.5	2.0	1.4
Candidate Refrigerant	L-41a	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	4	4	4	4	4
		Condenser Temperature Glide (°F)	4	3	4	4	4
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	450-500				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-10%	-10%	-11%	-12%	-12%
		Discharge Pressure (%)	-9%	-9%	-9%	-9%	-9%
		Pressure Ratio (%)	1%	2%	2%	3%	4%
		Capacity (%)	-6%	-3%	-3%	-3%	-3%
		Efficiency (%)	2%	4%	4%	5%	5%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133	145	93	63	36
		Discharge Pressure (psia)	333	492	381	381	356
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	52	76	87	95	160
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161	146	94	64	35
		Cooling Efficiency (COP)	4.8	3.0	2.5	2.0	1.4
Candidate Refrigerant	L-41b	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	7	6	7	7	7
		Condenser Temperature Glide (°F)	7	6	6	6	6
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	450-500				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-15%	-15%	-16%	-17%	-19%
		Discharge Pressure (%)	-13%	-12%	-12%	-12%	-13%
		Pressure Ratio (%)	3%	4%	5%	6%	8%
		Capacity (%)	-9%	-6%	-7%	-7%	-8%
		Efficiency (%)	2%	5%	5%	5%	6%

B.3.5: Candidates provided by Mexichem Fluor, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.0	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.9	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	Mexichem HPR1D	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	16	14	14	13	13
		Condenser Temperature Glide (°F)	17	14	16	16	16
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	~400				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-9%	-10%	-12%	-14%	-17%
		Discharge Pressure (%)	-5%	-5%	-5%	-5%	-5%
		Pressure Ratio (%)	5%	6%	8%	10%	14%
		Capacity (%)	-3%	-1%	-2%	-4%	-5%
		Efficiency (%)	1%	3%	3%	3%	4%

B.3.6: Candidates provided by National Refrigerants, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	R32	Suction Pressure (psia)	135.6	147.7	94.7	63.9	37.0
		Discharge Pressure (psia)	340.4	504.2	389.6	389.6	364.3
		Pressure Ratio ( )	2.5	3.4	4.1	6.1	9.8
		Compressor Discharge Superheat (°F)	79.3	115.4	134.6	157.2	246.9
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	173.2	162.8	105.8	73.5	40.1
		Cooling Efficiency (COP)	4.87	3.08	2.65	2.05	1.45
		GWP100	675				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	1.8%	1.9%	1.7%	1.5%	1.4%
		Discharge Pressure (%)	2.3%	2.5%	2.4%	2.4%	2.3%
		Pressure Ratio (%)	0.5%	0.6%	0.7%	0.8%	0.9%
		Capacity (%)	7.6%	11.5%	12.8%	14.4%	15.7%
		Efficiency (%)	1.1%	3.4%	4.6%	4.9%	5.6%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	95% R32 + 5% R134a	Suction Pressure (psia)	131.7	143.4	91.7	61.8	35.6
		Discharge Pressure (psia)	332.1	492.5	380.2	380.2	355.5
		Pressure Ratio ( )	2.5	3.4	4.1	6.2	10.0
		Compressor Discharge Superheat (°F)	77.8	112.9	131.6	153.3	241.1
		Evaporator Temperature Glide (°F)	1.1	1.0	1.1	1.1	1.2
		Condenser Temperature Glide (°F)	1.0	0.8	0.9	0.9	1.0
		Volumetric Capacity (Btu/ft³)	168.7	158.7	102.8	71.1	38.7
		Cooling Efficiency (COP)	4.88	3.09	2.66	2.05	1.45
		GWP100	1050				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-1.1%	-1.1%	-1.5%	-1.9%	-2.4%
		Discharge Pressure (%)	-0.2%	0.1%	-0.1%	-0.1%	-0.1%
		Pressure Ratio (%)	0.9%	1.2%	1.5%	1.8%	2.3%
		Capacity (%)	4.8%	8.6%	9.6%	10.8%	11.6%
		Efficiency (%)	1.2%	3.6%	4.7%	5.0%	5.7%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38
Candidate Refrigerant	95% R32 + 5% R152a	Suction Pressure (psia)	128.8	140.2	89.6	60.2	34.7
		Discharge Pressure (psia)	325.7	483.5	373.1	373.1	348.8
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.1
		Compressor Discharge Superheat (°F)	78.7	114.2	133.1	155.2	243.3
		Evaporator Temperature Glide (°F)	2.2	2.0	2.1	2.1	2.2
		Condenser Temperature Glide (°F)	2.0	1.6	1.9	1.9	1.9
		Volumetric Capacity (Btu/ft³)	165.8	156.2	101.1	69.8	37.9
		Cooling Efficiency (COP)	4.88	3.10	2.66	2.06	1.46
		GWP100	650				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-3.3%	-3.3%	-3.8%	-4.4%	-5.0%
		Discharge Pressure (%)	-2.1%	-1.7%	-2.0%	-2.0%	-2.0%
		Pressure Ratio (%)	1.2%	1.6%	2.0%	2.5%	3.1%
		Capacity (%)	3.0%	6.9%	7.8%	8.8%	9.5%
		Efficiency (%)	1.3%	3.8%	5.0%	5.2%	6.0%

B.4: R-22/R-407C Replacements

B.4.1: Candidates provided by Daikin Industries, Ltd.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R407C	Suction Pressure (psia)	84.6	91.7	56.9	37.1	20.4
		Discharge Pressure (psia)	225.4	338.5	259.3	259.3	241.9
		Pressure Ratio ( )	2.7	3.7	4.6	7.0	11.9
		Compressor Discharge Superheat (°F)	43.3	63.4	72.8	78.1	135.4
		Evaporator Temperature Glide (°F)	8.9	7.8	7.7	7.4	7.2
		Condenser Temperature Glide (°F)	9.1	7.8	8.7	8.7	9.0
		Volumetric Capacity (Btu/ft³)	112.5	103.6	64.1	41.9	21.5
		Cooling Efficiency (COP)	5.00	3.17	2.67	2.04	1.43
Candidate Refrigerant	D52Y	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	10	8	8	7	6
		Condenser Temperature Glide (°F)	11	10	11	11	11
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	<1000				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	1%	1%	2%	4%	7%
		Discharge Pressure (%)	-2%	-3%	-2%	-2%	-2%
		Pressure Ratio (%)	-3%	-4%	-5%	-6%	-8%
		Capacity (%)	-5%	-8%	-8%	-8%	-7%
		Efficiency (%)	-1%	-3%	-4%	-5%	-6%

B.4.2: Candidates provided by Honeywell International

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83	91	58	39	22
		Discharge Pressure (psia)	211	312	241	241	225
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	58	83	96	108	176
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	109	103	66	45	24
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.2	1.5
Candidate Refrigerant	L-20	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	13	12	11	11	11
		Condenser Temperature Glide (°F)	13	12	13	13	13
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	250-350				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	0%	-1%	-3%	-5%	-8%
		Discharge Pressure (%)	5%	6%	5%	5%	5%
		Pressure Ratio (%)	5%	7%	9%	11%	14%
		Capacity (%)	4%	3%	0%	-2%	-5%
		Efficiency (%)	-1%	-2%	-2%	-2%	-2%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83	91	58	39	22
		Discharge Pressure (psia)	211	312	241	241	225
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	58	83	96	108	176
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	109	103	66	45	24
		Cooling Efficiency (COP)	5.1	3.3	2.8	2.2	1.5
Candidate Refrigerant	N-20	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	9	8	7	7	6
		Condenser Temperature Glide (°F)	11	9	10	10	10
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	900-1000				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-20%	-21%	-23%	-26%	-30%
		Discharge Pressure (%)	-14%	-13%	-14%	-14%	-14%
		Pressure Ratio (%)	7%	10%	13%	17%	22%
		Capacity (%)	-17%	-20%	-24%	-28%	-33%
		Efficiency (%)	0%	-2%	-4%	-5%	-7%

B.4.3: Candidates provided by Mexichem Fluor, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53
Candidate Refrigerant	Mexichem LTR4X	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	12	11	10	10	10
		Condenser Temperature Glide (°F)	12	10	12	12	12
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	~1030				
		ASHRAE Safety Class	A1				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	5%	4%	2%	-1%	-4%
		Discharge Pressure (%)	10%	12%	11%	11%	11%
		Pressure Ratio (%)	5%	7%	9%	12%	15%
		Capacity (%)	6%	3%	-1%	-4%	-8%
		Efficiency (%)	-2%	-4%	-5%	-5%	-7%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53
Candidate Refrigerant	Mexichem LTR6A	Suction Pressure (psia)					
		Discharge Pressure (psia)					
		Pressure Ratio ( )					
		Compressor Discharge Superheat (°F)					
		Evaporator Temperature Glide (°F)	28	24	23	21	20
		Condenser Temperature Glide (°F)	32	27	30	30	31
		Volumetric Capacity (Btu/ft³)					
		Cooling Efficiency (COP)					
		GWP_{100}	~210				
		ASHRAE Safety Class	A2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	11%	8%	4%	0%	-4%
		Discharge Pressure (%)	20%	20%	20%	20%	20%
		Pressure Ratio (%)	8%	12%	15%	20%	25%
		Capacity (%)	16%	11%	7%	2%	-3%
		Efficiency (%)	-2%	-4%	-5%	-5%	-5%

B.4.4: Candidates provided by National Refrigerants, Inc.

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53
Candidate Refrigerant	R290	Suction Pressure (psia)	78.6	85.3	55.8	38.4	22.8
		Discharge Pressure (psia)	188.6	273.4	214.3	214.3	201.2
		Pressure Ratio ( )	2.4	3.2	3.8	5.6	8.8
		Compressor Discharge Superheat (°F)	31.1	45.2	52.5	53.3	100.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	93.5	86.5	55.9	38.2	21.0
		Cooling Efficiency (COP)	5.06	3.25	2.72	2.07	1.46
		GWP100	4				
		ASHRAE Safety Class	A3				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-5.5%	-6.0%	-3.4%	-0.9%	2.9%
		Discharge Pressure (%)	-10.4%	-12.3%	-11.1%	-11.1%	-10.8%
		Pressure Ratio (%)	-5.2%	-6.6%	-8.0%	-10.3%	-13.3%
		Capacity (%)	-14.0%	-16.4%	-15.6%	-15.2%	-13.6%
		Efficiency (%)	-0.3%	-1.4%	-2.9%	-3.7%	-4.6%

B.4.5: Candidates added by the Low-GWP AREP Technical Committee

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53
Candidate Refrigerant	R717	Suction Pressure (psia)	73.3	81.0	48.2	30.4	16.0
		Discharge Pressure (psia)	212.0	330.5	247.2	247.2	229.1
		Pressure Ratio ( )	2.9	4.1	5.1	8.1	14.4
		Compressor Discharge Superheat (°F)	135.4	195.7	231.5	285.2	431.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	119.1	120.1	73.4	48.1	24.3
		Cooling Efficiency (COP)	5.13	3.41	2.92	2.23	1.58
		GWP100	0				
		ASHRAE Safety Class	B2L				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-11.9%	-10.8%	-16.6%	-21.5%	-27.9%
		Discharge Pressure (%)	0.7%	6.1%	2.5%	2.5%	1.6%
		Pressure Ratio (%)	14.3%	18.9%	23.0%	30.6%	41.0%
		Capacity (%)	9.5%	16.2%	10.8%	6.8%	0.2%
		Efficiency (%)	1.1%	3.5%	4.3%	3.9%	3.2%

			Operating Conditions				
			Point 1	Point 2	Point 3	Point 4	Point 5
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105
		Evaporator Outlet Superheat (°F)	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40
		Subcooling (°F)	10	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53
Candidate Refrigerant	R1270	Suction Pressure (psia)	96.5	104.5	69.1	47.9	28.8
		Discharge Pressure (psia)	227.3	327.2	257.6	257.6	242.1
		Pressure Ratio ( )	2.4	3.1	3.7	5.4	8.4
		Compressor Discharge Superheat (°F)	39.1	56.6	65.3	68.9	121.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	112.2	103.8	68.1	47.3	26.4
		Cooling Efficiency (COP)	5.02	3.21	2.71	2.07	1.46
		GWP100	1 to 2				
		ASHRAE Safety Class	A3				
Comparison: Candidate relative to Baseline		Suction Pressure (%)	15.9%	15.1%	19.5%	23.7%	30.0%
		Discharge Pressure (%)	7.9%	5.0%	6.9%	6.9%	7.4%
		Pressure Ratio (%)	-6.9%	-8.8%	-10.6%	-13.6%	-17.4%
		Capacity (%)	3.2%	0.4%	2.9%	5.0%	8.8%
		Efficiency (%)	-1.2%	-2.5%	-3.3%	-3.7%	-4.3%

APPENDIX C: INFORMATION ON ALTERNATIVE REFRIGERANT CANDIDATES FOR PHASE II TESTING

The alternative refrigerant candidates listed in Table 2 and 3 of this document were provided by six chemical producers:

- Arkema Inc.
- ComStar International Inc.
- Daikin Industries, Ltd
- E. I. du Pont de Nemours & Co.
- Honeywell International, Inc.
- Mexichem Fluor Inc.

Some candidates' composition information is confidential. The individual testing companies are required to sign Non-Disclosure Agreement (NDA) with corresponding refrigerant suppliers in such a case. The candidates' thermodynamic cycle calculation is provided in this section compared to their baseline refrigerants. For candidates requiring NDAs, only listed were temperature glides and relative performance to baselines. The candidates' information in this section is based on the following assumptions:

- Compressor isentropic efficiency is 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.
- GWP values may be actual or estimated using 100 year integration time horizon and data from IPCC AR4. For candidates whose GWP values (single component) or components' GWP values (blends) are not listed in the IPCC AR4, their GWP values are from the UNEP 2010 RTOC Assessment Report.

Refrigerant Composition Information (also see Appendix B)

Temporary Designation	ASHRAE Designation	Composition	(Mass%)
ARC-1		not yet disclosed	
ARM-20a		not yet disclosed	
ARM-20b		not yet disclosed	
ARM-25a		not yet disclosed	
ARM-32b		not yet disclosed	
ARM-32c		not yet disclosed	
ARM-35		not yet disclosed	
ARM-71a		not yet disclosed	
BRB36		not yet disclosed	
D42Yb		not yet disclosed	
D42Yz		not yet disclosed	
D542HT		not yet disclosed	
DR-3		not yet disclosed	
DR-34	R452A	R32/R125/R1234yf	(11/59/30)
DR-5A	R454B [1]	R32/R1234yf	(68.9/31.1)
DR-55		not yet disclosed	
DR-91		not yet disclosed	
DR-93		not yet disclosed	
HDR110		not yet disclosed	
HPR2A		not yet disclosed	
L-20a	R444B	R32/R1234ze(E)/R152a	(41.5/48.5/10)
L-41-1	R446A	R32/R1234ze(E)/R600	(68/29/3)
L-41-2	R447A	R32/R1234ze(E)/R125	(68/28.5/3.5)
LPR1A		not yet disclosed	
N-20b		not yet disclosed	
N-40c	R448A	R32/R125/R134a/R1234yf/R1234ze(E)	(26/26/21/20/7)
	R442A	R32/R125/R134a/R152a/R227ea	(31/31/30/3/5)
	R449B [1]	R32/R125/R1234yf/R134a	(25.2/24.3/23.2/27.3)
	R1233zd(E)	R1233zd(E)	(100)

1. Pending ASHRAE's final approval and addendum publication.

C.1: R-134a Replacements

C.1.1: Candidates provided by Arkema Inc.

- ARM-42a (Cycle calculation is in Appendix B.1.1)

C.1.2: Candidates provided by Daikin Industries, Ltd.

- D4Y (Cycle calculation is in Appendix B.1.2)

C.1.3: Candidates provided by E. I. du Pont de Nemours & Co.

- Opteon^{TM}XP10 (Cycle calculation is in Appendix B.1.3)

C.1.4: Candidates provided by Honeywell International

- N-13b (Cycle calculation is in Appendix B.1.4)
- R-1234yf (Cycle calculation is in Appendix B.1.4)
- R-1234ze(E) (Cycle calculation is in Appendix B.1.4)

C.1.5: Candidates provided by Mexichem Fluor, Inc.

- AC5X (Cycle calculation is in Appendix B.1.5)
- AC5 (Cycle calculation is in Appendix B.1.5)

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R134a	Suction Pressure (psia)	49.7	54.7	33.1	21.2	11.3	60.1	33.1	21.2	11.3
		Discharge Pressure (psia)	138.9	213.4	161.1	161.1	149.7	243.9	213.4	213.4	199.3
		Pressure Ratio ( )	2.8	3.9	4.9	7.6	13.2	4.1	6.4	10.1	17.6
		Compressor Discharge Superheat (°F)	32.0	46.9	54.6	55.7	105.8	46.8	58.6	59.4	109.3
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft^3)	70.7	66.6	39.9	25.4	12.6	69.4	35.0	22.1	10.9
		Cooling Efficiency (COP)	5.14	3.32	2.77	2.10	1.48	3.07	2.05	1.60	1.14
Candidate Refrigeant	BRB36	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	1	1	1	1	1	1	1	1	1
		Condenser Temperature Glide (°F)	1	1	1	1	1	1	1	1	1
		Volumetric Capacity (Btu/ft^3)									
		Cooling Efficiency (COP)									
		GWP100	500 - 550								
		ASHRAE Safety Class	A1 (Estimated)								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-14%	-14%	-14%	-14%	-14%	-14%	-14%	-14%	-14%
		Discharge Pressure (%)	-13%	-13%	-13%	-13%	-13%	-13%	-13%	-13%	-13%
		Pressure Ratio (%)	1%	1%	1%	1%	1%	1%	1%	1%	1%
		Capacity (%)	-13%	-14%	-14%	-15%	-16%	-14%	-15%	-16%	-17%
		Efficiency (%)	0%	0%	0%	-1%	-1%	0%	-1%	-1%	-2%

C.2: R-404A Replacements

C.2.1: Candidates provided by Arkema Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigerant	ARM-20a	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	10	8	7	6	5	8	6	5	4
		Condenser Temperature Glide (°F)	13	12	13	13	13	12	12	12	13
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 150								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-26%	-26%	-28%	-31%	-33%	-26%	-29%	-31%	-34%
		Discharge Pressure (%)	-21%	-21%	-21%	-21%	-21%	-21%	-21%	-21%	-21%
		Pressure Ratio (%)	6%	7%	10%	14%	18%	7%	12%	15%	20%
		Capacity (%)	-15%	-12%	-13%	-14%	-17%	-10%	-6%	-6%	-9%
		Efficiency (%)	6%	10%	11%	11%	12%	13%	21%	23%	25%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigerant	ARM-20b	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	10	9	8	8	7	9	7	7	6
		Condenser Temperature Glide (°F)	12	10	11	11	12	10	10	10	11
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	~ 250								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-8%	-8%	-10%	-13%	-16%	-8%	-11%	-14%	-17%
		Discharge Pressure (%)	-4%	-3%	-4%	-4%	-4%	-3%	-3%	-3%	-3%
		Pressure Ratio (%)	5%	6%	8%	10%	14%	6%	9%	12%	16%
		Capacity (%)	3%	8%	8%	8%	7%	11%	18%	19%	18%
		Efficiency (%)	4%	8%	10%	11%	13%	10%	20%	22%	25%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigerant	ARM-25a	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	14	12	12	11	10	12	9	8	8
		Condenser Temperature Glide (°F)	15	13	15	15	15	11	13	13	13
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 150								
		ASHRAE Safety Class	A2/2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-4%	-6%	-7%	-8%	-10%	-6%	-9%	-10%	-13%
		Discharge Pressure (%)	-3%	-4%	-3%	-3%	-3%	-4%	-4%	-4%	-4%
		Pressure Ratio (%)	1%	2%	4%	6%	8%	2%	6%	8%	10%
		Capacity (%)	0%	3%	3%	3%	1%	3%	7%	7%	5%
		Efficiency (%)	1%	6%	6%	6%	7%	6%	11%	12%	13%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigerant	ARM-32b	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	6	6	7	6	5	5
		Condenser Temperature Glide (°F)	8	7	8	8	8	6	7	7	7
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	~ 1400								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-4%	-4%	-6%	-8%	-11%	-4%	-7%	-9%	-12%
		Discharge Pressure (%)	0%	1%	0%	0%	0%	1%	1%	1%	1%
		Pressure Ratio (%)	4%	5%	7%	9%	13%	6%	9%	11%	14%
		Capacity (%)	7%	10%	11%	11%	10%	12%	19%	20%	19%
		Efficiency (%)	4%	7%	9%	10%	12%	8%	16%	19%	21%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigeant	ARM-35	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	6	5	5	5	4	5	4	4	3
		Condenser Temperature Glide (°F)	7	5	6	6	6	5	5	5	6
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 2150								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	3%	3%	1%	0%	-1%	2%	0%	-1%	-2%
		Discharge Pressure (%)	5%	5%	5%	5%	5%	5%	5%	5%	5%
		Pressure Ratio (%)	2%	3%	4%	5%	6%	3%	5%	6%	7%
		Capacity (%)	6%	6%	5%	4%	4%	6%	5%	5%	4%
		Efficiency (%)	0%	1%	0%	1%	1%	0%	1%	2%	2%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.1	108.8	71.1	47.9	27.6	118.9	69.6	47.9	27.6
		Discharge Pressure (psia)	250.9	369.8	285.7	285.7	268.3	417.7	369.8	369.8	348.1
		Pressure Ratio ( )	2.5	3.4	4.0	6.0	9.7	3.5	5.3	7.7	12.6
		Compressor Discharge Superheat (°F)	29.7	46.3	49.5	47.7	90.7	47.2	54.4	52.4	94.3
		Evaporator Temperature Glide (°F)	0.7	0.7	0.7	0.7	0.7	0.5	0.5	0.5	0.7
		Condenser Temperature Glide (°F)	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	114.9	100.6	62.8	41.3	22.0	100.4	49.1	31.7	16.9
		Cooling Efficiency (COP)	4.76	2.87	2.38	1.79	1.24	2.58	1.58	1.21	0.85
Candidate Refrigerant	R-449B (provisional number pending approval)	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	6	6	7	6	5	5
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	1412								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-7%	-7%	-10%	-13%	-15%	-9%	-10%	-14%	-16%
		Discharge Pressure (%)	-3%	-2%	-3%	-3%	-3%	-2%	-2%	-2%	-3%
		Pressure Ratio (%)	4%	5%	4%	8%	10%	4%	7%	9%	11%
		Capacity (%)	3%	8%	8%	8%	6%	10%	17%	19%	16%
		Efficiency (%)	4%	8%	10%	11%	13%	10%	20%	22%	25%

C.2.2: Candidates provided by ComStar International Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.7	27.6	118.9	70.4	47.6	27.6
		Discharge Pressure (psia)	250.4	369.3	286.1	286.1	267.8	417.4	369.3	369.3	346.9
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.74	0.63	0.68	0.71	0.77	0.58	0.57	0.59	0.65
		Condenser Temperature Glide (°F)	0.62	0.46	0.58	0.58	0.60	0.40	0.46	0.46	0.49
		Volumetric Capacity (Btu/ft³)	115.8	101.4	63.5	42.0	22.1	101.6	50.9	33.2	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigerant	R442A	Suction Pressure (psia)	96.0	104.1	65.1	42.9	23.9	113.3	64.5	42.4	23.6
		Discharge Pressure (psia)	251.6	376.3	289.0	289.0	269.8	426.9	376.3	376.3	352.8
		Pressure Ratio ( )	2.6	3.6	4.4	6.7	11.3	3.8	5.8	8.9	14.9
		Compressor Discharge Superheat (°F)	46.3	67.7	77.6	84.0	143.3	68.8	86.7	92.9	152.5
		Evaporator Temperature Glide (°F)	8.70	7.77	7.80	7.64	7.63	7.38	6.90	6.71	6.71
		Condenser Temperature Glide (°F)	8.50	7.13	8.10	8.10	8.31	6.53	7.13	7.13	7.40
		Volumetric Capacity (Btu/ft³)	124.4	114.2	71.4	47.3	24.6	117.2	61.4	40.4	21.0
		Cooling Efficiency (COP)	4.94	3.12	2.63	2.01	1.42	2.86	1.92	1.51	1.09
		GWP100	1888								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-4.7%	-4.9%	-7.6%	-10.1%	-13.4%	-4.7%	-8.3%	-10.9%	-14.2%
		Discharge Pressure (%)	0.5%	1.9%	1.0%	1.0%	0.7%	2.3%	1.9%	1.9%	1.7%
		Pressure Ratio (%)	5.4%	7.2%	9.2%	12.3%	16.3%	7.3%	11.1%	14.3%	18.6%
		Capacity (%)	7.5%	12.7%	12.5%	12.5%	11.2%	15.4%	20.6%	21.8%	20.5%
		Efficiency (%)	3.0%	6.9%	9.1%	10.7%	13.4%	8.9%	16.6%	19.4%	22.9%

C.2.3: Candidates provided by Daikin Industries, Ltd.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.4	70.4	47.6	27.6	118.8	70.3	47.6	27.5
		Discharge Pressure (psia)	250.3	369.2	286.0	286.0	267.7	417.3	369.2	369.2	346.8
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8	0.6	0.6	0.6	0.6
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1	101.5	50.9	33.1	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigeant	D42Yb	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	6	5	4	4	4	4	4	3	3
		Condenser Temperature Glide (°F)	7	6	7	7	7	6	6	6	6
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	960								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-37%	-37%	-40%	-43%	-46%	-37%	-40%	-43%	-46%
		Discharge Pressure (%)	-31%	-29%	-30%	-30%	-31%	-29%	-29%	-29%	-30%
		Pressure Ratio (%)	9%	12%	16%	21%	28%	12%	18%	24%	31%
		Capacity (%)	-25%	-21%	-23%	-25%	-29%	-19%	-18%	-19%	-23%
		Efficiency (%)	6%	11%	12%	13%	15%	14%	21%	23%	25%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.4	70.4	47.6	27.6	118.8	70.3	47.6	27.5
		Discharge Pressure (psia)	250.3	369.2	286.0	286.0	267.7	417.3	369.2	369.2	346.8
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8	0.6	0.6	0.6	0.6
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1	101.5	50.9	33.1	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigeant	D42Yz	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	6	6	7	6	5	5
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	1280								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-32%	-32%	-35%	-38%	-42%	-31%	-36%	-39%	-43%
		Discharge Pressure (%)	-25%	-23%	-24%	-24%	-24%	-22%	-23%	-23%	-23%
		Pressure Ratio (%)	10%	13%	17%	23%	31%	13%	20%	26%	34%
		Capacity (%)	-17%	-11%	-14%	-15%	-18%	-8%	-6%	-7%	-10%
		Efficiency (%)	6%	12%	14%	16%	19%	15%	24%	27%	31%

- D2Y-65 (Cycle calculation is in Appendix B.2.2)

C.2.4: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.7	27.6	118.9	70.4	47.6	27.6
		Discharge Pressure (psia)	250.4	369.3	286.1	286.1	267.8	417.4	369.3	369.3	346.9
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.7	0.6	0.7	0.7	0.8	0.6	0.6	0.6	0.6
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	115.8	101.4	63.5	42.0	22.1	101.6	50.9	33.2	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigerant	DR-34	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	6	5	5	4	4	5	4	3	3
		Condenser Temperature Glide (°F)	7	6	6	6	6	5	6	6	6
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	<2150								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-2%	-2%	-3%	-4%	-6%	-2%	-4%	-5%	-6%
		Discharge Pressure (%)	1%	1%	1%	1%	1%	1%	1%	1%	1%
		Pressure Ratio (%)	2%	3%	4%	5%	7%	3%	5%	6%	8%
		Capacity (%)	2%	2%	2%	1%	0%	3%	3%	2%	1%
		Efficiency (%)	1%	1%	2%	2%	2%	2%	3%	3%	4%

- DR-33 (Cycle calculation is in Appendix B.2.3)
- DR-7 (Cycle calculation is in Appendix B.2.3)

C.2.5: Candidates provided by Honeywell International

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.6	27.6	118.9	70.4	47.6	27.6
		Discharge Pressure (psia)	250.4	369.2	286.1	286.1	267.8	417.4	369.2	369.2	347.0
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.9	0.9	1.0	1.1	1.2	0.8	1.0	1.1	1.2
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1	101.5	50.9	33.1	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigerant	HDR110	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	21	21	21	22	22	20	21	22	22
		Condenser Temperature Glide (°F)	17	15	17	17	17	13	15	15	15
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP_{100}	146								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)									
		Discharge Pressure (%)									
		Pressure Ratio (%)									
		Capacity (%)	0%	2%	2%	1%	0%	3%	6%	6%	5%
		Efficiency (%)	3%	5%	7%	8%	10%	7%	12%	14%	16%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R404A	Suction Pressure (psia)	100.7	109.5	70.4	47.6	27.6	118.9	70.4	47.6	27.6
		Discharge Pressure (psia)	250.4	369.2	286.1	286.1	267.8	417.4	369.2	369.2	347.0
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.7	3.5	5.2	7.8	12.6
		Compressor Discharge Superheat (°F)	27.6	42.2	46.7	44.9	88.7	42.7	50.4	48.4	91.6
		Evaporator Temperature Glide (°F)	0.9	0.9	1.0	1.1	1.2	0.8	1.0	1.1	1.2
		Condenser Temperature Glide (°F)	0.6	0.5	0.6	0.6	0.6	0.4	0.5	0.5	0.5
		Volumetric Capacity (Btu/ft³)	115.7	101.3	63.5	42.0	22.1	101.5	50.9	33.1	17.4
		Cooling Efficiency (COP)	4.80	2.92	2.41	1.82	1.25	2.63	1.65	1.26	0.88
Candidate Refrigerant	N40c	Suction Pressure (psia)	92.7	100.4	63.0	41.6	23.4	109.1	62.5	41.2	23.1
		Discharge Pressure (psia)	241.4	360.1	277.0	277.0	258.8	408.2	360.1	360.1	337.8
		Pressure Ratio ( )	2.6	3.6	4.4	6.7	11.1	3.7	5.8	8.7	14.6
		Compressor Discharge Superheat (°F)	40.6	59.9	68.1	72.0	126.6	60.9	75.6	79.2	133.9
		Evaporator Temperature Glide (°F)	10.1	10.0	10.4	10.7	10.9	9.9	10.4	10.7	10.9
		Condenser Temperature Glide (°F)	8.6	7.3	8.2	8.2	8.4	6.7	7.3	7.3	7.6
		Volumetric Capacity (Btu/ft³)	118.3	107.8	67.3	44.4	23.1	110.2	57.3	37.5	19.5
		Cooling Efficiency (COP)	4.94	3.11	2.61	1.99	1.40	2.84	1.89	1.48	1.06
		GWP_{100}	1273								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-8.0%	-8.3%	-10.5%	-12.6%	-15.4%	-8.2%	-11.2%	-13.4%	-16.2%
		Discharge Pressure (%)	-3.6%	-2.5%	-3.2%	-3.2%	-3.4%	-2.2%	-2.5%	-2.5%	-2.6%
		Pressure Ratio (%)	4.8%	6.3%	8.2%	10.8%	14.2%	6.5%	9.9%	12.6%	16.2%
		Capacity (%)	2.3%	6.4%	6.1%	5.9%	4.7%	8.6%	12.6%	13.3%	12.1%
		Efficiency (%)	3.0%	6.5%	8.3%	9.6%	11.8%	8.2%	14.8%	17.2%	20.0%

- L-40 (Cycle calculation is in Appendix B.2.4)

C.3: R-410A Replacements

C.3.1: Candidates provided by Arkema Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.4	145.0	92.8	62.4	36.3	156.6	92.8	62.4	36.3
		Discharge Pressure (psia)	332.1	493.1	380.0	380.0	355.3	556.9	493.1	493.1	462.7
		Pressure Ratio ( )	2.5	3.4	4.1	6.1	9.8	3.6	5.3	7.9	12.8
		Compressor Discharge Superheat (°F)	60.3	86.9	96.7	106.0	167.0	88.9	109.3	118.6	179.5
		Evaporator Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.0
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	159.4	144.1	86.7	58.8	34.4	146.0	76.5	51.5	28.4
		Cooling Efficiency (COP)	4.75	2.91	2.33	1.78	1.36	2.63	1.72	1.35	0.99
Candidate Refrigerant	ARM-71a	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	4	4	4	4	4	3	3	3	3
		Condenser Temperature Glide (°F)	4	3	4	4	4	3	3	3	3
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 500								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-9%	-9%	-9%	-10%	-11%	-9%	-10%	-10%	-11%
		Discharge Pressure (%)	-8%	-8%	-8%	-8%	-8%	-8%	-8%	-8%	-8%
		Pressure Ratio (%)	1%	1%	2%	2%	3%	1%	2%	2%	3%
		Capacity (%)	-6%	-3%	3%	4%	-3%	-2%	1%	1%	1%
		Efficiency (%)	2%	4%	11%	11%	5%	5%	8%	9%	9%

C.3.2: Candidates provided by Daikin Industries, Ltd.

- D2Y-60 (Cycle calculation is in Appendix B.3.2)
- R-32 (Cycle calculation is in Appendix B. 3.2)

C.3.3: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5	157.5	93.1	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1	556.7	492.1	492.1	462.0
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8	3.5	5.3	7.8	12.7
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1	77.4	98.1	106.3	171.5
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.1	146.2	93.9	64.2	34.7	148.7	79.9	54.4	29.5
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38	2.71	1.81	1.43	1.04
Candidate Refrigerant	DR-5A	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	2	2	2	2	2	2	2	2	2
		Condenser Temperature Glide (°F)	3	3	3	3	3	2	3	3	3
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	<460								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-7%	-7%	-7%	-7%	-6%	-7%	-7%	-7%	-7%
		Discharge Pressure (%)	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%
		Pressure Ratio (%)	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Capacity (%)	-4%	-2%	-2%	-1%	0%	-2%	1%	2%	2%
		Efficiency (%)	1%	3%	3%	4%	4%	4%	6%	6%	7%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5	157.5	93.1	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1	556.7	492.1	492.1	462.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8	3.5	5.3	7.8	12.7
		Compressor Discharge Superheat (°F)	52.4	76.1	86.9	95.4	160.1	77.4	98.1	106.3	171.5
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.1	146.2	93.9	64.2	34.7	148.7	79.9	54.4	29.5
		Cooling Efficiency (COP)	4.80	2.98	2.54	1.95	1.38	2.71	1.81	1.43	1.04
Candidate Refrigeant	DR-55	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	2	2	2	1	1	2	2	1	1
		Condenser Temperature Glide (°F)	2	2	2	2	2	2	2	2	2
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	650-700								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%
		Discharge Pressure (%)	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%	-5%
		Pressure Ratio (%)	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Capacity (%)	-3%	-1%	-1%	0%	1%	0%	2%	3%	3%
		Efficiency (%)	1%	2%	3%	3%	4%	3%	5%	6%	6%

C.3.4: Candidates provided by Honeywell International

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.1	63.0	36.5	157.5	93.1	63.0	36.5
		Discharge Pressure (psia)	332.8	492.0	380.6	380.6	356.1	556.7	492.0	492.0	462.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8	3.5	5.3	7.8	12.7
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1	77.4	98.1	106.3	171.5
		Evaporator Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7	148.6	79.9	54.3	29.5
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38	2.71	1.81	1.43	1.04
Candidate Refrigerant	L41-1	Suction Pressure (psia)	110.3	119.9	75.9	50.6	28.8	130.3	75.5	50.3	28.6
		Discharge Pressure (psia)	283.6	422.4	325.2	325.2	303.9	478.8	422.4	422.4	396.3
		Pressure Ratio ( )	2.6	3.5	4.3	6.4	10.6	3.7	5.6	8.4	13.9
		Compressor Discharge Superheat (°F)	63.1	91.6	105.5	119.4	192.0	93.5	120.2	133.9	207.4
		Evaporator Temperature Glide (°F)	8.9	8.8	9.1	9.3	9.5	8.7	9.1	9.3	9.5
		Condenser Temperature Glide (°F)	7.7	6.5	7.3	7.3	7.5	6.0	6.5	6.5	6.8
		Volumetric Capacity (Btu/ft³)	142.3	133.0	84.9	57.6	30.8	137.2	74.9	50.6	27.1
		Cooling Efficiency (COP)	4.91	3.12	2.67	2.05	1.46	2.87	1.97	1.57	1.14
		GWP_{100}	461								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-17.2%	-17.3%	-18.5%	-19.7%	-21.2%	-17.3%	-18.9%	-20.1%	-21.6%
		Discharge Pressure (%)	-14.8%	-14.1%	-14.5%	-14.5%	-14.7%	-14.0%	-14.1%	-14.1%	-14.2%
		Pressure Ratio (%)	2.9%	3.9%	4.9%	6.4%	8.2%	4.0%	5.9%	7.4%	9.4%
		Capacity (%)	-11.6%	-9.0%	-9.6%	-10.3%	-11.3%	-7.7%	-6.2%	-6.8%	-8.1%
		Efficiency (%)	2.0%	4.7%	5.2%	5.1%	5.9%	6.1%	9.1%	9.3%	9.8%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.1	63.0	36.5	157.5	93.1	63.0	36.5
		Discharge Pressure (psia)	332.8	492.0	380.6	380.6	356.1	556.7	492.0	492.0	462.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8	3.5	5.3	7.8	12.7
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1	77.4	98.1	106.3	171.5
		Evaporator Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7	148.6	79.8	54.3	29.5
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38	2.71	1.81	1.43	1.04
Candidate Refrigerant	L41-2	Suction Pressure (psia)	111.1	120.8	76.4	50.9	28.9	131.3	76.1	50.7	28.8
		Discharge Pressure (psia)	285.9	426.1	328.0	328.0	306.4	483.1	426.1	426.1	399.8
		Pressure Ratio ( )	2.6	3.5	4.3	6.4	10.6	3.7	5.6	8.4	13.9
		Compressor Discharge Superheat (°F)	64.6	93.8	108.1	122.7	197.0	95.8	123.4	137.8	213.1
		Evaporator Temperature Glide (°F)	8.4	8.3	8.6	8.8	9.0	8.3	8.6	8.8	9.0
		Condenser Temperature Glide (°F)	7.2	6.1	6.9	6.9	7.1	5.6	6.1	6.1	6.3
		Volumetric Capacity (Btu/ft³)	143.5	134.1	85.6	58.1	31.0	138.5	75.6	51.1	27.3
		Cooling Efficiency (COP)	4.90	3.12	2.66	2.05	1.45	2.87	1.97	1.56	1.14
		GWP_{100}	572								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-16.6%	-16.7%	-17.9%	-19.1%	-20.7%	-16.6%	-18.3%	-19.5%	-21.1%
		Discharge Pressure (%)	-14.1%	-13.4%	-13.8%	-13.8%	-13.9%	-13.2%	-13.4%	-13.4%	-13.5%
		Pressure Ratio (%)	3.0%	4.0%	5.0%	6.5%	8.5%	4.1%	6.0%	7.6%	9.7%
		Capacity (%)	-10.9%	-8.2%	-8.8%	-9.5%	-10.4%	-6.8%	-5.3%	-5.9%	-7.2%
		Efficiency (%)	1.8%	4.5%	5.0%	5.0%	5.7%	5.8%	8.9%	9.1%	9.6%

C.3.5: Candidates provided by Mexichem Fluor, Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R410A	Suction Pressure (psia)	133.2	145.0	93.2	63.0	36.5	157.5	93.1	63.0	36.5
		Discharge Pressure (psia)	332.8	492.1	380.6	380.6	356.1	556.7	492.1	492.1	462.1
		Pressure Ratio ( )	2.5	3.4	4.1	6.0	9.8	3.5	5.3	7.8	12.7
		Compressor Discharge Superheat (°F)	51.7	76.1	86.9	95.4	160.1	77.4	98.1	106.3	171.5
		Evaporator Temperature Glide (°F)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		Condenser Temperature Glide (°F)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
		Volumetric Capacity (Btu/ft³)	161.0	146.1	93.8	64.2	34.7	148.6	79.8	54.3	29.5
		Cooling Efficiency (COP)	4.82	2.98	2.54	1.95	1.38	2.71	1.81	1.43	1.04
Candidate Refrigeant	HPR2A	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	6	5	5	5	6	5	5	5	5
		Condenser Temperature Glide (°F)	5	4	5	5	5	4	4	4	4
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	600								
		ASHRAE Safety Class	A2L (Estimated)								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-12%	-12%	-14%	-15%	-16%	-12%	-14%	-15%	-16%
		Discharge Pressure (%)	-10%	-9%	-10%	-10%	-10%	-9%	-9%	-9%	-9%
		Pressure Ratio (%)	3%	4%	4%	6%	8%	4%	5%	7%	9%
		Capacity (%)	-6%	-3%	-3%	-3%	-4%	-1%	1%	1%	0%
		Efficiency (%)	2%	5%	5%	6%	6%	6%	10%	10%	11%

- HPR1D (Cycle calculation is in Appendix B.3.5)

C.4: R-22/R-407C Replacements

C.4.1: Candidates provided by Arkema Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R-22	Suction Pressure (psia)	82.7	89.9	58.0	39.2	21.8	98.6	58.0	39.2	21.8
		Discharge Pressure (psia)	210.3	311.8	240.8	240.8	224.8	352.4	311.8	311.8	293.0
		Pressure Ratio ( )	2.5	3.5	4.2	6.1	10.3	3.6	5.4	8.0	13.5
		Compressor Discharge Superheat (°F)	57.8	84.2	95.2	105.3	171.4	86.4	108.0	117.7	184.7
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	107.9	102.3	65.2	44.3	23.9	106.3	58.2	39.2	21.2
		Cooling Efficiency (COP)	5.07	3.28	2.78	2.14	1.52	3.03	2.08	1.64	1.19
Candidate Refrigerant	ARM-20b	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	10	9	8	8	7	9	7	7	6
		Condenser Temperature Glide (°F)	12	10	11	11	12	10	10	10	11
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	~ 250								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	11%	11%	9%	7%	5%	11%	8%	6%	4%
		Discharge Pressure (%)	15%	15%	15%	15%	15%	15%	15%	15%	15%
		Pressure Ratio (%)	3%	4%	5%	7%	9%	4%	7%	8%	11%
		Capacity (%)	10%	6%	4%	1%	-2%	5%	-1%	-4%	-6%
		Efficiency (%)	-3%	-6%	-6%	-7%	-8%	-6%	-9%	-10%	-11%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	82.7	89.9	58.0	39.2	21.8	98.6	58.0	39.2	21.8
		Discharge Pressure (psia)	210.3	311.8	240.8	240.8	224.8	352.4	311.8	311.8	293.0
		Pressure Ratio ( )	2.5	3.5	4.2	6.1	10.3	3.6	5.4	8.0	13.5
		Compressor Discharge Superheat (°F)	57.8	84.2	95.2	105.3	171.4	86.4	108.0	117.7	184.7
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	107.9	102.3	65.2	44.3	23.9	106.3	58.2	39.2	21.2
		Cooling Efficiency (COP)	5.07	3.28	2.78	2.14	1.52	3.03	2.08	1.64	1.19
Candidate Refrigerant	ARM-32c	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	6	6	7	6	5	5
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 1400								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	11%	10%	9%	7%	5%	10%	8%	6%	4%
		Discharge Pressure (%)	14%	15%	14%	14%	14%	15%	15%	15%	15%
		Pressure Ratio (%)	3%	4%	5%	7%	9%	5%	7%	8%	11%
		Capacity (%)	10%	4%	2%	-1%	-4%	2%	-4%	-7%	-10%
		Efficiency (%)	-2%	-6%	-7%	-8%	-9%	-7%	-11%	-12%	-13%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.1	90.5	57.7	38.7	22.2	98.6	57.7	38.7	22.2
		Discharge Pressure (psia)	210.3	311.8	240.8	240.8	224.8	352.4	311.8	311.8	293.0
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.1	3.6	5.4	8.1	13.2
		Compressor Discharge Superheat (°F)	57.8	84.2	95.2	105.3	171.4	86.4	108.0	117.7	184.7
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	107.9	102.3	65.2	44.3	23.9	106.3	58.2	39.2	21.2
		Cooling Efficiency (COP)	5.07	3.28	2.78	2.14	1.52	3.03	2.08	1.64	1.19
Candidate Refrigeant	R-449B (provisional number pending approval)	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	6	6	7	6	5	5
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	1412								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	12%	11%	11%	8%	5%	10%	9%	7%	5%
		Discharge Pressure (%)	15%	16%	16%	16%	15%	16%	16%	16%	16%
		Pressure Ratio (%)	4%	5%	4%	8%	10%	4%	7%	9%	11%
		Capacity (%)	10%	6%	4%	1%	-3%	4%	-1%	-4%	-8%
		Efficiency (%)	-2%	-5%	-6%	-7%	-8%	-6%	-9%	-10%	-11%

C.4.2: Candidates provided by ComStar International Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Condenser Temperature Glide (°F)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Volumetric Capacity (Btu/ft³)	108.9	103.5	66.3	45.1	24.3	107.5	59.6	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigerant	R442A	Suction Pressure (psia)	96.0	104.1	65.1	42.9	23.9	113.3	64.5	42.4	23.6
		Discharge Pressure (psia)	251.6	376.3	289.0	289.0	269.8	426.9	376.3	376.3	352.8
		Pressure Ratio ( )	2.6	3.6	4.4	6.7	11.3	3.8	5.8	8.9	14.9
		Compressor Discharge Superheat (°F)	46.3	67.7	77.6	84.0	143.3	68.8	86.7	92.9	152.5
		Evaporator Temperature Glide (°F)	8.70	7.77	7.80	7.64	7.63	7.38	6.90	6.71	6.71
		Condenser Temperature Glide (°F)	8.50	7.13	8.10	8.10	8.31	6.53	7.13	7.13	7.40
		Volumetric Capacity (Btu/ft³)	124.4	114.2	71.4	47.3	24.6	117.2	61.4	40.4	21.0
		Cooling Efficiency (COP)	4.94	3.12	2.63	2.01	1.42	2.86	1.92	1.51	1.09
		GWP100	1888								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	15.3%	14.7%	12.7%	10.7%	8.0%	14.7%	11.7%	9.6%	6.8%
		Discharge Pressure (%)	19.4%	20.8%	19.9%	19.9%	19.7%	21.2%	20.8%	20.8%	20.5%
		Pressure Ratio (%)	3.6%	5.3%	6.4%	8.3%	10.8%	5.7%	8.1%	10.2%	12.9%
		Capacity (%)	14.3%	10.4%	7.7%	4.8%	1.3%	9.0%	3.1%	-0.1%	-3.5%
		Efficiency (%)	-2.6%	-5.2%	-6.0%	-6.4%	-7.3%	-6.4%	-9.0%	-9.6%	-10.5%

C.4.3: Candidates provided by Daikin Industries, Ltd.

- D52Y (Cycle calculation is in Appendix B.4.1)

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.2	90.7	57.8	38.7	22.1	98.7	57.8	38.7	22.1
		Discharge Pressure (psia)	210.5	311.5	241.0	241.0	225.4	352.0	311.5	311.5	292.6
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3	107.5	59.5	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigeant	D542HT	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	7	6	6	6	6	6	6	6	6
		Condenser Temperature Glide (°F)	7	5	6	6	6	5	5	5	6
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	1750								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	27%	26%	25%	23%	21%	26%	24%	22%	20%
		Discharge Pressure (%)	30%	31%	30%	30%	30%	31%	31%	31%	31%
		Pressure Ratio (%)	3%	4%	4%	6%	7%	4%	6%	7%	9%
		Capacity (%)	24%	20%	19%	16%	14%	19%	14%	12%	9%
		Efficiency (%)	-3%	-6%	-6%	-6%	-7%	-7%	-9%	-9%	-10%

C.4.4: Candidates provided by E. I. du Pont de Nemours & Co.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.9	103.5	66.3	45.1	24.3	107.5	59.6	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigerant	DR-3	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	11	9	9	8	8	9	7	7	6
		Condenser Temperature Glide (°F)	12	10	12	12	12	10	10	10	11
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	<150								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	0%	-2%	-2%	-3%	-4%	-2%	-4%	-5%	-6%
		Discharge Pressure (%)	2%	2%	2%	2%	2%	2%	2%	2%	2%
		Pressure Ratio (%)	2%	3%	4%	5%	6%	4%	6%	7%	8%
		Capacity (%)	-5%	-10%	-13%	-16%	-18%	-12%	-19%	-22%	-25%
		Efficiency (%)	-3%	-6%	-8%	-9%	-11%	-8%	-13%	-14%	-16%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.9	103.5	66.3	45.1	24.3	107.5	59.6	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigerant	DR-91	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	6	6	5	5	6	5	4	4
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	<999								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-13%	-14%	-16%	-18%	-20%	-14%	-17%	-19%	-21%
		Discharge Pressure (%)	-9%	-8%	-9%	-9%	-9%	-8%	-8%	-8%	-8%
		Pressure Ratio (%)	5%	7%	8%	11%	14%	7%	10%	13%	17%
		Capacity (%)	-14%	-18%	-21%	-25%	-29%	-19%	-26%	-30%	-34%
		Efficiency (%)	-1%	-4%	-6%	-8%	-9%	-5%	-10%	-12%	-14%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.3	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.1	241.1	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	58.5	82.9	96.1	107.9	176.3	84.1	108.6	120.1	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.9	103.5	66.3	45.1	24.3	107.5	59.6	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.10	1.66	1.21
Candidate Refrigerant	DR-93	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	8	7	7	7	6	7	6	6	5
		Condenser Temperature Glide (°F)	9	8	9	9	9	7	8	8	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	~1200								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	4%	4%	2%	0%	-2%	4%	1%	-1%	-3%
		Discharge Pressure (%)	8%	9%	8%	8%	8%	9%	9%	9%	9%
		Pressure Ratio (%)	3%	5%	6%	8%	10%	6%	8%	10%	12%
		Capacity (%)	3%	-2%	-5%	-8%	-12%	-3%	-10%	-14%	-17%
		Efficiency (%)	-3%	-5%	-7%	-8%	-8%	-7%	-10%	-11%	-13%

C.4.5: Candidates provided by Honeywell International

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.2	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.0	241.0	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3	107.4	59.5	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigerant	L20a	Suction Pressure (psia)	81.8	88.6	55.0	35.9	19.9	96.4	54.3	35.4	19.6
		Discharge Pressure (psia)	217.9	327.0	250.6	250.6	233.9	371.3	327.0	327.0	306.5
		Pressure Ratio ( )	2.7	3.7	4.6	7.0	11.8	3.9	6.0	9.2	15.7
		Compressor Discharge Superheat (°F)	52.7	76.5	88.0	97.2	161.3	77.8	99.1	108.1	172.9
		Evaporator Temperature Glide (°F)	16.1	16.0	16.5	16.9	17.3	15.9	16.5	16.9	17.3
		Condenser Temperature Glide (°F)	14.1	12.4	13.6	13.6	13.8	11.7	12.4	12.4	12.7
		Volumetric Capacity (Btu/ft³)	110.6	103.4	64.4	42.5	22.1	107.0	56.6	37.1	19.2
		Cooling Efficiency (COP)	5.02	3.23	2.73	2.09	1.48	2.98	2.03	1.60	1.16
		GWP_{100}	295								
		ASHRAE Safety Class	A2L								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-1.7%	-2.4%	-4.8%	-7.2%	-10.3%	-2.4%	-6.0%	-8.5%	-11.7%
		Discharge Pressure (%)	3.5%	5.0%	4.0%	4.0%	3.7%	5.5%	5.0%	5.0%	4.7%
		Pressure Ratio (%)	5.3%	7.6%	9.3%	12.1%	15.6%	8.1%	11.7%	14.7%	18.6%
		Capacity (%)	1.7%	0.0%	-2.7%	-5.7%	-9.1%	-0.4%	-5.0%	-8.0%	-11.6%
		Efficiency (%)	-1.0%	-2.0%	-2.5%	-2.8%	-3.2%	-2.5%	-3.6%	-4.0%	-4.5%

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R22	Suction Pressure (psia)	83.2	90.8	57.8	38.7	22.1	98.8	57.8	38.7	22.1
		Discharge Pressure (psia)	210.6	311.6	241.0	241.0	225.5	352.1	311.6	311.6	292.7
		Pressure Ratio ( )	2.5	3.4	4.2	6.2	10.2	3.6	5.4	8.0	13.2
		Compressor Discharge Superheat (°F)	57.9	82.9	96.1	107.9	176.3	84.1	108.2	119.7	189.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	108.8	103.4	66.2	45.1	24.3	107.4	59.5	40.4	21.7
		Cooling Efficiency (COP)	5.08	3.29	2.80	2.15	1.53	3.05	2.11	1.67	1.21
Candidate Refrigeant	N20b	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	10	10	10	10	11	10	10	10	11
		Condenser Temperature Glide (°F)	9	7	8	8	8	7	7	7	8
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP_{100}	900-1000								
		ASHRAE Safety Class	A1	A1	A1	A1	A1	A1	A1	A1	A1
Comparison: Candidate relative to Baseline		Suction Pressure (%)	-10%	-11%	-13%	-14%	-17%	-11%	-13%	-15%	-18%
		Discharge Pressure (%)	-6%	-5%	-6%	-6%	-6%	-5%	-5%	-5%	-5%
		Pressure Ratio (%)	4%	6%	8%	10%	13%	7%	10%	12%	16%
		Capacity (%)	-10%	-14%	-18%	-22%	-25%	-16%	-23%	-26%	-30%
		Efficiency (%)	-1%	-4%	-6%	-7%	-9%	-5%	-10%	-11%	-13%

- N-20 (Cycle calculation is in Appendix B.4.2)

C.4.6: Candidates provided by Mexichem Fluor, Inc.

- LTR4X (Cycle calculation is in Appendix B.4.3)
- LTR6A (Cycle calculation is in Appendix B.4.3)

C.5: R-123 Replacements

C.5.1: Candidates provided by Arkema Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R123	Suction Pressure (psia)	5.8	6.5	3.5	2.0	0.9	7.4	3.5	2.0	0.9
		Discharge Pressure (psia)	20.7	35.2	24.9	24.9	22.8	41.5	35.2	35.2	32.5
		Pressure Ratio ( )	3.6	5.4	7.2	12.3	26.2	5.6	10.1	17.4	37.3
		Compressor Discharge Superheat (°F)	30.6	43.7	53.8	55.6	110.2	42.5	56.5	58.0	113.2
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	11.0	11.0	5.9	3.5	1.3	12.1	5.4	3.0	1.3
		Cooling Efficiency (COP)	5.40	3.62	3.04	2.32	1.66	3.40	2.35	1.84	1.34
Candidate Refrigerant	ARC-1	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	0	0	0	0	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	< 15								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	46%	45%	48%	50%	54%	44%	48%	50%	54%
		Discharge Pressure (%)	40%	38%	39%	39%	40%	37%	38%	38%	38%
		Pressure Ratio (%)	-4%	-5%	-6%	-7%	-9%	-5%	-7%	-8%	-10%
		Capacity (%)	39%	38%	40%	42%	44%	37%	39%	41%	43%
		Efficiency (%)	-1%	-1%	-2%	-2%	-2%	-2%	-2%	-3%	-3%

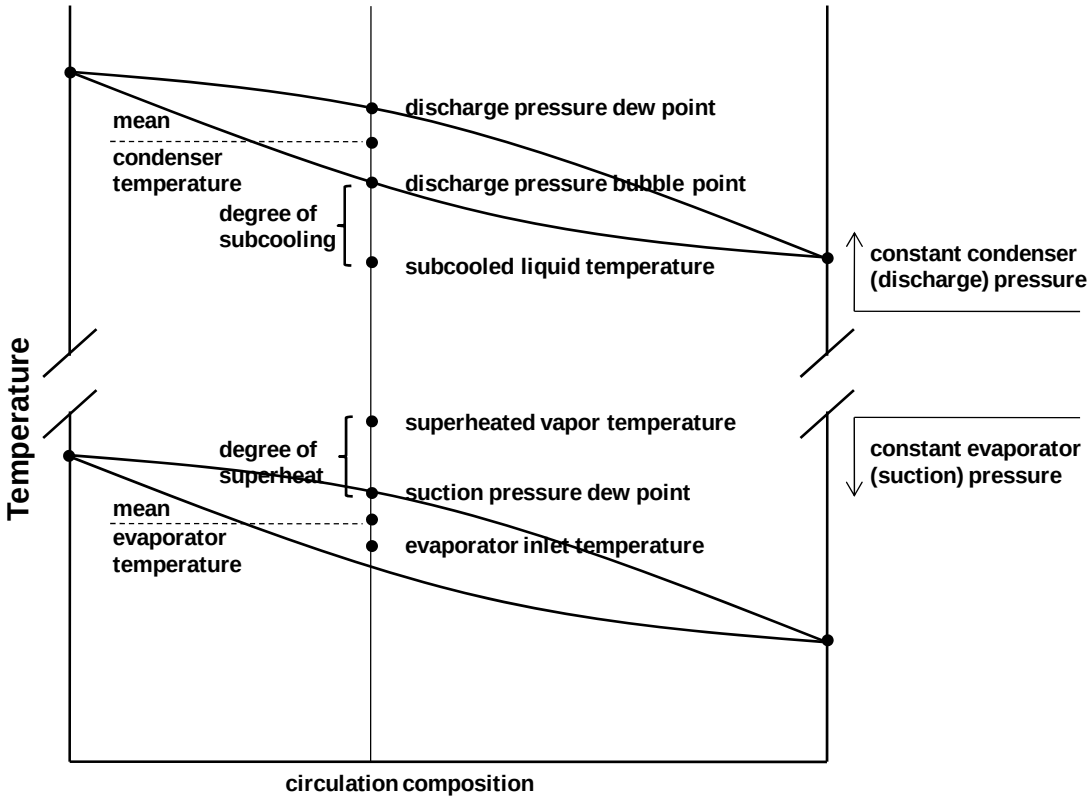
C.5.2: Candidates provided by Honeywell International

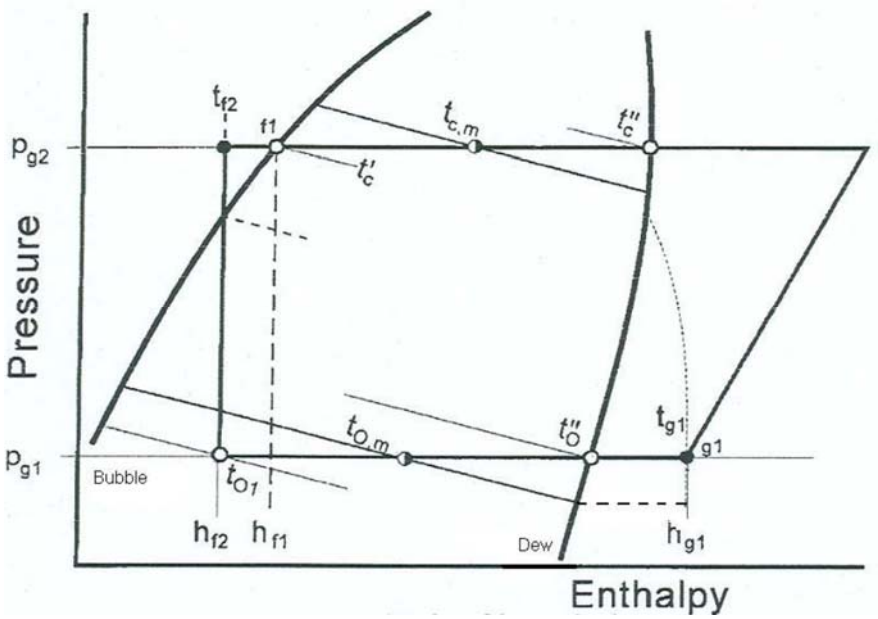
			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R123	Suction Pressure (psia)	5.8	6.5	3.5	2.0	0.9	7.3	3.5	2.0	0.9
		Discharge Pressure (psia)	20.8	35.2	25.0	25.0	22.8	41.5	35.2	35.2	32.4
		Pressure Ratio ( )	3.6	5.4	7.2	12.7	25.8	5.7	10.2	18.0	36.7
		Compressor Discharge Superheat (°F)	30.6	43.7	53.8	55.6	110.1	42.5	56.4	58.0	113.1
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	11.0	11.1	5.9	3.4	1.4	12.0	5.4	3.1	1.3
		Cooling Efficiency (COP)	5.39	3.62	3.04	2.32	1.66	3.40	2.35	1.84	1.34
Candidate Refrigerant	R1233ZD	Suction Pressure (psia)	8.4	9.5	5.1	3.0	1.4	10.6	5.1	3.0	1.4
		Discharge Pressure (psia)	29.1	48.4	34.7	34.7	31.8	56.7	48.4	48.4	44.7
		Pressure Ratio ( )	3.5	5.1	6.8	11.8	23.5	5.3	9.5	16.4	32.9
		Compressor Discharge Superheat (°F)	27.3	39.6	48.6	48.7	101.3	38.5	50.5	50.3	103.4
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	15.3	15.2	8.2	4.7	2.0	16.4	7.4	4.3	1.8
		Cooling Efficiency (COP)	5.35	3.57	2.98	2.27	1.61	3.35	2.28	1.78	1.29
		GWP_{100}	< 10								
		ASHRAE Safety Class	A1								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	45.7%	45.2%	48.0%	50.4%	53.5%	44.6%	48.0%	50.4%	53.5%
		Discharge Pressure (%)	39.8%	37.5%	39.0%	39.0%	39.4%	36.7%	37.5%	37.5%	37.8%
		Pressure Ratio (%)	-4.0%	-5.3%	-6.1%	-7.6%	-9.2%	-5.5%	-7.1%	-8.6%	-10.2%
		Capacity (%)	39.1%	37.4%	39.4%	40.8%	42.8%	36.5%	38.0%	39.3%	41.2%
		Efficiency (%)	-0.8%	-1.4%	-1.9%	-2.4%	-3.1%	-1.6%	-2.7%	-3.2%	-4.1%

C.5.3: Candidates provided by Mexichem Fluor, Inc.

			Operating Conditions								
			Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9
Thermodynamic Cycle Calculation Condition		Mean Evaporator Temperature (°F)	40	45	20	0	-25	50	20	0	-25
		Mean Condenser Temperature (°F)	100	130	110	110	105	140	130	130	125
		Evaporator Outlet Superheat (°F)	10	10	10	10	10	10	10	10	10
		Compressor Suction Superheat (°F)	10	20	20	10	40	20	20	10	40
		Subcooling (°F)	10	15	0	0	0	15	0	0	0
Baseline Refrigerant	R123	Suction Pressure (psia)	5.8	6.5	3.5	2.0	0.9	7.3	3.5	2.0	0.9
		Discharge Pressure (psia)	20.8	35.3	25.0	25.0	22.8	41.5	35.3	35.3	32.4
		Pressure Ratio ( )	3.6	5.4	7.2	12.7	25.8	5.7	10.2	18.0	36.7
		Compressor Discharge Superheat (°F)	30.6	43.7	53.8	55.6	110.1	42.5	56.4	57.9	113.1
		Evaporator Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Condenser Temperature Glide (°F)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Volumetric Capacity (Btu/ft³)	11.0	11.1	5.9	3.4	1.4	12.0	5.4	3.1	1.3
		Cooling Efficiency (COP)	5.40	3.62	3.04	2.32	1.66	3.40	2.35	1.84	1.34
Candidate Refrigeant	LPR1A	Suction Pressure (psia)									
		Discharge Pressure (psia)									
		Pressure Ratio ( )									
		Compressor Discharge Superheat (°F)									
		Evaporator Temperature Glide (°F)	0	0	0	0	0	0	0	0	0
		Condenser Temperature Glide (°F)	0	0	0	0	0	0	0	0	0
		Volumetric Capacity (Btu/ft³)									
		Cooling Efficiency (COP)									
		GWP100	<10								
		ASHRAE Safety Class	A2L (Estimated)								
Comparison: Candidate relative to Baseline		Suction Pressure (%)	109%	107%	118%	130%	149%	105%	118%	130%	149%
		Discharge Pressure (%)	88%	81%	86%	86%	87%	79%	81%	81%	82%
		Pressure Ratio (%)	-10%	-12%	-15%	-19%	-25%	-12%	-17%	-21%	-27%
		Capacity (%)	90%	88%	97%	107%	124%	85%	96%	106%	122%
		Efficiency (%)	0%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%

APPENDIX D: ZEOTROPIC BLEND VOCABULARY FOR COMPRESSOR CALORIMETER TESTS





Cycle Process for Zeotropic Refrigerant Mixtures (AHRI Standard 540-2007)

The schematic above shows "temperature glide" for zeotropic refrigerant mixtures at the evaporation and condensation processes. Standard reference temperatures are the dew-point temperatures t_0" at the evaporating pressure p_{g1} and t_c"at the condensing pressure p_{g2}.

The following equations may be used to calculate the mean evaporating temperature, mean condensing temperature, refrigerant superheating, and refrigerant subcooling:

- mean evaporating temperature: $t_{0,m} = (t_{01} + t_0'')/ 2$
- mean condensing temperature: $t_{c,m} = (t_c' + t_c'')/ 2$
- refrigerant superheating: $\Delta t_{sg} = t_{g1} - t_0''$
- refrigerant subcooling: $\Delta t_{Sf} = t_c' - t_{f2} = t_{f1} - t_{f2}$

Because $t_{01} = t_0''$ and $t_c' = t_c''$ for single-component refrigerants and azeotropic multi-component refrigerants, the cycle process model represents a particular kind of model for zeotropic refrigerant mixtures. In all reference systems:

- refrigerating capacity: $Q = \dot{m} (h_{g1} – h_{f2})$
- refrigerating capacity converted to no subcooling: $Q_0 = \dot{m} (h_{g1} – h_{f1})$

The reference systems described above allow one to calculate and present performance data for all kinds of refrigerants in a similar way.

Symbols:
f_1 = Bubble point at condensing process.
g_1 = Point where the refrigerant enters the compression process.
g_2 = Point where the refrigerant leaves the compression process
h_{f1} = Enthalpy of the refrigerant at bubble point of condensing process.
h_{f2} = Enthalpy of the subcooled refrigerant liquid entering the expansion process.
h_{g1} = Enthalpy of the refrigerant gas entering the compression process.
$\dot{m}$ = Refrigerant mass flow rate.
P_{g1} = Compressor suction dew point pressure.
P_{g2} = Compressor discharge dew point pressure.
Q = Refrigerating capacity.
Q_0 = Refrigerating capacity assuming no subcooling.
t_c = Condensing temperature.
t_c' = Bubble point temperature at condensing process.
t_c'' = Dew point temperature at condensing process.
$t_{c,m}$ = Mean condensing temperature.
t_{f1} = Temperature at which the subcooled liquid exits the expansion process
t_{f2} = Temperature at which the subcooled liquid enters the expansion process.
t_{g1} = Temperature of the refrigerant entering the compression process.
t_0 = Evaporating temperature.
t_0'' = Dew point temperature at evaporation process.
t_{01} = Temperature at the outlet of the expansion process and inlet to the evaporation process.
$t_{0,m}$ = Mean evaporating temperature.
Δt_{sf} = Refrigerant subcooling.
Δt_{sg} = Refrigerant superheat.

APPENDIX E: SAMPLE COMPRESSOR CALORIMETER TEST REPORT FORMAT

COMPRESSOR CALORIMETER TEST
OF
REFRIGERANT BLEND
R32/R134a (25%/75%)

Name of Researcher(s)

Company Name
Company Address

Date of Report

This Report is
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Until After Reviewed and Approved by the
Low-GWP AREP Technical Committee and AHRI Executive Committee

AREP COMPRESSOR CALORIMETER TEST REPORT FORMAT

1. Introduction:

   General discussion of the type tests, time and duration, location of test facilities, and refrigerants that are covered by the report.

2. Details of Test Setup:

   a. Description of Test Refrigerant-Lubricant and Charge

   Items to discuss· in this section are:
   - Refrigerant or refrigerant blend tested
     - blend components and composition (% refrigerant weight) if available
     - total refrigerant charge; lbs mass, (kg)
   - Lubricant
     - manufacturer/lubricant brand and generic name
     - viscosity grade of the lubricants
     - define any modifications to base lubricant (if known)

   b. Description of Compressor

   Items to discuss in this section are:
   - type of compressor, high-side or low-side design, and description of compressor drive
   - list of compressor modifications or accessories in place during test
   - manufacturer's name
   - model designation
   - motor nameplate rating

   If air flow over the compressor is required:
   - statement that air flow was required
   - quantity required
   - velocity and temperature of air
   - orientation of air flow in relation to the compressor

   Compressor operating conditions during test:
   - ambient air temperature
   - suction pressure and corresponding saturation temperature
   - refrigerant vapor temperature entering the compressor
   - discharge pressure and corresponding saturation temperature

- discharge temperature
- percent variation between primary and confirming test
- volts
- phase
- frequency; Hz
- speed; RPM (rad/s)
- system oil circulation; percent by mass (optional)

c. Description and Size of Test Loop

Items to be discussed in this section are:

- description of the test loop components
- description of instrumentation used, accuracy and measuring points (please include a diagram)

3. Results

This section should discuss the analysis of the results relative to the baseline refrigerant. If data is not measured directly, then provide a discussion of the measured data and describe how these were derived. Include all "correction factors". Actual presentation of data and charts should be placed in the appendices.

If the report contains refrigerants having temperature glide, the following content shall be added as the first paragraph to the Result section.

"*All compressor tests are performed at a refrigerant's dew point temperature for suction and discharge pressure conditions, per AHRI Standard 540 requirements. This does not have an impact on comparing compressor performance between two or more refrigerants that do not exhibit temperature glide. However, when refrigerants exhibit temperature glide, it is important to note that actual systems operate closer to the mid-point condition. When comparing compressor performance of one refrigerant with glide to another refrigerant without glide, or comparing two refrigerants with significantly different glides, comparison at pressures corresponding to the mid-point of the temperature glide rather than the dew point will yield results that are more representative of actual operation in a system.*"

Appendix A

Tabular Data

Performance data in tabular form within defined accuracies and ranges of operation. (AHRI Standard 540-2004)

- evaporating temperature (see note 1); ˚F, (˚C)

- condensing temperature (see note 2); ˚F, (˚C)
- discharge temperature; ˚F, (˚C)
- applicable superheating; ˚F, (˚C)
- applicable subcooling; ˚F, (˚C)
- compressor capacity; Btu/hr, (W)
- refrigerant mass flow rate; lbs mass/hr, (kg/hr)
- composition of blend at the compressor inlet; % mass of refrigerant component, if available
- amperes; A, (A)
- input power; W, (W)
- EER; Btu/h IW, (W/W)
- COP; W/W
- $COP_{alt}/COP_{baseline}$ at corresponding evaporator and condensing temperatures (Optional - additional data collected which are peculiar to the instrumentation of the test loop.)

Notes:

1. For zeotropic blends evaporator temperatures are not well defined. A suggested substitute is the mean of the suction pressure dew point and the expansion temperatures. In this case, each temperature and the mean will be reported.

2. For zeotropic blends condenser temperatures are not well defined. A suggested substitute is the mean of the discharge pressure bubble point and the discharge pressure dew point temperatures. In this case each temperature and the mean will be reported.

Appendix B
Performance Maps

- 10-Coefficient polynomial equation for each test refrigerant.

- For baseline and each alternative refrigerant tested, plot the following as a function of evaporator temperature for given condenser temperatures (one set of plots to a page for each refrigerant tested; see attached samples):
  - Capacity
  - Input Power
  - COP

- Comparative Analysis:
  - $COP_{alt}/COP_{Baseline}$ as a function of evaporator temperature at given condenser temperatures

APPENDIX F: SYSTEM DROP-IN TESTS DRAFT REPORT FORMAT GUIDE AND DATA FORM

SYSTEM DROP-IN TEST OF
REFRIGERANT BLEND
R-NUMBER (WEIGHT COMPOSITION)
IN
TYPE OF EQUIPMENT

Name of Researcher(s)

Company Name
Company Address

Date of Report

This Report is
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Low-GWP AREP Technical Committee and AHRI Executive Committee

Low-GWP AREP SYSTEM DROP-IN TEST -- REPORT FORMAT

1. Introduction:

   General discussion of the type of equipment and tests, time and duration of tests, location of test facilities, and refrigerants that are covered by the report.

2. Details of Test Setup:

   a. Description of System

      Items to discuss in this section include:

      - Name and model number of the tested system.
      - Nominal capacity of the system.
      - Baseline refrigerant, charge, flow rate, and lubricant type.

   b. Description of Modifications to System

      Discuss any changes made to the system, and the reasons for these changes (*The drop-in tests should be conducted with the alternative refrigerants placed in representative existing systems using baseline refrigerants with no or only minor modifications, if any, made to the equipment.*)

   c. Description of Tests Conducted

      Items to discuss in this section include:
      - Test set-up **(include schematic or diagram)**
      - Instrumentation used, accuracy thereof and measuring points

3. Results

   a. Data Form

      Please complete all items in the data form as appropriate. Additional lines or forms may be added if needed.

      Performance factors based on the type of equipment tested should be reported in accordance with corresponding performance rating standards defined in Appendix F.

   b. Other

      Include a discussion of results as deemed appropriate.

Low_GWP AREP SYSTEM DROP-IN TEST DATA FORM

Manufacturer: _____ Manufacturer's Notation: _____

Basic Information	
Alternative Refrigerant (If not proprietary, composition as Charged, % wt)	
Alternative Lubricant Type and ISO Viscosity	
Baseline Refrigerant and Lubricant	
Make and Model of System	
Nominal Capacity and Type of System	

Comparison Data			**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP UNits**	**Ratio**
Mode (Heating/Cooling)									
Compressor Type									
Compressor Displacement					m^3/min			ft^3/min	
Nominal Motor Size					hp				
Motor Speed					rpm				
Expansion Device Type									
Lubricant Charge					kg			lb	
Refrigerant Charge					kg			lb	
Refrigerant Mass Flow Rate					kg/min			lb/min	
Composition, at compr. inlet if applicable					% wt				
Ambient Temps.	Indoor	db			°C			°F	
		wb			°C			°F	
	Outdoor	db			°C			°F	
		wb			°C			°F	
Total Capacity					W			Btu/hr	
Sensible Capacity					W			Btu/hr	
Total System Power Input					W			W	
Compressor Power Input					W			W	
Energy Efficiency Ratio (EER)					W/W			Btuh/W	
Coeff. Of Performance (COP)									

Other System Changes

System Data	**Base.**	**Alt.**	**Ratio**
Degradation Coefficient – Cd			
Seasonal Energy Efficiency Ratio - SEER			
Heating Seasonal Performance Factor - HSPF			

Note: Cells that should not be filled in are shaded. Please fill in the blank cells, if applicable, with the appropriate information. Note that some information may not be required or even meaningful, depending on the type of equipment tested.

Low-GWP AREP SYSTEM DROP-IN TEST DATA FORM

Type of System: _____ Alternate Refrigerant: _____
(e.g., SSHP, window RAC, chiller, etc.) (and composition as charged, % weight, if not proprietary)

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid							
Flow Rate (gas)			m^3/min			ft^3/min	
Flow Rate (liquid)			L/min			gal/min	
Inlet Temperature			°C			°F	
Outlet Temperature			°C			°F	
Condenser							
Heat Exchange Fluid							
Flow Rate (gas)			m^3/min			ft^3/min	
Flow Rate (liquid)			L/min			gal/min	
Inlet Temperature			°C			°F	
Outlet Temperature			°C			°F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P [kPa]	T (°C)	P [kPa]	T [°F]	P [psia]	T [°F]	P [psia]
Compressor Suction								
Compressor Discharge								
Condenser Inlet								
Condenser Outlet								
Expansion Device Inlet								
Subcooling, at expan. device								
Evaporator Inlet								
Evaporator Outlet								
Evaporator Superheat								

Data Source(s) for Refrigerant Properties

Additional Notes

Submitted by: _____

Note: Cells that should not be filled in are shaded. Please fill in the blank cells, if applicable, with the appropriate information. Note that some information may not be required or even meaningful, depending on the type of equipment tested.

APPENDIX G: TESTS TO CONDUCT AND STANDARDS TO FOLLOW, FOR DROP-IN TESTING AND SOFT-OPTIMIZED SYSTEM TESTING

Minimum requirement is to test at standard rating conditions for each equipment type according to Table G1. **Additional testing at high ambient operating conditions is strongly encouraged. High ambient conditions are indicated in the column labeled "high" and further defined in Table G2.** Exceptions may be considered on a case by case basis.

Table G1

Equipment	Heat Rejection Method	Size (Btuh)	AHRI Standard	Test(s) to Conduct		Additional Standards	Examples of Calculations Required
				Standard	High		
Unitary AC	Air	0-65k	210/ 240	Steady State Cooling Tests A, B, C and Cyclic Cooling Test D	Table G2	ASHRAE Standard 37	-EER -SEER -Capacity
Unitary AC	-Water -Evap	all	210/ 240	Steady State Cooling Tests A, B, C and Cyclic Cooling Test D	Table G2 indoor conditions, and 90°F condenser water inlet temp	ASHRAE Standard 37	-EER -SEER -Capacity
Air-Source Unitary HP	Air	0-65k	210/ 240	-Steady State Cooling Tests A, B, C and Cyclic Cooling Test D -Standard Rating Conditions Steady State High Temperature Heating & Cyclic -Low Temperature Heating Steady State -Frost Accumulation	Table G2 for Cooling Tests	ASHRAE Standard 37	-EER &SEER (cooling) -COP &HSPF (heating) -Capacity
Water- Source HP		all	ISO-13256	-Standard Rating Cooling -Standard Rating Heating	Table G2 indoor conditions, and 90°F condenser water inlet temp	ASHRAE Standard 37	-EER (cooling) -COP (heating) -Capacity

Equipment	Heat Rejection Method	Size (Btuh)	AHRI Standard	Test(s) to Conduct		Additional Standards	Examples of Calculations Required
				Standard	High		
Ground Water-Source HP		all	ISO-13256	-Standard Rating Cooling (High and Low Temp.) -Standard Rating Heating (High and Low Temp.)	N/A	ASHRAE Standard 37	-EER (cooling) -COP (heating) -Capacity
Air-Source Commercial and Industrial Unitary HP		>65k	340/360	-Standard Rating Cooling - Standard Rating Heating (High and Low Temp.)	Table G2 for Cooling Tests	ASHRAE Standard 37	-EER (cooling) -COP (heating) -Capacity
Commercial and Industrial Unitary AC Equipment	-Air -Water -Evap.	>65k	340/360	-Standard Rating Cooling	-Air: Table G2 for Cooling Tests -Water/Evap.: Table G2 indoor conditions, and 90°F condenser water inlet temp	ASHRAE Standard 37	-EER (cooling) -Capacity
Chillers	-Air -Water -Evap.	all	550/590	-Standard Rating Conditions -(cooling) -(heat pump) -(heat reclaim)	-Air: 125°F -Water: 105°F entering condenser	ASHRAE Standard 30	-Capacity -COP
Mechanical Transport Refrigeration Units		all	1110	-Standard Rating Conditions (High and Low Temp.)	130°F condenser inlet air 70°F evaporator inlet air		-Net Total Refrigeration Capacity -COP
Transport AC		all	none	Performance at typical rating conditions	1. 104°F condenser inlet air, 104°F evaporator inlet air at RH=50% 2. 120°F condenser inlet air, 120°F evaporator inlet air at RH=50%		- Net Cooling Capacity - COP

Equipment	Heat Rejection Method	Size (Btuh)	AHRI Standard	Test(s) to Conduct		Additional Standards	Examples of Calculations Required
				Standard	High		
Ice Makers		all	810	-Standard Rating Conditions	110°F for ice making head and self-contained units 120°F for condensing units and condensers that are placed outdoors. Both types of machines are tested with 90°F water	ASHRAE Standard 29	-Ice Harvest Rate -Condenser Water Use Rate -Potable Water Use Rate -Energy Consumption Rate -Bin Theoretical Storage Capacity -Ice Hardness Factor
Commercial Refrigerator		all	1200/1201	-Standard Rating Conditions	N/A	ASHRAE Standard 72	-Compressor Energy Consumption -EER
Ductless VRF		all	1230	-Standard Rating Conditions	Table G2 outdoor conditions	AHRI Standard 1230	- Capacity -EER & SEER -Integrated Energy Efficiency Ratio, IEER
Single Package Vertical AC & HP	Air	0-400K	390	Cooling (Standard Rating) Heating (Standard Rating High Temperature) Optional: Heating (Standard Rating Low Temperature)	Table G2	ASHRAE Standard 37	-Capacity -EER or COP -IPLV

Table G2

Condition	Indoor		Outdoor		Reporting
	DB	WB	DB	WB	
1 (ISO T3)	84°F (29°C)	66°F (19°C)	115°F (46°C)	-	System performance (capacity and EER)
2	84°F (29°C)	66°F (19°C)	125°F (52°C)	-	Optional test condition, report the system performance, if system can be operated at this condition.

APPENDIX H: SOFT-OPTIMIZED SYSTEM TESTS DRAFT REPORT FORMAT GUIDE AND DATA FORM

SOFT-OPTIMIZED SYSTEM TEST OF
REFRIGERANT BLEND
R-NUMBER (WEIGHT COMPOSITION)
IN
TYPE OF EQUIPMENT

Name of Researcher(s)

Company Name
Company Address

Date of Report

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Low-GWP AREP SOFT-OPTIMIZED SYSTEM TEST -- REPORT FORMAT

1. Introduction:

   General discussion of the type of equipment and tests, time and duration of tests, location of test facilities, and refrigerants that are covered by the report.

2. Details of Test Setup:

   a. Description of Baseline System

      Items to discuss in this section include:

      - Name and model number of baseline system.
      - Nominal capacity of baseline system.
      - Baseline refrigerant, charge, flow rate, and lubricant type.

   b. Description of Modifications to System

      Discuss all changes made to soft-optimize the system, and the reasons for these changes:

      - Refrigerant charge
      - Lubricant
      - Compressor and/or Motor
      - Flow Control
      - Heat Exchanger Circuiting
      - Heat Transfer Area (including face area, type, number of fills, fins per inch, number of rows, etc.)
      - Inclusion of a Liquid-Line/Suction-Line Heat Exchanger
      - Size of Accumulators
      - Any other changes made

   c. Description of Tests Conducted

      Items to discuss in this section include:

      - Test set-up **(include schematic or diagram)**
      - Instrumentation used, accuracy thereof and measuring points

3. Results

   a. Data Form

      Please complete all items in the data form as appropriate. Additional lines or forms may be added if needed.

Performance factors based on the type of equipment tested should be reported in accordance with corresponding performance rating standards defined in Appendix F.

b. Other

Include a discussion of results as deemed appropriate.

Low-GWP AREP SOFT – OPTIMIZED SYSTEM TEST DATA FORM

Manufacturer: _____ Manufacturer's Notation: _____

Basic Information	
Alternative Refrigerant (Composition as Charged, % wt, if not proprietary)	
Alternative Lubricant Type and ISO Viscosity	
Refrigerant and Lubricant of Baseline System	
Make and Model of Baseline System	
Nominal Capacity and Type of Baseline System	

Comparison Data			**Base.**	**Alt.**	**SI Units**	**Base.**	**Alt.**	**IP UNits**	**Ratio**
Mode (Heating/Cooling)									
Compressor Type									
Compressor Displacement					m^3/min			ft^3/min	
Nominal Motor Size					hp				
Motor Speed					rpm				
Expansion Device Type									
Lubricant Charge					kg			lb	
Refrigerant Charge					kg			lb	
Refrigerant Mass Flow Rate					kg/min			lb/min	
Composition, at compr. Inlet if applicable					% wt				
Evaporator Face Area					m^2			ft^2	
Condenser Face Area					m^2			ft^2	
Ambient Temps.	Indoor	db			°C			°F	
		wb			°C			°F	
	Outdoor	db			°C			°F	
		wb			°C			°F	
Total Capacity					W			Btu/hr	
Sensible Capacity					W			Btu/hr	
Total System Power Input					W			W	
Compressor Power Input					W			W	
Energy Efficiency Ratio (EER)					W/W			Btuh/W	
Coeff. Of Performance (COP)									

Other System Changes (eg: llsl-hx, flow control, hx fins and circuiting, vapor/liquid injection, etc.)

System Data	**Base.**	**Alt.**	**Ratio**
Degradation Coefficient – Cd			
Seasonal Energy Efficiency Ratio - SEER			
Heating Seasonal Performance Factor - HSPF			

Low-GWP AREP SOFT – OPTIMIZED SYSTEM TEST DATA FORM

Type of System: _____ Alternate Refrigerant: _____
(e.g., SSHP, window RAC, chiller, etc.) (and composition as charged, % weight, if not proprietary)

Air/Water Side Data	Base.	Alt.	SI Units	Base.	Alt.	IP Units	Ratio
Evaporator							
Heat Exchange Fluid							
Flow Rate (gas)			m^3 /min			ft^3/min	
Flow Rate (liquid)			L/min			gal/min	
Inlet Temperature			°C			°F	
Outlet Temperature			°C			°F	
Condenser							
Heat Exchange Fluid							
Flow Rate (gas)			m^3/min			ft^3/min	
Flow Rate (liquid)			L/min			gal/min	
Inlet Temperature			°C			°F	
Outlet Temperature			°C			°F	

Refrigerant Side Data Temperatures & Pressures	Baseline		Alternative		Baseline		Alternative	
	T (°C)	P [kPa]	T (°C)	P [kPa]	T [°F]	P [psia]	T [°F]	P [psia]
Compressor Suction								
Compressor Discharge								
Condenser Inlet								
Condenser Outlet								
Expansion Device Inlet								
Subcooling, at expan. device								
Evaporator Inlet								
Evaporator Outlet								
Evaporator Superheat								

Data Source(s) for Refrigerant Properties

Additional Notes

Submitted by: _____

AREP SOFT-OPTIMIZED SYSTEM TESTS

Instructions for Soft-Optimized System Test Report Data Form

Boxes that should not be filled in are marked with grey shading. Please fill in the blank boxes, if applicable, with the appropriate information. Note that some information may not be required or even meaningful, depending on the type of equipment tested (e. g., HSPF for a window room air-conditioner). Please enter data in the units shown. This will facilitate comparison of results.

Explanation of some of the data required follows:

Manufacturer's Notation

You may use this to keep track of several data forms. For instance, you may want to call two different forms Table 1 and Table 2 and refer to the data forms as such in the textual part of your report.

Basic Information

Nominal Tons/Capacity and Type of Baseline System
E.g., 3 ton SSHP (split system heat pump), 20 ton chiller, 1 ton window RAC (room air- . conditioner), etc.

Comparison Data

Mode (Heating/Cooling)
Is the system operating under a heating or cooling load? Enter text in the area provided, or simply circle the correct choice and cross-out the incorrect choice.

Compressor Type
Scroll, screw, reciprocating, rotary, etc. Please explain any further details (e.g., hermetic or semi-hermetic) in the textual part of the report, the "Other System Changes" section of the data form, and/or the "Additional Notes" section of the data form, as appropriate.

Expansion Device Type
Fixed orifice, TX Valve, capillary tubes, etc. Please explain any further details (e.g., diameter of orifice) in the textual part of the report, the "Other System Changes" section of the data form, and/or the "Additional Notes" section of the data form, as appropriate.

Evaporator and Condenser Face Area
Please enter the face area (width times height) of the heat exchangers. Please explain any further details about the heat exchangers (type of fin, fins per inch, number of rows, etc.) in the textual part of the report, the "Other System Changes" section of the data form, and/or the "Additional Notes" section of the data form, as appropriate.

Other System Changes

Please note all changes made to soft-optimize the system, so that the reader can identify the changes made and easily compare them with other test reports. For instance, please indicate the total heat transfer area (face area may not be sufficient) of the evaporator and condenser, for both the baseline and alternative systems, if heat transfer area was shifted between the two heat exchangers in an attempt to soft-optimize the system.

Air/Water Side Data

Heat Exchange Fluid
Air, water, 40% ethylene glycol in water, etc. Indicate temperature of cooling air if other than ambient.

Flow Rate (gas or liquid)
Fill in the flow rates of the air, water, glycol, etc. used to cool the heat exchangers. Note that data will likely be required for only one line (either gas or liquid).

Data Source(s) for Refrigerant Properties

Please indicate source and version number, if applicable (e.g., REFPROP 8.0, REFPROP 9.0, page 30.35 of 2009 ASHRAE Fundamentals Handbook, etc.). If more than one source is used, indicate which source is used for which data/calculations.

Additional Notes

Include here any further description of the system tested or the data shown. Do not indicate significant changes between the baseline and alternative system here (these should be noted in the "Other System Changes" section).

If you wish to report additional data on a given test, please insert extra lines or pages, or use the textual part of the report.

Note that a different form will have to be completed for each run (i.e., heating vs. cooling mode, different ambient conditions, etc.) of the system. The "System Data" information (SEER and HSPF) should be repeated on all forms for test runs used to calculate these values.

APPENDIX I: THE LOW-GWP AREP TC CHECKLIST FOR REVIEWING AND APPROVING THE AREP TEST REPORTS

Refrigerant:

- Refrigerants' GWP values should be based on IPCC AR4, 100 year ITH.

- The reference information on the source of tested refrigerants' properties should be clearly identified. For instance, which version of NIST REFPROP was used?.

Charge:

- The report needs to clarify whether charge optimization was conducted, and what charge levels were used for the various refrigerants tested.

- It would be very helpful for testing companies to comment on how they chose the charge levels for the various refrigerants they compared, and what impact (if any) that might have had on the refrigerant comparisons.

- The same mass of refrigerant may or may not be optimum. Did companies test for charge sensitivity? If not, please state that charge was not optimized, and that optimal performance for the alternative candidate may have been better (but unknown how much). It would be helpful if they could explain whether they believe, based on their experience with the type of equipment tested, whether the charge level has any effect on the performance characteristics that they measured. If it does have some effect, how much performance change might be expected?

Oil:

- The author should list what type of lubricant was used in the testing. At minimum, the type of lubricant should be mentioned if the specific brand is confidential, i.e. POE, PVE, or something else.

Testing:

- Provide detailed description on the equipment used for the tests, and how the testing was performed.

- The test setup diagram should be legible (with sufficient resolution for graphic images).

- The report should include the information about standard(s) used for testing.

- Were the test conditions used in line with the required conditions defined in the Participant's Handbook?

(If conditions are slightly off, it is the TC who decides whether to accept reports as standard reports. If conditions are off largely, then the TC would categorize these reports as non-standard reports indicating that they are useful and informational, but do not exactly meet the requirements defined by the program. In either case, authors should clarify in the reports that the tests were

done using conditions different from the program requirements, and explain how the conditions were chosen.)

- Reports should include a description of instrumentation used, accuracy and measuring points.

- Changing the TXV (different valve size or different head) will be considered as not a true drop-in, and should be soft-optimization. Adjustment of the existing TXV is allowable as part of a drop-in test.

- If necessary, a nomenclature section should be created to show definitions of acronyms (such as WLHP, GWLP, and so forth).

Data:

- Raw data should be provided in the standard data form defined in the handbook and IP versions of the data should be shown.

- Report all COP values to the same decimal place.

- Ratios should be shown in the data tables in cases where they would be meaningful.

- Data tables should not be scattered over multiple pages. Formatting and size of tables should be adjusted so that each table fits on one page (no wrapping to next page).

- The AREP report template was created for many types of equipment; in the case of water-to-water heat pump it is okay to delete the reference to air and to remove the row with gas flow rate.

- The heating degradation coefficient should be shown in the heating test table, and cooling degradation coefficient should be shown in the cooling test table.

- (For compressor testing) Providing only the performance after curve fitting is not enough. The report should include the raw data from actual test points.

Results:

- Reports should have a text section discussing results. Show ratios/percentage changes of results for candidate refrigerant versus the baseline (or % difference) in tables and/or figures.

- Do reports lack comparison bar charts showing relative performance?

- Choose different shading density or cross-hatching for better chart visibility when printed in black and white.

- Tables and figures should have correct information free of missing/incorrect labels. Figures should have proper scales and labels should not be cut-off in figures.

- Clarify what is/are included in "system power" in addition to the compressor power.

Conclusion:

- The report should be neutral instead of being promotional, and only state the results. Authors should avoid language that suggests picking one candidate refrigerant versus another.

- Discussing the differences between candidates and baseline test results should clarify the conditions under which they were compared.

- Conclusions should stick to the relative comparisons but not make judgments, and should not include unrelated topics, such as cost and long term reliability.

- Conclusions should only be drawn from tested data, and not from speculation.