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Drop-in Testing of Next-Generation R134a Alternates in a Commercial Bottle Cooler/Freezer

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ABSTRACT

Next-generation refrigerants with lower Global Warming Potentials than traditional HFC's are being commercially introduced. Drop-in performance tests were conducted in a commercial bottle cooler/freezer. Tests were conducted with R134a as a baseline and several next-generation refrigerants and blends. The tests were conducted in accordance with ASHRAE Standard 72 at -5.6°C and 3.3°C bottle cooler temperature setpoints. Two ambient conditions were tested, 23.9°C/55% relative humidity and 26.7°C/55% relative humidity. In addition to the ASHRAE test conditions, full pull-down and half pull-down tests were conducted in accordance with a soft-drink bottler's specifications. Performance parameters such as discharge air temperatures, product simulator temperatures, suction pressure, discharge pressure, compressor mass flow rate, and compressor input power were measured and compared. With the exception of HFO1234ze(E), all the substitute refrigerants had similar performance as R134a. HFO1234ze(E) had lower density at compressor suction conditions and therefore resulted in longer compressor run times and longer pull-down times. A larger displacement compressor would likely bring HFO1234ze(E) to roughly the same performance as the other refrigerants.

1. INTRODUCTION

1.1 Refrigerants Tested

Table 1 compares some main properties of R134a to the alternates. These refrigerants have similar saturation pressures with the exception of HFO1234ze(E), which is lower than the others.

Table 1: Refrigerant properties

Refrigerant:	**R134a**	**HFO1234yf**	**XP10**	**HFO1234ze(E)**	**N13**
Class	A1	A2L	A1	A2L	A1
Approx. GWP	1300	Less than 10	600	Less than 10	600
Pressure* at -6.7°C (20°F)	228 kPa 33.1 psia	250 kPa 36.3 psia	250 kPa** 37 psia**	168 kPa 24.4 psia	220 kPa** 32 psia**
Pressure* at 48.9°C (120°F)	1280 kPa 185 psia	1270 kPa 183 psia	1300 kPa** 190 psia**	969 kPa 140 psia	1200 kPa** 180 psia**

* The pressure shown is the average of the liquid and vapor phase pressures
** Approximate values shown

1.2 Test Objectives

The main objectives of the evaluation were:

a) Conduct performance tests in accordance with ASHRAE Standard No. 72-2005.
   - Two bottle cooler thermostat settings were tested: -5.6°C (22°F) and 3.3°C (38°F)
   - Two test cell ambient conditions were tested: 23.9°C (75°F)/55% relative humidity and 26.7°C (80°F)/55% relative humidity

b) Conduct full pull-down and half pull-down tests in accordance with a soft-drink bottler's specifications.

c) Compare performance values such as discharge air temperatures, product simulator temperatures, suction pressure, discharge pressure, compressor mass flow, and compressor input power.

d) Repeat each series of tests with the following refrigerants: 1) R134a (baseline), 2) HFO1234yf, 3) XP10, 4) HFO1234ze(E), and 5) N13.

e) Note any other important observations.

2. TEST EQUIPMENT, INSTRUMENTATION, AND PROCUDURES

2.1 Bottle Cooler Details

Figures 1 shows a photo of the test unit, and Figure 2 shows a flow diagram of the refrigerant circuit. As shown, the bottle cooler had a single door, approximately 1.8 m (6 ft) tall. One important difference between this unit and a typical bottle cooler is that the test unit can operate below freezing, with a -5.6°C (22°F) setpoint. The unit is intended to be used with beer cans or bottles, and the -5.6°C setpoint is not quite cold enough to freeze beer. However, due to condensation, a layer of ice forms on a beer can when it is removed from the unit.

The evaporator and evaporator fan are located in the top-back of these coolers. The compressor, condenser, and condenser fan are located in the bottom. Other details are:

- Compressor: Fractional horsepower, hermetic, reciprocating type
- Condenser: Approximately 30 cm width x 28 cm height 3.3 cm depth, with 16 tubes total in an 8 x 2 staggered pattern with copper tubes and aluminum fins, 3.1 fin/cm
- Expansion device: Capillary tube 244 cm length with 1.24 mm ID. The capillary tube of these coolers is piped through the suction tube, thus providing a liquid-to-suction heat exchanger.
- Evaporator: Approximately 49 cm width x 18 cm height x 7 cm depth, with 21 tubes total in a 7 x 3 staggered pattern with copper tubes and aluminum fins, 2.4 fin/cm.
- Refrigerant: The normal charge for these units is 266 g of R134a. However, the additional charge needed to accommodate the refrigerant flow meter and connecting piping was calculated and included in the tests, thus 322 g of refrigerant was used for the tests. A refrigerant mass flow meter was installed in the compressor discharge line.

2.2 Instrumentation

Tests were conducted in Test Cell No. 11 at the Hussmann R&D Lab in Bridgeton, MO, USA from Oct 2010 through May 2011. The following data was recorded:

- Compressor suction pressure (absolute pressure transducer used, +/- 3.4 kPa accuracy)
- Compressor discharge pressure (gauge pressure transducer used, +/- 12 kPa accuracy)
- Refrigerant mass flow rate (+/- 0.14 kg/hr accuracy)
- Refrigerant pressure drops through evaporator, condenser, and refrigerant flow meter (+/- 0.7 kPa differential pressure accuracy)
- Compressor suction and discharge temperatures (ANSI Type T thermocouples used for all temperature measurements, +/-0.2°C accuracy)
- Evaporator refrigerant outlet temperature
- Condenser air inlet and outlet temperatures
- Condenser refrigerant inlet and outlet temperatures

- Discharge air temperatures, 5 cm from left end, center, and 5 cm from right end of discharge air duct
- Return air temperatures, 5 cm from left end, center, and 5 cm from right end of return air duct
- Test cell ambient dry and wet bulb temperatures
- Test unit voltage, current, and power (Power measurement accuracy +/-3.75 W)
- Compressor current and power
- Evaporator fan power (checked once, not recorded continuously)

A PC-based Data Acquisition System was used to record measurements. The system employed 12-bit analog to digital data conversion. Temperatures were recorded every 60 seconds, while other measurements, such as power, pressure, and differential pressure were recorded every 10 seconds. Data was summarized in spreadsheets in accordance with the corresponding test standard.

Figure 1: Commercial bottle cooler/freezer
Note discharge air temperature display in upper right reads 23°F (-5°C)

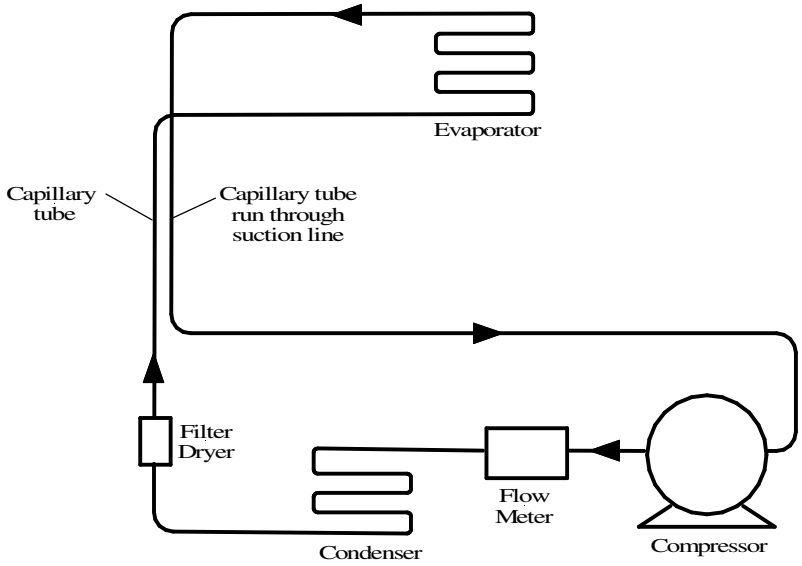

Figure 2. Flow diagram of refrigerant circuit

2.3 Procedures

Two types of tests were conducted: 1) "Steady-state" tests with door opening/closing cycles in accordance with ASHRAE Standard 72-2005, *Method of Testing Commercial Refrigerators and Freezers* and 2) full pull-down and half pull-down tests in accordance with a soft-drink bottler's specifications.

A detailed discussion of these two types of tests is beyond the scope of this report, but in short, the ASHRAE tests measure performance over a normal operating cycle including automated door openings and defrost period. The full pull-down test measures performance with the full product load "soaked" at 32°C (90°F). Similarly, the half pull-down test measures performance with half the product load soaked at 32°C.

An overview of the tests conditions is shown in Table 2.

Table 2: Overview of test conditions

Refrigerants:	R134a					
	HFO1234yf					
	XP10					
	HFO1234ze(E)					
	N13					
Test type:	ASHRAE 72				Full pull-down	Half pull-down
Test cell temperature °C (°F):	23.9 (75)	23.9 (75)	26.7 (80)	26.7 (80)	32.2 (90)	32.2 (90)
Test cell relative humidity:	55%	55%	55%	55%	65%	65%
Bottle cooler setpoint, °C (°F):	5.6 (38)	-3.3 (22)	5.6 (38)	-3.3 (22)	5.6 (38)	5.6 (38)

2.4 Fluid properties

Fluid properties were obtained using REFPROP software, Database 23, Version 8.0.

3. RESULTS AND DISCUSSION

3.1 ASHRAE 72 Tests

Tables 3 through 6 show averaged data over the duration of each test run. To make it easier to review the tables, each row has a number value and each column has a Test ID number. Note that the row values are not sequential. Many rows were to hidden reduce the length of this report.

Table 3 shows results at 23.9°C/55% relative humidity ambient conditions with the 3.3°C bottler cooler setpoint. Beginning with the left side of Table 3, three sets of baseline performance tests were conducted, Test ID Nos. 1, 2 and 3. The completion dates were 10/12/10, 2/16/11 and 5/09/11. These tests were conducted with R134a at the beginning, middle, and end of the overall program to verify that the baseline performance was repeatable. For example, if something had gone wrong with the compressor or instrumentation, large differences would likely be seen among these three tests.

As shown in Table 3, there were some modest differences among the three baseline measurements. For example, in Rows 11 and 12, the compressor mass flow dropped slightly from 6.37 kg/hr to 6.24 kg/hr and then further to 6.16 kg/hr, for Tests 1, 2, and 3, respectively. Thus, the mass flow was 3.4% lower in Test 3 versus Test 1. On the other hand, there was almost no difference in the compressor power (Row 66) for these three tests, with 116 w, 118 w and again 118 w for Tests 1, 2, and 3, respectively. One possible cause of these changes is slightly different refrigerant charge. Beginning in 2011, an improved scale was used to charge the system. The new scale had +/-1 gram (+/- 0.04 ounce) precision versus the previous scale, which had +/- 7 gram (+/- 0.25 ounce) precision.

Table 3
Results at 23.9°C (75°F)/55% relative humidity ambient conditions, 3.3°C (38°F) bottle cooler setpoint

Row 0	Refrigerant	R134a	R134a	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	ASHRAE	ASHRAE (repeat)	ASHRAE (repeat)	ASHRAE	ASHRAE	ASHRAE	ASHRAE
2	Test ID no.	1	2	3	4	5	6	7
4	**Test cell temperature, °C**	**23.9**	**23.9**	**23.9**	**23.9**	**23.9**	**23.9**	**23.9**
5	**Test cell relative humidity, %**	**55**	**55**	**55**	**55**	**55**	**55**	**55**
6	**Bottle cooler setpoint, °C**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
8	Completion date	10/12/10	02/16/11	05/09/11	11/28/10	01/11/11	03/01/11	03/27/11
9	**Suction pressure, kPa**	**285**	**283**	**279**	**303**	**305**	**205**	**264**
10	**Discharge pressure, kPa**	**702**	**704**	**704**	**730**	**727**	**558**	**674**
11	**Refrigerant flow rate, kg/hr**	**6.37**	**6.24**	**6.16**	**7.26**	**6.58**	**6.50**	**6.53**
12	**Difference, %**	**0%**	**-2.1%**	**-3.4%**	**13.9%**	**3.3%**	**2.0%**	**2.5%**
16	Compressor suction temperature, °C	19.4	20.2	20.4	20.1	21.0	18.2	20.4
17	Compressor discharge temperature, °C	40.0	40.9	41.3	41.3	40.9	40.0	41.6
18	Evaporator outlet temperature, °C	-0.2	0.7	1.0	1.3	1.9	0.0	0.9
23	Discharge air temperature 2" from left end, °C	2.5	2.5	2.5	2.4	2.5	2.5	2.4
24	Discharge air temperature center, °C	2.6	2.6	2.6	2.6	2.7	2.6	2.6
25	Discharge air temperature 2" from right end, °C	2.4	2.4	2.3	2.4	2.5	2.4	2.4
50	**Product Simulator Temperatures**							
51	Integrated average, °C	4.0	4.0	4.1	4.0	4.0	4.0	4.1
59	**Refrigerant charge, g**	322+/-7	326 +/-1	326 +/-1	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**116**	**118**	**118**	**120**	**119**	**114**	**117**
67	**Difference, %**	**0%**	**1.1%**	**1.3%**	**2.7%**	**2.1%**	**-2.3%**	**0.6%**
69	**Compressor run time, %**	**35.1%**	**35.1%**	**35.9%**	**35.0%**	**35.0%**	**42.6%**	**37.0%**
70	**Difference, %**	**0%**	**0.0%**	**2.4%**	**-0.2%**	**-0.2%**	**21.5%**	**5.5%**
73	Evaporating temperature (avg. of dew and bubble), °C	-0.8	-0.9	-1.3	-0.9	-1.5	-1.3	-1.8
74	Condensing temperature (avg. of dew and bubble), °C	26.8	26.9	26.9	27.9	27.8	28.8	27.2
75	Superheat at compressor inlet, °C	2.4	3.4	3.9	3.2	4.7	1.7	4.4

Keeping in mind the three sets of baseline results, some main results in Table 3 are:

- Rows 9 and 10: The suction and discharge pressure, 205 kPa and 558 kPa, respectively of HFO1234ze(E) were considerably lower than the other refrigerants.
- Row 11 and 12: The refrigerant flow rate of HFO1234yf (Test 4) was 13.9% higher than the baseline.
- Rows 23 through 25: The discharge air temperatures were nearly identical for all tests. We would expect this result since discharge air temperature was the basis for cycling the compressor on/off.
- Row 66 and 67: The compressor power was within +/- 2.7% for all tests.
- Rows 69 and 70: The compressor run time for HFO1234ze(E) (Test 6) was 21.5% higher than the baseline.

Table 4 shows results at 23.9°C/55% relative humidity ambient conditions with the -5.6°C bottle cooler setpoint. Some main results in this table are:

- Rows 9 and 10: The suction and discharge pressures, 132 kPa and 592 kPa, respectively of HFO1234ze(E) (Test 11) were considerably lower than the other refrigerants.
- Rows 11 and 12: The mass flow rate of HFO1234yf (Test 9) was 19.6% higher than the baseline.
- Rows 23 through 25: The discharge air temperatures were nearly identical for all tests. Again, we would expect this result since discharge air temperature was the basis for cycling the compressor on/off.
- Row 66: Compared to the baseline, the compressor power values were 8.0% higher, 6.5% higher, 4.4% lower, and 1.4% higher for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.

- Rows 69 and 70: The compressor run time for HFO1234ze(E) (Test 11) was 18.1% higher than the baseline**.**

These results show that the unit used somewhat less power at the -5.6°C setpoint when HFO1234ze(E) was used as the refrigerant. However, we should be careful about interpreting the lower power as being caused by the refrigerant. To illustrate this point, consider that the compressor run time for HFO1234ze(E) was 18.1% higher than the baseline. Independent of the refrigerant, it seems likely that all things being equal, higher compressor run time and fewer on/off cycles would result in lower power use due to better matching of the compressor to the cooling load. To put this another way, it seems reasonable to theorize that we would see similar lower power values if the other refrigerants were tested with a smaller displacement compressor.

Table 4
Results at 23.9°C (75°F)/55% relative humidity ambient conditions, -5.6°C (22°F) bottle cooler setpoint

Row 0	Refrigerant	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	ASHRAE	ASHRAE	ASHRAE	ASHRAE	ASHRAE
2	Test ID no.	8	9	10	11	12
4	**Test cell temperature, °C**	**23.9**	**23.9**	**23.9**	**23.9**	**23.9**
5	**Test cell relative humidity, %**	**55**	**55**	**55**	**55**	**55**
6	**Bottle cooler setpoint, °C**	**-5.6**	**-5.6**	**-5.6**	**-5.6**	**-5.6**
8	Completion date	10/07/10	11/21/10	01/09/11	03/06/11	03/29/11
9	**Suction pressure, kPa**	**189**	**205**	**209**	**132**	**175**
10	**Discharge pressure, kPa**	**796**	**822**	**829**	**592**	**749**
11	**Refrigerant flow rate, kg/hr**	**8.06**	**9.64**	**8.68**	**7.41**	**8.04**
12	**Difference, %**	**0.0%**	**19.6%**	**7.7%**	**-8.2%**	**-0.3%**
16	Compressor suction temperature, °C	9.5	10.8	14.9	12.4	13.1
17	Compressor discharge temperature, °C	47.7	47.7	49.7	47.9	49.8
18	Evaporator outlet temperature, °C	-10.2	-10.4	-9.3	-10.4	-9.9
23	Discharge air temperature 2" from left end, °C	-6.4	-6.5	-6.4	-6.6	-6.6
24	Discharge air temperature center, °C	-6.5	-6.6	-6.4	-6.7	-6.6
25	Discharge air temperature 2" from right end, °C	-6.7	-6.8	-6.6	-6.9	-6.8
50	**Product Simulator Temperatures**					
51	Integrated average, °C	-4.6	-4.6	-4.5	-4.7	-4.5
59	**Refrigerant charge, g**	322+/-7	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**165**	**178**	**176**	**158**	**168**
67	**Difference, %**	**0%**	**8.0%**	**6.5%**	**-4.4%**	**1.4%**
69	**Compressor run time, %**	**60.6%**	**59.7%**	**55.1%**	**71.6%**	**61.0%**
70	**Difference, %**	**0%**	**-1.5%**	**-9.0%**	**18.1%**	**0.7%**
73	Evaporating temperature (avg. of dew and bubble), °C	-11.5	-11.8	-11.7	-12.6	-12.6
74	Condensing temperature (avg. of dew and bubble), °C	31.2	32.4	32.7	30.8	30.9
75	Superheat at compressor inlet, °C	3.2	4.8	8.9	7.3	7.9

Table 5 shows results at 26.7°C/55% relative humidity ambient conditions with the 3.3°C bottle cooler setpoint. Some main results in this table are:

- Rows 9 and 10: The suction and discharge pressures, 201 kPa and 612 kPa, respectively of HFO1234ze(E) (Test 16) were considerably lower than the other refrigerants.
- Rows 11 and 12: The refrigerant flow rate of HFO1234yf (Test 14) was 14.8% higher than the baseline.
- Rows 23 through 25: As with the other test conditions, the discharge air temperatures were nearly identical for all tests.
- Row 67: With the exception of HFO1234ze(E) (Test 16), the compressor power values were within +/- 2.5% of the baseline. HFO1234ze(E) had 4.3% lower power than the baseline.
- Rows 69 and 70: The compressor run time for HFO1234ze(E) (Test 16) was 20.0% higher than the baseline.

As mentioned earlier, we should be careful about concluding that using HFO1234ze(E) results in lower compressor power. Similar to Table 4, the compressor run time was 20.0% higher than the baseline. The lower power may be caused by better matching of the compressor to the cooling load.

Table 6 shows results at 26.7°C/55% relative humidity ambient conditions with the -5.6°C bottle cooler setpoint. Some main results in this table are:

- Rows 9 and 10: The suction and discharge pressures, 127 kPa and 644 kPa, respectively of HFO1234ze(E) (Test 21) were considerably lower than the other refrigerants.

- Rows 11 and 12: The refrigerant flow rate of HFO1234yf (Test 19) was 22.3% higher than the baseline.

Table 5

Results at 26.7°C (80°F)/55% relative humidity ambient conditions, 3.3°C (38°F) bottle cooler setpoint

Row 0	Refrigerant	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	ASHRAE	ASHRAE	ASHRAE	ASHRAE	ASHRAE
2	Test ID no.	13	14	15	16	17
4	**Test cell temperature, °C**	**26.7**	**26.7**	**26.7**	**26.7**	**26.7**
5	**Test cell relative humidity, %**	**55**	**55**	**55**	**55**	**55**
6	**Bottle cooler setpoint, °C**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
8	Completion date	10/19/10	12/02/10	01/03/11	03/13/11	04/06/11
9	**Suction pressure, kPa**	**281**	**299**	**302**	**201**	**259**
10	**Discharge pressure, kPa**	**766**	**783**	**792**	**612**	**727**
11	**Refrigerant flow rate, kg/hr**	**6.88**	**7.90**	**7.39**	**7.04**	**7.06**
12	**Difference, %**	**0%**	**14.8%**	**7.3%**	**2.3%**	**2.5%**
16	Compressor suction temperature, °C	21.1	21.9	22.7	20.2	22.1
17	Compressor discharge temperature, °C	44.7	44.8	46.2	44.4	46.0
18	Evaporator outlet temperature, °C	-0.6	1.2	1.4	-0.4	0.8
23	Discharge air temperature 2" from left end, °C	2.3	2.4	2.3	2.4	2.3
24	Discharge air temperature center, °C	2.4	2.5	2.5	2.5	2.5
25	Discharge air temperature 2" from right end, °C	2.2	2.3	2.3	2.3	2.2
50	**Product Simulator Temperatures**					
51	Integrated average, °C	4.0	4.0	4.0	4.1	4.1
59	**Refrigerant charge, g**	322+/-7	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**132**	**133**	**135**	**126**	**130**
67	**Difference, %**	**0%**	**1.3%**	**2.5%**	**-4.3%**	**-1.1%**
69	**Compressor run time, %**	**39.0%**	**37.7%**	**38.1%**	**46.8%**	**41.1%**
70	**Difference, %**	**0%**	**-3.3%**	**-2.2%**	**20.0%**	**5.4%**
73	Evaporating temperature (avg. of dew and bubble), °C	-1.2	-1.3	-1.8	-1.9	-2.3
74	Condensing temperature (avg. of dew and bubble), °C	29.8	30.6	26.0	31.9	29.8
75	Superheat at compressor inlet, °C	4.5	5.4	6.7	4.4	6.6

Table 6

Results at 26.7°C (80°F)/55% relative humidity ambient conditions, -5.6°C (22°F) bottle cooler setpoint

Row 0	Refrigerant	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	ASHRAE	ASHRAE	ASHRAE	ASHRAE	ASHRAE
2	Test ID no.	18	19	20	21	22
4	**Test cell temperature, °C**	**26.7**	**26.7**	**26.7**	**26.7**	**26.7**
5	**Test cell relative humidity, %**	**55**	**55**	**55**	**55**	**55**
6	**Bottle cooler setpoint, °C**	**-5.6**	**-5.6**	**-5.6**	**-5.6**	**-5.6**
8	Completion date	10/24/10	12/06/10	01/05/11	03/10/11	04/03/11
9	**Suction pressure, kPa**	**187**	**204**	**205**	**127**	**172**
10	**Discharge pressure, kPa**	**836**	**863**	**894**	**644**	**795**
11	**Refrigerant flow rate, kg/hr**	**8.19**	**10.01**	**9.29**	**7.80**	**8.35**
12	**Difference, %**	**0%**	**22.3%**	**13.5%**	**-4.8%**	**2.0%**
16	Compressor suction temperature, °C	14.6	13.9	16.6	15.2	16.1
17	Compressor discharge temperature, °C	52.5	52.3	54.1	53.6	53.6
18	Evaporator outlet temperature, °C	-10.6	-10.4	-9.7	-10.9	-10.0
23	Discharge air temperature 2" from left end, °C	-6.4	-6.4	-6.4	-6.8	-6.5
24	Discharge air temperature center, °C	-6.5	-6.5	-6.5	-6.9	-6.6
25	Discharge air temperature 2" from right end, °C	-6.7	-6.8	-6.7	-7.2	-6.9
50	**Product Simulator Temperatures**					
51	Integrated average, °C	-4.3	-4.4	-4.3	-4.8	-4.4
59	**Refrigerant charge, g**	322+/-7	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**181**	**192**	**192**	**172**	**177**
67	**Difference, %**	**0%**	**5.8%**	**6.3%**	**-4.8%**	**-2.0%**
69	**Compressor run time, %**	**66.2%**	**62.6%**	**62.3%**	**78.2%**	**65.8%**
70	**Difference, %**	**0%**	**-5.5%**	**-5.9%**	**18.2%**	**-0.5%**
73	Evaporating temperature (avg. of dew and bubble), °C	-11.7	-12.1	-12.2	-13.6	-13.0
74	Condensing temperature (avg. of dew and bubble), °C	32.9	34.2	35.6	33.7	33.0
75	Superheat at compressor inlet, °C	8.5	8.3	11.0	11.0	11.3

- Rows 23 through 25: The discharge air temperatures were nearly identical for all tests.
- Row 67: The compressor power values were 5.8% higher, 6.3% higher, 4.8% lower and 2.0% lower for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.
- Rows 69 and 70: The compressor run time for HFO1234ze(E) (Test 21) was 18.2% higher than the baseline.

3.2 Full and half pull-down tests

Table 7 shows full pull-down results. Some main items in this table are:

- Rows 9 and 10: The suction and discharge pressures, 182 kPa and 789 kPa, respectively of HFO1234ze(E) (Test 26) were considerably lower than the other refrigerants.
- Rows 11 and 12: The refrigerant flow rate of HFO1234yf (Test 24) was 19.9% higher than the baseline.
- Rows 23 through 25: The discharge air temperatures were nearly identical for all tests.
- Row 67: The compressor power values were 4.8% higher, 2.4% higher, 11.2% lower and 2.9% lower for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.
- Rows 69 and 70: The compressor run times were within +/- 2.2% with the exception of HFO1234ze(E) (Test 26), which was 12.5% higher than the baseline.
- Rows 108 and 109: The amount of time until the compressor started cycling was within +/- 5.2% with the exception of HFO1234ze(E) (Test 26), which took 31.3% longer.

Table 7
Full pull-down test results

Row 0	Refrigerant	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	Pulldown	Pulldown	Pulldown	Pulldown	Pulldown
2	Test ID no.	23	24	25	26	27
4	**Test cell temperature, °C**	**32.2**	**32.2**	**32.2**	**32.2**	**32.2**
5	**Test cell relative humidity, %**	**65**	**65**	**65**	**65**	**65**
6	**Bottle cooler setpoint, °C**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
8	Completion date	10/28/10	12/14/10	01/18/11	03/16/11	05/04/11
9	**Suction pressure, kPa**	**251**	**271**	**268**	**182**	**238**
10	**Discharge pressure, kPa**	**1043**	**1087**	**1081**	**789**	**979**
11	**Refrigerant flow rate, kg/hr**	**9.96**	**11.94**	**10.80**	**9.77**	**10.40**
12	**Difference, %**	**0%**	**19.9%**	**8.4%**	**-1.9%**	**4.4%**
16	Compressor suction temperature, °C	25.7	26.9	26.8	25.4	25.6
17	Compressor discharge temperature, °C	63.3	64.1	65.2	60.2	63.1
18	Evaporator outlet temperature, °C	-0.6	-0.6	1.4	0.3	-0.2
23	Discharge air temperature 2" from left end, °C	2.4	2.5	2.6	3.0	2.7
24	Discharge air temperature center, °C	2.5	2.5	2.7	3.2	2.8
25	Discharge air temperature 2" from right end, °C	2.2	2.3	2.3	2.9	2.5
50	**Product Simulator Temperatures**					
51	Integrated average, °C	7.6	7.8	7.8	8.2	7.9
59	**Refrigerant charge, g**	322+/-7	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**214**	**224**	**219**	**190**	**207**
67	**Difference, %**	**0%**	**4.8%**	**2.4%**	**-11.2%**	**-2.9%**
69	**Compressor run time, %**	**61.0%**	**61.0%**	**59.7%**	**68.7%**	**61.9%**
70	**Difference, %**	**0%**	**0.0%**	**-2.2%**	**12.5%**	**1.5%**
73	Evaporating temperature (avg. of dew and bubble), °C	-4.2	-4.2	-5.1	-4.7	-4.6
74	Condensing temperature (avg. of dew and bubble), °C	40.9	43.3	43.1	40.9	40.7
75	Superheat at compressor inlet, °C	12.1	13.3	14.2	12.4	12.4
99	**Energy consumed during test (measured at the end of pull down), kWh**	**3.80**	**3.99**	**3.89**	**3.86**	**3.79**
108	Amount of time until compressor cycling starts, minutes	291	291	306	382	305
109	**Difference, %**	**0%**	**0.0%**	**5.2%**	**31.3%**	**4.8%**
	72 hour minimum thermal soak time for pulldown and half pulldown tests					

As discussed earlier, the compressor was relatively undersized for use with HFO1234ze(E), and this was probably a contributing reason for lower energy use – a system, not refrigerant, effect. With the pull-down tests, longer pull-down time is a main disadvantage of an undersized compressor.

Table 8 shows half pull-down results. Some main results in this table are:

- Rows 9 and 10: The suction and discharge pressures, 184 kPa and 756 kPa, respectively of HFO1234ze(E) (Test 31) were considerably lower than the other refrigerants.
- Rows 11 and 12: The refrigerant flow rate of HFO1234yf (Test 29) was 17.4% higher than the baseline.
- Rows 23 through 25: The discharge air temperatures were nearly identical for all tests.
- Row 67: The compressor power values were 2.7% higher, 4.2% higher, 5.2% lower and 0.5% lower for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.
- Rows 69 and 70: The compressor run times were 0.8% higher, 8.2% higher, 20.0% higher and 11.3% higher for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.
- Rows 108 and 109: The amount of time until the compressor started cycling were 10% lower, 3.8% lower, 40.8% higher and 50.8% higher for HFO1234yf, XP10, HFO1234ze(E), and N13, respectively.

The time until compressor cycling started for the N13 blend seems inconsistent with the other values. Given the other results, we expected this value to be closer to the baseline. The root cause of this unexpected result is not known.

Table 8
Half pull-down test results

Row 0	Refrigerant	R134a	HFO1234yf	XP10	HFO1234ze	N13
1	Test type	Half-Pulldown	Half-Pulldown	Half-Pulldown	Half-Pulldown	Half-Pulldown
2	Test ID no.	28	29	30	31	32
4	**Test cell temperature, °C**	**32.2**	**32.2**	**32.2**	**32.2**	**32.2**
5	**Test cell relative humidity, %**	**65**	**65**	**65**	**645**	**65**
6	**Bottle cooler setpoint, °C**	**3.3**	**3.3**	**3.3**	**3.3**	**3.3**
8	Completion date	11/08/10	12/21/10	02/09/11	03/21/11	04/19/11
9	**Suction pressure, kPa**	**258**	**276**	**263**	**184**	**33**
10	**Discharge pressure, kPa**	**949**	**966**	**976**	**756**	**900**
11	**Refrigerant flow rate, kg/hr**	**8.54**	**10.02**	**9.10**	**8.70**	**8.67**
12	**Difference, %**	**0%**	**17.4%**	**6.6%**	**1.9%**	**1.6%**
16	Compressor suction temperature, °C	25.0	25.0	25.1	24.9	25.1
17	Compressor discharge temperature, °C	57.8	57.5	60.4	57.4	59.7
18	Evaporator outlet temperature, °C	-0.8	0.3	1.7	-0.9	1.2
23	Discharge air temperature 2" from left end, °C	2.0	1.9	2.2	2.1	2.2
24	Discharge air temperature center, °C	2.0	2.0	2.4	2.1	2.3
25	Discharge air temperature 2" from right end, °C	1.8	1.7	1.9	1.9	1.9
50	**Product Simulator Temperatures**					
51	Integrated average, °C	5.6	5.5	5.7	5.7	5.8
59	**Refrigerant charge, g**	322+/-7	322+/-7	326 +/-1	326 +/-1	326 +/-1
66	**Compressor power, W**	**179**	**184**	**187**	**170**	**178**
67	**Difference, %**	**0%**	**2.7%**	**4.2%**	**-5.2%**	**-0.5%**
69	**Compressor run time, %**	**51.7%**	**52.1%**	**55.9%**	**62.0%**	**57.5%**
70	**Difference, %**	**0%**	**0.8%**	**8.2%**	**20.0%**	**11.3%**
73	Evaporating temperature (avg. of dew and bubble), °C	-3.4	-3.6	-5.6	-4.2	-5.7
74	Condensing temperature (avg. of dew and bubble), °C	37.4	38.6	39.0	39.5	37.5
75	Superheat at compressor inlet, °C	10.6	10.8	13.0	11.3	12.9
99	**Energy consumed during test (measured at the end of pull down), kWh**	**2.45**	**2.47**	**2.43**	**2.34**	**2.69**
108	Amount of time until compressor cycling starts, minutes	130	117	125	183	196
109	**Difference, %**	**0%**	**-10.0%**	**-3.8%**	**40.8%**	**50.8%**
	72 hour minimum thermal soak time for pulldown and half pulldown tests					

4. CONCLUSIONS

4.1 ASHRA 72 Tests

All things being equal, we consider compressor power to be a main result for this series of tests. With the exception of HFO1234ze(E), there were relatively little differences between the baseline R134a and the other refrigerants. HFO1234ze(E) gave lower average power values at the -5.6°C bottle cooler setpoint. However, these lower power values may have at least partially be caused by the system effect of better matching the compressor capacity to the

cooling load. An improved test procedure would use a variable speed compressor so that compressor capacity could exactly match cooling load.

4.2 Full and half pull-down tests

With the full and half pull-down tests, the amount of time until the compressor cycling started is a main result. Because HFO1234ze(E) has lower density than the other refrigerants, it required longer pull-down times. The pull-down times could be shorter if a larger displacement compressor were used.

5. REFERENCES

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