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Heat Pump/Air Conditioner Field Test Data for an HCFC-22 Alternative Containing HFC-32, HFC-125, and HFC-134a

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Experimental Evaluation of R-22 Alternative Refrigerants in Unitary Air Conditioning Equipment

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ABSTRACT

This paper will focus on the experimental evaluation of zero ODP alternative refrigerants in unitary air conditioning equipment. Tests were run on a nominal 10 SEER 2.5 ton split-system air conditioner using both a scroll and a reciprocating compressor. Refrigerants evaluated include: R-22, an azeotrope of HFC-32 & HFC-125[1], HFC-134a, and a blend of HFC-32, HFC-125, and HFC-134a. When testing with the 32/125 azeotrope or HFC-134a, special compressors were used with either reduced or increased displacement. This normalized the capacity of the air conditioner to R-22. The only other change for the first series of tests was to replace the expansion valve with one designed for the pressure of the alternative refrigerant. A second series of tests involved "soft-optimized" heat exchangers and evaluation of liquid-suction heat exchangers. The heat exchanger optimization process was limited to re-circuiting the heat exchangers for the particular refrigerant under test.

INTRODUCTION

Despite the fact that HCFCs are considered interim solution to the ozone depletion problem caused by CFCs, these fluids still contain chlorine and contribute to some ozone depletion as well (albeit to a much smaller extent). As a result of this environmental concern, HCFCs have been included in recent revisions of the Montreal Protocol and the U.S. Clean Air Act. The consumption of HCFCs will be restricted beginning in 1996 and will be completed phased-out by 2030.

The air conditioning industry is currently evaluating alternative refrigerants for HCFC-22. Under the auspices of the Air-Conditioning & Refrigeration Institute (ARI), a program (the Alternative Refrigerant Evaluation Program or AREP)[2] involving major equipment manufacturers around the world, was formed to conduct an evaluation of the performance of HCFC-22 (& R-502) alternatives in representative equipment. As a result of early tests, three leading candidates were identified. These candidates are: HFC-134a, an azeotrope of HFC-32 & HFC-125 (termed AZ-20 by AlliedSignal), and a zeotrope of HFC-32, HFC-125, & HFC-134a (termed AC9000 by Dupont and Klea 66 by ICI).

In order to determine the performance of a representative air conditioner operating with these alternative refrigerants, a test program was initiated at an independent test laboratory where industry standard tests could be run.

TEST DESCRIPTIONS

A Rheem 2.5 ton air conditioner was instrumented with thermocouples and pressure transducers surrounding most major components. The unit was then installed in a psychometric test chamber at ETL Testing Laboratory in Red Bud, Illinois.

Baseline tests were performed using HCFC-22 in accordance with ARI Standard 210/240[3]. At the beginning of every series of tests, an optimum refrigerant charge determination was conducted. The refrigerant charge that resulted in the maximum efficiency at Test "A" conditions was used for the remaining tests in any particular series. The baseline tests were performed both with a scroll compressor (Copeland Model No. ZR28K1) and a reciprocating compressor (Bristol Model No. H25B28Q). Two sets of baseline tests were performed with the scroll compressor. The first series of tests used an evaporator coil composed of three inverted V's that is termed a "pleated" coil. The second series of baseline tests used a more conventional "A" coil.

A summary of the tests are shown on Table I and some of the details are shown on Table II. Test "A" conditions are 95°F outdoor temperature and 80°F DB (dry bulb) / 67°F WB (wet bulb) indoor conditions. Test "B" conditions are 82°F outdoor temperature and the same indoor conditions.

The first alternative refrigerant test series was run in hardware with little or no alterations. Due to the differences in capacity and pressure of both HFC-32/125 and HFC-134a from that of R-22, compressor displacements and thermostatic expansion valves needed to be changed to obtain meaningful test results for these refrigerants.

Another series of alternative refrigerant tests was run in equipment that was modified to better suite the particular refrigerant under test. The higher pressure of HFC-32/125 allows a higher pressure drop for the same change in saturation temperature. Therefore systems optimized for this refrigerant will have higher refrigerant velocities as a result of either reduced number of parallel heat exchanger circuits or smaller tube diameters or both. Tube diameters were not changed in this test program. However, changes were made in the number of circuits. The number of circuits in the evaporator was reduced from six to three. The condenser with a two into one circuit arrangement was modified to have only one.

Changes for R-134a was restricted to enlarging the suction line and increasing numbers of parallel circuits in the indoor coil. Modelling results of the heat exchangers did not suggest any changes in the outdoor coil that would result in any significant performance improvement. The compressor used for this series of tests did not utilize a motor ideally sized for the application. Additional testing will be conducted with a compressor more optimally configured for R-134a.

Two modifications aimed at improving the performance of the 32/125/134a blend were evaluated. The first modification was the re-circuiting of the evaporator to approach a counterflow arrangement of air flow and refrigerant flow within this heat exchanger. The other change was to add a suction-liquid heat exchanger to the air-conditioner. This was accomplished by inserting the suction line into a larger liquid line. Suction-liquid heat exchange will benefit both the 32/125/134a blend and R-134a. Therefore both of these refrigerants will be tested with this device.

It should be noted that the first test series with the scroll compressor and HFC-32/125 used a 1.5 ton compressor that was 3-4% less efficient than the baseline 2.5 ton compressor. Since this efficiency difference existed with R-22, it was assumed that HFC-32/125's performance would also suffer by a similar factor. A more efficient compressor was obtained for the soft-optimized test series.

TEST RESULTS

The results of most of the test series showed the capacity at Test "A" conditions were within 3-4% of R-22. The only exceptions were the original HFC-134a test and the original HFC-32/125/134a with the reciprocating compressor. There were more significant differences in EER values between the test series. An examination of these values at Test "B" conditions (SEER ratings are determined from EER at these conditions) show a range from +6% for HFC-32/125 to more than 20% lower for the original HFC-134a test. These are all relative to R-22. Excluding the HFC-134a results because of the less than optimized compressor configuration for this refrigerant, the maximum decrease is about 9% for the original HFC-32/125/134a blend with the reciprocating compressor.

Looking at the individual refrigerants in more detail, the utilization of HFC-32/125 generally improved the performance of the air conditioner from R-22 levels. The original configuration test results for the scroll compressor showed slightly lower performance (<2%) but the compressor used for this test series suffered from lower baseline (R-22) performance, as discussed previously. The next series of "soft-optimized" tests with a higher efficiency scroll compressor (more comparable to the 2.5 ton compressor used for baseline tests), the same reciprocating compressor, and re-circuited heat exchangers resulted in an efficiency gain of over 5% for both the scroll and reciprocating compressor.

The testing of the HFC-32/125/134a blend with the scroll compressor resulted in comparable capacity to R-22 but poorer efficiency (5% lower than R-22). Testing with the reciprocating compressor resulted in both decreased capacity (-6%) and efficiency (-9%) relative to R-22.

In an effort to try to take advantage of the temperature glide of this refrigerant, a standard "A" coil evaporator was re-circuited to approach a counterflow arrangement between the air flow and refrigerant flow. Since the baseline R-22 test was run with the pleated coil, an additional baseline test was run with the "A" coil to serve as a comparison for the HFC-32/125/134a testing with the counterflow evaporator. The results of these tests were somewhat disappointing. There was no difference from the original configuration. Poor airside flow distribution may have contributed to the lack of any performance gain. With less airflow at the bottom of the coil, two of the six circuits were not as effective as the rest. Further re-circuiting of the coil may reduce this effect (crossing-over from the bottom to the top). Tests of this coil are planned.

Since HFC-32/125/134a should benefit from liquid-suction heat exchange, a heat exchanger was added to the air conditioner to promote this heat exchange. It was fabricated by inserting the suction line into a larger tube. Liquid refrigerant flowed through the annulus between the two tubes. A limitation of this type of heat exchanger is that it could only be used on an air conditioner and not on a heat pump (it would have an adverse impact on heating performance).

The suction-liquid heat exchanger reduced the capacity slightly (<1%) but increased EER by 3%, still remaining 4% below the R-22 level.

As previously mentioned the performance of HFC-134a was significantly lower than R-22 (20% lower EER), even after increasing the suction line to reduce the high pressure drop between the indoor and outdoor units. A contributing factor was the performance of the compressor due to less than optimum component selection. Tests with a better suited HFC-134a compressor are planned. However it is not expected that the performance of HFC-134a would match that of R-22.

CONCLUSIONS

Tests of a typical 2.5 air conditioner showed that an azeotropic blend of HFC-32 and HFC-125 could outperform R-22. With only minor changes to heat exchanger circuitry, a 5 to 6% gain in EER was achieved. Testing of the HFC-32/125/134a blend revealed a shortfall in EER values as compared to R-22. Although the results of HFC-134a tests are somewhat inconclusive due to the compressor tested, significant reductions in EER relative to R-22 would be expected in equipment sized for R-22.

All three alternative refrigerants have issues that must be dealt with. HFC-32/125's higher capacity and higher pressure requires redesign of some of the air conditioning components such as the compressor. However, these changes could lead to more compact and less expensive equipment that achieves the same efficiency as the baseline R-22 design.

Although probably requiring the least number of hardware changes, the HFC-32/125/134a blend will require increases to heat exchanger areas, and therefore cost, to bring the EER to the level of R-22. The other issue is the complications involved in the use of a moderate glide blend. Segregation, more complicated servicing and trouble-shooting, and premature coil frosting are some of the issues the air conditioning industry must deal with if this type of fluid is to be used successfully.

The third alternative refrigerant, HFC-134a, will likely require significantly larger, more expensive equipment to achieve the same performance as R-22. At this point in time, it appears that this candidate has more obstacles in its path to replace R-22 in unitary air conditioning and heat pump equipment.

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REFERENCES

1. AlliedSignal Inc. 1990. U.S. Patent 4,978,467. Buffalo, NY, AlliedSignal Inc.

2. ARI. 1992 R-22 Alternative Refrigerants Evaluation Program (AREP).

3. ARI. 1989. ARI Standard 210/240, Unitary air-conditioning and air-source heat pump equipment. Air-Conditioning and Refrigeration Institute.

System Test Results - Performance Summary

Compressor: Scroll									
Test Series	Refrigerant	ARI Test A				ARI Test B			
		Capacity	%	EER	%	Capacity	%	EER	%
Baseline (P)	R-22	26852	100.0%	9.362	100.0%	28380	100.0%	11.156	100.0%
Original (P)	HFC-32/125 *	26513	98.74%	9.126	97.48%	28285	99.67%	10.956	98.21%
	HFC-32/125/134a	26960	100.40%	8.863	94.67%	28528	100.52%	10.601	95.03%
	HFC-134a	24952	92.92%	7.404	79.09%	26407	93.05%	8.7955	78.84%
"Soft Optimized" (P)	HFC-32/125	26564	98.93%	9.831	105.01%	28319	99.79%	11.736	105.20%
	HFC-134a	25947	96.63%	7.478	79.88%	N/A	N/A	N/A	N/A
Baseline (A)	R-22	26862	100.0%	9.115	100.0%	28408	100.0%	10.956	100.0%
Original (A)	HFC-32/125/134a	26130	97.27%	8.165	89.58%	28418	100.04%	10.146	92.61%
Counter Flow (A)	HFC-32/125/134a	26448	98.46%	8.163	89.56%	28735	101.15%	10.129	92.45%
Suction LHX (A)	HFC-32/125/134a	25971	96.68%	8.654	94.94%	27782	97.80%	10.492	95.76%

* #1 Scroll compressor, 3-4% less eff.

Compressor: Reciprocating									
Test Series	Refrigerant	ARI Test A				ARI Test B			
		Capacity	%	EER	%	Capacity	%	EER	%
Baseline (P)	R-22	26981	100.0%	9.041	100.0%	28982	100.0%	10.55	100.0%
Original (P)	HFC-32/125	26537	98.35%	9.157	101.28%	29311	101.14%	10.93	103.58%
	HFC-32/125/134a	25203	93.41%	8.587	94.98%	27051	93.34%	9.57	90.72%
"Soft Optimized" (P)	AZ-20	27617	102.36%	9.415	104.14%	30338	104.68%	11.15	105.65%

A - A-coil used for indoor unit
P - Pleat coil used for indoor unit

Table I

Table II System Test Results - Performance Details

Compressor: Scroll

Test Series	Refrigerant	ARI Test A					ARI Test B				
		Suct. Sat. Temp. [F]	Cond. Sat. Temp. [F]	Suct. Temp. [F]	Disch. Temp. [F]	Liquid Temp. [F]	Suct. Sat. Temp [F]	Cond. Sat. Temp [F]	Suct. Temp. [F]	Disch. Temp. [F]	Liquid Temp. [F]
Baseline (P)	R-22	48.3	124.8	58.7	196.1	112.8	47.2	111.9	58.5	176.6	100.0
Original (P)	HFC-32/125	47.3	122.9	56.8	183.6	107.6	47.1	111.3	54.2	164.5	95.0
	HFC-32/125/134a	45.8	126.2	58.0	188.1	105.4	44.5	114.4	57.1	170.6	92.2
	HFC-134a	39.2	127.7	55.9	181.9	109.6	37.5	115.1	55.0	166.6	95.6
"Soft Optimized" (P)	HFC-32/125	48.6	123.5	57.1	180.4	104.9	46.6	112.3	55.7	164.7	92.3
	HFC-134a	41.6	130.8	61.2	191.4	109.5					
Baseline (A)	R-22	47.2	128.0	58.5	195.4	113.8	46.9	115.0	56.9	174.2	102.7
Original (A)	HFC-32/125/134a	45.3	130.7	56.0	183.9	111.4	44.5	118.0	56.0	165.9	98.6
Counter Flow (A)	HFC-32/125/134a	44.8	132.1	57.3	188.2	108.3	44.2	119.1	56.2	168.5	96.6
Suction LHX (A)	HFC-32/125/134a	46.3	124.8	110.7	224.0	96.1	45.6	112.7	98.5	195.8	88.1

Compressor: Reciprocating

Test Series	Refrigerant	ARI Test A					ARI Test B				
		Suct. Sat. Temp. [F]	Cond. Sat. Temp. [F]	Suct. Temp. [F]	Disch. Temp. [F]	Liquid Temp. [F]	Suct. Sat. Temp [F]	Cond. Sat. Temp [F]	Suct. Temp. [F]	Disch. Temp. [F]	Liquid Temp. [F]
Baseline (P)	R-22	47.7	124.2	58.2	196.3	114.0	46.4	112.1	56.7	178.0	101.59
Original (P)	HFC-32/125	48.6	123.3	57.3	183.8	108.7	47.0	111.9	54.4	166.3	96.44
	HFC-32/125/134a	41.8	124.5	56.3	185.4	101.1	39.9	112.9	56.1	173.0	90.3
"Soft Optimized" (P)	HFC-32/125	49.7	124.5	57.8	184.3	104.7	48.2	113.7	55.3	167.5	92.85

HEAT PUMP/AIR CONDITIONER FIELD TEST DATA FOR AN HCFC-22 ALTERNATIVE CONTAINING HFC-32, HFC-125, AND HFC-134a

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ABSTRACT

Hydrochlorofluorocarbon refrigerants have been added to the list of chlorine containing refrigerants scheduled for phase-out by the Montreal Protocol (1993). To better understand HCFC-22 retrofit opportunities for residential and light commercial air conditioning and heat pump equipment, a ternary blend of HFC-32, HFC-125, and HFC-134a (a similar pressure alternative to HCFC-22) has been tested in installed commercial and residential equipment for 20 months. These field retrofits are instrumented to determine the performance characteristics of the refrigerants in the system versus HCFC-22. The data gathered from these retrofits offers a field comparison between this ternary blend and HCFC-22.

BACKGROUND

Hydrochlorofluorocarbon (HCFC) refrigerants, including chlorodifluoromethane (HCFC-22) are scheduled for phase-out by the Montreal Protocol. Hydrofluorocarbon (HFC) alternatives are being developed to replace HCFC-22 in residential and light commercial positive displacement, direct expansion air conditioning and heat pump equipment. Similar pressure HFC alternatives are required so that the existing base of equipment designed for HCFC-22 pressures can be used for its entire expected life. Suva® AC9000, a zeotropic ternary blend of HFC-32, HFC-125, and HFC-134a (23%/25%/52wt.%), is an alternative for HCFC-22 with similar pressure and performance in air conditioning and heat pump equipment. Field retrofits of residential heat pumps have been operating using this ternary blend for 20 months*. The field retrofits are instrumented to determine the performance characteristics of the ternary blend versus HCFC-22. The data gathered from these retrofits will offer a "real world" comparison between this ternary blend and HCFC-22.

Historically, heat pumps and air conditioners which use HCFC-22 as the refrigerant also use mineral oil as the compressor lubricant. The HCFC-22/mineral oil pair provides existing compressors with the required lubricity and refrigerant-lubricant miscibility to return the lubricant to the compressor as it circulates through the air conditioning system. In moving to an HFC refrigerant, mineral oil may not provide the proper miscibility. If there is improper miscibility, there may not be adequate oil return, fouling the heat exchangers and reducing system performance and reliability.

EQUIPMENT

In order to get a broader understanding of the retrofit needs of the HCFC-22 market, two different types of air conditioning/heat pump equipment were retrofitted in this field study. These units were located in areas that were easy to monitor. Because neither location was occupied as a residence, conditions were more easily controlled.

Two split system home heat pump/air conditioning units provided information on residential retrofits. These units have provides the cooling and heating for a model home jointly operated by DuPont

* Suva® AC9000 was first formulated as 30/10/60 weight percent HFC-32/HFC-125/HFC-134a. The units studied ran on this formulation of the ternary blend for approximately 9 months. This blend was reformulated to 23/25/52 weight percent when refined test procedures shifted the flammability boundary. Analysis of the lubricant used during operation with both formulations is presented in this paper.

and Deck House, Inc. in Chester, New Jersey for 2 years. Each unit has a nominal capacity of 5 tons of cooling. These units contain reciprocating compressors. The heat pump performance data generated in this study was recorded on the first floor unit (referred to as Unit A1). This unit provides almost all of the heating for the house. The air conditioning performance data generated in this study was recorded on the second floor unit (referred to as Unit A2). This unit generates most of the cooling for this home.

A 5 ton capacity packaged rooftop unit provided data for light industrial or commercial retrofits. The unit is mounted on the roof of the power house at DuPont's Chestnut Run site and provides cooling and heating to the offices and lunch room for the site HVAC group. This unit contains a reciprocating compressor and has been installed and operating for 7 years. This rooftop unit is referred to as Unit B.

RETROFIT PROCEDURES AND EXPERIENCES

For additional information refer to Retrofit Guidelines for SUVA® HP62 in Stationary Equipment.

1) Obtain baseline performance data with HCFC-22
2) Recover HCFC-22 charge
3) Remove compressor
4) Drain lubricant from compressor and replace with polyol ester lubricant recommended by equipment manufacturer
5) Install compressor
6) Replace filter/drier
7) Evacuate system
8) Confirm leak free system using vacuum gauge or other means
9) Charge system with Suva® AC9000
10) Start up heat pump and adjust charge until system is operating normally, based on data from HCFC–22 operation

Polyol ester lubricants appear to provide the miscibility required for use with an HFC refrigerant. When retrofitting an existing HCFC-22/mineral oil system to an HFC/polyol ester pair, both the HCFC-22 and mineral oil are removed from the system. Some residual mineral oil will remain in the system. Lubricant samples were taken from the field retrofits in this study to determine if the polyol ester lubricants provide the required lubricity and refrigerant-lubricant miscibility and to measure the amount of residual mineral oil left in the system.

The ternary mixture provides performance similar to HCFC-22. However, there are some special considerations to take into account when retrofitting a unit to a ternary mixture.

First, the ternary mixture has a lower liquid density than HCFC-22 (see Table 1). Because positive displacement compression systems operate using a constant volume of refrigerant in the system, the amount, by weight, of the ternary mixture to be charged to the system will be less than the amount of HCFC-22 the system originally held. A good practice for charging a ternary mixture to a unit is to initially charge the unit with 80 weight percent of the original HCFC-22 charge. The ternary mixture charge should then be optimized by slowly adding more refrigerant to the system until the desired operating temperatures (evaporator, superheat and subcooled temperatures) are achieved. Since factors such as equipment design and components can alter the optimum charge size for a system, optimal charge may range from 85% to over 100% of the original HCFC-22 charge. For the retrofits in this study, the optimized ternary mixture charge was approximately 90-95 weight percent of the original HCFC-22 charge.

Table 1 - Refrigerant Liquid Densities

Refrigerant	Liquid Density at 77 °F (25 °C)
HCFC-22	0.0431 lb./in^3 (1.194 g/cm^3)
32/125/134a (23% / 25% / 52%)	0.0410 lb./in^3 (1.136 g/cm^3)

A second consideration, removing liquid refrigerant from the cylinder, arises from the zeotropic nature of the ternary mixture. A refrigerant blend is a zeotrope when, at a given pressure and temperature, the compositions of the equilibrium liquid and vapor phases are different. To insure the correct refrigerant composition in the system, this refrigerant should only be removed from its cylinder as a liquid.

Third, the compressor discharge pressure in the system retrofit to this ternary mixture will be 4% to 14% higher than that of HCFC-22. Use pressure vs. temperature charts or tables for Suva® AC9000 to determine proper operating pressures for the desired temperatures.

Finally, one of the most important parts of any refrigerant retrofit is the gathering of baseline data. When baseline data is not obtained, understanding of the performance of a system is limited. In order to optimize for the proper conditions with the retrofit refrigerant, it is necessary to know what the proper operating conditions are.

EXPERIMENTAL PROCEDURES

These retrofits were carefully monitored to determine differences in operation between the ternary blend and HCFC-22. Instrumentation included:

- temperature readings for both air and refrigerant sides in the heat exchangers
- pressure readings on suction and discharge ports
- current draw readings for the compressors.

The data were recorded on compact ACR SmartReader dataloggers and periodically down loaded to spread sheets.

After 12 months of run time on Unit B and 16 months of run time on Units A1 and A2, lubricant samples were removed from the systems and analyzed. The lubricant samples were analyzed for wear metals to make sure the lubricant/refrigerant pair provided proper lubricity. Residual fluoride analysis and acid number determination were used to determine refrigerant and lubricant stability. The amount of moisture and residual mineral oil in the lubricant were also measured.

The refrigerant was sampled as well from Units A1 and A2 after 16 months of run time and tested for composition, residual fluoride, and moisture. This data would provide information about composition shifting in the event of a leak and any refrigerant instability.

PERFORMANCE RESULTS

HVAC units in the field can yield valuable information that is not readily available from laboratory testing. When the unit follows the weather and the varying day to day conditions inside a house or workspace, transient effects and external loads, such as sunlight, play an important role. The heat pump/air conditioning units in this test were instrumented for temperature, pressure, and current draw so refrigerant comparisons could be made under field conditions.

The air conditioning/heat pump units in this test were monitored for over a year. It is not appropriate to compare overall data from the whole run time of a unit in this report. Instead, a "typical day" was chosen for each condition/unit. Ambient temperature (but not relative humidity) conditions for the two refrigerants were compared and two similar days were chosen for each refrigerant. Furthermore, air conditioning data reflects the time period from 8:00 AM to 5:00 PM, and heat pump data represents the time period from 12:00 AM to 8:00 AM to more effectively encompass the normal time of operation. In order for an appropriate comparison to be made between the data taken for both the ternary blend and HCFC-22, the data presented in this paper were recorded when the following conditions occurred:

1) Outside ambient temperature for heat pump comparison was:

   Unit A1 - average outside ambient temperature of 33°F (0.6 °C), with total ambient temperature range from 30°F to 39°F (-1.1 °C to 3.9 °C).

2) Outside ambient temperature for air conditioning comparison was:

Unit A2 - average outside ambient of 83°F (28 °C), with total ambient temperature range from 65°F (18 °C) at 8:00 AM to 97 °F (36 °C) at the warmest part of the day.

Unit B - average outside ambient of 55°F (13 °C), with total ambient temperature range from 50 °F (10 °C) to 59 °F (15 °C). This unit works against abnormal heat loads, so the unit runs in air conditioning mode until the outside ambient temperature reaches about 30 °F (-1.1 °C).

3) Indoor thermostat control was held constant for both refrigerants during testing. During cooling, the thermostat was set at approximately 75 °F (24 °C). For heating, the thermostat was set at approximately 68 °F (20 °C).

Measured data were used to establish proper system operation as well as to make refrigerant comparisons. Two key parameters for comparing the "working capacity" of the refrigerants are the air temperature change (ΔT_{evap}) across the evaporator coil and the compressor duty cycle. A larger ΔT_{evap} is a sign of higher capacity, since ΔH_{air} (enthalpy change of air across the heat exchanger) is proportional to ΔT_{evap} and capacity is the air mass flow multiplied by ΔH_{air}.

Duty cycle is also an indicator of system capacity. Compressor duty cycle is defined as the total time the compressor is operating divided by the total time period being evaluated (converted to percent). For example, in one 24 hour period, the compressor may operate a total of 10 times, for 0.5 hours each time. The compressor duty cycle will then be 10 x 0.5 / 24 = 0.21, or 21% duty cycle. A shorter duty cycle suggests that the unit does not have to run as long with one refrigerant to provide the same level of cooling as the unit when it contains the other refrigerant with the longer duty cycle.

Table 1 shows a comparison of these parameters between HCFC-22 and the ternary blend. The data in the table were taken over 8 hour periods.

Table 2 - Capacity Comparisons

Refrigerant	Mode	Air ΔT_{evap} - °F(°C)			Duty Cycle (% on time)		
		Unit A1	**Unit A2**	**Unit B**	**Unit A1**	**Unit A2**	**Unit B**
HCFC-22	AC	--	20.2 (11.2)	16.1 (8.9)	--	26.0%	30.8%
	HP	20.7 (11.5)	--	--	66.0%	--	--
32/125/134a	AC	--	16.5 (9.2)	15.5 (8.6)	--	23.8%	31.7%
	HP	21.1 (11.7)	--	--	57.3%	--	--

In air conditioning mode, HCFC-22 had a higher air ΔT_{evap} than the ternary blend. This would normally indicate a higher capacity for HCFC-22, but the duty cycle of HCFC-22 is also longer than that of the alternative. If the comparison days are assumed to be equivalent in terms of passive solar heating load, the capacities of the two refrigerants would be the same because the duty cycle and air ΔT_{evap} would balance out. The thermistor location on the air outlet could also be a cause of the air ΔT_{evap} difference.

HCFC-22 heat pump data in Table 2 and Table 3 are not representative of optimal HCFC-22 heat pump performance in this unit. The unit was undercharged by about 6 oz. (28 g) during this test. Discharge pressure for the system was only running at 200 psig (1.48 MPa) which only corresponds to a refrigerant temperature in the heat exchanger of 102 °F (39 °C). This temperature is much lower than the temperature normally seen in this unit for heating. Data presented orally will reflect the proper charge size.

Compressor power usage has a strong effect on energy efficiency. To gather power data in the field at minimal cost and safety risk, dataloggers were attached to inductive current sensors. This approach assumes voltage supplied to the compressor and power factor are constant or at least consistent between tests. Amp draw readings were also taken during the same 8 hour time period as the ΔT_{evap} and the duty cycle readings in Table 2. Table 3 shows the average amp draw for the two refrigerants while the compressor was in operation.

Table 3 - Compressor Power Comparison

Refrigerant	Mode	Current Draw - amperes		
		Unit A1	Unit A2	Unit B
HCFC-22	AC		23.7	5.3
	HP	27.1		--
32/125/134a	AC		23.9	4.6
	HP	19.3		--

The current readings for the units in air conditioning mode show that there is little difference between the ternary blend and HCFC-22 in efficiency. These numbers can be considered the same within the experimental uncertainty of the test procedures. The heat pump data reflect the low charge in the unit when HCFC-22 baseline data was being gathered. More data will be presented orally to give a valid heat pump comparison.

ANALYSIS RESULTS

The refrigerants and lubricants in the systems were sampled and analyzed to determine if there were any indications of potential problems due to the retrofit. These samples were taken after at least a year of service. The lubricant analysis results are listed in Table 4.

Table 4 - Lubricant Analysis Results

	Unit A1	**Unit A2**	**Unit B**
POE Lubricant	Mobil Arctic EAL 22	Mobil Arctic EAL 22	Castrol Icematic SW-32
Existing Mineral Oil	3GS	3GS	150 SUS naphthenic MO
Wear Metals (ppm)			
Copper	6	4	4
Iron	< 1	1	9
Phosphorus	5	9	16
Aluminum	none detected	none detected	none detected
Acid No. (mg. KOH/g.)	0.03	0.02	0.19
Fluorides (ppm)	< 0.1	< 0.1	< 0.1
Moisture (ppm)	311	214	60
Residual Mineral Oil (wt%)	16	15	5

These analysis results are within acceptable ranges. Acid numbers are all normal for these lubricants. Units A1 and A2 show higher levels of moisture than Unit B due to the sampling method and the humidity level on the day samples were taken. The residual mineral oil levels are slightly high in the A units. This does not appear to have affected the units' performance.

Table 5 - Refrigerant Analysis Results

	Unit A1	**Unit A2**	**Nominal**
Weight % HFC-32	24.6	24.4	23
Weight % HFC-125	25.7	25.6	25
Weight % HFC-134a	49.7	50.0	52
Moisture (ppm)	7	6	--
Fluorides (ppm)	< 0.1	< 0.1	--

The refrigerant samples for analysis were taken when the unit was not running. The compositions are close to the original compositions. The moisture and fluorides numbers are well within acceptable parameters.

CONCLUSIONS

Suva® AC9000 is a good retrofit alternative to replace HCFC-22 in heat pump and air conditioning systems. The cooling and heating performance of the ternary blend were similar to those of HCFC-22 in the systems tested. Slight decreases in efficiency and similar capacity are theoretically expected with the ternary blend. The cooling mode change in air temperature across the indoor heat exchanger and duty cycle for Unit A2 and Unit B show that the capacities of this ternary blend and HCFC-22 are similar. Comparisons of heat pump data for Unit A1 are not valid due to the non-optimal charge in the system during the HCFC-22 run.

Proper retrofit procedures for Suva® AC9000 differ little from the procedures used for other Suva® refrigerants. This similarity will allow service technicians with experience with Suva® HP62 and other refrigerant blends to use the skills they have already developed to retrofit systems with this ternary blend.

Lubricant analysis results give preliminary indications that the heat pump/AC unit is operating well after 20 months with the alternative refrigerant. Wear metals in all units are low, indicating that the lubricant/refrigerant pair is providing adequate lubrication to the compressor. Fluoride levels are below the detectable range and acid numbers are normal, indicating that the refrigerant and lubricants are stable (as expected) in these units.

REFERENCES

UNEP. 1993. United Nations Environmental Programme. Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer. Third Edition, Ozone Secretariat, August 1993.

"Retrofit Guidelines for Suva® HP62 in Stationary Equipment", DuPont Fluorochemicals Bulletin ART-22, January 1994.