1996

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J. W. Linton
National Research Council Canada

W. K. Snelson
National Research Council Canada

P. F. Hearty
National Research Council Canada

A. R. Triebe
National Research Council Canada

F. T. Murphy
ICI Klea

See next page for additional authors

Authors
J. W. Linton, W. K. Snelson, P. F. Hearty, A. R. Triebe, F. T. Murphy, R. E. Low, and B. E. Gilbert

COMPARISON OF R-407C AND R-410A WITH R-22 IN A 10.5 kW (3.0 TR) RESIDENTIAL CENTRAL HEAT PUMP

J.W. Linton, W.K. Snelson, P.F. Hearty and A.R. Triebe
National Research Council Canada, Thermal Technology Centre
Ottawa, Canada

F.T. Murphy, R.E. Low and B.E. Gilbert
ICI Klea
New Castle, Delaware

ABSTRACT

The performance of two long term replacements R-407C (HFC-32/125/134a (23%/25%/52%)) and R-410A (HFC-32/125 (50%/50%)) was compared to R-22 in a 10.5 kW (3.0 TR) residential central heat pump. The performance evaluations were carried out in a psychrometric calorimeter test facility located at NRC using the Canadian Standards Association (CSA) / Air-Conditioning and Refrigeration Institute (ARI) rating conditions.

The performance of R-407C was measured with the same reciprocating compressor that was supplied with the R-22 system. However, the performance evaluation of R-410A required a change to an appropriately sized scroll compressor in order to provide a comparison at approximately the same cooling capacity. Performance characteristics were measured including compressor power, cooling and heating capacity, refrigerant mass flow, and cooling energy efficiency ratio (EER) and heating coefficient of performance (COP).

To identify areas where the energy efficiency could be improved the heat pump evaporator was also partially optimized to suit the characteristics of R-407C. The optimization included changing the direction of the air flow (inverting the evaporator coil) to get an approximation of a counterflow heat exchanger to take advantage of R-407C's temperature glide.

INTRODUCTION

With the phaseout of CFCs now completed in the industrialized countries attention is now focusing on the future phaseout of HCFCs, especially R-22. According to the Montreal Protocol the phase out of R-22 will commence in 1996 with a consumption cap, followed by a 35% reduction in consumption starting in 2004, and a complete phaseout is slated for 2020 in Canada. The phaseout for R-22 has already been advanced in Europe, with Germany having a phaseout for new equipment starting in 2000.

Two refrigerant blends: R-407C, a zeotrope of HFC-32/HFC-125/HFC-134a (23/25/52 wt.%) and R-410A a near azeotrope of HFC-32/HFC-125 (50/50 wt.%) were evaluated previously by NRC (Murphy et al. 1995) using a 10.5 kW residential air-conditioner. R-407C has thermodynamic properties that make it a "look alike" replacement for R-22, with compressor capacities and system pressures and temperatures that are similar. The major difference of R-407C is that it has a temperature glide of about 6°C (10.8°F) for typical air-conditioning evaporating temperatures. R-410A however, differs in several areas from R-22, it is a higher pressure refrigerant blend and will require modifications to the compressor displacement and refrigerant line sizes.

This paper provides a performance comparison of R-407C and R-410A with R-22 in a residential size central heat pump. Test data were used to compare important compressor characteristics including compressor power, pressure ratio and compressor discharge temperature. System performance characteristics were also measured including cooling and heating capacity, refrigerant mass flow, and cooling energy efficiency ratio (EER) and heating coefficient of performance (COP).

TEST DESCRIPTION

The performance evaluation was completed in the Calorimetric Test Facility located at the Thermal Technology Centre, NRC using the standard industry rating conditions. The Calorimeter consists of two environmentally controlled test chambers that simulate indoor and outdoor conditions with precise control of the air dry bulb and wet bulb temperatures.

In order to compare the performance of R-407C and R-410A with R-22, a series of tests were performed on a standard 10.0 SEER Carrier 10.5 kW (3.0 TR) cooling capacity air-to-air residential heat pump. The unit was equipped with a reciprocating compressor, and fixed orifice type expansion devices. The indoor coil consisted of a single sloped fin and tube coil with three tube rows and five refrigerant circuits. The outdoor coil was a single row fin and tube type coil with three refrigerant circuits. According to Canadian Standards Association (CSA) / Air-Conditioning and Refrigeration Institute (ARI) standard rating conditions (CSA 1991) four steady-state test conditions were used to measure the cooling performance and two test conditions used to measure the heating performance of the unit. Table 1 lists the six standard CSA indoor and outdoor test conditions for a split system air-to-air heat pump.

Type of Test	Indoor Conditions	Outdoor Conditions
"A" Steady State Wet-Coil	27°C DB / 19°C WB	35°C DB
"B" Steady State Wet-Coil	27°C DB / 19°C WB	28°C DB
"C" Steady State Dry Coil	27°C DB / 14°C WB	28°C DB
Maximum Operating Condition (AC)	35°C DB / 21.7°C WB	40°C DB
High Temperature Heating	21°C DB / 16°C WB (max)	8.3°C DB / 6.1°C WB
Low Temperature Heating	21°C DB / 16°C WB (max)	-8.3°C DB / -9.4°C WB

Table 1: CSA / ARI cooling test conditions for a split system residential air-to-air heat pumps

To achieve a fair comparison of a zeotrope to a single refrigerant or near azeotrope, the refrigerant cycle operating conditions need to be defined. The evaporating temperature was defined as the mean of the evaporator outlet pressure dew point and the evaporator inlet temperature. The condensing temperature was defined as the mean of the dew point and bubble point at the average condensing pressure. The superheat was measured from the evaporator outlet pressure dew point and the subcooling temperature from the expansion valve inlet pressure bubble point respectively. The refrigerant thermodynamic properties of all the test refrigerants were determined from a commercially available software program (REFPROP V4). These values were confirmed with property data sheets provided by the refrigerant manufacturers.

The heat pump was extensively instrumented, and the air enthalpy and refrigerant mass flow rate methods were used to determine the unit's indoor coil steady state cooling and heating capacity. Energy balances between the air and refrigerant side were within 1% to 2% for R-22 and within 4% to 5% for R-407C and R-410A. It is believed that the larger discrepancies in the energy balance for R-407C and R-410A are related to uncertainties of the refrigerant properties. The cooling and heating capacities reported in this paper were from the air side measurement data. Refrigerant temperatures were recorded using type T (copper-constantan) thermocouples soldered to the refrigerant tubing. The uncertainty of the thermocouple temperature measurements was ±0.6°C (1.1°F). Refrigerant pressures were measured using pressure transducers connected to static pressure taps located at strategic points in the system. The pressure transducers were calibrated to ±3 kPa. Refrigerant mass flow was measured directly with a Coriolis effect mass flowmeter mounted in the liquid line leaving the condenser. The mass flowmeter was calibrated to provide an accuracy of ±0.5% of measurement. Power input to the compressor and indoor and outdoor fans was measured with watt/VAR transducers with an accuracy of ±1.0% of reading, and the supply voltage to the compressor and indoor and outdoor fans was regulated at 230 volts. The EERs and COPs reported in the paper were based on the total power consumption of the compressor and the indoor and outdoor fans. The indoor air quantity was set so that a minimum external resistance of 37.5 Pa (0.15 inches H_2O) was maintained at the outlet of the unit by adjusting an auxiliary fan located on the outlet of the test section duct work.

For the R-22 and R-407C performance tests the only change made to the heat pump was the installation of electronic expansion valves (EEV) and bypass check valves in place of the factory supplied combination fixed orifice and check valves. The EEV allowed accurate setting of the superheat for each refrigerant. The R-410A performance tests also used the EEV and required changing the original reciprocating compressor to a smaller displacement scroll compressor (approximately 66% of R-22 compressor displacement) to maintain about the same unit cooling capacity as R-22

For air-conditioning operation the EEV orifice setting for the three refrigerants was set to provide an evaporator outlet superheat of about 5.6°C (10.0°F) at the "A" test condition. For the "B", "C" and Maximum Operating test conditions the expansion valve was set in a manual operating mode at the same orifice setting that was used for the "A" test condition. The EEV orifice setting for heat pump operation was set to obtain the maximum COP at the high temperature heating test condition. The same orifice setting was used for the low temperature heating test condition. Setting the EEVs in this way closely duplicates the operation of the heat pump with the fixed orifices that it was originally equipped with.

The baseline performance tests were completed for R-22 using a polyol ester (POE) lubricant with a viscosity of 32 mm^2/s at 40°C (104°F). The performance tests were then repeated with R-407C and the same POE lubricant used in the R-22 tests. Finally, the performance evaluation of R-410A was completed with the scroll compressor and the same POE lubricant.

R-407C Evaporator Coil Optimization

The indoor coil of the heat pump had an approximate cross-parallel flow configuration between the air and refrigerant flow during air-conditioning operation. As a first attempt to optimize the heat pump for the temperature glide of R-407C during air-conditioning, the indoor coil (evaporator coil) was inverted (air flow enters from the opposite side of the evaporator coil) so that the air to refrigerant flow approximated a cross-counterflow configuration. For operation in the heat pump mode the original indoor coil was already in an approximate cross-counterflow configuration, and inverting the indoor coil then changed this to a cross-parallel flow configuration The same performance tests were completed with the inverted indoor coil to determine if the temperature glide of R-407C could provide any performance improvements during air-conditioning operation or cause any decrease in performance when operating in the heat pump mode.

TEST RESULTS AND DISCUSSION

Refrigerant Operating Charge

Before starting performance testing of R-22, R-407C and R-410A the operating refrigerant charge that provided the highest EER with a reasonable amount of liquid subcooling had to first be determined. Each refrigerant charge was evaluated with a constant evaporator superheat of 5.6°C (10.0°F) while operating at the air-conditioning "A" test condition. R-22 had a maximum EER at a refrigerant charge of 3.69 kg (which provided about the same amount of liquid subcooling as the manufacturer recommended). The operating charge for R-407C was also 3.69 kg, and the refrigerant charge selected for R-410A was 3.61 kg. The above selected refrigerant charges were used for all the test conditions.

System Operating Conditions

Table 2 shows the changes in system operating conditions for the three refrigerants, and with the original indoor coil configuration and the counterflow (C-F) indoor coil configuration for R-407C at the "A" and "high temperature heat" CSA test conditions. The Table shows that for air-conditioning R-22 and R-407C had similar evaporator outlet pressures, with R-407C and the original evaporator coil having the lowest pressure. When the evaporator coil was changed to the counterflow configuration (C-F) there was an increase in R-407C's evaporator outlet pressure. For heat pump operation the evaporator pressures of R-22 and R-407C were also similar, but the inverted indoor coil (R-407C C-F) was then in a cross-parallel flow situation, and the evaporator pressure was lower than with R-407C and the original coil. The condenser inlet pressures of R-22 were 7.2% to 10.7% lower than R-407C for the these test conditions. R-410A is a higher pressure refrigerant than R-22 and it had evaporator outlet pressures that ranged from 56% to 65% higher that R-22 and condenser inlet pressures that were 56% higher than R-22. The compressor pressure ratio of R-407C with the original coil configuration was up to 12.7% higher during air-conditioning operation than R-22, but when the evaporator coil was changed to counterflow the pressure ratio dropped to 10% higher than R-22. During heat pump operation the compressor pressure ratio of R-407C was 4.3% higher for the original indoor coil and 8.6% higher for the inverted coil. R-410A had compressor pressure ratios that ranging from 1.7% to 6.0% lower than R-22. The measured evaporating and condensing temperatures of all the refrigerants were similar, with R-407C showing a slight increase in evaporating temperature when the evaporator coil was changed to the counterflow configuration. Compressor power requirements for R-407C for both indoor coil configurations were less than 2% higher than R-22. Compared to R-22, R-410A required a 3% increase in compressor power at the "A" test condition and 10.8% higher at the heat pump condition. The compressor discharge temperature was measured at the outlet of the compressor. For all the test conditions R-407C and R-410A had compressor discharge temperatures that were about 7°C (12.6°F) lower than R-22 for the air-conditioning condition and 11°C to 17°C (19.8°F to 30.6°F) lower for the heat pump test condition.

	"A" Test Condition				"High Temp Heat" Test Condition			
	R-22	R-410A	R-407C	R-407C C-F	R-22	R-410A	R-407C	R-407C C-F
Evaporator outlet press (kPa)	660	1031	634	646	485	800	499	493
Evaporating temperature (°C)	10.2	9.1	9.5	9.8	1.4	1.4	2.2	2.1
Condenser inlet press (kPa)	1814	2841	1967	1957	1659	2588	1782	1836
Condensing temperature (°C)	46.3	46.7	47.0	46.8	41.5	42.6	43.0	44.8
Subcooling temperature (°C)	6.5	6.5	6.3	4.6	14.0	4.7	10.0	5.8
Evaporator superheat (°C)	5.5	5.7	5.0	4.3	0	0	0	0
Compressor disch temp. (°C)	89.1	81.1	82.0	81.2	80.6	64.6	63.2	69.4
Compressor pressure ratio	2.91	2.86	3.28	3.20	3.48	3.27	3.63	3.78
Compressor power (kW)	2.98	3.07	3.00	3.01	2.59	2.87	2.64	2.64
Refrigerant mass flow (kg/min)	4.06	4.27	3.88	3.97	3.02	3.64	3.16	3.04

Table 2: System performance results for "A" and "High temperature heating" test conditions

Relative Cooling and Heating Capacity

The relative heat pump cooling capacity compared to R-22 is shown in Figure 1 and the relative heating capacity in Figure 2 for the refrigerants tested including R-407C with the original and inverted indoor coil configuration for the six CSA air-to-air heat pump test conditions. The experimental values of cooling and

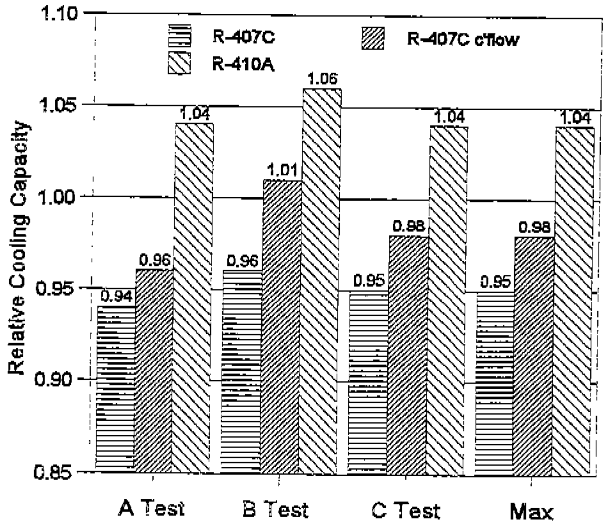

Figure 1. Relative Cooling Capacity Compared to R-22

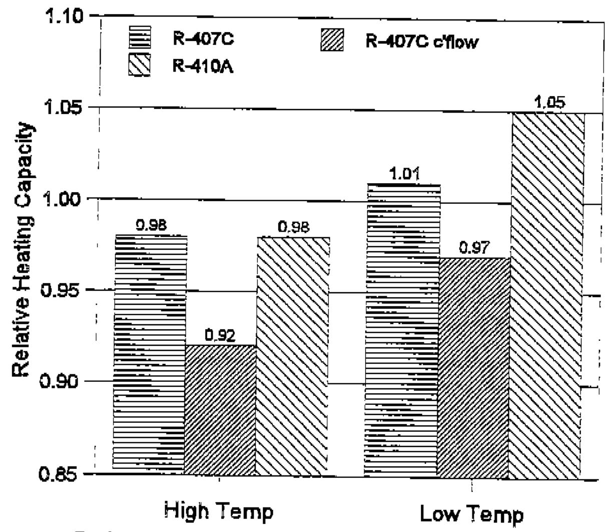

Figure 2. Relative Heating Capacity Compared to R-22

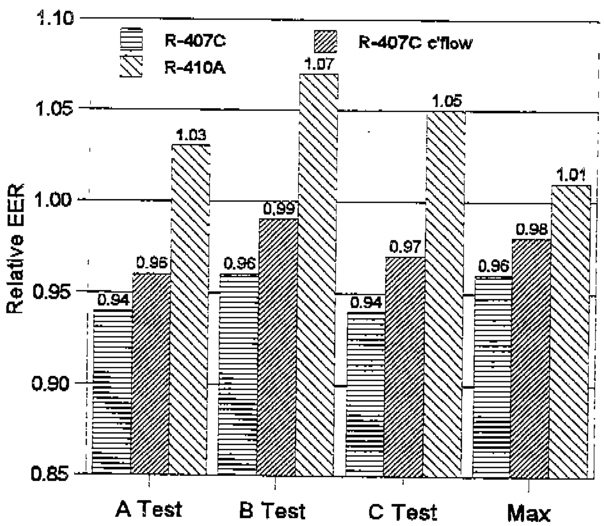

Figure 3. Relative EER (Cooling) Compared to R-22

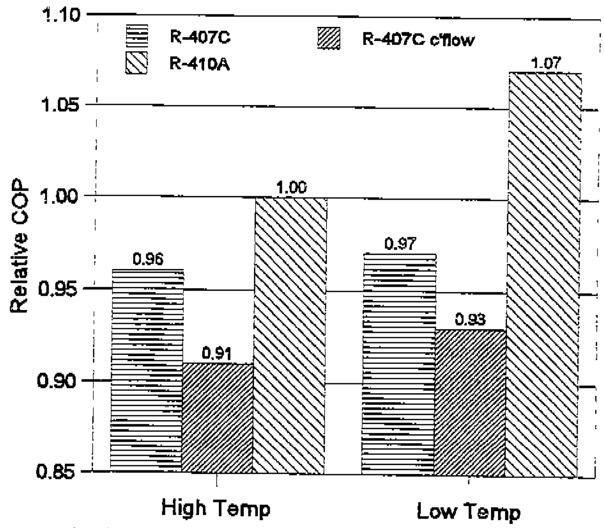

Figure 4. Relative COP (Heating) Compared to R-22

heating capacities were obtained from air enthalpy measurements between the inlet and outlet of the indoor unit. Figure 1 shows that the relative cooling capacity of R-407C with the original indoor coil ranged from 0.94 to 0.96. The benefits of operating the indoor coil in the cross-counterflow configuration (coil inverted) can clearly be seen by the improvement in the relative cooling capacities of R-407C ranging from 0.96 to 1.01. Figure 2 shows that the relative heating capacity of R-407C with the original indoor coil configuration (cross-counter flow for heating) ranged from 0.98 to 1.01. The relative capacity of R-407C with the inverted indoor coil (cross-parallel flow for heating) ranged from 0.92 to 0.97, which was a drop in capacity compared to the original coil. A direct comparison of cooling and heating capacities for R-410A was more complicated than for R-407C due to the different types of compressors used for the tests (reciprocating vs. scroll) and also because R-410A's compressor displacement was approximately 66% that of the reciprocating compressor used for R-22. In order to make the relative cooling and heating capacity comparison with R-22 more meaningful, the capacity of R-410A was adjusted with a correction factor. The correction factor for R-410A was based on adjusting the capacity of the R-410A compressor (based on manufacturers' compressor calorimeter measurements) to match the capacity of the R-22 compressor at each of the test conditions. Figure 1 shows that the relative cooling capacity of R-410A ranged from 1.04 to 1.06 compared to R-22, and Figure 2 shows the relative heating capacity ranged from 0.98 to 1.05.

Relative EER and COP

Figure 3 shows the relative energy efficiency ratio (EER) for cooling and Figure 4 shows the coefficient of performance (COP) for heating of R-407C with the original and inverted indoor coil and for R-410A with respect to R-22. The EER and COP were derived by dividing the cooling or heating capacity (measured on the air side) by the power input to the compressor and the indoor and outdoor fans. Figure 3 shows that the relative EER of R-407C with the original indoor coil ranged from 0.94 to 0.96. The EER of the heat pump increased by 2% to 3% when the indoor coil was changed to the cross-counterflow configuration and was able to partly take advantage of the temperature glide of R-407C. Figure 4 shows that the relative COP of R-407C with the original indoor coil configuration ranged from 0.96 to 0.97. The relative COP of R-407C with the inverted indoor coil ranged from 0.91 to 0.93, which was a drop in relative COP compared to the original coil (coil was cross-parallel for heating). The relative heat pump efficiency when using R-410A was also adjusted with a compressor correction factor based on adjusting the EER of the R-410A scroll compressor (based on manufacturers' compressor calorimeter measurements) to match the EER of R-22 reciprocating compressor at each of the test conditions. Figure 3 shows that the relative EER of R-410A ranged from 1.01 to 1.07 compared to R-22, and Figure 4 shows the the relative COP ranged from 1.00 to 1.07

CONCLUSIONS

A comparison was made of the performance of long term replacements R-407C and R-410A with the reference case R-22 in a 10.5 kW (3.0 TR) residential size central heat pump.

For the R-22 and R-407C performance tests the only change made to the heat pump was the installation of electronic expansion valves in place of the factory supplied fixed orifice. R-410A required changing the original reciprocal compressor to a smaller displacement scroll compressor (approximately 66% of R-22 capacity) to maintain about the same unit cooling capacity as R-22.

The relative cooling and heating capacities of R-407C with the original indoor coil supplied with the heat pump ranged from 0.92 to 1.01. Operating the indoor coil in the inverted configuration improved the cooling capacity, but had a detrimental effect on the heating capacity. Compared to R-22, the relative cooling and heating capacity of R-410A, with a compressor correction factor applied, ranged from 0.98 to 1.06.

The relative EER and COP of R-407C with the original indoor coil ranged from 0.91 to 0.94. With the indoor coil in the inverted configuration the cooling EER improved, but the heating COP decreased. The EER and COP of R-410A with a compressor correction factor applied ranged from 1.01 to 1.07 compared to R-22.

ACKNOWLEDGMENTS

The authors would like to thank ICI Klea, the Program on Energy Research and Development (PERD), Natural Resources Canada and Environment Canada for their contribution to the financial support of this project. We would also like to acknowledge Carrier Corp. for the supply of the heat pump and Copeland Corp. for supply of the scroll compressor.

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