Experimental Study of an R-407C Drop-In Test on an Off-the-Shelf Air Conditioner with a Counter-Cross-Flow Evaporator

Vince C. Mei, Ph.D., P.E. **R. Domitrovic** **Fang C. Chen, Ph.D., P.E.**
Member ASHRAE

ABSTRACT

An off-the-shelf two-ton window air conditioner having an energy efficiency ratio of 10 was used to perform a drop-in test with R-407C. Laboratory tests were performed using a parallel-cross-flow (PCF) evaporator and a counter-cross-flow (CCF) evaporator. The CCF configuration is designed to take advantage of the temperature glide of R-407C so that the warm evaporator inlet air will be in contact with the higher temperature part of the evaporator coils first.

Test results indicated that, at the ARI-rated indoor and outdoor conditions, the cooling capacity was 8% higher and system coefficient of performance about 3.8% higher for the CCF evaporator than for the PCF evaporator. The test results also showed that the latent load for CCF was 30.6% higher than for PCF. The far better dehumidification effect provided by the CCF evaporator design is desirable for areas where the latent load is high. The experimental findings should be useful for future efforts to design a dehumidifier that uses a zeotropic refrigerant that provides a significant temperature glide. R-22 test data from a previous project are included as a reference.

INTRODUCTION

The refrigerant R-407C is a nonazeotropic refrigerant that exhibits an 8°F to 10°F temperature glide for typical evaporator operating pressures. To take advantage of this temperature glide in an air conditioner or heat pump, a counter-cross-flow (CCF) arrangement between the refrigerant and the airflow has been proposed. Kuo (1994), for example, found that such an arrangement improved system performance by approximately 3% over that of a parallel-cross-flow (PCF) evaporator using nonazeoptropic R-407D, which has a glide of about 5°F to 10°F. Murphy et al. (1996) tested a 3-ton heat pump with R-407C for both PCF and CCF three-row evaporator arrangements. For a CCF evaporator, the cooling capacity improved by 2% to over 3%. The changes in sensible and latent capacities were not mentioned. When the system was switched to heating mode operation, the refrigerant flow direction was reversed; CCF for cooling mode operation became PCF for heating mode operation, and the heating capacity dropped by 4% to 6%.

In this study, an off-the-shelf window air conditioner was used for the R-407C tests in which both refrigerant-side and air-side performance were measured. Usually refrigerant-side performance is more accurate and is easier to measure. Air-side performance measurement, however, provides the assurance that the refrigerant-side measurement is correct. Also, air-side measurement enables calculation of the sensible and latent capacities separately, which refrigerant-side measurement cannot do.

The air conditioner used in this study had been tested in an Army-sponsored effort using R-22 refrigerant (Mei et al. 1996). At Air-Conditioning and Refrigeration Institute (ARI) rated indoor and outdoor conditions (80°F db and 67°F wb indoors and 95°F db outdoors), the unit provided the rated cooling capacity of 2 tons. The R-407C test results indicated that at ARI indoor and outdoor conditions, the cooling capacity for PCF evaporator operation was 5.2% less than the cooling capacity when R-22 was used (rated cooling capacity). However, with the CCF evaporator, the cooling capacity was 4.4% higher than when R-22 was used. The latent capacity of CCF operation is about 30.6% higher than that of PCF operation, and the system COP for CCF is 3.8% better than for PCF operation. It is evident that if R-407C is to be used as the alternative for R-22 in air conditioners, the evaporator should be designed for CCF. Based on the findings from this study, the CCF evaporator design should be considered for future dehumidifier design if R-407C is chosen as the refrigerant.

Vince C. Mei is on the research staff and **R. Domitrovic** is an engineer at Lockheed-Martin Energy Research, Inc., Oak Ridge, Tenn. **Fang C. Chen** is a program manager at Oak Ridge National Laboratory, Oak Ridge, Tenn.

TEST EQUIPMENT, SETUP, AND TEST PROCEDURES

Equipment

An off-the-shelf 2-ton window air conditioner with a rated energy efficiency ratio (EER) of 10 was selected for the test. The unit has a reciprocating compressor, and the evaporator has four circuits and four rows. Each circuit is connected to a capillary tube. Figure 1 shows the evaporator coil arrangement. The unit was tested with R-22 to confirm the rated performance. The original oil was drained from the system, and the compressor was rinsed with ester-based oil before R-407C was charged. R-407C for both the baseline (PCF) and CCF operations was charged at 95°F ambient temperature with 7°F ± 0.5°F suction line superheat to the compressor.

Test Setup

Figures 2 and 3 show the laboratory refrigerant-side and air-side test setup. Refrigerant-side temperatures were measured with calibrated thermocouples and pressures with transducers. Refrigerant flow rate was measured by a turbine meter. The evaporator inlet and outlet air temperatures were measured by two thermopiles to determine the average inlet and outlet temperatures. Wet-bulb temperatures were measured with thermocouples covered with wetted wicks. The airflow rate was measured with a duct air monitor, which measured the average velocity head coupled with a micromanometer and checked with a pitot-tube and the micromanometer.

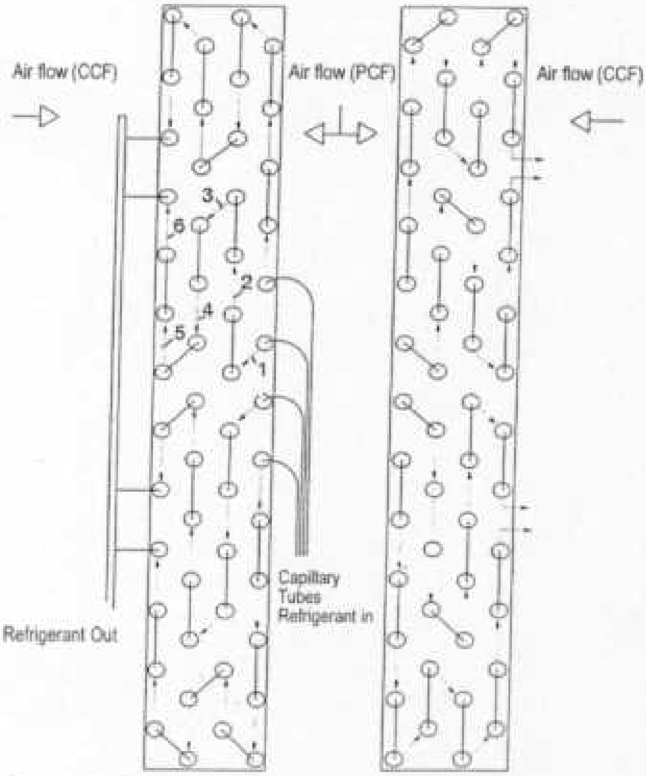

Figure 1 Evaporator coils.
Note: U-bend numbers are for Figures 6 and 7.

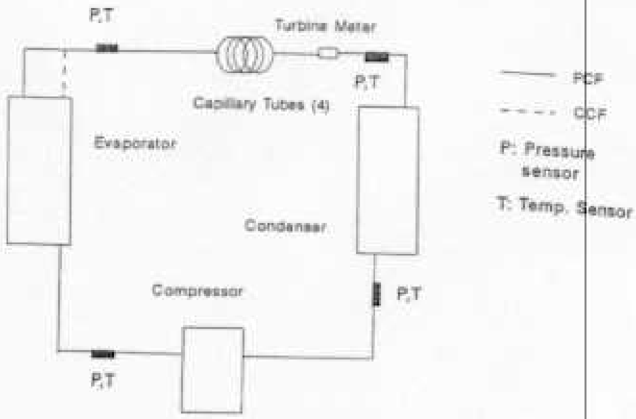

Figure 2 Refrigerant-side schematic.

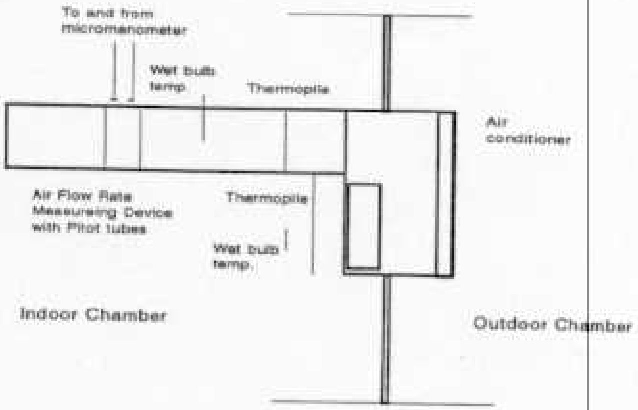

Figure 3 Air-side schematic.

The air conditioner was tested for PCF performance in an environmental chamber. The refrigerant charge was considered optimized when the superheat at the compressor inlet was around 7°F. For CCF evaporator tests, also, the refrigerant was charged until the superheat at the compressor suction line was around 7°F. The same air conditioner was tested for R-22 and for R-407C with PCF and CCF evaporator arrangements.

Our past experience in air conditioner testing indicated that the refrigerant-side measurement is more accurate because of the scattering of wet-bulb temperature measurements. The refrigerant temperature and pressure measurement devices are usually very accurate. Refrigerant mass flow rate is much lower than air mass flow rate; consequently, the refrigerant enthalpy differential between the evaporator inlet and exit is high enough that it is not too sensitive to the total cooling capacity calculation if small errors occur in the refrigerant temperature and pressure measurements. The air mass flow rate is usually very high, and the enthalpy differential of the evaporator inlet and outlet air is very small, so a small error in the dry-bulb or wet-bulb measurements will result in a large deviation in cooling capacity. In this study, we found that the cooling capacities of the refrigerant side and air side were within 5% (maximum deviation) of each other for the majority of the tests, which was considered a good match.

Test Procedures

The air conditioner was operated at ARI-rated indoor conditions of 80°F dry-bulb and 67°F wet-bulb. The outdoor chamber temperature setting varied from 80°F to 110°F at intervals of 5°F, which included the ARI-rated outdoor condition. For each outdoor temperature setting, the air conditioner was operated until steady-state operation was reached, and then the data collection (temperatures, pressures, power consumption, and refrigerant volumetric flow rates) started and continued for about five minutes. The data were then averaged. Airflow rate was measured with a micromanometer at the beginning of data collection. The data provide the system performance at the rated and off-design conditions. Because the system usually would be operated at off-design conditions, the off-design data base should be useful.

Test Results and Discussion

Figure 4 shows the cooling capacities for PCF and CCF evaporators. At ARI-rated outdoor conditions, the cooling capacity for CCF is 10.6% higher than that of the baseline (PCF) operation. In addition, CCF outperformed baseline operation over the entire tested outdoor temperature range, from 80°F to 110°F. At 80°F ambient, the cooling capacity of CCF was 15.3% higher than that of the PCF system. The advantages of the CCF evaporator over the baseline PCF evaporator decreased as the ambient temperature was increased. At 110°F ambient, the cooling capacity for CCF was only about 5.3% better than that of the baseline system because the coils were almost flooded in both PCF and CCF operation. Cooling capacity for R-22 operation was between that of CCF and PCF operation using R-407C. Cooling capacity for CCF operation was 5% higher than cooling capacity when R-22 was used at 95°F ambient temperature.

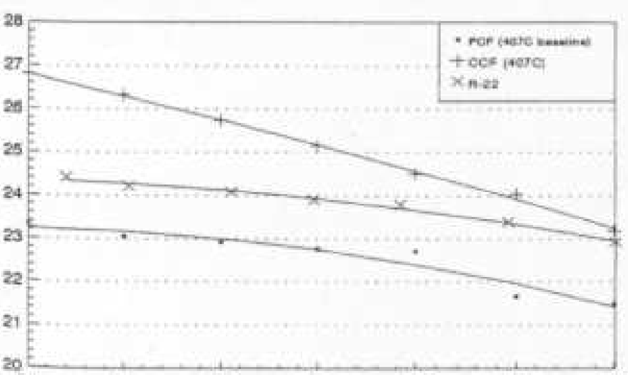

Figure 4 Refrigerant-side cooling capacity (kBtu/h), CCF vs. PCF.

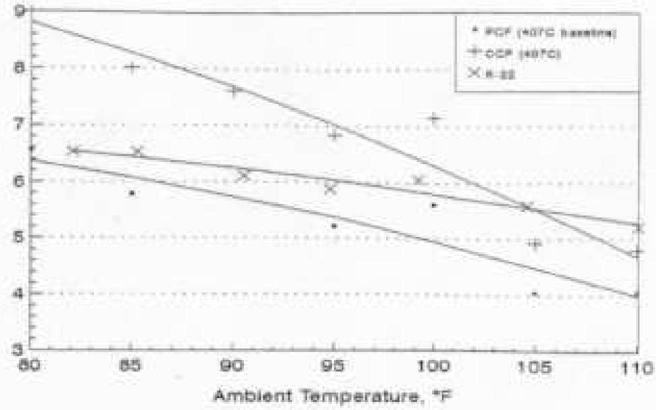

Figure 5 Latent cooling capacity (kBtu/h), CCF vs. PCF.

Figure 5 shows the latent capacity comparison. At 95°F ambient, the latent capacity for CCF is 30.6% higher than that of PCF and is 16.6% better than operation using R-22. At 80°F ambient, the advantage increased to 35.9%, and at 110°F, the latent capacity of CCF is still 17.5% higher than that of PCF. However, R-22 performed better than CCF using R-407C at ambient temperatures 105°F or higher.

For CCF operation, the refrigerant temperature at the evaporator exit should be higher because of the CCF arrangement. When the suction line superheat is adjusted to 7°F for both CCF and PCF operation, the CCF case has more refrigerant charge and the evaporator coils for the CCF case will have a smaller dryout section and, thus, higher sensible and latent cooling capacities. Figures 6 and 7 show the evaporator coil temperatures for both CCF and PCF operation. Figure 6 shows that the CCF coil dryout occurred only at the last leg of the coils; Figure 7 shows that the coil dryout section for the PCF evaporator is larger.

Because of the higher evaporator temperature (higher suction temperature and higher vapor density) for CCF operation, the refrigerant mass flow rate for CCF increases. Higher mass flow rate results in higher power consumption. Figures 8 and 9 show the comparison of refrigerant mass flow rate and

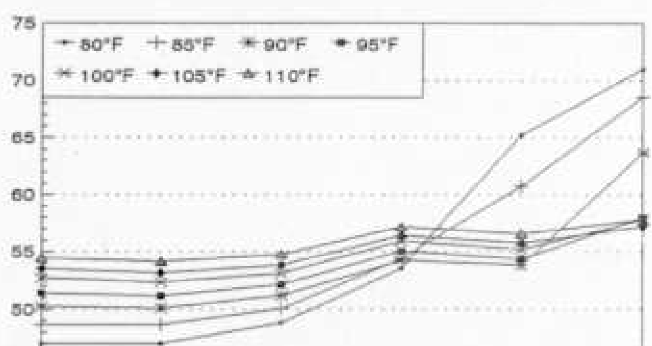

Figure 6 CCF evaporator coil temperature distribution.

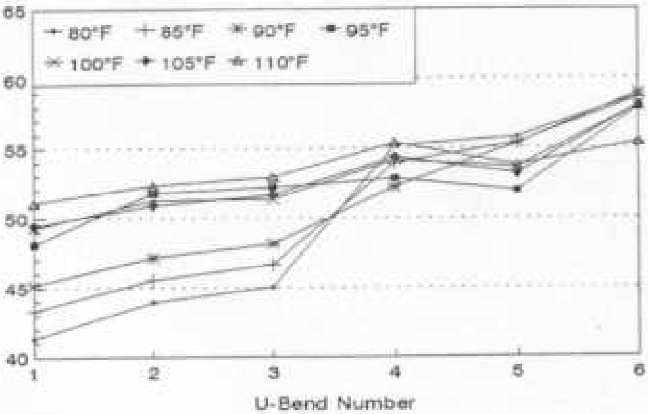

Figure 7 *PCF evaporator coil temperature distribution.*

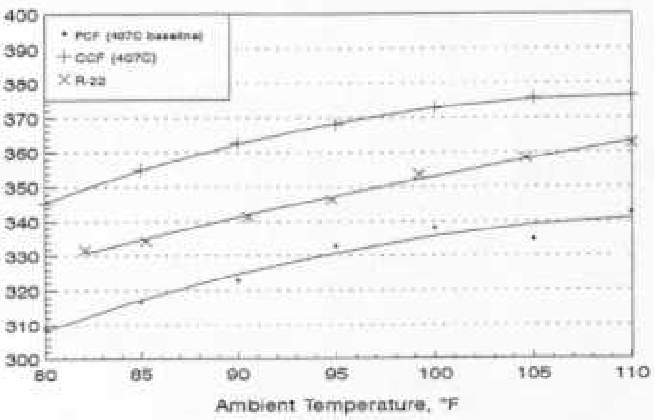

Figure 8 *Refrigerant mass flow rate (lb/h), CCF vs. PCF.*

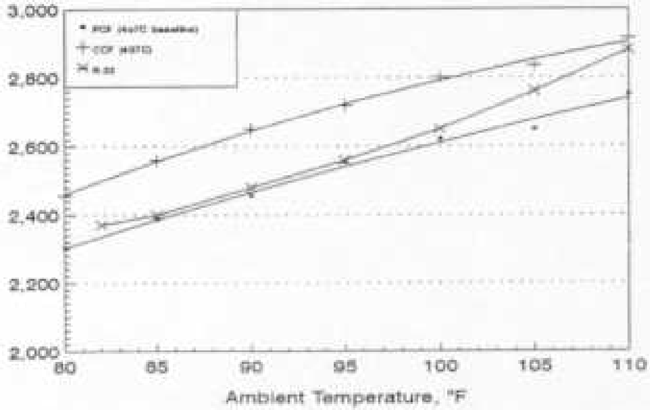

Figure 9 *Total power consumption (W), CCF vs. PCF.*

power consumption for CCF and PCF evaporators, respectively. The mass flow rate and the power consumption for R-22 operation are between those of CCF and PCF operation.

Figure 10 shows the system COPs. Although CCF operation delivers higher cooling capacity, it also consumes more power. However, CCF is still 3.8% higher in COP than PCF over the tested ambient temperature range, mainly because of the improvement in cooling capacity. CCF operation and R-22

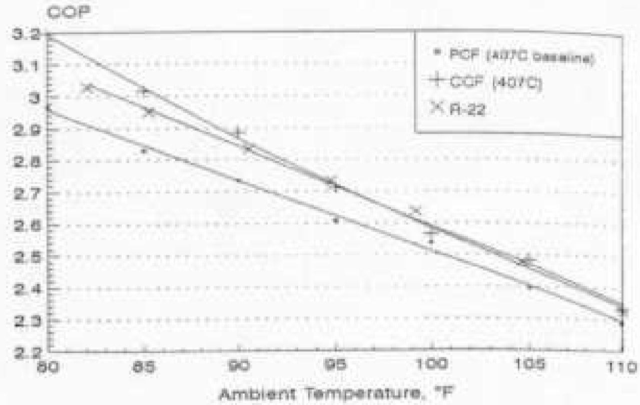

Figure 10 *COP, CCF vs. PCF.*

operation have almost identical COPs, with CCF higher in a low ambient region and R-22 slightly higher in a high ambient area.

CONCLUSIONS

The off-the-shelf window air conditioner was designed for R-22 operation. It is not surprising that R-407C does not perform as well as R-22 in drop-in tests. One reason is that the evaporator becomes PCF. The test results showed that the PCF configuration and the temperature glide of R-407C contribute to a 5% to 6% cooling capacity drop at the ARI-rated point. However, a minor modification of the evaporator—turning the evaporator 180° to make it CCF to take advantage of the temperature glide—improved system performance. The cooling capacity increased by about 10.5% and system COP by 3.8%. The latent cooling capacity improvement of over 30.6% was unexpected. Most of the cooling capacity improvement from making the evaporator CCF is in latent load capacity. This indicates that the CCF evaporator with R-407C is particularly suitable for areas with high humidity. The findings in this study should be applicable to dehumidifier design as well, if R-407C is used as the refrigerant.

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Conversion Table

1.	Temperature, °C	= (°F − 32) /1.8
2.	Capacity, kW	= (kBtu/h) /3.413
3.	Mass flow rate, kg/h	= (lb/h) / 2.204

DISCUSSION

Leon Tang, Manager, Heat Transfer Technology, Outokumpu Copper, Franklin, Ky.: Did you test R-22 under counterflow situation?

Vince Mei: For R-22 tests, the evaporator was thermally counterflow, even though the refrigerant and air were in parallel flow arrangement. We did not test the thermally parallel flow evaporator for R-22 because the performance would deteriorate.

Dan Manole, Senior Project Engineer, Tecunseh Products Co.: The latent load increase might be beneficial to a dehumidifier but not for AC.

Vince Mei: The latent load did increase substantially with counter-crossflow evaporator, but the sensible load capacity also improved. The net effect is that the air conditioner's sensible capacity/total capacity ratio is reduced. This is important and desirable because the houses are now being built better than before with better insulation and window design, and with other improvements. The sensible load of the house is reduced, but not the latent load. The future air conditioners should have lower sensible capacity/total capacity ratio than that of the current units. The authors agree with Mr. Manole that R-407C with counter-cross-flow evaporator will be beneficial to the dehumidifier.

Ron Shimon, Senior Project Engineer, Tecunseh Products Co., Tecunseh, Mich.: What oil was used in the R407C tests?

Vince Mei: We used synthetic ester-based oil.