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EXPERIMENTAL PERFORMANCE ASSESSMENT OF A RETROFITTED WINDOW AIR CONDITIONER WITH R-407C

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ABSTRACT

This paper presents the experimental performance study of a retrofitted window air-conditioner with R-407C as a substitute to HCFC-22. The air-conditioner is a 1.5 TR unit designed for HCFC-22. The air conditioner has been tested as per the Indian standard 1391 (1992) Part I, for unitary air-conditioners. These test conditions are closer to Air-Conditioning & Refrigeration Institute (ARI) standard 210/240-1989 for unitary air conditioning and air source heat pump for cooling mode. The performance of the air-conditioner with R-407C is compared with the baseline performance with HCFC-22.The performance parameters considered are cooling capacity, coefficient of performance, energy consumption, and discharge pressure.

Test results show that R-407C has 2.1% lower cooling capacity for the lower outdoor conditions and 7.93% lower for the higher outdoor conditions with respect to HCFC-22. The cooling efficiency for R-407C is 7.9% lower for the lower outdoor conditions and 13.47% lower for the higher outdoor conditions. The energy consumption of the unit with R-407C is generally higher in the range 6-7% than HCFC-22. The discharge pressures measured for R-407C were higher in the range 11-13% than HCFC-22.

Keywords: Window Air Conditioner, Refrigerant, R-407C, Performance, and Cooling Capacity

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NOMENCLATURE

CFC	chlorofluorocarbon
DBT	dry-bulb temperature
EER	energy efficiency ratio (Btu/hr/W)
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydroflurocarbon
ODP	ozone depletion potential

TR ton of refrigeration
WBT wet-bulb temperature

Subscripts

22 HCFC-22
407 R-407C

INTRODUCTION

In the last six decades, the CFCs and HCFCs have been used extensively in the field of refrigeration and air-conditioning due to their favourable characteristics. It was estimated that, in the world market the annual production of unitary air-conditioners is about 33.7 million units (Carlo, 1998). HCFC-22 is one of the important refrigerants used in air-conditioning all over the world. HCFC-22 has an ODP of 0.055 and is controlled under the Montreal Protocol. It has to be phased out by 2030 in developed nations and 2040 in developing nations. Some European counties have voluntarily stopped the production of systems with HCFC-22 since 1st January 2000. Developed nations have already started using new units with alternatives to HCFC-22, particularly R-410A and R-407C.

The Air-conditioning and Refrigeration Institute (ARI, 1997), considering the need for the replacement of HCFC-22 and established the Alternative Refrigerant Evaluation Program (AREP) in February 1992. Through AREP many refrigerants were assessed. The most potential alternative refrigerants identified were R-410A, R-407C, HFC-134a and HC-290. Later, the list was revised to include HFC-32, and a non-azeotropic refrigerant mixture of HFC-125, HFC-134a and HC-600 (46.6/50.0/3.4 by %wt.). R-407C is a non-azeotropic refrigerant mixture of HFC-32, HFC-125, and HFC-134a (23/25/52 by %wt.) having temperature glide of about 7^oC.

Dongsoo et al. (2000) assessed R-407C along with other refrigerant mixtures in a breadboard type heat pump. Linton et al. (1996 and 2000), Lunger et al. (1994), Shiflett, (1994), and Spatz et al. (1994), have tested unitary air-conditioners of capacities in the range 8.8 to 17.6 kW with R-407C. Spatz (2000) and Motta et al. (2000) had done simulation studies on air-conditioner using alternatives to HCFC-22. Devotta et al. (2000, 2001a, and 2001b) have theoretically assessed the various refrigerants, including HFC-134a, R-407C, R-410A, HC-290, HFC blends and CO_2 as alternatives to HCFC-22 for window air-conditioners. Most of these studies indicate that R-407C is a potential refrigerant for retrofitting HCFC-22 systems.

The main objective of this paper is the assessment of R-407C in a window air conditioner under varying ambient conditions. In the Indian market, window A/C models are available in the capacity range 0.5 TR to 2 TR. Invariably, reciprocating hermetic compressors are mostly used in these systems, although some rotary compressors are also used. A typical window A/C of capacity 1.5 TR was selected for the tests. The tests were conducted according to the Indian Standard 1391 (1992) Part I, for unitary air conditioners. These test conditions are closer to Air-Conditioning & Refrigeration Institute (ARI) standard 210/240-1989 for unitary air conditioning and air source heat pump for cooling mode. The A/Cr was tested for capacity and energy consumption under varying outdoor conditions with HCFC-22 and R-407C. The performance data with HCFC-22 is used as base line data.

TEST DESCRIPTION

The performance evaluation of a window A/C is prescribed in IS 1391 (1992) Part I. There are many tests to assess the performance of window A/Cs. The important tests for energy efficiency are capacity rating test, power consumption test, and maximum operating conditions test. The capacity rating tests are for Indian market and the other two tests are for the purpose of export. The conditions of air on both sides of window A/C for capacity rating tests and maximum operating test are prescribed in Table 1.

TABLE 1. CAPACITY RATING TEST AND MAXIMUM OPERATING TEST CONDITIONS

Room	Indoor Room Conditions		Outdoor Room Conditions	
Test Type	**Dry-bulb Temp. (^oC)**	**Wet-bulb Temp. (^oC)**	**Dry-bulb Temp. (^oC)**	**Wet-bulb Temp. (^oC)**
Domestic Test (DT)	27	19	35	30
Export Test A (ETA)	27	19	35	24
Export Test B (ETB)	29	19	46	24
Max. Operating Test (MOT)	35	24	46	27

The purpose of capacity rating test is to determine the magnitude of the net total cooling effect, net dehumidifying effect, net sensible cooling effect and net total air capacity for cooling. The test conditions for energy consumption test specified in the IS 1391 are the same as the capacity rating test as presented in Table 1. The total power consumed by compressor motor, outdoor fan motor and indoor blower motor is measured. The objective of maximum operating test is to check that A/C works satisfactorily under the maximum operating conditions. As per the test requirements, the A/C is operated for two hours after the establishing the conditions given in Table 1 and power supplied to the system is cut off for 3 minutes and then restored for one hour.

EXPERIMENTATION

As per the IS 1391, the A/C was tested in a psychrometric chamber. The chamber consists of two rooms of equal size, one on evaporator side and the other on condenser side. In this method, measurements of dry-bulb and wet-bulb temperatures of entering and leaving air and the associated flow rates were used to calculate the cooling capacity. The airflow rate through the evaporator was measured using a nozzle type airflow measurement device. Temperatures were recorded with the help of precision thermometers. An electronic panel recorded the power consumed by the A/C, input voltage, supply frequency, and power factor. Refrigerant pressures were measured by using precision Bourdon's tube pressure gauges.

The required conditions on both sides of A/C were established for different tests by using the humidifiers, dehumidifiers, air heaters and A/Cs. After confirming steady state, temperatures of air (dry-bulb and wet-bulb) at condenser and evaporator inlet/exit were recorded for two hours at an interval of 15 minutes. The performance data of HCFC-22/mineral oil (ISO VG 32) were used as the base line data. After the completion of all tests with HCFC-22, the A/C was retrofitted with R-407C and polyol ester oil (ISO VG 32).

The steps were followed for retrofitting:

1. HCFC-22 was recovered from the A/C.
2. The compressor was taken out from the A/C to drain the oil.
3. The mineral oil was drained and the quantity measured.
4. The compressor was charged with a small quantity of fresh polyol ester oil, and run dry. The oil was then drained. This was repeated at least twice.
5. The compressor was reinstalled in the system.
6. The filter-drier was replaced by a solid core filter-drier compatible with HFC.
7. The system was checked for leak with dry nitrogen at a pressure of 12.41 bar (180 psig).

8. The system was kept for evacuation for an hour.
9. A fresh charge of polyol ester oil of 950 ml (same as the mineral oil quantity) was charged.
10. The system was evacuated to a vacuum of 500 microns.
11. The system was charged with R-407C. The charge of R-407C was 95 percent of the original HCFC-22 charge.

RESULTS AND DISCUSSION

Table 2 gives the various measured system parameters for different test conditions.

TABLE 2 RATED CAPACITY TEST RESULTS FOR HCFC-22 AND R-407C.

Test Type	Evaporator Side Average Temperatures				Comp. & Fan Power (W)	Suction Pressure (kPa)	Discharge Pressure (kPa)	Cooling Capacity (kW)	EER (Btu/hr/W)	COP
	Air Entering		Air Leaving							
	DBT (^oC)	WBT (^oC)	DBT (^oC)	WBT (^oC)						
DT_{22}	27.1	19.0	12.2	11.8	2130	517	2193	5.466	8.765	2.57
DT_{407}	27.0	19.0	13.0	12.5	2264	586	2482	5.351	8.071	2.36
ETA_{22}	27.0	18.9	12.8	12.4	2104	538	2330	5.182	8.411	2.46
ETA_{407}	27.0	19.0	13.3	12.4	2252	586	2647	4.941	7.490	2.19
ETB_{22}	28.9	19.0	15.5	13.9	2288	565	2784	4.211	6.286	1.84
ETB_{407}	29.0	19.0	15.9	14.1	2434	607	3103	3.877	5.440	1.59

Cooling Capacity: While testing the alternative refrigerants, the cooling capacity is an important parameter. If the cooling does not match with the base line data, then the compressor has to be redesigned. Therefore, if an alternative refrigerant gives closer cooling capacity then only it can be considered for retrofitting. Figure 1 shows the variation of cooling capacity for both HCFC-22 and R-407C for a range of outdoor conditions. HCFC-22 gave a cooling capacity of 5.466 kW for the lower outdoor conditions and 4.211 kW for the higher outdoor conditions. Test results show that R-407C had 2.1% lower cooling capacity for the lower outdoor conditions and 7.93% lower for the higher outdoor conditions with respect to HCFC-22. Capacities of both the refrigerants were lower for the higher outdoor conditions with a similar trend.

Coefficient of Performance: Figure 2 shows the variation of COP for both HCFC-22 and R-407C for a range of outdoor conditions. COP for HCFC-22 was 2.57 for the lower outdoor conditions and 1.84 was for the higher outdoor conditions. For R-407C, for the higher outdoor conditions, the COP was higher than HCFC-22. The cooling efficiency for R-407C was 7.9% lower for the lower outdoor conditions and 13.47% lower for the higher outdoor conditions.

Energy Consumption: Figure 3 shows that the energy consumed by the system with R-407C was higher, for all the outdoor conditions, than HCFC-22. The power consumed by the system with HCFC-22 was in the range 2.13 to 2.29 kW. The power consumed with R-407C was higher by 6 to 7%. As per IS 1391(1992), the power consumption should be below 2.2 kW at the rated capacity conditions for the domestic test. However, the power consumed by the system retrofitted with R-407C was higher by 65 W than the prescribed limit. There may be potential to improve the performance with some optimization.

Discharge Pressure: Figure 4 shows the discharge pressure of R-407C and HCFC-22 for a range of outdoor conditions. The discharge pressure of HCFC-22 was 2193 kPa for the lower outdoor conditions and 2784 kPa for the higher outdoor conditions. The mixture had higher pressures than HCFC-22. The discharge pressure of R-407C for all operating conditions varied in the range 11-13% higher than HCFC-22.

Operation at Maximum Operating Conditions: It was observed that during the entire test, the window A/C was working without any visible and audible damage and without tripping with both HCFC-22 and R-407C. After a shut down period for 3 minutes, the A/C started again and remained in operation for the next one hour without tripping for both HCFC-22 and R-407C.

CONCLUSIONS

Based on the experimental investigation on the performance of R-407C as a drop in substitute to HCFC-22 for window A/Cs, the following conclusions could be drawn.

a) The cooling capacity of R-407C was lower in the range 2.1 to 7.9%.
b) Efficiency of R-407C was lower in the range 7.9 to 13.5%.
c) Discharge pressures were higher in the range 11 to 13%.
d) The percentage drop in capacity and energy efficiency increased with the increase in the outdoor conditions for R-407C.

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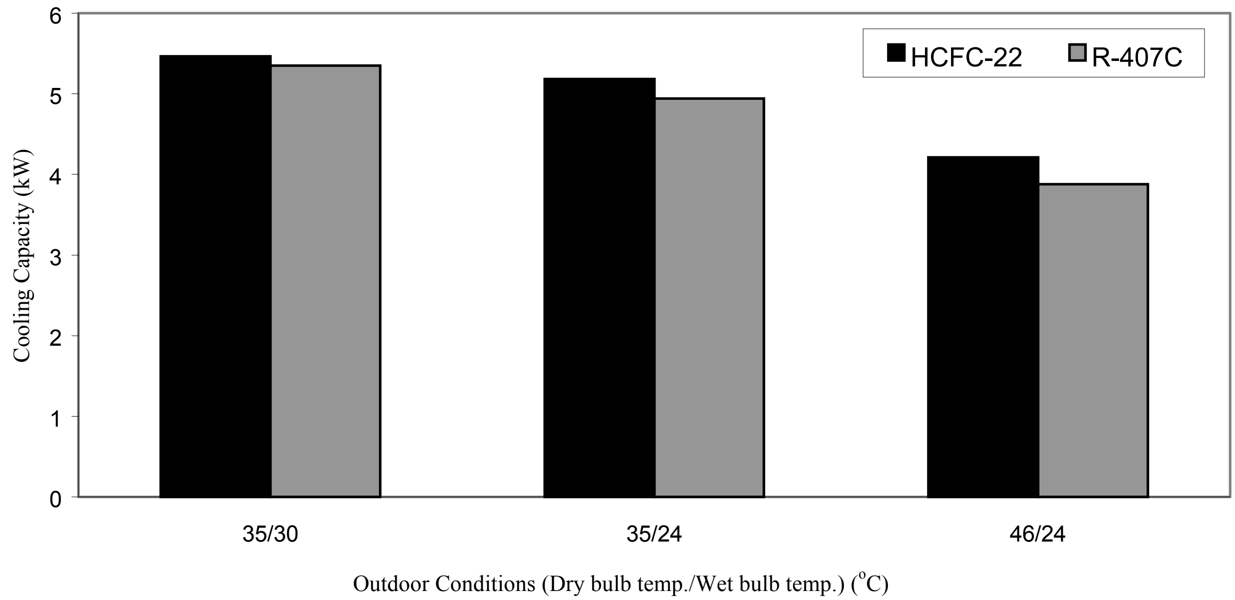

Fig.1 Cooling capacities of HCFC-22 and R-407C at various outdoor conditions.

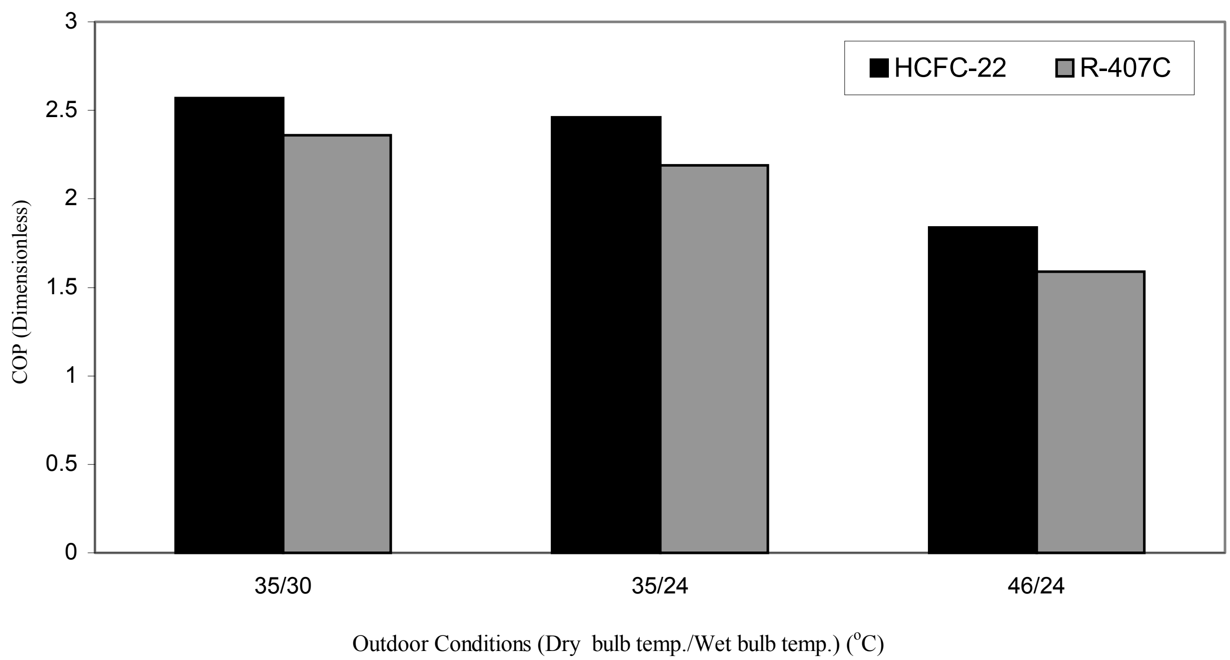

Fig. 2 COPs of HCFC-22 and R-407C at various outdoor conditions.

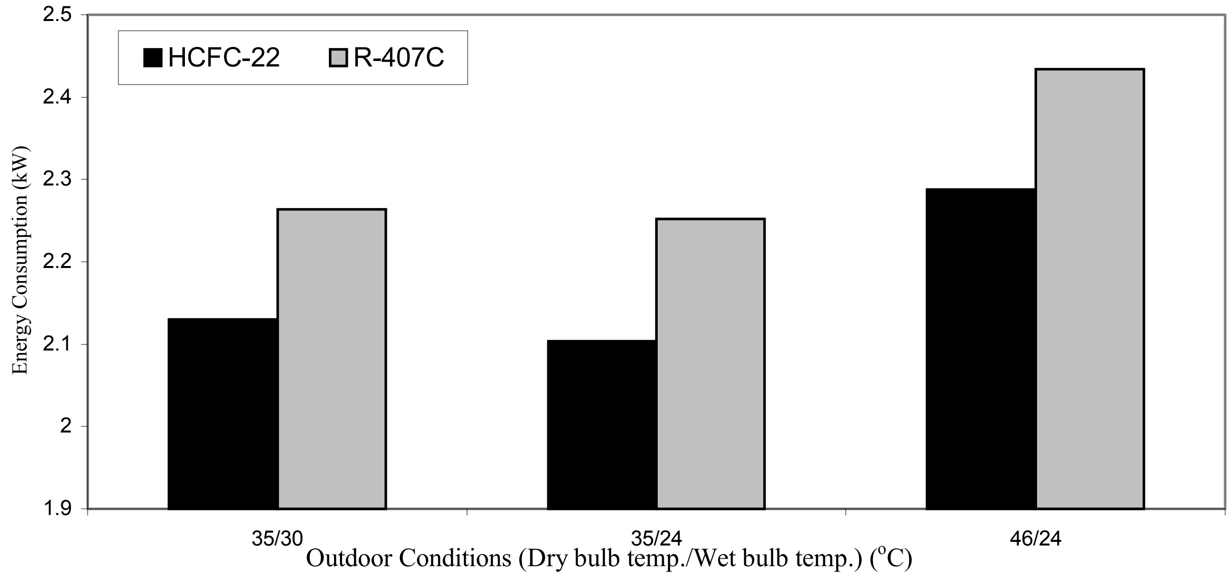

Fig. 3 Energy consumption of HCFC-22 and R-407C at various outdoor conditions.

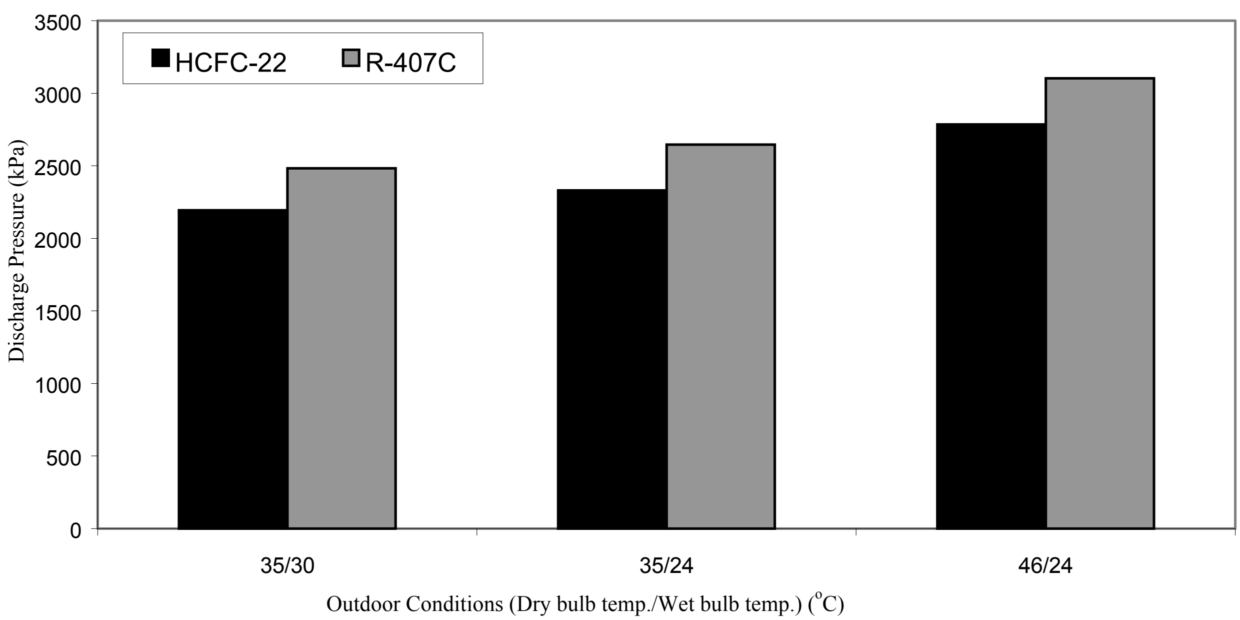

Fig. 4 Discharge pressures of HCFC-22 and R-407C at various outdoor conditions.