SIMULATION OF HEAT EXCHANGERS OF A WINDOW AIR CONDITIONER RETROFITTED WITH R-407C

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ABSTRACT

This paper presents simulation results for the heat exchangers of an HCFC-22 window air conditioner retrofitted with R-407C. The test conditions are per the Indian Standard IS 1391 (1992) for unitary air conditioners. The simulation was carried out using EVAP-COND, a heat exchanger model developed by NIST. A typical Indian window air conditioner of capacity 5.13 kW (1.5 TR) was selected for the study. The performance of the heat exchangers with R-407C is compared with the baseline performance with HCFC-22. The simulation results are validated by comparing to experimental data for a window air conditioner retrofitted with R-407C. The assessment parameters are temperatures of refrigerant and air, and refrigerant pressures and pressure drops.

The simulated evaporator capacity with R-407C is lower by 3.3 % for the lower outdoor conditions and 6 % lower for the higher outdoor conditions with respect to HCFC-22. R-407C has 6.1 % lower condenser capacity for the lower outdoor conditions and 10.6 % lower for the higher outdoor conditions with respect to HCFC-22. The simulated evaporator capacities are within ± 3 % of the experimentally measured cooling capacities for both refrigerants. The exit temperatures of R-407C are lower by 1.9 °C to 5.2 °C in the condenser and are higher by 3.2 °C to 3.8 °C in the evaporator as compared to HCFC-22. The evaporating pressures of R-407C are higher by 4.5 % to 5.3 % as compared to HCFC-22. The condensing pressures of R-407C are higher by 10.3 % to 14.1 % as compared to HCFC-22. The pressure drop of R-407C is lower in both the evaporator and the condenser as compared to HCFC-22. The outlet temperatures of air for HCFC-22 and R-407C in both heat exchangers are nearly the same.

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INTRODUCTION

The predicted world demand of air conditioners for 2004 is about 47.2 million, which includes room air conditioners and packaged air conditioners. Out of this, 36.3 million will be room air conditioners, mostly window mounted (JARN, 2002). In India, it is estimated that about 1 million room air conditioners will be manufactured with HCFC-22 every year, comprising approximately 75 % of the window units. Window air conditioners manufactured in India, range in capacities from 1.71 kW (0.5 TR) to 6.84 kW (2.0 TR). Considering the average life of a typical window air conditioner to be about 15 years, implies that millions of window air conditioners are operating with HCFC-22. As per the Montreal Protocol, HCFC-22 can be used until 2040 in developing countries. However, many developed countries are planning to phase out HCFC-22 much earlier than the prescribed date of 2030. In Europe, HCFCs have already been phased out in new equipment (below 100 kW capacity) in 2002, and the total phase out of HCFCs is scheduled for 2015. The phase out schedule of HCFC-22 may occur much earlier than the targeted date in developing countries such as India due to market forces. It should be possible to retrofit existing systems with a more environmentally friendly refrigerant.

Many refrigerants were assessed through the Alternative Refrigerant Evaluation Program (AREP) (ARI, 1997) as potential replacements for HCFC-22. The most promising alternative refrigerants that emerged were R-410A, R-407C, HFC-134a, and HC-290. The list has since been 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 mass fraction). Dongsoo *et al*. (2000) assessed R-407C along with other refrigerant mixtures in a breadboard type heat pump. Recently, Linton *et al*. (2000) tested unitary air conditioners with R-407C. Spatz (2000) and Motta and Domanski (2000) presented simulation results for air conditioners operating with HCFC-22 alternatives. Devotta *et al*. (2000, 2001) theoretically assessed the various refrigerants, including HFC-134a, R-407C, R-410A, HC-290, HFC blends, and carbon dioxide as alternatives to HCFC-22 for window air conditioners. Devotta *et al*. (2002) experimentally tested a window air conditioner retrofitted with R-407C for various operating conditions. Most of these studies indicate that R-407C is a potential retrofit refrigerant for existing HCFC-22 systems. Therefore, there is considerable interest to assess heat exchanger performances for window air conditioners operating with R-407C under retrofit conditions.

This paper presents the results of a simulation study of heat exchangers for window air conditioner using EVAP-COND, a heat exchanger model developed by the National Institute of Standards and Technology, USA (NIST, 2003). The study compares heat exchanger performances for R-407C operating in a HCFC-22 window air conditioner for various ambient conditions. A typical window air conditioner of capacity 5.13 kW (1.5 TR) is used for the analysis. The ambient conditions are according to the Indian Standard IS 1391 (1992) Part I (BIS, 1992) for unitary air conditioners. Experimental performance data for the heat exchangers operating with HCFC-22 are used as the baseline data. The simulation results are validated by comparing them to experimental data for a window air conditioner retrofitted with R-407C.

1 TEST CONDITIONS

IS 1391 (1992) Part I prescribes the performance evaluation of window air conditioners. In this standard, there are several tests to assess the performance of window air conditioners. However, the important tests for energy efficiency are ones for capacity rating and ones for power consumption. There is a capacity rating test for the Indian domestic market and two tests for the export market. The purpose of the capacity rating tests 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 the energy consumption test are the same as for the capacity rating test. Table 1 shows the conditions of air on both sides of the window air conditioner.

Table 1: Rated capacity test conditions

Test Type	**Indoor room conditions**		**Outdoor room conditions**	
	Dry bulb temp. (^{o}C)	**Wet bulb temp. (^{o}C)**	**Dry bulb temp. (^{o}C)**	**Wet bulb temp. (^{o}C)**
Domestic Test (DT)	27	19	35	30
Export Test A (ETA)	27	19	35	24
Export Test B (ETB)	29	19	46	24

2 SIMULATION

These window air conditioners typically use air-cooled, finned-tube, cross flow type heat exchangers. The computer model 'EVAP-COND' has been developed by NIST for finned-tube heat exchangers. It calculates the heat transfer for each tube separately on the basis of inlet air and refrigerant properties, heat exchanger parameters and mass flow rates. The total capacity of the heat exchanger is based on the performance of each tube in a tube assembly of the heat exchanger.

The evaporator consists of 10 mm diameter tubes with wavy fins in three rows. It has two parallel refrigerant circuits. The condenser consists of 10 mm diameter tubes with wavy fins in three rows. The condenser has a single refrigerant circuit. The uncertainty associated with the measurements of tests is approximately 5 % for a 95 % confidence interval.

The simulation model determined the capacities of the evaporator and the condenser with HCFC-22 and R-407C. The evaporator tube configuration, fin configuration, inlet air temperature, inlet air humidity, inlet air pressure, airflow rate, exit saturation temperature of the refrigerant, degree of superheat, and mass flow rate of the refrigerant were used to calculate the evaporator capacity. The cooling capacities of the evaporator were determined for the test conditions given in Table 1. Table 2 shows the refrigerant conditions at the evaporator outlet for the different tests. The airflow rate for the evaporator was the same for all test conditions.

Table 2: Refrigerant conditions at the evaporator outlet

Test	HCFC-22		R-407C	
	Exit dew point temp. (^oC)	**Superheat (^oC)**	**Exit dew point temp. (^oC)**	**Superheat (^oC)**
DT	5.5	2	8.9	2
ETA	6.5	2	9.8	2
ETB	8.0	2	11.5	2

The condenser tube configuration, fin configuration, inlet air temperature, inlet air humidity, air flow rate, inlet pressure of refrigerant, inlet temperature of the refrigerant, and mass flow rate of the refrigerant were used to determine the condenser capacity. The condenser capacities were determined for the test conditions given in Table 1. Table 3 shows the inlet conditions of the refrigerants at the condenser inlet for the various tests. Similar to the evaporator, the airflow rate was the same for the condenser for all test conditions. The air was assumed to enter both heat exchangers at a uniform axial velocity at atmospheric pressure (Xu *et al*., 1996). The assessment parameters for both heat exchangers are the temperature distributions of refrigerant and air, the pressure variation of the refrigerant, and the refrigerant pressure drop.

Table 3: Refrigerant conditions at the condenser inlet

Test	HCFC-22		R-407C	
	Inlet pressure (kPa)	**Inlet temp. (^oC)**	**Inlet pressure (kPa)**	**Inlet temp. (^oC)**
DT	2293.8	99.9	2583.4	88.5
ETA	2431.7	102.0	2748.8	92.4
ETB	2914.3	115.8	3203.9	126.6

3 RESULTS AND DISCUSSION

3.1 Heat Exchanger Capacities

Figure 1 shows the simulated capacities of the heat exchangers working with HCFC-22 and R-407C for various test conditions. The measured cooling capacities of the HCFC-22 evaporator for lower and higher outdoor conditions were 5.466 kW and 4.211 kW respectively. Similarly the corresponding capacities when retrofitted with R-407C were 5.351 kW and 3.877 kW (*Devotta et al*., 2002). The simulated evaporator capacities are within $\pm$ 3 % of the experimentally measured cooling capacities for both refrigerants. Simulation results show that R-407C has 3.3 % lower cooling capacity for the lower outdoor conditions and 6 % lower for the higher outdoor conditions as compared to HCFC-22. Simulated condenser capacity for HCFC-22 is 7.32 kW for the lower outdoor conditions and 5.46 kW for the higher outdoor conditions. R-407C has 6.1 % lower condenser capacity for the lower outdoor conditions and 10.6 % lower for the higher outdoor conditions as compared to HCFC-22. The lower capacities for the heat exchangers operating with R-407C are based on its lower volumetric capacity and the temperature glide of R-407C.

3.2 Refrigerant Temperature Profiles in the Condenser

Figure 2 shows the simulated temperature profiles of HCFC-22 and R-407C along the condenser length for the rated capacity domestic test conditions. The outlet refrigerant temperature for HCFC-22 is 42.2 ^oC. R-407C has a lower outlet temperature by 5.2 ^oC. For the other two test conditions, this difference was lower by 1.9 ^oC to 2.8 ^oC. Figure 2 show that the condensation of R-407C requires a smaller area of the heat exchanger. The area required for condensation of HCFC-22 and R-407C are approximately 60 % and 48 %, respectively. Area optimization is possible by designing a counter-cross flow circuitry (Judge and Radermacher, 1997). During condensation of

R-407C, the temperature profile shows a refrigerant temperature glide of 5.3 ^{o}C. This temperature glide could be used to improve the performance for R-407C in a counter-cross flow circuit.

3.3 Refrigerant Temperature Profiles in the Evaporator

Figure 3 shows the temperature profiles of HCFC-22 and R-407C in the evaporator for the rated capacity domestic test conditions. The exit temperature of HCFC-22 is 7.1 ^{o}C. R-407C has a higher outlet temperature as compared to HCFC-22 by 3.6 ^{o}C. For the other two tests, the outlet temperature difference was higher by 3.2 ^{o}C to 3.8 ^{o}C. Figure 3 shows that the temperature of R-407C increases during evaporation by 4 ^{o}C because of the temperature glide while for HCFC-22 it decreases by 1.1 ^{o}C before superheating starts. The frictional pressure drop decreases the evaporating temperature of HCFC-22 and minimizes the temperature glide for a zeotropic mixture (Jung and Radermacher, 1997).

3.4 Pressure Drop of Refrigerants

The pressure variations along the length of the heat exchangers are shown in Figures 4 and 5. Mean evaporating pressures of R-407C are higher by 4.5 % to 5.3 % as compared to HCFC-22. The condensing pressures of R-407C are higher by 10.3 % to 14.1 % as compared to HCFC-22. In the evaporator, HCFC-22 has a pressure drop of 20.9 kPa for the lower outdoor conditions and a pressure drop of 12.0 kPa for the higher outdoor conditions as shown in Figure 6. For R-407C, the pressure drop in the evaporator is lower by 11.8 % to 16.6 %. HCFC-22 has a pressure drop of 118.2 kPa in the condenser for the lower outdoor conditions and a pressure drop of 51.4 kPa for the higher outdoor conditions. Similar to the evaporator, the pressure drops for R-407C in the condenser are lower by 35.4 % to 41.5 %.

3.5 Air Temperatures in the Heat Exchangers

Figure 7 shows the air temperatures leaving the tube surfaces for the rated capacity domestic test conditions. For each row of tubes, the air temperature is the average of the air temperatures leaving the individual tubes in that particular row. Air enters the evaporator at 27 ^{o}C and the condenser at 35 ^{o}C. The temperature of air leaving the evaporator for HCFC-22 is 12.5 ^{o}C. For R-407C, it is higher by 0.5 ^{o}C. Air leaves the condenser at 52.6 ^{o}C for HCFC-22. For R-407C, it is lower by 1.3 ^{o}C. The comparison between experimental and simulated outlet air temperatures from the evaporator and the condenser at various test conditions is given in Table 4 (*Devotta et al.*, 2002).

Table 4: Comparison between experimental and simulated outlet air temperatures

Refrigerant	Test	Evaporator outlet air temperature (^{o}C)		Condenser outlet air temperature (^{o}C)	
		Experimental	Simulated	Experimental	Simulated
HCFC-22	DT	12.2	12.5	52.5	52.6
	ETA	12.8	13.0	52.8	51.4
	ETB	15.5	15.4	63.9	58.7
R-407C	DT	13.0	12.9	51.5	51.3
	ETA	13.3	13.4	52.2	51.0
	ETB	15.9	16.0	62.3	58.0

CONCLUSIONS

The heat exchanger simulation results for a room air conditioner designed for HCFC-22 but retrofitted with R-407C show that the exit temperature of R-407C in the condenser is lower by 1.9 ^{o}C to 5.2 ^{o}C and in the evaporator higher by 3.2 ^{o}C to 3.8 ^{o}C as compared to HCFC-22. Evaporating pressures of R-407C are higher by 4.5 % to 5.3 % as compared to HCFC-22. The pressure drop of R-407C is lower by 11.8 % to 16.6 % in the evaporator, while in the condenser it is lower by 35.4 % to 41.5 % as compared to HCFC-22. The outlet temperatures of air in both heat exchangers for both HCFC-22 and R-407C are nearly the same. The evaporator capacity with R-407C is lower by 3.3 % for the lower outdoor conditions and lower by 6 % for the higher outdoor conditions as compared to HCFC-22. The condenser capacity with R-407C is lower by 6.1 % to 10.6 % as compared to HCFC-22.

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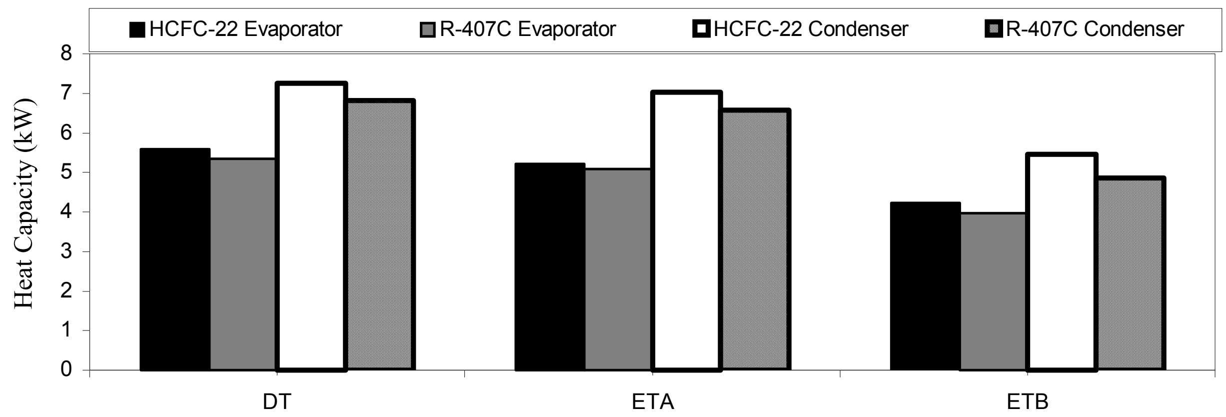

Figure1. Heat Exchanger Capacities for HCFC-22 and R-407C

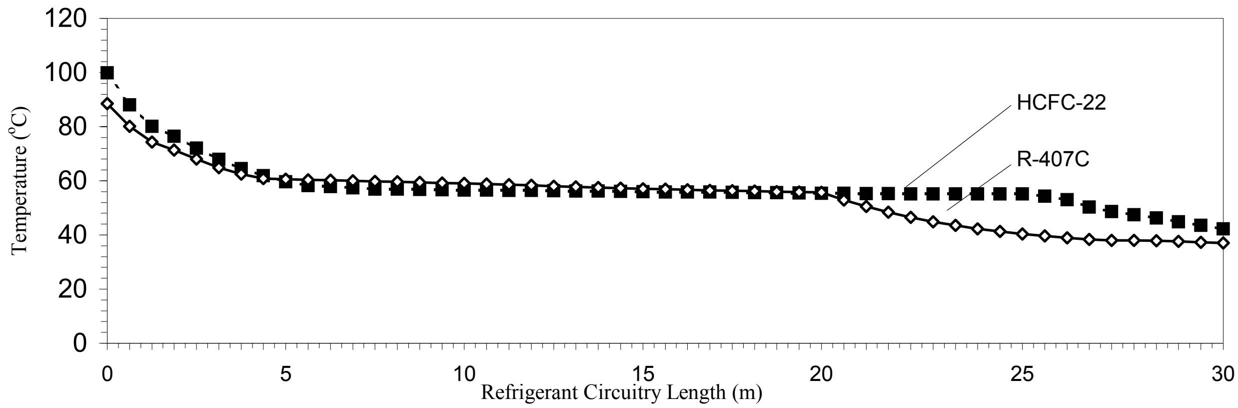

Figure 2. Temperature Profiles of HCFC-22 and R-407C in the Condenser (air enters at 35 °C and 69.5 % RH).

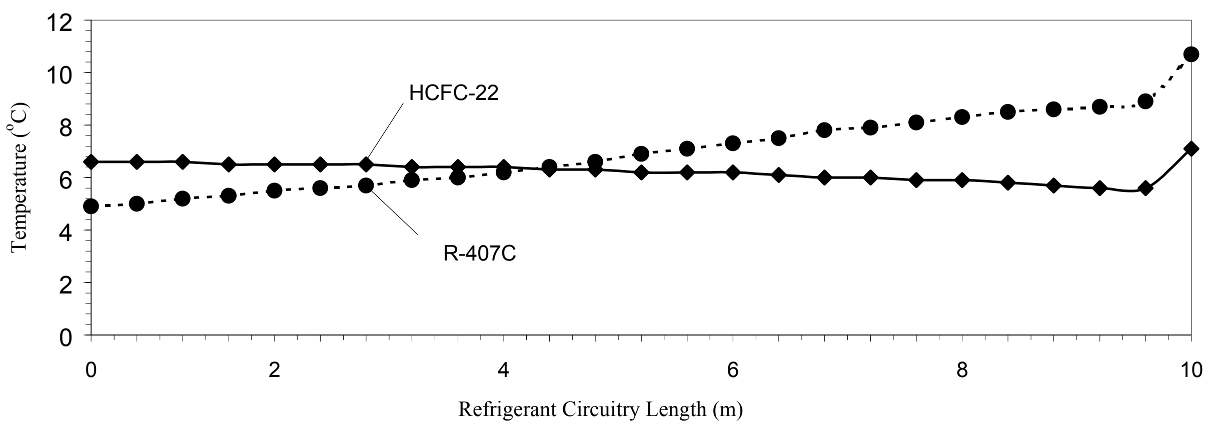

Figure 3. Temperature Profiles of HCFC-22 and R-407C in the Evaporator (air enters at 27 °C and 47 % RH).

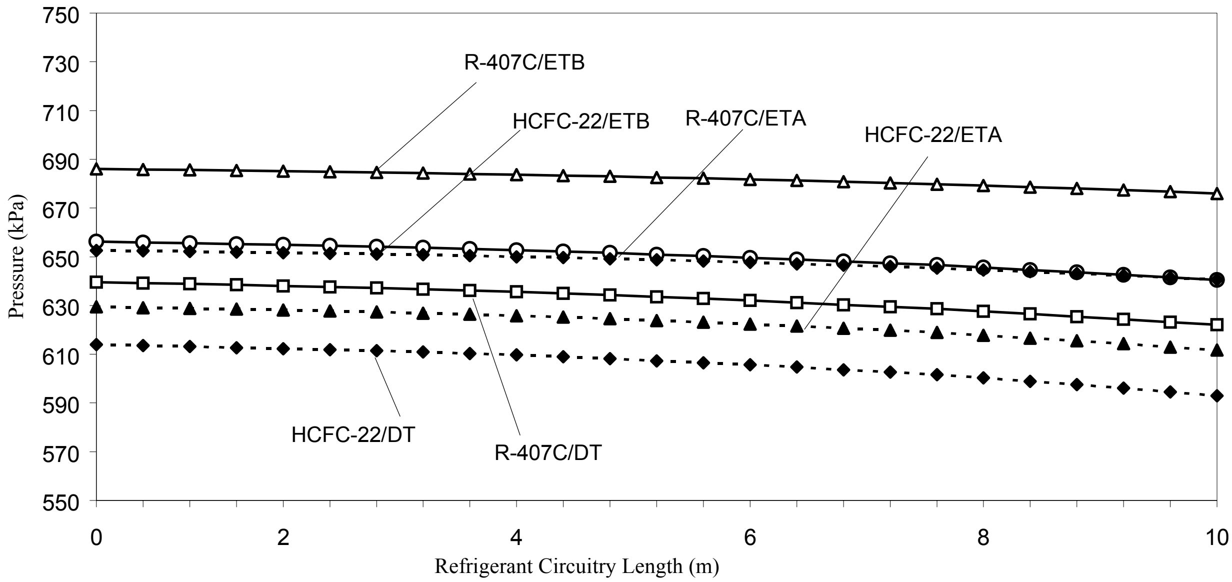

Figure 4. Pressure Variation of HCFC-22 and R-407C in the Evaporator

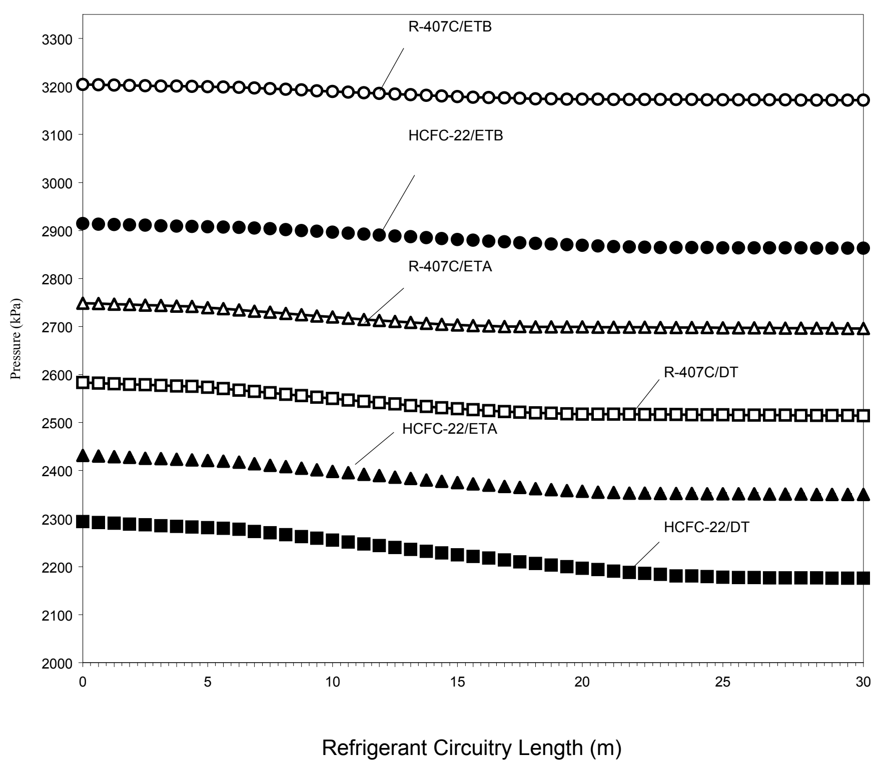

Figure 5. Pressure Variation of HCFC-22 and R-407C in the Condenser

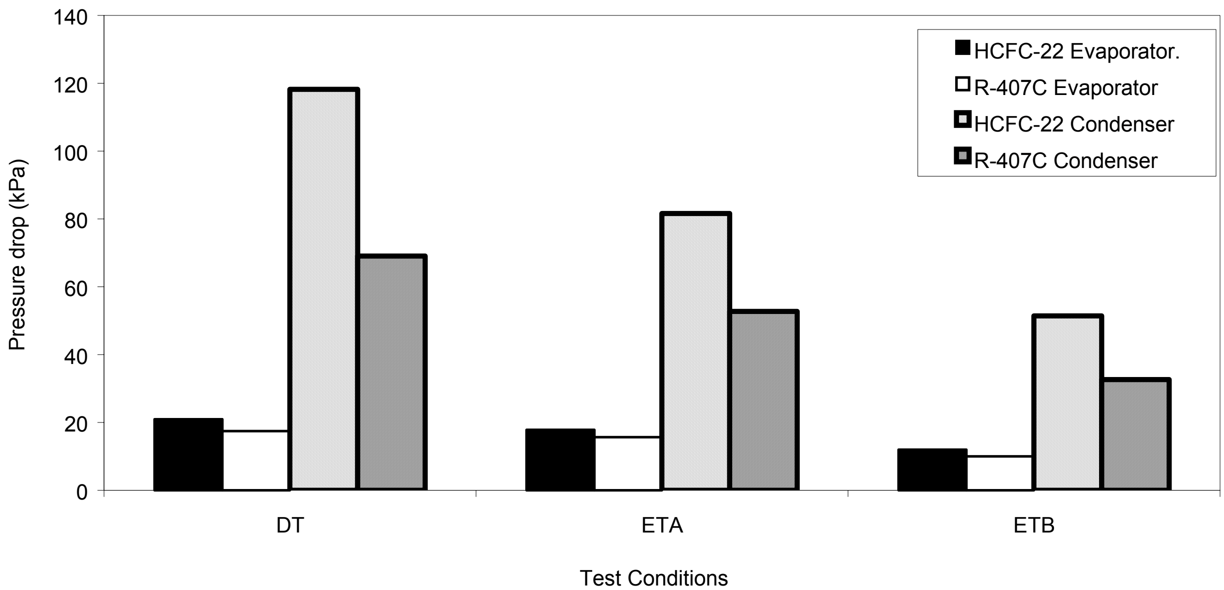

Figure 6. Pressure Drops of HCFC-22 and R-407C in the Evaporator and Condenser

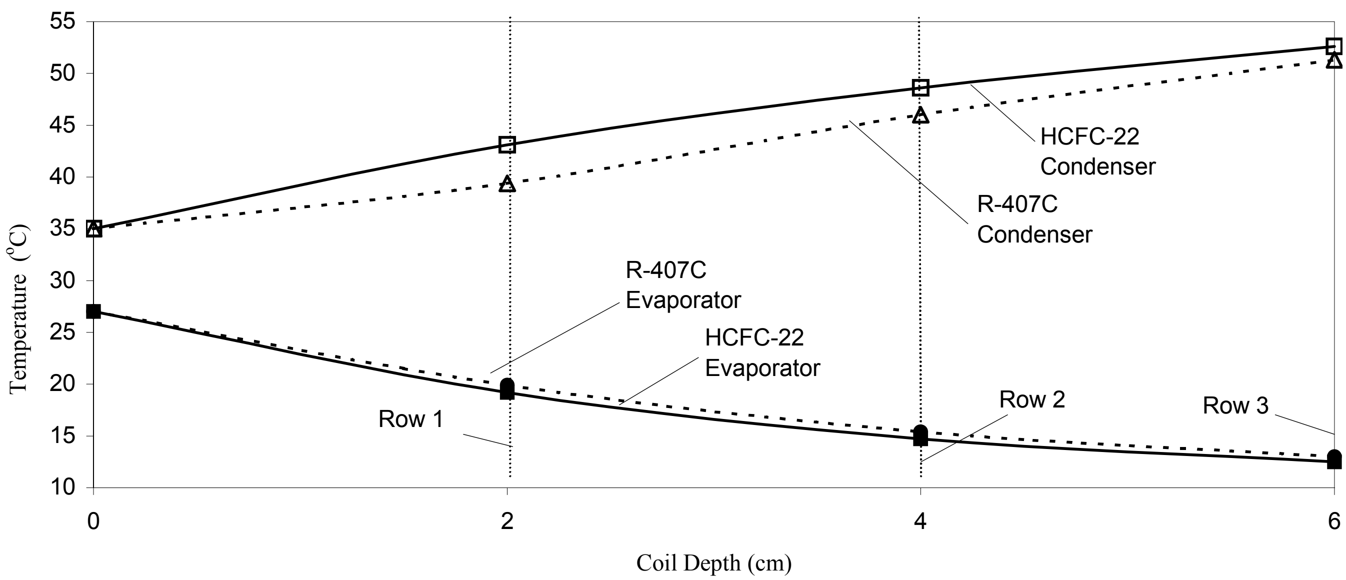

Figure 7. Temperature Profiles of Air in the Evaporator and Condenser (air enters at 27 °C and 47 % RH in the evaporator and 35 °C and 69.5 % RH in the condenser)