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A Comparative Study of the Performance Characteristics of Alternative Refrigerants to R-22 in Room Air-conditioners

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Abstract

This paper presents the simulation results of a 1.5Ton (5.276kW/18000 BTU/Hr) Capacity room air conditioner with some selected refrigerants that have been assessed for their suitability as alternative refrigerants to R-22 for air-conditioning applications. Only those refrigerants with zero ozone depletion potential are considered in the study. The Performance of the selected refrigerants viz., R-22, R-134a, R407C, R410A, R404A, R507A, R290, and R600a is considered in the analysis. The thermodynamic analysis of eight selected refrigerants is carried out using the simulation software COOL PACK version 1.49 and a comparative study is made.

Key words: Room Air-conditioner, R-22, performance, COP, Alternate refrigerant

1. Introduction

Air conditioning systems are available in the range from 2kW to 33 MW (0.5ton to 9500 tons). Most of the air conditioners are operating on standard vapor compression refrigeration cycle. CFC (chlorofluorocarbon) and HCFC (hydro chlorofluorocarbon) refrigerants which have been used as refrigerants in vapor compression refrigeration systems were known to be the principal cause to ozone layer depletion and global warming. HCFC-22 is one of the important refrigerants used in air-conditioning all over the world.HCFC-22 is a controlled substance under the Montreal protocol[1] The Kyoto Protocol was initially adopted on December 1997 and entered in to force on February 2005. This protocol intends a reduction of four green house gases (Carbon dioxide, methane, nitrous oxide, Sulphur hexafluoride) and two groups of gases (hydroflurocarbons and per fluorocarbons). It has to be phased out by 2030 in developed countries and 2040 in developing countries. The growing awareness of the need to sustain the ecology of the planet has resulted in the phase out of the harmful refrigerants containing chlorine atoms, such as chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs). Although a replacement for CFCs has been found, the search for good alternatives for HCFCs especially R-22 is still on.

2. Literature Survey

Major investigations in the area of alternate refrigerants are reviewed below from the point of view of their ability to match the performance of the widely used R22 refrigerant.

Zaghdoudi et al. [2] have Simulated the performance of ten alternate refrigerants such as [R134a, R290, R600, R404A, R407A, R407C, R407D, R410A, R410B and R417A] to replace R22 in Air conditioner of 9000BTU/hr (0.75TR) capacity by using NIST Cycle_D. The simulation results are tabulated in Table 2 of the present paper. Devotta et.al [3] assessed the suitability of various alternative refrigerants to R-22 for air conditioning applications. They have selected only zero ozone depleting potential refrigerants. NIST Cycle_D has been used for the comparative thermodynamic analysis. The objective of the analysis is to identify fluids that are likely to be close to HCFC-22 operating conditions. Among the refrigerants studied are HFC-134a, HC290, R407C, R410A, and three blends of HFC-32, HFC134a and HFC-125.They have concluded that Pressure ratios for R410A are slightly lower than that of R-22 but operating pressures are fairly large compared to R-22 at evaporator temperature of 7.2ºC and condenser temperature of 55ºC.Masanobu et.al [4] have conducted performance tests with HFC32/HFC-134a (30/70 by wt%). HFC-32/HFC-134a (25/75 by wt %) and HFC-32/HFC-125 (50/50 by wt %) i.e. R-410A. Due to large mass flow rate of R410A the cooling capacity was greater than other mixtures by more than 50%and due to higher compressor power required for R410A the energy efficiency ratio was lesser than other refrigerants mixture by 1-5%.Devotta.et al [5, 6] have tested the window air conditioner of 1.5 TR capacity for the experimental performance analysis with HCFC-22 and R-407C in the psychrometry lab. They have retrofitted the window air conditioner by replacing HCFC-22 with R-407C and mineral oil with polyoesteroil and concluded that cooling capacity of R-407C is lower in the range 2.1-7.9%, Power consumption is higher in the range 6-7%, COP of R-407C is lower in the range of 8.2-13.6%, discharge pressures of R-407C are higher in the range of 11-13% and it is also observed that the pressure drops of R-407C are always lower. These authors also tested the window air conditioner of 1.5 TR capacity for the experimental performance analysis with HCFC-22 and R-290 in the psychrometry lab, They have tested the window air conditioner by replacing HCFC-22 with R-290 and mineral oil with poly ester oil (POE) and concluded that cooling capacity of R-R-290 is lower in the range 6.6-9.7%, Power consumption of air conditioner with R-290 is lower in the range 12.4-13.5%, COP of R-290 is higher in the range of 2.8-7.9%, discharge pressures of R-290 are lower in the range of 13.7-18.2%. Domanski and Didion [7] evaluated the performance of nine R-22 alternatives.

The study is conducted using a semi theoretical (cycle_11) model. They havetested R22 (100%), R32/125 (60%/40%), R32/125//134a/290 (20%/55%/20%/5%), R32/125/134a (10%/70%/20%), R290 (100%), R32/125//134a (30%/10%/60%), R32/227ca (35%/65%), R32/134a (30%/70%), R-32/R134a (25%/75%), R-134a (100%). COP of none of the selected refrigerant exceeded the COP of R-22. It is suggested that utilization of the liquid line- suction line heat exchanger may be warranted for some of the alternative refrigerants. Godwin [8] presented the results from some of the compressor calorimeter and system drop in tests conducted as part of alternative refrigerants evaluation program (AREP). The blend R-22/R-125/R-134a (30%/60%/10%) showed a performance quite similar to that of R-22. It is also found that R-32/R-134a (60%/40%) had poor efficiency. Drop in test using R-32/R-125/R-134a (30%/10%/60%) for a unit showed that cooling capacity decreased by 5-10%.Chen et al [9] investigated the feasibility of using hydrocarbon refrigerant mixtures in residential air conditioners and heat pumps. The mixture of HC-290 and HC-600 gave the highest COP. It is considered to represent the best balance between COP and volumetric capacity for hydrocarbons. Also concluded that this mixture has low volumetric capacity and hence it requires larger compressor. In the present work the performance of seven alternative refrigerants proposed as an alternative to the traditionally used R22 and is simulated using the analysis software COOL PACK. A comprehensive study of the performance of these refrigerants is made based on the results of the analysis. The properties of selected refrigerants is shown in Table.1

3. Properties of different refrigerants used for the analysis [10]

Table 1

S.No	Property	R22	R134a	R404A	R407C	R410A	R507A	R290	R600a
1	Chemical formula/ blend composition	$CHClF_2$	CH_2 FCF_3	44%R125 + 52%R125a + 4%R134a	23%R32 + 25%R125 + 52%R134a	50%R32 + 50%R125	50%R125 + 50%R143a	CH_3 CH_2CH_3 propane	CH_3CH_2 CH_2CH_3 butane
2	Molar mass (kg/kmol)	86.468	102.03	97.604	86.204	72.585	98.859	44.1	58.12
3	Critical point temperature T_c (ºC)	96.145	101.06	72.046	86.034	71.358	70.617	96.7	152
4	Critical pressure (P_c) (bar)	49.9	40.593	37.289	46.298	49.026	37.050	42.5	38
5	Critical density (kg/m^3)	523.84	511.90	486.583	484.23	459.53	490.77	-	-
6	Boiling point (ºC)	-40.810	-26.074	-46.2	-43.8/-36.7	-51.4	-47.1	-42.1	-0.5
7	ODP	0.05	0	0	0	0	0	0	0
8	GWP	1810	1300	3920	1770	2000	3985	~20	~20

3.1 Details of system and software

The cycle consists of a compressor, discharge line, condenser, expansion device, evaporator, compressor suction line, and an optional suction line heat exchanger. The simulation cycle is outlined by different states as shown in the Fig 1. These state points are the following: the suction gas (1) is compressed and discharged into the discharge line (2). The discharge line leads the refrigerant to the inlet of the condenser (3). The condensed and sub cooled refrigerant in the condenser outlet (4) is either lead to the liquid inlet of the suction gas heat exchanger (SGHX) if this has been selected, or directly to the inlet of the expansion valve. If a SGHX is included the exit condition (5) will be different from condition (4). From the expansion valve outlet (6) the refrigerant is lead to the evaporator. The evaporated and superheated refrigerant in the evaporator outlet (7) is lead through the suction line, either to the gas side inlet of the SGHX, if this has been selected, or to the compressor inlet (1). If a SGHX is included the exit condition (8) will be different from condition (1). The P-h diagram of this cycle is shown in fig 2.

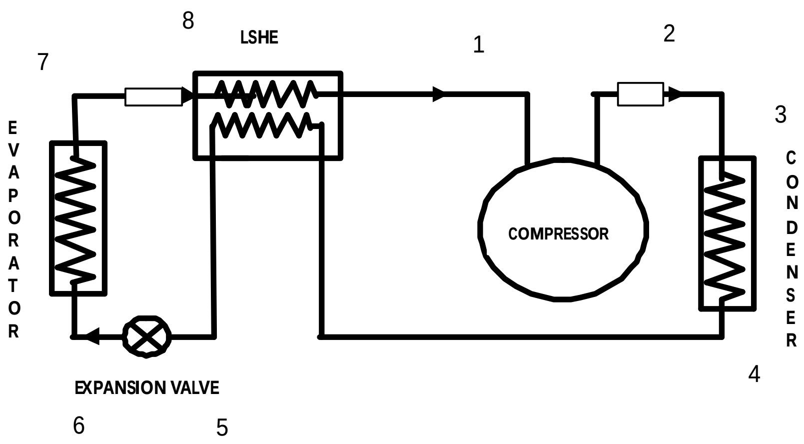

Fig.1. Vapor compression refrigeration cycle with different states.

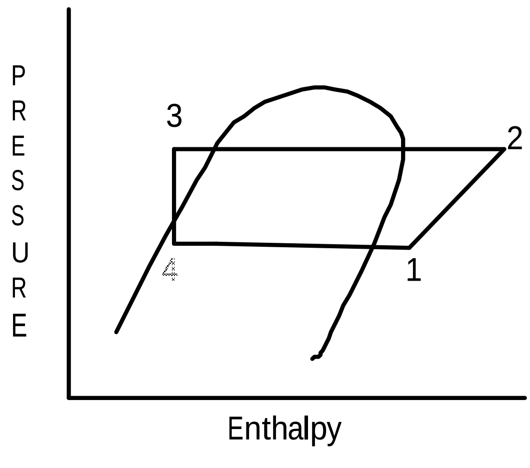

Fig 2. P-h chart

3.2 COOL PACK SOFT WARE [11]

covers calculation of refrigeration properties (property plots, thermodynamic and thermo physical data, refrigerant comparisons), cycle analysis- comparison of single stage and multi stage, system dimensioning- calculation of component sizes from general configuration criteria, System simulation-calculation of operating conditions in a system with known components with their operating parameters, evaluation of operation and evaluation of the system coefficient of performance with less power consumption. Fig 3 (a) & (b) shows typical screen shots during the usage of COOL PACK in the analysis.

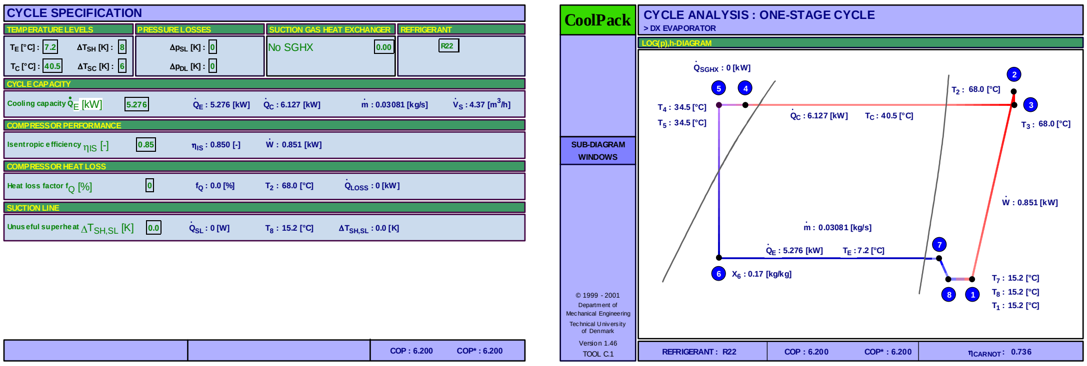

Figure 3 (a) & (b). Description of model and refrigeration cycle

3.3 Thermodynamic Analysis of the refrigeration cycle for various refrigerants.

This topic presents the simulation results of a 1.5Ton (5.276kW/18000 BTU/Hr) Capacity room air conditioner with selected refrigerants that have been assessed for their suitability as alternative refrigerants to R-22 for air-conditioning applications. The Performance of the refrigerants R-22, R-134a, R407C, R410A, R404A, R507A, R290, and R600a is considered.

3.4 Cycle Inputs for simulation.

The cycle inputs are evaporating temperature of 7.2ºC and condensing temperature which is varying between 30ºC and 70ºC.condenser sub cooled temperature is 8ºC and super heat is fixed to 6ºC.Pressure losses in the condenser and evaporator is neglected. Cooling capacity in the evaporator is selected as 5.276kW (1.5Ton), isentropic efficiency of compressor is taken as 0.85, compressor heat loss factor is considered as zero also suction line super heat is considered as zero.

4. Results

The results of analysis of performance of the various competing alternate refrigerants are presented as plots of different parameters Vs condensing temperature. Also presented are bar charts of percentage variation in these parameters with respect to R22 against various condensing temperatures.

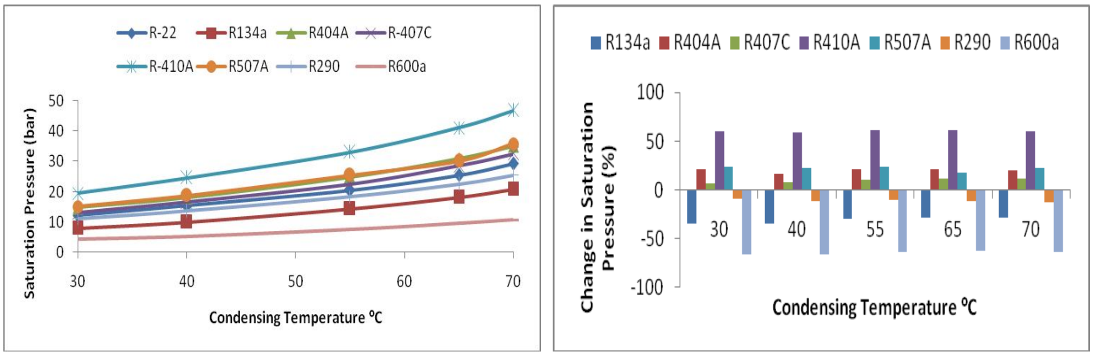

Fig.4 (a) and (b) Variation of Saturation pressure with condensing temperature and change in Saturation pressure in comparison with R22.

Fig.4 (a) and 4 (b) show the variation of saturation pressure with condensing temperature. For all the refrigerants the saturation pressure values are increase with an increase in condensing temperature. The change in saturation pressures for various refrigerants are as follows R134a (-34.67% to -28.794%), R404A (20.65% to 20.27%), R407C (6.96% to 11.30%), R410A (59.67% to 60.44%), R507A (23.36% to 22.87%), R290 (-8.93% to -12.80%) and R600a (-65.73% to -63.42%).For the refrigerants, R134a, R290 and R600a the change in the saturation pressure values decrease whereas the change in saturation pressure values for R404A, R407C, R410A, R507A increase as condensing temperature increases.

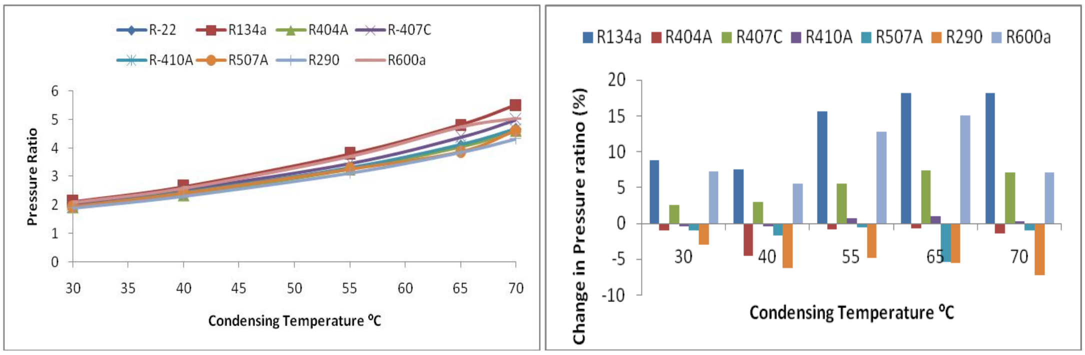

Fig.5 (a) and (b) Variation of Pressure Ratio with condensing temperature and change in Pressure Ratio in comparison with R22

The variation of pressure ratio with condensing temperature is shown in Fig. 5 (a) and 5 (b). It is observed that the change in pressure ratios for different refrigerants are R134a (8.71% to 18.20%), R404A (-1% to -1.49%), R407C (2.56% to 7.06%), R410A (-0.51% to 0.21%), R507A (-1.02% to -1.07%), R290 (-3.07% to -7.28%), R600a (7.17% to 7%). For the refrigerants R134a, R407C and R600a, there is an increase in pressure ratios with condensing temperatures where as for the refrigerants

R404A, R410A, R507A, R290 there is a decrease in pressure ratios with increase in condensing temperatures.

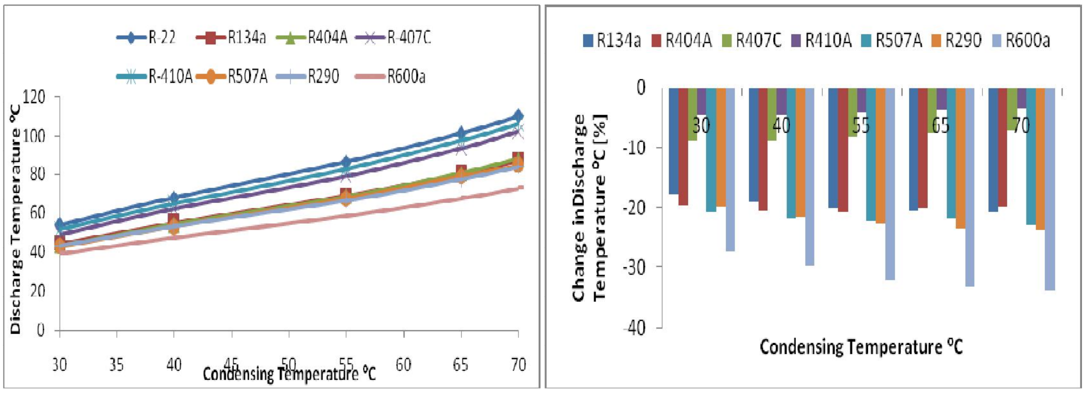

Fig.6 (a) and (b) Variation of Discharge temperature with condensing temperature and change in Discharge temperature in comparison with R22.

Fig.6 (a) and (b) Shows the variation of discharge temperature with condensing temperature and change in Discharge temperature in comparison with R22.It is observed that the change in discharge temperature as follows R134a (-17.62% to -20.67%), R404A (-19.67% to -19.85%), R407C (-8.72% to -7.01), R410A (-4.45% to -3.46%), R507A (-20.59% to -22.95%), R600a (-27.27% to -33.6%). It indicates there is a decrease in discharge temperature with trend with increase in condensing temperatures, it very good indication for the compressor motor life point of view which safe guards the compressor motor.

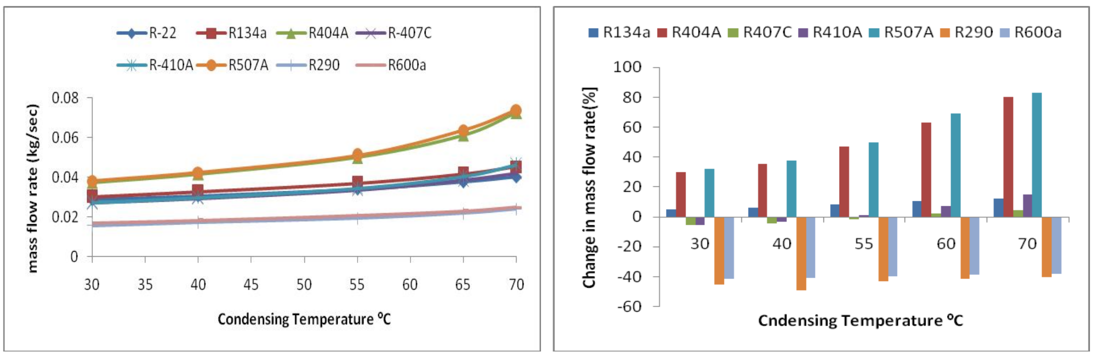

Fig.7 (a) and (b) Variation of mass flow rate with condensing temperature and change in mass flow rate in comparison with R22.

The variation of mass flow rates with condensing temperature is shown in fig 8 (a), in all the cases mass flow rate of a refrigerant increases with increase in condensing temperature. Fig 7 (b) shows the change in mass flow rate of refrigerant with condensing temperature. The mass flow rate of refrigerant calculated for R134a, R404A and 507A are higher in comparison with R22 where as for R407C, R290 and R600a are lower in comparison with R22.The variation in each refrigerant with condensing temperature is as follows R134a (5% to 12.46%), R404A (30% to 79.93%), R407C (-5.55% to 4.46%), R410A (-5.24% to + 15.287%), R507A (32.25% to 83.02%), R290 (-44.9% to -40.41%), R600a (-41.21% to -38.2%).

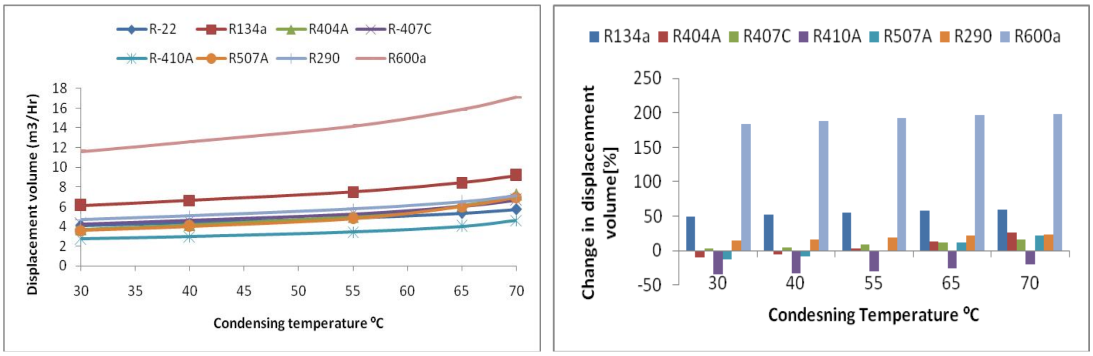

Fig.8 (a) and (b) Variation of displacement volume with condensing temperature and change in displacement volume in comparison with R22.

Fig 8 (a) gives the variation of displacement volume with condensing temperature. It indicates that as the condensing temperature increases the displacement volume rate increasing. The increase in displacement volume for R134a and R600a are very high in comparison with R22 and for R410A it is w in comparison with R22. Fig 8 (b) gives the change in percentage f displacement volume in comparison with R22. The variation in change in percentage of displacement volume in each refrigerant with condensing temperature is as follows R134A (49.63% to 60.20), R404A (-9.04% to + 25.82%), R407C (3.67% to 16.23%), R410A (-33.74% to -19.37%), R507A (-12.22% to + 21.47%), R290 (14.67% to 23.90), R600a (183.86% to 198.60%).

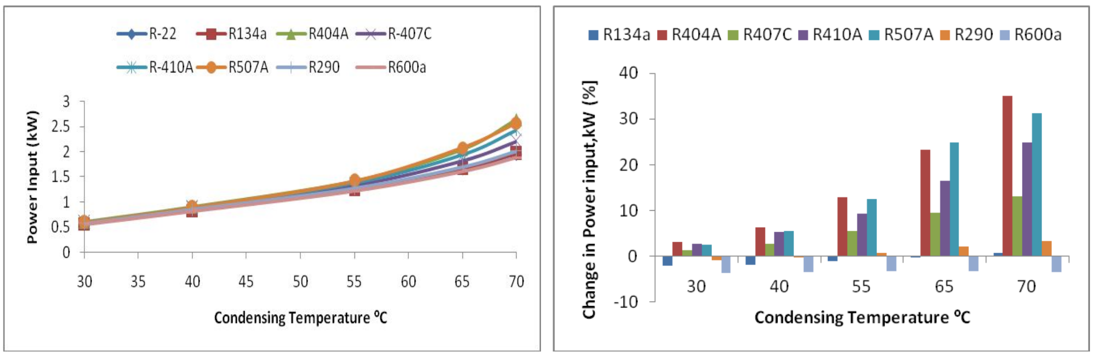

Fig.9 (a) and (b) Variation of Power input with condensing temperature and change in Power input in comparison with R22.

Fig.9 (a) Illustrates the Variation of Power input with condensing temperature. It is observed that for all the refrigerants under consideration the power input is increasing with increase in condensing temperature. The increase in power input is same up to a condensing temperature 55ºC and after that there is variation in the increase from refrigerant to refrigerant. Fig.9 (b) Gives the Change in percentage of Power input for each refrigerant as compared to R22. The Change in percentage of Power input for each refrigerant as compared to R22 is as follows R134a (-1.96% to 0.71%), R404A (3.22% to 35%), R407C (1.31% to 13.13%), R410A (2.73% to 24.83%), R507A (2.63% to 31.32%), R290 (-0.76% to 2.021%), R600a (-3.57% to -3.474%).

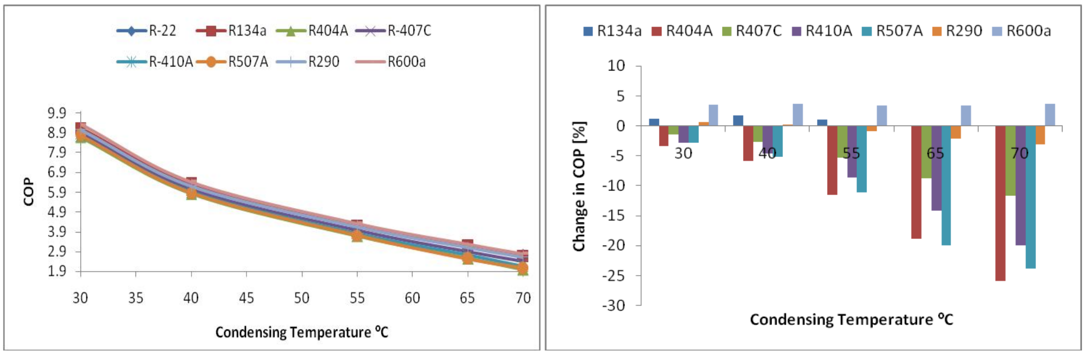

Fig.10 (a) and 9 (b) Variation of COP with condensing temperature and change in COP in comparison with R22.

Fig.10 (a) Shows the variation of COP with condensing temperature. It is found that COP of air conditioning system is decreasing with increase in Condensing temperature for all the refrigerants and Fig.10 (b) gives the percentage Change in COP of all the refrigerants as compared to R22.The change in percentage of COP for all the refrigerants in comparison with R22 is as follows R134a (1.2% to 0%), R404A (-3.33% to -25.9%), R407C (-1.5% to -11.6%), R410A (-2.85% to -19.91%), R507A (-2.76% to -23.85%), R290 (+ 0.56% to -3.15%), R600a (3.48% to 3.60%).

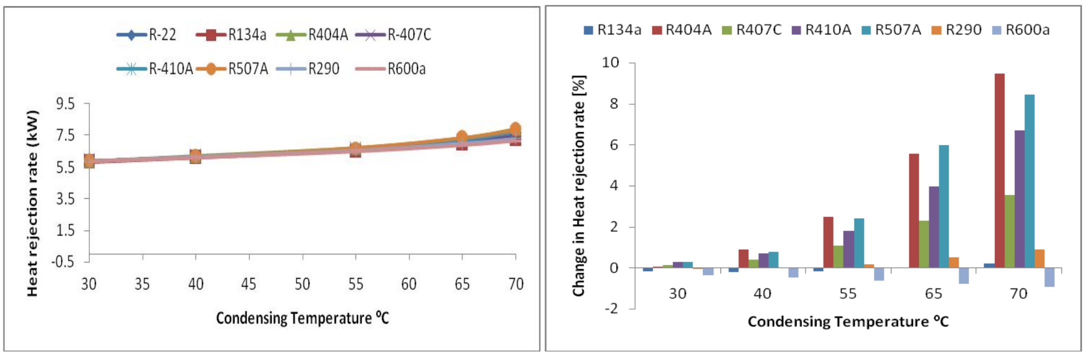

Fig.11 (a) and (b) Variation of Heat rejection rate with condensing temperature and change in Heat rejection in comparison with R22.

Fig.11 (a) Shows the variation of Heat rejection rate with condensing temperature. It is observed that as condensing temperature increases the heat rejection rate increases and as it is observed that up to a condensing temperature of 54ºC the increase in heat rejection rate is similar for all the refrigerants whereas after 54ºC the increase in heat rejection rate is slightly differs from refrigerant to refrigerant also fig.11 (b) shows the variation in change in heat rejection rate as compared to R22.The variation in change in heat rejection rate for each refrigerant is as follows R134a (-0.187% to + 0.19%), R404A (0.055% to 9.47%), R407C (0.136% to 3.553%), R410A (0.273% to 3.96%), R507A (0.273% to 8.44%), R290 (-0.0682% to 0.884%) and R600a (-0.358% to -0.94%).

5. Conclusions

Since direct comparison of present results with those of other authors is not possible in view of simulation of different air conditioning systems by different authors, a qualitative comparison is made below. The results of Zaghdoudi et al [2] are compared with those from the present investigations in the table 2 below.

Table 2. Comparison of Results

S. No	Parameter	Highest	Lowest	Same as R22
1	Pressure ratio	R410A[2] R134a	R290[2] R290	R410B [2] R404A, R507A
2	Discharge temperature	R410A[2] R410A	R600[2] R600a, R290	R407C[2] -----------
3	Mass flow rate	R404A[2] R507A, R404A	R600[2] R600a, R290	*R407B[2] R407C and R410A
5	Compressor Power	R410A and R404A[2] R404A, R410A and R507A	R134a and R290[2] R134a and R290	R134a and R290[2] R134a and R290
6	COP	R600[2] R600a	R404A, R407C and R410A[2] R404A, R407C, R410A and R507A	R134a and R290[2] R134a and R290

Note: Results not in [ ] brackets are from present work.
* Refrigerant not considered in the present work.

It is evident from the present investigations that COOL PACK software, which is simple and direct to use software, can be used to assess the performance of air conditioning system based on any refrigerant and hence base its design on those results, among HFC group refrigerants R410A can be considered as the prominent refrigerant to replace R22 in air conditioning systems as its discharge temperatures are lower and also displacement volume is much lower as compared to R22.

References

[1] United Nation Environmental Program, Montreal protocol on substances that deplete the ozone layer. Final act New York (1987)

[2] Zaghdoudi M.C., S.Maalej, Y.Saad and M.Bouchaala, A Comparative study on the Performance and Environmental Characteristics of Alternatives toR22 in Residential Air Conditioners for Tunisian Market, Journal of Environmental science and Engineering, Volume 4, No.12 (2010)

[3] Devotta S., Waghmare A. V., Sawant N.N and Domkundwar B.M. Alternatives to HCFC-22 for air conditioners Applied thermal Engineering, volume 21 (2001) pp703-715.

[4] Masanobu S., Akihiro O., Yoshiyuki N., Haruki S., Koichi W., Noboru K and Toshiya Y Performance of refrigeration cycle with R32/143a and R32/125 based on the reliable thermodynamic property data International Refrigeration conference at purdue, Purdue University USA (1994) pp 67-72.

[5] Devotta S., Padalkar A.S and Sane N.K. Performance assessment of HCFC-22 window air conditioner with R-407C.Applied Thermal Engineering Volume25, (2005) pp2937-2949.

[6] Devotta S., Padalkar A.S., Sane N.K. Performance assessment of HC-290 as a drop-in substitute to HCFC-22 in a window air conditioner. International Journal of Refrigeration Volume 28 (2005) pp 594-604.

[7] Domanski P.A and, Didion D.A., Thermodynamic evaluation of R-22 alternative Refrigerants and Refrigerant mixtures, Ashrae Transactions 99 (1993) pp636-648 part 2.

[8] Godwin D.S. Alternative refrigerants evaluation program (AREP) compressor calorimeter and system drop- in tests with R-22 alternatives, Report- Air conditioning and Refrigeration Institute, (1994) Arlington, Virginia 22203, USA.

[9] Chen S., Judge J.F., Groll R and Radermacher R., Theoretical analysis of hydrocarbon refrigerant mixtures as a replacement for HCFC-22 for residential uses. Proceedings of 1994 International Refrigeration conference at purdue, Purdue University, West Lafaytte, Indiana, USA (1994), pp225-230.

[10] NIST REFPROP-Thermodynamic and transport Properties of refrigerants and refrigerant mixtures, standard Reference database reference 23- version 6.01.National Institute of Technology, Gaithersburg, MD.

[11] Cool Pack Version 1.49 Refrigeration and Air Conditioning Simulation tool.