Performance computation of window air conditioner with very low GWP near azeotropic refrigerant mixtures as a drop in Substitutes to R22

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Abstract. The principal objective of the present study is to compute the thermodynamic performance of window air conditioner based on standard vapour compression refrigeration cycle using R22, R407C and nineteen refrigerant mixtures. In this work nineteen R290/R1270 blends at different compositions are developed. A MATLAB code is developed to compute the thermodynamic performance parameters of all the studied refrigerants at condensing and evaporating temperatures of 54.4^{0}C and 7.2^{0}C respectively. The performance parameters are cooling effect, compressor work, COP, compressor discharge temperature, power per ton of refrigeration and volumetric cooling capacity respectively. Analytical results revealed that COP of new binary mixture R290/R1270 (90/10 by mass %) is 2.82% higher among R22, R407C and nineteen studied refrigerants. Energy required by the compressor per ton of refrigeration for R290/R1270 (90/10 by mass %) is 2.73% lower among R22, R407C and nineteen studied fluids. The discharge temperature of the compressor for all the nineteen investigated blends are reduced by 6.0-8.9oC compared to R22. Overall thermodynamic performance of window air conditioner with R290/R1270 (90/10 by mass %) is better than R22 with significant savings in energy consumption and hence it is an energy efficient ecofriendly refrigerant mixture as a drop in substitute to R22.

Keywords: COP; Discharge temperature; GWP; Ecofriendly: Energy savings; R290/R1270 blends

1 Introduction

Hydrochlorofluorocarbon (HCFC) refrigerant R22 was extensively used in air conditioning as well as heat pump industries from past several years. Since R22 has better thermophysical and thermodynamic properties. But R22 contains ozone layer desctruction substance called chlorine. Therefore R22 was eventually phase out in all the developed nations by the year 2030 as per Monetreal protocal [1-3]. Till now no pure refrigerant is avialble to replace R22. Therefore it is essential to develop new ecofriendly refrigerant blends. Earlier several theoretical and expermintal investigations were carried to find an appropriate fluid to replace R22. From the past several years refrigerants R407C and R410A were the foremost substitues to R22 [4]. Theorotical results reported that R444B was a viable refrigerant to replace R22 [5]. Experimental results reported that R407C was a suitable retrofit candidate to R22 [6]. Experimental test was conducted in an air conditioner with R290 as a drop in refrigerant. Test results exhibited that performance of R290 was 2.8-

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7.9% higher than R22 [7]. Experimental tests revealed that the ternary refrigerant mixture R32/R125/R161 (15/34/51 by weight percentage) was suitable choice to replace R407C. Since COP of above mixture was better than R407C [8]. Experimental studies reported that performance of binary mixture R170/R290 (4/96 by mass %) was similar to that of performance of R22 [9]. A detailed review paper suggested that hydrocarbons and its blends were most suitable candidates to air conditioning and refrigeration sectors [10]. Experimental studies were conducted in a heat pump apparatus with R22 and binary blend R431A (R290/R152a 71/29 by mass %) used for heat pump and air conditioning applications. Test results exhibited that COP of R431A was 3.5 – 3.8 % superior than R22 [11]. Performance tests were done in a heat pump equipment with R22 and binary blend R432A (R1270/RE170 80/20 by mass %) used for heat pump and air conditioning applications. Experimental results showed that performance of R432A was 8.5-8.7% superior than the R22 [12]. Experimental investigations were carried out in a heat pump device with R22 and binary blend R433A (R1270/R290 30/70 by mass %) used for heat pump and air conditioning applications. Test results revealed that performance of R433A was 4.9-7.6% superior than R22 [13]. The present study mainly focuses on finding an alternative refrigerant to replace R22. For this thermodynamic performance computation of nineteen refrigerant blends (R290/R1270) is carried out based on standard vapour compression refrigeration system.

2 Properties of refrigerants

In the present study apart from R22 and R407C, total nineteen refrigerant blends (R290/R1270) of various compositions are developed. All the nineteen binary refrigerant blends R290/R1270 (Refrigerants 2 to 20 as given in table 2) are closer to azeotropic in nature. Since their temperature glide is less than 0.5oC. A MATLAB code is developed to compute the thermodynamic properties of refrigerants like R22, R407C and R290/R1270 blends by using Martin-Hou equation of state [14]. Since thermodynamic properties of considered refrigerants are useful for the computation of thermodynamic performance of an air conditioner.

$$P = \frac{RT}{v-b} + \frac{a_2 + b_2T + c_2e^{\frac{-5.475T}{T_C}}}{(v-b)^2} + \frac{a_3 + b_3T + c_3e^{\frac{-5.475T}{T_C}}}{(v-b)^3} + \frac{a_4}{(v-b)^4} + \frac{b_5T}{(v-b)^5} \quad (1)$$

The computed properties of R22 and R407C shows good agreement with the experimental reported properties available in ASHRAE fundamental data hand book. The deviation of computed properties of R22 and R407C from that of ASHRAE is within 2 to 4% for the given operating conditions. Therefore the developed MATLAB code is reliable and hence it can be used for the development of thermodynamic properties of other new refrigerant blends. The properties of new refrigerants blends (R290/R1270) are not available in literature and hence they are not compared. However properties of refrigerant R290/R1270 blends are compared with REFPROP. The deviation of properties from that of REFPROP is within 1.5 to 4 % for the given working conditions. Hence the same developed thermodynamic properties are used in the thermodynamic analysis. The code followed for the refrigerants is given in table 1 and the basic physical and critical properties of R22, R407C and nineteen refrigerant blends (R290/R1270) taken from REFPROP is given below in table 2 respectively[15].

Table 1. Code of the refrigerants

Refrigerant code	Composition (by mass %)
1 (R22)	Pure fluid
2 (R290/R1270)	5/95
3 (R290/R1270)	10/90
4 (R290/R1270)	15/85
5 (R290/R1270)	20/80
6 (R290/R1270)	25/75
7 (R290/R1270)	30/70
8 (R290/R1270)	35/65
9 (R290/R1270)	40/60
10 (R290/R1270)	45/55
11 (R290/R1270)	50/50
12 (R290/R1270)	55/45
13 (R290/R1270)	60/40
14 (R290/R1270)	65/35
15 (R290/R1270)	70/30
16 (R290/R1270)	75/25
17 (R290/R1270)	80/20
18 (R290/R1270)	85/15
19 (R290/R1270)	90/10
20 (R290/R1270)	95/5
21 (R407C R32/R125/R134a)	23/25/52

Table 2. Basic physical and environmental properties of investigated refrigerants

Refrigerant code	M (kg/kmol)	T_b (°C)	P_c (Mpa)	T_c (K)	ODP	GWP (100 years)	T_g (°C)
1	86.5	-40.81	4.99	369.3	0.055	1760	0
2	42.176	-47.45	4.538	364.3	0	<3	0.03
3	42.273	-47.27	4.521	364.4	0	<3	0.05
4	42.37	-47.07	4.505	364.5	0	<3	0.09
5	42.468	-46.85	4.490	364.7	0	<3	0.13
6	42.566	-46.62	4.475	364.9	0	<3	0.16
7	42.665	-46.37	4.460	365.1	0	<3	0.21
8	42.764	-46.11	4.445	365.3	0	<3	0.25
9	42.864	-45.84	4.431	365.6	0	<3	0.29
10	42.964	-45.56	4.417	365.9	0	<3	0.32
11	43.064	-45.27	4.403	366.2	0	<3	0.35
12	43.165	-44.97	4.388	366.5	0	<3	0.37
13	43.267	-44.67	4.374	366.8	0	<3	0.38
14	43.368	-44.36	4.360	367.2	0	<3	0.39
15	43.471	-44.04	4.345	367.5	0	<3	0.38
16	43.574	-43.73	4.330	367.9	0	<3	0.35
17	43.677	-43.41	4.315	368.3	0	<3	0.31
18	43.781	-43.08	4.299	368.7	0	<3	0.27
19	43.885	-42.76	4.284	369.1	0	<3	0.19
20	43.99	-42.44	4.267	369.4	0	<3	0.10
21	86.204	-43.63	4.631	359.3	0	1774	7.0

3 Thermodynamic performance methodology

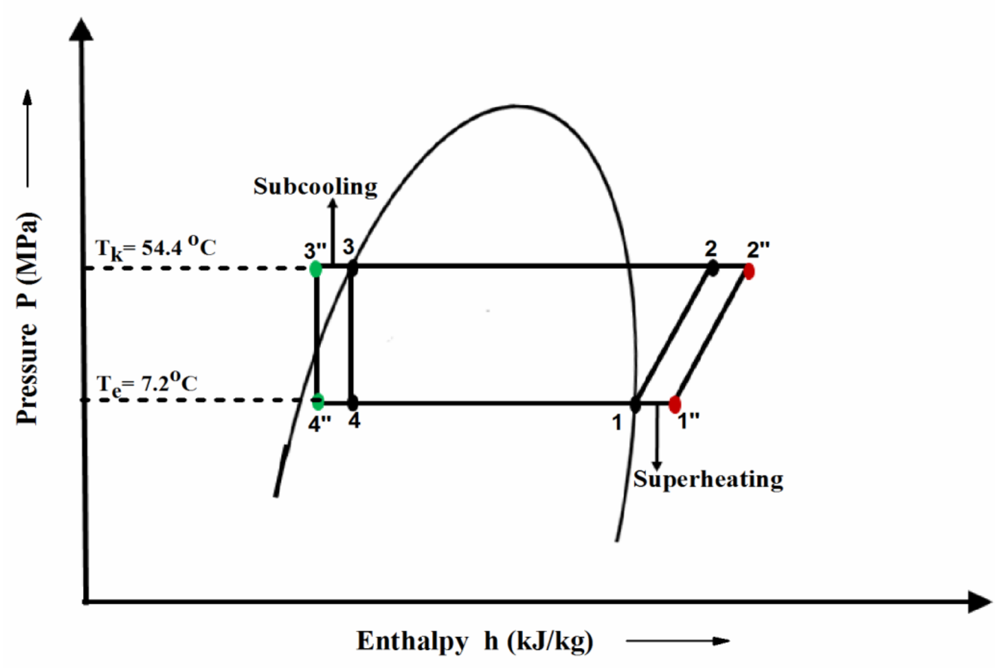

Fig 1. P-h diagram of standard vapour compression refrigeration cycle.

Computational thermodynamic analysis of R22, R407C and nineteen refrigerant blends (R290/R1270) is done based on standard vapour compression refrigeration cycle. The p-h diagram of corresponding cycle is shown in figure 1 [16-17]. In this methodology the various pressure losses and heat losses or heat gains occurred at the various components of the system are ignored. The degree of superheating and subcooling can be taken as 5°C respectively. In this study a MATLAB code is developed to compute the thermodynamic performance parameters of refrigerants at ARI conditions (T_k=54.4°C and T_e=7.2°C) respectively. The various performance parameters are refrigeration effect, compressor work, coefficient of performance, compressor discharge temperature, power per ton of refrigeration and volumetric cooling capacity.

The capacity and operating conditions of air conditioner considered in the present study for R22, R407C and nineteen binary refrigerant blends are Q=1.5 TR, T_k=54.4°C and T_e=7.2°C respectively. The summary of results for the considered refrigerants are given in table 3.

4. Mathematical computations

The mathematical computations involved in the thermodynamic analysis of for the considered refrigerants are given below.

Refrigerant mass flow rate is computed by

$$\dot{m} = Q/RE \qquad (2)$$

Isentropic compressor work is computed as

$$W_c = h_{2''} - h_{1''} \quad (3)$$

Refrigerating effect (Cooling effect) is calculated as

$$RE = h_{1''} - h_{4''} \quad (4)$$

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Coefficient of performance (COP) is calculated as

$$COP = RE/W_c \quad (5)$$

Energy (Power) consumption by the compressor per ton of refrigeration is computed by

$$PPTR = 3.5167/COP \quad (6)$$

Volumetric cooling capacity is calculated as

$$VCC = \rho_{1''} \times RE \quad (7)$$

The compressor discharge temperature (T_d) is computed using superheated property tables and interpolating for the degree of superheat corresponding to the entropy difference.

Table 3. Summary of results for the various considered refrigerant blends

Refrigerant code	$\dot{m}$ (kg/min)	RE (kJ/kg)	W_c (kJ/kg)	COP	T_d (°C)	PPTR (kW/TR)	VCC (kJ/m³)
1	2.261	139.944	34.958	4.003	78.09	0.878	3646
2	1.309	241.723	64.187	3.765	69.34	0.933	3560
3	1.297	243.930	64.454	3.784	69.26	0.929	3553
4	1.286	246.007	67.343	3.653	71.87	0.962	3543
5	1.276	247.954	64.951	3.817	69.17	0.921	3524
6	1.266	249.833	65.139	3.835	69.15	0.916	3508
7	1.257	251.599	67.751	3.713	71.59	0.946	3494
8	1.249	253.257	67.845	3.732	71.54	0.942	3479
9	1.241	254.858	67.913	3.752	71.51	0.937	3464
10	1.234	256.374	67.941	3.773	71.49	0.931	3451
11	1.227	257.792	67.952	3.793	71.5	0.926	3437
12	1.221	259.152	67.891	3.817	71.5	0.921	3426
13	1.215	260.418	65.583	3.970	69.3	0.885	3414
14	1.209	261.590	67.731	3.862	71.55	0.910	3405
15	1.204	262.718	65.422	4.015	69.41	0.875	3394
16	1.199	263.755	65.265	4.041	69.47	0.870	3385
17	1.195	264.704	67.297	3.933	71.74	0.894	3376
18	1.191	265.612	67.086	3.959	71.82	0.888	3367
19	1.187	266.433	64.718	4.116	69.74	0.854	3356
20	1.184	267.162	66.712	4.004	72.07	0.878	3338
21	2.296	137.816	42.645	3.231	78.07	1.088	3172

5 Results and discussions

The results and discussions of various performance parameters of R22, R407C and nineteen refrigerant blends (R290/R1270) are given below.

5.1 Refrigeration effect

Figure 2 shows the cooling effect (refrigeration effect) of various refrigerants blends. Referring to figure 2 it is noticed that refrigeration effect of nineteen refrigerant blends R290/R1270 (2 to 20) are higher than the R22 and R407C. This is due to high latent heat of vaporization of refrigerants when compared to R22 and R407C.

5.2 Compressor work

Figure 3 shows the work input required by the compressor for the various refrigerant blends. From the figure 3 it is observed that the compressor work of all the nineteen investigated refrigerant mixtures (2 to 20) are higher than the R22 and R407C. This is due to high vapour enthalpy of the refrigerant blends compared to R22 and R407C.

5.3 Coefficient of performance

Figure 4 shows the coefficient of performance of various studied refrigerants. COP is measured as an index of energy efficiency of the device charged with specific refrigerant. COP is the ratio of refrigeration effect to the compressor work. From the table 3 it is noticed that both cooling (refrigeration effect) effect and compressor work increase for all the nineteen investigated refrigerant blends. Therefore combined effect of cooling effect and compressor work of these refrigerants on coefficient of performance may be either increases or decreases or remains same which depends on the type and composition of the refrigerant blend and also on the working conditions of the device. From the figure 4 and table 3 it is clear that the COP of new binary refrigerant blend R290/R1270 (90/10 by mass %) is 2.82 % higher among R22, R407C and nineteen studied refrigerants.

5.4 Compressor discharge temperature

While introducing the new refrigerant blend into the equipment the consistency and lifespan of compressor motor should be studied. This can be achieved by computing the compressor discharge temperature of new refrigerants. Referring to figure 5 it is noticed that compressor discharge temperature of all the nineteen investigated refrigerants (2 to 20) are reduced by 6.0-8.9oC when compared to R22 and R407C. This is due to lower adiabatic index of refrigerant blends. Hence all the nineteen studied fluids exhibits better reliability and lifespan of compressor motor.

5.5 Power per ton of refrigeration

Figure 6 shows the power (energy) spent by the compressor per ton of refrigeration for various studied refrigerants. It denotes the electrical energy required to the compressor to produce per ton of refrigeration. Referring to figure 6 it is observed that electrical energy spent by the compressor per ton of refrigeration for the refrigerant blend R290/R1270 (90/10 by mass %) is 2.73 % lower among R22, R407C and nineteen investigated refrigerants. This is due to type and composition of refrigerants and also due to operating conditions of the given device.

5.6 Volumetric cooling capacity

Figure 7 shows the volumetric cooling capacity of various refrigerant blends. Volumetric capacity depends on density of vapour refrigerant and cooling effect of the given fluid. It indicates the cooling capacity per unit volume of refrigerant vapour at the evaporator outlet. And also it denotes the volume of refrigerant handled by the compressor for the given fluid. From the figure 7 it is evident that volumetric cooling capacity of all the nineteen investigated refrigerants are closer to that of volumetric capacity of R22. Hence same size of compressor can be used for all the nineteen fluids as that of R22 with little modifications.

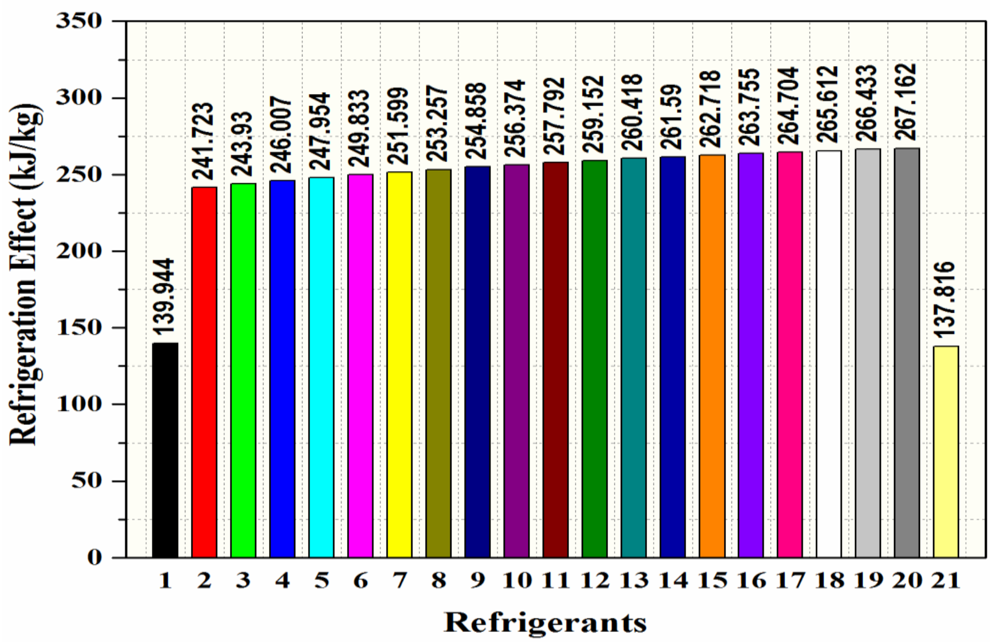

Fig 2. Refrigeration effect of various R22 alternative blends

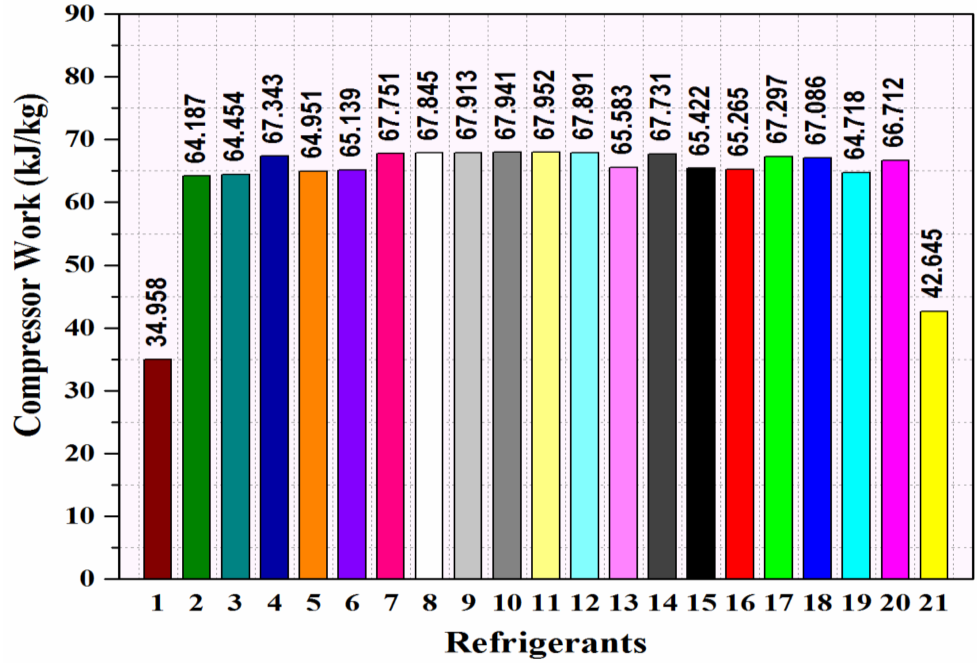

Fig 3. Compressor work of various R22 alternative blends

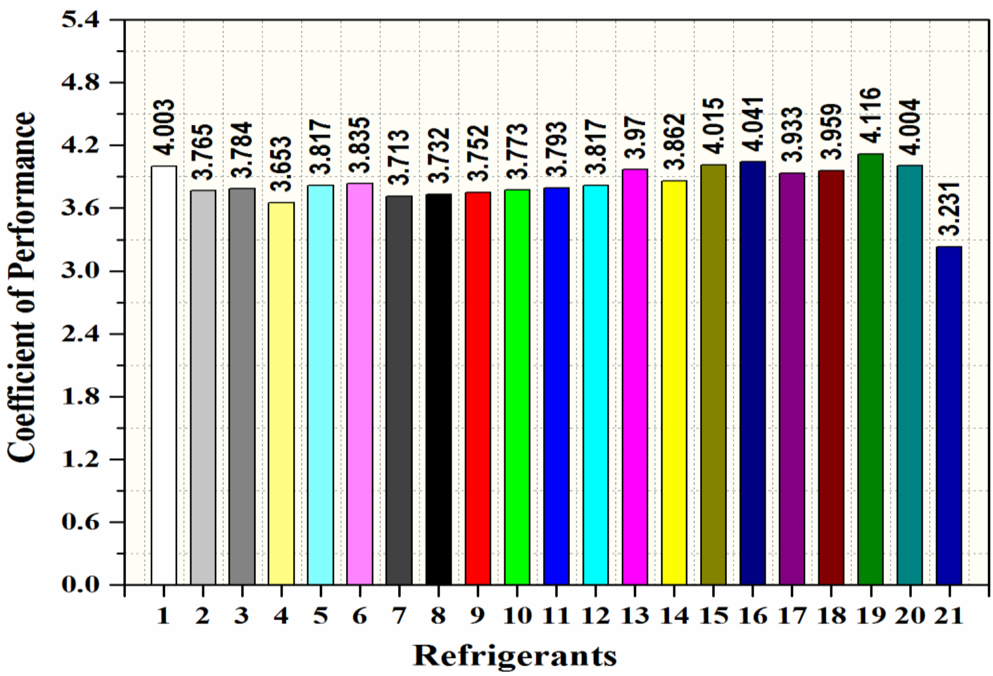

Fig 4. COP of various R22 alternative blends

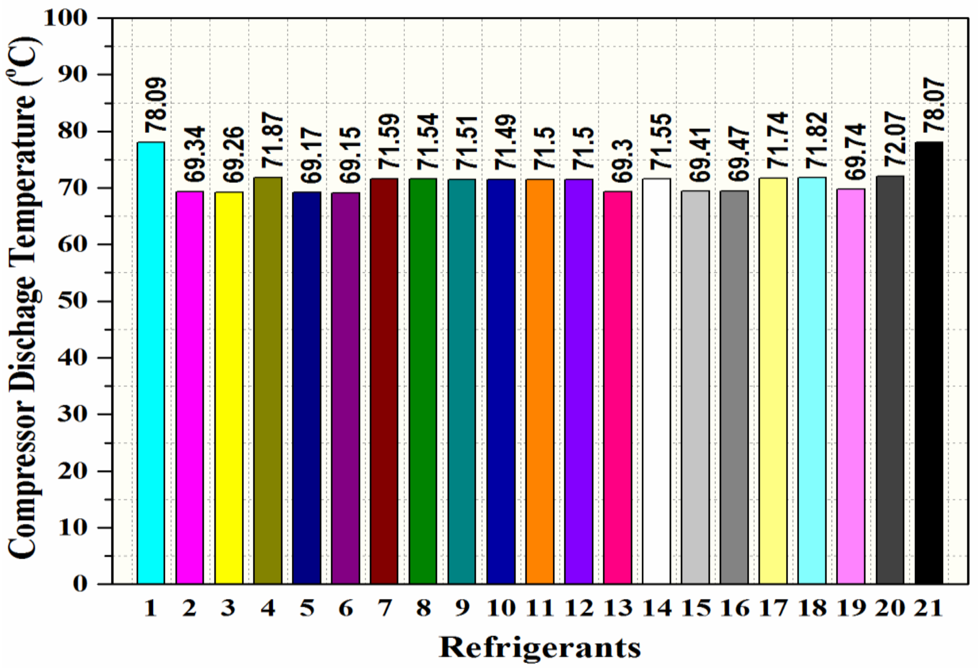

Fig 5. Compressor discharge temperature of various R22 alternative blends

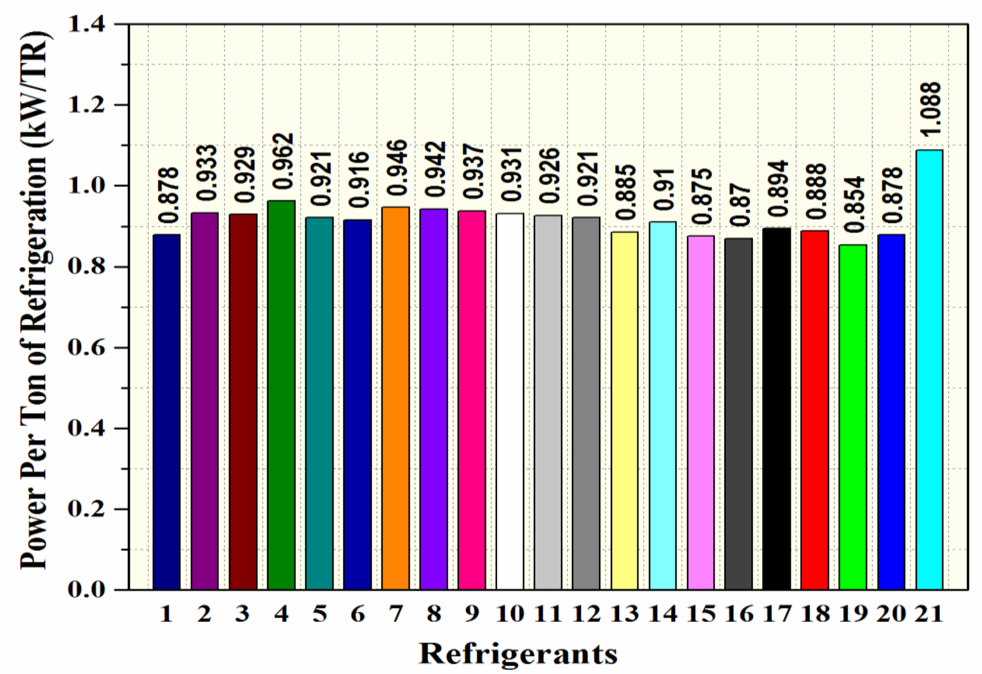

Fig 6. Power per ton of refrigeration of various R22 alternative blends

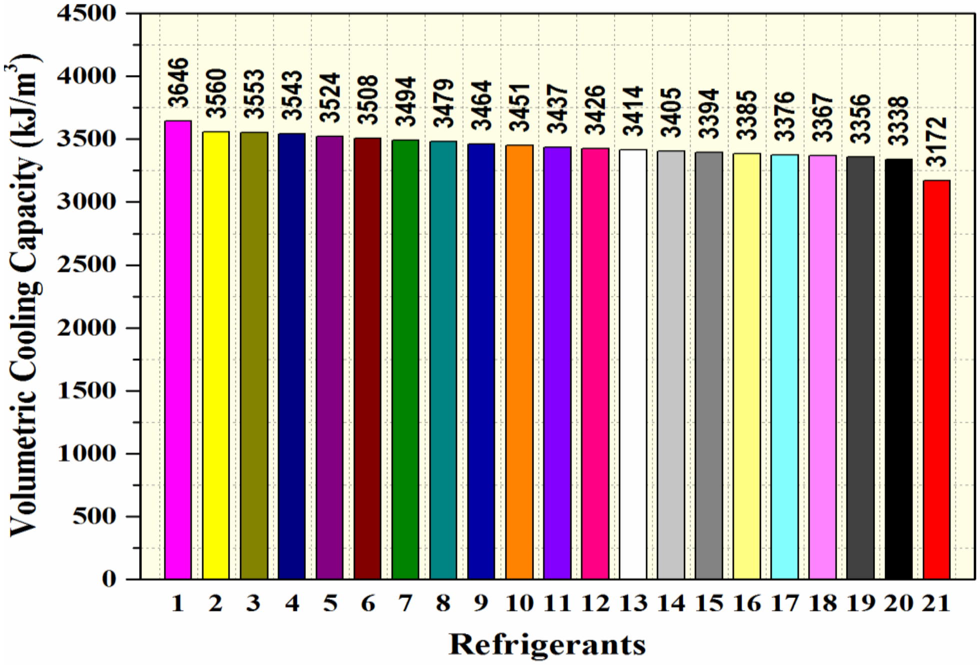

Fig 7. Volumetric cooling capacity of various R22 alternative blends

6 Conclusions

From the performance computation of various refrigerant blends the following conclusions can be drawn.

1. COP of new binary refrigerant blend R290/R1270 (90/10 by mass %) was 2.82 % higher among R22, R407C and nineteen studied refrigerants.
2. Compressor discharge temperature of all the nineteen refrigerant blends were reduced by 6.0-8.9^oC compared to R22 and R407C. Therefore all the nineteen studied fluids would be advantageous from the standpoint of lifespan of compressor motor.
3. Energy (Power) spent by the compressor per ton of refrigeration for the refrigerant R290/R1270 (90/10 by mass %) was 2.73% lower among R22, R407C and nineteen studied refrigerants.
4. Volumetric cooling capacity of all the nineteen studied fluids were closer to that of volumetric capacity of R22. Hence same size of compressor can be used for all the nineteen refrigerants as that of R22 with very little modifications.
5. Overall thermodynamic performance of window air conditioner with R290/R1270 (90/10 by mass %) was better than R22 with significant savings in energy consumption and hence it is an energy efficient sustainable refrigerant mixture as a drop in substitute to R22.

Nomenclature

ARI	Air conditioning and refrigeration institute	P_c	Critical pressure (MPa)
GWP	Global warming potential	Q	Refrigeration capacity (kW)
ODP	Ozone depletion potential	R	Universal gas constant (J/molK)
RE	Refrigeration effect (kJ/kg)	T_b	Boiling point (^oC)
TR	Ton of refrigeration (kW)	T_c	Critical temperature (K)
		T_d	Discharge temperature (^oC)

$h_{1''}$	Enthalpy at the compressor entry (kJ/kg)	T_e	Evaporating temperature (°C)
$h_{2''}$	Enthalpy at the compressor exit (kJ/kg)	T_g	Temperature glide (°C)
$h_{4''}$	Enthalpy at the evaporator inlet (kJ/kg)	T_k	Condensing temperature (°C)
$\dot{m}$	Mass flow rate of refrigerant (kg/min)	v	Specific volume (m^3/kg)
M	Molecular weight (kg/kmol)	W_c	Compressor work (kJ/kg)

References

1. United Nations Environmental Programme, Montreal Protocol on substances that deplete the ozone layer, Final act. New York: United Nations; 1987.
2. RL. Powell, J. Fluorine Chem, 114, 237-250 (2002)
3. M. Mohanraj, S. Jayaraj, C. Muraleedharan, Int. J. Greenh Gas Control 3, 108-119 (2009)
4. J.M. Calm, P.A. Domanski, ASHRAE J, 46, 29-39, (2004)
5. Atilla Gencer Devecioğlu, Vedat Oruc, j.egypro, 75, 1452-1457 (2015)
6. S. Devotta, A.V. Waghmare, N.N. Sawant, B.M. Domkundwar, Appl. Therm. Eng 21, 703-715 (2001)
7. S. Devotta, A.S. Padalkar, N.K. Sane, Int. J. Refrigeration, 28, 594-604, 2005.
8. X.H. Han, Q. Wang, Z.W. Zhu, G.M. Chen, Appl. Therm. Eng , 27, 2559-2565, (2007)
9. Ki-Jung Park, Dongsoo Jung, Appl. Energy, 86, 2598-2603, (2009)
10. B.O. Bolaji, Z. Huan, Renew. Sustainable Energy Rev, 18, 49-54, (2013)
11. Ki-Jung Park, Yun-Bo Shim, Dongsoo Jung, Energy Convers. Manage 50, 1671-1675, (2009)
12. Ki-Jung Park, Yun-Bo Shim, Dongsoo Jung, Appl. Therm. Eng, 29, 597-600, (2009)
13. Ki-Jung Park, Yun-Bo Shim, Dongsoo Jung, Appl. Energy, 85, 896-900, (2008)
14. Martin Joseph J, Yu-Chun Hou, AlChE J, 1, 142-151, (1955)
15. EW Lemmon, ML Huber, MO McLinden, "NIST Standard Reference Database 23, Version 9.1 Reference Fluid Thermodynamic and Transport Properties-REFPROP, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg, (2013).
16. C P. Arora, Refrigeration and Air conditioning (Tata McGraw-Hill, New Delhi, 2009)
17. R.C. Arora, Refrigeration and Air conditioning (PHI learning Private Limited, New Delhi, 2010)