Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Low-GWP Alternative Refrigerants Evaluation Program (Low-GWP AREP)

TEST REPORT #17

Compressor Calorimeter Test of Refrigerants R-22 and R-1270

Guilherme Borges Ribeiro
Gabriel Marchi Di Gennaro

EMBRACO – Empresa Brasileira de Compressores
Rui Barbosa, 1020 – zip code 89219-901 - Joinville - SC – Brazil

July 8, 2013

This report has been made available to the public as part of the author company's participation in the AHRI's Low-GWP AREP.

The tests in this report were conducted using different conditions from the program's requirements. The AHRI Low-GWP AREP Technical Committee found the results useful and informative, and approved them for publication as a non-standard Low-GWP AREP report.

Air-Conditioning, Heating, and Refrigeration Institute
2111 Wilson Boulevard, Suite 500
Arlington VA 22201
(703) 524-8800
www.ahrinet.org

1. Introduction

The purpose of this work is to evaluate promising alternative refrigerants with low GWP (Global Warming Potential).

The compressor used for this study is manufactured by Embraco light commercial refrigeration and air-conditioners. For this report, two refrigerants were chosen, R-22 as baseline refrigerant and R-1270 as alternative refrigerant.

Twenty-four tests were performed according to standard ASHRAE 23 during a month. Due to the number of tests and short time, just one level of superheating was applied in this work. Because of restrictions of calorimeter components, tests were executed using different conditions than specified by the Low-GWP AREP participant's handbook. The version 7.0 of NIST REFPROP was used for thermodynamic properties computation.

2. Details of Test Setup:

- Description of Test Refrigerant-Lubricant
- Baseline Refrigerant
  - R-22
- Alternative Refrigerant
  - R-1270 (propylene)
- Lubricant
  - The mineral lubricant oil was, AVIA FC 32 with viscosity ISO 32, manufactured by BANTLEON.
  - No changes were applied for this lubricant.

b. Description of Compressor

The NJ7240F is a reciprocating compressor, hermetic, low-side design (motor exposed to suction pressure). This compressor is manufactured by Embraco and its compressor label is shown below.

Figure 1 - Compressor Label

Tables 1 presents the test conditions applied for R-22 and R-1270.

Table 1- Operating conditions for the baseline and alternative refrigerants.

	Suction Pressure [bar]	Suction Saturation Temperature [°C]	Discharge Pressure [bar]	Discharge Saturation Temperature [°C]	Applicable Superheating [°C]	Suction Temperature $T_{sup}-T_{evap}$ [°C]	Ambient Temperature [°C]
R-22 – Baseline Refrigerant	3,548	-10	10,439	25	11,1	1,1	32
	3,548	-10	13,548	35	11,1	1,1	32
	3,548	-10	17,292	45	11,1	1,1	32
	3,548	-10	21,751	55	11,1	1,1	32
	4,218	-5	10,439	25	11,1	6,1	32
	4,218	-5	13,548	35	11,1	6,1	32
	4,218	-5	17,292	45	11,1	6,1	32
	4,218	-5	21,751	55	11,1	6,1	32
	5,841	5	11,92	30	11,1	16,1	32
	5,841	5	13,548	35	11,1	16,1	32
	5,841	5	17,292	45	11,1	16,1	32
	5,841	5	21,751	55	11,1	16,1	32
R-1270 – Alternative Refrigerant	4,281	-10	11,545	25	11,1	1,1	32
	4,281	-10	14,695	35	11,1	1,1	32
	4,281	-10	18,430	45	11,1	1,1	32
	4,281	-10	22,819	55	11,1	1,1	32
	5,016	-5	11,545	25	11,1	6,1	32
	5,016	-5	14,695	35	11,1	6,1	32
	5,016	-5	18,430	45	11,1	6,1	32
	5,016	-5	22,819	55	11,1	6,1	32
	6,762	5	13,050	30	11,1	16,1	32
	6,762	5	14,695	35	11,1	16,1	32
	6,762	5	18,430	45	11,1	16,1	32
	6,762	5	22,819	55	11,1	16,1	32

c. <u>Description and Size of Test Loop</u>

The figure below shows a schematic drawing of the calorimeter and its main components.

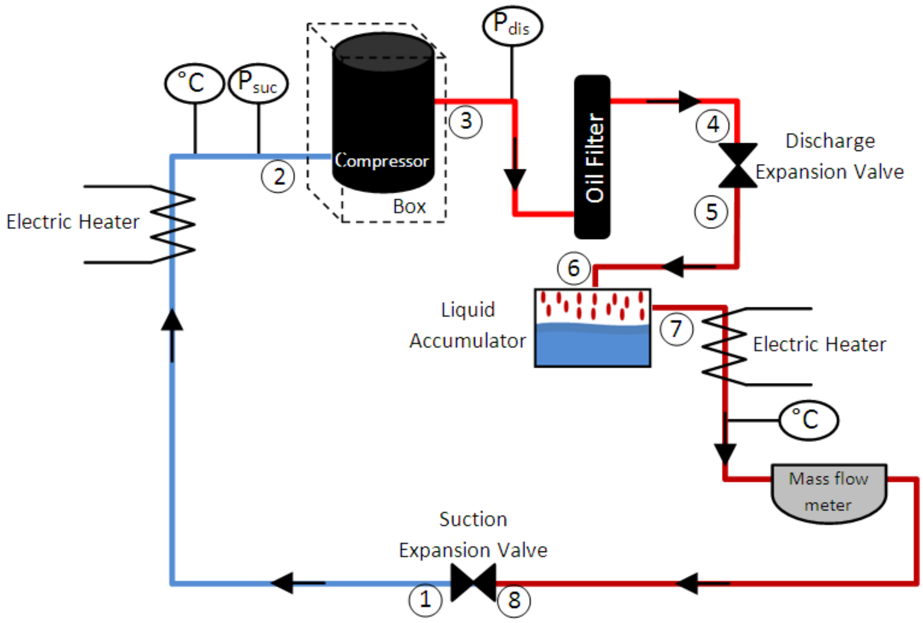

Figure 2 - Calorimeter test apparatus

Pressure and temperature are measured by absolute pressure transducers and resistance temperature detectors (PT100), respectively. Both expansion valves are used to determining the compressor inlet and outlet pressure, whereas the electric heaters were used to guarantee that only fluid at the superheated state will enter at the mass flow meter and the compressor. A pressure-enthalpy diagram is shown in the Figure 3. It is important to mention that a heat loss along the apparatus tubing is presented from point 5 to 6 on the pressure-enthalpy diagram.

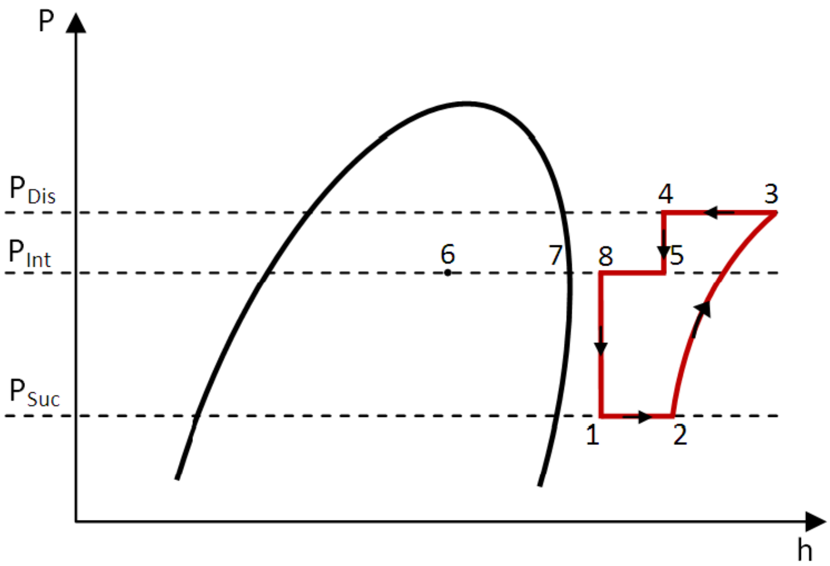

Figure 3 – Pressure x Enthalpy diagram

The air temperature control inside the box maintained via an electric heater and an embedded refrigerating system, as shown in the Figure 4.

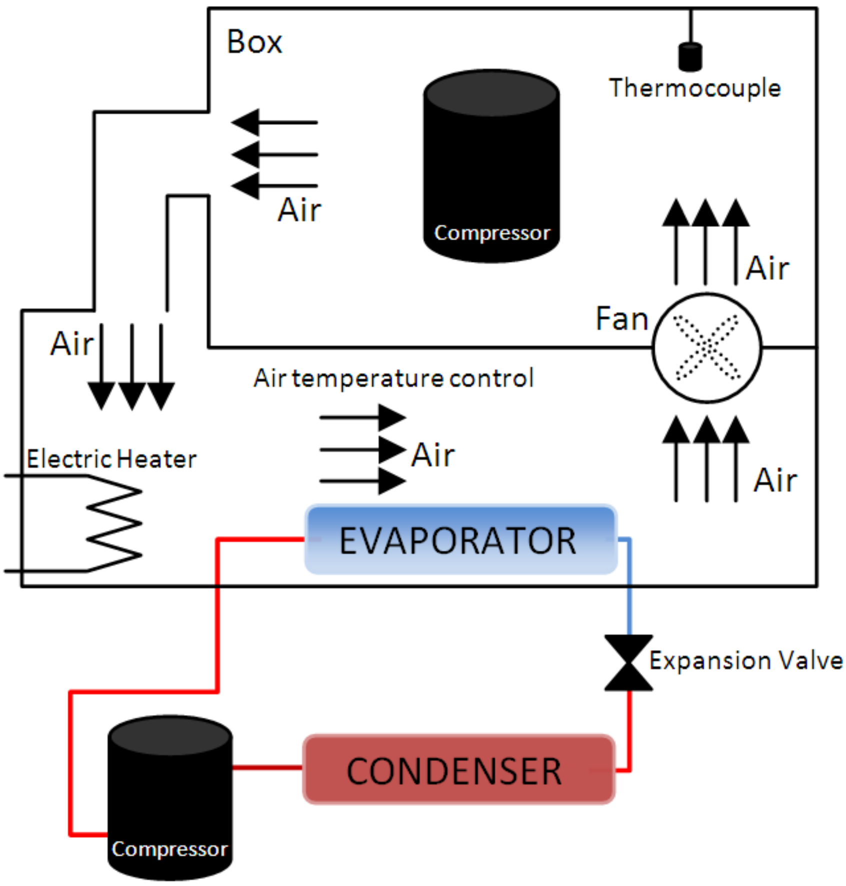

Figure 4 - Compressor Box

Figure 5 - Calorimeter

The measurement instruments used in the calorimeter are listed in Table 2, with the associated accuracy.

Table 2 - Instrumentation and catalog accuracy

Type	Model	Accuracy
Mass Flow meter	Micro Motion – CMF025	±0,35% of flow rate
Power transducer	Yokogawa – WT210	±0,2% of range
Suction Pressure Transducer	Wika – P10 0-10 bar	±0,05% of full scale
Discharge Pressure Transducer	Wika – P10 0-120 bar	±0,1% of full scale
PT100	-	±(0,15+0,002*T) where T is the measured temperature. E_{max}= ±0,45°C
Data acquisition	Agilent – HP 34790a	±0,004%

3. Results

The comparison results discussed in this topic are tabulated in Appendix A. All results presented are raw test data, except for Tables 6, 7 and 8.

Appendix A

Tabular Data

The uncertainties calculated for Table 4 and 5, were obtained according with the equations presented below:

$$\boldsymbol{u}(\boldsymbol{E_{max}}) = \frac{\boldsymbol{E_{max}}}{\sqrt{\boldsymbol{3}}}$$

$$\boldsymbol{U} = \pm\, \boldsymbol{u}(E_{max}) \times \boldsymbol{t}$$

Where:

$\boldsymbol{E_{max}}$: $\boldsymbol{Maximum\ error}$

$\boldsymbol{u}(\boldsymbol{E_{max}})$: $\boldsymbol{Standard\ uncertainty\ relative\ for\ maximum\ error}$

$\boldsymbol{U}$: $\boldsymbol{Expanded\ uncertainty}$

$\boldsymbol{t}$: $\boldsymbol{Student's\ coefficient\ for\ 95{,}45\%\ of\ probability\ and}$

$\boldsymbol{infinite\ degrees\ of\ liberty}$

Table 3 - Performance data in tabular form within defined accuracies and ranges of operation

R-22													
Points Evaluated	UNIT	1	2	3	4	5	6	7	8	9	10	11	12
Evaporating Temperature	°F (ºC)	14 (-10)	14 (-10)	14 (-10)	14 (-10)	23 (-5)	23 (-5)	23 (-5)	23 (-5)	41 (5)	41 (5)	41 (5)	41 (5)
Condensing Temperature	°F (ºC)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)	86 (30)	95 (35)	113 (45)	131 (55)
Discharge Temperature	°F (ºC)	214 (101)	237 (114)	263 (129)	292 (144)	205 (96)	223 (106)	246 (119)	272 (133)	198 (92)	206 (97)	226 (108)	251 (122)
Applicable Superheating	°F (ºC)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)
Applicable Subcooling	°F (ºC)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)
Compressor Capacity	Btu/h (W)	12620 (3699)	11088 (3250)	9479 (2778)	7953 (2331)	15692 (4599)	14007 (4105)	12230 (3584)	10339 (3030)	21632 (6340)	20466 (5998)	18119 (5310)	15543 (4555)
Refrigerant mass flow rate	kg/h (lbm/h)	72,03 (159)	67,90 (150)	62,77 (138)	57,55 (127)	88,53 (195)	84,70 (187)	79,91 (176)	73,73 (163)	123,43 (272)	120,91 (267)	115,44 (255)	107,83 (238)
Mass flow rate uncertainty	% kg/h	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32
Current	A	6,85	7,35	7,91	8,38	7,63	8,12	8,61	9,2	9,25	9,58	10,38	11,41
Current uncertainty	A	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05
Power Input	W	1476,4	1586,7	1693,1	1799,2	1642,6	1750,4	1875,2	1999,5	1980,8	2048,4	2217,7	2427,1
Power Input uncertainty	W	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2
EER	Btu/h/W	8,55	6,99	5,60	4,42	9,55	8,00	6,52	5,17	10,92	9,99	8,17	6,40
COP	W/W	2,51	2,05	1,64	1,30	2,80	2,35	1,91	1,52	3,20	2,93	2,39	1,88
COP_{R1270}/ COP_{R22}	-	1,22	1,17	1,15	1,11	1,18	1,12	1,07	1,04	1,20	1,18	1,14	1,10
Suction Pressure	bar	3,548± 0,006	3,548± 0,006	3,548± 0,006	3,548± 0,006	4,218± 0,006	4,218± 0,006	4,218± 0,006	4,218± 0,006	5,841± 0,006	5,841± 0,006	5,841± 0,006	5,841± 0,006
Discharge Pressure	bar	10,439 ±0,139	13,548 ±0,139	17,292 ±0,139	21,751 ±0,139	10,439 ±0,139	13,548 ±0,139	17,292 ±0,139	21,751 ±0,139	11,92± 0,139	13,548 ±0,139	17,292 ±0,139	21,751 ±0,139

Table 4 - Performance data in tabular form within defined accuracies and ranges of operation

R-1270													
Points Evaluated	UNIT	1	2	3	4	5	6	7	8	9	10	11	12
Evaporating Temperature	°F (ºC)	14 (-10)	14 (-10)	14 (-10)	14 (-10)	23 (-5)	23 (-5)	23 (-5)	23 (-5)	41 (5)	41 (5)	41 (5)	41 (5)
Condensing Temperature	°F (ºC)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)	86 (30)	95 (35)	113 (45)	131 (55)
Discharge Temperature	°F (ºC)	214 (101)	237 (114)	263 (129)	292 (144)	205 (96)	223 (106)	246 (119)	272 (133)	198 (92)	206 (97)	226 (108)	251 (122)
Applicable Superheating	°F (ºC)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)	20 (11,1)
Applicable Subcooling	°F (ºC)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)	10 (5)
Compressor Capacity	Btu/h (W)	15735 (4611)	13670 (4006)	11656 (3416)	9550 (2799)	18790 (5507)	16544 (4848)	14119 (4138)	11713 (3433)	25804 (7562)	24036 (7044)	20894 (6123)	17546 (5142)
Refrigerant mass flow rate	kg/h (lbm/h)	49,52 (109)	46,72 (103)	43,76 (96)	39,97 (88)	58,23 (128)	55,60 (123)	52,04 (115)	48,03 (106)	80,67 (178)	78,24 (173)	74,36 (164)	69,20 (153)
Mass flow rate uncertainty	% kg/h	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0,32	±0, 32	±0,32	±0,32	±0,32
Current	A	7,09	7,83	8,46	9,09	7,81	8,63	9,28	10,08	9,12	9,54	10,59	11,71
Current uncertainty	A	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	±0,05	± 0,05	±0,05	±0,05	±0,05
Power Input	W	1509,5	1669,9	1814,8	1938,6	1663,2	1841,7	2016,1	2178,0	1964,5	2045,9	2249,0	2484,9
Power Input uncertainty	W	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	±19,2	± 19,2	±19,2	±19,2	±19,2
EER	Btu/h/W	10,42	8,19	6,42	4,93	11,30	8,98	7,00	5,38	13,14	11,75	9,29	7,06
COP	W/W	3,06	2,40	1,88	1,44	3,31	2,63	2,05	1,58	3,85	3,44	2,72	2,07
COP_{R1270}/ COP_{R22}	-	1,22	1,17	1,15	1,11	1,18	1,12	1,07	1,04	1,20	1,18	1,14	1,10
Suction Pressure	bar	4,281± 0,006	4,281± 0,006	4,281± 0,006	4,281± 0,006	5,016± 0,006	5,016± 0,006	5,016± 0,006	5,016± 0,006	6,762± 0,006	6,762± 0,006	6,762± 0,006	6,762± 0,006
Discharge Pressure	bar	11,545 ±0,139	14,695 ±0,139	18,430 ±0,139	22,819 ±0,139	11,545 ±0,139	14,695 ±0,139	18,430 ±0,139	22,819 ±0,139	13,050 ±0,139	14,695 ±0,139	18,430 ±0,139	22,819 ±0,139

Table 5 - Percentage gain of R1270 over R22.

Conditions				
Evaporating Temperature [°C]	Condensing Temperature [°C]	Capacity	Input Power	COP
-10	25	25%	2%	22%
-10	35	23%	5%	17%
-10	45	23%	7%	15%
-10	55	20%	8%	11%
-5	25	20%	1%	18%
-5	35	18%	5%	12%
-5	45	15%	8%	7%
-5	55	13%	9%	4%
5	30	19%	-1%	20%
5	35	17%	0%	18%
5	45	15%	1%	14%
5	55	13%	2%	10%

Appendix B

Performance Maps

- Performance map for R-22
  - Polynomial equation

Table 6 - Polynomial coefficients

R-22				
Coefficients	Mass Flow Rate	Capacity	Input Power	COP
A_0	119,61	7627,25	2547,53	4,64
A_1	4,37	316,33	124,44	0,12
A_2	-0,39	-35,41	-36,04	-0,02
A_3	-0,04	-3,77	-3,53	0,00
A_4	0,09	-33,75	-0,12	-0,03
A_5	-0,01	-0,47	0,23	0,00
A_6	0,00	0,00	0,00	0,00
A_7	0,02	-0,27	-0,71	0,00
A_8	0,00	-0,02	0,01	0,00
A_9	0,00	-0,03	0,02	0,00

$$X = A_0 + (A_1 \times S) + (A_2 \times S^2) + (A_3 \times S^3) + (A_4 \times D) + (A_5 \times D^2) + (A_6 \times D^3) + (A_7 \times S \times D) + (A_8 \times S \times D^2) + (A_9 \times D \times S^2)$$

where:

A: Equation coefficient, represents compressor performance

S: Suction dew point temperature, [°C]

D: Discharge dew point temperature, [°C]

X can represent any of the following variables:

- Power Input, [W]
- Mass flow rate, [kg/h]
- Capacity, [W]
- COP, [W/W]

  - Graphics

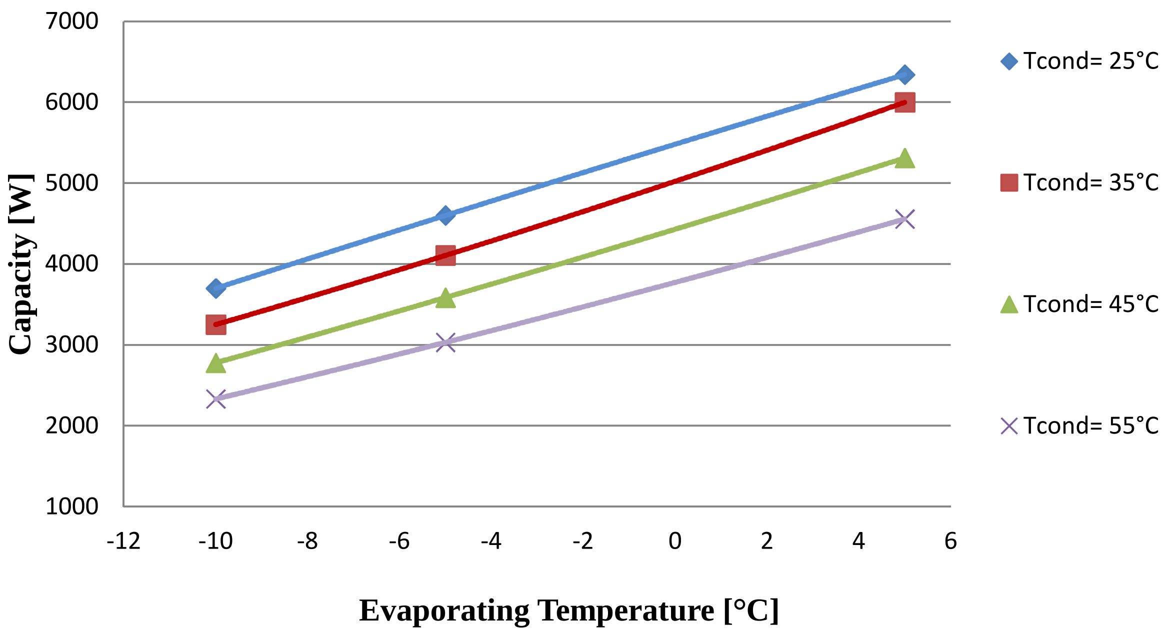

Figure 6 – Cooling capacity for R-22

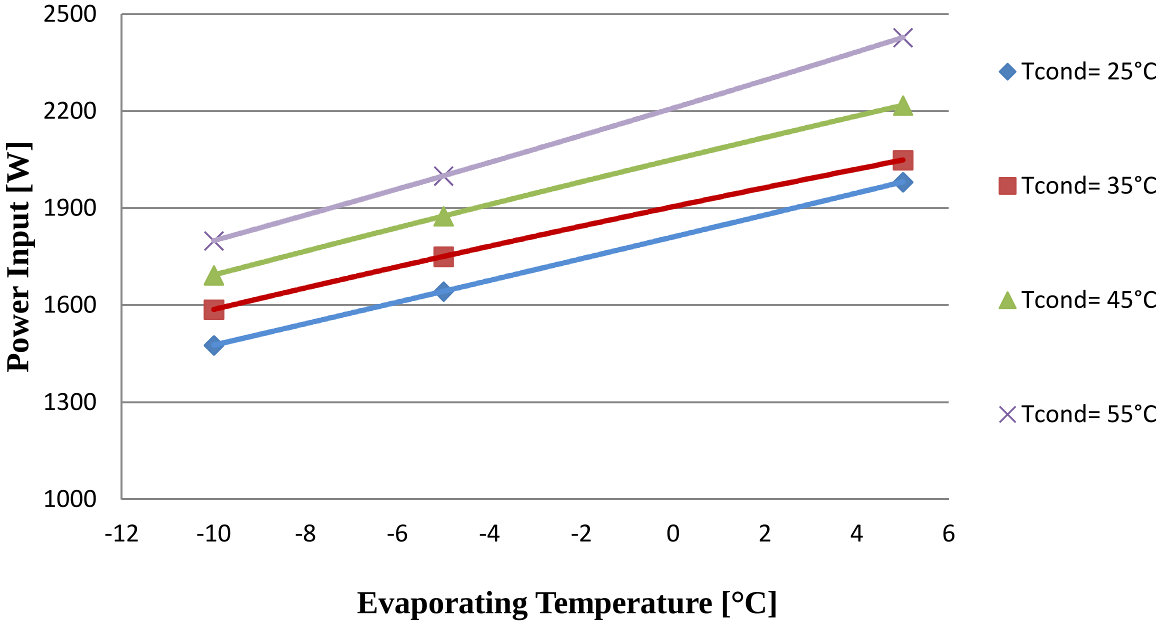

Figure 7 - Power Input for R-22

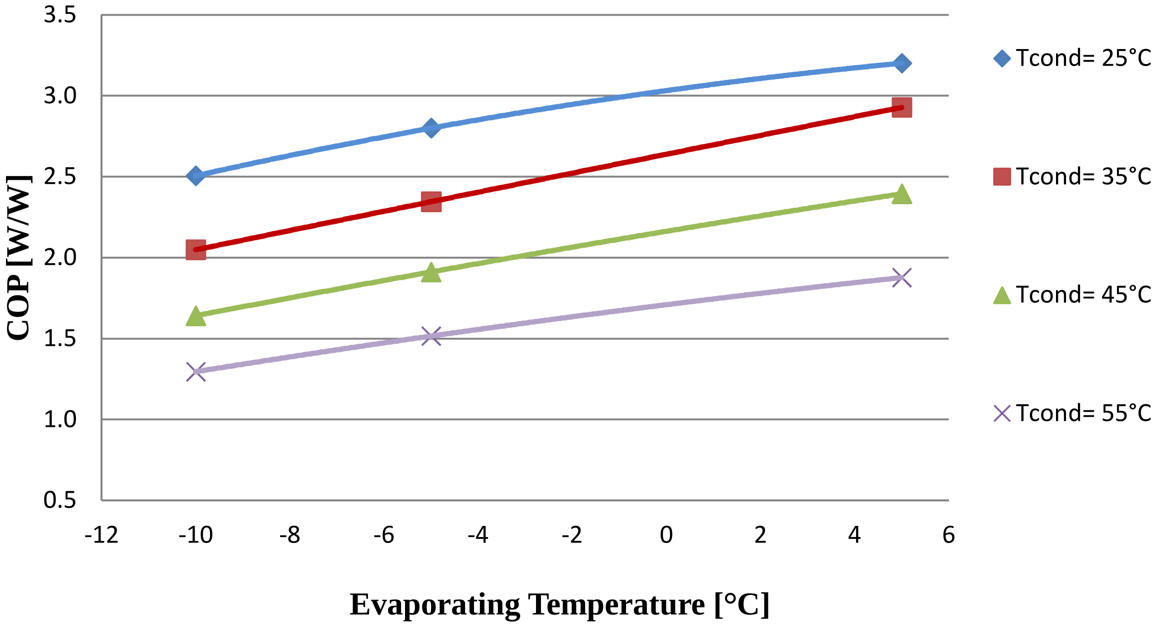

Figure 8 - COP for R-22

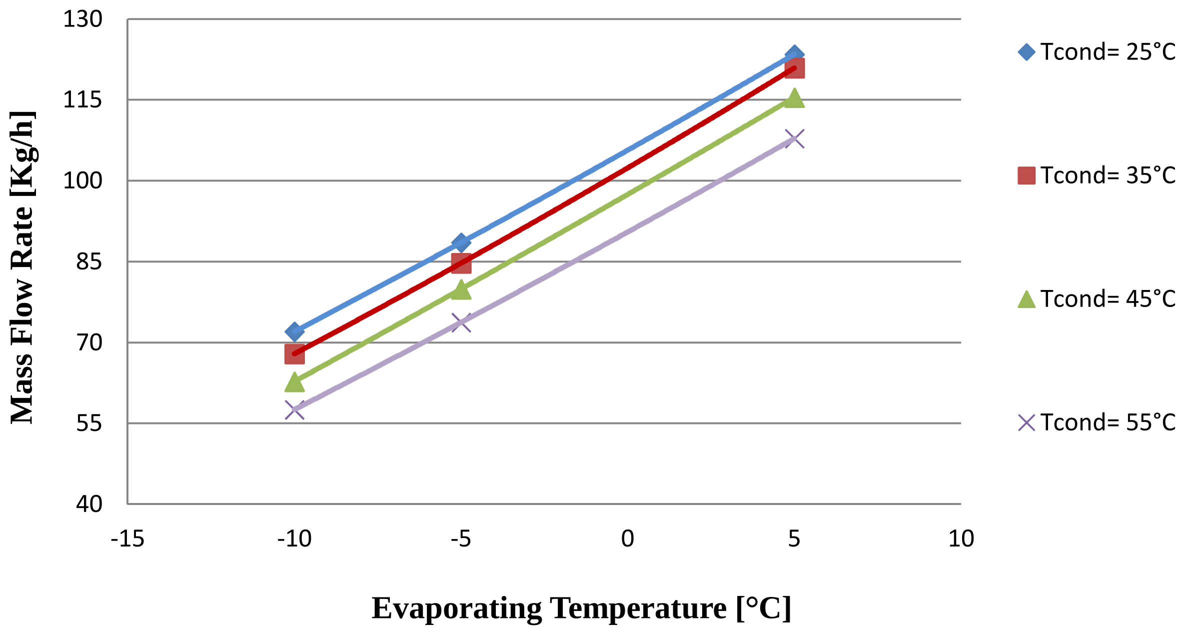

Figure 9 - Mass flow rate for R-22

- Performance map for R-1270
    - Polynomial equation

Table 7 - Polynomial coefficients

R-1270				
Coefficients	Mass Flow Rate	Capacity	Input Power	COP
A_0	94,57	9483,12	1728,88	7,45
A_1	4,25	390,03	66,65	0,24
A_2	-0,58	-20,77	-10,20	-0,04
A_3	-0,06	-2,68	-1,00	0,00
A_4	-0,48	-92,65	8,41	-0,13
A_5	0,01	0,34	0,19	0,00
A_6	0,00	0,00	0,00	0,00
A_7	-0,01	-2,95	-1,26	0,00
A_8	0,00	0,00	0,02	0,00
A_9	0,00	-0,06	-0,02	0,00

$$X = A_0 + (A_1 \times S) + (A_2 \times S^2) + (A_3 \times S^3) + (A_4 \times D) + (A_5 \times D^2) + (A_6 \times D^3) + (A_7 \times S \times D) + (A_8 \times S \times D^2) + (A_9 \times D \times S^2)$$

where:

A: Equation coefficient, represents compressor performance

S: Suction dew point temperature, [°C]

D: Discharge dew point temperature, [°C]

X can represent any of the following variables:

- Power Input, [W]
- Mass flow rate, [kg/h]
- Capacity, [W]
- COP, [W/W]

- Graphics

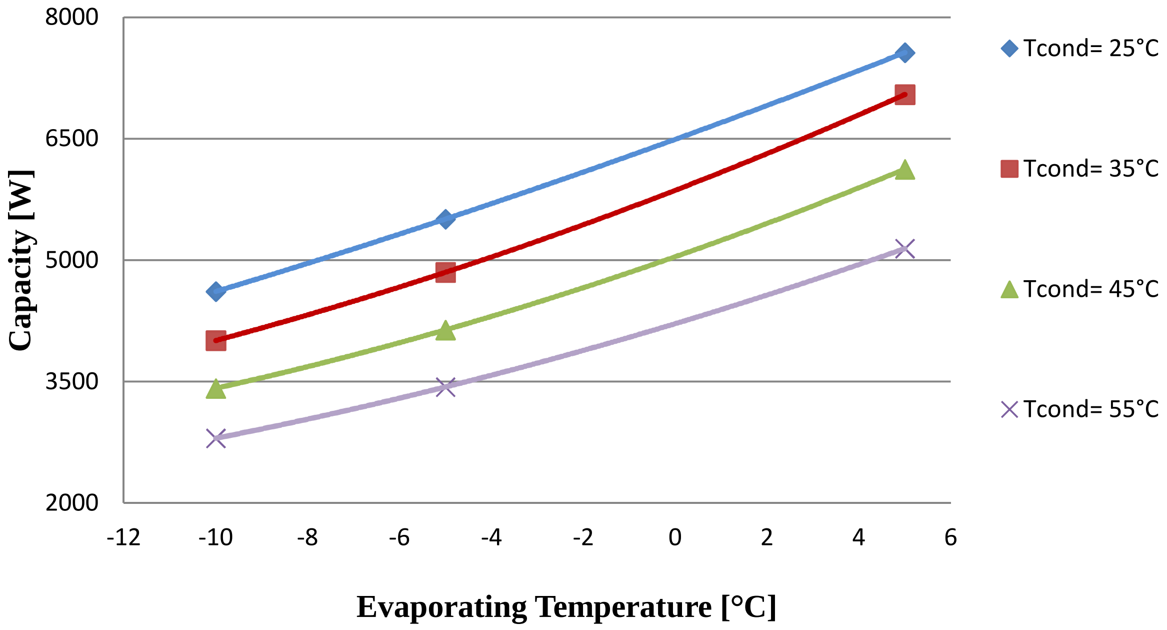

Figure 10 - Cooling capacity for R-1270

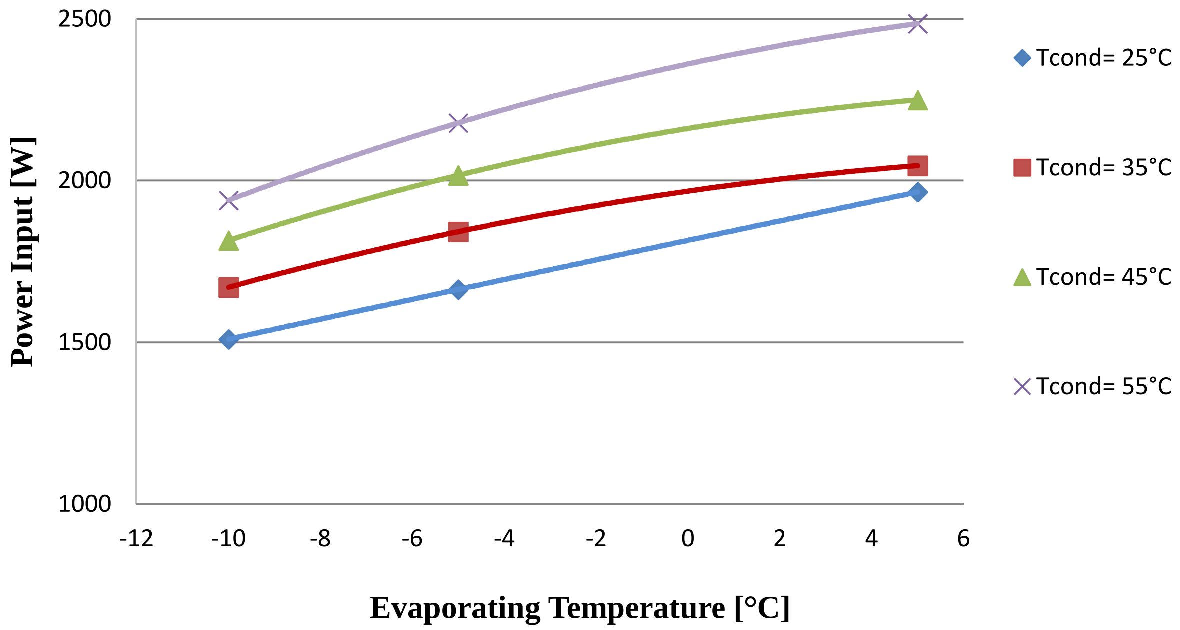

Figure 11 - Power Input for R-1270

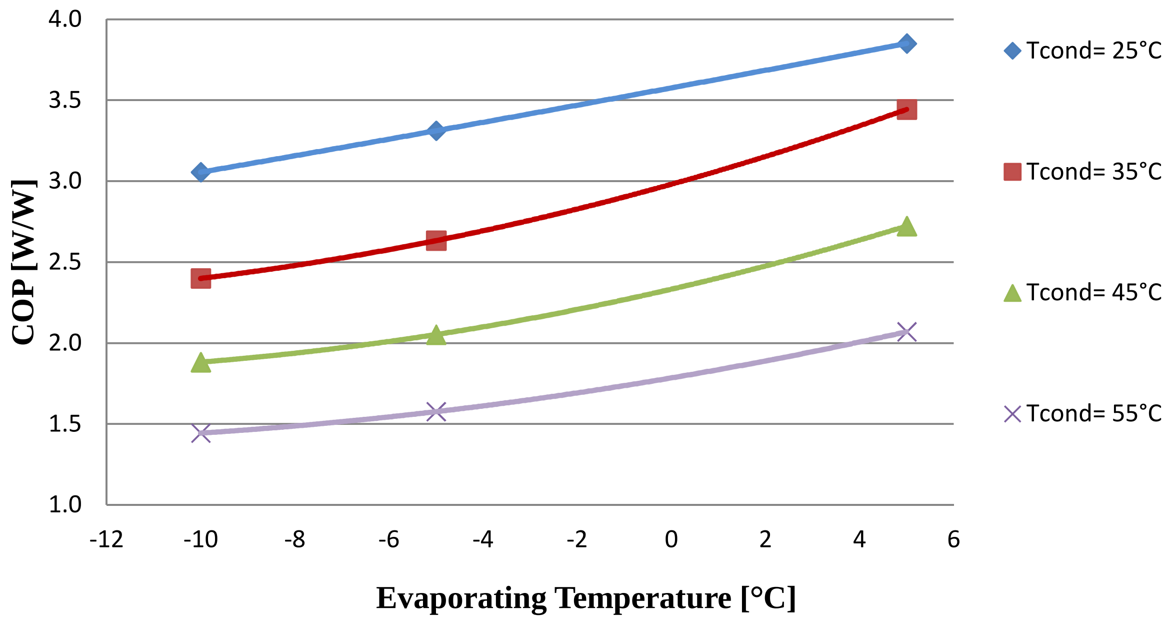

Figure 12 - COP for R-1270

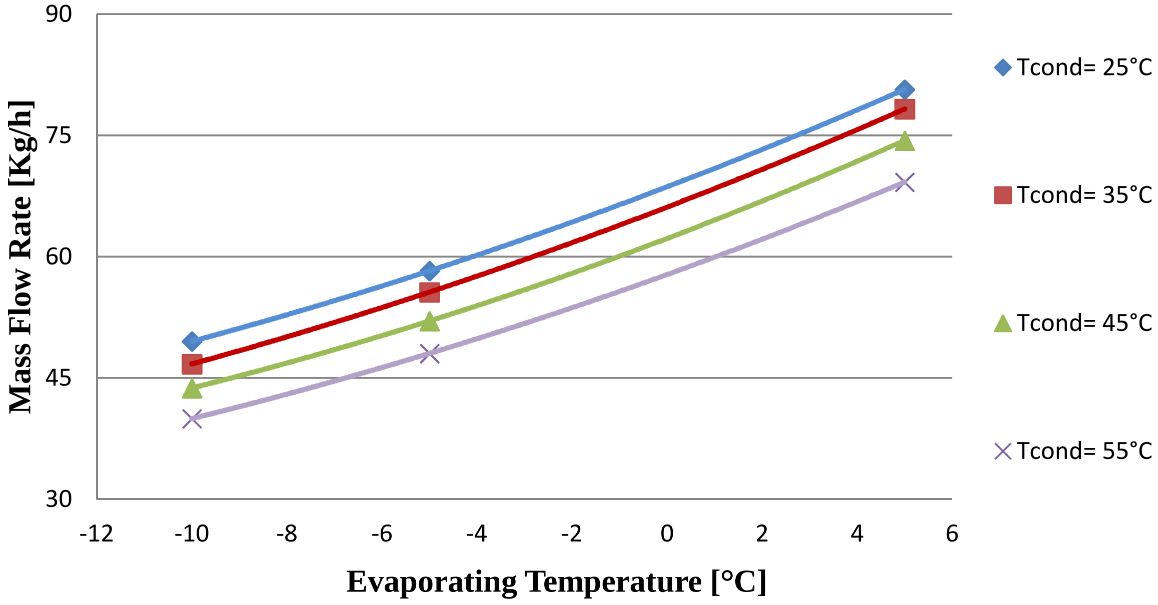

Figure 13 - Mass flow rate for R-1270

- Comparative performance map for R-22 and R-1270
  - Polynomial equation

Table 8 - Polynomial coefficients

R-1270 / R-22	
Coefficients	COP_{R1270}/COP_{R22}
A_0	1,56
A_1	0,00
A_2	0,00
A_3	0,00
A_4	-0,03
A_5	0,00
A_6	0,00
A_7	0,00
A_8	0,00
A_9	0,00

$$X = A_0 + (A_1 \times S) + (A_2 \times S^2) + (A_3 \times S^3) + (A_4 \times D) + (A_5 \times D^2) + (A_6 \times D^3) + (A_7 \times S \times D) + (A_8 \times S \times D^2) + (A_9 \times D \times S^2)$$

where:

A: Equation coefficient, represents compressor performance

S: Suction dew point temperature, [°C]

D: Discharge dew point temperature, [°C]

X: COP_{R1270}/COP_{R22}

- Graphic

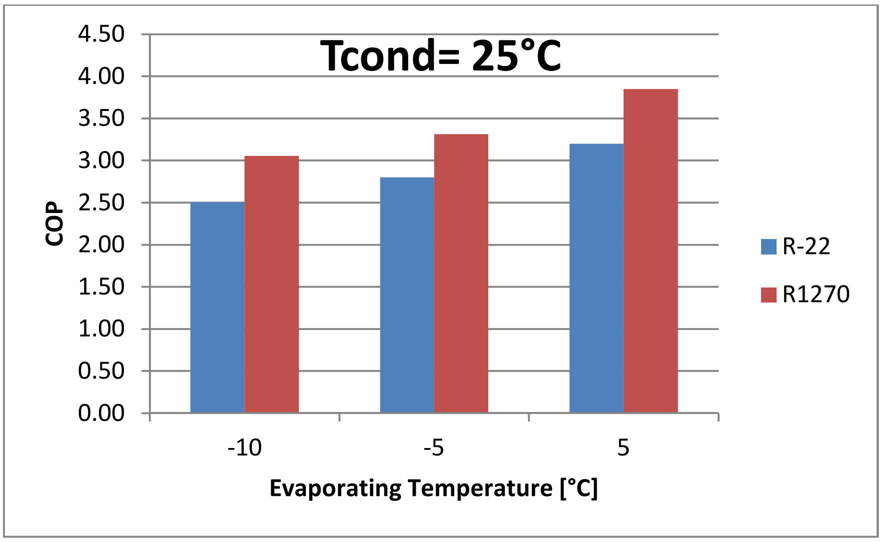

Figure 14 - Comparative COP

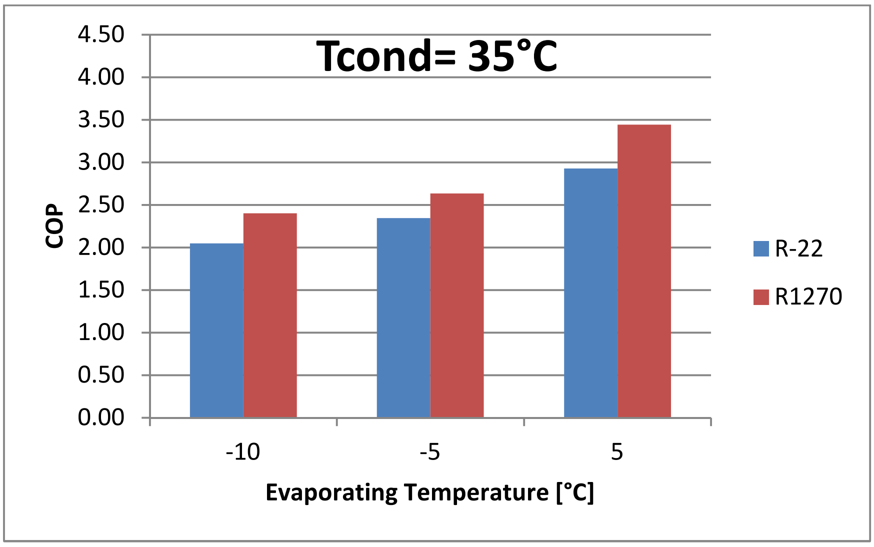

Figure 15 - Comparative COP

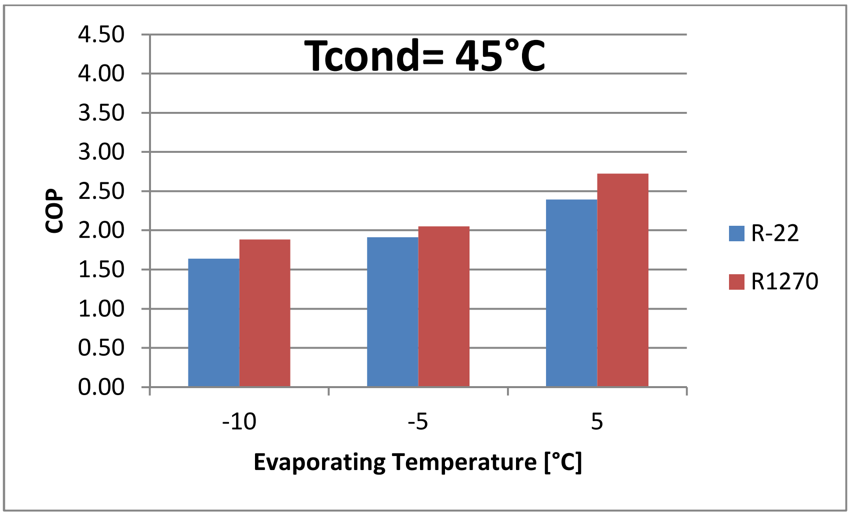

Figure 16 - Comparative COP

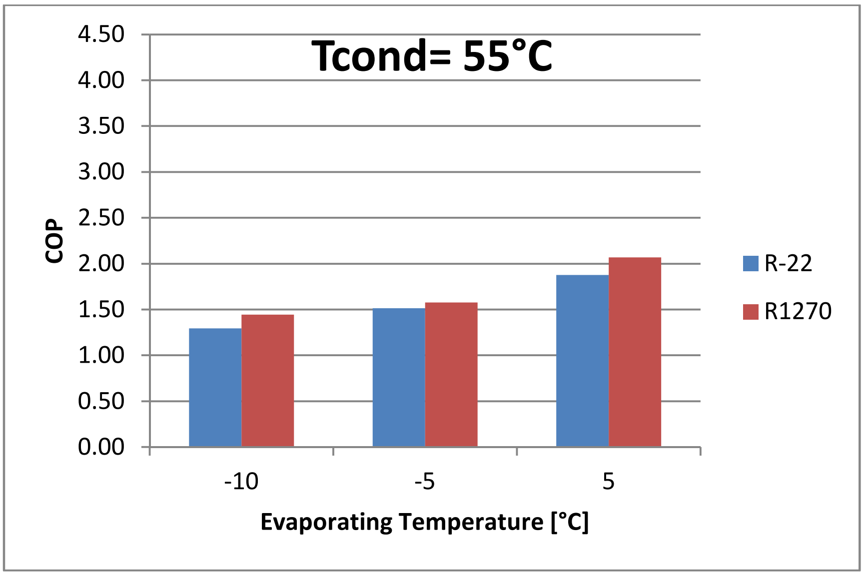

Figure 17 - Comparative COP