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

TEST REPORT #19

Compressor Calorimeter Test of Refrigerants R-134a and N-13a

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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.

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List of Tested Refrigerant’s Compositions (Mass%)

N-13a	R-134a/R-1234yf/R-1234ze(E) (42/18/40)

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 consists in a miniaturized compressor manufactured by Embraco. For this report, two refrigerants were chosen, R-134a as baseline refrigerant and N-13a as alternative refrigerant.

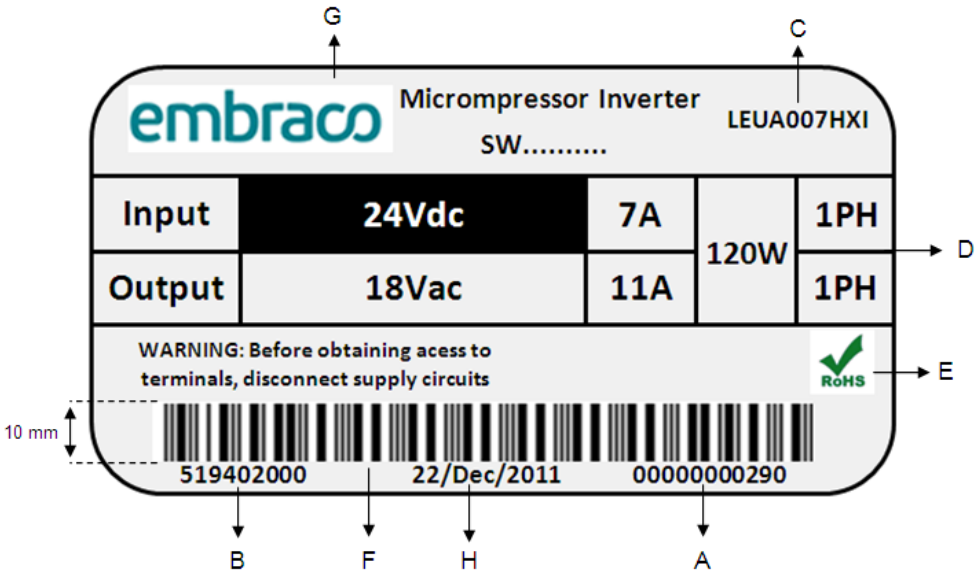
Twenty-four tests were performed according to standard ASHRAE 23 during a month. Due to the number of tests and short time, just one level of superheating was applied in this work. Due to calorimeter control restriction, the ambient temperature of 25°C was specified. Because of restrictions of calorimeter 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-134a
- Alternative Refrigerant
  - N-13a
- Lubricant
  - No oil.

b. Description of Compressor

The Microcompressor is a hermetic linear compressor. This compressor is manufactured by Embraco and its compressor label is shown below.



A – Traceable serial number

B – Inverssor code / Part number

C – Compressor designation

D – Number of phases input - 1 PH

Number of phases output - 1 PH

Voltage input - 24 Vdc

Voltage output - 18 Vac

Current input - 7 A

Current output - 11 A

Power input - 120 W

E – Logos indicate institute approval of compressor

F – Bar code 39 (ration 3:1 and 6.5 mils)

G – Paper: White

Graphics: Black

Size: 70 x 38 mm (2.76" x 1.50")

H – Date of manufacture

Figure 1 - Compressor Label

Tables 1 presents the test conditions applied for R-134a an N-13a.

Table 1- Operating conditions with the tested 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-134a – Baseline Refrigerant	3,260	3	6,654	25	22,2	25,2	25
	3,260	3	8,870	35	22,2	25,2	25
	3,260	3	11,599	45	22,2	25,2	25
	3,260	3	14,915	55	22,2	25,2	25
	3,497	5	6,654	25	22,2	27,2	25
	3,497	5	8,870	35	22,2	27,2	25
	3,497	5	11,599	45	22,2	27,2	25
	3,497	5	14,915	55	22,2	27,2	25
	4,146	10	6,654	25	22,2	32,2	25
	4,146	10	8,870	35	22,2	32,2	25
	4,146	10	11,599	45	22,2	32,2	25
	4,146	10	14,915	55	22,2	32,2	25
N-13a – Alternative Refrigerant	3,171	3	6,389	25	22,2	25,2	25
	3,171	3	8,476	35	22,2	25,2	25
	3,171	3	11,036	45	22,2	25,2	25
	3,171	3	14,136	55	22,2	25,2	25
	3,397	5	6,389	25	22,2	27,2	25
	3,397	5	8,476	35	22,2	27,2	25
	3,397	5	11,036	45	22,2	27,2	25
	3,397	5	14,136	55	22,2	27,2	25
	4,015	10	6,389	25	22,2	32,2	25
	4,015	10	8,476	35	22,2	32,2	25
	4,015	10	11,036	45	22,2	32,2	25
	4,015	10	14,136	55	22,2	32,2	25

c. Description and Size of Test Loop

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

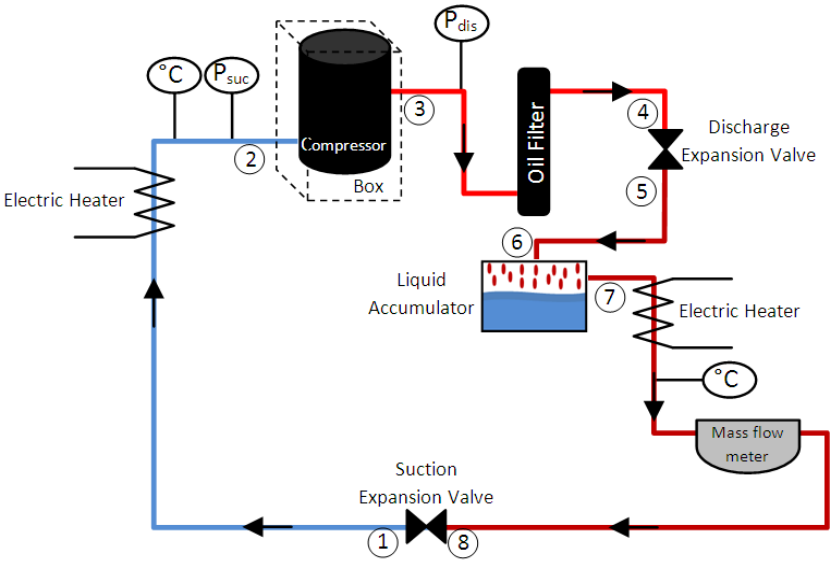


Figure 2 - Calorimeter test apparatus

Pressure and temperature are measured by absolute pressure transducers and resistance temperature detectors (PT100), respectively. Both expansion valves were used to control the compressor inlet and outlet pressure, whereas the electric heaters were used to guarantee that only fluid at the superheated state entered 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 the point 5 to 6 on the pressure-enthalpy diagram.

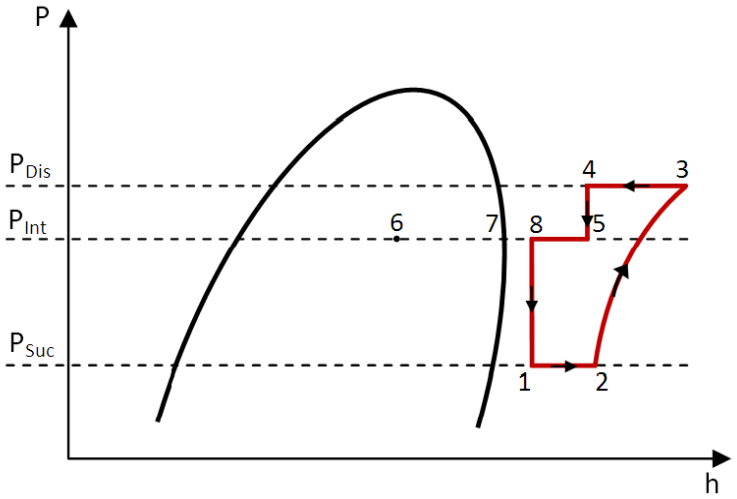


Figure 3 – Pressure x Enthalpy diagram

The air temperature inside the box was controlled by an electric heater and an embedded refrigerating system, as shown in the Figure 4.

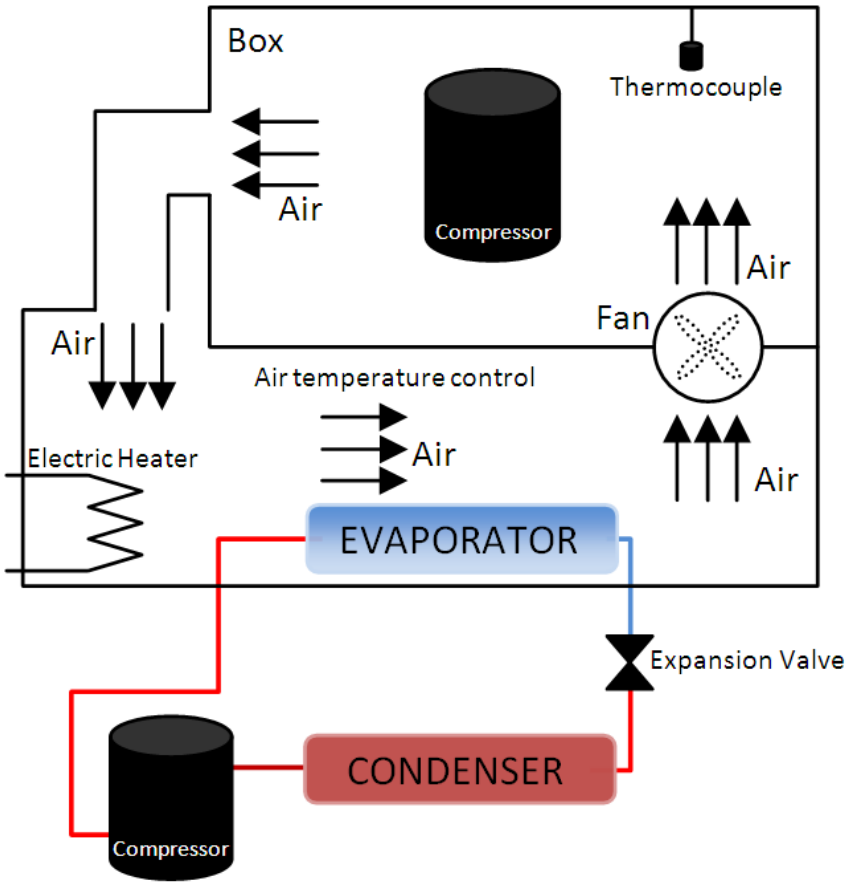


Figure 4 - Compressor Box

Figure 5 – Calorimeter

Figure 6 – Calorimeter

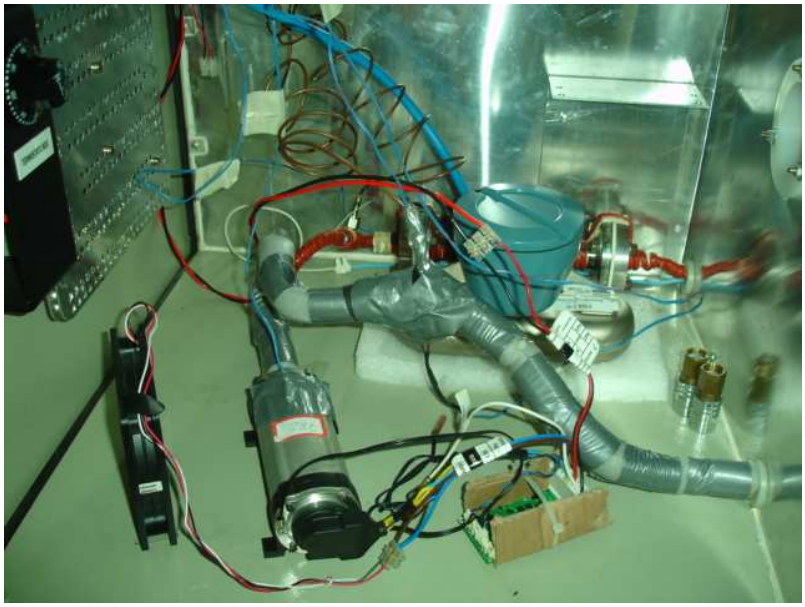


Figure 7 - Calorimeter and the microcompressor

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

Table 2 - Instrumentation and catalog accuracy

Type	Model	Accuracy
Mass Flow meter	Micro Motion – 2700	±0,35% of flow rate
Power transducer	Yokogawa – 2385A	±0,2% of range
Suction Pressure Transducer	Wika – P10 0-10 bar	±0,05% of full scale
Discharge Pressure Transducer	Wika – P10 1-39 bar	±0,05% of full scale
PT100	-	±(0,15+0,002*T) where T is the measured temperature. E_{max}= ±0,45°C
Data acquisition	National Instruments SCXI 1000 / SCXI1102 / SCXI 1303	±0,05%

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 3 and 4, were obtained according with the equations presented below:

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

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

Where:

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

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

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

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

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

R-134a													
Points Evaluated	UNIT	1	2	3	4	5	6	7	8	9	10	11	12
Evaporating Temperature	°F (ºC)	37 (3)	37 (3)	37 (3)	37 (3)	41 (5)	41 (5)	41 (5)	41 (5)	50 (10)	50 (10)	50 (10)	50 (10)
Condensing Temperature	°F (ºC)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)
Discharge Temperature	°F (ºC)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)
Applicable Superheating	°F (ºC)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)
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)	624 (183)	534 (156)	385 (113)	292 (86)	698 (205)	599 (176)	443 (130)	331 (97)	906 (265)	768 (225)	614 (180)	446 (131)
Refrigerant mass flow rate	kg/h (lbm/ h)	3,42 (7,5)	3,15 (6,9)	2,48 (5,5)	2,07 (4,6)	3,79 (8,4)	3,51 (7,7)	2,83 (6,2)	2,32 (5,1)	4,84 (10,7)	4,42 (9,7)	3,84 (8,5)	3,07 (6,8)
Mass flow rate uncertainty	% kg/h	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35
Current	A	1,83	2,20	2,38	2,50	1,82	2,36	2,46	2,64	1,94	2,50	2,95	3,01
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	44,1	52,2	55,1	59,1	43,1	54,2	57,4	62,3	46,4	58,1	67,1	70,0
Power Input uncertainty	W	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2
EER	Btu/h/ W	14,17	10,23	6,98	4,95	16,19	11,06	7,71	5,30	19,53	13,22	9,15	6,38
COP	W/W	4,15	3,00	2,04	1,45	4,74	3,24	2,26	1,55	5,72	3,87	2,68	1,87
COP_{N-13a}/ COP_{R-134a}	-	0,98	0,94	0,97	0,81	0,9	0,94	0,93	0,95	0,98	0,97	0,95	0,96
Suction Pressure	bar	3,260± 0,006	3,260± 0,006	3,260± 0,006	3,260± 0,006	3,497± 0,006	3,497± 0,006	3,497± 0,006	3,497± 0,006	4,146± 0,006	4,146± 0,006	4,146± 0,006	4,146± 0,006
Discharge Pressure	bar	6,654± 0,023	8,870± 0,023	11,599 ±0,023	14,915 ±0,023	6,654± 0,023	8,870± 0,023	11,599 ±0,023	14,915 ±0,023	6,654± 0,023	8,870± 0,023	11,599 ±0,023	14,915 ±0,023

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

N-13a													
Points Evaluated	UNIT	1	2	3	4	5	6	7	8	9	10	11	12
Evaporating Temperature	°F (ºC)	37 (3)	37 (3)	37 (3)	37 (3)	41 (5)	41 (5)	41 (5)	41 (5)	50 (10)	50 (10)	50 (10)	50 (10)
Condensing Temperature	°F (ºC)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)	77 (25)	95 (35)	113 (45)	131 (55)
Discharge Temperature	°F (ºC)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)	132 (55,6)	132 (55,6)	141 (60,6)	141 (60,6)
Applicable Superheating	°F (ºC)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)	40 (22,2)
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)	638 (187)	513 (150)	381 (112)	241 (71)	693 (203)	569 (167)	428 (125)	306 (90)	871 (255)	744 (218)	581 (170)	430 (126)
Refrigerant mass flow rate	kg/h (lbm/ h)	3,77 (8,3)	3,29 (7,2)	2,68 (5,9)	1,87 (4,1)	4,06 (9,0)	3,62 (8,0)	2,98 (6,6)	2,35 (5,2)	5,01 (11,0)	4,63 (10,2)	3,96 (8,7)	3,22 (7,1)
Mass flow rate uncertainty	% kg/h	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35	±0,35
Current	A	1,92	2,25	2,39	2,52	1,98	2,32	2,50	2,54	1,93	2,45	2,80	2,97
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	45,9	53,5	56,5	60,1	47,5	54,8	59,6	60,8	45,4	58,0	66,8	70,6
Power Input uncertainty	W	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2	±1,2
EER	Btu/h/ W	13,91	9,59	6,75	4,00	14,61	10,38	7,17	5,03	19,18	12,83	8,70	6,09
COP	W/W	4,08	2,81	1,98	1,17	4,28	3,04	2,10	1,48	5,62	3,76	2,55	1,78
COP_{N-13a}/ COP_{R-134a}	-	0,98	0,94	0,97	0,81	0,90	0,94	0,93	0,95	0,98	0,97	0,95	0,96
Suction Pressure	bar	3,171± 0,006	3,171± 0,006	3,171± 0,006	3,171± 0,006	3,397± 0,006	3,397± 0,006	3,397± 0,006	3,397± 0,006	4,015± 0,006	4,015± 0,006	4,015± 0,006	4,015± 0,006
Discharge Pressure	bar	6,389± 0,023	8,476± 0,023	11,036 ±0,023	14,136 ±0,139	6,389± 0,023	8,476± 0,023	11,036 ±0,023	14,136 ±0,139	6,389± 0,023	8,476± 0,023	11,036 ±0,023	14,136 ±0,139

Table 5 - Percentage gain of N-13a over R-134a.

Conditions				
Evaporating Temperature [°C]	Condensing Temperature [°C]	Capacity	Power Input	COP
3	25	2,2%	4,1%	-1,8%
3	35	-3,9%	2,5%	-6,3%
3	45	-1,0%	2,4%	-3,3%
3	55	-17,6%	1,8%	-19,1%
5	25	-0,7%	10,0%	-9,7%
5	35	-5,1%	1,2%	-6,2%
5	45	-3,4%	3,9%	-7,0%
5	55	-7,5%	-2,5%	-5,1%
10	25	-3,9%	-2,1%	-1,8%
10	35	-3,1%	-0,2%	-2,9%
10	45	-5,3%	-0,5%	-4,9%
10	55	-3,7%	0,8%	-4,5%

Appendix B

Performance Maps

- Performance map for R-134a
  - Polynomial equation

Table 6 - Polynomial coefficients

R-134a				
Coefficients	Capacity	Power Input	COP	Mass Flow Rate
A_0	2584,43	604,14	-1,14	58,01
A_1	-1603,56	-391,55	6,15	-36,68
A_2	305,87	73,30	-1,02	6,98
A_3	-16,99	-4,06	0,06	-0,39
A_4	12,90	3,82	-0,23	0,29
A_5	-0,42	-0,09	0,00	-0,01
A_6	0,00	0,00	0,00	0,00
A_7	0,05	0,22	-0,02	0,00
A_8	0,00	0,00	0,00	0,00
A_9	0,00	0,00	0,00	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:

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

    - Graphics

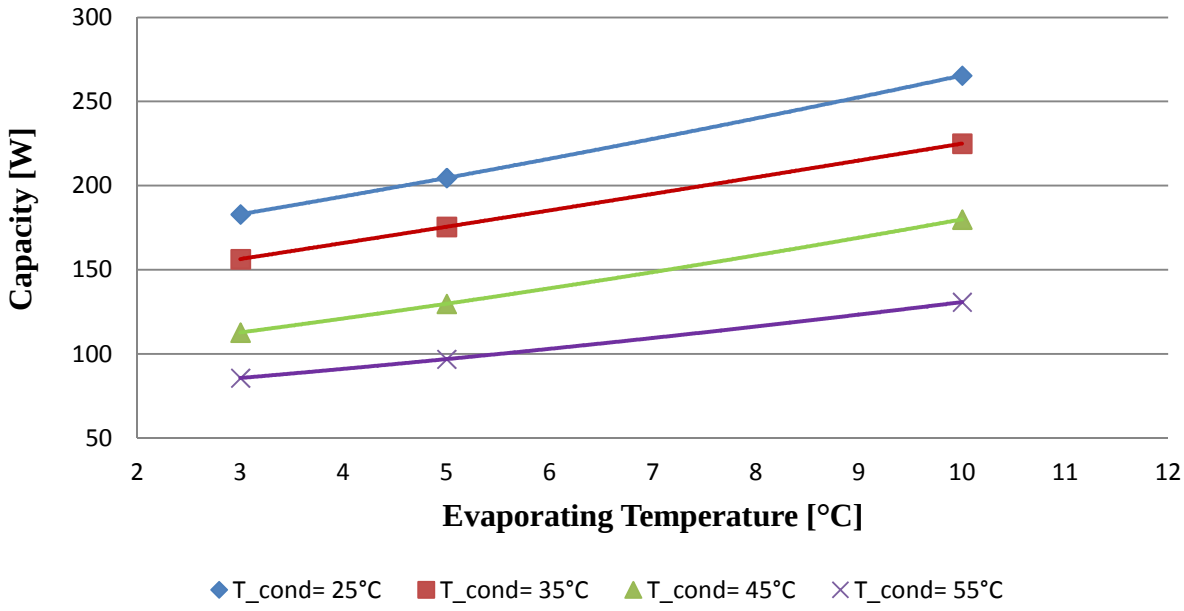


Figure 8 – Cooling capacity for R-134a

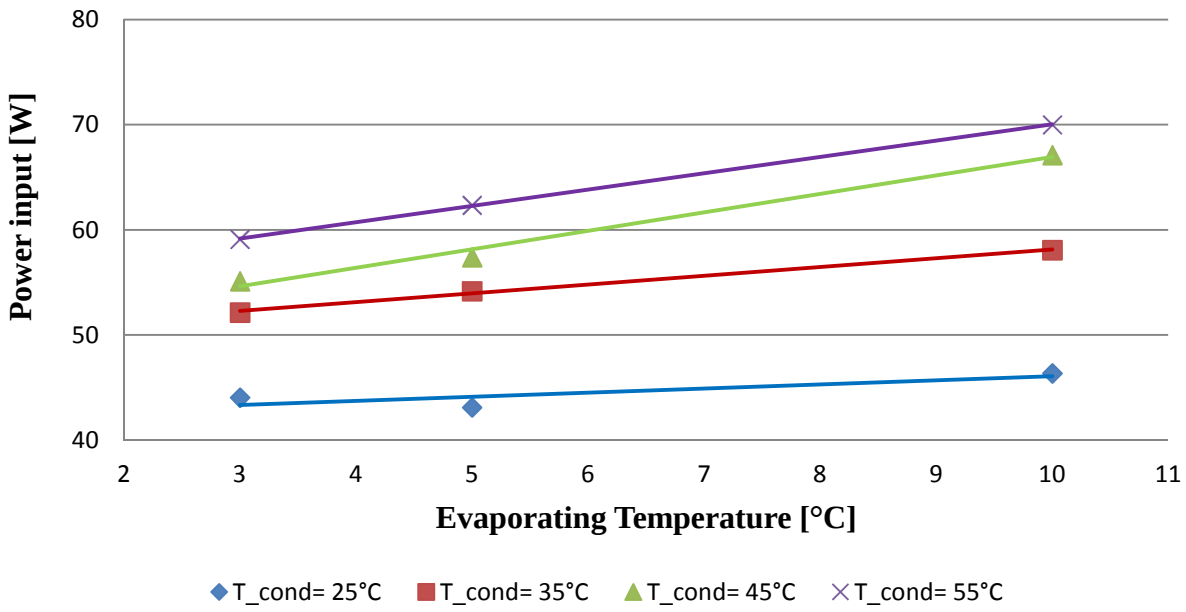


Figure 9 - Power Input for R-134a

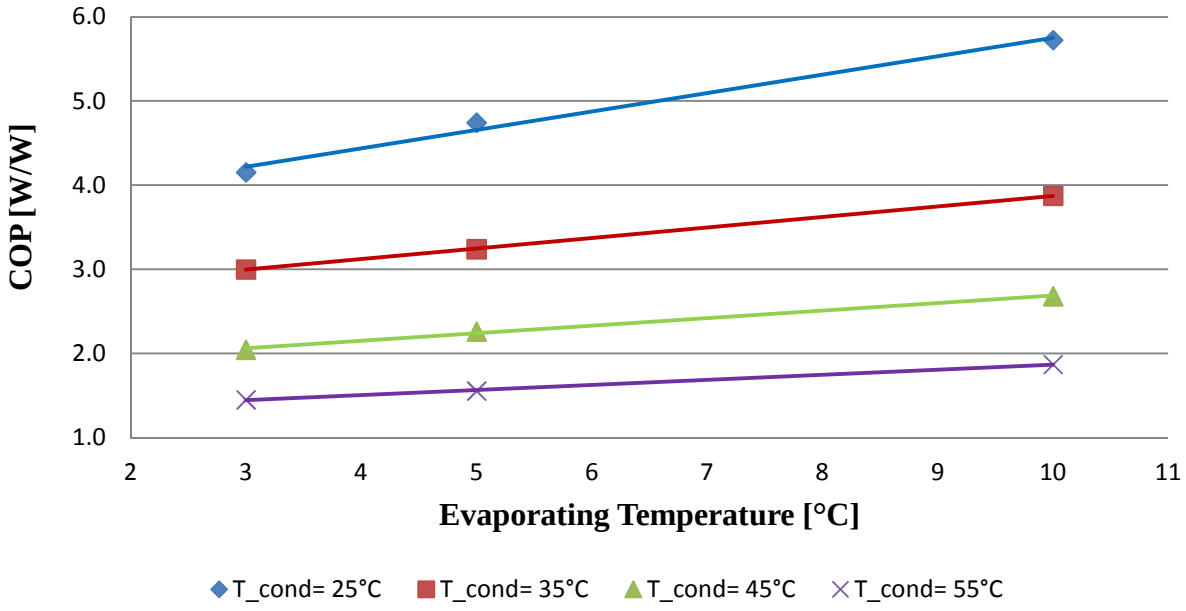


Figure 10 - COP for R-134a

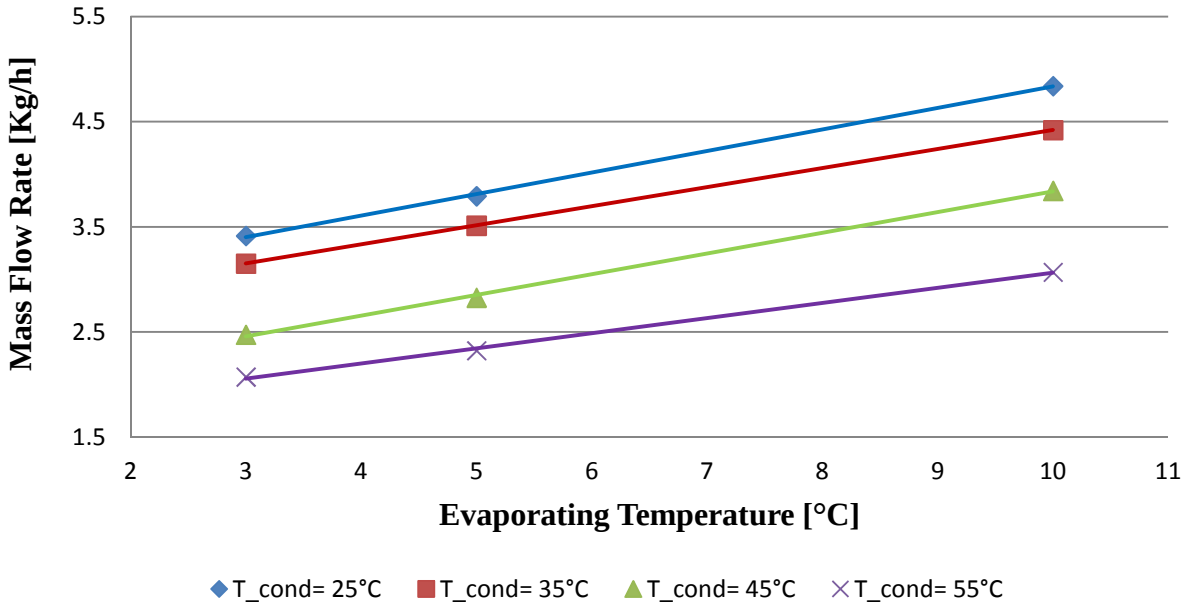


Figure 11 - Mass flow rate for R-134a

- Performance map for N-13a
  - Polynomial equation

Table 7 - Polynomial coefficients

N-13a				
Coefficients	Capacity	Power Input	COP	Mass Flow Rate
A_0	832,16	419,57	-2,96	26,53
A_1	-398,79	-258,14	7,86	-14,67
A_2	75,98	48,90	-1,44	2,78
A_3	-4,17	-2,74	0,08	-0,15
A_4	1,61	1,83	-0,31	0,06
A_5	-0,15	-0,02	0,00	0,00
A_6	0,00	0,00	0,00	0,00
A_7	0,31	0,03	-0,01	0,01
A_8	0,00	0,00	0,00	0,00
A_9	-0,02	0,01	0,00	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:

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

o Graphics

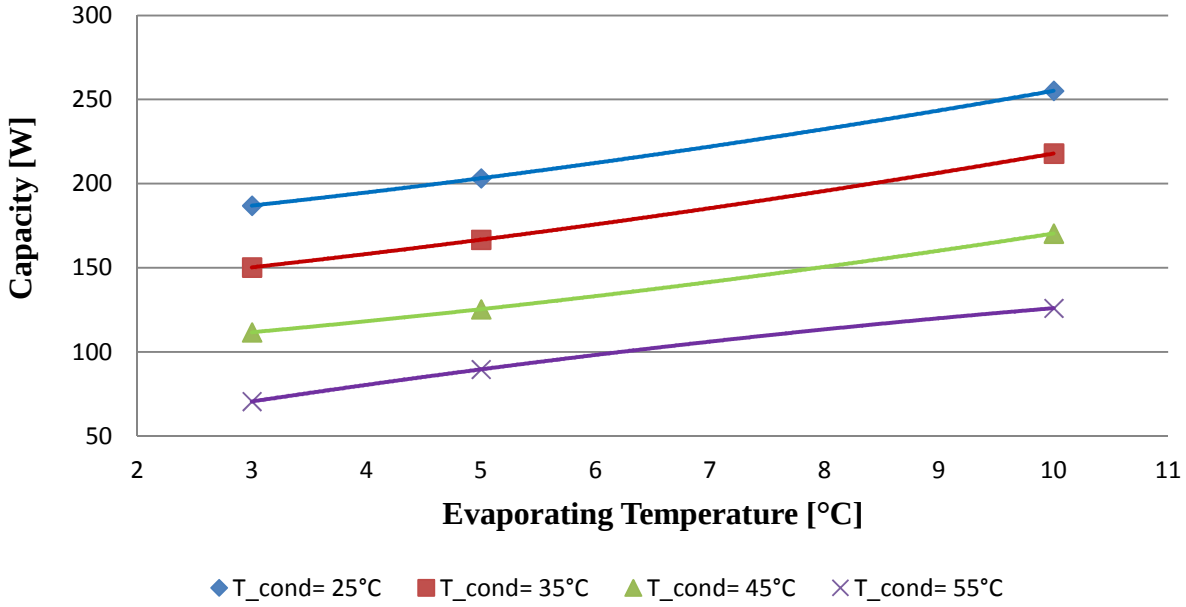


Figure 12 - Cooling capacity for N-13a

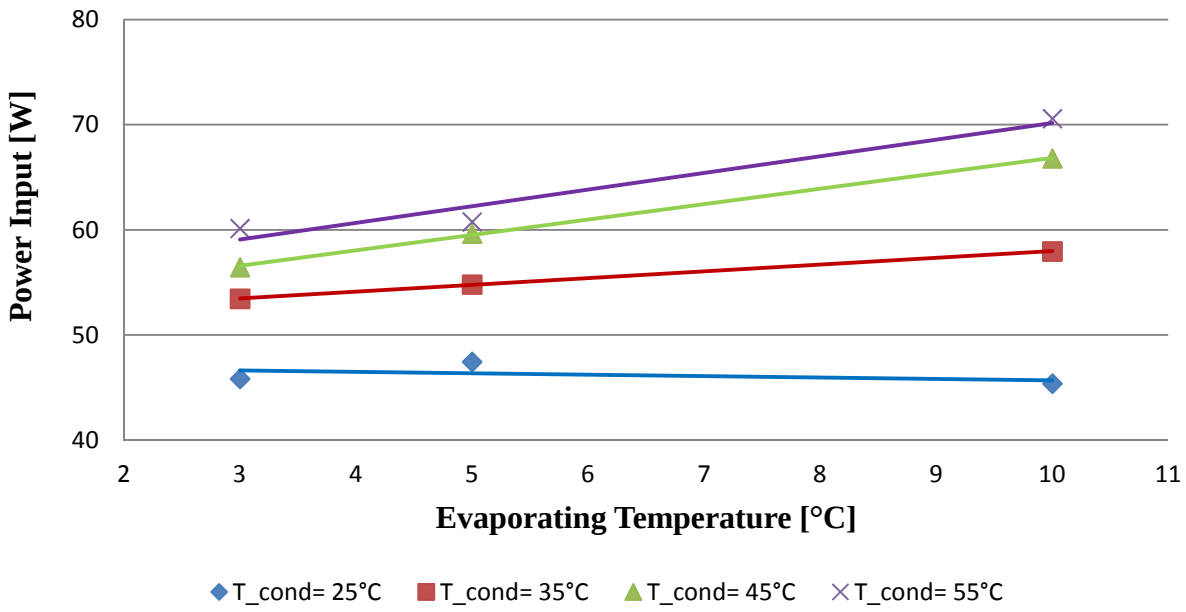


Figure 13 - Power Input for N-13a

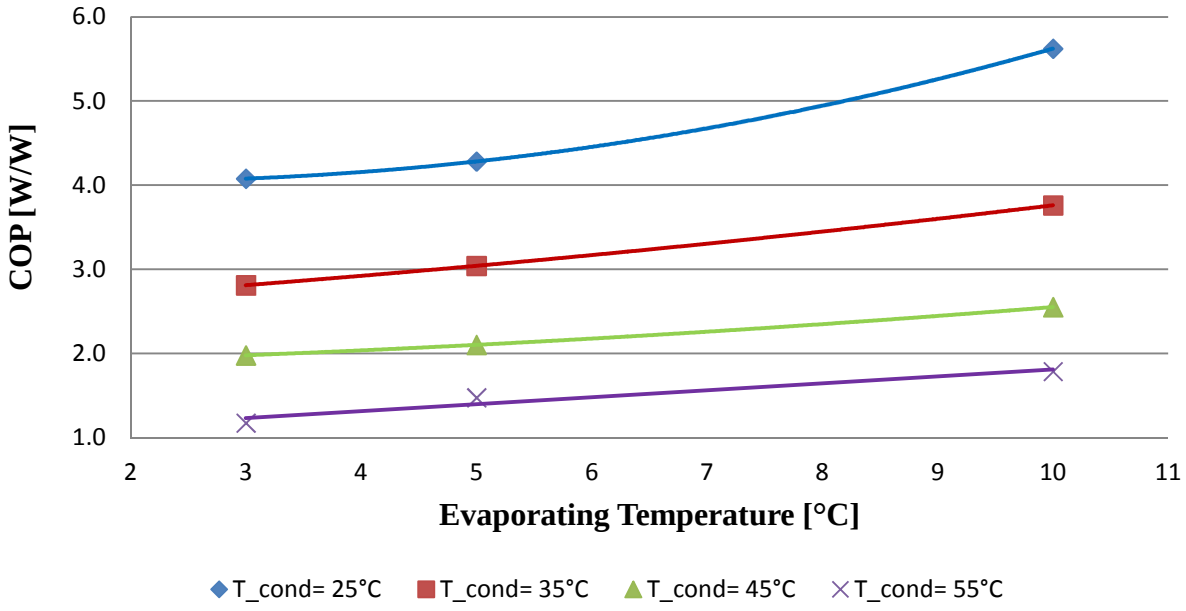


Figure 14 - COP for N-13a

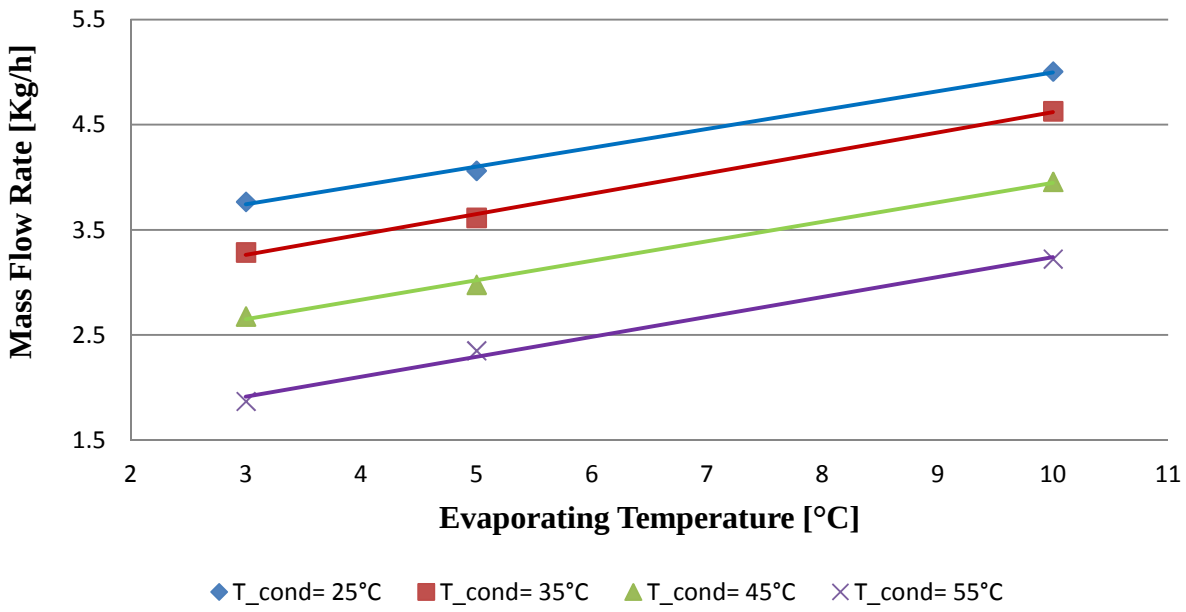


Figure 15 - Mass flow rate for N-13a

- Comparative performance map for R-134a and N-13a
  - Polynomial equation

Table 8 - Polynomial coefficients

N-13a / R-134a	
Coefficients	COP_{N-13a}/COP_{R-134a}
A_0	0,47
A_1	0,55
A_2	-0,13
A_3	0,01
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_{N-13a}/COP_{R-134a}

- Graphic

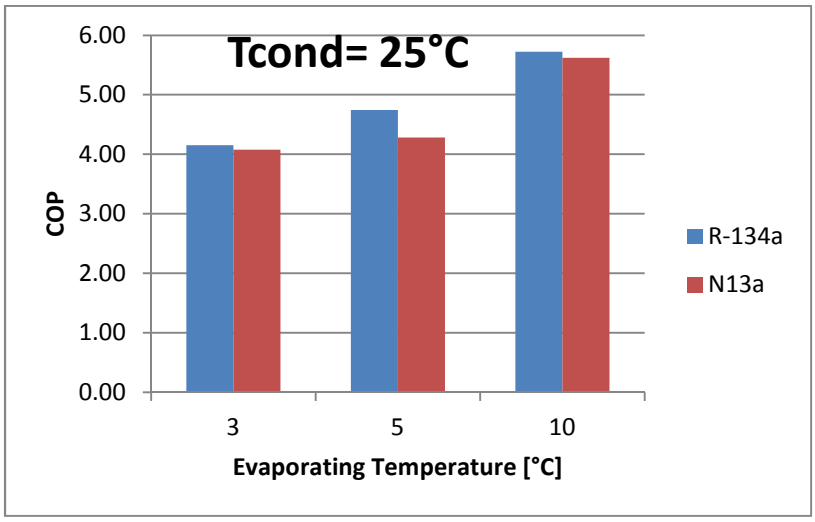


Figure 16 - Comparative COP

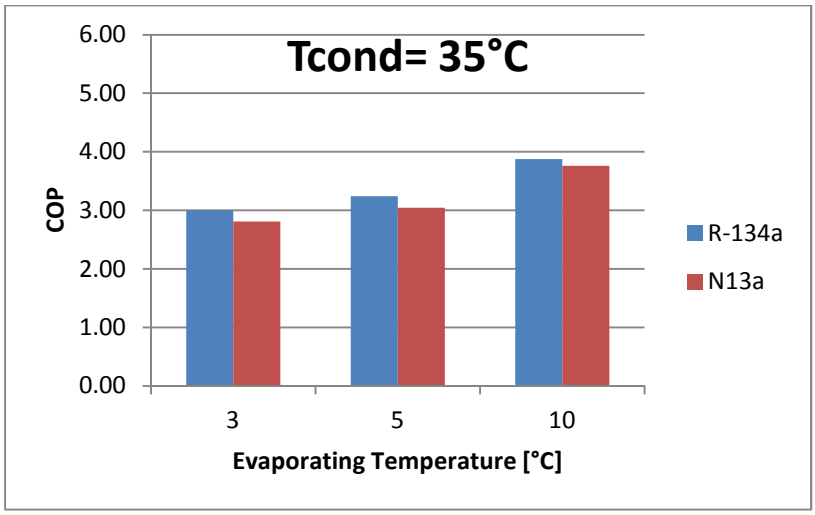


Figure 17 - Comparative COP

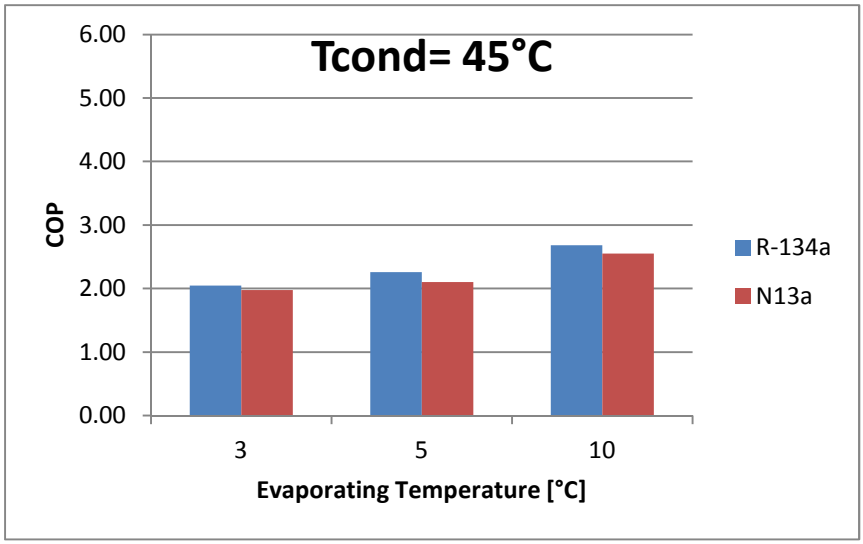


Figure 18 - Comparative COP

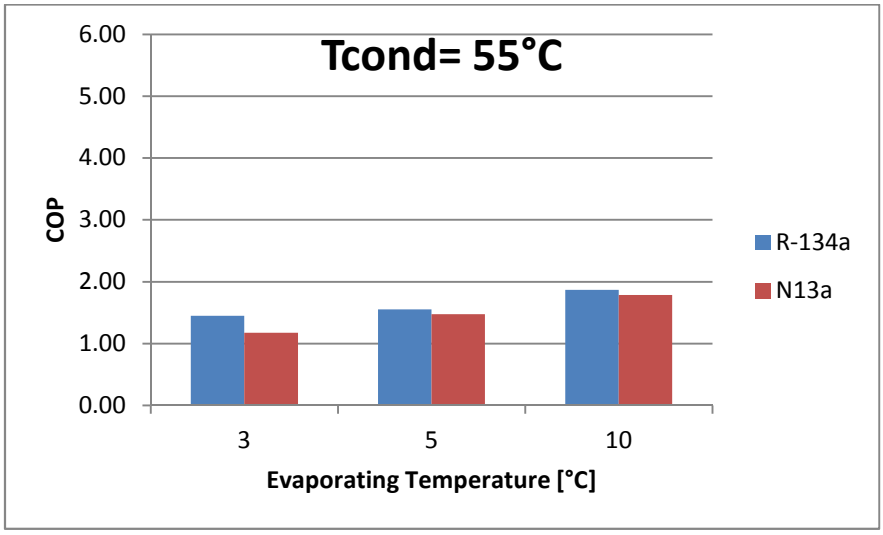


Figure 19 - Comparative COP