Novel HFO Refrigerant Blend R-474A for GWP <1 Automotive Heatpump Application

(266)

Ivan Rydkin, Tsubasa Nakaue, Alvaro Leon

Alvaro.DeLeon@daikinchem.de

Introduction

- Electric cars are expected to represent 30% to 50+% of new car sales by 2030 in the US, China and Japan
- Wide adoption increases vehicle demands across all climate zones.
- Lack of “Free” engine heat currently requires vehicles to utilize electric resistive heaters (COP 1)
- Winter range decrease of 25+% is observed
- Fast charging increases heating and cooling load on the vehicle

NEWSROOM

News Resources People

Automotive

Icy Temperatures Cut Electric Vehicle Range Nearly in Half

AAA research finds HVAC use in frigid temperatures causes substantial drop in electric vehicle range

Ellen Edmonds
Director, External Communications
eedmonds@national.aaa.com
2/7/2019

ORLANDO, Fla. (Feb. 7, 2019) – As freezing temperatures plague much of the country, electric vehicle owners may experience a decrease in driving range, compounded by the use of the vehicle's interior climate control. New research from AAA reveals that when the mercury dips to 20°F and the HVAC system is used to heat the inside of the vehicle, the average driving range is decreased by 41 percent. This means for every 100 miles of combined urban/highway driving, the range at 20°F would be reduced to 59 miles. When colder temperatures hit, AAA urges electric vehicle

CR Consumer Reports

Find the Best....

Cars Home & Garden Appliances Electronics News Deals Gift Guide More +

Cars / Hybrids/EVs / Cold Temperatures Affect An Electric Vehicle's Driving Range

How Much Do Cold Temperatures Affect an Electric Vehicle's Driving Range?

The cold, hard truth about winter's effects on EV batteries

By Devin Pratt
December 19, 2021

Photo: Adobe Stock

With a proliferation of choices covering electric vehicle styles and driving range, more Americans are considering purchasing an EV. One

GREEN CAR REPORTS NEWS FIRST DRIVES ELECTRIC CARS HYBRIDS GUIDES GREEN LIFE

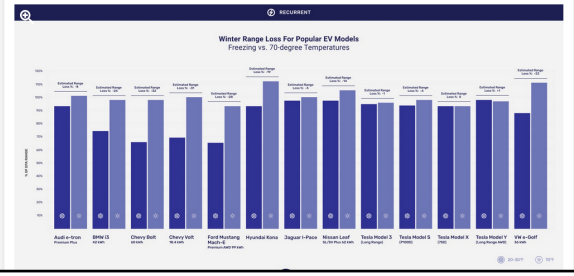
Cold weather affects EV range differently for each model: Here are some examples

STEPHEN EDELSTEIN DECEMBER 16, 2021 71 COMMENTS View Gallery

All electric cars experience some range loss in cold weather, but many factors can affect how much, according to a new report from battery analysis firm Recurrent.

Range loss is an inevitable result of cold temperatures for two reasons, Recurrent noted. Cold temperatures slow down the chemical reactions in battery cells, and because they don't have heat-producing engines, EVs must use additional battery power to warm their cabins. Beyond that, though, there can be major differences between models.

A crucial element is the availability of a heat pump, which can warm the interior without drawing as much power from the battery pack. Recurrent's data showed that the heat-pump-equipped Audi E-Tron and Jaguar I-Pace generally retained most of their EPA-rated range in winter.

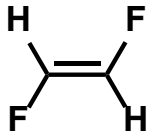


Introduction

Development Needs:

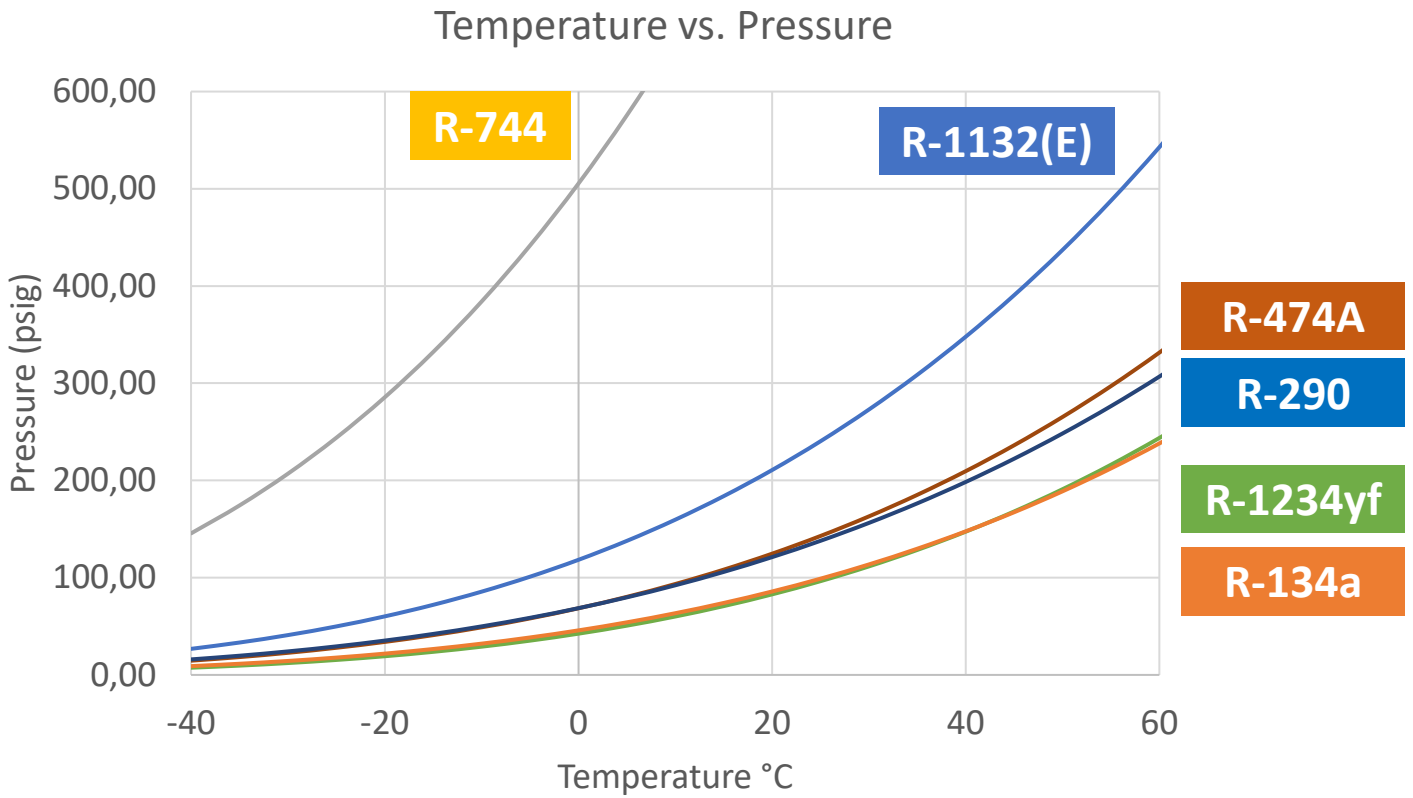
- GWP
  - EPA SNAP & EU MAC Directive requires GWP <150
  - Phasedown modeling and demand in other refrigerant consuming markets indicates a real maximum GWP of <80 and preferred GWP of <1 for any future refrigerant
- Operation temperature
  - -20°F (-29°C) at full capacity and COP >1.5
  - -30°F (-34°C) for operation and COP >1
- Safety
  - A2L for ‘drop-in’ for existing direct expansion systems
  - A2 + risk assessment + cabin concentration limit for direct expansion per SNAP
  - A2/A3 + Risk Assessment for secondary loop
- Operation Pressure
  - Similar range (+/- 20%) required to operate with existing approved component supply chain

Introduction



HFO-1132(E)
1,2-Difluoroethene

		HFO-1132(E)
Molecular formula		CHF=CHF
Molecular weight	g/mol	64.0
Critical temperature	℃	75.7 1)
Critical pressure	MPa	5.17 1)
Boiling point (101.3kPa)	℃	-52.5 1)
Vapor pressure at 25 ℃	kPa	1,666 1)
Vapor density at 25℃	kg/m3	56.4
Liquid density at 25℃	kg/m3	938
Latent heat at 25℃	kJ/kg	213.7
Lower flammability limit	vol%	4.4
Burning velocity	cm/s	30.2
GWP		0.0036 2)

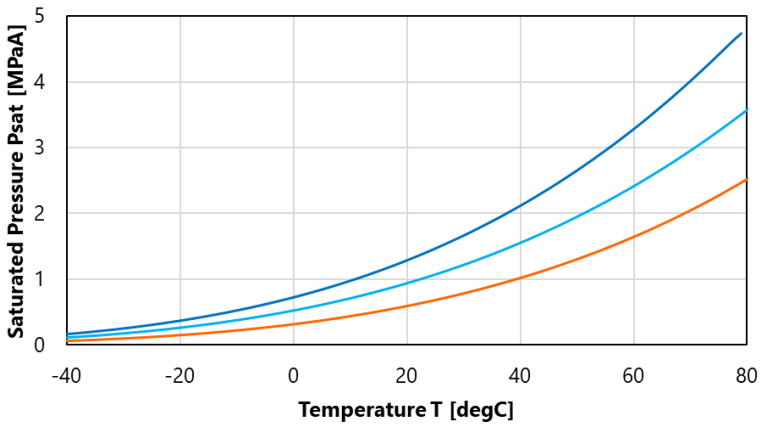


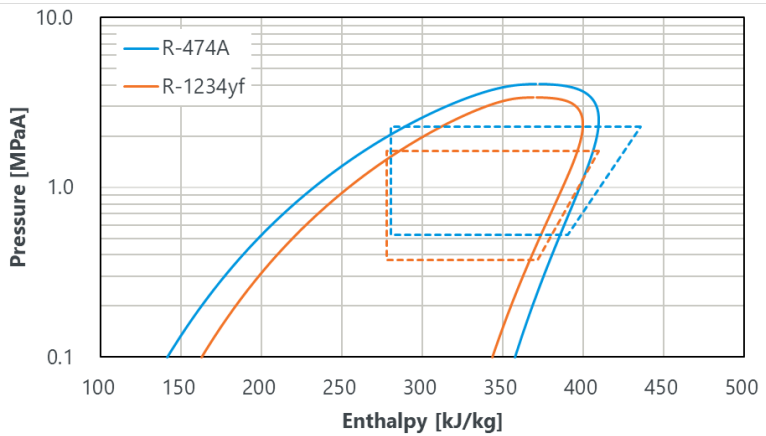
Introduction

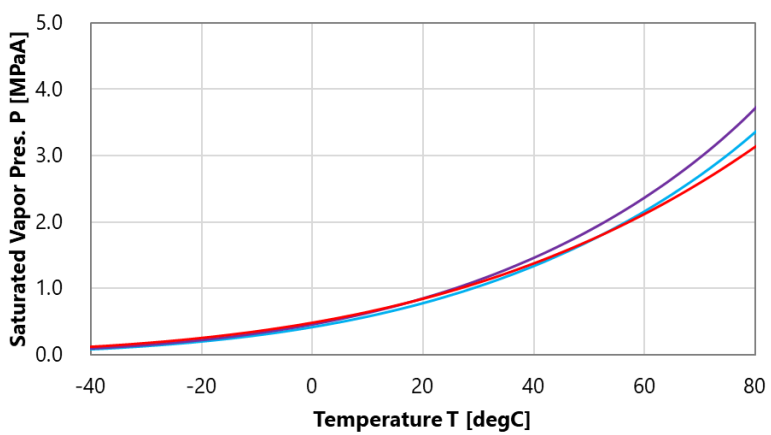
Candidate	GWP	Performance								Safety		
		COP	Capacity	Glide Eva/Cond	Disch. Temp.	Condensing Pressure	Evaporating Pressure	Boiling Point	Critical Temp.	Safety	LFL	Burning Velocity
		R1234yf=100	R1234yf=100	[K]	[degC]	[MPaA]	[MPaA]	[degC]	[degC]	ASHRAE Class	[vol%]	[cm/s]
R-474A*	<1	99	140	3.6/5.0	80	2.29	0.52	-43	87	A2L	5.5	2.9
R-1234yf	1	100	100	0/0	70	1.64	0.37	-29	95	A2L	6.2	1.5
R-290	3	105	146	0/0	81	2.12	0.55	-42	97	A3	2.1	43
R-152a	124	114	110	0/0	96	1.50	0.31	-24	113	A2	4.8	23

Condition: Te=5[degC], Tc=60[degC], SH=5[K], SC=5[K], Comp Efficiency=70[%]

* R-1132(E)/R-1234yf = 23/77%







Laboratory Tests

Compressor Calorimtery

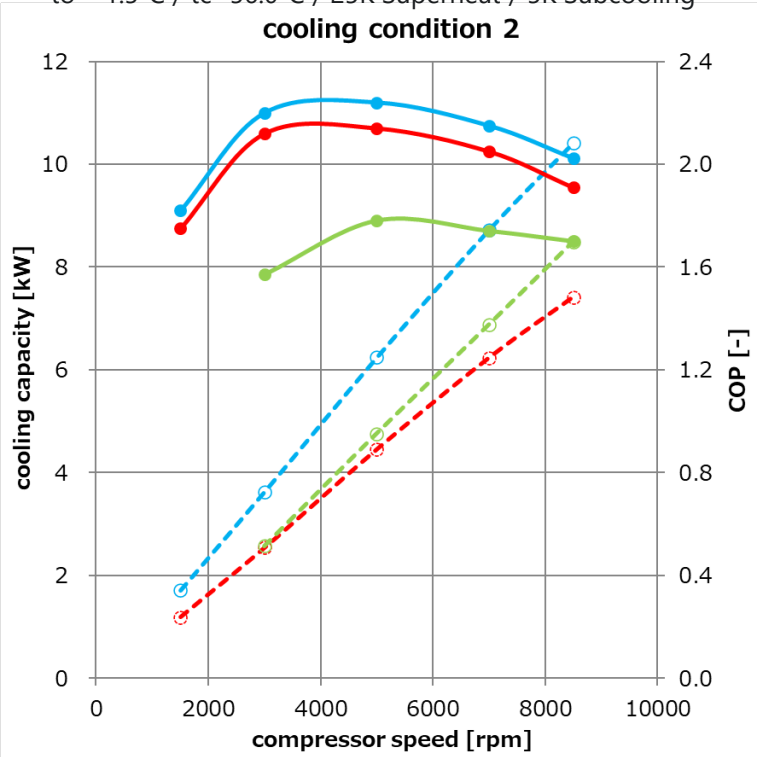
Specs and condition

Compressor	-	Brose
Displacement	[cc]	34
Oil	-	PAG
Super heat	[K]	25
Sub cool	[K]	10

Air Conditioning points

Test condition		R1234yf	R-474A	R744
Discharge pressure	[MPaA]	1.5	2.0	10.5
Suction pressure	[MPaA]	0.3	0.405	3.5

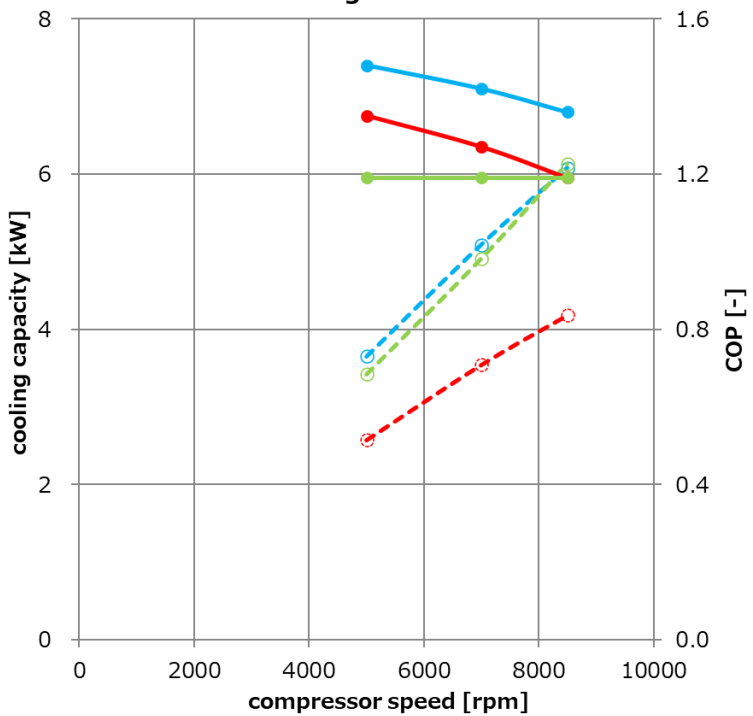
to=-1.5°C / tc=56.0°C / 25K Superheat / 5K Subcooling



Heat Pump points

Test condition		R1234yf	R-474A	R744
Discharge pressure	[MPaA]	1.5	2.0	10.5
Suction pressure	[MPaA]	0.2	0.27	0.264

to=-12.8°C / tc=56.0°C / 10K Superheat / 5K Subcooling



Compressor Calorimetry

Cooling Point 1

	Compressor RPM				
	1500	3000	5000	7000	8500
1234yf COP	1.75	2.12	2.14	2.05	1.91
R474A COP	1.82	2.2	2.24	2.15	2.024
R134a COP	1.9	2.2	2.3	2.2	2.1
R744 COP		1.57	1.78	1.74	1.7
1234yf Capacity	1.19	2.54	4.45	6.23	7.41
R474A Capacity	1.71	3.63	6.24	8.72	10.41
R134a Capacity	1.39	2.96	5.10	7.15	8.53
R744 Capacity	0.00	2.57	4.76	6.88	8.49

Cooling Point 2

	Compressor RPM				
	1500	3000	5000	7000	8500
1234yf COP		0.92	1.01	1.02	0.98
R474A COP	0.76	0.97	1.08	1.09	1.05
R134a COP		2.2	3.7	5.2	6.2
R744 COP			0.91	0.91	0.91
1234yf Capacity		1.62	2.87	4.02	4.8
R474A Capacity	1.35	2.39	4.17	5.86	7.03
R134a Capacity		2.15	3.73	5.21	6.22
R744 Capacity			3.01	4.41	5.52

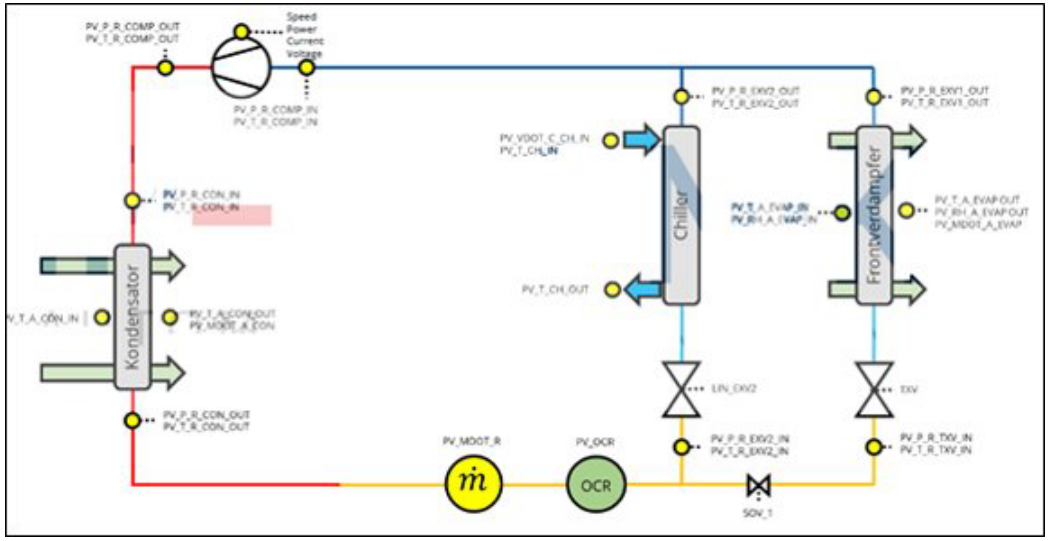
Heating Point 1

	Compressor RPM				
	1500	3000	5000	7000	8500
1234yf COP			1.02	0.97	0.92
R474A COP			1.14	1.1	1.05
R744 COP			1.2	1.2	1.2
1234yf Capacity			1.85	2.57	3.03
R474A Capacity			2.57	3.58	4.28
R744 Capacity			3.42	4.91	6.13

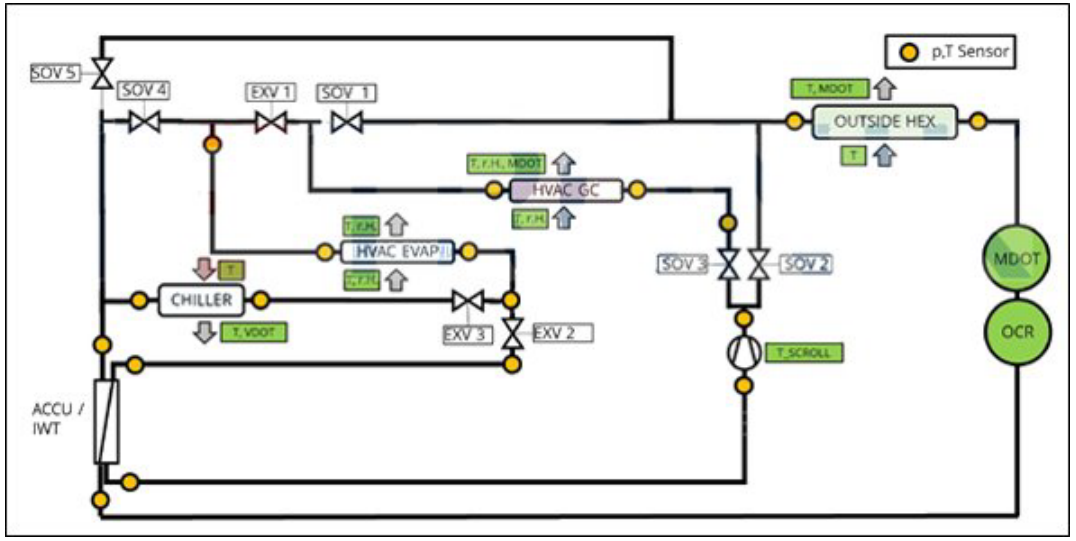
Heating Point 2

	Compressor RPM				
	1500	3000	5000	7000	8500
1234yf COP			0.57	0.55	0.52
R474A COP			0.67	0.66	0.637
R744 COP			1	0.98	0.97
1234yf Capacity			1.07	1.55	1.83
R474A Capacity			1.72	2.42	2.88
R744 Capacity			2.64	3.82	4.76

Bench Test

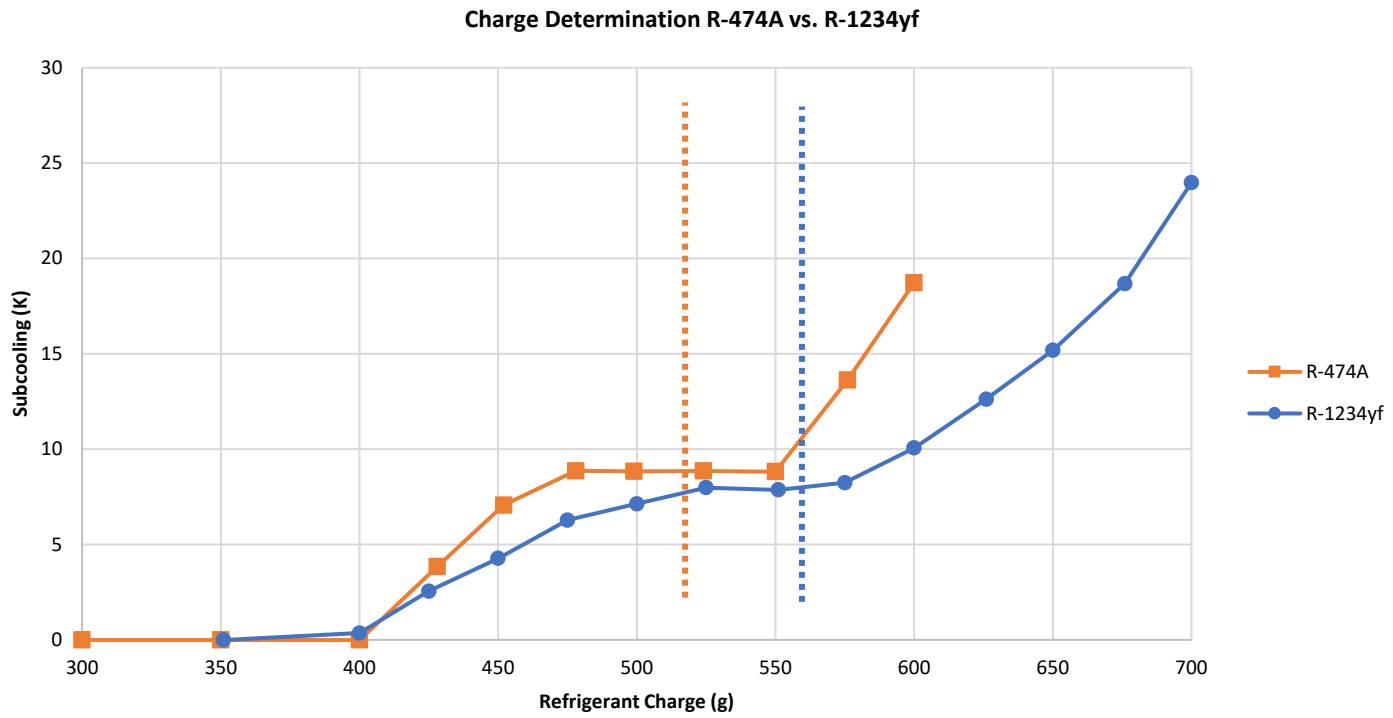


R1234yf system



R744 system

Bench Test



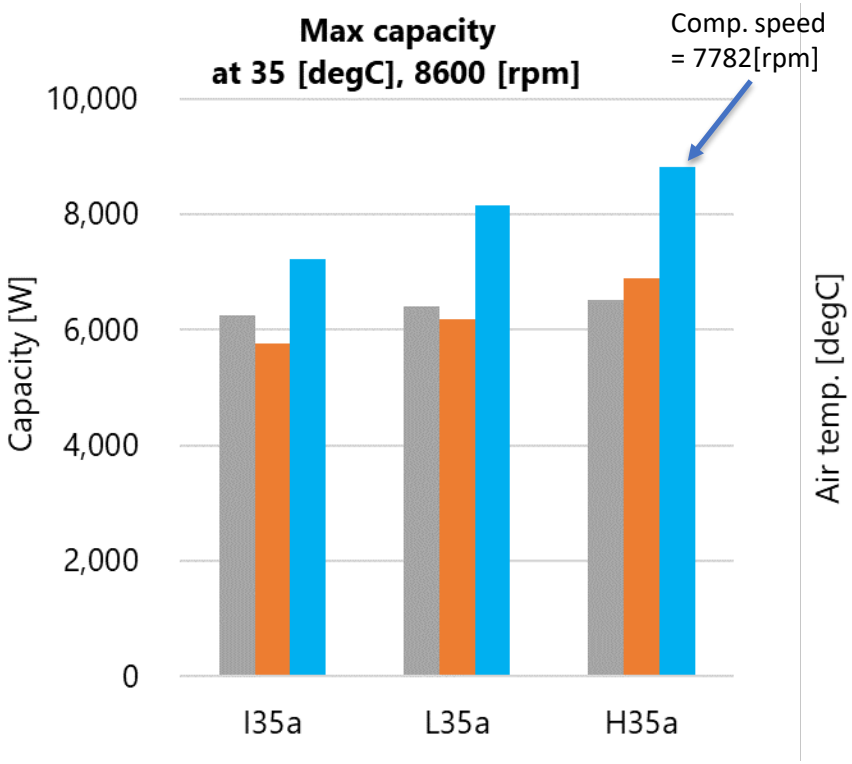
Optimal charge for R474A at drop-in is around 91% of R1234yf for this system

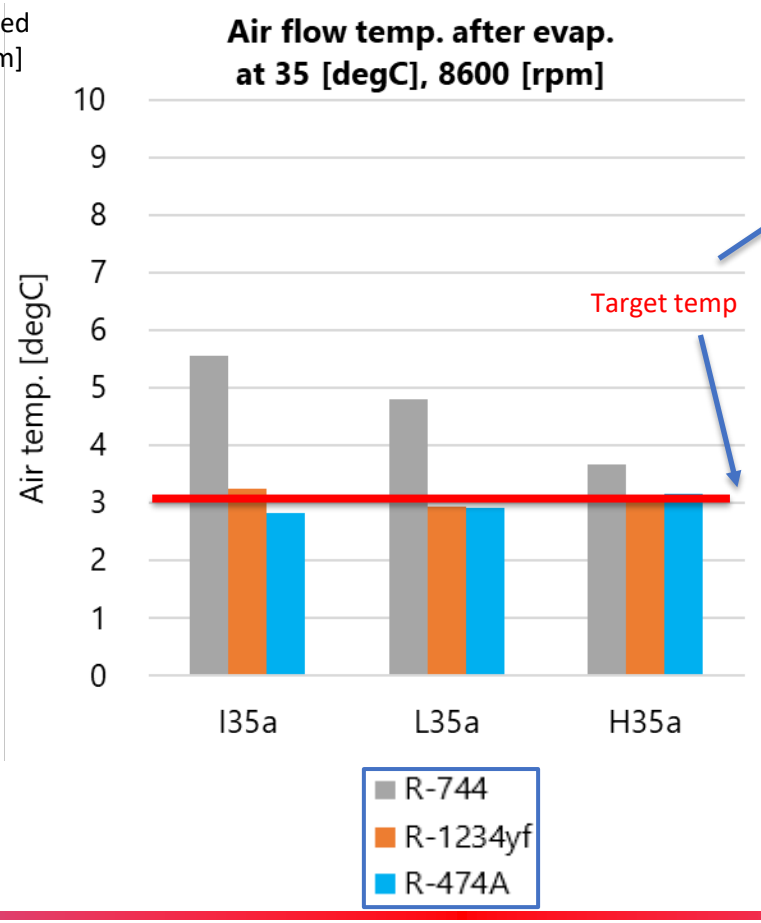
Bench Test

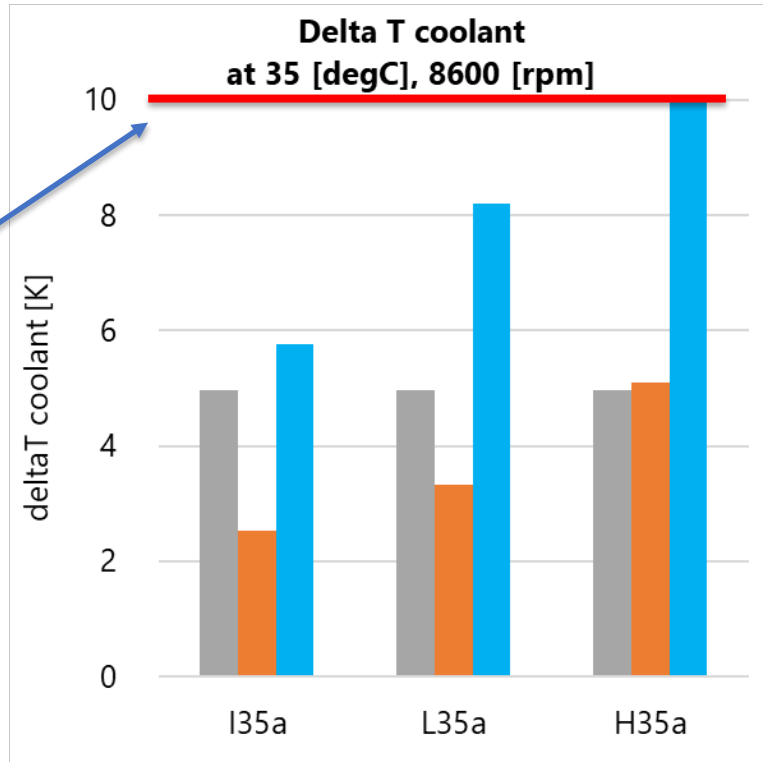
Test	Condenser Air Temp (° C)	Condenser Air Flow (m/s)	Evaporator Air Temp (° C)	Evaporator Humidity (%)	Evaporator Air Mass Flow (kg/h)	Chiller Inlet Temperature (° C)	Coolant Flow Rate (l/min)	Air Temperature Target (° C)	Coolant ΔT (K)
I60	60	1.5	35	25	300	40	10	3	10
I45	45	1.5	35	25	300	40	10	3	10
M45	45	3	35	25	300	40	10	3	10
H45a	45	4	35	25	300	40	10	3	10
I50a	50	1.5	35	40	300	30	6.7	3	10
I35a	35	1.5	35	40	300	30	6.7	3	10
L35a	35	2	35	40	300	30	6.7	3	10
H35a	35	4	35	40	300	30	6.7	3	10
I40a	40	1.5	25	80	210	25	2.0	3	5
I25a	25	1.5	25	80	210	25	2.0	3	5
H25a	25	4	25	80	210	25	2.0	3	5
I40c	40	1.5	25	50	210	25	2.0	3	5
I25c	25	1.5	25	50	210	25	2	3	5
I30	30	1.5	15	80	210	Off	Off	3	Off
I15	15	1.5	15	80	210	Off	Off	3	Off

Results – Max Capacity

Inside temperature and humidity : 35°C and 40 RH%
Air mass flow : 300 kg/h
Air temp. after evap. : 3°C
Coolant inlet : 30°C
Coolant flow rate : 6.7 L/min
Delta T coolant : 10 K

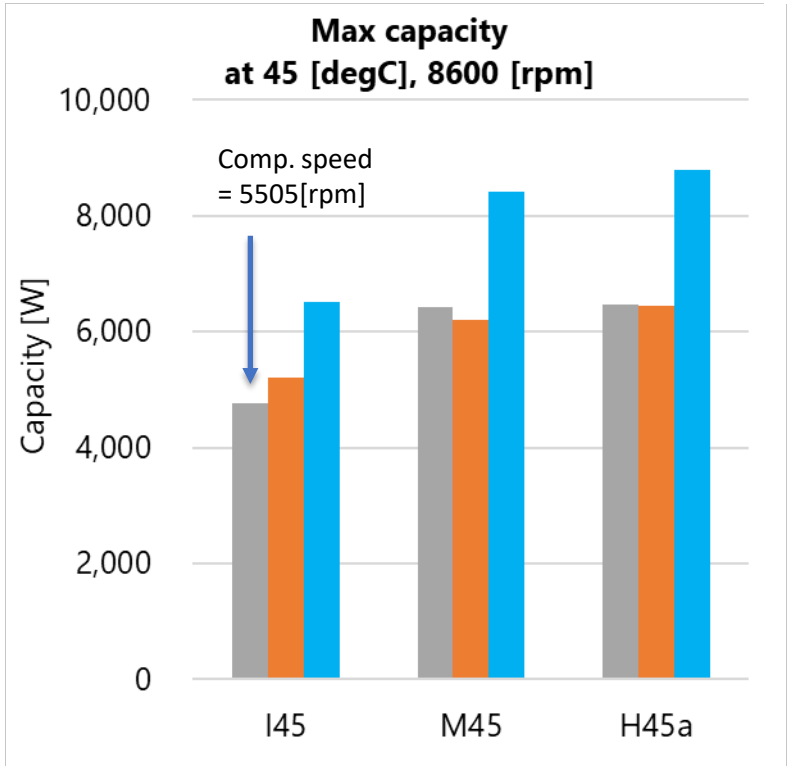


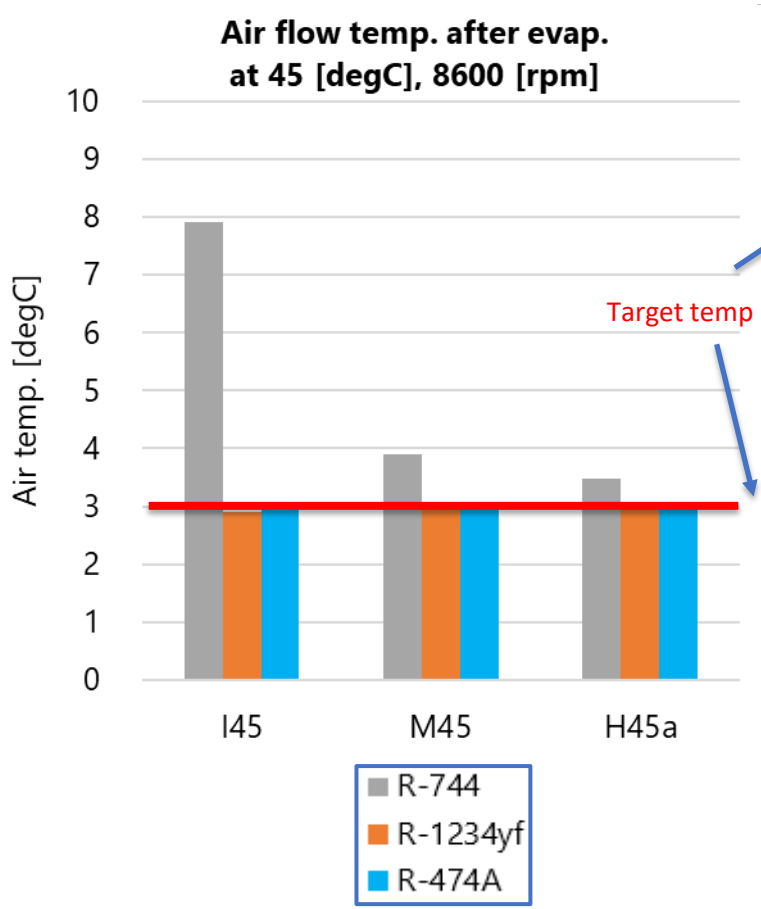


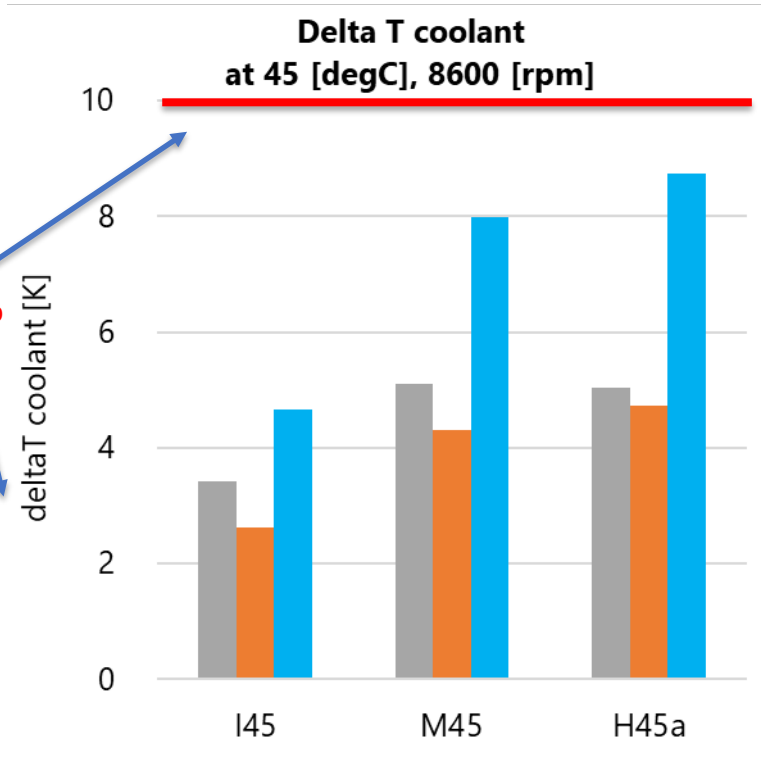


Results – Max Capacity

Inside temperature and humidity : 35°C and 25 RH%
Air mass flow : 300 kg/h
Air temp. after evap. : 3°C
Coolant inlet : 40°C
Coolant flow rate : 6.7 L/min
Delta T coolant : 10 K



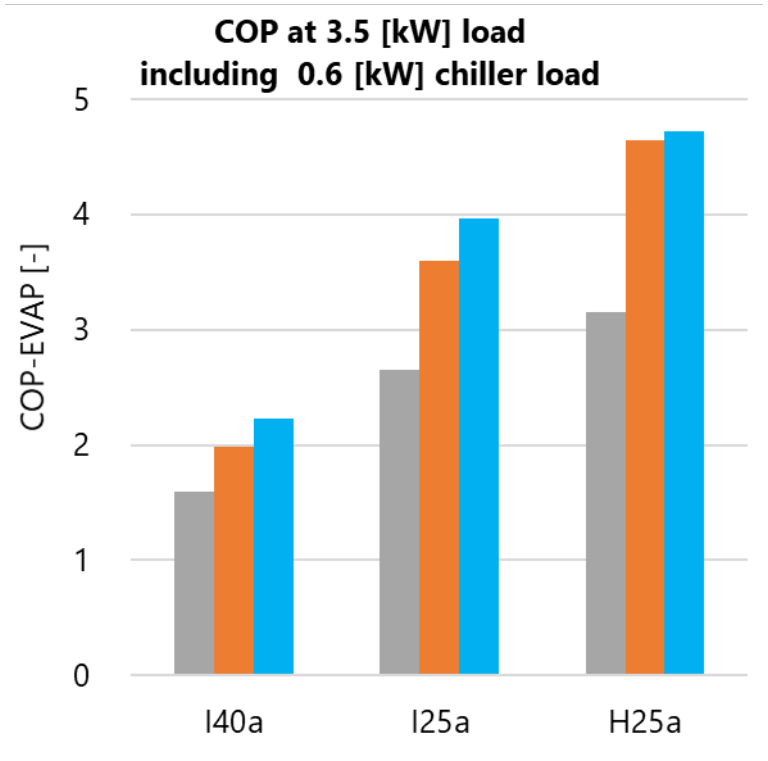


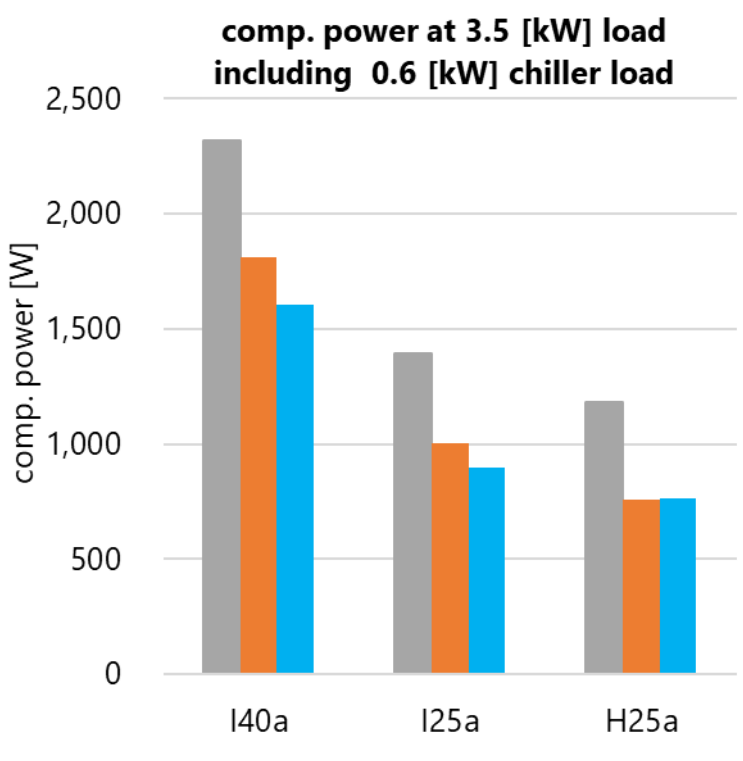


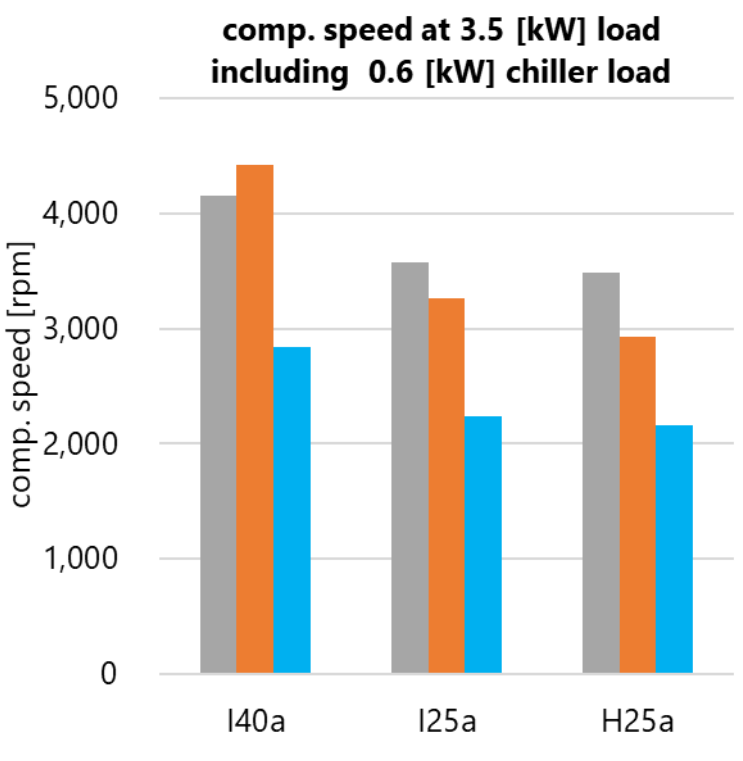
Results – Fixed Capacity

Inside temperature and humidity : 25°C and 80 RH%
Air mass flow : 210 kg/h
Air temp. after evap. : 3°C
Coolant flow rate : 2.0 L/min
Delta T coolant : 5 K

R-744
R-1234yf
R-474A



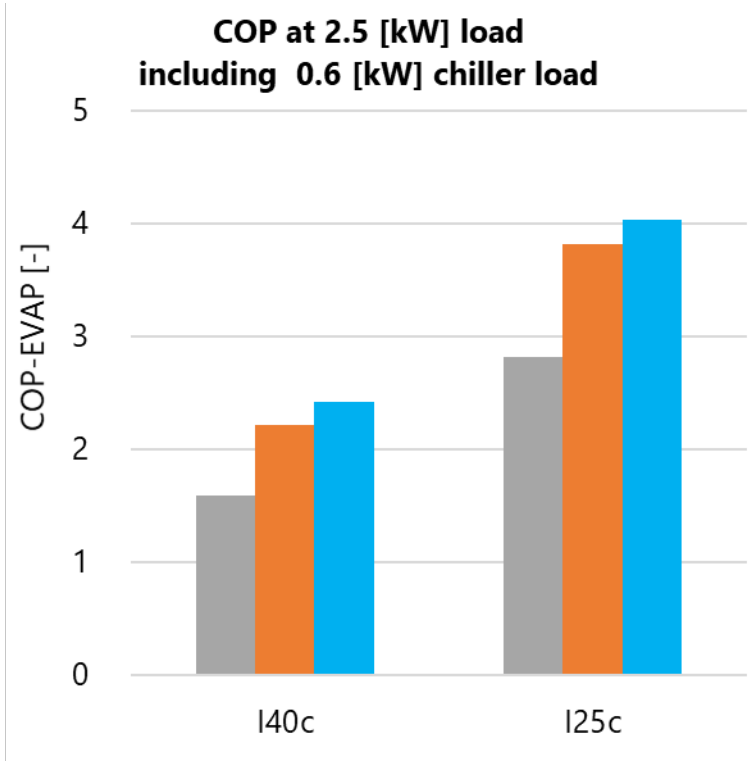


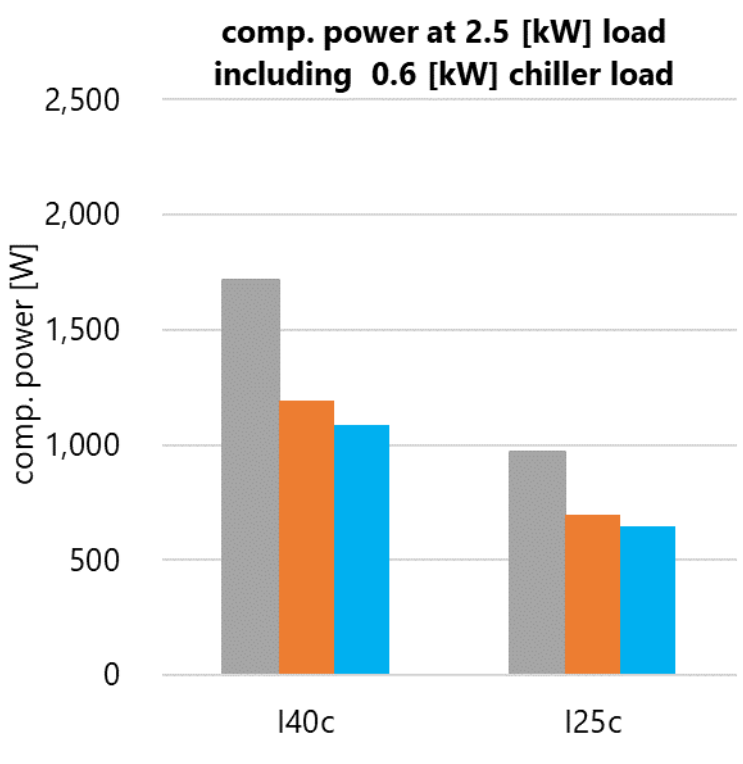


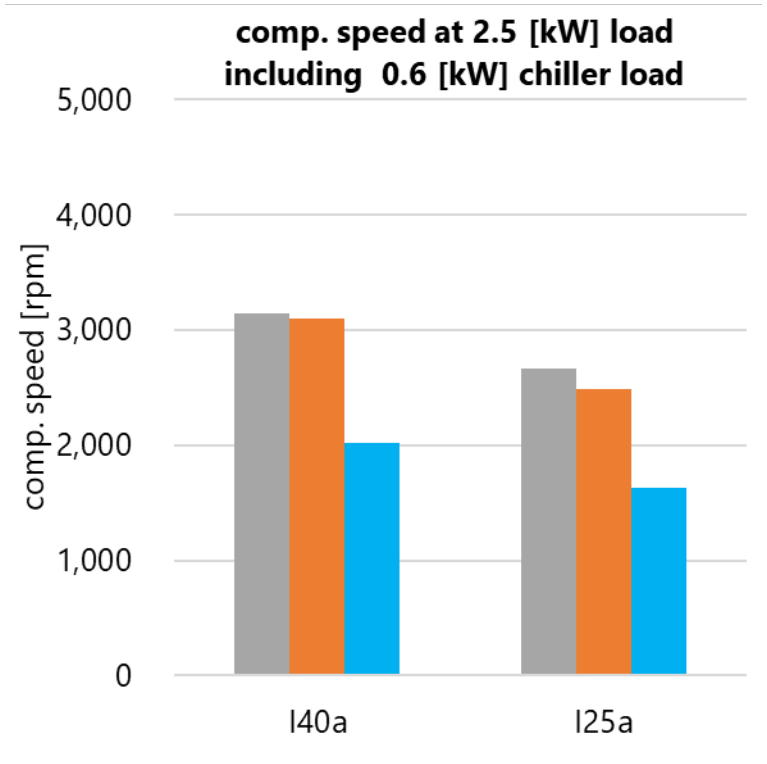
Results – Fixed Capacity

Inside temperature and humidity : 25°C and 50 RH%
Air mass flow : 210 kg/h
Air temp. after evap. : 3°C
Coolant flow rate : 2.0 L/min
Delta T coolant : 5 K

R-744
R-1234yf
R-474A







Conclusion

• Based on the bench test results observed, R-474A is capable of extending the heating range of a traditional R-1234yf heatpump system beyond 0° C to -10° C and with this trend extending likely a significant amount of heat being available at -20° C. This indicates that a reduction in the quantity and use of PTC heaters Is possible as a potential weight and cost savings.

• Additionally at mild cooling conditions when matching capacity, there is a significant improvement in COP, indicating that for a typical automotive drive cycle, there is opportunity to reduce total HVAC energy consumption and thus improve cruising range.

• Furthermore, charge determination experiment indicates that the total refrigerant charge for an R-474A system when dropped into an existing commercial system can be as much as 10%.

• Lastly, the significant observed improvement in capacity is shown at many of the test points. This can be utilized to either improve HVAC system noise vibration and harshness (NVH) characteristics by reducing RPM, which is significantly more important in generally quieter electric vehicles, or to down size the compressor.