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

TEST REPORT #12

System Drop-In Tests of Refrigerant Blends N-13a and AC5 in Bus Air-Conditioning Unit Designed for R-134a

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List of Tested Refrigerants' Compositions (Mass%)

N-13a	R-134a/R-1234yf/R-1234ze(E) (42/18/40)
AC5	R-32/R-152a/R-1234ze(E) (12/5/83)

1. **Introduction:**

This report presents the results of cooling performance drop-in tests on a typical Thermo King bus air-conditioning unit with refrigerant R-134a as a baseline and two alternative blends.

<u>The alternative refrigerants involved in this evaluation are listed below:</u>

Alternative (Manufacturer): AC5 (Mexichem)
N-13a (Honeywell)

Cooling capacity tests were performed in May 2012 at Ingersoll-Rand's Engineering and Technology Center in Prague, Czech Republic. The HVAC test labs in the Technology Center are capable of performing bus and rail air-conditioning tests according Thermo King Standards.

2. **Details of Test Setup:**

The unit tested was a Thermo King Athenia™ S-805 standard rooftop bus air conditioner. The S-805 employs R-134a as the refrigerant and it has a nominal cooling capacity of 24 kW under Thermo King's standard rating conditions as shown in Table 1 and at a nominal compressor speed of 3000 RPM. The unit works with a Thermo King open-shaft 4 cylinder reciprocating compressor with a displacement of 492 cm^3 (30 cu in).

Bus air conditioners typically employ an open-shaft compressor, which is belt driven from the bus engine. The unit is connected to the compressor by hoses and tubes. The basic bus HVAC circuit consists of a compressor, a condenser coil, an expansion valve and an evaporator coil. Figure 1[1] shows the layout of major components for a roof –mounted system. Electrical power for the condenser fans and evaporator blowers are usually supplied from a 24 V DC alternator mounted on the bus engine.

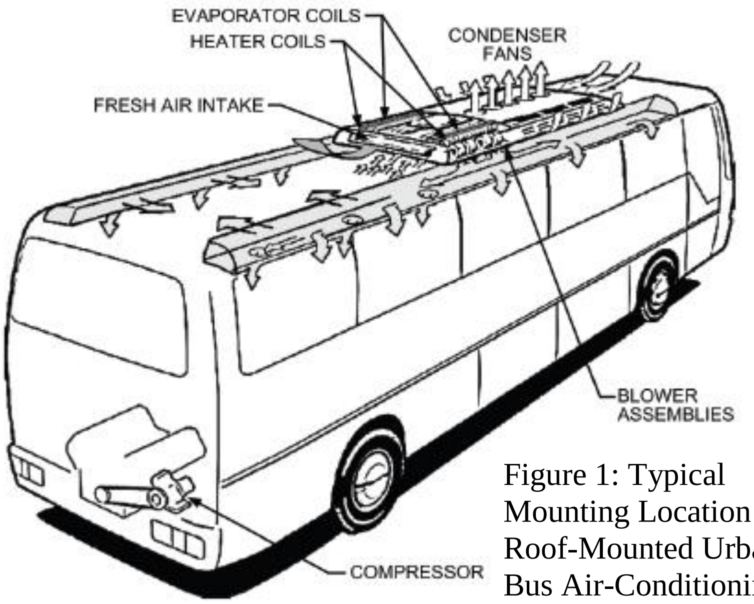

Figure 1: Typical Mounting Location of Roof-Mounted Urban Bus Air-Conditioning Equipment with Single Compressor

[1] 2011 ASHRAE Handbook, HVAC Applications, Chapter 11 MASS TRANSIT, page 11.5.

A test stand with an electric motor is used for cooling capacity measurements of bus HVAC units in a laboratory environment. The HVAC compressor is driven from the electric motor and the rotational speed and compressor shaft torque are measured in order to exclude power losses of the electric motor. The compressor input power is then determined from measured torque and rotational speed. The input power of 24 V DC electric blowers and fans is directly measured by a power analyzer. Total bus HVAC unit power input is a summation of the compressor input power calculated from compressor rotational speed and torque and electric components input power directly measured by power analyzer.

All tests were performed with the Thermo King standard 35 cSt polyol ester compressor lubricant. The oil and filter drier were changed at the end of the testing for each refrigerant.

Table 1: Test temperature conditions

Condenser Air Inlet Temperature (CAIT)		Evaporator Air Inlet Temperature (EAIT)		Evaporator Dew Point Inlet Temperature (EDPIT)		Note:
[°C]	[°F]	[°C]	[°F]	[°C]	[°F]	
35.0	95.0	26.7	80.1	15.6	60.1	TK Standard rating condition
40.0	104.0	40.0	104.0	27.6	81.7	MAX capacity (50 % RH at 40°C)
48.9	120.0	48.9	120.0	15.6	60.1	TK MAX

The HVAC test cell is shown in Figure 2 and consists of a condenser (hot) room, evaporator room and control room. The tested unit and the compressor are installed in the hot room with requested condenser ambient temperature. The evaporator room consists of technology for setting requested evaporator conditions – return air temperature and humidity. The cooling capacity on the air side is calculated at steady state conditions from the measured air flow rate and air enthalpy difference between evaporator inlet and outlet temperatures. The calculation is performed according to ANSI/ASHRAE Standard 37-2009 with measurement uncertainty ± 5 % from measured value.

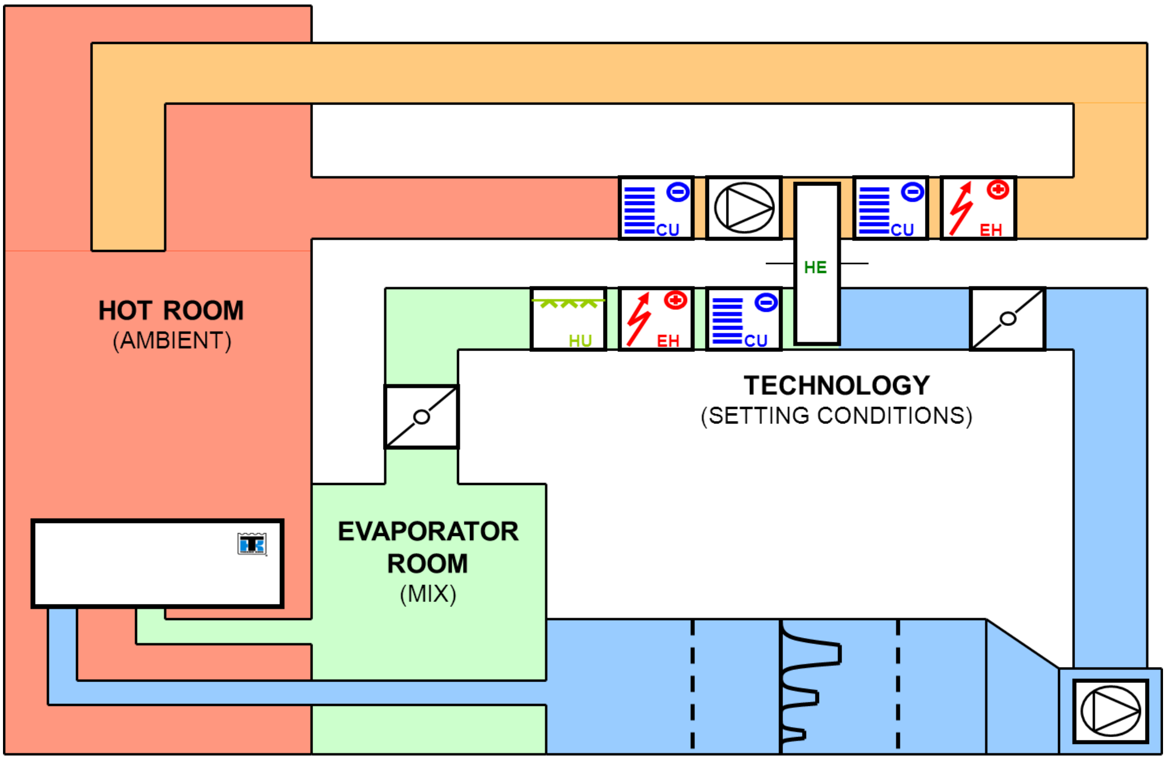

Figure 2: HVAC test lab design

HVAC test lab stability:

- Temperature ± 0.5 °C
- Static pressure ± 5 Pa
- Dew point temperature ± 0.2 °C

The tested unit was installed on the test stand in the hot room of the HVAC lab and the compressor was installed on the compressor test stand for torque measurement. Afterwards, the unit was charged with R-134a according to the unit specification and the thermal expansion valve (TXV) setting was verified. After the nominal cooling capacity was verified at standard rating conditions and at a compressor speed of 3000 RPM, the cooling capacity tests were performed at several levels of compressor speeds and under the temperature conditions shown in Table 1.

After the baseline tests were completed, the R-134a refrigerant was recovered, the filter drier and oil were changed, and the unit was then charged with N-13a refrigerant. The N-13a charge and TXV position were adjusted at TK Standard rating conditions and at a compressor speed of 3000 RPM in order to achieve optimal cooling capacity before repeating the R-134a test conditions. The N-13a test procedure was repeated for the AC5 refrigerant.

The refrigeration system cycle diagram and probe placement is illustrated in Figure 2. All drop-in tests were conducted with the alternative refrigerants placed in the representative system with no modifications made to the equipment except for refrigerant charge and TXV adjustments.

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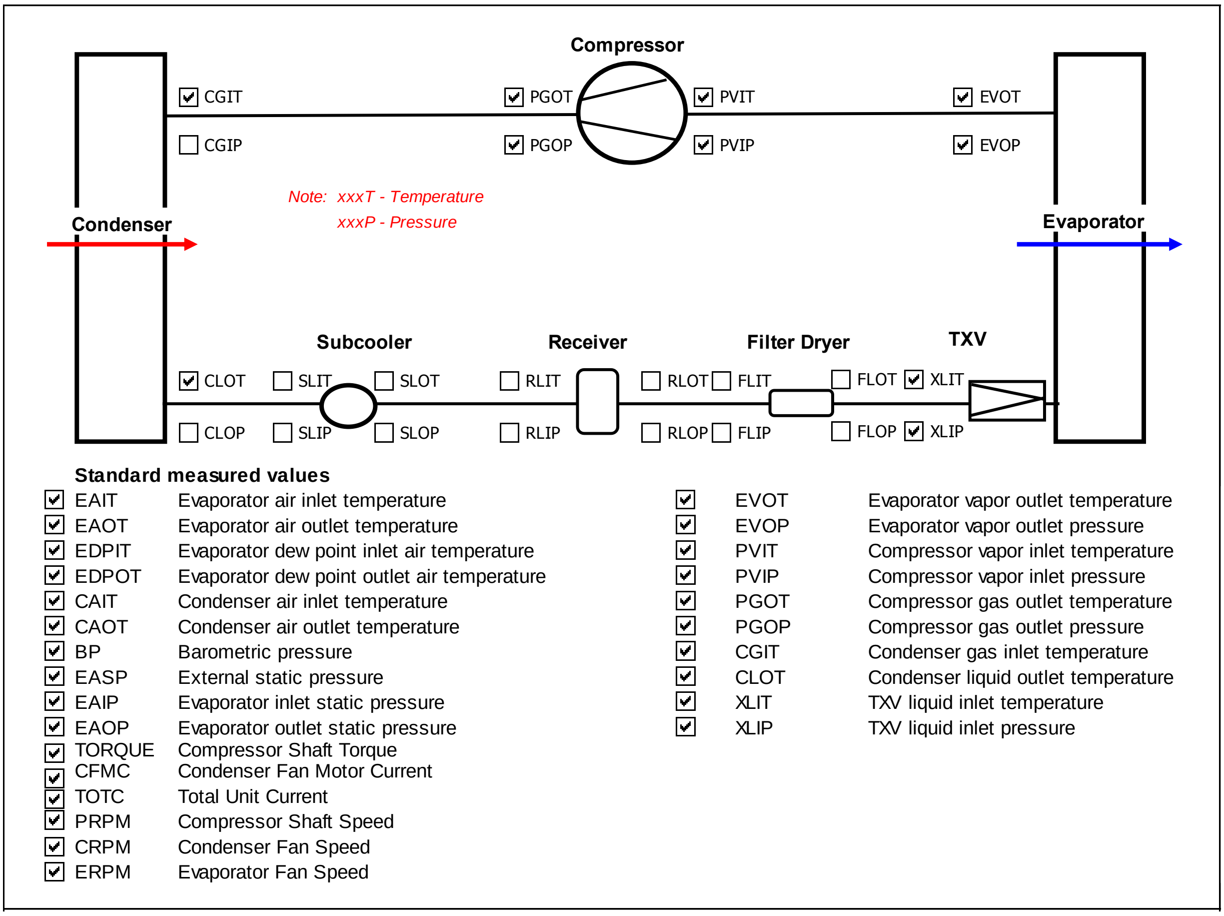

Figure 2: Refrigeration system cycle diagram and probe placement

<u>Measurement instrumentation:</u>

Air side temperatures – Pt100 A-class sensors
Humidity – dew point devices DewMaster2001, DewPrime-C1-S2
Air pressures – Fischer Rosemount sensors
Refrigerant pressures – ZPA sensors
Refrigerant temperature – Pt100 A-class sensors
Torque – tenzometrical sensor Drehmoment Messwellen T1A
Revolutions – Optical sensors
Information temperatures –Thermocouples Cu-Co
Electrical data – Power analyzer NORMA

The Technology Center has ISO 9001 certification. All the testing equipment and measuring devices used are regularly inspected and calibrated.

3. Results

The following tables and charts present a comparison summary of the results calculated from measurements. The TXV was adjusted with focus on optimal performance at typical rating conditions. The refrigerant properties were provided by Honeywell (N-13a) and Mexichem (AC5). The evaporator superheat temperature, ESH, is calculated as a difference between the temperature measured at the evaporator outlet, EVOT, and evaporating temperature, $EVOT_{sat}$.

The evaporating temperature, $EVOT_{sat}$, is a function of the evaporating pressure, EVOP, and therefore the NIST database REFPROP version 8 was used for the correct determination of evaporating and condensing temperatures. The compressor input power was calculated from compressor rotational speed and torque and the fans' power input from measured voltage and current. The following equations were used to determine total value of COP:

$$COP = \frac{Q_0}{P_{UNIT}} \text{ [-]}$$

where

$$P_{UNIT} = P_{COMPRESSOR} + P_{FANS} \quad \text{[W]}$$

The net total cooling capacity, Q_0, was determined from air flow and air enthalpy difference across the evaporator. Table 2 shows the comparison of N-13a main parameters relative to the R-134a baseline. Table 3 shows the comparison of AC5 relative to the R-134a baseline. The following calculations were employed for determination of differences and ratios relative to R-134a for both alternative refrigerants.

Evaporating temperatures difference: $d(EVOT_{sat}) = (EVOT_{sat})_{Alt} - (EVOT_{sat})_{R-134a}$ [°F]

Evaporating superheat difference: $d(ESH) = ESH_{Alt} - ESH_{R-134a}$ [°F]

Condensing temperatures difference: $d(PGOT_{sat}) = (PGOT_{sat})_{Alt} - (PGOT_{sat})_{R-134a}$ [°F]

Suction pressures difference: $d(PVIP) = PVIP_{Alt} - PVIP_{R-134a}$ [psia]

Suction temperatures difference: $d(PVIT) = PVIT_{Alt} - PVIT_{R-134a}$ [°F]

Discharge pressures difference: $d(PGOP) = PGOP_{Alt} - PGOP_{R-134a}$ [psia]

Discharge temperatures difference: $d(PGOT) = PGOT_{Alt} - PGOT_{R-134a}$ [°F]

Unit input power ratio: $(P_{unit})_R = (P_{unit})_{Alt}/(P_{unit})_{R-134a}$ [-]

Net cooling capacity ratio: $(Q_o)_R = (Q_o)_{Alt}/(Q_o)_{R-134a}$ [-]

Total COP ratio: $(COP)_R = (COP)_{Alt}/(COP)_{R-134a}$ [-]

Refrigerant charge ratio: $(Charge)_R = (Charge)_{Alt}/(Charge)_{R-134a}$ [-]

Table 2: Comparison of main parameters for system charged N-13a relative to R-134a.

Comparison of N-13a relative to R-134a															
Conditions					**Evaporator**		**Condenser**	**Compressor**				**Unit Parameters**			
CAIT	EAIT	EDPIT	Comp. Speed	Evap. Fan Speed	d(EVOT_sat)	d(ESH)	d(PGOT_sat)	d(PVIP)	d(PVIT)	d(PGOP)	d(PGOT)	Punit_R	Qo_R	Charge_R	COP_R
[°F]	[°F]	[°F]	[RPM]	[-]	[°F]	[°F]	[°F]	[psia]	[°F]	[psia]	[°F]	[-]	[-]	[-]	[-]
95,0	80,1	60,1	1000	HS	1,4	-0,7	0,1	-2,1	-2,0	-11,5	-10,6	0,97	0,97	1,00	1,00
95,0	80,1	60,1	2000	HS	1,4	-0,2	0,4	-1,7	-0,9	-13,9	-16,5	0,95	0,96	1,00	1,01
95,0	80,1	60,1	3000	HS	1,9	-0,1	2,0	-1,4	-0,9	-10,9	-16,9	0,95	0,92	1,00	0,98
95,0	80,1	60,1	1000	LS	1,2	-0,5	0,8	-1,9	-0,7	-9,2	-10,6	0,97	0,98	1,00	1,01
95,0	80,1	60,1	2000	LS	0,9	0,7	1,7	-1,6	1,1	-9,3	-11,9	0,95	0,97	1,00	1,02
95,0	80,1	60,1	3000	LS	1,7	1,4	5,0	-0,8	2,2	-0,8	-10,6	0,95	0,95	1,00	0,99
104,0	104,0	81,7	1000	HS	0,4	1,7	-0,9	-5,8	-1,9	-17,7	-15,3	0,97	0,97	1,00	1,00
104,0	104,0	81,7	2000	HS	-0,1	-1,5	-2,6	-5,4	-2,5	-28,6	-21,0	0,91	0,91	1,00	1,00
104,0	104,0	81,7	3000	HS	-0,4	0,1	-3,4	-4,4	-3,0	-35,0	-25,5	0,90	0,87	1,00	0,97
120,0	120,0	60,1	1000	HS	0,3	3,5	-1,7	-6,4	0,6	-25,2	-16,4	0,95	0,90	1,00	0,94
120,0	120,0	60,1	2000	HS	1,0	2,2	-1,7	-4,4	1,4	-30,0	-18,9	0,92	0,92	1,00	1,00
120,0	120,0	60,1	2400	HS	2,3	-0,7	-2,2	-3,3	-1,3	-33,4	-24,2	0,93	0,90	1,00	0,96
120,0	120,0	60,1	3000	HS	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*

* For information only (safety cut-out shut down the unit charged with R-134a at compressor speed 2400 RPM, with N-13a no problem with high pressure up to compressor speed 3000 RPM)

Table 3: Comparison of main parameters for system charged AC5 relative to R-134a.

Comparison of AC5 relative to R-134a																
Conditions					**Evaporator**		**Condenser**	**Compressor**				**Unit Parameters**				
CAIT	EAIT	EDPIT	Comp. Speed	Evap. Fan Speed Mode	d(EVOT_sat)	d(ESH)	d(PGOT_sat)	d(PVIP)	d(PVIT)	d(PGOP)	d(PGOT)	Punit_R	Qo_R	Charge_R	COP_R
[°F]	[°F]	[°F]	[RPM]	[-]	[°F]	[°F]	[°F]	[psia]	[°F]	[psia]	[°F]	[-]	[-]	[-]	[-]
95,0	80,1	60,1	1000	HS	7,2	-1,6	14,5	2,6	0,8	27,8	-1,3	1,07	1,01	0,95	0,94
95,0	80,1	60,1	2000	HS	7,2	-3,2	8,6	1,5	-2,2	13,8	-14,7	1,04	0,92	0,95	0,89
95,0	80,1	60,1	3000	HS	6,4	-2,1	6,7	1,5	-0,5	8,5	-8,8	1,03	0,96	0,95	0,92
95,0	80,1	60,1	1000	LS	5,8	-1,5	13,3	1,3	2,0	23,5	8,0	1,06	1,02	0,95	0,96
95,0	80,1	60,1	2000	LS	5,8	-1,1	7,5	1,4	2,8	9,6	0,2	1,03	0,98	0,95	0,96
95,0	80,1	60,1	3000	LS	5,0	-1,0	7,4	1,0	2,3	10,1	-0,6	1,03	0,99	0,95	0,97
104,0	104,0	81,7	1000	HS	5,1	2,4	10,7	-0,2	3,4	20,9	-1,9	1,05	0,99	0,95	0,94
104,0	104,0	81,7	2000	HS	3,2	-2,3	6,1	-2,3	0,0	7,6	-7,3	0,99	0,94	0,95	0,95
104,0	104,0	81,7	3000	HS	1,0	6,2	3,4	-2,9	5,4	-2,6	-1,4	0,97	0,93	0,95	0,95
120,0	120,0	60,1	1000	HS	4,9	3,2	8,2	0,1	4,9	15,3	-1,4	1,03	0,94	0,95	0,91
120,0	120,0	60,1	2000	HS	4,5	-2,3	7,0	-1,0	0,3	13,4	-9,7	1,00	0,93	0,95	0,93
120,0	120,0	60,1	2100	HS	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*	N/A*

* For information only (safety cut-out shut down the unit charged with AC5 at compressor speed 2100 RPM)

Overall performance results are illustrated in Figures 3 to 7. Figure 3 shows comparison of net cooling capacity for N-13a and AC5 relative to R-134a. The cooling capacity was down to 13 % for N-13a, but also the total unit power consumption was down to 10 % (see Figure 4). Therefore, the difference in COP was insignificant and within the measurement uncertainty as shown in Figure 5. AC5 cooling performance was comparable or smaller down to 8 % relative to R-134a, but total unit input power was also comparable or up to 7 %, and thus COP was worse down to 11 %.

Comparison of compressor discharge pressures and temperatures relative to R-134a is shown in Figures 6 and 7. The measured discharge pressures for the unit charged with N-13a were significantly lower compared to R-134a and consequently the unit was able to operate at high temperature conditions (CAIT 120 °F / EAIT 120 °F / EDPIT 60 °F) up to compressor speed 3000 RPM compared to R-134a, in which case the safety cut-out shut down the unit at a compressor speed of 2400 RPM. The measured discharge pressures for the unit charged with AC5 were up to 15 % higher compared to R-134a and therefore the unit was only able to operate at high temperature conditions (CAIT 120 °F / EAIT 120 °F / EDPIT 60 °F) up to a compressor speed of 2100 RPM. The measured compressor discharge temperatures were lower for the system charged with N-13a and slightly lower for the system charged with AC5, see Figure 7.

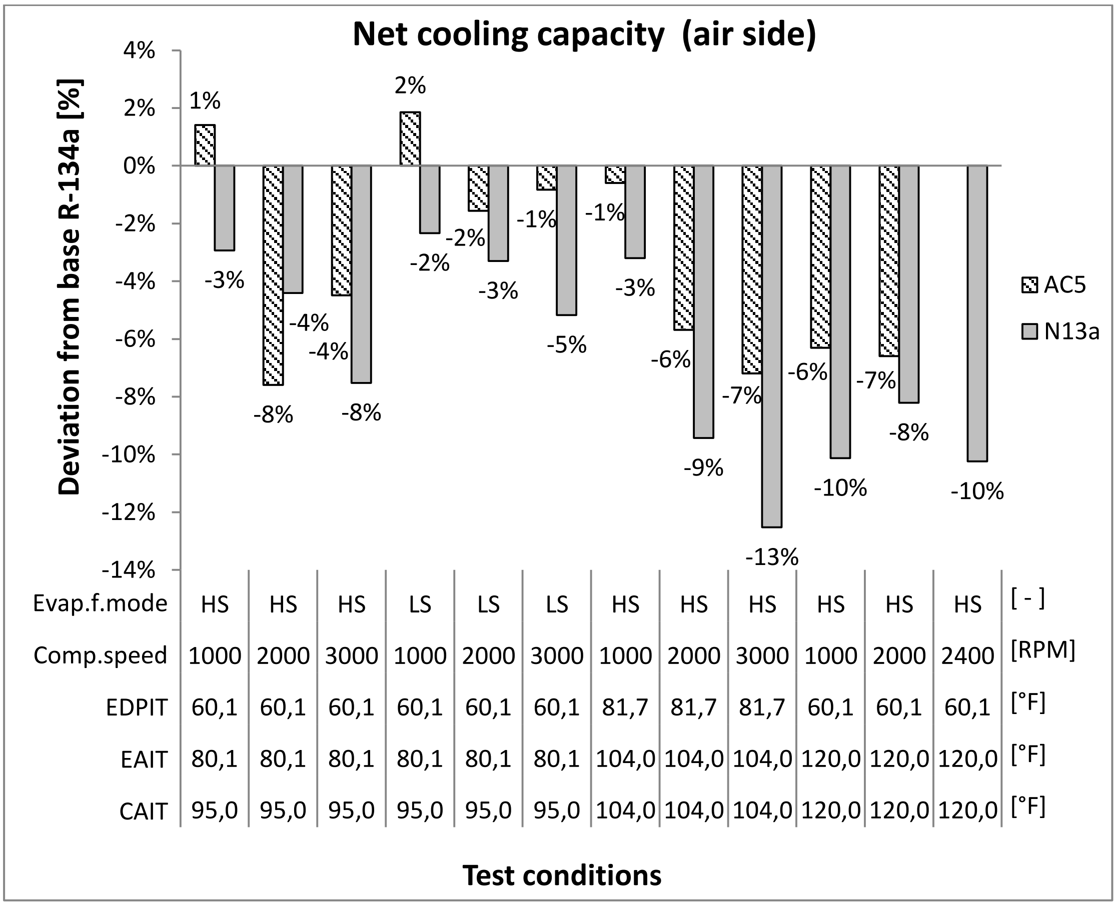

Figure 3: Comparison of net cooling capacity (air side) relative to R-134a.

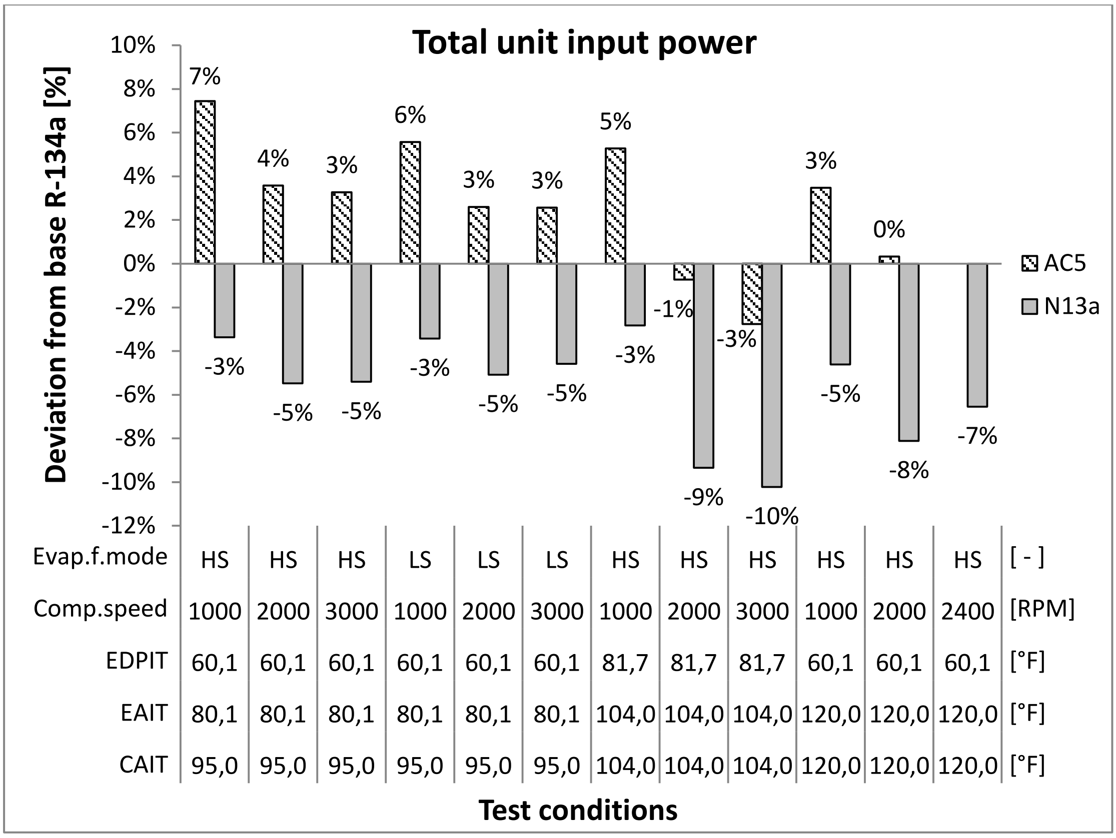

Figure 4: Comparison of total unit input power relative to R-134a.

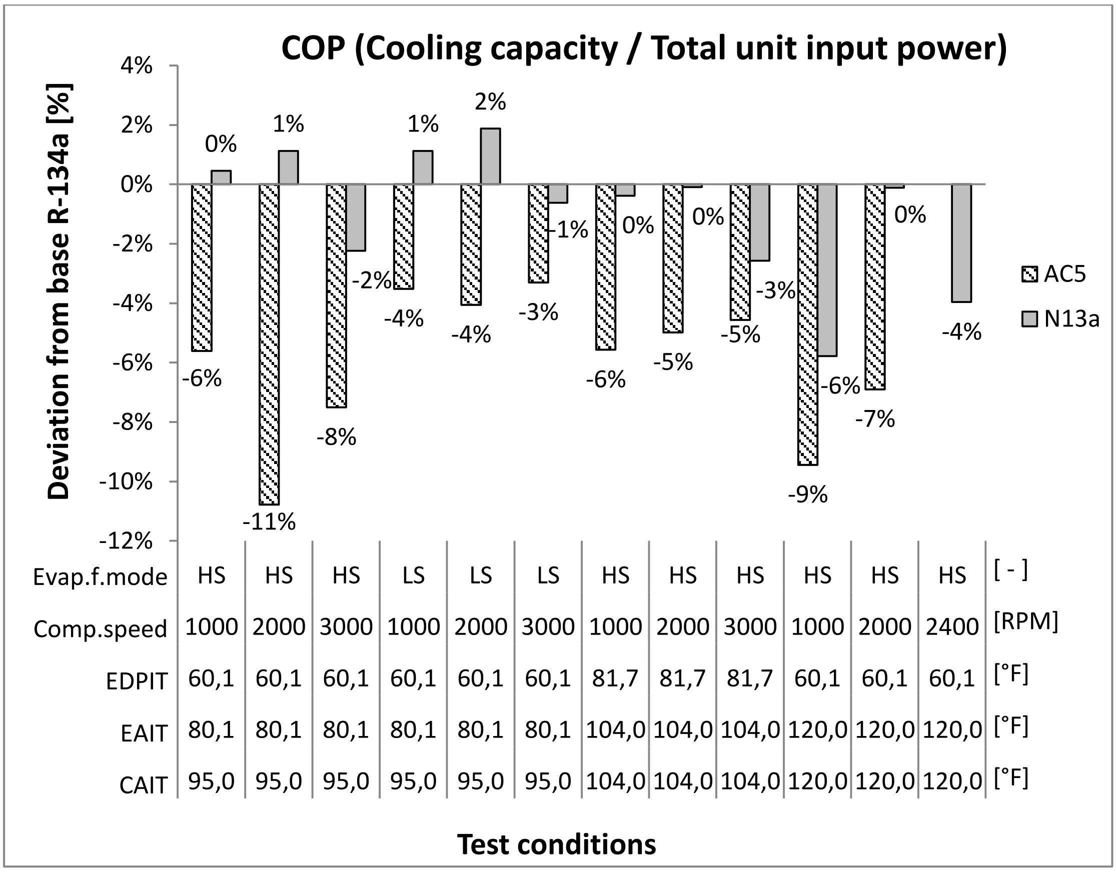

Figure 5: Comparison of COP relative to R-134a.

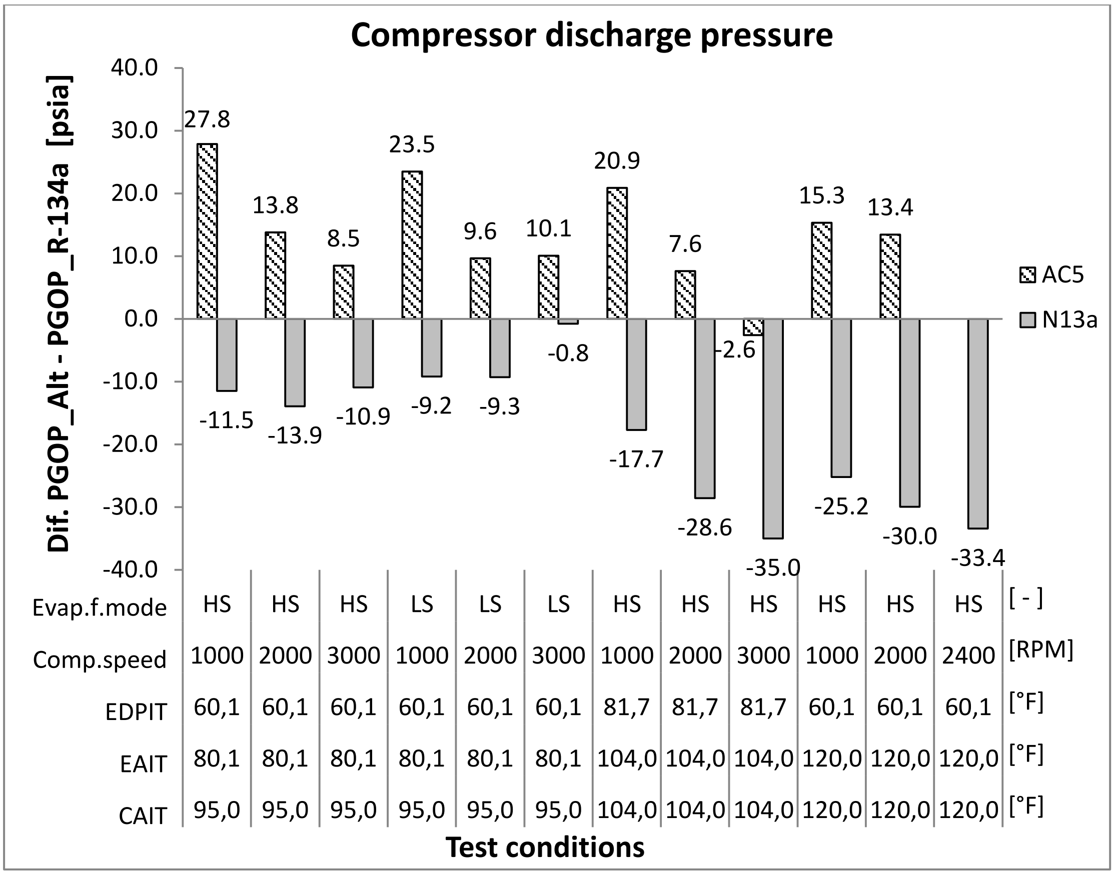

Figure 6: Comparison of compressor discharge pressure relative to R-134a.

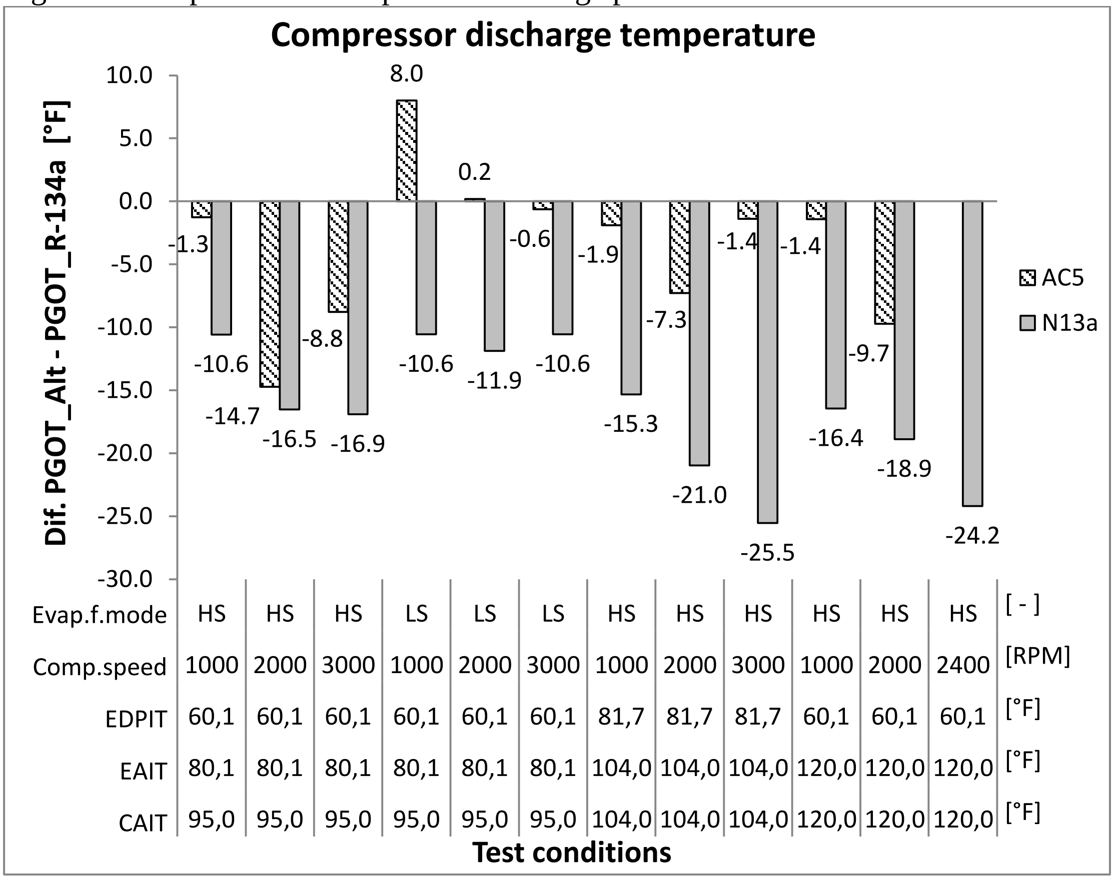

Figure 7: Comparison of compressor discharge temperature relative to R-134a.