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

TEST REPORT #9

System Drop-In Tests of Refrigerant Blends L-40, DR-7 and ARM-30a in a Trailer Refrigeration Unit Designed for R-404A

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List of Tested Refrigerants' Compositions (Mass%)

ARM-30a	R-32/R-1234yf (29/71)
DR-7	R-32/R-1234yf (36/64)
L-40	R-32/R-152a/R-1234yf/R-1234ze(E) (40/10/20/30)

1. **Introduction:**

This report presents the results of the cooling performance drop-in tests on a typical Thermo King trailer refrigeration unit with refrigerant R-404A as a baseline and three alternative blends.

The alternative refrigerants involved in this evaluation are listed below:

Alternative (Manufacturer):	L-40	(Honeywell)
	DR-7	(DuPont)
	ARM-30a	(Arkema)

Cooling capacity tests were performed in June and July 2012 in a calorimeter cell at Ingersoll-Rand's Engineering and Technology Center in Prague, Czech Republic. The calorimeter cell in the Technology Center is an isothermal chamber designed for measuring cooling capacities of truck and trailer units in accordance with AHRI Standard 1110-2006.

2. **Details of Test Setup:**

The unit tested was a Thermo King SLX-300 trailer refrigeration unit and it employs R-404A as the refrigerant. The unit's rated net cooling capacities at high speed engine operation under the following ATP[1] conditions are: 15 kW at 30 ºC ambient/0 ºC evaporator return air temperatures and 8.1 kW at 30 °C ambient/-20 °C evaporator return air temperatures. The unit works with a Thermo King open-shaft 4 cylinder reciprocating compressor with a displacement of 492 cm^3 (30 cu in). The compressor is driven from a diesel engine, which is integrated in the unit. 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 testing for each refrigerant.

The tested unit is installed in the test chamber and the lab technology maintains required temperatures inside and outside the chamber. The calorimetric chamber thermal losses are determined before the testing is initialized. During the cooling mode the tested unit dissipates heat generated by electric heaters with fans, which are controlled in order to achieve the requested temperatures. After temperature conditions are stabilized, the cooling capacity is determined from the measured input power to the fans/heaters and thermal losses through chamber walls. The cooling capacity is calculated within a measurement uncertainty of ± 2 % from measured values.

The cooling capacity tests were performed on the SLX-300 operating on high-speed and low-speed engine modes for standard transport refrigeration rating temperature conditions presented in Table 1. Tests were carried out in compliance with requirements defined in AHRI Standard 1110-2006 and cooling capacities are reported under the standard ratings conditions. Cooling capacities are also reported under ATP rating conditions for mechanically refrigerated equipment.

[1] Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage (ATP). UNECE Transport Division publication ECE/TRANS/219.

Table 1: Test temperature conditions

Condenser Air Inlet Temperature (CAIT)		Evaporator Air Inlet Temperature (EAIT)		Note:
[°C]	[°F]	[°C]	[°F]	
37.8	100.0	1.7	35.0	AHRI condition
37.8	100.0	-17.8	0.0	AHRI condition
37.8	100.0	-28.9	-20.0	Added test point
30.0	86.0	0	32.0	ATP condition
30.0	86.0	-10.0	14.0	Added test point
30.0	86.0	-20.0	-4.0	ATP condition

The refrigeration system cycle diagram and probe placements are illustrated in Figure 2. All drop-in tests were conducted with the alternative refrigerants placed in the representative unit with no system modifications except for refrigerant charge and thermal expansion valve adjustments.

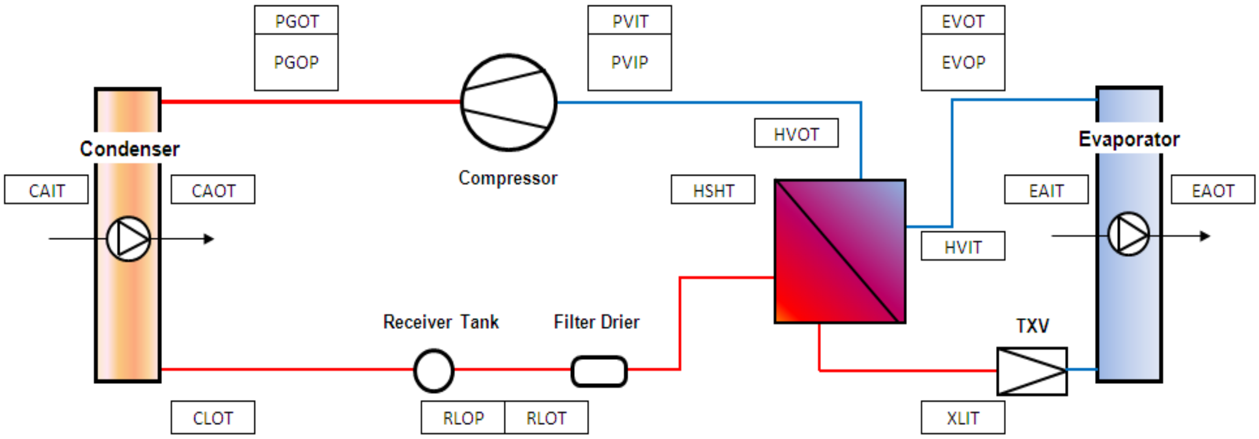

Figure 1: The refrigeration cycle diagram and probe placement

<u>Measurement instrumentation:</u>
Temperature sensors Pt 100, T 1025 and T 1027 class A
Pressure transducers DMP 331 and DMP 333

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

Testing sensors nomenclature:

CAIT	Condenser Air Inlet Temperature
CAOT	Condenser Air Outlet Temperature
CLOT	Condenser Liquid Outlet Temperature
EAIT	Evaporator Air Inlet Temperature
EAOT	Evaporator Air Outlet Temperature
EVOP	Evaporator Vapor Outlet Pressure
EVOT	Evaporator Vapor Outlet Temperature
ESHT	Evaporator Superheat Temperature
HSHT	Heat Exchanger Superheat Temperature
HVIT	Heat Exchanger Vapor Inlet Temperature
HVOT	Heat Exchanger Vapor Outlet Temperature
PGOP	Compressor Gas Outlet Pressure
PGOT	Compressor Gas Outlet Temperature
PSHT	Compressor Superheat Temperature
PVIP	Compressor Vapor Inlet Pressure
PVIT	Compressor Vapor Inlet Temperature
RLOP	Receiver Liquid Outlet Pressure
XLIT	Expansion Valve Liquid Inlet Temperature

The tested unit was charged with R-404A according to the unit specification and the thermal expansion valve (TXV) setting was verified. After the nominal cooling capacity was verified at ATP standard rating conditions (-20 °C temperature inside the chamber and 30 °C ambient temperature) on high-speed engine mode, cooling capacity tests were performed at high and low engine speed modes under the temperature conditions shown in Table 1. Diesel fuel consumption was measured for all tested conditions.

After the baseline tests were completed, the R-404A refrigerant was recovered, the filter drier and oil were changed, and the unit was then charged with L-40 refrigerant. The L-40 charge and TXV position were adjusted at ATP standard rating conditions (-20 °C temperature inside the chamber and 30 °C ambient temperature) on high-speed engine mode in order to achieve optimal cooling capacity before repeating the R-404A test conditions. The L-40 test procedure was repeated for DR-7 and ARM-30a refrigerants.

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 ATP typical rating conditions. The refrigerant properties were provided by Honeywell (L-40), DuPont (DR-7) and Arkema (ARM-30a). 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 net cooling capacity was determined from measured input power of fans/heaters and thermal losses through the chamber walls. Table 2 shows the comparison of L-40 main parameters relative to the R-404A baseline. Table 3 shows the comparison of DR-7 relative to the R-404A baseline and Table 4 shows the comparison of ARM-30a relative to the R-404A baseline. The following calculations were employed for determination of differences and ratios relative to R-404A for all alternative refrigerants.

Evaporator temperatures difference: $d(EVOT_{sat}) = (EVOT_{sat})_{Alt} - (EVOT_{sat})_{R-404A}$ [°F]

Evaporator superheating difference: $d(ESH) = ESH_{Alt} - ESH_{R-404A}$ [°F]

Condensing temperatures difference: $d(PGOT_{sat}) = (PGOT_{sat})_{Alt} - (PGOT_{sat})_{R-404A}$ [°F]

Suction pressures difference: $d(PVIP) = PVIP_{Alt} - PVIP_{R-404A}$ [psia]

Suction temperatures difference: $d(PVIT) = PVIT_{Alt} - PVIT_{R-404A}$ [°F]

Discharge pressures difference: $d(PGOP) = PGOP_{Alt} - PGOP_{R-404A}$ [psia]

Discharge temperatures difference: $d(PGOT) = PGOT_{Alt} - PGOT_{R-404A}$ [°F]

Diesel consumption ratio: $(C_D)_R = (C_D)_{Alt}/(C_D)_{R-404A}$ [-]

Net cooling capacity ratio: $(Q_o)_R = (Q_o)_{Alt}/(Q_o)_{R-404A}$ [-]

Refrigerant charge ratio: $(Charge)_R = (Charge)_{Alt}/(Charge)_{R-404A}$ [-]

Energy efficiency ratio: $\left(\frac{Q_o}{C_D}\right)_R = \left(\frac{Q_o}{C_D}\right)_{Alt} \Big/ \left(\frac{Q_o}{C_D}\right)_{R-404A}$ [-]

Table 2: Comparison of main parameters for system charged L-40 relative to R-404A.

Comparison of L-40 relative to R-404A													
Conditions			**Evaporator**		**Condenser**	**Compressor**				**Unit Parameters**			
CAIT	EAIT	Engine speed mode	d(EVOT_sat)	d(ESH)	d(PGOT_sat)	d(PVIP)	d(PVIT)	d(PGOP)	d(PGOT)	Cd_R	Qo_R	Charge_R	(Qo/Cd)_R
[°F]	[°F]	[-]	[°F]	[°F]	[°F]	[psia]	[°F]	[psia]	[°F]	[-]	[-]	[-]	[-]
100,0	-20,0	LS	6,5	-0,9	0,7	-4,3	8,5	-2,8	54,0	0,94	0,81	0,83	0,86
100,0	-20,0	HS	7,7	-1,6	-0,7	-3,4	5,8	-8,4	55,4	0,92	0,79	0,83	0,86
86,0	-4,0	LS	8,4	-3,2	-0,3	-4,0	3,6	-6,1	51,5	0,75	0,92	0,83	1,23
86,0	-4,0	HS	9,4	-3,8	-1,5	-2,8	2,9	-10,4	51,7	1,02	0,92	0,83	0,91
100,0	0,0	LS	11,7	-3,1	1,6	-1,8	1,1	0,4	49,0	1,06	1,02	0,83	0,96
100,0	0,0	HS	12,2	-4,5	0,6	-1,2	-0,9	-3,8	49,1	1,00	1,01	0,83	1,01
86,0	14,0	HS	12,7	-5,8	1,5	-0,8	-10,6	0,0	35,3	1,21	1,00	0,83	0,83
86,0	14,0	LS	12,0	-5,0	0,7	-1,9	-12,6	-2,7	32,4	1,00	0,96	0,83	0,96
86,0	32,0	LS	16,3	-5,7	3,0	2,1	-22,1	5,5	14,0	1,16	1,04	0,83	0,90
86,0	32,0	HS	16,3	-6,8	3,4	2,6	-18,5	7,0	18,0	1,03	1,10	0,83	1,06
100,0	35,0	LS	15,6	-6,8	2,6	1,5	-20,5	4,1	19,4	1,05	1,05	0,83	1,00
100,0	35,0	HS	12,9	-7,7	1,8	-0,6	-15,1	0,2	28,3	0,79	1,04	0,83	1,32

Table 3: Comparison of main parameters for system charged DR-7 relative to R-404A.

Comparison of DR-7 relative to R-404A														
Conditions			**Evaporator**		**Condenser**	**Compressor**				**Unit Parameters**				
CAIT	EAIT	Engine speed mode	d(EVOT_sat)	d(ESH)	d(PGOT_sat)	d(PVIP)	d(PVIT)	d(PGOP)	d(PGOT)	Cd_R	Qo_R	Charge_R	(Qo/Cd)_R
[°F]	[°F]	[-]	[°F]	[°F]	[°F]	[psia]	[°F]	[psia]	[°F]	[-]	[-]	[-]	[-]
100,0	-20,0	LS	4,5	-0,4	0,1	-0,3	4,9	19,9	42,3	0,94	1,00	0,83	1,07
100,0	-20,0	HS	6,1	-1,6	-0,5	0,4	1,8	17,7	39,4	0,96	1,02	0,83	1,07
86,0	-4,0	LS	5,5	-1,9	-0,2	0,2	2,2	17,4	37,4	0,95	1,03	0,83	1,09
86,0	-4,0	HS	6,6	-2,4	-0,6	1,1	0,4	16,4	34,4	1,08	1,04	0,83	0,96
100,0	0,0	LS	7,6	-1,0	0,5	1,9	1,1	21,9	35,1	0,83	1,11	0,83	1,33
100,0	0,0	HS	7,7	-2,0	0,3	2,0	-0,2	21,6	34,2	0,96	1,10	0,83	1,14
86,0	14,0	HS	6,7	-2,4	0,4	1,6	-0,4	20,8	32,9	1,21	1,07	0,83	0,89
86,0	14,0	LS	7,0	-2,0	0,3	1,5	-1,8	20,1	30,4	1,06	1,04	0,83	0,99
86,0	32,0	LS	9,6	-1,5	2,0	4,6	-4,3	27,8	22,3	1,05	1,11	0,83	1,05
86,2	32,0	HS	8,4	-2,7	1,9	3,5	-2,0	28,0	27,2	0,93	1,10	0,83	1,18
100,0	35,1	LS	6,5	-2,1	-0,1	1,4	-3,1	21,4	28,4	1,05	1,06	0,83	1,01
100,0	35,1	HS	6,1	-3,3	0,5	1,4	-1,4	24,3	32,0	0,64	1,04	0,83	1,64

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Table 4: Comparison of main parameters for system charged ARM-30a relative to R-404A.

Comparison of ARM-30a relative to R-404A													
Conditions			**Evaporator**		**Condenser**	**Compressor**				**Unit Parameters**			
CAIT	EAIT	Engine speed mode	d(EVOT_sat)	d(ESH)	d(PGOT_sat)	d(PVIP)	d(PVIT)	d(PGOP)	d(PGOT)	Cd_R	Qo_R	Charge_R	(Qo/Cd)_R
[°F]	[°F]	[-]	[°F]	[°F]	[°F]	[psia]	[°F]	[psia]	[°F]	[-]	[-]	[-]	[-]
100,0	-20,0	LS	3,8	1,0	8,7	-3,7	4,1	-9,7	24,8	0,94	0,84	0,83	0,89
100,0	-20,0	HS	4,6	0,5	8,1	-3,3	2,7	-12,0	24,3	0,96	0,81	0,83	0,85
86,0	-4,0	LS	6,2	-1,5	8,9	-3,4	1,4	-9,0	20,9	0,80	0,95	0,83	1,19
86,0	-4,0	HS	7,1	-1,5	8,4	-2,4	1,6	-10,6	20,7	1,04	0,95	0,83	0,91
100,0	0,0	LS	9,0	-0,9	9,6	-1,2	-2,3	-6,3	14,6	0,94	1,04	0,83	1,10
100,0	0,0	HS	8,6	-1,6	8,9	-1,4	-1,6	-8,6	17,5	0,89	0,99	0,83	1,11
86,0	14,0	HS	8,2	-2,1	9,0	-1,8	-3,1	-8,4	14,4	1,17	0,99	0,83	0,85
86,0	14,0	LS	9,4	-2,2	10,0	-1,2	-13,7	-5,0	2,0	1,00	1,00	0,83	1,00
86,0	32,0	LS	12,4	-2,3	11,4	1,5	-17,1	0,8	-7,0	1,11	1,05	0,83	0,95
86,0	32,0	HS	11,7	-2,9	11,1	0,9	-9,2	-0,2	3,2	1,07	1,05	0,83	0,98
100,0	35,1	LS	10,2	-3,4	9,1	-0,7	-16,4	-7,4	-1,8	1,10	1,02	0,83	0,93
100,0	34,9	HS	9,7	-3,8	9,5	-1,1	-7,7	-5,5	7,4	0,97	1,03	0,83	1,06

Overall performance results are illustrated in Figures 3 to 8. Figure 3 and 4 shows comparison of net cooling capacity for L-40, DR-7 and ARM-30a relative to R-404A. The cooling capacity was down to 21 % for L-40 and down to 19 % for ARM-30a at low return air temperature - 20 °F. At higher return air temperatures the cooling capacity was comparable to R-404A or up to 10 % for L-40 and up to 5 % for ARM-30a at return air temperature 32 °F. DR-7 cooling performance was comparable at low return air temperatures relative to R-404A and up to 11 % at higher return air temperatures.

Comparison of compressor discharge pressures relative to R-404A is shown in Figures 5 and 6. The measured discharge pressures for the unit charged with L-40 and ARM-30a were comparable or lower down to 4 % compared to R-404A. The measured discharge pressures for the unit charged with DR-7 were higher up to 9 % compared to R-404A.

Comparison of compressor discharge temperatures relative to R-404A is shown in Figures 7 and 8. The measured compressor discharge temperatures were higher for the circuit working with all alternative refrigerants, the most significant difference from R-404A was for L-40 and DR-7.

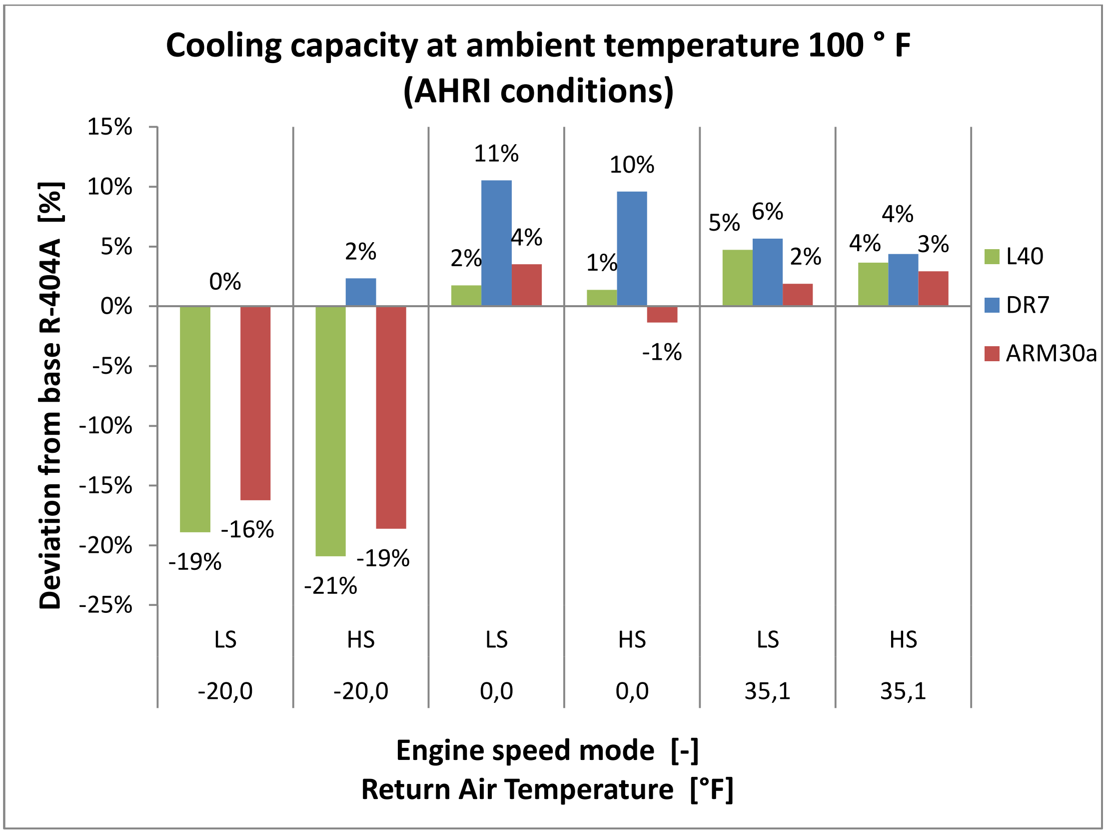

Figure 3: Comparison of net cooling capacity relative to R-404A under AHRI conditions.

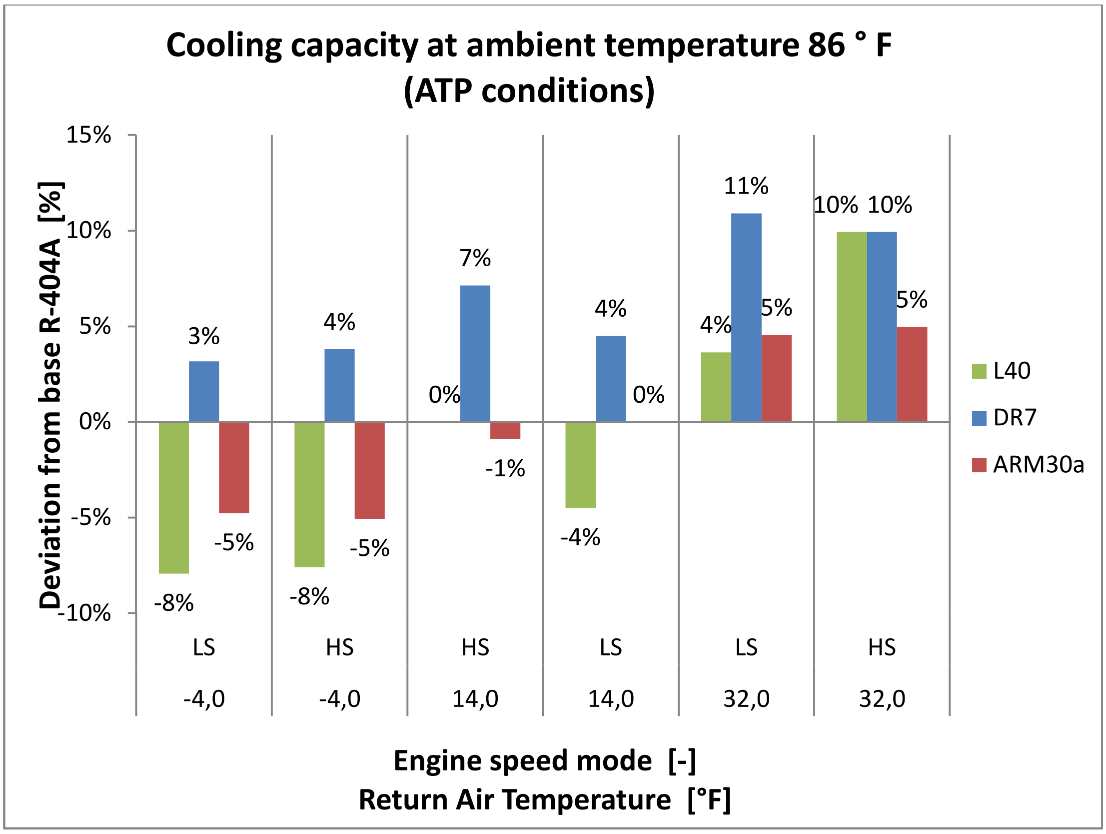

Figure 4: Comparison of net cooling capacity relative to R-404A under ATP conditions.

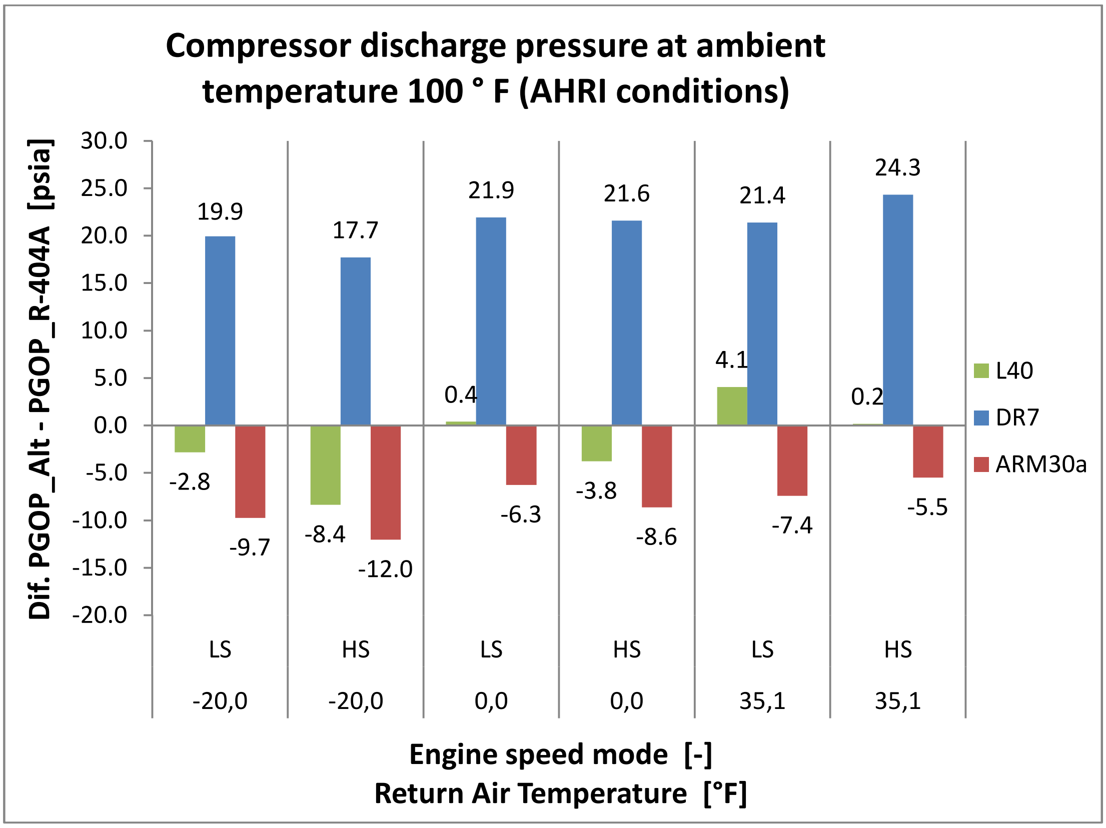

Figure 5: Comparison of compressor discharge pressure relative to R-404A under AHRI conditions.

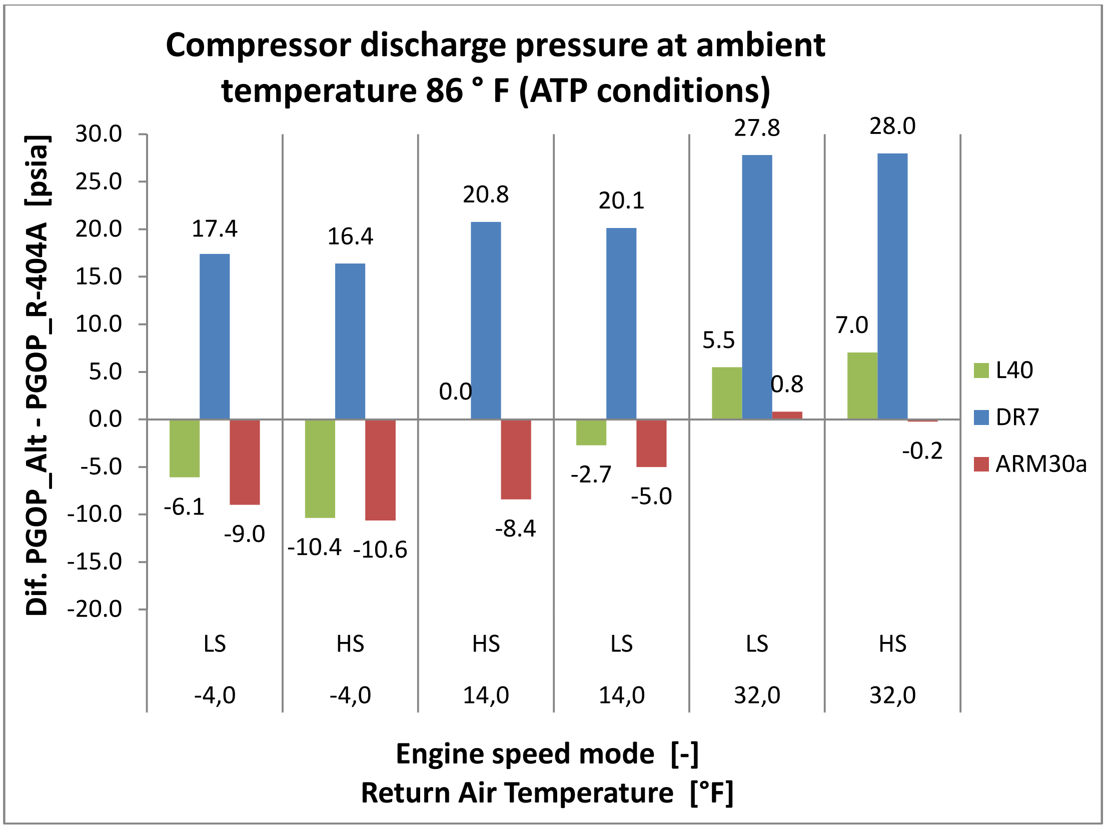

Figure 6: Comparison of compressor discharge pressure relative to R-404A under ATP conditions.

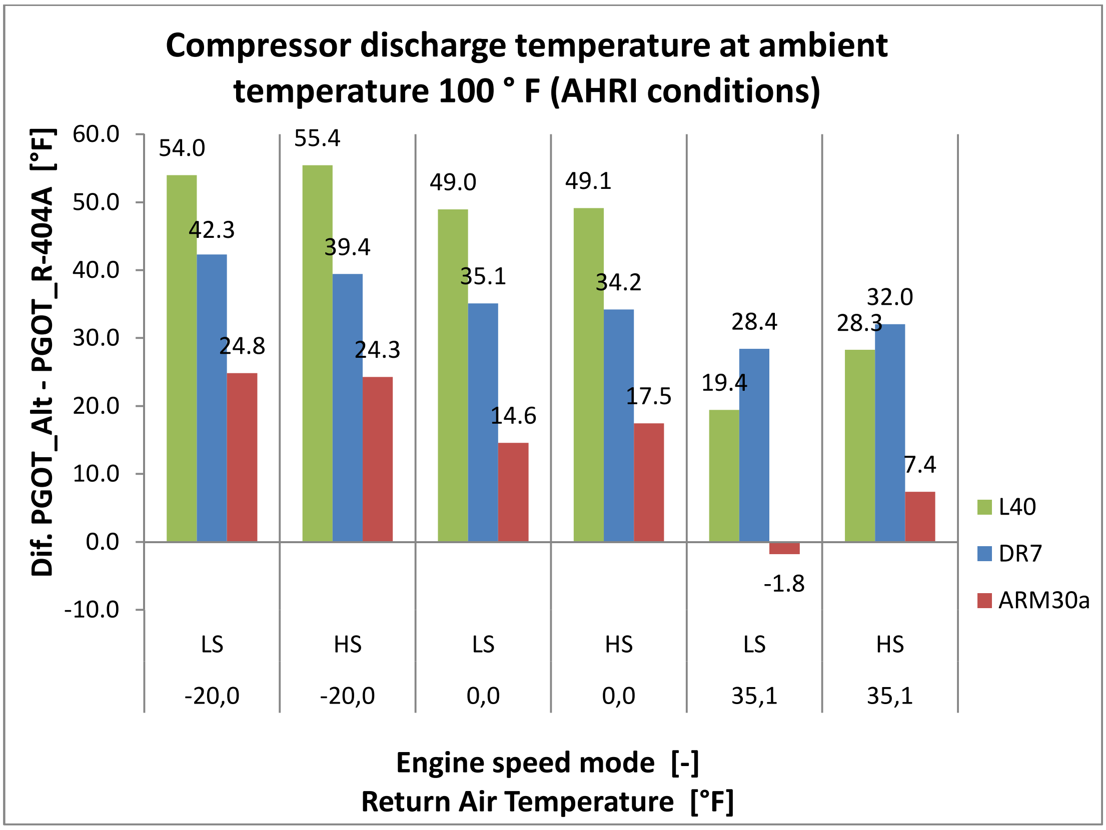

Figure 7: Comparison of compressor discharge temperature relative to R-404A under AHRI conditions.

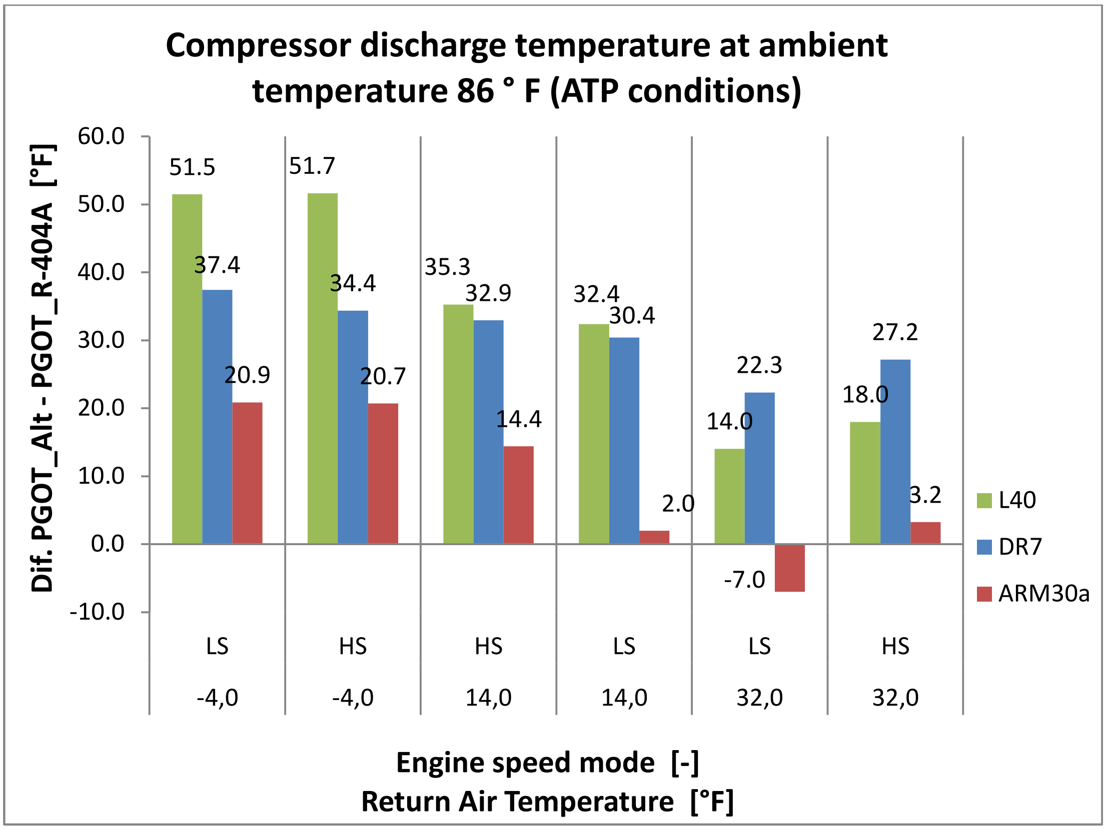

Figure 8: Comparison of compressor discharge temperature relative to R-404A under ATP conditions.