PROPERTIES AND EFFICIENCIES OF R-410A, R-421A, R-422B, AND R-422D COMPARED TO R-22

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SUMMARY

This report addresses selected properties for four refrigerant blends marketed as alternatives for R-22 for use in air-conditioning and in medium- and high-temperature residential, commercial, and industrial refrigeration applications. They include R-410A, R-421A, R-422B, and R-422D. The report compares representative properties, pressure-temperature (PT) relationships, and thermodynamic efficiency limits for the blends to those for R-22.

REFRIGERANTS EXAMINED

R-22, currently the most widely used refrigerant on a global basis, is a single-compound refrigerant with the chemical name chlorodifluoromethane, formula $CHClF_2$, and Chemical Abstract Service (CAS) registry number 75-45-6. R-22 production (other than for use as a chemical intermediate) is pending phaseout as an ozone-depleting substance. R-22's molar mass is 86.4684464 g/mol (0.190630 lb/mol).[1] The substance has low acute toxicity; ASHRAE Standard 34-2007 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[2]

R-410A, marketed by a number of refrigerant vendors among them Honeywell as *Genetron AZ-20*®, is a binary zeotrope formulated as 50.0+0.5,-1.5% R-32 and 50+1.5,-0.5% R-125 by mass – R-32/125 (50.0/50.0) (+0.5,-1.5/+1.5,-0.5). Its molar mass is 72.58481 g/mol (0.160022 lb/mol) and component mole fractions are 69.762 and 30.238 %, respectively. Both components are hydrofluorocarbons (HFCs). The blend has low acute toxicity; ASHRAE Standard 34-2007 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[1,2]

R-421A, marketed by RMS of Georgia as *Choice Refrigerant R-421A*, is a binary zeotrope formulated as 58.0±1.0% R-125 and 42.0±1.0% R-134a by mass – R-125/134a (58.0/42.0) (±1.0/±1.0). Its molar mass is 111.74591 g/mol (0.246358 lb/mol) and component mole fractions are 54.001 and 45.999 %, respectively. Both components are HFCs. The blend has low acute toxicity; ASHRAE Standard 34-2007 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[1,2]

R-422B, marketed by ICOR International as *NU-22B*™, is a ternary zeotrope formulated as 55.0±1.0% R-125, 42.0±1.0% R-134a, and 3.0+0.1,-0.5% R-600a (isobutane) by mass – R-125/134a/600a (55.0/42.0/3.0) (±1.0/±1.0/+0.1,-0.5). Its molar mass is 108.51787 g/mol (0.239241 lb/mol) and component mole fractions are 49.729, 44.670, and 5.601 %, respectively. The first two components are HFCs while the third is a hydrocarbon (HC). The blend has low acute toxicity; ASHRAE Standard 34-2007 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[1,2]

R-422D, marketed by DuPont Fluorochemicals as *Isceon® MO29*, is a variant of the same components in a different formulation. It is a ternary zeotrope formulated as 65.1+0.9,-1.1% R-125, 31.5±1.0% R-134a, and 3.4+0.1,-0.4% R-600a by mass – R-125/134a/600a (65.1/31.5/3.4) (+0.9,-1.1/±1.0/+0.1,-0.4). Its molar mass is 109.93470 g/mol (0.242365 lb/mol) and component mole fractions are 59.629, 33.940, and 6.431 %, respectively. The first two components are HFCs while the third is an HC. The blend has low acute toxicity; ASHRAE Standard 34-2007 classifies it as an "A1" refrigerant, signifying "lower toxicity" and "no flame propagation" for prescribed safety criteria.[1,2]

Table 1 compares representative properties of the five refrigerants based on data calculations using NIST REFPROP 8.0 combined with additional physical, environmental, and safety data.[1-3]

Table 1: Properties Comparison

properties	R-22	R-410A	R-421A	R-422B	R-422D
composition	chlorodifluoro-methane	R-32/125 (50.0/50.0)	R-125/134a (58.0/42.0)	R-125/134a/600a (55.0/42.0/3.0)	R-125/134a/600a (65.1/31.5/3.4)
molar mass					
g/mol	86.4684464	72.58481	111.74591	108.51787	109.93470
lb/mol	0.190630	0.160022	0.246358	0.239241	0.242365
normal boiling or bubble point					
°C	**-40.8**	-51.4	**-40.7**	-41.3	-43.2
°F	**-41.5**	-60.6	**-41.2**	-42.4	-45.8
blend dew point					
°C		-51.4	-35.4	-35.9	-38.3
°F		-60.5	-31.7	-32.6	-37.0
density, saturated liquid					
kg/m^3	1409	1350	1461	1398	1402
lb/cf	87.97	84.26	91.19	87.25	87.51
density, saturated vapor					
kg/m^3	4.70	4.17	5.98	5.82	5.96
lb/cf	0.294	0.261	0.373	0.363	0.372
NBP latent heat of vaporization					
kJ/kg	233.8	273.0	191.8	195.7	190.0
Btu/lb	100.5	117.4	82.4	84.1	81.7
kJ/m^3 vapor	1098.9	1138.4	**1147.0**	1139.0	1132.4
Btu/cf vapor	29.6	30.6	**30.7**	30.5	30.4
saturated vapor pressure					
at 20 °C in kPa	910.0	1443.0	820.7	831.9	903.7
at 68 °F in psia	131.99	556.1	119.03	120.65	131.07
saturated vapor pressure					
at 60 °C in kPa	2427	3834	2333	2346	2512
at 140 °F in psia	352.1	556.1	338.3	340.3	364.3
critical point temperature					
°C	96.1	71.4	82.8	83.2	79.6
°F	205.1	160.4	181.0	181.8	175.2
critical point pressure					
kPa	4990	4902	3919	3958	3905
psia	723.7	711.0	568.4	574.1	566.4
ozone depletion potential (ODP)					
model-derived to R 11	0.034	**<0.000015**	<0.000024	<0.000023	<0.000024
semi-empirical to R-11	0.050	0.000	0.000	0.000	0.000
regulatory	0.055	**0**	**0**	**0**	**0**
global warming potential (GWP)					
20 yr to CO_2	5160	4300	5300		
120 yr to CO_2	**1810**	2100	2600	2500	2700
500 yr to CO_2	549	650	820		
ASHRAE 34 / ISO 817 safety classification	**A1**	**A1**	**A1**	**A1**	**A1**
ASHRAE 34 Refrigerant Concentration Limit (RCL)					
ppm v/v	59,000	130,000	61,000	56,000	58,000
lb/Mcf	13	25	17	16	16

Table 2 compares the pressure-temperature (PT) relationships for coexisting vapor and liquid at saturated conditions (for liquid at the bubble-point for the blends) of the five refrigerants.

Table 2: Pressure-Temperature Data Comparisons

temperature (°C)	pressure (kPa)				
	R-22	R-410A	R-421A	R-422B	R-422D
-40	105	176	105	108	118
-35	132	219	131	135	147
-30	164	270	163	167	182
-25	201	331	201	205	223
-20	245	401	245	250	270
-15	296	482	296	301	326
-10	355	575	355	360	389
-5	422	681	422	428	461
0	498	801	499	505	543
5	584	936	585	592	636
10	681	1088	683	689	740
15	789	1258	792	799	856
20	910	1448	914	920	985
25	1044	1657	1049	1056	1128
30	1192	1889	1199	1205	1286
35	1355	2145	1364	1370	1460
40	1534	2426	1545	1550	1651
45	1729	2734	1744	1749	1860
50	1943	3071	1961	1965	2089
55	2175	3439	2198	2201	2338
60	2428	3842	2456	2458	2609
65	2701	4282	2736	2738	2904
temperature (°F)	**pressure (psig)**				
	R-22	**R-410A**	**R-421A**	**R-422B**	**R-422D**
-40	0.6	10.8	0.5	0.9	2.4
-30	4.9	17.8	4.8	5.4	7.1
-20	10.2	26.3	10.1	10.7	12.9
-10	16.5	36.5	16.5	17.1	19.8
0	24.0	48.4	24.0	24.7	27.9
10	32.8	62.4	32.8	33.6	37.5
20	43.1	78.7	43.1	43.9	48.5
30	55.0	97.4	55.0	55.9	61.3
40	68.6	118.8	68.7	69.6	75.9
50	84.1	143.2	84.3	85.3	92.6
60	101.6	170.7	102.0	103.0	111.4
70	121.4	201.8	122.0	123.0	132.6
80	143.6	236.5	144.4	145.4	156.3
90	168.4	275.4	169.5	170.4	182.8
100	195.9	318.6	197.4	198.2	212.2
110	226.4	366.4	228.3	229.0	244.7
120	260.0	419.4	262.4	263.1	280.7
130	296.9	477.9	300.1	300.6	320.2
140	337.4	542.5	341.5	341.8	363.7
150	381.7	613.9	386.9	387.1	411.4

Table 3 repeats the PT comparison for R-421A, shown in Table 2 to match R-22 most closely on a PT basis, with an added column quantifying the very small difference.

Table 3: Pressure-Temperature Data for R-22 and R-421A

temperature (°C)	pressure (kPa)		difference (%)
	R-22	R-421A	
-40	105	105	-0.60
-35	132	131	-0.47
-30	164	163	-0.35
-25	201	201	-0.25
-20	245	245	-0.16
-15	296	296	-0.08
-10	355	355	0.00
-5	422	422	0.07
0	498	499	0.14
5	584	585	0.21
10	681	683	0.27
15	789	792	0.34
20	910	914	0.41
25	1044	1049	0.49
30	1192	1199	0.55
35	1355	1364	0.64
40	1534	1545	0.73
45	1729	1744	0.83
50	1943	1961	0.93
55	2175	2198	1.03
60	2428	2456	1.16
65	2701	2736	1.29

temperature (°F)	pressure (psig)		difference (%)
	R-22	R-421A	
-30	4.9	4.8	-1.81%
-20	10.2	10.1	-0.81%
-10	16.5	16.5	-0.42%
0	24.0	24.0	-0.20%
10	32.8	32.8	-0.05%
20	43.1	43.1	0.06%
30	55.0	55.0	0.16%
40	68.6	68.7	0.24%
50	84.1	84.3	0.32%
60	101.6	102.0	0.39%
70	121.4	122.0	0.48%
80	143.6	144.4	0.56%
90	168.4	169.5	0.65%
100	195.9	197.4	0.75%
110	226.4	228.3	0.84%
120	260.0	262.4	0.95%
130	296.9	300.1	1.07%
140	337.4	341.5	1.21%
150	381.7	386.9	1.35%

The reason the difference values appear very slightly higher in the inch-pound (IP) portion of the table compared to the metric (SI) portion, for example at 60 °C and 140 °F that are the same, is the SI pressures indicated are absolute and the IP are gauge, consistent with common convention for the respective units. When converted to consistent absolute or gauge pressures, the difference values are the same. The important conclusion is that the saturation pressure-temperature dependence for R-421A is nearly identical to R-22 with less than 1% difference for most of the temperature range of interest.

Figure 1 plots the data from Table 2 for graphical comparison.

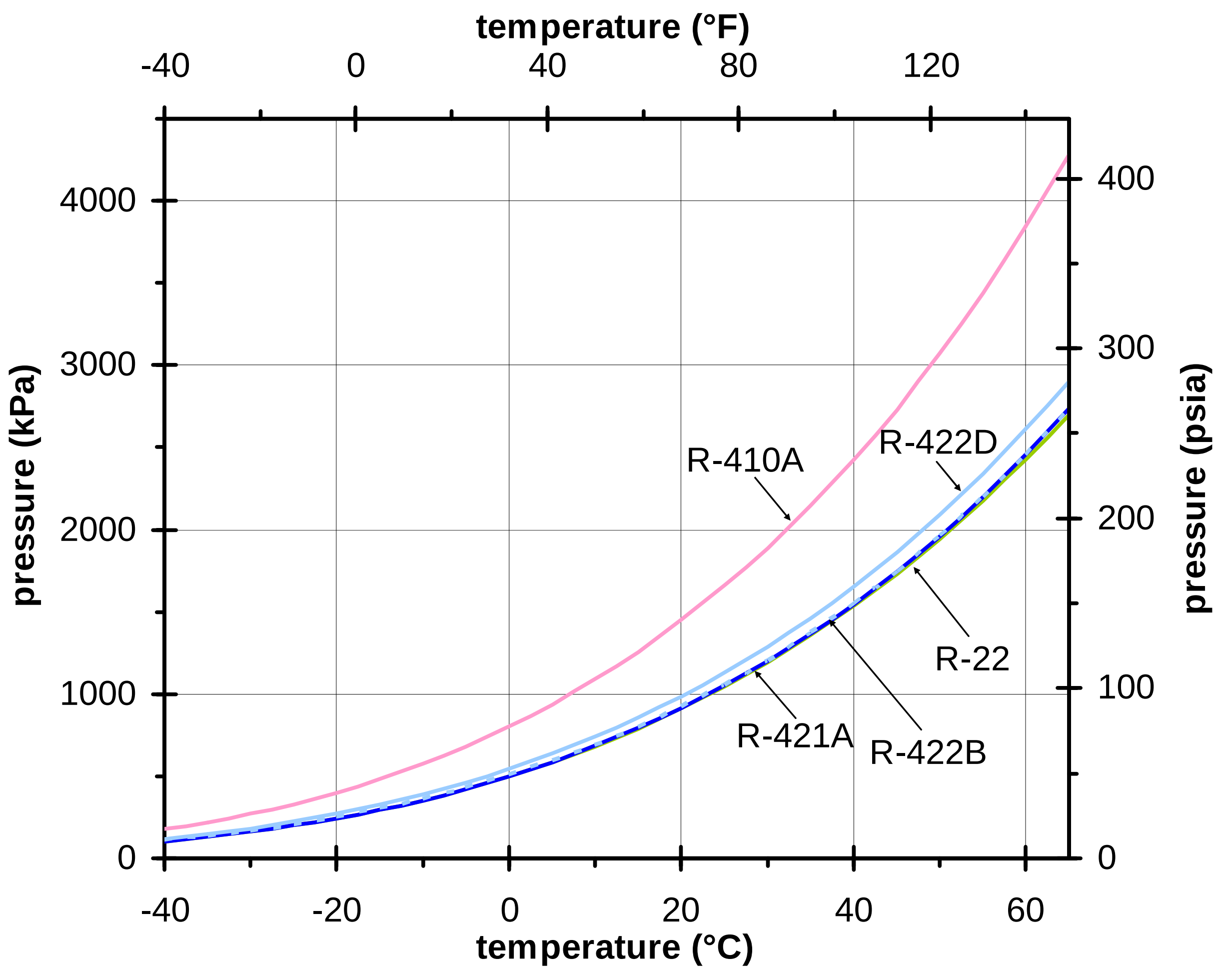

Figure 1: Pressure-Temperature Comparisons

PERFORMANCE

The following discussion addresses comparative performance relative to R-22 based on ideal cycle analyses using the NIST CYCLE_D program.[4] Thermodynamic cycle analyses for theoretical conditions indicate the limits or comparative limits to attainable performance for simple cycles without regard to differences in equipment and component deviations from ideal, heat transfer, additional thermophysical properties, and lubricant differences. The results indicate thermodynamic limits to what is attainable for different refrigerants in comparably optimized systems, but do not imply either that all systems will achieve such performance or that performance rankings of different refrigerants would not change in order of preference for systems not comparably optimized for the individual refrigerants.[5,6] Although excluded from the analyses herein to focus on refrigerant influences, real-world equipment performance properties will be lower than theoretical limits not only for the reasons mentioned, but also because fan, control, and sometimes pump burdens as well as start-up transients also factor into standard equipment ratings.

Table 4 summarizes the cycle conditions, consistent with those used in prior studies by Calm and Domanski, used for the analyses addressed herein. Omission of the fan and control power burdens facilitates focus on the refrigerant influences on performance, and would not change relative rankings of the candidates considered if included.

Table 4: Conditions for Performance Comparison

parameter	theoretical cycle limit for air conditioning
average evaporating temperature	
input temperature	10 °C (50 °F)
superheat	0 °C (0 °F)
average condensing temperature	
input temperature	35-65 °C (95-149 °F)
superheat	0 °C (0 °F)
compressor efficiencies	
isentropic	100%
volumetric	100%
motor	100%
piping losses (drop)	
suction line	none: 0 °C (0 °F)
discharge line	none: 0 °C (0 °F)
suction line / liquid line heat exchanger	none (0%)
fans and control power burdens	
indoor fan / chilled water pump	not included (0 W)
outdoor fan / condensing water pump	not included (0 W)
controls	not included (0 W)

The following figure compares the coefficient of performance (COP) for cooling (air conditioning) for a range of refrigerant condensing temperatures (necessarily higher than a corresponding range of ambient temperatures for air-cooled equipment). The plot spans a range a condensing temperatures of 35-65 °C (95-149 °F), corresponding to outside ambient air temperatures approximately 5-10 °C (9-18 °F) cooler to account for the heat transfer approach temperatures. Although the high-end of the range exceeds standard equipment rating temperatures, it is relevant to reflect performance at temperature extremes when cooling is most needed, that result in the highest cooling loads, and that can occur at lower ambient temperatures for condensing units installed on dark rooftops and/or in direct sunlight especially or with discharge air recirculation.

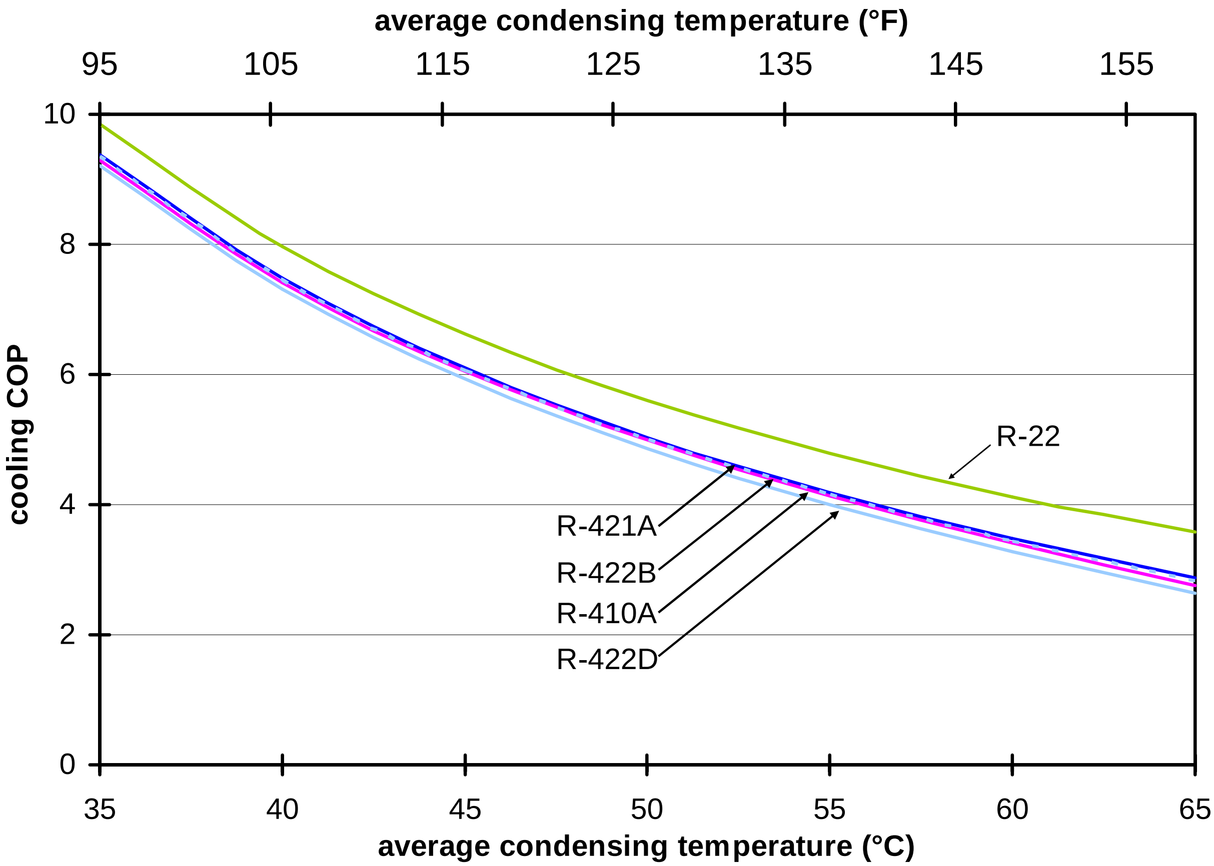

Figure 2: Cooling Coefficient of Performance (COP) Comparison

As shown, all four blends are thermodynamically less efficient than R-22 on an ideal-cycle basis. Of the four blends analyzed, R-421A offers the highest comparative efficiency, ranging from 4.8% to 19.8% lower than R-22 at 35-65 °C (95-149 °F) average condensing temperature. The lowest of the four ranges from 6.4% to 26.0% lower than R-22 for the same temperatures.

Figure 3 depicts the comparative cooling efficiency of the four blends at increasing condensing temperatures relative to that of R-22 for cycles optimized for equivalent performance at 35 °C (95 °F), the primary product rating condition with ideal but unattainable heat transfer (an approach temperature of zero), again excluding control, fan power, and similar power burdens.[7]

This comparison does not imply comparable costs, since the efficiency differences depicted in Figure 2 require increased heat exchanger sizing and other component and cycle optimization to overcome the thermodynamic differences and to overcome refrigerant selection influences towards achieving comparable capacities. It also does not account for lubricant differences.

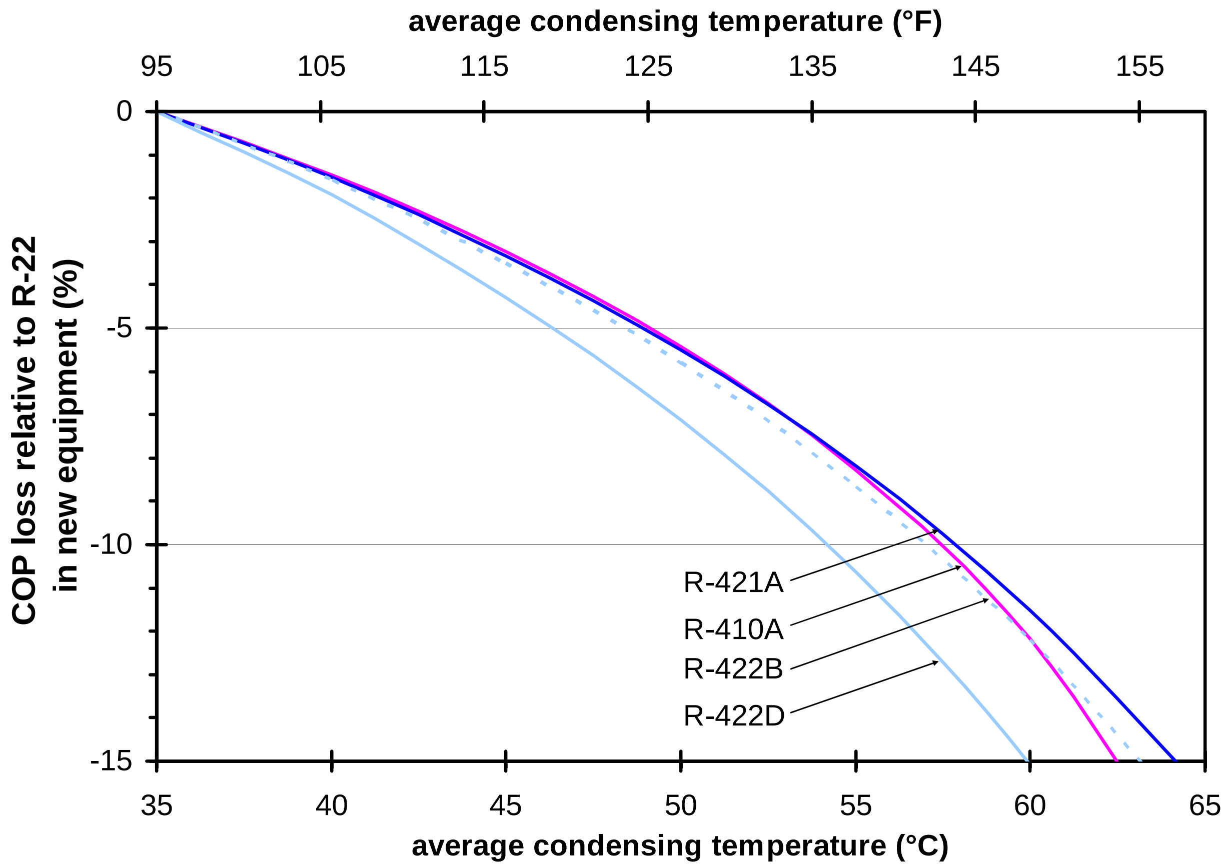

Figure 3: Relative COP Degradation with Increasing Condensing Temperature for Equipment Designed for Equivalent Performance at the Nominal Rating Point (35 °C, 95 °F)

As shown, the efficiencies of R410A, R-421A, and R-422B remain very similar for the low end of the temperature range illustrated, but R-421A's efficiency suffers the least degradation with increasing condensing temperatures (more extreme ambient temperatures).

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