

**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}

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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.

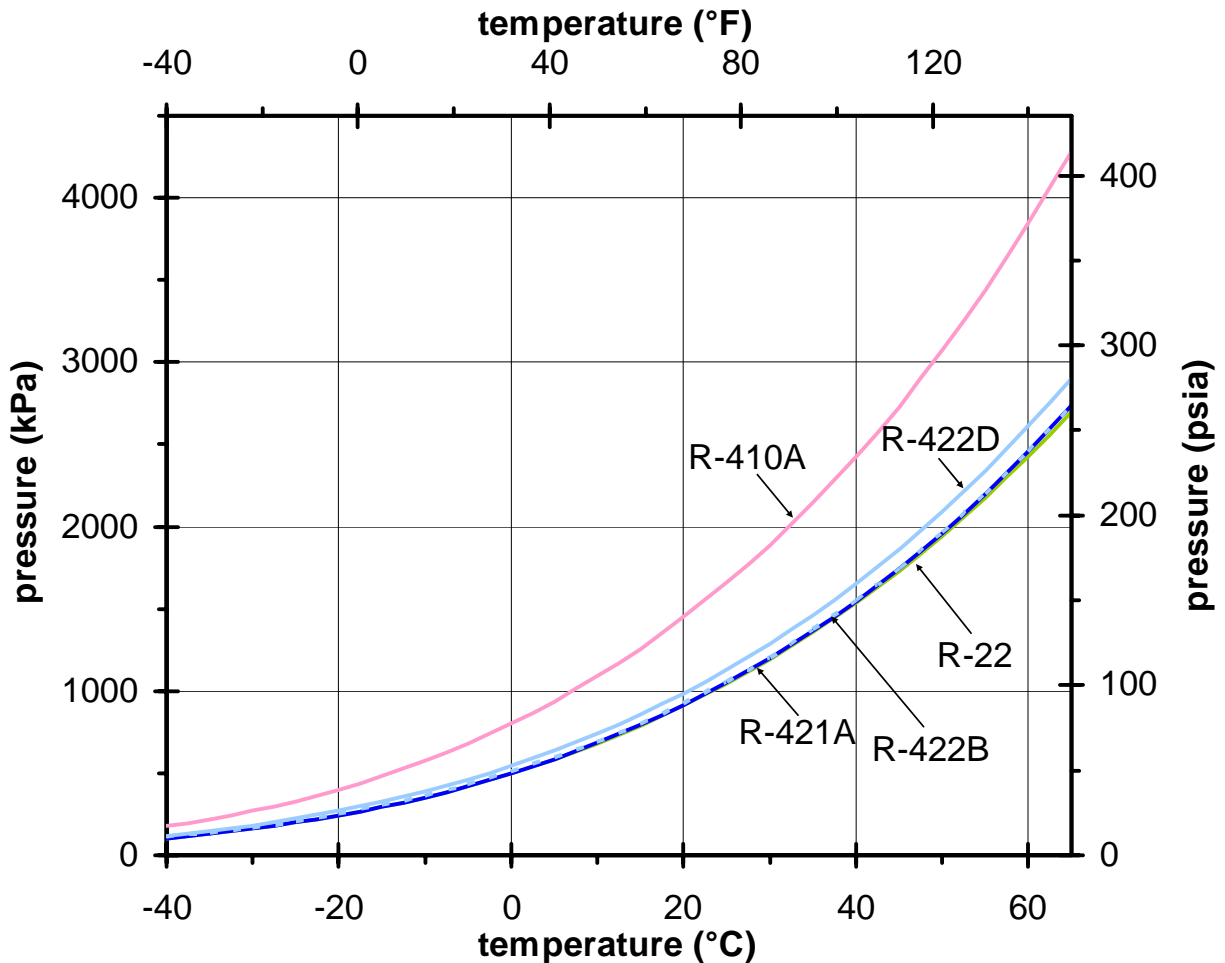


Figure 1: Pressure-Temperature Comparisons

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 |
|---|---|
| <u>average evaporating temperature</u> | |
| input temperature | 10 °C (50 °F) |
| superheat | 0 °C (0 °F) |
| <u>average condensing temperature</u> | |
| input temperature | 35-65 °C (95-149 °F) |
| superheat | 0 °C (0 °F) |
| <u>compressor efficiencies</u> | |
| isentropic | 100% |
| volumetric | 100% |
| motor | 100% |
| <u>pipng losses (drop)</u> | |
| suction line | none: 0 °C (0 °F) |
| discharge line | none: 0 °C (0 °F) |
| suction line / liquid line heat exchanger | none (0%) |
| <u>fans and control power burdens</u> | |
| 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.

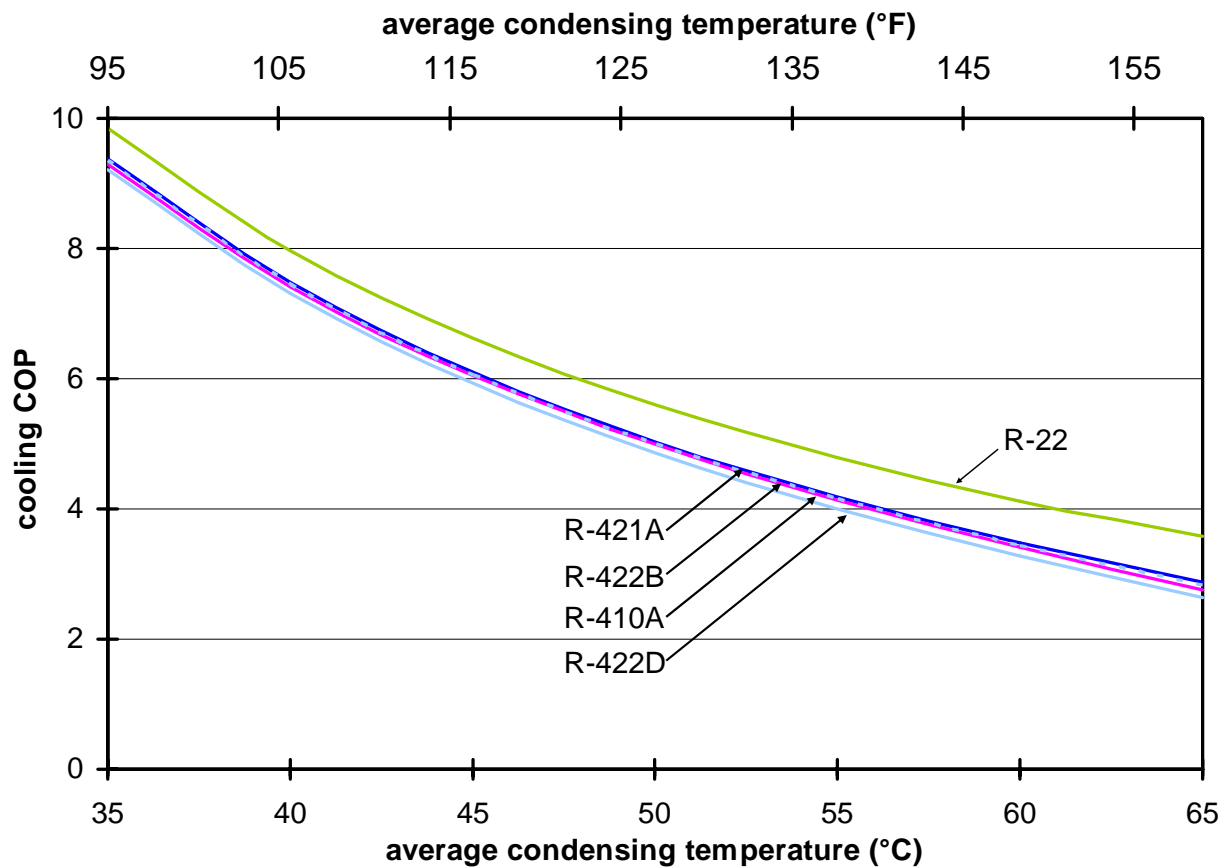


Figure 2: Cooling Coefficient of Performance (COP) Comparison

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.

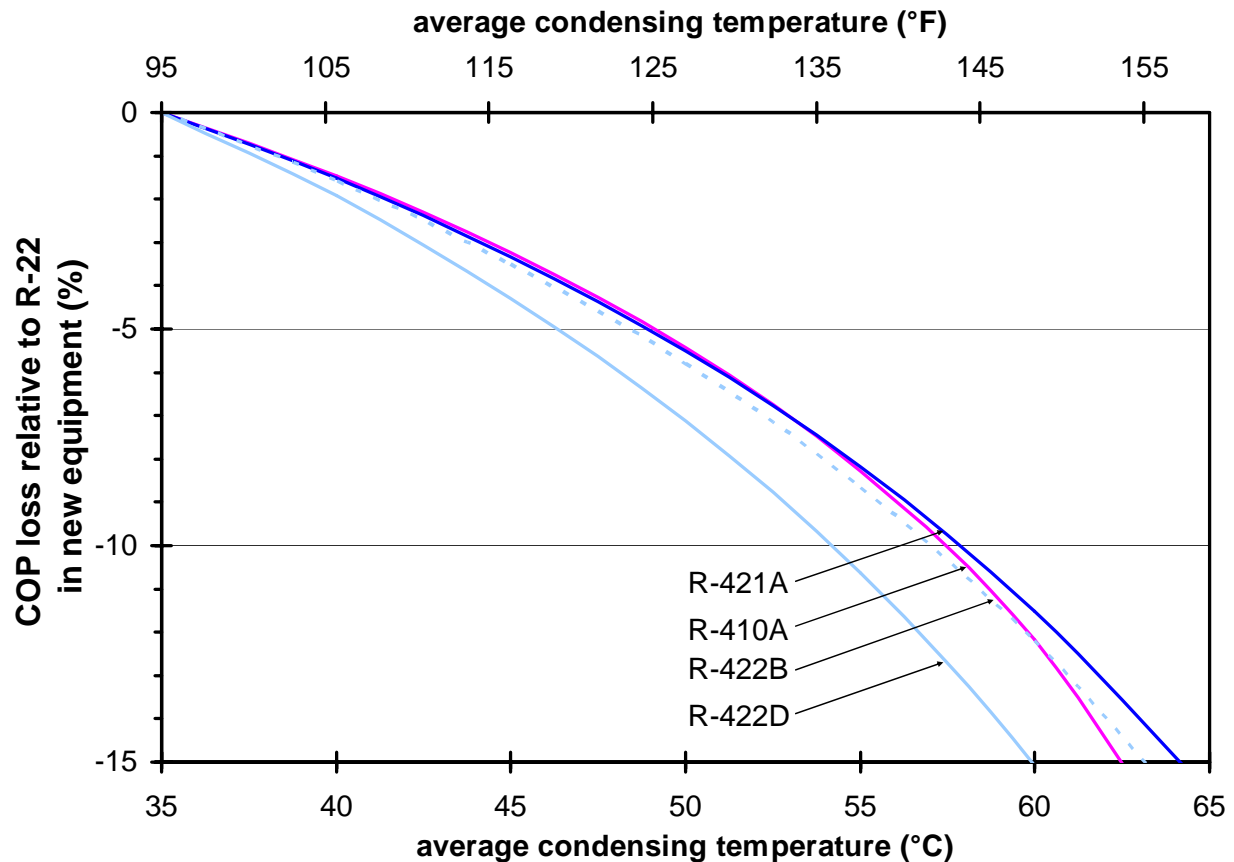


Figure 3: Relative COP Degradation with Increasing Condensing Temperature for Equipment Designed for Equivalent Performance at the Nominal Rating Point (35 °C, 95 °F)

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).

REFERENCES

- 1 J. M. Calm and G. C. Hourahan, "Refrigerant Data Update," *Heating/Piping/Air Conditioning Engineering*, 79(1):50-64, January 2007
- 2 *Designation and Safety Classification of Refrigerants*, ANSI/ASHRAE Standard 34-2007, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, USA, 2007
- 3 E. W. Lemmon, M. L. Huber, and M. O. McLinden, NIST Reference Fluid Thermodynamic and Transport Properties - REFPROP," Standard Reference Database (SRD) 23 version

- 8.0, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA, April 2007
- 4 P. A. Domanski, D. A. Didion, and J. S. W. Chi, *CYCLE_D: NIST Vapor-Compression Design Program* (version 3.0), Standard Reference Database 49, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA, 2003, modified with NIST REFPROP 8 fluid and additional mixture models
 - 5 J. M. Calm and D. A. Didion, "Trade-Offs in Refrigerant Selections: Past, Present, and Future," *Refrigerants for the 21st Century* (proceedings of the ASHRAE/NIST Refrigerants Conference, Gaithersburg, MD, 6-7 October 1997), 6-19, American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Atlanta, GA, USA, 1997
 - 6 J. M. Calm and P. A. Domanski, "R-22 Replacement Status," *ASHRAE Journal*, 46(8):29-39, August 2004; erratum, 46(10):8, October 2004
 - 7 *Performance Rating of Unitary Air-Conditioning and Air-Source Heat Pump Equipment*, ARI Standard 210-240-2006, Air-Conditioning and Refrigeration Institute (ARI) now the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Arlington, VA, USA, 2006