

Selection of Ozone-Safe, Nonazeotropic Refrigerant Mixtures for Capacity Modulation in Residential Heat Pumps

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ABSTRACT

Many combinations of refrigerants have been tested in an effort to improve the efficiency of residential heat pumps. Up to this point, there has been no systematic approach for determining which fluid pairs have the greatest potential for improving heat pump performance. The primary purpose of this work was to perform a comprehensive screening of refrigerant pairs which, through a shift in composition, could improve the performance of heat pump systems by modulating their capacity to better follow a building load. Secondary goals were to select a mixture with (1) a gliding temperature difference that matches that of the heat transfer fluid in both heat exchangers and (2) a higher capacity relative to R22 at low outdoor temperatures. The number of pure components was pared on the basis of boiling point, stability, ozone depletion potential, and toxicity. Pairs were then assembled from the pure components using the temperature glide (the constant-pressure temperature change that the fluid undergoes in the two-phase region as it passes through the heat exchanger) and the coefficient of performance to determine those pairs with the highest potential. The conclusions were that mixtures of R32/R124, R32/R142b, R143a/R124, R143a/R142b, and R143a/C318 were the best candidates for accomplishing the project goals. Although the mixtures were tailored for residential heat pumps with an emphasis on capacity modulation, the screening process could be used for other refrigeration applications as well.

INTRODUCTION

In heat pump systems, nonazeotropic refrigerant mixtures (NARMs) are purported to have several advantages over pure refrigerants. Among these advantages are improved coefficient of performance (COP), capacity control, and increased capacity at low ambient temperatures. Each of these advantages has been proven individually in previous research efforts. For example, improvements in COP have been achieved for an air-conditioning

application by matching the temperature glide of the mixture to that of the heat transfer fluid in both heat exchangers (Mulroy et al. 1988). In addition, a Japanese company has developed a method for accomplishing capacity control in which it reports a 15% increase, relative to R22, in the heating capacity and energy efficiency with a mixture of R22/R13B1 (Matsunaga et al. 1986).

The goal of a future test program is to utilize capacity control and matching of the temperature glides in both heat exchangers to improve the COP. In the attempt to incorporate these performance improvements concurrently, a tradeoff had to be made between them, since both are a function of the boiling point differential of the pure components. For example, to achieve a large shift in capacity, it is necessary to select pure components with boiling points as far apart as possible. However, the temperature glide of the mixture increases as the boiling point differential increases. Based on previous research (Radermacher 1986), as the temperature glide exceeds 30°F (16.7°C), efficiency gains begin to decrease. Since a large shift in capacity would result in exceeding a 30°F (16.7°C) temperature glide, we chose to limit the amount of capacity control in favor of better matching of the temperature glides in the heat exchangers.

METHODOLOGY

Several criteria were considered in the process of selecting the pure compounds that would make up the components of a NARM. These criteria can be broken down into two groups, "hard" criteria, which are characteristics that cannot be compromised and would eliminate a refrigerant from consideration, and "soft" criteria, which are items that may be used as a basis for elimination but can be changed or relaxed to allow for including refrigerants that are needed to fill in a gap for a capacity or boiling point of interest. Examples of hard criteria are: (1) toxicity, (2) instability, and (3) ozone depletion potential. Soft criteria include: (1) flammability, (2) boiling point, and (3) commercial availability. In the initial evaluation, flam-

Table 1
In IP Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°F)	Freezing Pt. (°F)	Critical Properties		
						Temperature (°F)	Pressure (psia)	Volume (ft ³ /lb)
704	Helium	He	4.00	-452.10	None	-450.30	33.21	0.2311
702p	Hydrogen (para)	H ₂	2.02	-423.20	-434.80	-400.30	187.50	0.5097
702n	Hydrogen (norm.)	H ₂	2.02	-423.00	-434.80	-399.90	190.80	0.5320
720	Neon	Ne	20.18	-410.90	-415.50	-379.70	493.10	0.0332
728	Nitrogen	N ₂	28.01	-320.40	-346.00	-232.40	492.90	0.0509
729	Air	—	28.97	-317.80	—	-232.40	547.40	0.0488
740	Argon	Ar	39.95	-302.60	-308.70	-188.10	710.40	0.0299
732	Oxygen	O ₂	32.00	-297.30	-361.80	-181.10	736.90	0.0375
50	Methane	CH ₄	16.40	-258.70	-296.00	-116.50	673.10	0.0990
14	Tetrafluoromethane	CF ₄	88.01	-198.30	-299.00	-50.20	543.00	0.0256
1150	Ethylene	CH ₂ =CH ₂	28.05	-154.70	-272.00	48.80	742.20	0.0700
744A	Nitrous Oxide	N ₂ O	44.02	-129.10	-152.00	97.70	1048.00	0.0355
170	Ethane	CH ₃ CH ₃	30.07	-127.85	-297.00	90.00	709.80	0.0830
503	R23/R13 40.1/59.9%	—	87.50	-127.60	—	67.10	607.00	0.0326
1132a	Vinylidene Fluoride	CH ₂ =CF ₂	64.04	-117.40	—	85.50	646.80	0.0384
23	Trifluoromethane	CHF ₃	70.02	-115.70	-247.00	78.10	701.40	0.0311
13	Chlorotrifluoromethane	CClF ₃	104.47	-114.60	-294.00	83.90	561.00	0.0277
116	Hexafluoroethane	CF ₃ CF ₃	138.01	-109.30	—	75.80	480.00	0.0267
744	Carbon Dioxide	CO ₂	44.01	-109.20	-89.90	87.90	1070.00	0.0342
41	Methyl Fluoride	CH ₃ F	34.03	-109.10	—	112.30	852.00	0.0582
1114	Tetrafluoroethene	CF ₂ =CF ₂	100.00	-105.30	-224.50	91.90	—	—
1141	Vinyl Fluoride	CH ₂ =CHF	46.05	-98.00	—	130.50	760.00	0.0501
—	Sulfur Hexafluoride	SF ₆	146.05	-82.80	—	114.00	545.50	0.0218
—	Bis(trifluoromethyl) ether	CF ₃ OCF ₃	154.02	-74.20	—	—	—	—
13B1	Bromotrifluoromethane	CBrF ₃	148.93	-71.95	-270.00	152.60	575.00	0.0215
504	R32/R115 48.2/51.8%	—	79.20	-71.00	—	151.50	690.50	0.0324
32	Methylene Fluoride	CH ₂ F ₂	52.00	-60.90	—	173.12	742*	0.0403*
1123	Trifluoroethene	CF ₂ =CHF	82.00	-59.80	-108.40	—	—	—
125	Pentafluoroethane	CHF ₂ CF ₃	120.03	-55.30	—	154*	499*	0.0296*
1270	Propylene	CH ₂ =CHCH ₃	42.09	-53.86	-301.00	197.20	670.30	0.0720
143a	Trifluoroethane	CH ₃ CF ₃	84.04	-53.70	—	163.58	545.37	0.0369
502	R22/R115 48.8/51.2%	—	111.63	-49.80	—	179.90	591.00	0.0286
290	Propane	CH ₃ CH ₂ CH ₃	44.10	-43.73	-305.80	206.30	617.40	0.0728
22	Chlorodifluoromethane	CHClF ₂	86.48	-41.36	-256.00	204.80	721.90	0.0305
115	Chloropentafluoroethane	CClF ₂ CF ₃	154.48	-38.40	-159.00	175.90	457.60	0.0261
218	Octafluoropropane	CF ₃ CF ₂ CF ₃	188.00	-38.20	-297.40	161*	390*	0.0262*
161	Fluoroethane	CH ₃ CH ₂ F	48.00	-35.00	—	—	—	—
—	Pentafluorodimethyl ether	CHF ₂ OCF ₃	136.03	-31.00	—	—	—	—
500	R12/R152a 73.8/26.2%	—	99.31	-28.30	-254.00	221.90	641.90	0.0323
C270	Cyclopropane	CH ₂ CH ₂ CH ₂	42.00	-28.30	—	—	—	—
717	Ammonia	NH ₃	17.03	-28.00	-107.90	271.40	1657	0.0680
C216	Perfluorocyclopropane	CF ₂ CF ₂ CF ₂	150.00	-24.70	—	—	—	—
12	Dichlorodifluoromethane	CCl ₂ F ₂	120.93	-21.62	-252.00	233.60	596.90	0.0287
505	R12/R31 78.0/22.0%	—	103.43	-21.29	—	244.00	686.00	0.0298
1216	Perfluoropropene	CF ₂ =CFCF ₃	150.00	-20.20	-249.20	—	—	—
1132	1,2-Difluoroethene	CHF=CHF	64.00	-18.40	—	—	—	—
1113	Chlorotrifluoroethylene	CClF=CF ₂	116.47	-18.20	—	222.40	589.50	0.0291
134a	1,1,1,2-tetrafluoroethane	CH ₂ FCF ₃	102.00	-15.70	-149.80	214.00	589.80	0.0313
152a	1,1-Difluoroethane	CHF ₂ CH ₃	66.05	-13.00	-178.60	236.30	652.00	0.0439
—	Dimethyl ether	CH ₃ OCH ₃	46.07	-12.68	-222.70	263.80	771.75	0.0590
40	Methyl Chloride	CH ₃ Cl	50.49	-11.60	-144.00	289.60	968.70	0.0454
1131a	1-Chloro-1-fluoroethene	CClF=CH ₂	80.45	-11.20	-272.20	—	—	—
1261ya	2-Fluoropropene	CH ₃ CF=CH ₂	60.00	-11.20	—	—	—	—
—	Trifluoromethylmethyl ether	CF ₃ OCH ₃	100.04	-11.20	—	—	—	—
—	Trifluoromethyl-pentafluoroethyl ether	CF ₃ OCF ₂ CF ₃	204.03	-9.94	—	—	—	—

* Indicates properties that are calculated or estimated.

Table 1 (Continued)
In IP Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°F)	Freezing Pt. (°F)	Temperature (°F)	Critical Properties	
							Pressure (psia)	Volume (ft ³ /lb)
115B1	Bromopentafluoroethane	CBrF ₂ CF ₃	200.00	- 7.60				
1225zc	1,1,1,3,3-pentafluoropropane	CF ₃ CH = CF ₂	132.00	- 5.80	- 243.40	237*	497*	0.0336*
134	1,1,2,2-Tetrafluoroethane	CHF ₂ CHF ₂	102.00	- 3.50		260.60		
1122	1-Chloro-2,2-difluoroethane	CHCl = CF ₂	98.45	- 1.22	- 217.30			
227ea	1,1,1,2,3,3,3-Heptafluoropropane	CF ₃ CHFCF ₃	170.00	- 0.40				
1243zl	1,1,1-Trifluoropropene	CF ₃ CH = CH ₂	96.00	- 0.40				
245cb	1,1,1,2,2-Pentafluoropropane	CF ₃ CF ₂ CH ₃	134.00	0.10				
227ca	1,1,1,2,2,3,3-Heptafluoropropane	CF ₃ CF ₂ CHF ₂	170.00	1.40				
22B1	Bromodifluoromethane	CHBrF ₂	130.90	5.00				
1140	Chloroethene	CHCl = CH ₂	62.50	7.00		288.00	749.00	0.0297
506	R31/R114 55.1/44.9%	—	93.69	9.60	—	294.30	514*	0.0297*
124	2-Chloro-1,1,1,2-tetrafluoroethane	CHClCF ₃	136.48	10.40				
600a	Isobutane	C ₄ H ₁₀	58.13	10.89	- 255.50	275.00	529.10	0.0725
124a	1-Chloro-1,1,2,2-tetrafluoroethane	CHF ₂ CClF ₂	136.48	13.60	—	260.10	539.50	0.0287
764	Sulfur Dioxide	SO ₂	64.07	14.00	- 103.90	315.50	1143.00	0.0306
142b	Chlorodifluoroethane	CH ₃ CClF ₂	100.50	14.40	- 204.00	278.80	598.00	0.0368
—	Trifluoromethyl-1,2,2,2-tetrafluoroethyl ether	CF ₃ OCHFCF ₃	186.04	15.08				
281ea	2-Fluoropropane	CH ₃ CHFCH ₃	62.00	15.10	- 208.00			0.0379*
31	Chlorofluoromethane	CH ₂ ClF	68.50	15.60	—	378*	816*	—
630	Methylamine	CH ₃ NH ₂	31.06	19.90	- 134.50	314.40	1082.00	—
C318	Octafluorocyclobutane	C ₄ F ₈	200.04	21.50	- 42.50	239.60	403.60	0.0258
31.10	Perfluorobutane	CF ₃ CF ₂ CF ₂ CF ₃	238.00	23.00				
1122a	1-Chloro-1,2-difluoroethene	CClF = CHF	98.50	23.00				
12B1	Bromochlorodifluoromethane	CBrClF ₂	165.40	24.80				
1131 (l)	1-Chloro-2-fluoroethene	CHCl = CHF	80.50	24.80				
2811a	1-Fluoropropane	CH ₂ FCH ₂ CH ₃	62.00	27.50				
217ba	2-Chloroperfluoropropane	CF ₃ CClFCF ₃	204.50	28.00				
217ca	1-Chloroperfluoropropane	CClF ₂ CF ₂ CF ₃	204.50	28.40				
113B1	Bromotrifluoroethene	CBrF = CF ₂	160.90	28.40				
236fa	1,1,1,3,3,3-Hexafluoropropane	CF ₃ CH ₂ CF ₃	152.00	30.70				
600	Butane	C ₄ H ₁₀	58.13	31.10	- 217.30	305.60	550.70	0.0702
272ca	2,2-Difluoropropane	CH ₃ CF ₂ CH ₃	80.00	31.30				
254eb	1,1,2,2-Tetrafluoropropane	CHF ₂ CF ₂ CH ₃	116.00	32.00				
236cb	1,1,1,2,2,3-Hexafluoropropane	CF ₃ CF ₂ CH ₂ F	152.00	34.20				
—	Bis(difluoromethyl) ether	CHF ₂ OCHF ₂	118.04	35.60				
114a	1,1-Dichlorotetrafluoroethane	CCl ₂ FCF ₃	170.94	37.40	- 69.90	293.70	479.20	0.0275
114	1,2-Dichlorotetrafluoroethane	CClF ₂ CClF ₂	170.94	38.50	- 137.00	294.30	473.00	0.0275
40B1	Bromomethane	CH ₃ Br	95.00	39.50				
143	1,1,2-Trifluoroethane	CHF ₂ CH ₂ F	84.04	41.00		316*	543*	0.0381*
C1316	Hexafluorocyclobutene	C ₄ F ₆	162.00	41.90	- 76.00	160.16		
—	Trifluoromethyl-2,2,2-trifluoroethyl ether	CF ₃ OCH ₂ CF ₃	169.05	42.01				
236ea	1,1,1,2,3,3-Hexafluoropropane	CF ₃ CHFCHF ₂	152.00	42.80				
1122B1	1-Bromo-2,2-difluoroethene	CHBr = CF ₂	142.90	42.80				

Table 1 (Continued)
In IP Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°F)	Freezing Pt. (°F)	Temperature (°F)	Critical Properties	
							Pressure (psia)	Volume (ft ³ /lb)
2316	Perfluorobutadiene	CF ₂ =CFCF=CF ₂	162.00	43.00				
133a	Chlorotrifluoroethane	CH ₂ ClCF ₃	118.50	44.40	- 157.90	316*	557*	0.0323*
272fb	1,1-Difluoropropane	CHF ₂ CH ₂ CH ₃	80.00	46.40				
21	Dichlorodifluoromethane	CHCl ₂ F	102.92	47.80	- 211.00	353.30	750.00	0.0307
—	2,2-Dimethylpropane	(CH ₃) ₄ C	72.00	49.10				
236ca	1,1,2,2,3,3-Hexafluoropropane	CHF ₂ CF ₂ CHF ₂	152.00	50.00				
1131	1-Chloro-2-fluoroethane	CHCl = CHF	80.45	50.00				
217caB1	1-Bromoperfluoropropane	CBBrF ₂ CF ₂ CF ₃	248.90	53.60				
160	Ethylchloride	CH ₃ CH ₂ Cl	64.52	54.32	- 216.90	369.00	764.40	0.0485
214cb	1,1,1,3-Tetrachloro-2,2,3,3-tetrafluoropropane	CCl ₃ CF ₂ CClF ₂	253.80	57.60	- 135.00			
151a	1-Chloro-1-fluoroethane	CHClFCH ₃	82.45	61.00				
631	Ethyl Amine	CH ₃ CH ₂ NH ₂	45.08	61.88	- 113.00	361.40	815.60	—
133	1-Chloro-1,2,2-trifluoroethane	CHClFCHF ₂	118.50	62.60				
31B1	Bromofluoromethane	CH ₂ BrF	112.9	63.50	—	375.80		
1112a	1,1-Dichlorodifluoroethylene	CCl ₂ = CF ₂	133.00	66.20				
1112	1,2-Dichlorodifluoroethylene	CClF = CClF	133.00	70.70				
11	Trichlorofluoromethane	CCl ₃ F	137.38	74.87	- 168.00	388.40	639.50	0.0289
12B2	Dibromofluoromethane	CBBr ₂ F ₂	209.80	76.10	- 221.80	388.80		
C317	Chloroheptafluorocyclobutane	C ₄ ClF ₇	216.50	78.10				
133aB1	1-Bromo-2,2,2-trifluoroethane	CH ₂ BrCF ₃	162.90	78.80	- 137.20			
C1418	Perfluorocyclopentene	C ₅ F ₈	152.00	80.60				
123	Dichlorotrifluoroethane	CHCl ₂ CF ₃	152.91	81.70	—	363*	523*	0.0298*
123a	1,2-Dichlorotrifluoroethane	CClF ₂ CHClF ₂	152.91	82.40				
123b	1,1-Dichloro-1,2,2-trifluoroethane	CCl ₂ FCHF ₂	152.91	—				
—	Difluoromethylfluoromethyl ether	CHF ₂ OCH ₂ F	100.04	86.18				
152	1,2-Difluoroethane	CFH ₂ CFH ₂	66.05	87.20				
611	Methyl Formate	HCOOCH ₃	60.05	89.20	- 146.00	417.20	870.00	0.0459
141b	1,1-Dichloro-1-fluoroethane	CCl ₂ FCH ₃	116.90	89.60				
—	Trifluoromethyl-1,1,2,2-tetrafluoroethyl ether	CF ₃ OCF ₂ CHF ₂	186.04	93.20				
610	Ethyl Ether	C ₂ H ₅ OC ₂ H ₅	74.12	94.30	- 177.30	381.20	523.00	0.0607
142	1-Chloro-2,2-difluoroethane	CH ₂ ClCHF ₂	100.50	95.20				
142a	1-Chloro-1,2-difluoroethane	CHClFCH ₂ F	100.50	—				
1121	1,2-Dichlorodifluoroethane	CClF = CHCl	114.90	95.20				
216	Dichlorohexafluoropropane	C ₃ Cl ₂ F ₆	220.93	96.24	- 193.70	356.00	399.50	0.0279
—	Difluoromethyl-1,1-difluoroethyl ether	CHF ₂ OCF ₂ CH ₃	132.06	97.70				
30	Methylene Chloride	CH ₂ Cl ₂	84.93	104.40	- 142.00	458.60	882.00	—
21B1	Bromochlorofluoromethane	CHBrClF	147.35	100.40	- 175.00			
113a	1,1,1-Trichlorotrifluoroethane	CCl ₃ CF ₃	187.40	114.39	57.20			
114B2	1,2-Dibromotetrafluoroethane	CBBrF ₂ CBBrF ₂	259.80	115.50	- 166.90	418.10		
132b	1,2-Dichloro-1,1-difluoroethane	CClF ₂ CH ₂ Cl	135.00	115.70				
113	Trichlorotrifluoroethane	CCl ₂ FCClF ₂	187.39	117.63	- 31.00	417.40	489.90	0.0278
1130	Dichloroethylene	CHCl = CHCl	96.95	118.00	- 58.00	470.00	795.00	—
123B1	1-Bromo-1-chloro-2,2,2-trifluoroethane	CHBrClCF ₃	197.35	122.40				
225da	1,2-Dichloro-1,1,3,3,3-pentafluoropropane	CClF ₂ CHClCF ₃	202.90	122.70				
11B1	Bromodichlorofluoromethane	CBBrCl ₂ F	181.80	125.60				
151	1-Chloro-1-fluoroethane	CH ₂ ClCH ₂ F	82.45	127.80				
123aB1	1-Bromo-2-chloro-1,1,2-trifluoroethane	CBBrF ₂ CHClF	197.35	122-131				
—	Fluoromethylchlorofluoromethyl ether	CH ₂ FOCHClF	116.49	131.54				

Table 1 (Continued)
In IP Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°F)	Freezing Pt. (°F)	Temperature (°F)	Critical Properties	
							Pressure (psia)	Volume (ft ³ /lb)
150a	1,1-Dichloroethane	CHCl ₂ CH ₃	98.96	134.60				
142B1	1-Bromo-2,2-difluoroethane	CH ₂ BrCHF ₂	144.90	135.10				
132	1,2-Dichloro-1,2-difluoroethane	CHClFCHClF	135.00	137.30				
132a	1,1-Dichloro-1,2-difluoroethane	CHCl ₂ CHF ₂	135.00	137.30				
132c	1,1-Dichloro-1,2-difluoroethane	CCl ₂ FCH ₂ F	232.90	139.10				
C316	Dichlorohexafluorocyclobutane	C ₄ Cl ₂ F ₆	119.50	143.10				
20	Chloroform	CHCl ₃	270.90	145.40	- 90.40			
318nbb	2,2-Dichloroperfluorobutane	CF ₃ CClF- CClFCF ₃	182.08	147.20				
—	Bis(1,1,1-trifluoroethyl) ether	CF ₃ CH ₂ OCH ₂ CF ₃	191.80	149.00	79.70			
21B2	Dibromodifluoromethane	CHBr ₂ F						

Table 1
In SI Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°C)	Freezing Pt. (°C)	Temperature (°C)	Critical Properties	
							Pressure (kPa)	Volume (M ³ /Kg)
704	Helium	He	4.00	- 268.94	NONE	- 267.94	228.98	0.01443
702p	Hydrogen (para)	H ₂	2.02	- 252.89	- 259.33	- 240.17	1292.81	0.03182
702n	Hydrogen (norm.)	H ₂	2.02	- 252.78	- 259.33	- 239.94	1315.57	0.03321
720	Neon	Ne	20.18	- 246.06	- 248.61	- 228.72	3399.92	0.00207
728	Nitrogen	N ₂	28.01	- 195.78	- 210.00	- 146.89	3398.55	0.00318
729	Air	—	28.97	- 194.33	—	- 146.89	3774.32	0.00305
740	Argon	Ar	39.95	- 185.89	- 189.28	- 122.28	4898.21	0.00187
732	Oxygen	O ₂	32.00	- 182.94	- 218.78	- 118.39	5080.93	0.00234
50	Methane	CH ₄	16.40	- 161.50	- 182.22	- 82.50	4641.02	0.00618
14	Tetrafluoromethane	CF ₄	88.01	- 127.94	- 183.89	- 45.67	3743.98	0.00160
1150	Ethylene	CH ₂ = CH ₂	28.05	- 103.72	- 168.89	9.33	5117.47	0.00437
744A	Nitrous Oxide	N ₂ O	44.02	- 89.50	- 102.22	36.50	7225.96	0.00222
170	Ethane	CH ₃ CH ₃	30.07	- 88.81	- 182.78	32.22	4894.07	0.00518
503	R23/R13 40.1/59.9%	—	87.50	- 88.67	—	19.50	4185.26	0.00204
1132a	Vinylidene Fluoride	CH ₂ = CF ₂	64.04	- 83.00	—	29.72	4459.69	0.00240
23	Trifluoromethane	CHF ₃	70.02	- 82.06	- 155.00	25.61	4836.15	0.00194
13	Chlorotrifluoromethane	CClF ₃	104.47	- 81.44	- 181.11	28.83	3868.10	0.00173
116	Hexafluoroethane	CF ₃ CF ₃	138.01	- 78.50	—	24.33	3309.60	0.00167
744	Carbon Dioxide	CO ₂	44.01	- 78.44	- 56.61	31.06	7377.65	0.00214
41	Methyl Fluoride	CH ₃ F	34.03	- 78.39	—	44.61	5874.54	0.00363
1114	Tetrafluoroethene	CF ₂ = CF ₂	100.00	- 76.28	- 142.50	33.28	0.00	0.00000
1141	Vinyl Fluoride	CH ₂ = CHF	46.05	- 72.22	—	54.72	5240.20	0.00313
—	Sulfur Hexafluoride	SF ₆	146.05	- 63.78	—	45.56	3761.22	0.00136
—	Bis(trifluoromethyl) ether	CF ₃ OCF ₃	154.02	- 59.00	—	67.00	3964.62	0.00134
13B1	Bromotrifluoromethane	CBrF ₃	148.93	- 57.75	- 167.78	66.39	4761.00	0.00202
504	R32/R115 48.2/51.8%	—	79.20	- 57.22	—	78.40		
32	Methylene Fluoride	CH ₂ F ₂	52.00	- 51.61	—			
1123	Trifluoroethene	CF ₂ = CHF	82.00	- 51.00	- 78.00	68*	3834*	0.00226*
125	Pentafluoroethane	CHF ₂ CF ₃	120.03	- 48.50	—	91.78	4621.72	0.00449
1270	Propylene	CH ₂ = CHCH ₃	42.09	- 47.70	- 185.00	73.10	3760.33	0.00230
143a	Trifluoroethane	CH ₃ CF ₃	84.04	- 47.61	—	82.17	4074.94	0.00179
502	R22/R115 48.8/51.2%	—	111.63	- 45.44	—	96.83	4256.97	0.00454
290	Propane	CH ₃ CH ₂ CH ₃	44.10	- 42.07	- 187.67	96.00	4977.50	0.00190
22	Chlorodifluoromethane	CHClF ₂	86.48	- 40.76	- 160.00			

* Indicates properties that are calculated or estimated

Table 1 (Continued)
In SI Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°C)	Freezing Pt. (°C)	Temperature (°C)	Critical Properties	
							Pressure (kPa)	Volume (M ³ /Kg)
115	Chloropentafluoroethane	CClF ₂ CF ₃	154.48	-39.11	-106.11	79.94	3155.15	0.00163
218	Octafluoropropane	CF ₃ CF ₂ CF ₃	188.00	-39.00	-183.00	72*	2689*	0.00163*
161	Fluoroethane	CH ₃ CH ₂ F	48.00	-37.22				
—	Pentafluorodimethyl ether	CHF ₂ OCF ₃	136.03	-35.00				
500	R12/R152a 73.8/26.2%	—	99.31	-33.50	-158.89	105.50	4425.90	0.00202
C270	Cyclopropane	CH ₂ CH ₂ CH ₂	42.00	-33.50				
717	Ammonia	NH ₃	17.03	-33.33	-77.72	133.00		
C216	Perfluorocyclopropane	CF ₂ CF ₂ CF ₂	150.00	-31.50				
12	Dichlorodifluoromethane	CCl ₂ F ₂	120.93	-29.79	-157.78	112.00	4115.63	0.00179
505	R12/R31 78.0/22.0%	—	103.43	-29.61	—	117.78	4729.97	0.00186
1216	Perfluoropropene	CF ₂ =CFCF ₃	150.00	-29.00	-156.22			
1132	1,2-Difluoroethene	CHF=CHF	64.00	-28.00				
1113	Chlorotrifluoroethylene	CClF=CF ₂	116.47	-27.89		105.78	4064.60	0.00182
134a	1,1,1,2-tetrafluoroethane	CH ₂ FCF ₃	102.00	-26.50	-101.00	101.11	4066.67	0.00195
152a	1,1-Difluoroethane	CHF ₂ CH ₃	66.05	-25.00	-117.00	113.50	4495.54	0.00274
—	Dimethyl ether	CH ₃ OCH ₃	46.07	-24.82	-141.50	128.80	5321.20	0.00271
40	Methyl Chloride	CH ₃ Cl	50.49	-24.22	-97.78	143.11	6679.19	0.00283
1131a	1-Chloro-1-fluoroethene	CClF=CH ₂	80.45	-24.00	-169.00			
1261ya	2-Fluoropropene	CH ₃ CF=CH ₂	60.00	-24.00				
—	Trifluoromethylmethyl ether	CF ₃ OCH ₃	100.04	-24.00				
—	Trifluoromethyl- pentafluoroethyl ether	CF ₃ OCF ₂ CF ₃	204.03	-23.30				
115B1	Bromopentafluoroethane	CBrF ₂ CF ₃	200.00	-22.00				
1225zc	1,1,1,3,3-pentafluoropropane	CF ₃ CH=CF ₂	132.00	-21.00	-153.00			
134	1,1,2,2-Tetrafluoroethane	CHF ₂ CHF ₂	102.00	-19.72		114*	3430*	0.00210*
1122	1-Chloro-2,2-difluoroethene	CHCl=CF ₂	98.45	-18.46	-138.50	127.00		
227ea	1,1,1,2,3,3,3- Heptafluoropropane	CF ₃ CHFCF ₃	170.00	-18.00				
1243zf	1,1,1-Trifluoropropene	CF ₃ CH=CH ₂	96.00	-18.00				
245cb	1,1,1,2,2-Pentafluoropropane	CF ₃ CF ₂ CH ₃	134.00	-17.72				
227ca	1,1,1,2,2,3,3- Heptafluoropropane	CF ₃ CF ₂ CHF ₂	170.00	-17.00				
22B1	Bromodifluoromethane	CHBrF ₂	130.90	-15.00				
1140	Chloroethene	CHCl=CH ₂	62.50	-13.89				
506	R31/R114 55.1/44.9%	—	93.69	-12.44		142.22	5164.36	0.00185
124	2-Chloro-1,1,1,2- tetrafluoroethane	CHClFCF ₃	136.48	-12.00		145.72	3544*	0.00185*
600a	Isobutane	C ₄ H ₁₀	58.13	-11.73	-159.72	135.00	3648.14	0.00453
124a	1-Chloro-1,1,2,2- tetrafluoroethane	CHF ₂ CClF ₂	136.48	-10.22		126.72	3719.65	0.00179
764	Sulfur Dioxide	SO ₂	64.07	-10.00	-75.50	157.50	7880.99	0.00191
142b	Chlorodifluoroethane	CH ₂ CClF ₂	100.50	-9.78	-131.11	137.11	4123.21	0.00230
—	Trifluoromethyl- 1,2,2,2-tetrafluoroethyl ether	CF ₃ OCHF ₂ CF ₃	186.04	-9.40				
281ea	2-Fluoropropene	CH ₃ CHFCH ₃	62.00	-9.39	-133.33			
31	Chlorofluoromethane	CH ₂ ClF	68.50	-9.11				
630	Methylamine	CH ₃ NH ₂	31.06	-6.72	-92.50	156.89	7460.39	
C318	Octafluorocyclobutane	C ₄ F ₈	200.04	-5.83	-41.39	115.33	2782.82	0.00161
31.10	Perfluorobutane	CF ₃ CF ₂ CF ₂ CF ₃	238.00	-5.00				
1122a	1-Chloro-1,2-difluoroethene	CClF=CHF	98.50	-5.00				
12B1	Bromochlorodifluoromethane	CBrClF ₂	165.40	-4.00				
1131 (f)	1-Chloro-2-fluoroethene	CHCl=CHF	80.50	-4.00				
281fa	1-Fluoropropane	CH ₂ FCH ₂ CH ₃	62.00	-2.50				
217ba	2-Chloroperfluoropropane	CF ₃ CClFCF ₃	204.50	-2.22				
217ca	1-Chloroperfluoropropane	CClF ₂ CF ₂ CF ₃	204.50	-2.00				
113B1	Bromotrifluoroethene	CBrF=CF ₂	160.90	-2.00				

Table 1 (Continued)
In SI Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°C)	Freezing Pt. (°C)	Temperature (°C)	Critical Properties	
							Pressure (kPa)	Volume (M ³ /Kg)
236fa	1,1,1,3,3,3-Hexafluoropropane	CF ₃ CH ₂ CF ₃	152.00	- 0.72				
600	Butane	C ₄ H ₁₀	58.13	- 0.50	- 138.50	152.00	3797.08	0.00438
272ca	2,2-Difluoropropane	CH ₃ CF ₂ CH ₃	80.00	- 0.39				
254eb	1,1,2,2-Tetrafluoropropane	CHF ₂ CF ₂ CH ₃	116.00	0.00				
236cb	1,1,1,2,2,3-Hexafluoropropane	CF ₃ CF ₂ CH ₂ F	152.00	1.22				
—	Bis(difluoromethyl) ether	CHF ₂ OCHF ₂	118.04	2.00				
114a	1,1-Dichlorotetrafluoroethane	CCl ₂ FCF ₃	170.94	3.00	- 56.61	145.39	3304.08	0.00172
114	1,2-Dichlorotetrafluoroethane	CClF ₂ CClF ₂	170.94	3.61	- 93.89	145.72	3261.33	0.00172
40B1	Bromomethane	CH ₃ Br	95.00	3.61		158*	3741*	0.00238*
143	1,1,2-Trifluoroethane	CHF ₂ CH ₂ F	84.04	5.00		71.20		
C1316	Hexafluorocyclobutene	C ₄ F ₆	162.00	5.50	- 60.00			
—	Trifluoromethyl- 2,2,2-trifluoroethyl ether	CF ₃ OCH ₂ CF ₃	169.05	5.56				
236ea	1,1,1,2,3,3-Hexafluoropropane	CF ₃ CHFCF ₂	152.00	6.00				
1122B1	1-Bromo-2,2-difluoroethene	CHBr = CF ₂	142.90	6.00				
2316	Perfluorobutadiene	CF ₂ = CFCF = C- F ₂	162.00	6.11				
133a	Chlorotrifluoroethane	CH ₂ ClCF ₃	118.50	6.89	- 105.50			
272fb	1,1-Difluoropropane	CHF ₂ CH ₂ CH ₃	80.00	8.00		178.50	5171.25	0.00192
21	Dichlorodifluoromethane	CHCl ₂ F	102.92	8.78	- 135.00			
—	2,2-Dimethylpropane	(CH ₃) ₄ C	72.00	9.50				
236ca	1,1,2,2,3,3-Hexafluoropropane	CHF ₂ CF ₂ CHF ₂	152.00	10.00				
1131	1-Chloro-2-fluoroethane	CHCl = CHF	80.45	10.00				
217caB1	1-Bromoperfluoropropane	CBrF ₂ CF ₂ CF ₃	248.90	12.00		187.22	5270.54	0.00303
160	Ethylchloride	CH ₃ CH ₂ Cl	64.52	12.40	- 138.28			
214cb	1,1,1,3-Tetrachloro- 2,2,3,3-tetrafluoroethane	CCl ₃ CF ₂ CClF ₂	253.80	14.22	- 92.78			
151a	1-Chloro-1-fluoroethane	CHClFCH ₃	82.45	16.11	- 60.56	183.00	5623.56	
631	Ethyl Amine	CH ₃ CH ₂ NH ₂	45.08	16.60				
133	1-Chloro-1,2,2-trifluoroethane	CHClFCHF ₂	118.50	17.00		191.00		
31B1	Bromofluoromethane	CH ₂ BrF	112.90	17.50				
1112a	1,1-Dichlorodifluoroethylene	CCl ₂ = CF ₂	133.00	19.00				
1112	1,2-Dichlorodifluoroethylene	CClF = CClF	133.00	21.50				
11	Trichlorofluoromethane	CCl ₃ F	137.38	23.82	- 111.11	198.00	4409.35	0.00180
12B2	Dibromodifluoromethane	CBBr ₂ F ₂	209.80	24.50	- 141.00	198.22		
C317	Chloroheptafluorocyclobutane	C ₄ ClF ₇	216.50	25.61				
133aB1	1-Bromo-2,2,2-trifluoroethane	CH ₂ BrCF ₃	162.90	26.00	- 94.00			
C1418	Perfluorocyclopentene	C ₅ F ₈	152.00	27.00				
123	Dichlorotrifluoroethane	CHCl ₂ CF ₃	152.91	27.61				
123a	1,2-Dichlorotrifluoroethane	CClF ₂ CHClF ₂	152.91	28.00				
123b	1,1-Dichloro- 1,2,2-trifluoroethane	CCl ₂ FCHF ₂	152.91					
—	Difluoromethylfluoromethyl ether	CHF ₂ OCH ₂ F	100.04	30.10				
152	1,2-Difluoroethane	CFH ₂ CFH ₂	66.05	30.67				
611	Methyl Formate	HCOOCH ₃	60.05	31.78	- 98.89	214.00	5998.65	0.00287
141b	1,1-Dichloro-1-fluoroethane	CCl ₂ FCH ₃	116.90	32.00				
—	Trifluoromethyl- 1,1,2,2-tetrafluoroethyl ether	CF ₃ OCF ₂ CHF ₂	186.04	34.00				
610	Ethyl Ether	C ₂ H ₅ OC ₂ H ₅	74.12	34.61	- 116.28	194.00	3606.08	0.00379
142	1-Chloro-2,2-difluoroethane	CH ₂ ClCHF ₂	100.50	35.11				
142a	1-Chloro-1,2-difluoroethane	CHClFCH ₂ F	100.50					
1121	1,2-Dichlorodifluoroethane	CClF = CHCl	114.90	35.11				
216	Dichlorohexafluoropropane	C ₃ Cl ₂ F ₆	220.93	35.69	- 125.39	180.00	2754.55	0.00174

Table 1 (Continued)
In SI Units

Refrigerant Number	Name	Chemical Formula	Molecular Weight	Boiling Pt. (°C)	Freezing Pt. (°C)	Temperature (°C)	Critical Properties	
							Pressure (kPa)	Volume (M ³ /Kg)
—	Difluoromethyl-1,1-difluoroethyl ether	CHF ₂ OCF ₂ CH ₃	132.08	36.50				
30	Methylene Chloride	CH ₂ Cl ₂	84.93	40.22	- 96.67	237.00	6081.39	
21B1	Bromochlorofluoromethane	CHBrClF	147.35	38.00	- 115.00			
113a	1,1,1-Trichlorotrifluoroethane	CCl ₃ CF ₃	187.40	45.77	14.00			
114B2	1,2-Dibromotetrafluoroethane	CBrF ₂ CBrF ₂	259.80	46.39	- 110.50	214.50		
132b	1,2-Dichloro-1,1-difluoroethane	CClF ₂ CH ₂ Cl	135.00	46.50				
113	Trichlorotrifluoroethane	CCl ₂ FCClF ₂	187.39	47.57	- 35.00	214.11	3377.86	0.00174
1130	Dichloroethylene	CHCl = CHCl	96.95	47.78	- 50.00	243.33	5481.53	
123B1	1-Bromo-1-chloro-2,2,2-trifluoroethane	CHBrClCF ₃	197.35	50.22				
225da	1,2-Dichloro-1,1,3,3,3-pentafluoropropane	CClF ₂ CHClCF ₃	202.90	50.39				
11B1	Bromodichlorofluoromethane	CBBrCl ₂ F	181.80	52.00				
151	1-Chloro-1-fluoroethane	CH ₂ ClCH ₂ F	82.45	53.22				
123aB1	1-Bromo-2-chloro-1,1,2-trifluoroethane	CBBrF ₂ CHClF	197.35					
—	Fluoromethylchlorofluoromethyl ether	CH ₂ FCHClCF	116.49	55.30				
150a	1,1-Dichloroethane	CHCl ₂ CH ₃	98.96	57.00				
142B1	1-Bromo-2,2-difluoroethane	CH ₂ BrCHF ₂	144.90	57.28				
132	1,2-Dichloro-1,2-difluoroethane	CHClFCHClF	135.00	58.50				
132a	1,1-Dichloro-2,2-difluoroethane	CHCl ₂ CHF ₂	135.00	58.50				
132c	1,1-Dichloro-difluoroethane	CCl ₂ FCH ₂ F	135.00					
C316	Dichlorohexafluorocyclobutane	C ₄ Cl ₂ F ₆	232.90	59.50				
20	Chloroform	CHCl ₃	119.50	61.72				
318nbb	2,2-Dichloroperfluorobutane	CF ₃ CClF ₂ CClF ₂ CF ₃	270.90	63.00	- 68.00			
—	Bis(1,1,1-trifluoroethyl) ether	CF ₃ CH ₂ OCH ₂ CF ₃	182.08	64.00				
21B2	Dibromofluoromethane	CHBr ₂ F	191.80	65.00	26.50			

mability was included in the hard criteria category. It was later changed to a soft criterion to allow more refrigerants to be evaluated.

Once a compound was determined to be suitable for further analysis on the basis of the hard and soft criteria, its performance was evaluated using computer models to determine capacity and COP at the DOE standard rating conditions for an air-source heat pump. These performance estimates were then used in conjunction with estimates for the temperature glide of the mixtures to determine which refrigerant pairs exhibited the greatest potential for accomplishing the goals of the project.

In assessing the results, the specific application, residential heat pumps, greatly influenced which compounds were selected. In addition, the list could be impacted by disagreement on the criteria for eliminating refrigerants. For instance, a manufacturer may feel that problems, such as toxicity, could be dealt with, and therefore should not be a basis for elimination. For these reasons, we have listed all the compounds that were

evaluated (Table 1) to allow additions or deletions based on personal preference.

The list of potential components (Table 1) was compiled from several sources that included vendors, researchers, and trade organizations such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 1985; Bivens, n.d.; Braker and Mossman 1971; Reid et al. 1977). Most of the combinations and structural isomers obtained from substituting chlorine and fluorine on methane, ethane, and propane are included. Property values were obtained from chemical handbooks, tables, and vendor contacts. The resultant list is quite comprehensive in that it contains relatively new chemical compounds as well as some in various stages of development.

As seen in Table 1, there is insufficient critical property data to determine performance for many of the compounds. Following the initial evaluation, a few gaps were discovered where critical properties were needed for refrigerants with a high probability for good performance

based on their normal boiling point and heat capacity. Using approximation procedures (Reid et al. 1977), it was possible to estimate critical properties and determine relative COP and capacity.

From the list of refrigerants in Table 1, a graph was constructed (Figure 1) that contains refrigerants in the boiling point range (see paragraph regarding soft criteria) with an indication of the level of available property information. In the graph, Level 1 indicates a large amount of available information while level 4 indicates very little. One can see from the graph that there is insufficient property information for many of the refrigerants and that very few prospects have all the desirable characteristics.

Hard Criteria

Toxicity was a primary concern in eliminating several of the refrigerants from consideration. It was decided that toxic refrigerants would be difficult to manufacture due to strict Environmental Protection Agency regulations. Also, toxicity would pose a significant risk to heat pump manufacturers in regard to liability for both the homeowner and for assembly-line workers involved in the manufacturing process.

Instability was another characteristic that eliminated compounds from the list of potential components. Any compound that exhibited the possibility of reacting with itself or with any of the materials used in heat pumps, such as copper, aluminum, or steel, was undesirable and was therefore eliminated from further consideration. For example, methyl chloride cannot be used with aluminum in any form because explosive reactions result from the combination. Any compound that could react with compressor lubricating oil was removed from the list. Also, some compounds are known to polymerize (unsaturated compounds), and their use could result in coatings on the inside tube surfaces that impede heat transfer. All compounds known to exhibit this characteristic were discarded.

The signing of the Montreal agreement (Cox 1988), which limits the international production of chlorofluorocarbons (CFCs), led us to add ozone depletion potential to our list of hard criteria. The swift reaction of the research community in reaching an agreement to significantly reduce emission levels indicates a definite movement away from the use of refrigerants that are fully halogenated. All compounds that are fully halogenated and contain chlorine or bromine were deleted from our list of potential refrigerants. We did include those compounds that contain a hydrogen atom in the structure and would therefore break down in the lower atmosphere.

Soft Criteria

Seven refrigerants remained after the initial evaluation process was completed. The remaining refrigerants were R125, R22, R218, R134a, R124, R124a, and C318. To allow for the inclusion of more refrigerants in this study, the requirements for deleting refrigerants were reassessed to see if the criteria could be relaxed. The decision was made to allow flammability to be changed from a hard to a soft criterion for two reasons. Flammable refrigerants would not introduce a risk to the homeowner that is not already a part

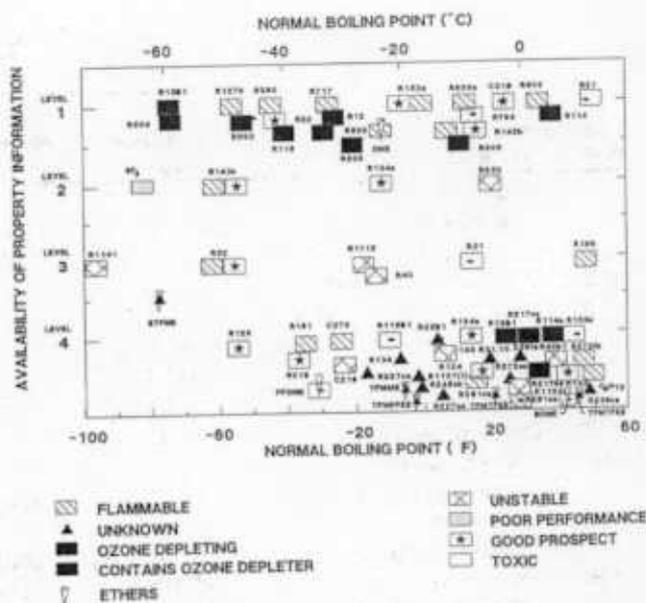


Figure 1 Refrigerant characteristics chart

of the present environment. For instance, natural gas is already used for water heating, space heating, and cooking. Second, a nonflammable mixture can be obtained by mixing a flammable compound with a nonflammable compound, thus reducing the risk of fire or explosion.

The refrigeration capacity of a heat pump is a strong function of the boiling point of the refrigerant circulating in the system. Compounds with similar boiling points will produce similar capacities in the same compressor. Based on this information, selection of a range of boiling points was possible using estimates of the building load as a function of outdoor temperature and capacities of common refrigerants. Based on capacities of R114 for the low-capacity refrigerant and R13 for the high-capacity refrigerant, a range of boiling points from approximately 50°F (10°C) to -115°F (-81.7°C) was selected.

For this study, commercial availability of a refrigerant was defined to be any refrigerant that either was presently available from a major vendor or one that, depending on market demand, could be synthesized at a reasonable cost. Manufacturers stated that the high cost of producing small quantities of relatively unknown compounds could be reduced if enough interest warranted research into more efficient methods of synthesis. In this context, availability is more a justification for including some "exotic" refrigerants than a basis for elimination.

Performance

As a final step, the relative performance of the refrigerants was determined using two models to calculate the COP and the capacity at the DOE standard rating conditions of 47°F (8.3°C), 17°F (-8.3°C) heating, and 82°F (27.8°C), 95°F (35.0°C) cooling. A national laboratory's heat pump model (Fischer and Rice 1981), which is a precise model that includes the losses associated with the equipment in its calculational procedure, did not allow an analysis of many of the refrigerants due to the form in which

the thermodynamic and thermophysical data had to be entered. Therefore it was necessary to use an additional model to obtain as much information as possible about the performance of the remaining refrigerants. The CYCLE5A model (McLinden, n.d.), which performs an ideal cycle analysis assuming an isentropic compressor efficiency and log mean temperature difference for the heat exchangers, made it possible to analyze a larger number of refrigerants, although at a lower level of complexity. Since more refrigerants could be analyzed using the CYCLE5A model, it was selected as the basis for determining relative performance. The national laboratory's model was used as a cross-reference and for establishing compressor and heat exchanger efficiencies for the CYCLE5A model. Following is a brief description of each model and the main assumptions that were used in performing the analyses.

The national laboratory's heat pump model was developed to predict the steady-state heating and cooling performance of residential heat pumps. The model is based on physical principles and generalized correlations to avoid empirical equations derived from manufacturers' performance data. This approach allows more flexibility in studying various design configurations for their related performance tradeoffs. For this study, all necessary inputs to the model regarding hardware, such as physical dimensions of the heat exchangers, fan efficiencies, and compressor map data, were based on a high-efficiency heat pump presently in production by a major manufacturer. Other parameters, such as compressor inlet and exit refrigerant conditions, were specified based on standard practice.

The CYCLE5A model performs an ideal cycle analysis using the Carnahan-Starling-DeSantis equation of state to calculate refrigerant properties. Coefficients for this equation were obtained from saturated vapor pressure, vapor density, and liquid density data for compounds of interest. The advantages of using this model are that it is simple to

run and can be used to obtain performance predictions for fluids that do not have necessary thermodynamic and thermophysical property data to use in more sophisticated performance models. The main inputs to this model, other than the property data, are the log mean temperature difference for both heat exchangers and compressor isentropic efficiency. Input parameters were initially varied over a reasonable range to approximate the performance values for R22 data obtained from the other heat pump model. The same values for isentropic compressor efficiency and log mean temperature difference were then used for all the refrigerants.

The results of computer simulation runs with the CYCLE5A model are shown in Table 2. All refrigerants of interest, with the exception of R218, R124a, and R143, could be analyzed using one or both models. The results show that most of the pure components have COPs comparable to those of R22. Only R125 and C318 have COPs that are significantly lower (10% or greater). Data in the table indicate that some of the mixtures could result in capacity shifts of up to 4:1 in cooling and 3:1 in heating by changing the composition from one pure component to the other.

Temperature Glide

Once theoretical performance of the pure refrigerants was known, it became necessary to estimate the temperature glide of the mixtures to determine which mixtures would best match the temperature glides occurring in the condenser and evaporator heat transfer fluids. By use of property data subroutines (McLinden, n.d.), the temperature glide was determined for a variety of 50/50 weight percent compounds at a pressure equivalent to an average of the evaporator and condenser saturation pressures (approximately 160 psia [1102 kpa]). Knowing the boiling point differential of the compounds, it was possible to construct a plot (Figure 2) for estimating the

TABLE 2
COP AND CAPACITY DATA - CYCLE PROGRAM MODEL
Refrigerants selected for NARM Test Program

Refrigerant	95 F, Cooling		82 F, Cooling		47 F, Heating		17 F, Heating	
	COP	Capacity (Btu/hr)						
R32	2.6	59,180	3.0	69,270	3.1	52,890	2.4	28,000
R125	2.0	30,720	2.4	39,450	2.6	31,560	2.1	17,150
R143a	2.3	38,500	2.7	47,390	2.8	36,070	2.3	19,080
R22	2.6	34,320	3.0	40,440	3.0	32,930	2.4	16,050
R218	--	--	--	--	--	--	--	--
R134a	2.5	22,080	2.9	26,630	2.9	20,230	2.3	9,230
R152a	2.7	21,880	3.1	25,610	3.0	19,500	2.5	9,050
R124	2.4	11,650	2.8	14,200	2.8	9,530	2.3	4,260
R124a	--	--	--	--	--	--	--	--
R142b	2.6	12,430	3.0	14,550	3.0	10,840	2.4	4,890
C318	2.2	9,240	2.6	11,690	2.6	8,480	2.1	3,710
R143	--	--	--	--	--	--	--	--

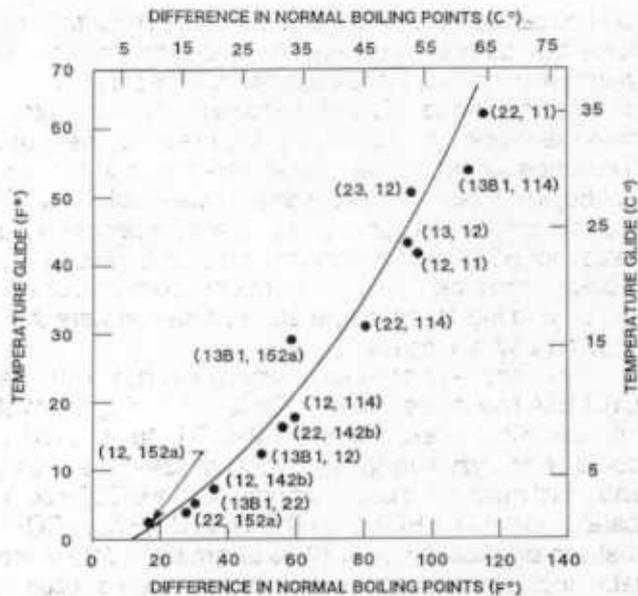


Figure 2 Temperature glide as a function of boiling point difference for 50/50 weight percent compositions

temperature glide of compounds that could not be run in the CYCLE5A subroutines due to the unavailability of data.

RESULTS

From the data in Figure 2, it was possible to construct a matrix (Table 3), that shows the temperature glide for 50/50 weight percent mixtures of 12 preferred refrigerants. The shaded portion of the matrix consists of those mixtures having the most potential for matching the temperature glide in the heat exchangers. A plot (Figure 3) was then made from the data in Table 2 with an estimated building load line superimposed on the plot. The building load line was estimated for an 1800 ft² ranch house in an average climate, with minimum insulation (as defined by Housing and Urban Development guidelines). The results show that only mixtures containing R32 or R143a would have an increased capacity, relative to R22, at low ambient temperatures. Looking at the implications for cooling, and assuming selection of either of these two pure components, we see that R143a has only a slight capacity increase over that of R22, while R32 is much higher in capacity and could be used only at compositions lower than 100%. For the high boiling component, the best choices would be R142b, R124, or C318. However, R142b or R124 would be preferred over C318, because it has lower theoretical performance.

It can be seen by coupling the results of Figure 3 with those of Table 3, that the best mixtures would be R32/R124, R32/R142b, R143a/R124, R143a/R142b, and R143a/C318. We recognize that every one of these mixtures contains at least one flammable component. It is possible to choose a mixture with no flammable components; however, it would compromise the goals of the project by reducing the amount of capacity control and by eliminating the capacity increase at low outdoor temperatures. In ranking these mixtures, R32/R124 and R143a/R124 would probably

TABLE 3
Mixture Components and Related Temperature Glides for 50/50 Weight Percent Compositions

32	3	3	4	4	8	8	23	23	23	28	44
125	3	3	4	6	6	19	19	19	23	40	
143a	3	4	5	5	17	17	17	23	38		
22	3	4	4	11	11	11	15	29			
218	3	3	7	7	7	10	23				
134a	3	3	3	3	5	11					
152a	3	3	3	4	8						
124	3	3	3	4							
124a	3	3	4								
142b	3	4									
C318	3										
											143

come first, based on the probability of being able to choose compositions that are nonflammable. Next would come R32/R142b and R143a/R142b, based on the fact that a nonflammable mixture is not possible. R143a/C318 would be last, based on the low COP for C318.

FUTURE WORK

In previous research efforts, several mixtures were investigated for improving the performance of refrigeration equipment (Herrmann 1985). Most of those mixtures, shown in Table 4, do not satisfy the requirements that have been stipulated for this study. The majority were eliminated because one of the components exhibited potential ozone depletion characteristics. The others, such as R14/R23, have boiling point temperatures outside the range of consideration for this study. The only mixtures that were found to be of some interest in our study, R22/R124 and R22/R142b, had not been experimentally tested. Since no experimental work has been performed on any of the preferred mixtures, an experimental test program is planned to verify the potential benefits of the ozone-safe NARMs that were selected in this study.

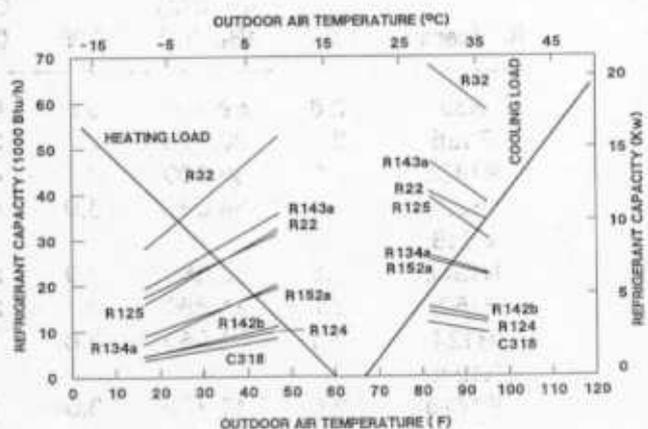


Figure 3 Refrigerant capacity vs. outdoor temperature

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