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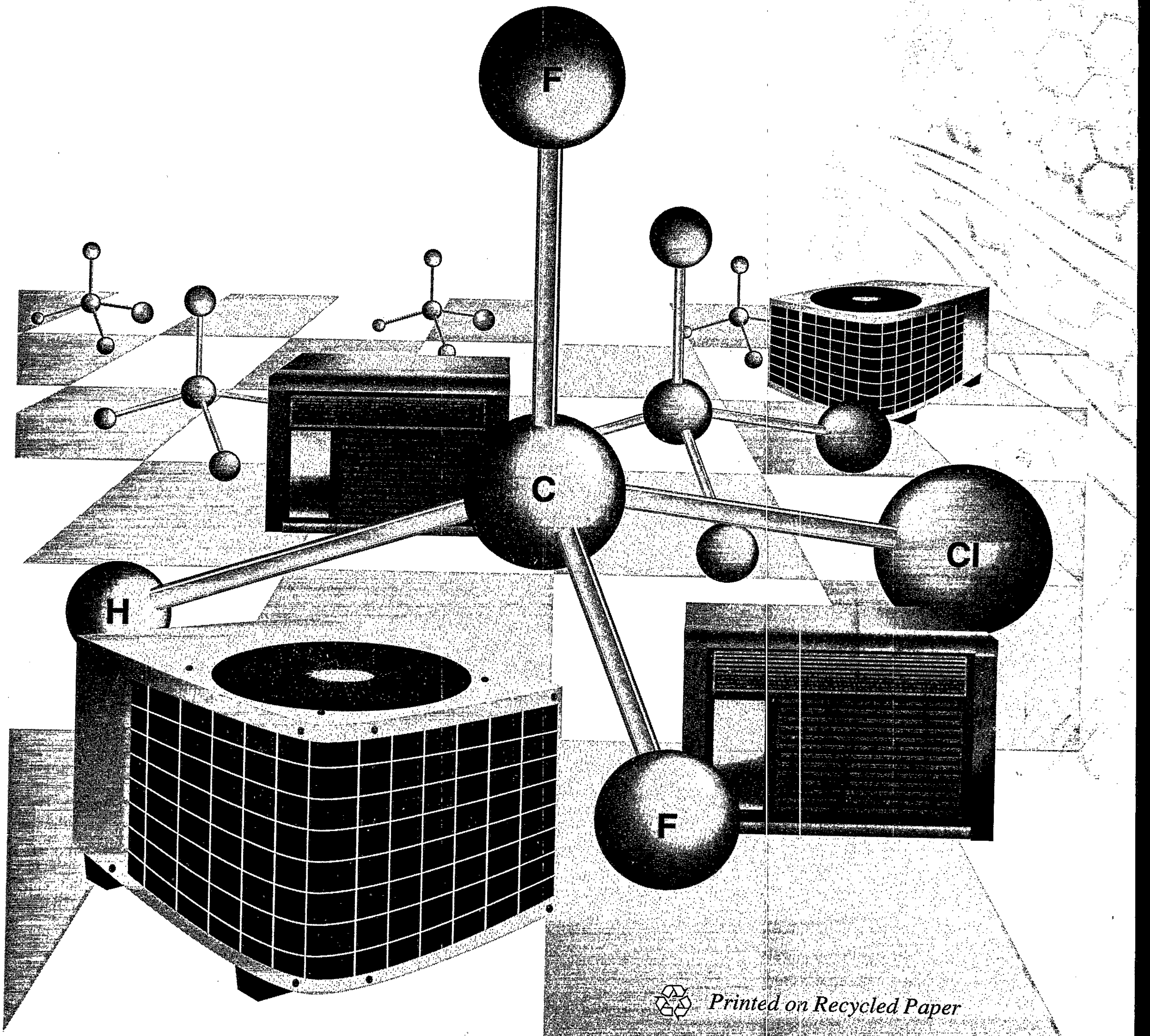
Theoretical Analysis of Replacement Refrigerants for R22 for Residential Uses



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THEORETICAL ANALYSIS OF REPLACEMENT REFRIGERANTS FOR R22 FOR RESIDENTIAL USES

Prepared for

US Environmental Protection Agency
Global Change Division
Office of Atmospheric and Indoor Air Programs
Office of Air and Radiation

by

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THEORETICAL ANALYSIS OF REPLACEMENT REFRIGERANTS FOR R22

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Abstract

Future risks of stratospheric ozone depletion and the relatively high global warming potential of R22 might eventually lead to further limitations on the use of R22 in heat pump and air-conditioning systems. This report investigates the feasibility of replacement refrigerants that would cause the least disruption to current technology. It is desirable that any substitute is at least as energy efficient as R22 so that the indirect effect on global warming does not outweigh the direct effect. To date, no acceptable pure component has been identified as a drop-in substitute for R22. However, binary and ternary mixtures appear to be candidates that warrant further investigation.

The coefficient of performance (COP) and the seasonal performance factor (SPF) were calculated in a model for binary and ternary substitutes. The ternary mixture of R32/R152a/R124 showed the best performance with an increase in COP of 13.7 % over R12. The best chlorine-free ternary mixture is R32/R152a/R134 with a 12.6 % increase. The best chlorine-free binary mixture is R32/R152a with a 12.1 % improvement in COP over R22. The binary mixture of R32/R134a shows a performance improvement of six percent over R22. Since it contains 70 % R134a it may not be flammable.

Significant design changes to the system will be necessary to realize all these gains with mixtures, likely requiring a considerable research and development effort. Some of the design changes could reduce the energy savings. On the other hand, modelling predicts that the SPF can be improved by modulating the capacity by changing mixture concentration.

The greenhouse warming potential of the R32/R152a/R124 mixture and its ozone depletion potential are reduced by a factor of 5 compared to R22. The greenhouse warming potential of R32/R152a/R134 is reduced by a factor of 3 compared to R22 and the ozone depletion potential is zero. The greenhouse warming potential of R32/R152a is reduced by a factor of 6 compared to R22 and the ozone depletion potential is zero.

In practice, the ranking of the substitutes presented in this report may change due to the influence of transport properties and other variables which have been ignored in the model.

THEORETICAL ANALYSIS OF REPLACEMENT REFRIGERANTS FOR R22

FOR RESIDENTIAL USES

Findings

-- Evaluation of R22 substitutes has to occur because of concerns about ozone depletion and greenhouse warming effect.

-- There is currently no pure fluid that is considered to be a suitable drop-in substitute for R22.

-- Any substitute should seek to have at least the same energy efficiency as R22. Otherwise, the indirect global warming effect may offset any gains in the reduced global warming potential of the substitute. Selection of the final substitute should consider a balanced trade-off between direct and indirect global warming effect, ozone depletion and other health and safety concerns.

-- There are several binary and ternary mixtures of refrigerants that warrant further investigation as substitutes for R22.

-- Models predict that a mixture containing R32 and R152a and R32 and R124 show potential for significant performance improvements of up to 13.7 % in COP over R22 in residential air-conditioners, heat pumps and window air-conditioners.

-- Hardware changes (counter-flow heat exchangers) will be necessary to achieve this improvement and requirements like increased fan power may offset the predicted energy savings.

-- The most energy efficient replacement mixture, R32/R152a/R124, as predicted by modelling, has a global warming potential and ozone depletion potential that is five times lower than the values for R22 (based on a 100 year time horizon).

-- The replacement mixture with the least direct impact on the environment is R32/R152a with a global warming potential that is six times lower than for R22 and an ozone depletion potential of zero. Its predicted COP is 12.1% above that of R22.

-- The ranking of the substitutes may change due to the influence of transport properties and other variables not considered in this report.

-- The use of mixtures offers the potential advantage that the concentration can be shifted to meet capacity requirements. This can lead to a reduction in resistance heat and increased seasonal performance.

-- For some superior mixtures all constituents are presently available or have been commercially produced; for other alternatives they will be available in the near future; for some alternatives they are not yet scheduled for commercial production.

-- The mixtures with the most significant improvement in COP are flammable (R32/R152a) or contain flammable components so that they may be flammable (R32/R152a/R124, R32/R152a/R134). However, it is expected that the addition of a third nonflammable component will reduce the fire hazard.

-- The binary mixture of 30% R32 and 70% R134a shows a six percent performance improvement over R22 and may be nonflammable.

-- Further work in the following areas is required in order to facilitate the use of the proposed mixtures:

Materials compatibility,
Flammability,
Oil compatibility,
Compressor life,
Chemical stability,
Thermodynamic properties,
Transport properties,
Performance in actual cycles,
Design of means for concentration shift, and
Redesign of air-conditioning and heat pump systems.

-- The possibility still exists that pure fluids can be found or developed that may be acceptable substitutes for R22.

Acknowledgement

The authors thank the numerous reviewers and EPA personnel for constructive criticism and their contributions to the report. The support of this project by the US Environmental Protection Agency through ICF Inc. and the University of Maryland is greatfully acknowledged.

THEORETICAL ANALYSIS OF REPLACEMENT REFRIGERANTS FOR R22 FOR RESIDENTIAL USES

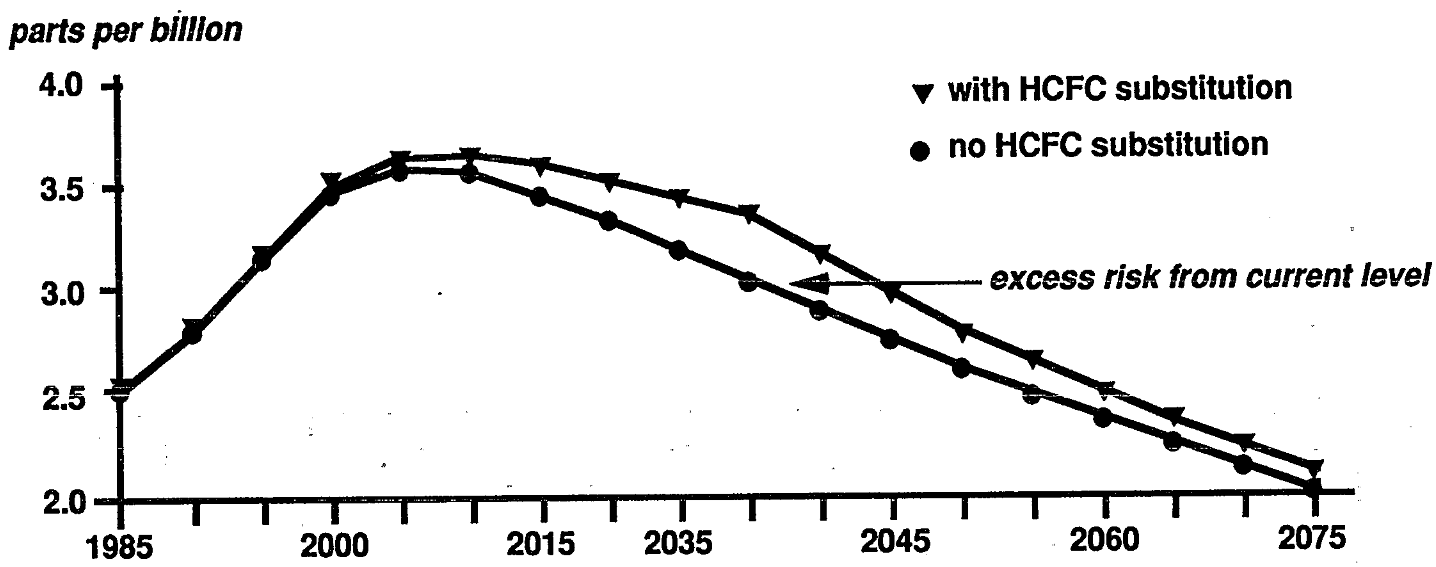
1.0 Background and Objective

R22 is widely used as a refrigerant in commercial refrigeration and commercial and residential air-conditioning and heat pumping. R22 has favorable thermodynamic and transport properties and well known material compatibility characteristics.

However, questions have been raised about the long term viability of R22. Its ozone depletion potential is 0.05, much less than R11 or R12. But because the level of stratospheric chlorine is expected to rise during the next decade, Exhibit 1, extensive use of R22 could contribute to surplus chlorine and thus ozone depletion for a long time. In Exhibit 1, the area enclosed between the two curves is a measure for the increased long term risk if there is an additional amount of Cl_x available in the stratosphere. Currently, scientists are concerned that additional chlorine will cause significant ozone depletion /1/. If it does, there will be inevitably calls for more stringent reductions in R22 than those recorded during the London revisions of the Montreal Protocol where a resolution was passed to phase out use in new machinery by 2015 or those proposed in the Clean Air Act revisions /2/.

Furthermore, the greenhouse warming potential of R22 is quite high compared to carbon dioxide, the most important green house gas. The United Nations Intergovernmental Panel on Climate Change (IPCC) has published a

Exhibit 1:
Total Clx Concentrations(1985-2100)



Assumptions:

- CFCs, Carbon Tetracholoride and Methyl Chloroform Global Phase-out in the year 2000; Carbon Tetracholoride and Methyl Chloroform controls begin in 1991
- HCFCs with an average ODP of 0.05 are substituted for 32% of CFC reductions (upper curve)
- HCFC global freeze in 2015; Phase-out in 2030

Source: 1990, ICF Inc.

Exhibit 2:
Greenhouse Warming Potential of R-22 and Other HCFC's and Carbon Dioxide

Fluid	Global Warming Potential		
	Integration Time Horizon, Years		
	20	100	500
Carbon Dioxide	1	1	1
Methane-inc indirect	63	21	9
Nitrous Oxide	270	290	190
CFC-11	4500	3500	1500
CFC-12	7100	7300	4500
HCFC-22	4100	1500	510
HFC-32*	2040	560	188
CFC-113	4500	4200	2100
CFC-114	6000	6900	5500
CFC-115	5500	6900	7400
HCFC-123	310	85	29
HCFC-124	1500	430	150
HFC-125	4700	2500	860
HFC-134a	3200	1200	420
HCFC-141b	1500	440	150
HCFC-142b	3700	1600	540
HFC-143a	4500	2900	1000
HFC-152a	510	140	47
$CC1_4$	1900	1300	460
CH_3CC1_3	350	100	34
CF_3Br	5800	5800	3200

* Reference /3/

report in which the higher greenhouse warming potential (GWP) of R22 is compared for different time periods to other HCFCs, HFCs and to carbon dioxide, Exhibit 2. As concern about the global warming heightens, the availability of R22 could be threatened. Its price could rise if "greenhouse gas taxes" are passed or if green house gases are limited in an allowance system under a comprehensive approach such as that proposed by the US at the first climate negatiations. (A tax as small as $ 0.01 per pound of carbon dioxide would result in an increase of $ 15.00 per pound using the 100 year equivalent global warming potential.)

However, it is important to recognize that for HCFC 22 the global warming potential is relatively small compared to the indirect global warming effect caused by the production of carbon dioxide to provide the power for air-conditioning or heat pumping. Estimates indicate that up to 10% of the total global warming caused by a typical air-conditioner is contributed by R22 /3/. Any replacement must, therefore, be at least as efficient as R22 in order to achieve a significant net reduction in the global warming effect.

Currently no pure fluid drop-in replacements for R22 have been identified. Refrigerant mixtures of already available or identified constituents, however, may be able to replace R22 in existing and future equipment and in future applications. This report examines the replacement of R22 from two points of view:

-- The feasibility of a drop-in replacement for residential heat pumps, air-conditioners and window air-conditioners is investigated.

-- Replacement of R22 by refrigerant mixtures that would potentially lead to energy savings by a completely new design of the heating and cooling equipment.

2.0 Simulation Approach

It is the goal of the theoretical analysis presented here to study only the effect of the thermodynamic properties of the working fluids. The cycle model used resembles the ideal vapor compression cycle as closely as possible. The only exceptions are a compressor efficiency of 0.7 and the use of air-to-refrigerant heat exchangers. The latter is necessary to ensure that the gliding temperature effect of mixtures is accounted for.

2.1 Computer Model

A computer model HAC1 was developed. It is a UA-model in which the product of the overall heat transfer coefficient and heat exchange area (UA) are given. Prior studies have shown that a comparison between pure and mixed working fluids provides meaningful results only when the fluids perform identical task. This implies that the air streams being heated or cooled undergo the same temperature changes at the same flow rates independent of whether or not a mixture or pure component is used /4/. This can be obtained in a consistent way with a UA-model. It is assumed that the temperature glide of the mixtures is linear, though this is not always true. The implications of this assumption are discussed under Results and Discussion. HAC1 uses the Newton-Raphson method to solve a set of eight non-linear equations simultaneously. To have the design of the heat pump affect the results of the calculations to the least possible degree, almost all operating parameters were set to ideal conditions. Input values are the evaporator air inlet and outlet temperatures and the air flow rate, the condenser air inlet temperature and flow rate, heat exchange areas and heat transfer coefficients (estimated based on actual equipment). Other variables such as pressure drops, superheat and subcooling at evaporator and condenser outlet, and superheating of the suction gas in the compressor are set to zero. It is assumed that the compressor displacement is always sufficiently large to pump whatever volume flow rate the evaporator provides. The isentropic efficiency is set to 0.7. For both, the evaporator and condenser, the overall heat transfer coefficients are 0.1 kJ/m^2K, and the areas are 4.0 and 5.0 m^2 respectively. The cooling load is assumed to be a sensible load only.

According to today's design criteria, the outdoor heat exchanger which is the condenser during air-conditioning operation was chosen to be the larger heat exchanger since the amount of heat rejected is larger than the cooling capacity. The evaporator has to be small to provide a cooling surface on a temperature low enough for dehumidification. Area and heat transfer coefficients are calculated based on actual designs. For most of the results presented here, it is assumed that all heat exchangers are counter-flow heat exchangers. The impact of cross-flow heat exchangers is investigated in Chapter 4.5. It is further assumed that during desuperheating of the vapor in the condenser, the inside tube surface temperature is below the saturation temperature of the vapor. Therefore, the heat transfer coefficient in the desuperheating region is assumed to be the same as for the two-phase region. The heat transfer process is governed by the difference between the dew point temperature and the air temperature. Each run of HAC1 produces an output file as shown in Exhibit 3 for pure R22. The first section of the output describes the program features in short and lists the air flow rates.

The second section of the output file states all input values, the specified refrigerant mixing coefficient, concentration (mass fraction), the ambient temperature and temperatures of the air streams into and out of the evaporator and into the condenser. Further compressor efficiency, pressure drops, super heat, subcooling, additional superheat, and overall heat transfer coefficients are listed followed by the heat capacity (calculated by multiplying mass flow rate with specific heat) and the cooling capacity. The end of this section of the output shows heat exchanger areas, adjustment factors (1.0 all the time) and the number of segments into which each heat exchanger is divided in order to account for the non-linearity of the temperature glide. For this investigation the number of segments was set to 1.0 to speed up the calculation procedure.

In the third section of the sample printout the calculated thermodynamic properties at each state point throughout the cycle are listed.

The fourth section states all other calculated results: compressor work, the amounts of heat exchanged, COP, refrigerant mass flow rate, volumetric capacity, pressure ratio, and compressor displacement. Other output values are not of concern here. Energy

Exhibit 3: Sample Printout of Computer Run with HAC1.

```
NEWTON-RAPHSON METHOD IS USED TO SOLVE A SET OF NONLINEAR EQUATIONS.
HTFs USED IN COND. AND EVAP. ARE BOTH AIR.
A VOLUME FLOW RATE OF HTF IN EVAP.(CFM): 400.00
A VOLUME FLOW RATE OF HTF IN COND.(CFM): 800.00
COOLING LOAD IS FIXED BY SPECIFYING HTF TEMPS. IN EVAP.
IN COND. SIDE, TEMP. OF HTF ENTERING COND. IS FIXED.
TEMP. OF HTF LEAVING COND. VARIES.
CONSTANT UAs ARE USED IN CON. AND EVAP.
CONSTANT COMPRESSOR EFF.

************** GIVEN PARAMETERS *****************
REFRIGERANTS R22    AND R22   ;  F =  .0000;  X = 1.000 MASS FRAC.R22
AMBIENT TEMP:   35.0 C
HX STREAM TEMPS:  SOURCE (IN, OUT):    26.0,    10.6 C
                  SINK   (IN):       35.0 C
COMPRESSOR EFFICIENCY : .7000
IMPOSED PRESSURE DROPS:  COND =      .0 KPA; EVAP =      .0 KPA
IMPOSED E SUPERHEAT, C SUBCOOLING, ASHC (C):     .0      .0      .0
UA (EVAP, COND):  400.0,  500.0 W/C
HEAT CAPACITY OF HTF (EVAP,COND):  227.8,  417.6 W/C
COOLING LOAD: 3514.9 WATTS
AREA EVAP, COND, FACTOR E, C, NSEGM :4.00000,5.00000,1.00000,1.00000    1

************** STATE PARAMETERS *****************
STATE          T (C)          P       H        V          S        XL     XV      XQ
            HX STR  REF    (KPA)  (KJ/KG)  (M^3/KG)  (KJ/KG K)  (MASS  FRAC)
1 EVAP OUT   26.0   6.6    613.6   253.4   3.86E-2     .000   1.000  1.000    .000
2 COMP IN      .0   6.6    613.6   253.4   3.86E-2     .000    .000   .000    .000
3 COMP DIS   45.9  87.1   2014.5   296.3   1.32E-2     .000    .000  1.000    .000
4 COND VST   44.0  51.5   2014.5   263.4   1.13E-2     .000    .000   .000    .000
5 COND LST   35.0  51.5   2014.5   109.1   9.31E-4     .000    .000   .000    .000
6 COND OUT   35.0  51.5   2014.5   109.1   9.31E-4     .000    .000   .000    .000
7 EVAP IN    10.6   6.6    613.6   109.1   0.00E+0     .000   1.000  1.000    .282
8 EVAP VST   26.0   6.6    613.6   253.4   3.86E-2     .000    .000   .000    .000
9 LSHX OUT     .0  51.5   2014.5   109.1   9.31E-4     .000    .000   .000    .000

************** CALCULATED PARAMETERS **************
WORK = 1043.5 QEVAP = 3514.8 QCOND = 4558.3 HX21 =      .0 HX67 =     .0 WATT
COP  =  3.368  REF. MDOT=  .0243529 KG/S  VCR=  3735. KJ/M^3  PR =  3.28
VOLUME FLOW RATE (CC/SEC) :  941.12
LMTD IN EVAP (GIVEN, CAL), LMTD IN COND     8.787     8.787    11.641
AIR TEMP DROP, REF TEMP GLIDE IN EVAP    15.430      .000
AIR TEMP GLIDE, REF TEMP DROP IN COND    10.915      .000
COMPRESSOR DISPLACEMENT VOLUME =20.4592 CC/REV
ENERGY BALANCE:E SUP,C SUB,SUP(FRAC HEAT):  .00     .04 800.52
ENERGY BALANCE:E SUP,C SUB,SUP(UALMTD    ):  .00     .04 800.54
EVAP SUPERHEAT, COND SUBCOOLING & SUPERHEAT: (C)    .00     .00  35.55
FRACTIONS HEAT IN EVAP TP,SUP,COND SUB,TP,SUP:1.000  .000  .000  .824  .176
FRACTIONS AREA IN EVAP TP,SUP,COND SUB,TP,SUP:1.000  .000  .000  .728  .272
```

balances are used to verify thermodynamic consistency. Other data are available for detailed design of air-conditioners. The particular heat pump design modelled here implies that the four-way-valve, that switches from heating to cooling, maintains the counter-flow characteristic of the heat exchangers. This is not true for conventional systems. The air flow rates are 400 cfm for the indoor heat exchanger (the evaporator during the air-conditioning mode) and 800 cfm for the outdoor heat exchanger. These values are specified in the ASHRAE Standard for the respective heat exchangers for a cooling load of one refrigeration ton.

2.2 Refrigerant Properties

The refrigerant properties are obtained based on the CSD equation of state that was developed at NIST /5/. The subroutine BDESC is listed in Appendix #1 which shows all coefficients of the pure refrigerants as they are used for this report. This facilitates reruns which may become necessary as coefficients are updated. For mixtures the CSD equation of state requires a mixing coefficient. For the work conducted here, the mixing coefficient is assumed to be -0.01 for all mixtures. This value is an average of the known values and was used because no mixing coefficients were available for the fluids under investigation.

2.3 Refrigerant Mixtures

The choice of substitutes was limited to fluids that are as similar to R22 as possible to minimize changes to current equipment. In selecting the pure refrigerants that can serve as constituents for mixtures, priority was given to those fluids that do not contain chlorine, with R124 as an exception because of its very low ozone depletion potential. Further, in order to limit the effect of the temperature glide to an acceptable range, the boiling point may not be too far from that of R22. The following refrigerants were selected: R143a, R32, R125, R152a, R134, R134a and R124. At this time no manufacturer plans to produce R134.

Refrigerants R143a, R32 and R125 are "low boilers" with boiling points below that of R22, while refrigerants R152a, R134, R134a and R124 are "high boilers" with boiling points above those of R22. The binary mixtures investigated here consist of one low boiler and one high boiler. During the course of the investigation, it became clear that mixtures containing R32 show a consistently better performance than those with other low boilers. Results are presented for the following mixtures:

R32/R134a,
R32/R152a,
R32/R134,
R32/R124,
R143a/R134a,
R143a/R152a,
R143a/R124,
R125/R134a,
R125/R152a,
R125/R124.

Since R32, R152a and R143a are flammable components, it was decided to also investigate the ternary mixtures:

R32/R152a/R134a,
R32/R152a/R134 and
R32/R152a/R124.

It is expected that the ternary mixtures can substitute for R32/R152a. The addition of a nonflammable component will reduce the overall flammability of the mixture. However, extensive tests are necessary to evaluate the flammability.

Future work will include the evaluation of ternary mixtures which contain small amounts of R22 increasing the likelihood that existing lubricants can be used.

2.4 Operating Conditions

Typical numbers for operating conditions are derived from performance data of existing residential air-conditioners as described in the ASHRAE testing and rating procedure /6/.

Air-conditioning:	Outdoor air inlet temperature	95 F
	Outdoor air outlet temperature	floating
	Indoor air inlet temperature	80 F
	Indoor air outlet temperature	52 F
	(based on the specified air flow rate of 400 cfm per ton of cooling)	

These temperatures represent the design point of the air-conditioner. At the above specified values, the air-conditioner meets the building load at steady state operation. For less severe cooling cases the thermostat cycles the equipment on and off. A second case is evaluated with 82 F outdoor temperature and all other conditions are unchanged. This value is usually measured under part load operation when the equipment is cycling on and off. The part load performance can be reduced by up to 25 % compared to steady state operation. However, when the air-conditioner has an automatic expansion valve this degradation, caused by fluid migration during the off-cycle, can be almost entirely eliminated /7/. It is assumed that the part-load performance is identical to the steady-state performance at that condition for the following reasons. Cyclic losses have two major sources, the heat capacity of the heat exchangers and of the working fluid, and the migration of the refrigerant during the off periods. Experimental results show that by eliminating the refrigerant migration, the cyclic losses are eliminated almost entirely, up to 90% /7/. These losses will not effect the ranking of the fluids investigated here assuming migration can be eliminated. Usually, thermostatic expansion valves, which represent state-of-the-art technology, prevent refrigerant migration. The performance of the air conditioner is linearly interpolated between the two rating points allowing for the entire cooling temperature range to be covered.

For heat pumping it is generally accepted design practice that the air-conditioner designed for the cooling application has to serve as a heat pump as well, although the unit's capacity is not optimized for this application. The simulation accounts for this fact. For heating applications the function of the outdoor heat exchanger and the indoor heat exchanger are reversed. Thus in the model, the heat pump condenser is now described with the evaporator air flow rate and UA value and vice versa. Calculations are performed at two cases. For both cases the indoor air conditions are:

Heat Pumping: Indoor air inlet temperature: 70 F

Indoor air outlet temperature: floating

and the first outdoor air case is:

Outdoor air inlet temperature: 47 F

Outdoor air outlet temperature: 33 F

(based on an air flow rate of 800 cfm)

The second operating condition is heat pump operation at 17 F outdoor air inlet temperature. Typically, even the continuously operating heat pump does not reach the full capacity required by the building and resistance heat has to be used to supplement the heat pump.

2.5 Capacity Modulation with Mixtures

It has been repeatedly reported and implemented in at least one commercial product that the capacity of a heat pump can be controlled, within certain limits by changing the concentration of the circulating mixture /8-11/. With this effect the capacity of the heat pump does not drop off as rapidly as it would with a pure refrigerant. In turn, the need for resistance heat (COP=1.0) is reduced. Since a heat pump has a COP larger than 1.0 even at severe operating conditions, energy savings can be accomplished by this maneuver.

Since the pressure controls the specific vapor volume, the mixture concentration determines the mass flow rate of a compressor with constant speed and displacement volume is able to establish. The range of pressure that can be covered depends on the device that accomplishes the concentration shift, the difference in boiling points of the constituents of the binary mixture, and the initial concentration. For ternary mixtures the situation is more complex and the range of pressures depends on the boiling point of the intermediate component as well.

The use of a mixture as a substitute for R22 implies that the concentration is selected so that the vapor pressure is close or equal to R22. This entails that the capacity of the mixture is also similar to the capacity of R22. These similarities mean the compressor and motor size do not have to be modified. However, by changing the mixture concentration, the vapor pressure changes and the capacity can be modulated.

The change in concentration can be achieved by passive means, which do not require any additional controls, or by active means such as rectification columns, which usually require controls, valves and possibly additional, parasitic power. The range of composition shift by passive means is limited.

The simplest way of affecting a shift in concentration is to use an accumulator at the evaporator outlet. This represents a passive means. Whenever liquid floods out of the evaporator because the outdoor temperature is dropping, it is stored in the accumulator. Since the liquid's concentration is different from the overall concentration circulating in the system, a concentration shift is accomplished. A higher pressure mixture is left circulating. The accumulator is a passive device. No auxiliary power, valves or other controls are required. Its capability to affect the concentration is limited.

The rectification column used in a Japanese heat pump is more effective in shifting the concentration /11/. However, active controls and valves are required. Other concepts suggest molecular sieves as a separation means /8/.

The use of a variable speed drive will accomplish the same goal of obtaining a variable capacity. By combining variable speed and shifting concentration the available range of capacity modulation is considerably increased.

The effect of the rectifier is modeled here by repeating the calculation for the low temperature heat pump case using the same mixture with a different concentration. It is assumed that a concentration change of 20 % is achievable with a rectifier. This is an arbitrary number, but rectification processes far exceed such a composition shift and a twenty percent change is achievable with rather simple equipment.

Concentration shift requires that part of the charge is stored somewhere in the heat pump. The system has to be designed to operate independent of the amount of charge, and the charge required is expected to be larger than for a conventional heat pump.

In an experimental project it was determined that a heat pump operating on a mixture of R13B1/R152a that utilizes composition shift using just an accumulator, yielded an 11 % performance increase over a heating season /10/.

3.0 Seasonal Performance Evaluation

The seasonal performance expressed by the seasonal performance factor (SPF) is defined as the ratio of the total amount of cooling provided during a season divided by the total amount of electrical energy consumed during that season for the purpose of cooling.

This factor is very similar to the coefficient of performance (COP). The only difference is that the COP is an instantaneous value of a continuously operating air-conditioner while the SPF represents an average over the entire season. The heating seasonal performance factor (HSPF) is defined in an analogous way: the total amount of heating supplied to a building divided by the total amount of electrical energy consumed for heating purposes. Total electrical energy consumption refers to compressor power and additional electrical heaters required to meet the building load. Fans and controls are not included. In this report the abbreviation CSPF refers to the cooling SPF, and HSPF refers to the heating SPF.

In order to determine the SPF the ASHRAE Temperature Bin Method is employed as outlined in the testing and rating standards for heat pumps /6/. For the purpose of the bin method the outdoor temperature scale is divided into temperature intervals or 'bins' each of a span of 5 F, for example from 70 F to 75 F. Each bin is characterized by an average temperature. For example the bin from 70 F to 75 F has an average temperature of 72 F. It is assumed that whenever an outdoor temperature is found in the range from 70 F to 75 F that the equipment performs as if the temperature were 72 F for that time period. It is necessary to know how many hours a temperature is found in the respective bin during an entire season. The number of hours varies with the climate. Exhibit 4 lists the bin temperatures for one generalized cooling climate and six typical heating climates spanning the various climate zones in the

Exhibit 4:
Fractional Temperature Bin Hours for Six Heating Climates of the Continental US

Region		I	II	III	IV	V	VI
Heating Load Hours		750	1250	1750	2250	2750	2750*
Outd. Design T. (°F)		37	27	17	5	-10	30
Bin #	**Bin Temp.**	**Fractional Bin Hours**					
1	62	.291	.215	.153	.132	.106	.113
2	57	.239	.189	.142	.111	.092	.206
3	52	.194	.163	.138	.103	.086	.215
4	47	.129	.143	.137	.093	.076	.204
5	42	.081	.112	.135	.100	.078	.141
6	37	.041	.088	.118	.109	.087	.076
7	32	.019	.056	.092	.126	.102	.034
8	27	.005	.024	.047	.087	.094	.008
9	22	.001	.008	.021	.055	.074	.003
10	17	0	.002	.009	.036	.055	0
11	12	0	0	.005	.026	.047	0
12	7	0	0	.002	.013	.038	0
13	2	0	0	.001	.006	.029	0
14	-3	0	0	0	.002	.018	0
15	-8	0	0	0	.001	.010	0
16	-13	0	0	0	0	.005	0
17	-18	0	0	0	0	.002	0
18	-23	0	0	0	0	.001	0

* In Pacific Coast Region

Exhibit 4a:
Fractional Temperature Bin Hours for a Generalized Cooling Climate of the Continental US

Bin #	Bin Temp.	Fractional Bin Hour
1	67	.214
2	72	.231
3	77	.216
4	82	.161
5	87	.104
6	92	.052
7	97	.018
8	102	.004

US. Exhibit 5 shows a map indicating the heating climates.

In Exhibit 4 the total number of cooling load hours (CLH) and heating load hours (HLH) are specified (that is the number of hours in a season during which cooling or heating are required) and fractions of total load hours for each temperature bin. The air-conditioning performance is evaluated for one standardized climate where the total number of hours that require cooling capacity (CLH) is 3825 hours.

For climates where heating is required, there are six typical climate regions distinguished by their total heating load hours (HLH) and the heating load design temperature. The first region has a total of 750 heating load hours. It represents a very moderate climate found in Florida or southern Texas, Exhibit 5. The lowest temperature bin encountered is usually in the range of 22 F for about one hour during a typical season. The most severe climate region (Region V) is found in a belt through the northern states in the US and the total heating load hours are given as 2750 hours. The lowest temperature bin is at -23 F. A sixth region is introduced to account for the Pacific North West. The number of cooling load hours is very high, 2750 hours, even though the temperatures are very moderate, the lowest temperature bin is at 22 F just as in Region I, i.e. Florida. With the help of the map in Exhibit 5, it is possible to select for any location in the US the appropriate region and determine the seasonal heating performance for a heat pump.

Exhibit 5:

Map of the US Displaying Lines of Constant Heating Load Hours

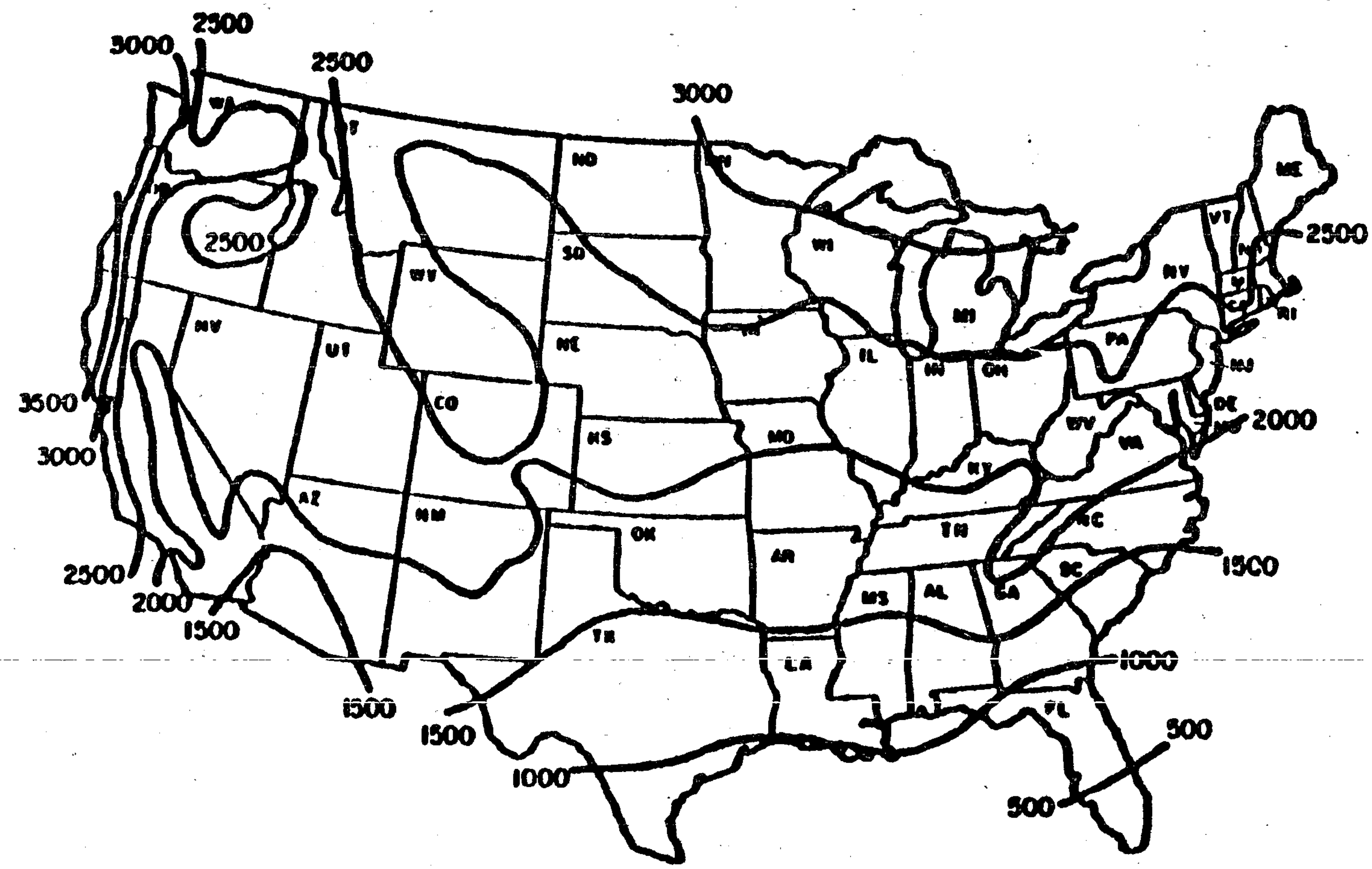
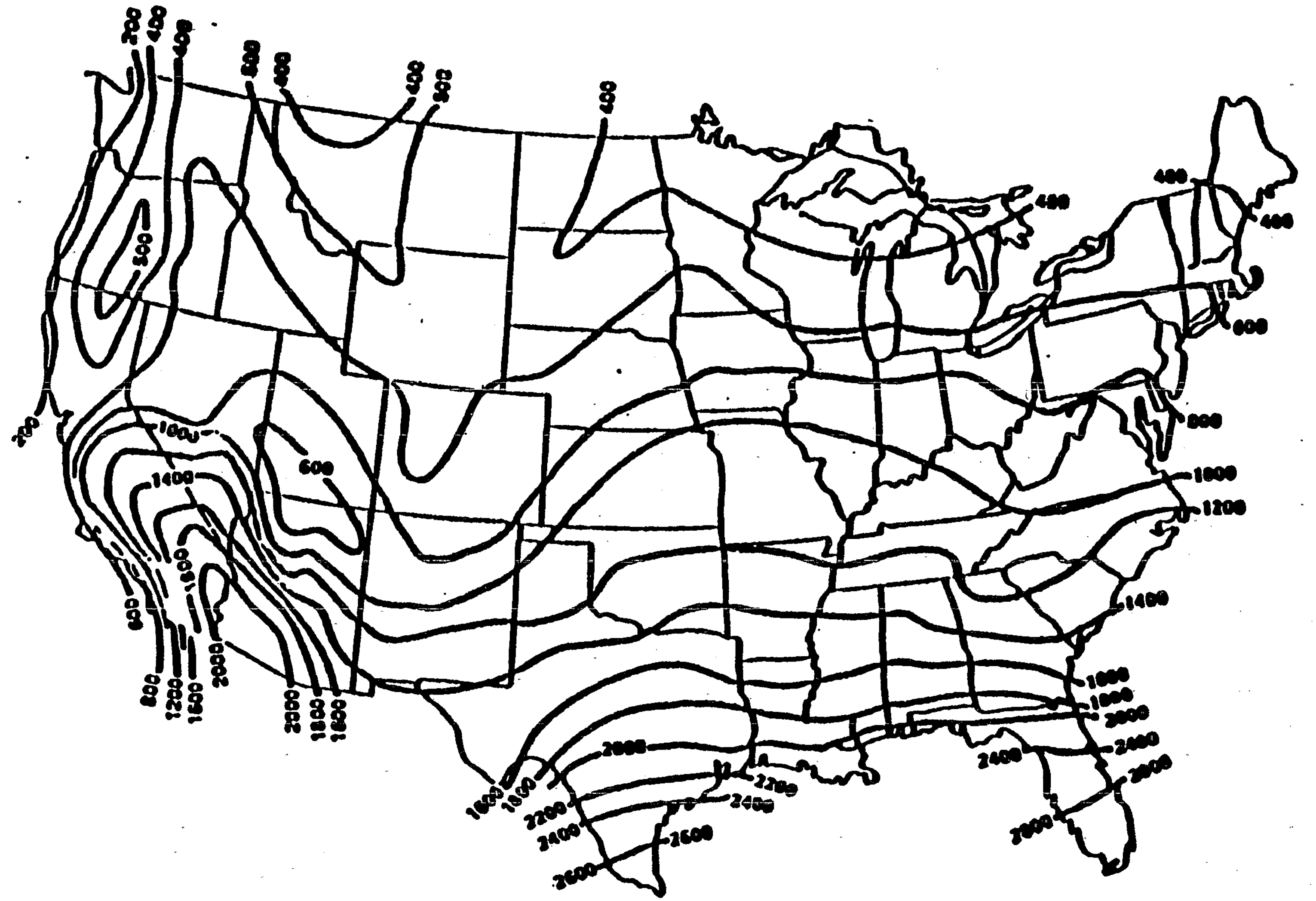


Exhibit 5a:

Map of the US Displaying Lines of Constant Cooling Load Hours



In the evaluation of the HSPF, resistance heat is included. The resistance heat is treated as an additional power input to the heat pump with a coefficient of performance (COP) of 1.0 whenever the heating capacity of the heat pump drops below the building requirement. For the results presented here no concentration shift is considered which is discussed later in detail. Exhibit 6 shows a sample calculation. The upper section pertains to cooling, the lower to the first of the six heating cases. In the upper left hand corner, the name of the refrigerant is listed (here R22/R22, since this is the case of pure R22). In addition, the CLH of 3825 hours and the cooling design temperature of 95 F are given. Next, the COP's are listed for two conditions, 95 F and 82 F outdoor temperatures respectively, and the design cooling capacity of 3.5 kW is given. The first column lists the bin number, the second lists the characteristic bin temperature in F, and the third the temperature in K. The fourth column gives the fraction of time during which a temperature is found in the respective bin, the fifth lists the cooling capacity, the sixth column shows the amount of cooling provided for one hour and the seventh column the COP of the air-conditioner for the respective temperature bin. The COP is linearly interpolated based on the two values listed above. The eighth column gives the power requirement for the compressor. The ninth column lists the amount of electric energy consumed for one hour of cooling while the temperature is in the respective temperature bin. The over all results are listed in the tenth

Exhibit 6: Sample Seasonal Performance Calculation.

FLUID R22/R22

SEASONAL COOLING PERFORMANCE

CLH 3825 DESIGN T: 95

COP (95) 3.37

COP (82) 4.34

DESIGN CAPACITY 95 F (kW): 3.5

BIN #	BIN TEMP F	K	CLH FRAC.	CLOAD kW	CLOAD kWh/h	COP	POWER kW	kWh/h		
1	67	292.6	0.214	0.233	0.050	5.46	0.043	0.009		
2	72	295.4	0.231	0.817	0.189	5.09	0.161	0.037		
3	77	298.2	0.216	1.400	0.302	4.71	0.297	0.064		
4	82	300.9	0.161	1.983	0.319	4.34	0.457	0.074		
5	87	303.7	0.104	2.567	0.267	3.97	0.647	0.067		
6	92	306.5	0.052	3.150	0.164	3.59	0.876	0.046	kWhel	CSPF
7	97	309.3	0.018	3.733	0.067	3.22	1.159	0.021	1238.	4.25
8	102	312.0	0.004	4.317	0.017	2.85	1.516	0.006	CkWh	
TOTAL ENERGY					1.376			0.324	5261.	

SEASONAL HEATING PERFORMANCE

HLH	750	DESIGN T:	37	kWhel	HSPF
COP (47)	3.67		47	284.	3.55
COP (17)	2.57			HkWh	
DESIGN CAPACITY 35 F (kW):			3.5	1006.	

BIN #	BIN TEMP F	K	HLH FRAC.	HLOAD kW	HLOAD kWh/h	COP	POWER kW	kWh/h	RESISTANCE kW	kWh/h
1	62	289.8	0.291	0.350	0.102	4.22	0.083	0.024	0	0
2	57	287.0	0.239	0.933	0.223	4.04	0.231	0.055	0	0
3	52	284.3	0.194	1.517	0.294	3.85	0.394	0.076	0	0
4	47	281.5	0.129	2.100	0.271	3.67	0.572	0.074	0	0
5	42	278.7	0.081	2.683	0.217	3.49	0.770	0.062	0	0
6	37	275.9	0.041	3.267	0.134	3.30	0.989	0.041	0	0
7	32	273.2	0.019	3.850	0.073	3.12	1.234	0.023	0.35	0.006
8	27	270.4	0.005	4.433	0.022	2.94	1.510	0.008	0.93	0.005
9	22	267.6	0.001	5.017	0.005	2.75	1.822	0.002	1.52	0.002
10	17	264.8	0	5.600	0.000	2.57	2.179	0.000	2.10	0
11	12	262.0	0	6.183	0.000	2.39	2.591	0.000	2.68	0
12	7	259.3	0	6.767	0.000	2.20	3.071	0.000	3.27	0
13	2	256.5	0	7.350	0.000	2.02	3.639	0.000	3.85	0
14	-3	253.7	0	7.933	0.000	1.84	4.319	0.000	4.43	0
15	-8	250.9	0	8.517	0.000	1.65	5.151	0.000	5.02	0
16	-13	248.2	0	9.100	0.000	1.47	6.190	0.000	5.60	0
17	-18	245.4	0	9.683	0.000	1.29	7.526	0.000	6.18	0
18	-23	242.6	0	10.267	0.000	1.10	9.305	0.000	6.77	0
TOTAL ENERGY					1.342			0.365		0.013

column as total electric energy consumed for the season in kWhel and total amount of cooling provided in kWhc. The ratio of these two numbers yields the CSPF of 4.25.

The lower section of Exhibit 6 refers to the same calculation for the first heating case. In this case the lowest temperature bin for which heating is required is 22 F. The meaning of the first nine columns is the same as for the upper section of the table, with the term 'cooling' replaced by 'heating'. The tenth and eleventh columns show the power requirement and consumption of electric energy due to the resistance heat. Zeros in the eleventh column indicate that no resistance heat is needed because the heat pump capacity is sufficient (for high bin temperatures) or no heating is required at all (below a bin temperature of 22 F in this case).

All seasonal performance calculations were performed according to this method for the fluids listed in the Chapter 4.2.

4.0 Results and Discussions

4.1 Performance Under Design Conditions

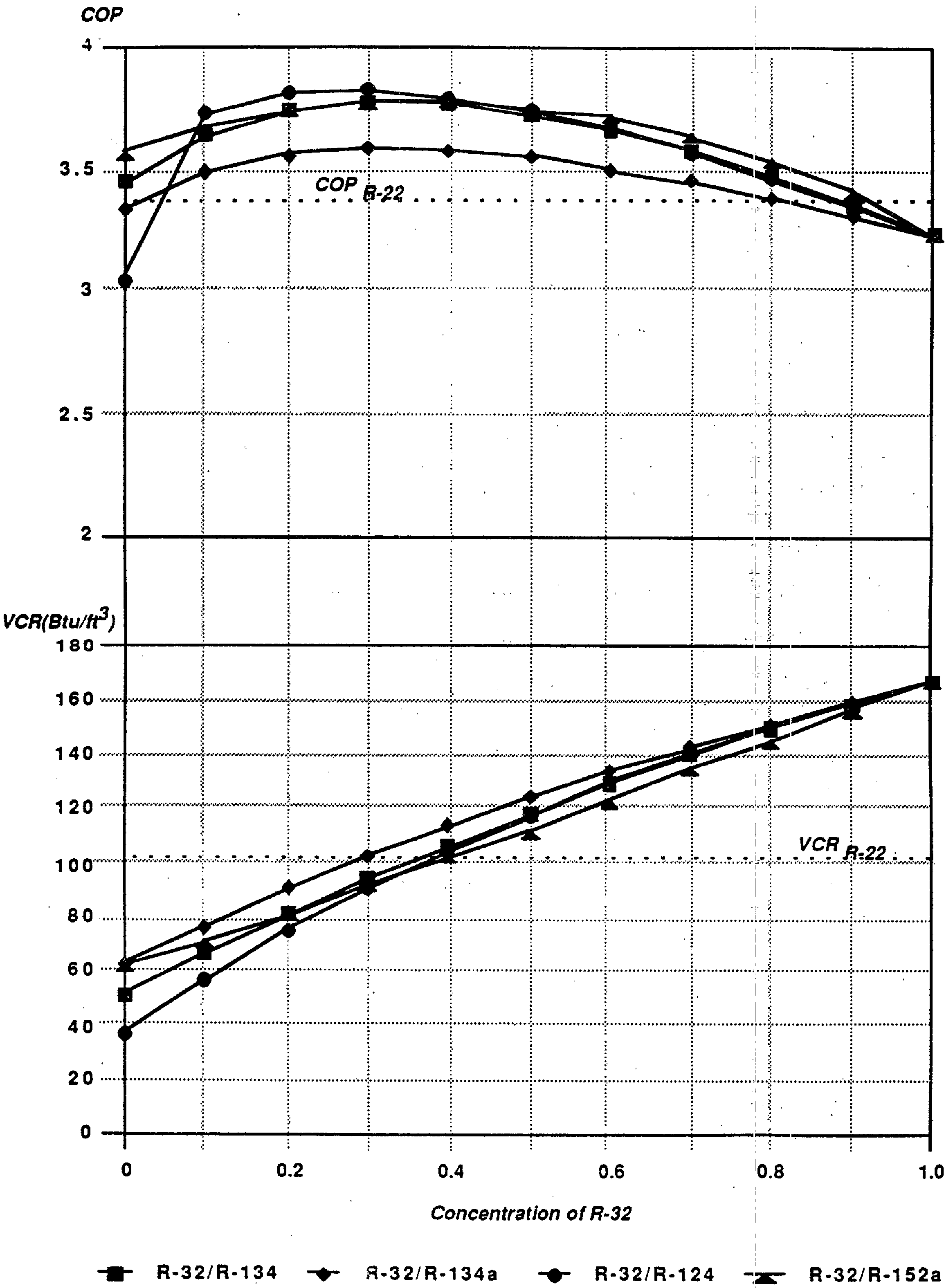
A total of 500 runs were conducted with HAC1 to determine the performance of the pure components and their mixtures listed in Chapter 2.3. An additional 190 runs were conducted with the ternary version, HACT1, for the three ternary mixtures. The results for all runs are available in data files that contain complete printouts as shown in Exhibit 3. Each run also generates a short output file that contains the most crucial results. The short output files for all runs are listed in Appendix 2 with a list of code numbers for the refrigerants. The following parameters are listed in the short output files: fluid code numbers, R1, R2; mixing coefficient, F0; concentration, x (mass fraction); COP; volumetric capacity, VCR; pressure ratio, PR; suction pressure, Ps; discharge pressure, Pd; cooling load, CLOAD; compressor work, WORK; the compressor discharge temperature, Tsup;

and the evaporator air inlet temperature in C, Tairin. The first set lists all mixture runs at design conditions. The second set lists those runs that were used for seasonal performance calculations. It contains R22 values for comparison.

In this chapter the results are discussed that were obtained for the design conditions at 95 F outdoor air temperature for air conditioning and 47 F outdoor air temperature for heating.

Exhibits 7 through 9 show the COP and volumetric capacity for the cooling cases of the binary mixtures listed in Chapter 2.3. R22 has a cooling COP 3.37 and a volumetric capacity of 3735 kJ/m^3. In this simulation, the heating COP is calculated for a cooling case under heating conditions. Therefore, in order to obtain the true heating COP the values shown in the Appendix have to be increased by 1.0. This was considered in the evaluation of the seasonal performance. Based on the peak performance for cooling, the mixture concentration is selected that will be used for the investigation of the seasonal performance. A comparison of the concentrations at which optimum performance is achieved for cooling and those at which the heating performance is optimum yields that there are only minor differences of less than 0.1. Therefore, the

Exhibit 7: Cooling COP and Volumetric Capacity for Binary Refrigerant Mixtures.



<u>Exhibit 8: Cooling COP and Volumetric Capacity for Binary Refrigerant Mixtures.</u>

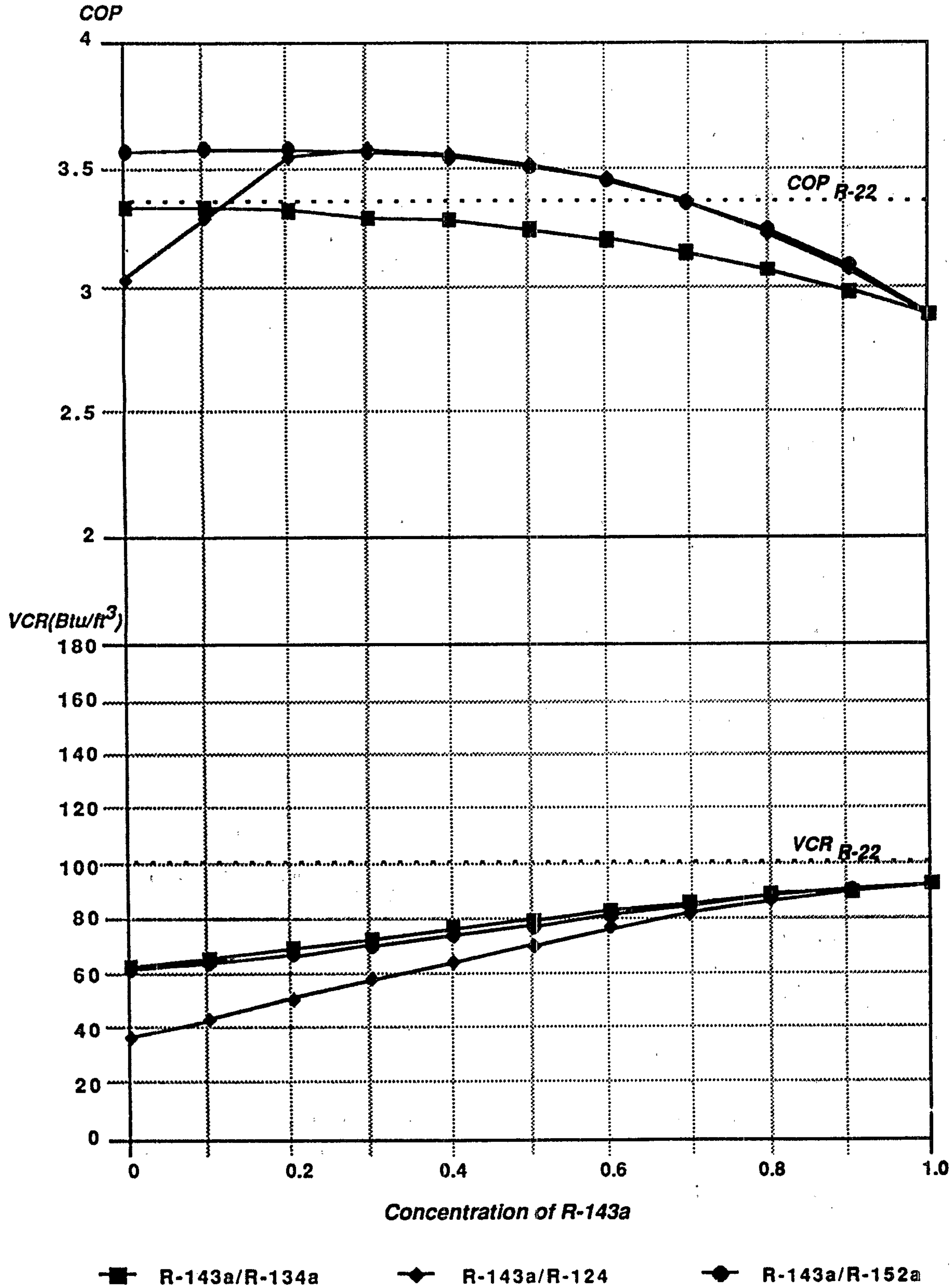
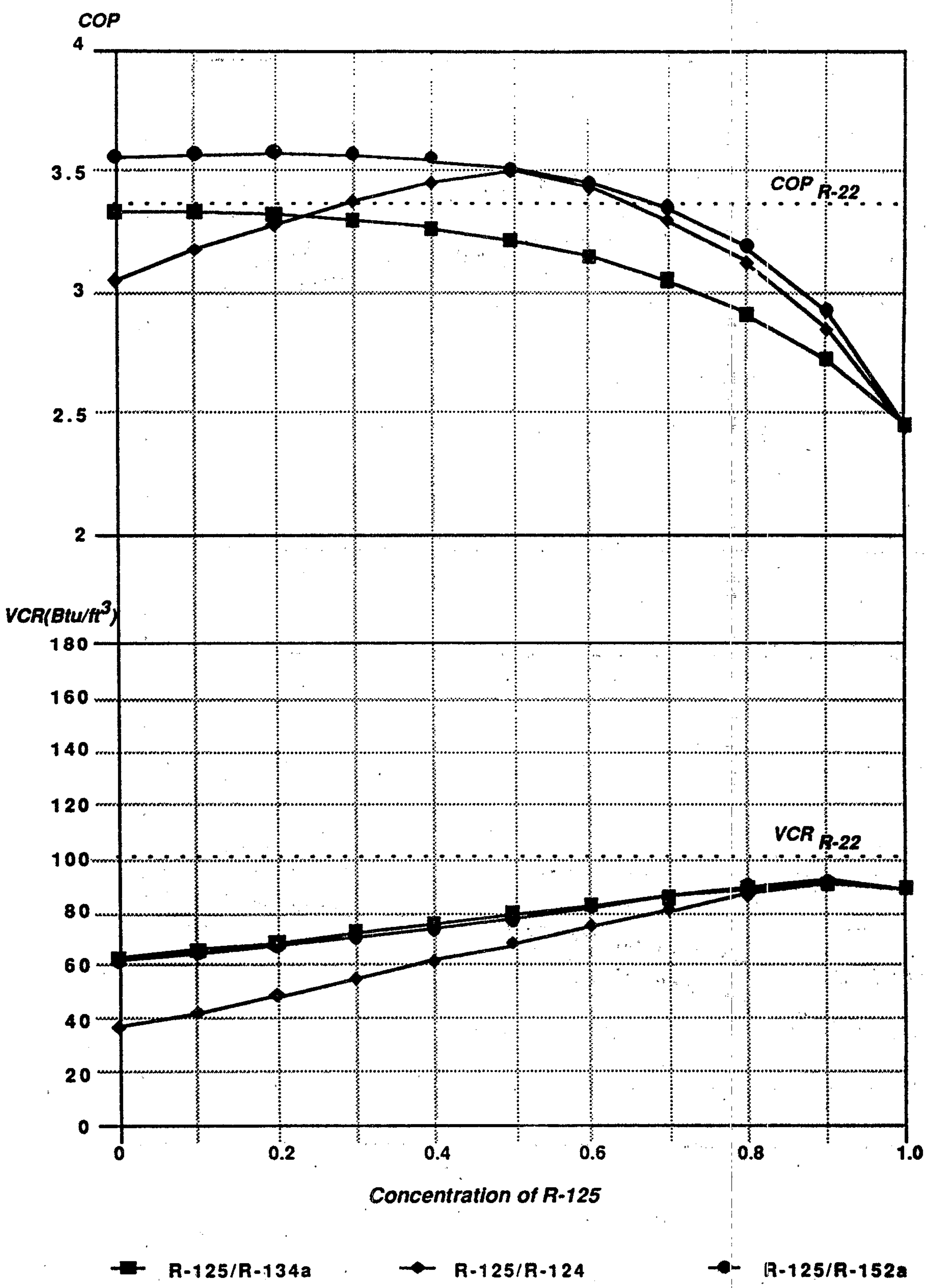


Exhibit 9: Cooling COP and Volumetric Capacity for Binary Refrigerant Mixtures.



same concentration can be used for both cases without any significant penalties in COP.

As a comparison of the Exhibits 7-9 shows, the cooling COP spans a rather wide range from 2.45 for R125 to a maximum of 3.83 for the mixture of R32/R152a/R124 with a concentration of 0.2/0.2/0.6.

The results obtained for binary and ternary mixtures are summarized in Exhibits 10 and 10a. R22 is listed first as reference. Mixtures are listed in sequence according to their performance.

The best mixture was found to be a ternary of R32/R152a/R124. The COP is 13.7 % larger and the volumetric capacity 23 % smaller than the respective values for R22.

The mixture R32/R124 is the best binary fluid pair. The COP is 13.4 % larger and the volumetric capacity 9.6 % smaller than for R22. The ternary mixture of R32/R152a/R134 ranks third and is the best chlorine-free fluid, followed by the binary mixture R32/R152a with 12.1 % improvement in COP and with a volumetric capacity that is 2 % larger as that of R22. R32/R152a provides essentially the same capacity than R22 and could be used as a drop-in replacement. The fifth ranked mixture is the binary R32/R134. The sixth mixture which is the last showing an improvement in excess of 11 % in COP over R22 is R32/R152a/R134a. The best heating performance is found for the same (or only marginally different) concentrations that show maximum cooling performance. Since the operating conditions in heating are more severe, i.e. the temperature lift is larger, the increase in COP is less pronounced than for cooling.

Exhibit 10: COP of Mixtures in Sequence According to Their Performance.

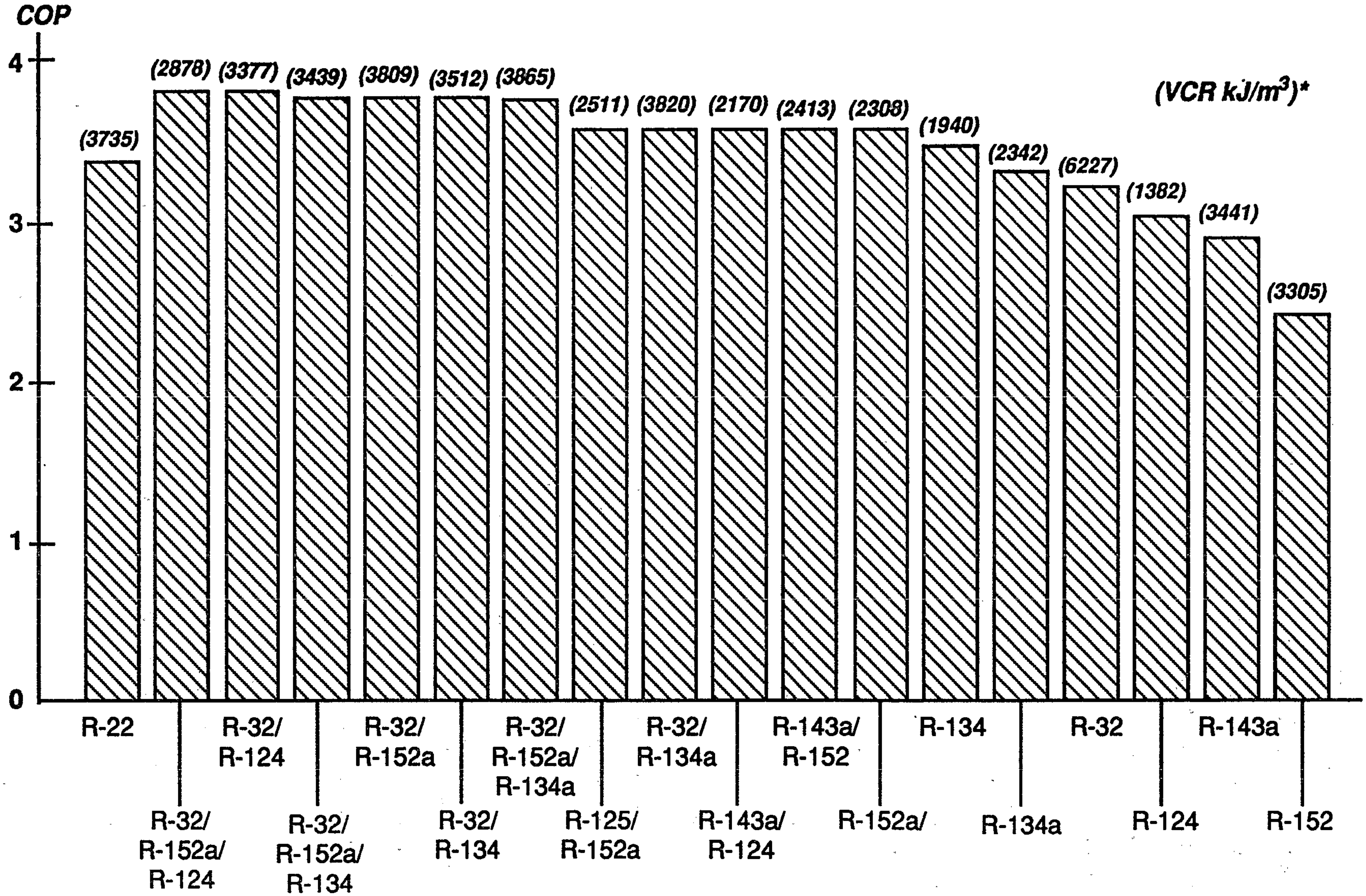
R22 is listed first as reference. For ternaries the amount of R152a was traded for amounts of the third component. (concentration in mass fraction)

IR1	IR2	IR3	X1	X2	X3	COP	Change %	VCR kJ/m3	PR	PSUC kPa	PDIS kPa	Tsup K
R22	R22		1			3.37	0	3735	3.3	614	2015	360
R32	R152a	R124	0.2	0.2	0.6	3.83	13.7	2878	3.4	412	1409	352
R32	R124		0.3	0.7		3.82	13.4	3377	3.3	495	1650	355
R32	R152a	R134	0.3	0.4	0.3	3.79	12.6	3439	3.4	493	1672	363
R32	R152a		0.4	0.6		3.78	12.1	3809	3.3	551	1833	363
R32	R134		0.3	0.7		3.77	11.8	3512	3.4	512	1740	354
R32	R152a	R134a	0.4	0.5	0.1	3.76	11.7	3865	3.3	563	1872	358
R125	R152a		0.2	0.8		3.58	6.2	2511	3.6	372	1324	348
R32	R134a		0.3	0.7		3.58	6.2	3820	3.4	589	1993	354
R143a	R124		0.3	0.7		3.57	5.9	2170	3.5	339	1175	338
R143a	R152a		0.1	0.9		3.57	5.9	2413	3.6	353	1271	350
R152a	R152a		1			3.56	5.8	2308	3.7	332	1219	351
R134	R134		1			3.44	2.0	1940	3.84	287	1104	338
R134a	R134a		1			3.33	-1.2	2342	3.72	369	1373	340
R32	R32		1			3.23	-4.2	6227	3.35	1005	3363	382
R124	R124		1			3.04	-9.8	1382	3.94	208	817	337
R143a	R143a		1			2.89	-14.3	3441	3.11	740	2301	339
R125	R125		1			2.45	-27.4	3305	3.31	821	2718	336

IR1	IR2	IR3	X1	X2	X3	COP	Change %	VCR BTU/ft3	PR	PSUC psia	PDIS psia	Tsup F
R22	R22		1			3.37	0	100	3.3	89	292	189
R32	R152a	R124	0.2	0.2	0.6	3.83	13.7	77	3.4	60	204	174
R32	R124		0.3	0.7		3.82	13.4	91	3.3	72	240	180
R32	R152a	R134	0.3	0.4	0.3	3.79	12.6	92	3.4	72	243	194
R32	R152a		0.4	0.6		3.78	12.1	102	3.3	80	266	194
R32	R134		0.3	0.7		3.77	11.8	94	3.4	74	252	177
R32	R152a	R134a	0.4	0.5	0.1	3.76	11.7	103	3.3	82	272	185
R125	R152a		0.2	0.8		3.58	6.2	67	3.6	54	192	167
R32	R134a		0.3	0.7		3.58	6.2	102	3.4	86	289	177
R143a	R124		0.3	0.7		3.57	5.9	58	3.5	49	171	149
R143a	R152a		0.1	0.9		3.57	5.9	65	3.6	51	184	171
R152a	R152a		1			3.56	5.8	62	3.7	48	177	173
R134	R134		1			3.44	2.0	52	3.8	42	160	148
R134a	R134a		1			3.33	-1.2	63	3.7	53	199	152
R32	R32		1			3.23	-4.2	167	3.4	146	488	227
R124	R124		1			3.04	-9.8	37	3.9	30	119	147
R143a	R143a		1			2.89	-14.3	92	3.1	107	334	151
R125	R125		1			2.45	-27.4	89	3.3	119	394	146

Exhibit 10a:

Best Substitutes for R-22, (R-22 Listed First as Refrence)



* Numbers in parentheses represent the volumetric capacity (VCR kJ/m^3) for each refrigerant

Of the pure fluids R152a ranks best with a 5.8 % improvement over R22, followed by R134 with 2 % improvement and R134a with a 1 % decrease. These results indicate that R152a, R134 and R134a can be used as replacement refrigerants, achieving better or about equal performance as R22. However, the volumetric capacity of these replacements is about 40 % smaller, which requires the use of a 40 % larger compressor.

In Appendix 2 all summary data for all binary mixture runs are listed in English units. In Appendix 3 results for the calculations with ternary refrigerant mixtures are presented in English units.

The best ternary mixture contains R124 with a concentration of 0.6 indicating that the flammability could be reduced compared to the pure constituents, R32 and R152a. For the other ternary fluids this effect is less pronounced.

This analysis presents an idealized condition. To what extent the savings found in this study can be implemented will depend strongly on the actual equipment design and on secondary effects such as the influence of pressure drops, superheating of the refrigerant in the compressor, and superheating and subcooling in the evaporator and condenser.

4.2 Seasonal Performance

The calculation of the seasonal performance was conducted for the following fluids and mixtures: the reference fluid R22, R32/R152a, R32/R134, R32/R134a and R32/R124. The ternary mixtures are not included to shorten calculation times. It is expected that the seasonal performance of the ternary mixtures will be quite similar to the binary mixture of the same performance level.

Since the steady state performance under design conditions showed clearly that mixtures containing R32 are the primary candidates for replacing R22, the seasonal performance evaluation is limited to these mixtures. The pure components were included to demonstrate that the fluid with the better performance under design conditions shows also the better seasonal performance.

Exhibit 11 shows a bar chart of the seasonal performance factor (SPF) for both heating and cooling seasons. The first group of bars represents the cooling seasonal performance factor, CSPF, and the subsequent groups represent the six climate regions for heating. A comparison of the fluids indicates, that when a fluid performs better in the cooling case it will usually be better in the heating case. Since the actual performance of any working fluids depends strongly on the hardware design, the ranking may vary with actual applications. The mixtures containing R32 show significant improvements, while some of the pure fluids show a reduction in the SPF compared to R22. As can be expected from previous discussions, the mixture R32/R152a exhibits the best seasonal performance, followed by R32/R134 and R32/R134a, while pure R125 shows the poorest. The last four lines in this table are explained in the section 'Concentration Shift'.

Exhibit 11:
Seasonal Performance of R-22 and the Five Best Replacements for One Cooling and Six Heating Climates

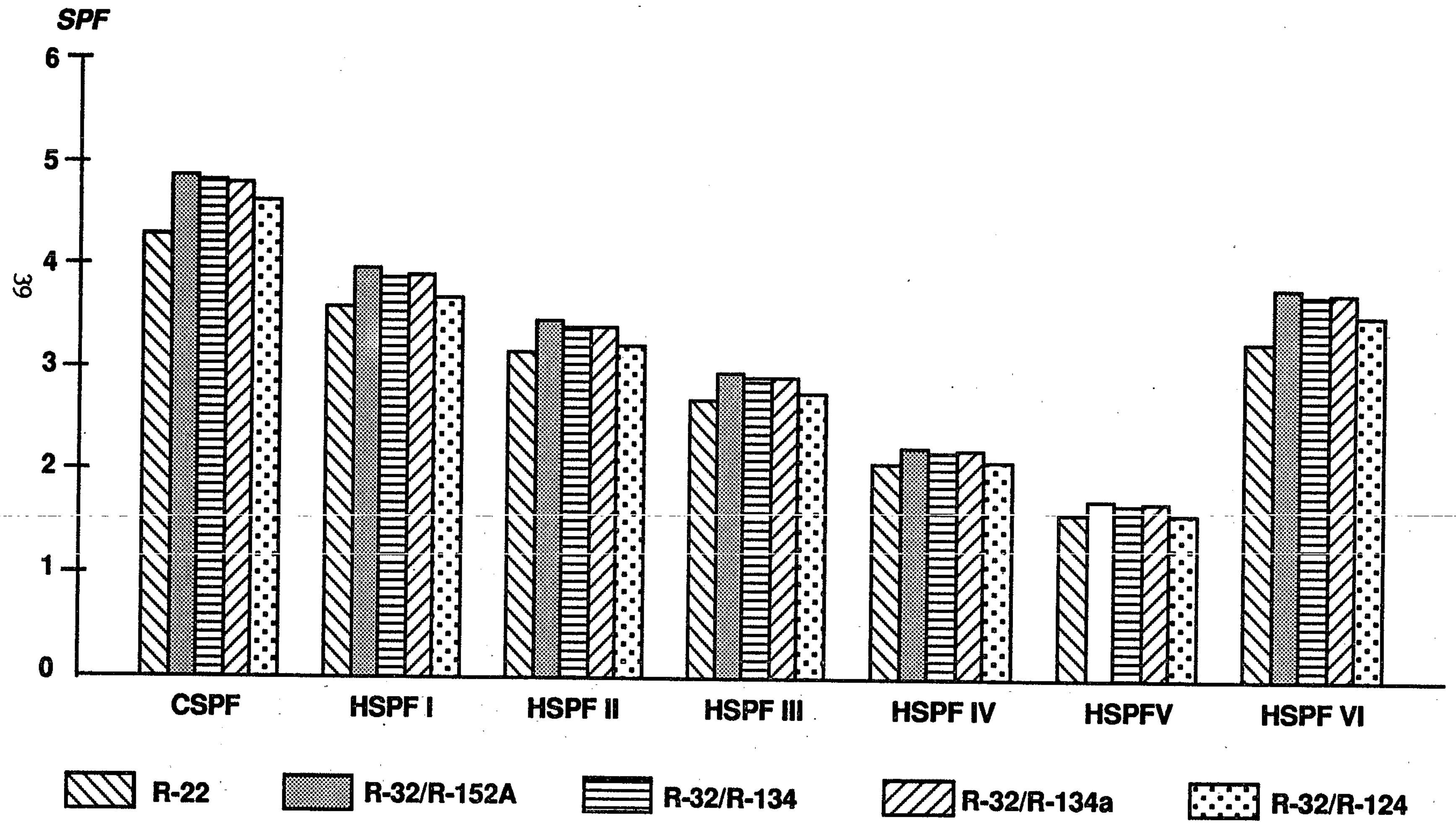


Exhibit 12: Seasonal Performance Factors (SPF) for One Cooling and Six Heating Climates.

The last four lines pertain to the influence of composition shift, when a rectifier is used.

FLUID	CSPF	HSPF I	HSPF II	HSPF III	HSPF IV	HSPF V	HSPF VI
R22	4.25	3.55	3.13	2.7	2.06	1.58	3.24
R32/R124	4.84	3.94	3.44	2.94	2.2	1.67	3.78
R32/R134	4.79	3.86	3.38	2.9	2.17	1.65	3.71
R32/R152a	4.77	3.88	3.39	2.91	2.19	1.66	3.73
R143a/R124	4.59	3.67	3.21	2.75	2.07	1.56	3.52
R32/R134a	4.57	3.71	3.25	2.79	2.11	1.6	3.56
R125/R152a	4.5	3.7	3.24	2.8	2.12	1.61	3.56
R143a/R152a	4.47	3.7	3.25	2.8	2.12	1.62	3.56
R152a	4.45	3.7	3.25	2.8	2.12	1.62	3.56
R125/R124	4.45	3.62	3.15	2.7	2.03	1.52	3.47
R134a	4.23	3.48	3.06	2.64	2.01	1.53	3.35
R32/R152a	4.77	3.82	3.34	2.87	2.16	1.65	3.67
R32/R152a	4.84	3.62	3.21	2.79	2.13	1.65	3.5
R32/R124	4.84	3.94	3.44	2.94	2.2	1.67	3.78
R32/R124	3.949	3.908	3.629	3.209	2.439	1.807	3.801

4.3 Concentration Shift

In order to determine the suitability of the mixtures for capacity control by concentration shift, the ratios of the maximum to minimum capacity are compared. The numeric values are listed in Exhibit 13. The maximum and minimum values are for the pure fluids which constitute a given mixture. Although in reality only a fraction of this ratio can be accomplished without very sophisticated controls, it indicates the suitability of a given mixture. It can be seen from Exhibit 13 that R32/R124 has the widest range of composition shift, a capacity ratio of 5.2, followed by the second best mixture, R32/R134, with a ratio of 3.60. The best performing chlorine-free binary mixture ranks fourth with a ratio of 2.95.

Exhibit 13: Ratio of Heating Capacities.

The R22 value is given for reference purposes. Ternary mixtures are not listed since fluid separation is less efficient. The capacities are listed in kJ/m^3.

Mixture	Capacity 1st comp.	Capacity 2nd com.	Ratio
R22	3050	3050	1.00
R32/R152a	5179	1755	2.95
R32/R134	5179	1444	3.60
R32/R124	5179	999	5.20
R32/R134a	5179	1811	2.87
R143a/R152a	3035	1755	1.73
R125/R152a	3007	1755	1.71
R125/R124	3007	999	3.01
R143a/R134a	3035	1811	1.68
R125/R134a	3007	1811	1.66

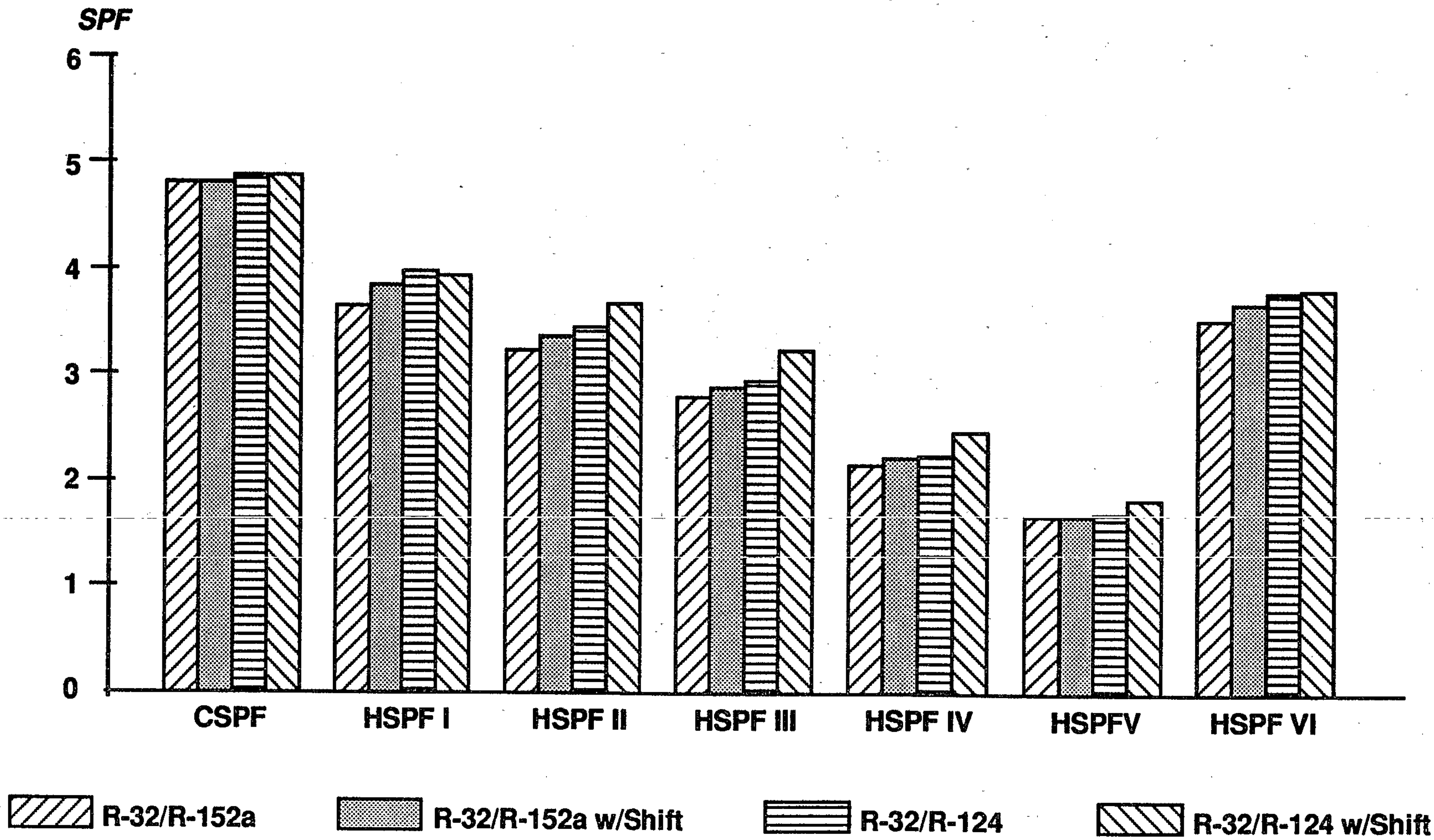
Assuming that a realistic concentration shift of 0.2 can be accomplished with rather simple means (short distillation column), the SPF was evaluated for two mixtures, R32/R152a and R32/R124. The first represents an example for a medium range capacity ratios, and the second exhibits the largest capacity ratio. The results are listed in the last four lines of both sections of Exhibit 12. Exhibit 14 shows a bar graph that reflects the influence of a concentration shift. For cooling there is no change in concentration and performance, assuming the original concentration is used. For heating the HSPF is consistently higher with a concentration shift. The increase in HSPF is as high as ten percent for R32/R124 and as high as six percent for R32/R152a. For severe conditions, climate regions II through V the mixture with the lower COP but larger capacity shift, R32/R124 has the better performance by up to 6 %. This is because none or little resistance heat is required with the higher capacity fluid. The strong influence concentration shift can have on the seasonal performance complicates the situation.

Depending on the given climate region one mixture may perform better than others. The amount of resistance heat that is required depends strongly on the design point of the heat pump. If the current design practice would be changed so that the heat pump application determines the size of the air-conditioner, the need for resistance heat could be reduced or eliminated, influencing the choice of the replacement mixture.

Actual energy savings achieved by employing concentration shifts depend strongly on the climate and on actual operating and design conditions over an entire year.

In this chapter, concentration shift is assumed to be initiated by active means. However, concentration shift can also be initiated by passive means and the mere fact that some parts of a heat pump store refrigerant. This concentration shift may influence the performance of the system and has to be considered in the design.

Exhibit 14:
Seasonal Performance of R-32/R-152a and R-32/R-124 With and Without a Rectifier



4.4 Drop-in Application vs. New Systems

Although the modelling results presented in this report demonstrate the potential for significant energy savings, only the application of the substitutes in actual machinery can demonstrate the real potential. The closer the machinery approaches the model assumptions the closer the predicted energy savings are achieved. Variables such as transport properties and oil compatibility which were not considered in the model because they are not known for most of the proposed substitute mixtures may significantly influence the actually achievable energy savings.

However, the mixtures discussed here may be near drop-in substitutes requiring only changes in the expansion device to adequately accommodate the substitute. Without changing heat exchangers, the performance of some of the better fluids most likely would be similar to that of R22. How closely the R22 efficiency is met depends on the selection of a suitable concentration, which primarily determines the capacity of the substitute and on the degree to what the existing heat exchangers approach counter-flow characteristics. It is expected that the performance of drop-in fluids for conventional designs is not very sensitive to the concentration selected. Therefore, the concentration would be chosen to match the capacity requirements, at least for initial tests.

Based on the simulation results, no reliable assessment can be made of the performance of drop-in substitutes. The actual performance can only be determined by tests in existing air-conditioners.

4.5 Implications of Counter-flow Design and the Use of Mixtures

A system designer developing a new system for operation with R22 substitutes should employ counter-flow heat exchangers, or at least those which resemble counter-flow as closely as possible, to take advantage of the gliding temperatures. Conventional design practice relies on cross-flow heat exchangers. This is the best choice considering the refrigerant saturation temperature is essentially constant and the pressure drop on the air side very small. The fan power requirement is also small.

In this study, it was assumed that counter-flow heat exchangers are available, and that the temperature-enthalpy curve in the two-phase range of a refrigerant mixture is linear (linear temperature profile). This is not always true. Any deviation from a linear temperature profile reduces the performance to some degree. To investigate the penalty that cross-flow heat exchangers inflict on refrigerant mixtures, the model was updated to include cross-flow heat exchangers. The NTU method was implemented for counter- and cross-flow heat exchangers. For R22 the result is the same for both heat exchangers as expected. The mixture R32/R124 was chosen as an example since this fluid mixture has the largest temperature glide. With counter-flow heat exchangers the improvement over R22 for R32/R124 is 13.4 % as shown in Exhibit 10. With cross-flow heat exchangers the improvement over R22 is reduced to 8 %. This result indicates, in order to take full advantage of the performance increase mixtures offer, counter-flow heat exchangers should be used. This finding has to be verified by experiments with refrigerant-to-air heat exchangers.

When more than four tube banks are necessary in order to approximate counter-flow, the pressure drop on the air side will increase, leading to higher fan power requirements. The energy savings mixtures offer may therefore be offset by additional parasitic losses.

On the other hand, in order to take advantage of the refrigerant temperature glide, the heat exchanger area could be increased and the air flow rate could be reduced. Thus the net fan power may not change as a result. This would lead to higher air temperatures leaving the condenser, a feature that should be advantageous for heat pump applications.

The use of mixtures would complicate the maintenance of heat pump systems. One component may escape preferentially when a leakage occurs. The development of devices that allow the simple determination of the concentration of the remaining refrigerant charge and of the amount of the components that have to be added can eliminate this difficulty. Another solution could be to replace the entire charge, which is practical only when the original charge can be reclaimed and recycled.

4.6 Sensitivity Considerations and Accuracy

The accuracy of the results depends to a large degree on the model itself. The model describes a heat pump or air-conditioner almost as an ideal refrigeration cycle. The only deviations from an ideal cycle are the compressor efficiency of 0.70 and the use of fixed air temperatures instead of fixed saturation temperatures of the refrigerant. The latter choice was necessary to account for the gliding temperature range of mixtures. As has been shown, another choice may either favor the pure component or the mixture /4/. Whether or not an actual design achieves the predicted performance depends largely on the system designer and to what degree the idealized assumption can be met. The closure on the energy balance in this model is better than 0.1 %. The model applied here assumes that the temperature glide is linear in the two-phase range. For most mixtures this is not true. Taking into consideration any non linearities will increase the calculation effort considerably but could potentially change the ranking of the mixtures of Exhibit 10. This is true especially when comparing binary and ternary mixtures.

However, there are other factors to consider. The accuracy of the refrigerant data is one. The work presented here is based on the CSD equation of state as published and provided by NIST /3/. The version used here is current, but the data for some of the replacement refrigerants could be updated in the future. Any update on refrigerant properties will effect the results reported here to an undetermined degree which depends on the magnitude of the changes.

Another uncertainty results from the use of a mixing coefficient of -0.01. The mixing coefficient effects the results to some extent. An as yet unpublished study conducted at EPA suggests that for mixtures with boiling points in close proximity of one another, as is the case here, a deviation in COP of less than 3% can be expected /11/. This could also affect the ranking of the mixtures in this report.

The analysis of the seasonal performance is accurate within the accuracy of the bin method employed. Generally the bin method is suitable for providing overview information and is used in connection with the rating of air-conditioners and heat pumps. The model employed here uses the same information and reasoning as will be used later for actual testing of equipment. Therefore, it is ensured that this method and actual tests correspond.

4.7 Global Warming Potential (GWP) and Ozone Depletion Potential (ODP)

Exhibit 15 shows the effects of using pure and mixed refrigerants on direct global warming, indirect global warming, total global warming and ozone depletion. The value for the GWP of R32 is based on a lifetime estimate from EPA /3/. The GWP and ODP values are calculated by linearly interpolating between the pure components of a mixture and weighted with the specific volume of the liquid leaving the condenser as compared to these values of R22. In this way the GWP and ODP is evaluated based on the actual charge within a system (columns entitled "Charge Based"). The underlying assumption is made that a system charged with any fluid to the same liquid level as a system would be charged with R22 is optimally charged. The values for the pure substances are taken from /1/.

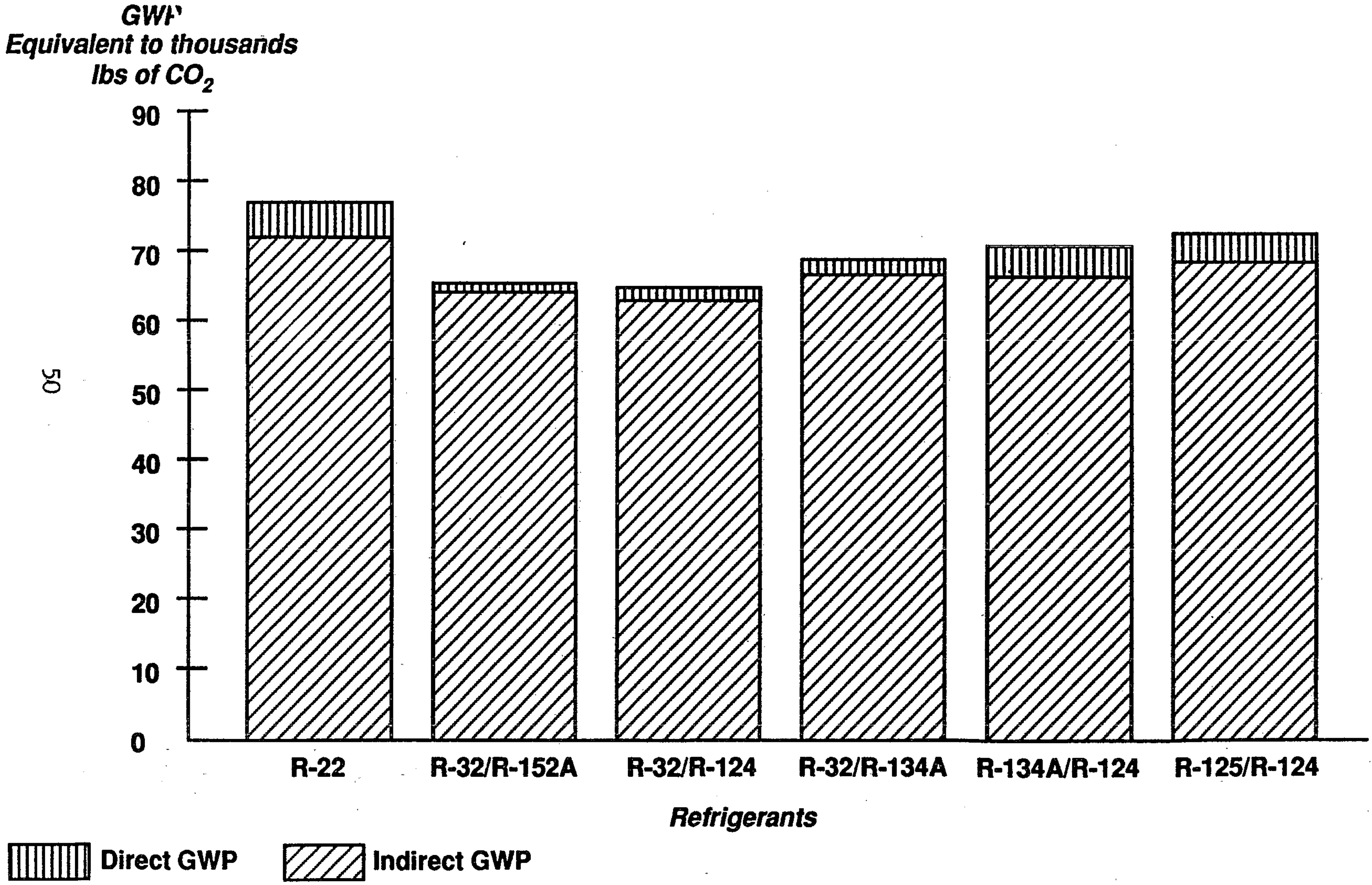
The GWP is based on the integrated time horizon based on 100 years.

The direct and indirect contribution to global warming were calculated based on the seasonal performance factor for the substitute mixtures based on a refrigerant charge that is equivalent to seven pounds of R22 for the life time of ten years for a heat pump. It is assumed that 1.6lb of carbon dioxide is generated per kWh of electricity. The results for the direct and the indirect contributions are shown in the remaining columns of Exhibit 15. Exhibit 16 shows a bar chart displaying the direct and indirect contributions. The results show clearly that the proposed substitutes show less impact on the global warming than R22. R32/R152a and R32/R124 have the lowest GWP. The first because the contribution of the fluids is low, the second because of the calculated COP is high. Only tests in actual machinery can demonstate which of the fluids will have the least global warming impact.

Exhibit 15: Greenhouse Warming (100 yr. Horizon) and Ozone Depletion Potential.

FLUID	CONC.	VOL. m3/kg	GWP	ODP	GWP CHARGE	ODP BASED	GWP TOT.CHAR	SPF cooling	Indir. GWP	Total GWP
R22	1	0.000907	1500	0.05	1500	0.050	4755	4.25	72000	76755
R32	1	0.00115	560	0	442	0.000	1400			
R152A	1	0.00119	140	0	107	0.000	338			
R134	1	0.000834	1200	0	1305	0.000	4137			
R134A	1	0.000887	1200	0	1227	0.000	3890			
R143A	1	0.0012	2900	0	2192	0.000	6948			
R125	1	0.000693	2500	0	3272	0.000	10372			
R124	1	0.000771	430	0.02	506	0.024	1604			
R32/R152A	0.4	0.00118	308	0.000	237	0.000	750	4.77	64151	64901
R32/R124	0.6	0.00104	508	0.008	443	0.007	1404	4.84	63223	64628
R32/R134A	0.7	0.00109	752	0.000	626	0.000	1984	4.57	66958	68942
R143A/R124	0.3	0.000882	1171	0.014	1204	0.014	3817	4.59	66667	70484
R125/R124	0.3	0.000795	1051	0.014	1199	0.016	3801	4.45	68764	72565

Exhibit 16:
Direct and Indirect Contributions to Global Warming



Of the pure fluids considered here, R125 and R143a show a higher GWP than R22, Exhibit 15. The only refrigerant with some ODP is R124 with a value of 40 % of that of R22. However, when these components are used as part of a mixture their contribution is diminished. The mixture with the lowest GWP 237 is R32/R152a with an ODP of 0.0, followed by R32/R124 with a GWP of 443 and an ODP of 0.007. Among the ternary mixtures, it is expected that those with the smaller additive of R124, R134 or R134a show the smaller environmental impact. It is concluded that the binary mixture of R32/R152a is the most favorable fluid from an environmental point of view with regard to all aspects, GWP, ODP and potential for energy savings. While the addition of a third, nonflammable component reduces the risk of flammability, it increases the GWP and ODP. Again there seems to be a trade-off between global risks as described by GWP and ODP and local risks caused by the flammability of the fluids.

5.0 Flammability and Materials Compatibility

5.1 Flammability

Out of the seven refrigerants used in this investigation, three are flammable: R32, R143a and R152a. Phone calls to refrigerant manufacturers produced no further conclusive and referable information.

It is expected that R32 has the lowest heat of combustion and the lowest flammability of the three components. It presents the least danger. R152a shows the highest flammability. The concentration ranges for combustible refrigerant-air mixtures are 12.7 - 33.4 vol% for R32, 4 -17 vol% for R152a and 7 - 18 vol% for R143a. With regard to mixtures there seems to be general agreement that mixing flammable with non-flammable refrigerants reduces the flammability. However, we were unable to ascertain the flammability limits of the mixtures.

5.2 Materials Compatibility

Inquiries to refrigerant manufacturers yielded reluctance on their behalf to the release of information on refrigerant- materials compatibility. The use of the ARI data base was recommended. The data base contains currently eighty reports from various sources, mostly manufacturers. Since the data base is not computerized yet, a list of titles was obtained with the following information of concern here: There are 13 reports concerning R134a, 2 for R22/R142b, 2 for R124, and 1 for R125. None were available for any other fluid investigated in this report. All reports that were screened are listed below. The data available and reported are very scattered. There is no complete set of information available for a single refrigerant nor the information concerning the same material for all refrigerants. Taking this in to consideration, it is not possible to generate a general table or chart. This is a clear indication that further research in this area is needed.

Allied Signal Incorporated

R.H.P. Thomas and H.T. Pham, Evaluation of Environmentally Acceptable Refrigerant/Lubricant Mixtures for Refrigeration and Air Conditioning (R134a)

Refrigerant Breakdown Voltage for Isotron 22/142b Blends for Refrigeration: Material Compatibility

Pennwalt Corporation

Isotron 22/142b Blends for Refrigeration: Material Compatibility

Carrier Corporation

Solubility of R-123 and R134a in Oils
Motor Materials in R-123 and R-134a
UL 984 Tests with R-134a and Oils
Polymer and Elastomer Performance in R-123 and R-134a
Sealed-Tube Texts of R-123 and R-134a with Mineral Oils
Sealed-Tube Tests of R-12 and R-134a with PAGS

Copeland Corporation

Evaluation of Polyalkylene Glycol Candidates with HFC-134a in Refrigeration Compressors

E.I. Dupont de Nemours and Company, Incorporated

Compatibility of Elastomers with HFC-134a at About 25°
Solubility of Refrigerants in Lubricants; HFC-134a

Compatibility of HFC-134a with Refrigeration System Materials

Compatibility of Alternative Refrigerants with Elastomers (R124)

Mutual Solubilities of Water with Fluorocarbons and Fluorocarbon-hydrate Formation (R124, R15, R134a)

Disassembly and Inspection of Compressor in Laboratory Refrigerator Charged with R-134a

ICI Chemicals and Polymers Limited

Compatibility of Nonmetallic Materials with Refrigerants and Lubricants

Tecumseh Products Company

Materials Compatibility of R-134a in Refrigerant Systems

6.0 Further Work

To implement a fluid mixture proposed in this report, a number of parameters have to be considered and investigated. They include material compatibility, flammability and toxicity as well as thermodynamic and transport properties, oil compatibility, compressor life, and cost. In addition, the actual performance of the fluids and mixtures in air-conditioning and heat pump units has to be verified by experiment. This includes the complete redesign of systems. Lastly, concentration shift using rectifiers (or other means) has to be investigated. Parallel to this effort computer simulation programs have to be extended to account for the non linearity of the temperature glide.

References

1. Draft report of the United States Intergovernmental Panel on CFC emissions. (This reference will be updated as soon as more detailed information is available.)

2. Draft of the Revision to the Clean Air Act.

3. William Kopko, Private Communication, U.S. Environmental Protection Agency, Global Change Division, Washington D.C., March 1991.

4. McLinden, Mark O. and R. Radermacher, Methods of Comparing the Performance of Pure and Mixed Refrigerants in Vapor Compression Cycles, International Journal of Refrigeration, 10, 6, 318- 325, (1987).

5. Application of a Hard Sphere Equation of State to Refrigerants and Refrigerant Mixtures, G. Morrison, M.O. McLinden, NBS Technical Note 1226 (1988).

6. ANSI/ASHRAE Standard 116 (1983).

7. Laboratory Investigation of Refrigerant Migration in a Split Unit Air-conditioner, W. Mulroy, D.A. Didion, NBSIR 83-2756, (1983).

8. Bedeutung der nicht azeotropen Zwei-Stoff-Kaeltemittel beim Einsatz Waermepumpen und Kalteanlagen, H. Kruse, R. Jakobs, Ki Klima und Kaelte Ingenieur, 8, 564-571, (1977).

9. The Use of NARMs and Their Display in Ln(p)-h Diagrams, H. Schwind, Kaeltetechnik, 14, 98-103, (1962).

10. Performance of a Conventional Residential Heat Pump Operating With Nonazeotropic Refrigerant Mixtures, W. Mulroy, D.A. Didion, NBSIR 86-3422, (1986).

11. Development of Rectifying Circuit With Mixed Refrigerants, Y. Yoshida, S. Suzuki, Y. Mukai, K. Nakatani and K. Fujiwara, International Journal of Refrigeration, 12, 182-187, (1989).

12. Thermal Environmental Engineering, J.L. Threlkeld, Second Edition, Prentice-Hall Inc. Englewood Cliffs, NJ, (1970).

13. Cynthia Gage, Private Communication, U.S. EPA, Research Triangle Park, NC, June 1990.

14. Oak Ridge National Laboratory, Private Communication.

APPENDIX #1

The following pages of this appendix list the Subroutine BDESC which contains all parameters for the CSD equation of state that were used to evaluate the properties of the pure refrigerants.

```
      BLOCK DATA BDESC
C
C   THIS ROUTINE INITIALIZES THE COMMON BLOCKS CONTAINING INFORMATION
C   ABOUT THE PURE COMPONENTS.  IT IS NOT REFERENCED DIRECTLY BY ANY
C   OTHER SUBROUTINE BUT MUST BE INCLUDED IN THE EXECUTABLE ELEMENT.
C   DATA ARRAYS ARE DIMENSIONED TO ACCOMODATE ADDITIONAL
C   PURE COMPONENTS.
C
C   EXPLANATION OF CONSTANTS:
C      COEFF(I,J) - FOR REFRIGERANT J, COEFFICIENTS OF A, B, CP0
C         CURVE FITS:
C         A = A0 * EXP(A1*T + A2*T*T)  (KJ M**3/KMOL**2)
C         B = B0 + B1*T + B2*T*T  (M**3/KMOL)
C         CP0 = C0 + C1*T + C2*T*T (KJ/KMOL K)
C         (STORED IN ORDER A0,A1,A2,B0,B1,B2,C0,C1,C2)
C      CRIT(I,J) - FOLLOWING INFORMATION FOR REFRIGERANT J:
C         I = 1 - MOLECULAR WEIGHT
C             2 - REFERENCE TEMPERATURE FOR ENTHALPY AND ENTROPY (K)
C             3 - CRITICAL TEMPERATURE (K)
C             4 - CRITICAL PRESSURE (KPA)
C             5 - CRITICAL VOLUME (M**3/KMOL)
C      HREF(J) - REFRIGERANT NAME (ASHRAE DESIGNATION)
C      HZERO(J) - VALUE OF SATURATED LIQUID ENTHALPY OF REFRIGERANT
C         J AT ITS REFERENCE TEMPERATURE (KJ/KMOL)
C      SZERO(J) - VALUE OF SATURATED LIQUID ENTROPY AT REFERENCE
C         TEMPERATURE (KJ/KMOL K)
C      R - GAS CONSTANT (KJ/KMOL K)
C      TOLR - RELATIVE CONVERGENCE TOLERANCE FOR ITERATION LOOPS
         SHOULD BE AT LEAST 10 TIMES LARGER THAN MACHINE PRECISION
C      ITMAX - MAXIMUM ITERATION COUNT FOR ITERATIVE LOOPS
C      LUP - LOGICAL UNIT TO WHICH ANY WARNING MESSAGES ARE WRITTEN
C
C   A, B COEFFFICIENTS EVALUATED FROM ASHRAE (1981) SATURATION
C   DATA UNLESS INDICATED.
C
      IMPLICIT REAL (A-H,O-Z)
      DIMENSION COEFF(9,20),CRIT(5,20),HZERO(20),SZERO(20)
      CHARACTER*6 HREF(20)
      COMMON /ESDATA/ COEFF,CRIT
      COMMON /HREF1/ HREF
      COMMON /HSZERO/ HZERO,SZERO
      COMMON /RDATA4/ R
      COMMON /TOL/ TOLR,ITMAX,LUP
      COMMON /TOLSH/ TOLH,TOLS
      DATA R /8.314/
      DATA TOLR /1.0E-7/
      DATA TOLH,TOLS /0.01,0.001/
      DATA ITMAX,LUP /20,6/
C
C   DATA FOR R11, R12, R13, R13B1, R14, R22, R23, R113, R114,
C   R142B, R152A, R261A, R123, R143A, ISOBUTANE, R125, R134
C   R134A, R32, METHANE
C
C   R11, TRICHLOROFLUOROMETHANE
C
      DATA HREF(1) /'R11'/
      DATA (CRIT(I,1),I=1,5) /137.37E0,233.15E0,471.2E0,4467.E0,.247E0/
      DATA HZERO(1),SZERO(1) /0.0,0.0/
      DATA (COEFF(I,1),I=1,9) /5394.655E0,-2.709516E-3,1.168022E-7,
     1  .1869326E0,-2.318627E-4,4.275137E-8,
     1  23.48052E0,.2510723E0,-2.28722E-4/
C
C  R12, DICHLORODIFLUOROMETHANE
C
```

```
      DATA HREF(2) /'R12'/
      DATA (CRIT(I,2),I=1,5) /120.91E0,233.15E0,384.95E0,4180.E0,.217E0/
      DATA HZERO(2),SZERO(2) /0.0,0.0/
      DATA (COEFF(I,2),I=1,9) /3819.876E0,-3.319879E-3,2.419441E-7,
     1  .1653502E0,-2.657584E-4,9.138782E-8,
     1  18.4874E0,.2417816E0,-2.045946E-4/
C
C   R13, CHLOROTRIFLUOROMETHANE
C
      DATA HREF(3) /'R13'/
      DATA (CRIT(I,3),I=1,5) /104.46,233.15,302.0,3921.,0.181/
      DATA HZERO(3),SZERO(3) /0.0,0.0/
      DATA (COEFF(I,3),I=1,9) /2518.99E0,-4.206832E-3,1.854713E-7,
     1  .1414323E0,-2.982745E-4,1.339647E-7,
     1  13.86910E0,.2323698E0,-1.830952E-4/
C
C  R13B1, BROMOTRIFLUOROMETHANE
C
      DATA HREF(4)/'R13B1'/
      DATA (CRIT(I,4),I=1,5) /148.91,233.15,340.2,4017.,0.200/
      DATA HZERO(4),SZERO(4) /0.0,0.0/
      DATA (COEFF(I,4),I=1,9) /4095.393E0,-5.743494E-3,3.740058E-6,
     1  0.1813461E0,-4.813153E-4,4.548773E-7,
     1  20.68068E0,0.2112316E0,-1.61476E-4/
C
C  R14, TETRAFLUOROMETHANE
C
      DATA HREF(5) /'R14'/
      DATA (CRIT(I,5),I=1,5) /88.00,200.00,227.5,3795.,0.141/
      DATA HZERO(5),SZERO(5) /0.0,0.0/
      DATA (COEFF(I,5),I=1,9) /1272.405E0,-3.429461E-3,-6.475736E-6,
     1 0.09966432E0,-1.57113E-4,-2.950201E-7,
     1  14.42957E0,.1845298E0,-9.518905E-5/
C
C   R22, CHLORODIFLUOROMETHANE
C
      DATA HREF(6) /'R22'/
      DATA (CRIT(I,6),I=1,5) /86.47,233.15,369.3,5054.,0.169/
      DATA HZERO(6),SZERO(6) /0.0,0.0/
      DATA (COEFF(I,6),I=1,9) /2730.846E0,-2.979927E-3,-7.651239E-7,
     1 .1203449E0, -1.627592E-4,-1.132347E-8,
     1  21.98390E0,.1277439E0,-4.788723E-5/
C
C   R23, TRIFLUOROMETHANE
C
      DATA HREF(7) /'R23'/
      DATA (CRIT(I,7),I=1,5) /70.01,233.15,299.1,4900.,0.133/
      DATA HZERO(7),SZERO(7) /0.0,0.0/
      DATA (COEFF(I,7),I=1,9) /1778.200E0,-3.676280E-3,-8.794795E-7,
     1  0.09321863E0,-1.513167E-4,1.773370E-9,
     1  23.60294E0,.08228732E0,3.182653E-5/
C
C   R113, 1,1,2-TRICHLOROTRIFLUOROETHANE
C
      DATA HREF(8) /'R113'/
      DATA (CRIT(I,8),I=1,5) /187.38,233.15,487.5,3456.,0.329/
      DATA HZERO(8),SZERO(8) /0.0,0.0/
      DATA (COEFF(I,8),I=1,9) /7608.63E0,-2.41486E-3,-4.38971E-7,
     1  0.2365185E0,-2.228472E-4,-5.601952E-8,
     1  76.2637E0,0.119641E0,7.18786E-5/
C
C   R114, 1,2-DICHLOROTETRAFLUOROETHANE
C
      DATA HREF(9) /'R114'/
      DATA (CRIT(I,9),I=1,5) /170.92,233.15,418.8,3248.,0.307/
      DATA HZERO(9),SZERO(9) /0.0,0.0/
      DATA (COEFF(I,9),I=1,9) /5929.736E0,-2.860181E-3,-4.815203E-7,
     1  0.2218744E0,-2.883043E-4,1.81892E-8,
     1  37.2482E0,.337339E0,-2.39995E-4/
C
C   R142B, 1-CHLORO-1,1-DIFLUOROETHANE
C
```

```
      DATA HREF(10) /'R142B'/
      DATA (CRIT(I,10),I=1,5) /100.49,233.15,410.3,4120.,0.231/
      DATA HZERO(10),SZERO(10) /0.0,0.0/
      DATA (COEFF(I,10),I=1,9) /4512.576E0,-3.229507E-3,2.608976E-7,
     1  0.1730507E0,-2.648172E-4, 1.032608E-7,
     1  16.39145E0,.2717191E0,-1.589334E-4/
C
C   R152A, 1,1-DIFLUOROETHANE
C
      DATA HREF(11) /'R152A'/
      DATA (CRIT(I,11),I=1,5) /66.05,233.15,386.7,4492.,0.181/
      DATA HZERO(11),SZERO(11) /0.0,0.0/
      DATA (COEFF(I,11),I=1,9) /3106.312E0,-2.776653E-3,-6.258540E-7,
     1  .1283451E0,-.1726218E-3,2.790653E-8,
     1  22.28316E0,.1539874E0,-3.015434E-6/
C
C   R115, PENTAFLUOROMONOCHLOROETHANE, C2CLF5
C
      DATA HREF(12) /'R115'/
      DATA (CRIT(I,12),I=1,5) /154.465,233.15,353.05,3153.,0.252/
      DATA HZERO(12),SZERO(12) /0.0,0.0/
      DATA (COEFF(I,12),I=1,9) /6177.259E0,-5.540229E-3,2.635930E-6,
     1  .2474781E0,-6.346145E-4,5.512517E-7,
     1  20.0246E0,.3765849E0,-2.703487E-4/
C
C   R123, 1,1-DICHLORO-2,2,2-TRIFLUOROETHANE
C
      DATA HREF(13) /'R123'/
      DATA (CRIT(I,13),I=1,5) /152.930,233.15,456.94,3674.,0.278/
      DATA HZERO(13),SZERO(13) /0.0,0.0/
      DATA (COEFF(I,13),I=1,9) /5885.629E0,-2.2446861E-3,-1.0342735E-6,
     1  .1957662E0,-1.6784282E-4,-9.9567402E-8,
     1  29.2604E0,.302994E0,-1.92907E-4/
C
C   R143A, 1,1,1-TRIFLUOROETHANE
C
      DATA HREF(14) /'R143A'/
      DATA (CRIT(I,14),I=1,5) /84.04,233.15,346.3,3758.,0.194/
      DATA HZERO(14),SZERO(14) /0.0,0.0/
      DATA (COEFF(I,14),I=1,9) /3092.03,-3.42907E-3,1.49460E-7,
     1  0.137902,-1.96301E-4,1.78383E-8,
     1  14.0656,0.254765,-1.29865E-4/
C
C   R124:  1-CHLORO-1,2,2,2-TETRAFLUOROETHANE (R124)
C
      DATA HREF(15) /'R124'/
      DATA (CRIT(I,15),I=1,5) /136.475,233.15,395.65,3660.,0.244/
      DATA HZERO(15),SZERO(15) /0.0,0.0/
      DATA (COEFF(I,15),I=1,9) /4718.786E0,-2.847854E-3,-1.0857E-6,
     1  .1818017E0,-2.256066E-4,-3.890926E-8,
     1  30.97765E0,.2542056E0,-9.364136E-5/
C
C   R125:  PENTAFLUOROETHANE
C
      DATA HREF(16) /'R125'/
      DATA (CRIT(I,16),I=1,5) /120.03,233.15,339.45,3630.6,0.210/
      DATA HZERO(16),SZERO(16) /0.0,0.0/
      DATA (COEFF(I,16),I=1,9) /2971.488E0,-2.111917E-3,-3.734385E-6,
     1  .1443116E0,-1.410596E-4,-1.969504E-7,
     1  22.65024E0,.2956679E0,-1.694896E-4/
C
C   R134:  1,1,2,2-TETRAFLUOROETHANE
C
      DATA HREF(17) /'R134'/
      DATA (CRIT(I,17),I=1,5) /102.034,233.15,392.1,4562.,0.189/
      DATA HZERO(17),SZERO(17) /0.0,0.0/
      DATA (COEFF(I,17),I=1,9) /3689.1E0,-2.83434E-3,-1.22280E-6,
     1  .144618E0,-1.84369E-4,-.253676E-7,
     1  32.5208E0,.222819E0,-1.06829E-4/
C
C   R134A  1,1,2,2-TETRAFLUOROETHANE
C
```

```
      DATA HREF(18) /'R134A'/
      DATA (CRIT(I,18),I=1,5) /102.030,233.15,374.3,4067.,0.199/
      DATA HZERO(18),SZERO(18) /0.0,0.0/
      DATA (COEFF(I,18),I=1,9) /3611.8E0,-2.89497E-3,-1.28106E-6,
     1 .144618E0,-1.84368E-4,-.253676E-7,
     1 19.6704E0,.258433E0,-1.178714E-4/
C
C  R32:  DIFLUOROMETHANE
C
      DATA HREF(19) /'R32'/
      DATA (CRIT(I,19),I=1,5) /52.024,233.15,351.55,5814.23,.1211/
      DATA HZERO(19),SZERO(19) /0.0,0.0/
      DATA (COEFF(I,19),I=1,9) /1463.431,-1.212964E-3,-3.811882E-6,
     1 0.07560431,-5.783178E-5,-8.592812E-8,
     1 26.53804,0.05489753,1.574905E-5/
C
C  R141B
C
      DATA HREF(20) /'R141B'/
      DATA (CRIT(I,20),I=1,5) /116.95,233.15,477.85,4400.,0.25205/
      DATA HZERO(20),SZERO(20) /0.0,0.0/
      DATA (COEFF(I,20),I=1,9) /4778.65,-1.54402E-3,-1.53332E-6,
     1 0.169895,-1.003E-4,-0.144243E-6,
     1 21.0244,0.277793,-1.73962E-4/
C
C  R216A, 1,3-DICHLOROHEXAFLUOROPROPANE
C
C       DATA HREF(12) /'R216A'/
C       DATA (CRIT(I,12),I=1,5) /220.93,233.15,453.14,2754.1,0.3847/
C       DATA HZERO(12),SZERO(12) /0.0,0.0/
C       DATA (COEFF(I,12),I=1,9) /8431.44,-2.45916E-3,-9.91754E-7,
C      1 0.265720,-2.20418E-4,-1.68111E-7,
C      1 8.79769,0.654246,-5.39923E-4/
C
C  R216B, 1,2-DICHLOROHEXAFLUOROPROPANE
C
C      DATA HREF(13) /'R216B'/
C      DATA (CRIT(I,13),I=1,5) /220.93,233.15,453.14,2754.1,0.3847/
C      DATA HZERO(13),SZERO(13) /0.0,0.0/
C      DATA (COEFF(I,13),I=1,9) /8390.00,-2.45916E-3,-9.91754E-7,
C     1 0.265720,-2.20418E-4,-1.68111E-7,
C     1 8.79769,0.654246,-5.39923E-4/
C
C  ISOPENTANE
C
C      DATA HREF(14) /'I-PENT'/
C      DATA (CRIT(I,14),I=1,5) /72.151,233.15,460.4,3384.255,0.305/
C      DATA HZERO(14),SZERO(14) /0.0,0.0/
C      DATA (COEFF(I,14),I=1,9) /4763.80,-6.8115E-4,-2.9477E-6,
C     1 0.2131,-1.6519E-4,-1.3550E-7,
C     1 0.0,0.0,0.0/
C
C  ISOBUTANE
C
C       DATA HREF(15) /'I-BUT'/
C       DATA (CRIT(I,15),I=1,5) /58.124,233.15,408.1,3647.7,0.263/
C       DATA HZERO(15),SZERO(15) /0.0,0.0/
C       DATA (COEFF(I,15),I=1,9) /3009.71,-1.4706E-4,-4.3998E-6,
C      1 0.1803,-1.8141E-4,-9.9068E-8,
C      1 27.6833,0.199384,1.06305E-4/
C
C  METHANE
C  COEFFICIENTS ARE BASED ON SATURATION DATA FROM IUPAC TABLES
C
C       DATA HREF(20) /'CH4'/
C       DATA (CRIT(I,20),I=1,5) /16.043,111.631,190.555,4595.0,0.09892/
C       DATA HZERO(20),SZERO(20) /0.0,0.0/
C       DATA (COEFF(I,20),I=1,9) /623.650,-4.42548E-3,-2.66667E-6,
C      1 0.0725603,-2.15762E-4,7.38690E-8,
C      1 35.8200,-0.0340480,1.12485E-4/
C
C  CHARACTERISTIC REFRIGERANT
```

```
C
C      DATA HREF(20) /'R-CHAR'/
C      DATA (CRIT(I,20),I=1,5) /100.0,50.,100.0,1000.0,0.0/
C      DATA HZERO(20),SZERO(20) /0.0,0.0/
C      DATA (COEFF(I,20),I=1,9) /1064.,-0.01204,0.0,
C     1  0.1680,-8.066E-4,0.0,
C     1  44.40,0.5560,0.0/
C
       END
```

APPENDIX #2

This appendix contains a listing of the short output files for all computer runs conducted for binary mixtures. The refrigerants are specified by code numbers according to the following table.

R22	6
R142b	10
R152a	11
R143a	14
R124	15
R125	16
R134	17
R134a	18
R32	19

IR1	IR	FO	XM	COP	VCR BTU/ft3	PR	PSUC psia	PDIS psia	CLOAD BTU/hr	WORK Watt	Tsup F	Tair C
6	6	0	1	3.37	100.1	3.28	89.1	292	11996	1043	189	78.8
11	11	0	1	3.56	61.9	3.67	48.2	177	11996	987	173	78.8
15	15	0	1	3.04	37.1	3.94	30.1	119	11996	1157	147	78.8
19	19	0	1	3.23	166.9	3.35	145.8	488	11996	1089	227	78.8
17	17	0	1	3.44	52.0	3.84	41.7	160	11996	1023	148	78.8
18	18	0	1	3.33	62.8	3.72	53.5	199	11996	1056	152	78.8
14	14	0	1	2.89	92.3	3.11	107.4	334	11996	1218	151	78.8
16	16	0	1	2.45	88.6	3.31	119.2	394	11996	1438	146	78.8
19	15	-0.01	0	3.04	37.1	3.94	30.1	119	11996	1157	147	78.8
19	15	-0.01	0.1	3.73	57.1	3.64	44.0	160	11996	944	157	78.8
19	15	-0.01	0.2	3.81	74.9	3.45	58.3	201	11996	922	170	78.8
19	15	-0.01	0.3	3.82	90.5	3.33	71.8	240	11996	921	180	78.8
19	15	-0.01	0.4	3.79	104.6	3.25	84.6	275	11996	928	188	78.8
19	15	-0.01	0.5	3.74	117.6	3.2	96.8	310	11996	940	194	78.8
19	15	-0.01	0.6	3.66	129.5	3.18	108.3	345	11996	960	200	78.8
19	15	-0.01	0.7	3.56	140.4	3.2	119.1	381	11996	986	206	78.8
19	15	-0.01	0.8	3.45	150.2	3.23	129.1	417	11996	1018	213	78.8
19	15	-0.01	0.9	3.34	159.1	3.28	138.0	453	11996	1053	220	78.8
19	15	-0.01	1	3.23	166.9	3.35	145.8	488	11996	1089	227	78.8
19	17	-0.01	0	3.44	52.0	3.84	41.7	160	11996	1023	148	78.8
19	17	-0.01	0.1	3.64	66.7	3.65	52.3	191	11996	966	159	78.8
19	17	-0.01	0.2	3.74	80.9	3.5	63.3	222	11996	941	169	78.8
19	17	-0.01	0.3	3.77	94.2	3.4	74.3	252	11996	933	177	78.8
19	17	-0.01	0.4	3.76	106.6	3.33	85.1	283	11996	936	185	78.8
19	17	-0.01	0.5	3.72	118.2	3.28	95.7	314	11996	946	192	78.8
19	17	-0.01	0.6	3.65	129.2	3.26	106.2	346	11996	962	199	78.8
19	17	-0.01	0.7	3.57	139.6	3.26	116.4	379	11996	985	206	78.8
19	17	-0.01	0.8	3.47	149.3	3.27	126.5	413	11996	1013	213	78.8
19	17	-0.01	0.9	3.35	158.5	3.3	136.3	450	11996	1048	220	78.8
19	17	-0.01	1	3.23	166.9	3.35	145.8	488	11996	1090	227	78.8
19	18	-0.01	0	3.33	62.8	3.72	53.5	199	11996	1056	152	78.8
19	18	-0.01	0.1	3.48	76.9	3.57	64.3	230	11996	1012	161	78.8
19	18	-0.01	0.2	3.55	90.1	3.46	75.1	260	11996	990	169	78.8
19	18	-0.01	0.3	3.58	102.4	3.38	85.5	289	11996	983	177	78.8
19	18	-0.01	0.4	3.57	113.7	3.33	95.6	318	11996	985	184	78.8
19	18	-0.01	0.5	3.54	124.2	3.3	105.1	347	11996	993	191	78.8
19	18	-0.01	0.6	3.49	134.0	3.29	114.2	375	11996	1006	198	78.8
19	18	-0.01	0.7	3.44	143.1	3.29	122.8	404	11996	1023	205	78.8
19	18	-0.01	0.8	3.37	151.5	3.3	131.0	432	11996	1043	213	78.8
19	18	-0.01	0.9	3.30	159.5	3.32	138.7	460	11996	1066	220	78.8
19	18	-0.01	1	3.23	166.9	3.35	145.8	488	11996	1090	227	78.8
19	11	-0.01	0	3.56	61.9	3.67	48.2	177	11996	987	173	78.8
19	11	-0.01	0.1	3.67	71.6	3.55	55.3	196	11996	957	178	78.8
19	11	-0.01	0.2	3.74	81.6	3.46	63.0	218	11996	940	184	78.8
19	11	-0.01	0.3	3.77	91.8	3.38	71.2	241	11996	932	189	78.8
19	11	-0.01	0.4	3.78	102.1	3.33	80.0	266	11996	931	194	78.8
19	11	-0.01	0.5	3.75	112.6	3.29	89.2	293	11996	937	200	78.8
19	11	-0.01	0.6	3.71	123.3	3.26	99.0	323	11996	949	205	78.8
19	11	-0.01	0.7	3.63	134.2	3.25	109.5	356	11996	968	210	78.8
19	11	-0.01	0.8	3.53	145.2	3.26	120.8	393	11996	996	215	78.8
19	11	-0.01	0.9	3.40	156.1	3.29	132.8	437	11996	1035	221	78.8
19	11	-0.01	1	3.23	166.9	3.35	145.8	488	11996	1090	227	78.8
14	18	-0.01	0	3.33	62.8	3.72	53.5	199	11996	1056	152	78.8
14	18	-0.01	0.1	3.33	66.2	3.64	57.5	209	11996	1056	152	78.8
14	18	-0.01	0.2	3.32	69.6	3.56	61.8	220	11996	1059	152	78.8
14	18	-0.01	0.3	3.30	73.0	3.48	66.3	231	11996	1064	153	78.8
14	18	-0.01	0.4	3.28	76.3	3.41	71.1	243	11996	1072	153	78.8
14	18	-0.01	0.5	3.25	79.6	3.35	76.3	255	11996	1083	153	78.8
14	18	-0.01	0.6	3.20	82.7	3.29	81.7	269	11996	1097	153	78.8
14	18	-0.01	0.7	3.15	85.6	3.24	87.5	283	11996	1117	153	78.8
14	18	-0.01	0.8	3.08	88.3	3.19	93.7	299	11996	1143	152	78.8
14	18	-0.01	0.9	2.99	90.5	3.15	100.3	316	11996	1176	152	78.8
14	18	-0.01	1	2.89	92.3	3.11	107.4	334	11996	1218	151	78.8
14	11	-0.01	0	3.56	61.9	3.67	48.2	177	11996	987	173	78.8

14	11	-0.01	0.1	3.57	64.7	3.6	51.3	184	11996	985	171	78.8
14	11	-0.01	0.2	3.57	67.7	3.53	54.7	193	11996	986	169	78.8
14	11	-0.01	0.3	3.56	70.8	3.46	58.5	203	11996	989	167	78.8
14	11	-0.01	0.4	3.53	74.2	3.4	62.9	214	11996	995	165	78.8
14	11	-0.01	0.5	3.50	77.6	3.34	67.8	226	11996	1006	163	78.8
14	11	-0.01	0.6	3.44	81.1	3.28	73.4	241	11996	1022	161	78.8
14	11	-0.01	0.7	3.36	84.6	3.23	79.8	258	11996	1045	159	78.8
14	11	-0.01	0.8	3.25	88.0	3.18	87.4	278	11996	1080	156	78.8
14	11	-0.01	0.9	3.10	90.7	3.14	96.4	303	11996	1133	154	78.8
14	11	-0.01	1	2.89	92.3	3.11	107.4	334	11996	1218	151	78.8

14	15	-0.01	0	3.04	37.1	3.94	30.1	119	11996	1157	147	78.8
14	15	-0.01	0.1	3.30	44.2	3.74	36.0	135	11996	1065	147	78.8
14	15	-0.01	0.2	3.53	51.4	3.58	42.4	152	11996	997	147	78.8
14	15	-0.01	0.3	3.57	58.2	3.47	49.2	171	11996	985	149	78.8
14	15	-0.01	0.4	3.55	64.7	3.37	56.3	190	11996	990	151	78.8
14	15	-0.01	0.5	3.51	70.8	3.29	63.7	210	11996	1001	152	78.8
14	15	-0.01	0.6	3.45	76.6	3.22	71.5	231	11996	1020	152	78.8
14	15	-0.01	0.7	3.36	81.8	3.17	79.7	253	11996	1048	153	78.8
14	15	-0.01	0.8	3.23	86.3	3.14	88.4	277	11996	1087	152	78.8
14	15	-0.01	0.9	3.08	89.9	3.11	97.6	304	11996	1142	152	78.8
14	15	-0.01	1	2.89	92.3	3.11	107.4	334	11996	1218	151	78.8

16	18	-0.01	0	3.33	62.8	3.72	53.5	199	11996	1056	152	78.8
16	18	-0.01	0.1	3.33	65.8	3.67	57.0	209	11996	1057	151	78.8
16	18	-0.01	0.2	3.32	69.0	3.61	60.9	220	11996	1060	150	78.8
16	18	-0.01	0.3	3.30	72.4	3.56	65.2	232	11996	1067	150	78.8
16	18	-0.01	0.4	3.26	75.8	3.51	70.1	246	11996	1078	149	78.8
16	18	-0.01	0.5	3.21	79.3	3.46	75.6	262	11996	1095	148	78.8
16	18	-0.01	0.6	3.14	82.8	3.42	81.8	280	11996	1119	148	78.8
16	18	-0.01	0.7	3.04	85.9	3.38	89.0	301	11996	1155	147	78.8
16	18	-0.01	0.8	2.91	88.5	3.34	97.4	326	11996	1209	147	78.8
16	18	-0.01	0.9	2.72	89.8	3.32	107.3	356	11996	1294	146	78.8
16	18	-0.01	1	2.45	88.6	3.31	119.2	394	11996	1438	146	78.8

16	11	-0.01	0	3.56	61.9	3.67	48.2	177	11996	987	173	78.8
16	11	-0.01	0.1	3.57	64.5	3.61	50.9	184	11996	984	170	78.8
16	11	-0.01	0.2	3.58	67.3	3.56	53.9	192	11996	983	167	78.8
16	11	-0.01	0.3	3.57	70.4	3.51	57.5	202	11996	984	165	78.8
16	11	-0.01	0.4	3.55	73.9	3.46	61.7	213	11996	990	162	78.8
16	11	-0.01	0.5	3.51	77.6	3.41	66.6	227	11996	1000	159	78.8
16	11	-0.01	0.6	3.45	81.5	3.37	72.6	245	11996	1019	156	78.8
16	11	-0.01	0.7	3.35	85.6	3.33	79.9	266	11996	1050	153	78.8
16	11	-0.01	0.8	3.19	89.5	3.3	89.3	295	11996	1103	151	78.8
16	11	-0.01	0.9	2.92	91.8	3.29	101.7	335	11996	1204	148	78.8
16	11	-0.01	1	2.45	88.6	3.31	119.2	394	11996	1438	146	78.8

16	15	-0.01	0	3.04	37.1	3.94	30.1	119	11996	1157	147	78.8
16	15	-0.01	0.1	3.17	42.8	3.82	34.7	132	11996	1109	148	78.8
16	15	-0.01	0.2	3.28	48.9	3.71	39.9	148	11996	1073	148	78.8
16	15	-0.01	0.3	3.37	55.3	3.62	45.8	166	11996	1043	148	78.8
16	15	-0.01	0.4	3.45	61.8	3.53	52.5	185	11996	1018	148	78.8
16	15	-0.01	0.5	3.49	68.4	3.46	59.9	207	11996	1006	147	78.8
16	15	-0.01	0.6	3.42	74.9	3.39	68.4	232	11996	1029	148	78.8
16	15	-0.01	0.7	3.30	81.1	3.34	78.1	261	11996	1065	147	78.8
16	15	-0.01	0.8	3.12	86.5	3.3	89.4	295	11996	1126	147	78.8
16	15	-0.01	0.9	2.85	89.8	3.29	102.9	338	11996	1233	146	78.8
16	15	-0.01	1	2.44	88.6	3.31	119.2	394	11996	1438	146	78.8

19	15	-0.01	0	3.97	40.4	3.17	30.1	96	11996	885	130	78.8
19	15	-0.01	0.1	4.85	62.9	2.91	45.0	131	11996	724	140	78.8
19	15	-0.01	0.2	4.95	81.9	2.79	59.5	166	11996	710	151	78.8
19	15	-0.01	0.3	4.95	98.3	2.71	72.9	198	11996	710	159	78.8
19	15	-0.01	0.4	4.92	113.0	2.66	85.6	227	11996	714	165	78.8
19	15	-0.01	0.5	4.87	126.6	2.62	97.6	256	11996	722	170	78.8
19	15	-0.01	0.6	4.78	139.2	2.61	109.0	284	11996	735	174	78.8
19	15	-0.01	0.7	4.66	150.8	2.62	119.6	313	11996	754	179	78.8
19	15	-0.01	0.8	4.52	161.4	2.65	129.4	343	11996	778	184	78.8
19	15	-0.01	0.9	4.36	171.0	2.7	138.2	373	11996	807	190	78.8
19	15	-0.01	1	4.20	179.3	2.76	145.8	402	11996	837	197	78.8

19	17	-0.01	0	4.42	56.4	3.11	41.7	130	11996	795	131	78.8

19	17	-0.01	0.1	4.72	72.7	2.94	52.8	155	11996	746	140	78.8
19	17	-0.01	0.2	4.85	88.0	2.83	64.1	181	11996	724	148	78.8
19	17	-0.01	0.3	4.90	102.0	2.76	75.2	207	11996	718	155	78.8
19	17	-0.01	0.4	4.89	115.1	2.71	86.0	233	11996	720	162	78.8
19	17	-0.01	0.5	4.84	127.3	2.68	96.5	258	11996	727	167	78.8
19	17	-0.01	0.6	4.76	138.9	2.66	106.8	285	11996	738	173	78.8
19	17	-0.01	0.7	4.66	149.9	2.66	117.0	312	11996	755	178	78.8
19	17	-0.01	0.8	4.53	160.3	2.68	126.9	340	11996	777	184	78.8
19	17	-0.01	0.9	4.37	170.2	2.71	136.5	370	11996	804	190	78.8
19	17	-0.01	1	4.20	179.3	2.76	145.8	402	11996	837	197	78.8
19	18	-0.01	0	4.32	68.7	3.03	53.5	162	11996	813	134	78.8
19	18	-0.01	0.1	4.53	84.2	2.9	64.7	187	11996	775	142	78.8
19	18	-0.01	0.2	4.64	98.5	2.81	75.8	213	11996	757	149	78.8
19	18	-0.01	0.3	4.68	111.5	2.75	86.3	237	11996	752	155	78.8
19	18	-0.01	0.4	4.67	123.5	2.71	96.3	261	11996	753	161	78.8
19	18	-0.01	0.5	4.63	134.5	2.69	105.8	285	11996	760	167	78.8
19	18	-0.01	0.6	4.57	144.7	2.69	114.8	309	11996	770	173	78.8
19	18	-0.01	0.7	4.49	154.3	2.69	123.3	332	11996	783	178	78.8
19	18	-0.01	0.8	4.40	163.2	2.71	131.3	355	11996	799	184	78.8
19	18	-0.01	0.9	4.30	171.5	2.73	138.8	379	11996	817	190	78.8
19	18	-0.01	1	4.20	179.3	2.76	145.8	402	11996	837	197	78.8
19	11	-0.01	0	4.54	66.0	2.99	48.2	144	11996	775	152	78.8
19	11	-0.01	0.1	4.70	76.6	2.89	55.6	161	11996	747	156	78.8
19	11	-0.01	0.2	4.81	87.4	2.81	63.5	179	11996	731	161	78.8
19	11	-0.01	0.3	4.87	98.4	2.75	71.9	198	11996	722	165	78.8
19	11	-0.01	0.4	4.88	109.4	2.71	80.7	219	11996	720	170	78.8
19	11	-0.01	0.5	4.86	120.5	2.68	89.9	241	11996	724	174	78.8
19	11	-0.01	0.6	4.80	131.9	2.67	99.7	266	11996	732	178	78.8
19	11	-0.01	0.7	4.72	143.5	2.66	110.1	293	11996	745	182	78.8
19	11	-0.01	0.8	4.59	155.4	2.67	121.2	324	11996	765	187	78.8
19	11	-0.01	0.9	4.42	167.4	2.7	133.1	359	11996	794	191	78.8
19	11	-0.01	1	4.20	179.3	2.76	145.8	402	11996	837	197	78.8
14	18	-0.01	0	4.32	68.7	3.03	53.5	162	11996	813	134	78.8
14	18	-0.01	0.1	4.34	72.7	2.96	57.6	170	11996	810	134	78.8
14	18	-0.01	0.2	4.35	76.7	2.9	62.0	180	11996	808	134	78.8
14	18	-0.01	0.3	4.35	80.7	2.84	66.6	189	11996	809	134	78.8
14	18	-0.01	0.4	4.33	84.7	2.79	71.5	199	11996	811	134	78.8
14	18	-0.01	0.5	4.30	88.7	2.74	76.7	210	11996	817	134	78.8
14	18	-0.01	0.6	4.26	92.5	2.7	82.1	222	11996	825	134	78.8
14	18	-0.01	0.7	4.20	96.1	2.67	87.9	234	11996	836	134	78.8
14	18	-0.01	0.8	4.13	99.5	2.63	94.0	248	11996	852	134	78.8
14	18	-0.01	0.9	4.03	102.5	2.61	100.5	262	11996	873	133	78.8
14	18	-0.01	1	3.91	105.1	2.59	107.4	278	11996	900	132	78.8
14	11	-0.01	0	4.54	66.0	2.99	48.2	144	11996	775	152	78.8
14	11	-0.01	0.1	4.56	69.3	2.94	51.4	151	11996	770	150	78.8
14	11	-0.01	0.2	4.58	72.8	2.88	54.9	158	11996	767	148	78.8
14	11	-0.01	0.3	4.59	76.6	2.83	58.8	166	11996	766	147	78.8
14	11	-0.01	0.4	4.58	80.5	2.78	63.2	176	11996	767	145	78.8
14	11	-0.01	0.5	4.55	84.6	2.74	68.2	187	11996	772	143	78.8
14	11	-0.01	0.6	4.51	88.9	2.69	73.8	199	11996	780	142	78.8
14	11	-0.01	0.7	4.43	93.4	2.66	80.3	213	11996	793	140	78.8
14	11	-0.01	0.8	4.32	97.8	2.63	87.8	231	11996	815	137	78.8
14	11	-0.01	0.9	4.15	101.9	2.6	96.7	252	11996	848	135	78.8
14	11	-0.01	1	3.91	105.1	2.59	107.4	278	11996	900	132	78.8
14	15	-0.01	0	3.97	40.4	3.17	30.1	96	11996	885	130	78.8
14	15	-0.01	0.1	4.34	48.7	3.01	36.4	109	11996	810	130	78.8
14	15	-0.01	0.2	4.64	56.8	2.89	43.0	124	11996	757	130	78.8
14	15	-0.01	0.3	4.70	64.5	2.8	50.0	140	11996	747	132	78.8
14	15	-0.01	0.4	4.70	71.9	2.73	57.1	156	11996	748	134	78.8
14	15	-0.01	0.5	4.66	78.9	2.68	64.6	173	11996	754	135	78.8
14	15	-0.01	0.6	4.59	85.4	2.63	72.3	191	11996	766	135	78.8
14	15	-0.01	0.7	4.49	91.5	2.6	80.5	209	11996	784	135	78.8
14	15	-0.01	0.8	4.34	97.0	2.58	89.0	230	11996	810	134	78.8
14	15	-0.01	0.9	4.15	101.6	2.58	97.9	252	11996	847	134	78.8
14	15	-0.01	1	3.91	105.1	2.59	107.4	278	11996	900	132	78.8
16	18	-0.01	0	3.33	62.8	3.72	53.5	199	11996	1056	152	78.8

16	18	-0.01	0.1	3.33	65.8	3.67	57.0	209	11996	1057	151	78.8
16	18	-0.01	0.2	3.32	69.0	3.61	60.9	220	11996	1060	150	78.8
16	18	-0.01	0.3	3.30	72.4	3.56	65.2	232	11996	1067	150	78.8
16	18	-0.01	0.4	3.26	75.8	3.51	70.1	246	11996	1078	149	78.8
16	18	-0.01	0.5	3.21	79.3	3.46	75.6	262	11996	1095	148	78.8
16	18	-0.01	0.6	3.14	82.8	3.42	81.8	280	11996	1119	148	78.8
16	18	-0.01	0.7	3.04	85.9	3.38	89.0	301	11996	1155	147	78.8
16	18	-0.01	0.8	2.91	88.5	3.34	97.4	326	11996	1209	147	78.8
16	18	-0.01	0.9	2.72	89.8	3.32	107.3	356	11996	1294	146	78.8
16	18	-0.01	1	2.45	88.6	3.31	119.2	394	11996	1438	146	78.8
16	11	-0.01	0	3.56	61.9	3.67	48.2	177	11996	987	173	78.8
16	11	-0.01	0.1	3.57	64.5	3.61	50.9	184	11996	984	170	78.8
16	11	-0.01	0.2	3.58	67.3	3.56	53.9	192	11996	983	167	78.8
16	11	-0.01	0.3	3.57	70.4	3.51	57.5	202	11996	984	165	78.8
16	11	-0.01	0.4	3.55	73.9	3.46	61.7	213	11996	990	162	78.8
16	11	-0.01	0.5	3.51	77.6	3.41	66.6	227	11996	1000	159	78.8
16	11	-0.01	0.6	3.45	81.5	3.37	72.6	245	11996	1019	156	78.8
16	11	-0.01	0.7	3.35	85.6	3.33	79.9	266	11996	1050	153	78.8
16	11	-0.01	0.8	3.19	89.5	3.3	89.3	295	11996	1103	151	78.8
16	11	-0.01	0.9	2.92	91.8	3.29	101.7	335	11996	1204	148	78.8
16	11	-0.01	1	2.45	88.6	3.31	119.2	394	11996	1438	146	78.8
16	15	-0.01	0	3.04	37.1	3.94	30.1	119	11996	1157	147	78.8
16	15	-0.01	0.1	3.17	42.8	3.82	34.7	132	11996	1109	148	78.8
16	15	-0.01	0.2	3.28	48.9	3.71	39.9	148	11996	1073	148	78.8
16	15	-0.01	0.3	3.37	55.3	3.62	45.8	166	11996	1043	148	78.8
16	15	-0.01	0.4	3.45	61.8	3.53	52.5	185	11996	1018	148	78.8
16	15	-0.01	0.5	3.49	68.4	3.46	59.9	207	11996	1006	147	78.8
16	15	-0.01	0.6	3.42	74.9	3.39	68.4	232	11996	1029	148	78.8
16	15	-0.01	0.7	3.30	81.1	3.34	78.1	261	11996	1065	147	78.8
16	15	-0.01	0.8	3.12	86.5	3.3	89.4	295	11996	1126	147	78.8
16	15	-0.01	0.9	2.85	89.8	3.29	102.9	338	11996	1233	146	78.8
16	15	-0.01	1	2.44	88.6	3.31	119.2	394	11996	1438	146	78.8
19	18	-0.01	0	2.60	42.7	5.14	36.7	189	11989	1350	155	46.99
19	18	-0.01	0.1	2.74	52.6	4.88	44.0	214	11989	1281	165	46.99
19	18	-0.01	0.2	2.82	62.0	4.69	51.4	241	11989	1248	175	46.99
19	18	-0.01	0.3	2.84	70.9	4.55	58.7	267	11989	1236	184	46.99
19	18	-0.01	0.4	2.84	79.2	4.47	65.9	294	11989	1238	193	46.99
19	18	-0.01	0.5	2.81	87.1	4.42	72.8	322	11989	1248	202	46.99
19	18	-0.01	0.6	2.78	94.5	4.39	79.6	350	11989	1265	211	46.99
19	18	-0.01	0.7	2.73	101.5	4.39	86.1	378	11989	1287	220	46.99
19	18	-0.01	0.8	2.68	108.2	4.4	92.4	407	11989	1312	229	46.99
19	18	-0.01	0.9	2.62	114.5	4.42	98.4	435	11989	1340	239	46.99
19	18	-0.01	1	2.56	120.4	4.46	104.0	464	11989	1370	249	46.99
19	11	-0.01	0	2.83	42.8	5.01	33.1	166	11989	1241	181	46.99
19	11	-0.01	0.1	2.93	49.5	4.81	37.9	182	11989	1199	187	46.99
19	11	-0.01	0.2	2.99	56.5	4.65	43.1	200	11989	1174	192	46.99
19	11	-0.01	0.3	3.02	63.7	4.53	48.7	221	11989	1162	198	46.99
19	11	-0.01	0.4	3.03	71.0	4.44	54.7	243	11989	1161	204	46.99
19	11	-0.01	0.5	3.01	78.6	4.38	61.2	268	11989	1169	211	46.99
19	11	-0.01	0.6	2.96	86.4	4.34	68.2	296	11989	1186	217	46.99
19	11	-0.01	0.7	2.90	94.5	4.33	75.9	329	11989	1212	225	46.99
19	11	-0.01	0.8	2.81	102.9	4.34	84.4	366	11989	1250	232	46.99
19	11	-0.01	0.9	2.70	111.6	4.38	93.7	411	11989	1301	240	46.99
19	11	-0.01	1	2.56	120.4	4.46	104.0	464	11989	1370	249	46.99
14	18	-0.01	0	2.60	42.7	5.14	36.7	189	11989	1350	155	46.99
14	18	-0.01	0.1	2.60	45.1	5.01	39.6	198	11989	1352	155	46.99
14	18	-0.01	0.2	2.59	47.5	4.88	42.6	208	11989	1358	156	46.99
14	18	-0.01	0.3	2.57	50.0	4.76	46.0	219	11989	1366	156	46.99
14	18	-0.01	0.4	2.55	52.5	4.65	49.5	230	11989	1379	156	46.99
14	18	-0.01	0.5	2.52	54.9	4.55	53.3	243	11989	1396	156	46.99
14	18	-0.01	0.6	2.48	57.3	4.46	57.5	256	11989	1419	156	46.99
14	18	-0.01	0.7	2.43	59.6	4.38	61.9	271	11989	1448	156	46.99
14	18	-0.01	0.8	2.36	61.7	4.3	66.8	287	11989	1487	156	46.99
14	18	-0.01	0.9	2.29	63.5	4.23	72.1	305	11989	1536	156	46.99
14	18	-0.01	1	2.19	65.0	4.17	78.0	325	11989	1601	155	46.99
14	11	-0.01	0	2.83	42.8	5.01	33.1	166	11989	1241	181	46.99

14	11	-0.01	0.1	2.83	44.8	4.9	35.3	173	11989	1241	178 46.99
14	11	-0.01	0.2	2.83	46.9	4.79	37.7	181	11989	1244	176 46.99
14	11	-0.01	0.3	2.81	49.1	4.69	40.5	190	11989	1250	173 46.99
14	11	-0.01	0.4	2.79	51.5	4.6	43.6	200	11989	1260	171 46.99
14	11	-0.01	0.5	2.75	54.0	4.5	47.1	212	11989	1277	168 46.99
14	11	-0.01	0.6	2.70	56.6	4.42	51.3	227	11989	1301	166 46.99
14	11	-0.01	0.7	2.63	59.2	4.34	56.1	244	11989	1336	163 46.99
14	11	-0.01	0.8	2.53	61.7	4.27	61.9	265	11989	1389	161 46.99
14	11	-0.01	0.9	2.39	63.9	4.21	69.1	291	11989	1469	158 46.99
14	11	-0.01	1	2.19	65.0	4.17	78.0	325	11989	1601	155 46.99
14	15	-0.01	0	2.41	24.6	5.55	20.4	113	11989	1460	149 46.99
14	15	-0.01	0.1	2.64	29.5	5.19	24.2	126	11989	1331	147 46.99
14	15	-0.01	0.2	2.79	34.4	4.92	28.5	140	11989	1258	147 46.99
14	15	-0.01	0.3	2.80	39.1	4.74	33.1	157	11989	1253	149 46.99
14	15	-0.01	0.4	2.79	43.7	4.59	38.1	175	11989	1260	151 46.99
14	15	-0.01	0.5	2.75	48.1	4.46	43.4	194	11989	1279	153 46.99
14	15	-0.01	0.6	2.69	52.4	4.36	49.1	214	11989	1308	154 46.99
14	15	-0.01	0.7	2.60	56.3	4.28	55.3	237	11989	1350	155 46.99
14	15	-0.01	0.8	2.49	59.9	4.23	62.1	263	11989	1408	155 46.99
14	15	-0.01	0.9	2.36	62.9	4.19	69.7	292	11989	1488	155 46.99
14	15	-0.01	1	2.19	65.0	4.17	78.0	325	11989	1601	155 46.99
16	18	-0.01	0	2.60	42.7	5.14	36.7	189	11989	1350	155 46.99
16	18	-0.01	0.1	2.60	44.7	5.05	39.1	198	11989	1353	154 46.99
16	18	-0.01	0.2	2.58	46.9	4.97	41.8	208	11989	1359	153 46.99
16	18	-0.01	0.3	2.56	49.2	4.89	44.9	219	11989	1371	152 46.99
16	18	-0.01	0.4	2.53	51.5	4.81	48.3	233	11989	1389	151 46.99
16	18	-0.01	0.5	2.48	53.9	4.74	52.3	248	11989	1416	150 46.99
16	18	-0.01	0.6	2.41	56.3	4.68	56.8	266	11989	1455	150 46.99
16	18	-0.01	0.7	2.32	58.4	4.63	62.2	288	11989	1513	149 46.99
16	18	-0.01	0.8	2.19	60.0	4.6	68.5	315	11989	1604	149 46.99
16	18	-0.01	0.9	2.00	60.3	4.6	76.2	350	11989	1753	149 46.99
16	18	-0.01	1	1.71	57.6	4.66	85.8	400	11989	2059	151 46.99
16	11	-0.01	0	2.83	42.8	5.01	33.1	166	11989	1241	181 46.99
16	11	-0.01	0.1	2.84	44.6	4.92	35.0	172	11989	1238	177 46.99
16	11	-0.01	0.2	2.84	46.5	4.84	37.1	180	11989	1238	174 46.99
16	11	-0.01	0.3	2.83	48.6	4.76	39.6	188	11989	1242	170 46.99
16	11	-0.01	0.4	2.81	50.9	4.69	42.5	199	11989	1251	167 46.99
16	11	-0.01	0.5	2.77	53.5	4.62	45.9	212	11989	1268	163 46.99
16	11	-0.01	0.6	2.71	56.2	4.56	50.2	229	11989	1296	159 46.99
16	11	-0.01	0.7	2.61	59.0	4.51	55.5	250	11989	1344	156 46.99
16	11	-0.01	0.8	2.46	61.5	4.48	62.5	280	11989	1427	152 46.99
16	11	-0.01	0.9	2.21	62.7	4.5	71.9	323	11989	1591	150 46.99
16	11	-0.01	1	1.71	57.6	4.66	85.8	400	11989	2059	151 46.99
16	15	-0.01	0	2.41	24.6	5.55	20.4	113	11989	1460	149 46.99
16	15	-0.01	0.1	2.52	28.4	5.33	23.3	124	11989	1392	148 46.99
16	15	-0.01	0.2	2.62	32.5	5.14	26.7	137	11989	1343	148 46.99
16	15	-0.01	0.3	2.69	36.8	4.97	30.6	152	11989	1307	147 46.99
16	15	-0.01	0.4	2.74	41.2	4.83	35.1	169	11989	1282	146 46.99
16	15	-0.01	0.5	2.75	45.7	4.71	40.2	189	11989	1279	146 46.99
16	15	-0.01	0.6	2.67	50.2	4.63	46.1	213	11989	1315	146 46.99
16	15	-0.01	0.7	2.56	54.5	4.56	53.1	242	11989	1375	147 46.99
16	15	-0.01	0.8	2.38	58.2	4.52	61.6	279	11989	1473	147 46.99
16	15	-0.01	0.9	2.13	60.4	4.54	72.2	328	11989	1651	148 46.99
16	15	-0.01	1	1.71	57.6	4.66	85.8	400	11989	2059	151 46.99
19	15	-0.01	0	2.41	24.6	5.55	20.4	113	11989	1460	149 46.99
19	15	-0.01	0.1	3.00	38.2	4.92	29.2	144	11989	1172	157 46.99
19	15	-0.01	0.2	3.09	50.3	4.62	38.4	177	11989	1136	171 46.99
19	15	-0.01	0.3	3.09	61.0	4.45	47.4	211	11989	1137	182 46.99
19	15	-0.01	0.4	3.05	71.0	4.34	56.2	244	11989	1152	192 46.99
19	15	-0.01	0.5	2.99	80.6	4.28	65.0	278	11989	1174	202 46.99
19	15	-0.01	0.6	2.92	89.8	4.25	73.8	314	11989	1204	211 46.99
19	15	-0.01	0.7	2.83	98.6	4.26	82.3	351	11989	1239	220 46.99
19	15	-0.01	0.8	2.74	106.7	4.31	90.4	389	11989	1280	229 46.99
19	15	-0.01	0.9	2.65	114.1	4.37	97.8	427	11989	1324	238 46.99
19	15	-0.01	1	2.56	120.4	4.46	104.0	464	11989	1370	249 46.99
19	17	-0.01	0	2.70	35.0	5.34	28.3	151	11989	1303	151 46.99

19	17	-0.01	0.1	2.89	45.1	4.99	35.2	176	11989	1216	162	46.99
19	17	-0.01	0.2	2.98	55.0	4.74	42.6	202	11989	1178	172	46.99
19	17	-0.01	0.3	3.01	64.3	4.58	50.0	229	11989	1166	182	46.99
19	17	-0.01	0.4	3.00	73.2	4.47	57.6	257	11989	1170	191	46.99
19	17	-0.01	0.5	2.97	81.8	4.4	65.2	287	11989	1184	201	46.99
19	17	-0.01	0.6	2.91	90.1	4.36	72.9	318	11989	1207	210	46.99
19	17	-0.01	0.7	2.84	98.1	4.35	80.6	351	11989	1237	219	46.99
19	17	-0.01	0.8	2.76	105.9	4.37	88.5	386	11989	1274	229	46.99
19	17	-0.01	0.9	2.66	113.4	4.4	96.3	424	11989	1319	239	46.99
19	17	-0.01	1	2.56	120.4	4.46	104.0	464	11989	1370	249	46.99
19	18	-0.01	0	1.45	19.0	11.72	18.8	220	11989	2416	184	17.01
19	18	-0.01	0.1	1.56	24.0	10.94	22.5	246	11989	2255	198	17.01
19	18	-0.01	0.2	1.62	29.0	10.34	26.5	274	11989	2175	211	17.01
19	18	-0.01	0.3	1.64	33.9	9.9	30.6	303	11989	2138	224	17.01
19	18	-0.01	0.4	1.65	38.6	9.59	34.7	333	11989	2130	238	17.01
19	18	-0.01	0.5	1.64	43.0	9.38	38.8	364	11989	2140	251	17.01
19	18	-0.01	0.6	1.62	47.3	9.24	42.8	396	11989	2163	265	17.01
19	18	-0.01	0.7	1.60	51.4	9.17	46.7	428	11989	2195	278	17.01
19	18	-0.01	0.8	1.57	55.3	9.14	50.5	461	11989	2234	292	17.01
19	18	-0.01	0.9	1.54	58.9	9.14	54.1	495	11989	2277	307	17.01
19	18	-0.01	1	1.51	62.4	9.18	57.5	528	11989	2325	321	17.01
19	11	-0.01	0	1.70	20.7	10.96	17.1	187	11989	2071	221	17.01
19	11	-0.01	0.1	1.75	24.0	10.48	19.5	204	11989	2005	229	17.01
19	11	-0.01	0.2	1.79	27.6	10.06	22.2	224	11989	1965	237	17.01
19	11	-0.01	0.3	1.81	31.4	9.72	25.3	246	11989	1946	246	17.01
19	11	-0.01	0.4	1.81	35.4	9.45	28.6	270	11989	1944	255	17.01
19	11	-0.01	0.5	1.79	39.5	9.24	32.3	298	11989	1959	264	17.01
19	11	-0.01	0.6	1.76	43.8	9.11	36.3	330	11989	1991	274	17.01
19	11	-0.01	0.7	1.72	48.2	9.03	40.7	368	11989	2039	285	17.01
19	11	-0.01	0.8	1.67	52.9	9.02	45.7	412	11989	2108	296	17.01
19	11	-0.01	0.9	1.60	57.6	9.06	51.2	465	11989	2201	309	17.01
19	11	-0.01	1	1.51	62.4	9.18	57.5	528	11989	2325	321	17.01
14	18	-0.01	0	1.45	19.0	11.72	18.8	220	11989	2416	184	17.01
14	18	-0.01	0.1	1.44	20.1	11.36	20.4	231	11989	2444	185	17.01
14	18	-0.01	0.2	1.42	21.2	11.03	22.1	243	11989	2478	186	17.01
14	18	-0.01	0.3	1.39	22.3	10.72	23.9	257	11989	2521	186	17.01
14	18	-0.01	0.4	1.36	23.3	10.42	26.0	271	11989	2576	187	17.01
14	18	-0.01	0.5	1.33	24.3	10.15	28.3	287	11989	2645	187	17.01
14	18	-0.01	0.6	1.28	25.3	9.91	30.8	305	11989	2735	188	17.01
14	18	-0.01	0.7	1.23	26.1	9.7	33.5	325	11989	2856	189	17.01
14	18	-0.01	0.8	1.16	26.5	9.53	36.6	349	11989	3027	190	17.01
14	18	-0.01	0.9	1.06	26.4	9.45	40.2	380	11989	3302	191	17.01
19	17	-0.01	0	1.54	15.6	12.3	14.2	175	11989	2279	178	17.01
19	17	-0.01	0.1	1.67	20.5	11.34	17.6	199	11989	2103	193	17.01
19	17	-0.01	0.2	1.74	25.6	10.58	21.5	227	11989	2021	207	17.01
19	17	-0.01	0.3	1.77	30.6	10.01	25.6	256	11989	1988	221	17.01
19	17	-0.01	0.4	1.77	35.6	9.63	29.8	287	11989	1987	235	17.01
19	17	-0.01	0.5	1.75	40.4	9.37	34.2	321	11989	2008	249	17.01
19	17	-0.01	0.6	1.72	45.0	9.21	38.7	356	11989	2046	263	17.01
19	17	-0.01	0.7	1.67	49.6	9.12	43.3	395	11989	2098	278	17.01
19	17	-0.01	0.8	1.63	54.1	9.1	48.0	437	11989	2162	292	17.01
19	17	-0.01	0.9	1.57	58.3	9.12	52.8	481	11989	2238	307	17.01
19	17	-0.01	1	1.51	62.4	9.18	57.5	528	11989	2325	321	17.01
19	15	-0.01	0	1.40	10.6	13.04	10.1	132	11989	2517	170	17.01
19	15	-0.01	0.1	1.73	17.1	11.29	14.3	161	11989	2035	184	17.01
19	15	-0.01	0.2	1.81	23.3	10.23	19.2	196	11989	1940	202	17.01
19	15	-0.01	0.3	1.83	29.3	9.58	24.3	232	11989	1924	219	17.01
19	15	-0.01	0.4	1.81	34.8	9.21	29.3	270	11989	1946	234	17.01
19	15	-0.01	0.5	1.77	40.1	9	34.4	309	11989	1989	249	17.01
19	15	-0.01	0.6	1.72	45.2	8.9	39.4	351	11989	2045	264	17.01
19	15	-0.01	0.7	1.67	50.1	8.89	44.5	395	11989	2109	278	17.01
19	15	-0.01	0.8	1.61	54.7	8.92	49.3	440	11989	2178	292	17.01
19	15	-0.01	0.9	1.56	58.9	9.02	53.8	485	11989	2249	306	17.01
19	15	-0.01	1	1.51	62.4	9.18	57.5	528	11989	2325	321	17.01
14	11	-0.01	0	1.70	20.7	10.96	17.1	187	11989	2071	221	17.01
14	11	-0.01	0.1	1.68	21.6	10.69	18.3	195	11989	2087	217	17.01

14	11	-0.01	0.2	1.67	22.5	10.44	19.6	204	11989	2110	214	17.01
14	11	-0.01	0.3	1.64	23.5	10.19	21.1	215	11989	2140	210	17.01
14	11	-0.01	0.4	1.61	24.6	9.95	22.8	227	11989	2181	206	17.01
14	11	-0.01	0.5	1.57	25.7	9.72	24.9	242	11989	2236	203	17.01
14	11	-0.01	0.6	1.52	26.8	9.51	27.3	259	11989	2314	200	17.01
14	11	-0.01	0.7	1.45	27.7	9.32	30.2	281	11989	2427	196	17.01
14	11	-0.01	0.8	1.35	28.4	9.17	33.7	309	11989	2601	193	17.01
14	11	-0.01	0.9	1.21	28.4	9.12	38.3	349	11989	2914	191	17.01
14	15	-0.01	0	1.40	10.6	13.04	10.1	132	11989	2517	170	17.01
14	15	-0.01	0.1	1.53	12.8	12.05	12.0	145	11989	2303	168	17.01
14	15	-0.01	0.2	1.54	15.0	11.41	14.2	162	11989	2275	172	17.01
14	15	-0.01	0.3	1.54	17.1	10.87	16.6	181	11989	2278	175	17.01
14	15	-0.01	0.4	1.52	19.3	10.4	19.3	201	11989	2308	178	17.01
14	15	-0.01	0.5	1.49	21.4	10.02	22.3	224	11989	2365	180	17.01
14	15	-0.01	0.6	1.43	23.3	9.71	25.6	249	11989	2453	182	17.01
14	15	-0.01	0.7	1.36	25.0	9.47	29.4	278	11989	2581	185	17.01
14	15	-0.01	0.8	1.27	26.3	9.31	33.6	313	11989	2775	187	17.01
14	15	-0.01	0.9	1.14	26.8	9.27	38.5	357	11989	3096	189	17.01

APPENDIX #3

This appendix contains a listing of the short output files for all computer runs conducted for ternary mixtures. The refrigerants are specified by code numbers according to the following table.

R22	6
R142b	10
R152a	11
R143a	14
R124	15
R125	16
R134	17
R134a	18
R32	19

IR1	IR2	IR3	F01	F02	F03	X1	X2	X3	COP	Vol.Flow ft3	PR	PSUC psia	PDIS psia	CAP BTU/hr	WORK watt	Tair F
19	11	15	-0.01	-0.01	-0.01	0	1	0	3.56	40.8	3.7	48.2	177	11996	987	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.9	0.1	3.57	41.9	3.7	47.0	172	11996	984	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.8	0.2	3.58	43.1	3.7	45.7	168	11996	982	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.7	0.3	3.58	44.5	3.7	44.3	163	11996	981	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.6	0.4	3.58	46.1	3.7	42.8	158	11996	981	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.5	0.5	3.58	48.1	3.7	41.2	152	11996	983	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.4	0.6	3.56	50.4	3.7	39.4	146	11996	986	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.3	0.7	3.54	53.3	3.7	37.4	140	11996	992	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.2	0.8	3.51	56.9	3.8	35.2	133	11996	1001	78.8
19	11	15	-0.01	-0.01	-0.01	0	0.1	0.9	3.39	61.7	3.8	32.8	126	11996	1036	78.8
19	11	15	-0.01	-0.01	-0.01	0	0	1	3.04	68.2	3.9	30.1	119	11996	1157	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0	0.9	3.72	44.3	3.6	44.0	160	11996	944	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.1	0.8	3.74	42.5	3.6	45.9	165	11996	939	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.2	0.7	3.75	41.0	3.6	47.5	169	11996	937	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.3	0.6	3.75	39.8	3.5	49.0	173	11996	937	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.4	0.5	3.75	38.8	3.5	50.3	178	11996	938	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.5	0.4	3.74	37.9	3.5	51.5	182	11996	941	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.6	0.3	3.72	37.1	3.5	52.5	186	11996	944	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.7	0.2	3.71	36.4	3.5	53.5	189	11996	948	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.8	0.1	3.69	35.8	3.5	54.4	193	11996	953	78.8
19	11	15	-0.01	-0.01	-0.01	0.1	0.9	0	3.67	35.3	3.6	55.3	196	11996	957	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.8	0	3.74	31.0	3.5	63.0	218	11996	940	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.7	0.1	3.76	31.2	3.4	62.6	215	11996	934	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.6	0.2	3.78	31.4	3.4	62.1	213	11996	929	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.5	0.3	3.80	31.7	3.4	61.6	211	11996	925	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.4	0.4	3.82	32.0	3.4	61.1	209	11996	921	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.3	0.5	3.83	32.3	3.4	60.5	206	11996	919	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.2	0.6	3.83	32.7	3.4	59.8	204	11996	918	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0.1	0.7	3.83	33.2	3.4	59.1	203	11996	918	78.8
19	11	15	-0.01	-0.01	-0.01	0.2	0	0.8	3.81	33.7	3.5	58.3	201	11996	922	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0	0.7	3.82	27.9	3.3	71.8	240	11996	921	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.1	0.6	3.83	27.8	3.3	71.7	238	11996	917	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.2	0.5	3.84	27.7	3.3	71.6	238	11996	916	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.3	0.4	3.84	27.7	3.3	71.5	238	11996	916	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.4	0.3	3.83	27.6	3.3	71.4	238	11996	919	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.5	0.2	3.81	27.6	3.4	71.3	239	11996	922	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.6	0.1	3.79	27.6	3.4	71.3	240	11996	927	78.8
19	11	15	-0.01	-0.01	-0.01	0.3	0.7	0	3.77	27.5	3.4	71.2	241	11996	932	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.6	0	3.78	24.7	3.3	80.0	266	11996	931	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.5	0.1	3.79	24.6	3.3	80.5	266	11996	927	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.4	0.2	3.80	24.5	3.3	81.1	267	11996	924	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.3	0.3	3.81	24.4	3.3	81.9	268	11996	922	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.2	0.4	3.81	24.3	3.3	82.7	270	11996	922	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0.1	0.5	3.81	24.2	3.3	83.6	272	11996	923	78.8
19	11	15	-0.01	-0.01	-0.01	0.4	0	0.6	3.79	24.1	3.3	84.6	275	11996	928	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0	0.5	3.74	21.5	3.2	96.8	310	11996	941	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0.1	0.4	3.76	21.7	3.2	94.9	305	11996	936	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0.2	0.3	3.77	21.9	3.2	93.2	301	11996	934	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0.3	0.2	3.77	22.1	3.2	91.7	298	11996	933	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0.4	0.1	3.76	22.3	3.3	90.4	295	11996	934	78.8
19	11	15	-0.01	-0.01	-0.01	0.5	0.5	0	3.75	22.4	3.3	89.2	293	11996	937	78.8
19	11	15	-0.01	-0.01	-0.01	0.6	0.4	0	3.70	20.5	3.3	99.0	323	11996	949	78.8
19	11	15	-0.01	-0.01	-0.01	0.6	0.3	0.1	3.71	20.3	3.2	100.9	327	11996	949	78.8
19	11	15	-0.01	-0.01	-0.01	0.6	0.2	0.2	3.70	20.0	3.2	103.1	332	11996	950	78.8
19	11	15	-0.01	-0.01	-0.01	0.6	0.1	0.3	3.69	19.8	3.2	105.5	338	11996	954	78.8
19	11	15	-0.01	-0.01	-0.01	0.6	0	0.4	3.66	19.5	3.2	108.3	345	11996	960	78.8
19	11	15	-0.01	-0.01	-0.01	0.7	0	0.3	3.56	18.0	3.2	119.1	381	11996	986	78.8
19	11	15	-0.01	-0.01	-0.01	0.7	0.1	0.2	3.60	18.3	3.2	115.5	371	11996	977	78.8
19	11	15	-0.01	-0.01	-0.01	0.7	0.2	0.1	3.62	18.6	3.2	112.3	363	11996	971	78.8
19	11	15	-0.01	-0.01	-0.01	0.7	0.3	0	3.63	18.8	3.2	109.5	356	11996	968	78.8
19	11	15	-0.01	-0.01	-0.01	0.8	0.2	0	3.53	17.4	3.3	120.8	393	11996	996	78.8
19	11	15	-0.01	-0.01	-0.01	0.8	0.1	0.1	3.50	17.1	3.2	124.6	404	11996	1005	78.8
19	11	15	-0.01	-0.01	-0.01	0.8	0	0.2	3.45	16.8	3.2	129.1	417	11996	1018	78.8
19	11	15	-0.01	-0.01	-0.01	0.9	0	0.1	3.34	15.9	3.3	138.0	453	11996	1053	78.8
19	11	15	-0.01	-0.01	-0.01	0.9	0.1	0	3.40	16.2	3.3	132.8	437	11996	1035	78.8
19	11	15	-0.01	-0.01	-0.01	1	0	0	3.23	15.1	3.3	145.8	488	11996	1090	78.8
19	11	17	-0.01	-0.01	-0.01	0	1	0	3.56	40.8	3.7	48.2	177	11996	987	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.9	0.1	3.56	41.5	3.7	47.4	175	11996	987	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.8	0.2	3.56	42.2	3.7	46.6	172	11996	988	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.7	0.3	3.55	42.9	3.7	45.8	170	11996	989	78.8

19	11	17	-0.01	-0.01	-0.01	0	0.6	0.4	3.54	43.7	3.7	45.0	168	11996	992	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.5	0.5	3.53	44.5	3.8	44.3	166	11996	995	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.4	0.6	3.52	45.3	3.8	43.6	165	11996	998	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.3	0.7	3.50	46.2	3.8	43.0	163	11996	1003	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.2	0.8	3.49	47.0	3.8	42.5	162	11996	1008	78.8
19	11	17	-0.01	-0.01	-0.01	0	0.1	0.9	3.46	47.8	3.8	42.0	161	11996	1015	78.8
19	11	17	-0.01	-0.01	-0.01	0	0	1	3.44	48.6	3.8	41.7	160	11996	1023	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0	0.9	3.64	37.9	3.6	52.3	191	11996	967	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.1	0.8	3.65	37.7	3.6	52.2	190	11996	962	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.2	0.7	3.67	37.5	3.6	52.3	189	11996	959	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.3	0.6	3.68	37.2	3.6	52.5	190	11996	956	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.4	0.5	3.68	36.9	3.6	52.8	190	11996	955	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.5	0.4	3.68	36.6	3.6	53.2	191	11996	954	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.6	0.3	3.68	36.3	3.6	53.7	192	11996	954	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.7	0.2	3.68	36.0	3.6	54.2	193	11996	955	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.8	0.1	3.68	35.6	3.6	54.7	195	11996	956	78.8
19	11	17	-0.01	-0.01	-0.01	0.1	0.9	0	3.67	35.3	3.6	55.3	196	11996	957	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.8	0	3.74	31.0	3.5	63.0	218	11996	940	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.7	0.1	3.75	31.1	3.5	62.7	217	11996	938	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.6	0.2	3.76	31.2	3.5	62.5	217	11996	936	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.5	0.3	3.76	31.3	3.5	62.3	216	11996	935	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.4	0.4	3.76	31.3	3.5	62.2	216	11996	934	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.3	0.5	3.76	31.4	3.5	62.2	217	11996	934	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.2	0.6	3.76	31.4	3.5	62.4	218	11996	935	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0.1	0.7	3.75	31.3	3.5	62.7	219	11996	938	78.8
19	11	17	-0.01	-0.01	-0.01	0.2	0	0.8	3.73	31.2	3.5	63.3	222	11996	941	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0	0.7	3.77	26.8	3.4	74.3	252	11996	933	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.1	0.6	3.78	27.0	3.4	73.3	249	11996	930	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.2	0.5	3.79	27.2	3.4	72.5	246	11996	928	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.3	0.4	3.79	27.3	3.4	72.0	244	11996	927	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.4	0.3	3.79	27.4	3.4	71.6	243	11996	927	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.5	0.2	3.79	27.5	3.4	71.4	242	11996	928	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.6	0.1	3.78	27.5	3.4	71.2	241	11996	929	78.8
19	11	17	-0.01	-0.01	-0.01	0.3	0.7	0	3.77	27.5	3.4	71.2	241	11996	932	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.6	0	3.78	24.7	3.3	80.0	266	11996	931	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.5	0.1	3.78	24.6	3.3	80.3	267	11996	929	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.4	0.2	3.79	24.5	3.3	80.9	269	11996	928	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.3	0.3	3.79	24.3	3.3	81.6	271	11996	928	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.2	0.4	3.78	24.2	3.3	82.5	274	11996	929	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0.1	0.5	3.77	24.0	3.3	83.6	278	11996	932	78.8
19	11	17	-0.01	-0.01	-0.01	0.4	0	0.6	3.76	23.7	3.3	85.1	283	11996	936	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0	0.5	3.72	21.4	3.3	95.7	314	11996	946	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0.1	0.4	3.74	21.6	3.3	93.8	308	11996	941	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0.2	0.3	3.75	21.9	3.3	92.2	303	11996	938	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0.3	0.2	3.76	22.1	3.3	91.0	299	11996	936	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0.4	0.1	3.76	22.3	3.3	90.0	296	11996	936	78.8
19	11	17	-0.01	-0.01	-0.01	0.5	0.5	0	3.75	22.4	3.3	89.2	293	11996	937	78.8
19	11	17	-0.01	-0.01	-0.01	0.6	0.4	0	3.70	20.5	3.3	99.0	323	11996	949	78.8
19	11	17	-0.01	-0.01	-0.01	0.6	0.3	0.1	3.70	20.3	3.3	100.3	327	11996	949	78.8
19	11	17	-0.01	-0.01	-0.01	0.6	0.2	0.2	3.69	20.1	3.3	101.9	332	11996	952	78.8
19	11	17	-0.01	-0.01	-0.01	0.6	0.1	0.3	3.68	19.8	3.3	103.8	338	11996	956	78.8
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19	11	17	-0.01	-0.01	-0.01	0.7	0	0.3	3.57	18.1	3.3	116.4	379	11996	985	78.8
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19	11	17	-0.01	-0.01	-0.01	0.8	0.1	0.1	3.51	17.2	3.3	123.4	402	11996	1003	78.8
19	11	17	-0.01	-0.01	-0.01	0.8	0	0.2	3.47	16.9	3.3	126.5	414	11996	1013	78.8
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19	11	17	-0.01	-0.01	-0.01	1	0	0	3.23	15.1	3.3	145.8	488	11996	1090	78.8
19	11	18	-0.01	-0.01	-0.01	0	1	0	3.56	40.8	3.7	48.2	177	11996	987	78.8
19	11	18	-0.01	-0.01	-0.01	0	0.9	0.1	3.55	40.9	3.7	48.2	177	11996	990	78.8
19	11	18	-0.01	-0.01	-0.01	0	0.8	0.2	3.54	41.0	3.7	48.3	178	11996	993	78.8
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19	11	18	-0.01	-0.01	-0.01	0	0.4	0.6	3.47	41.1	3.7	49.6	184	11996	1013	78.8
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19	11	18	-0.01	-0.01	-0.01	0	0.2	0.8	3.42	40.8	3.7	51.0	190	11996	1029	78.8
19	11	18	-0.01	-0.01	-0.01	0	0.1	0.9	3.38	40.5	3.7	52.1	194	11996	1041	78.8

19	11	18	-0.01	-0.01	-0.01	0	0	1	3.33	40.2	3.7	53.5	199	11996	1056	78.8
19	11	18	-0.01	-0.01	-0.01	0.1	0	0.9	3.47	32.9	3.6	64.3	230	11996	1012	78.8
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19	11	18	-0.01	-0.01	-0.01	0.1	0.2	0.7	3.56	33.7	3.6	60.6	216	11996	987	78.8
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19	11	18	-0.01	-0.01	-0.01	0.1	0.4	0.5	3.61	34.4	3.6	58.3	208	11996	973	78.8
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19	11	18	-0.01	-0.01	-0.01	0.2	0.6	0.2	3.72	30.5	3.5	64.7	224	11996	944	78.8
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19	11	18	-0.01	-0.01	-0.01	0.2	0.3	0.5	3.67	29.4	3.5	68.5	237	11996	958	78.8
19	11	18	-0.01	-0.01	-0.01	0.2	0.2	0.6	3.64	29.0	3.5	70.3	243	11996	965	78.8
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19	11	18	-0.01	-0.01	-0.01	0.2	0	0.8	3.55	28.0	3.5	75.1	260	11996	990	78.8
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19	11	18	-0.01	-0.01	-0.01	0.3	0.1	0.6	3.63	25.2	3.4	82.3	278	11996	968	78.8
19	11	18	-0.01	-0.01	-0.01	0.3	0.2	0.5	3.68	25.6	3.4	79.6	269	11996	956	78.8
19	11	18	-0.01	-0.01	-0.01	0.3	0.3	0.4	3.71	26.1	3.4	77.4	261	11996	948	78.8
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19	11	18	-0.01	-0.01	-0.01	0.3	0.5	0.2	3.75	26.9	3.4	73.8	250	11996	938	78.8
19	11	18	-0.01	-0.01	-0.01	0.3	0.6	0.1	3.76	27.2	3.4	72.4	245	11996	934	78.8
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19	11	18	-0.01	-0.01	-0.01	0.4	0.5	0.1	3.76	24.4	3.3	81.7	272	11996	935	78.8
19	11	18	-0.01	-0.01	-0.01	0.4	0.4	0.2	3.74	24.0	3.3	83.6	278	11996	940	78.8
19	11	18	-0.01	-0.01	-0.01	0.4	0.3	0.3	3.71	23.6	3.3	85.9	286	11996	946	78.8
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19	11	18	-0.01	-0.01	-0.01	0.5	0.1	0.4	3.61	20.8	3.3	100.8	332	11996	974	78.8
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19	11	18	-0.01	-0.01	-0.01	0.5	0.3	0.2	3.70	21.6	3.3	94.2	309	11996	950	78.8
19	11	18	-0.01	-0.01	-0.01	0.5	0.4	0.1	3.73	22.1	3.3	91.5	301	11996	942	78.8
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19	11	18	-0.01	-0.01	-0.01	0.7	0	0.3	3.43	17.7	3.3	122.8	404	11996	1024	78.8
19	11	18	-0.01	-0.01	-0.01	0.7	0.1	0.2	3.52	18.1	3.3	117.7	385	11996	999	78.8
19	11	18	-0.01	-0.01	-0.01	0.7	0.2	0.1	3.58	18.4	3.3	113.3	369	11996	981	78.8
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19	11	18	-0.01	-0.01	-0.01	0.8	0.2	0	3.53	17.4	3.3	120.8	393	11996	996	78.8
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19	11	18	-0.01	-0.01	-0.01	0.8	0	0.2	3.37	16.7	3.3	131.0	432	11996	1044	78.8
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19	11	18	-0.01	-0.01	-0.01	0.9	0.1	0	3.40	16.2	3.3	132.8	437	11996	1035	78.8
19	11	18	-0.01	-0.01	-0.01	1	0	0	3.23	15.1	3.3	145.8	488	11996	1090	78.8

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