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L. J. M. Kuijpers
Philips Research Laboratories

J. A. de Wit
Philips Research Laboratories

A. A. J. Benschop
Philips Research Laboratories

M. J. P. Janssen
Philips Research Laboratories

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L.J.M. Kuijpers
Member, IIR, Member, ASHRAE

J.A. de Wit

A.A.J. Benschop

M.J.P. Janssen

PHILIPS Research Laboratories
5600 JA Eindhoven
the Netherlands

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L.J.M. Kuijpers, J.A. de Wit, A.A.J. Benschop, M.J.P. Janssen
PHILIPS Research Laboratories, PO Box 80 000, Eindhoven (NL)

ABSTRACT

In the refrigeration sector domestic appliances form one of the areas most centered on when CFC substitutes are discussed. HFC substitutes are acceptable from an environmental point of view; however, lubricants for these refrigerants are difficult to develop. Moreover, there is still some uncertainty as to the energy efficiency of HFC-134a. A ternary blend, consisting of the HCFC refrigerants 22 and 124, and HFC-152a, has been propagated by one refrigerant manufacturer as an alternative refrigerant for CFC-12. The lubricant to be applied should not yield major problems. The energy efficiency should be equal or slightly better compared to CFC-12; this aspect has already been confirmed by first publications.
In this study an experimental verification of the behaviour of the blend is performed on a series of upright freezers of the static type. Each of these freezers is equipped with a capillary tube of a different capacity. One composition of the blend has been investigated: one that is determined to yield the highest COP, by the use of a steady-state cycle program. The main conclusion to be drawn is that a comparable energy consumption can be observed for both CFC-12 and the ternary blend for optimum capillary tube capacity.

Nomenclature

p	pressure	(N/m²)	subscripts	
P	power	(W)	c	condensation
Q	capacity	(W)	cool	cooling, refrigeration
T	temperature	(K)	comp	compressor
t	time	(s)	e	evaporation

1. INTRODUCTION

The refrigerant normally considered as the future substitute for CFC-12 in domestic equipment is HFC-134a. In recent years, first indications have been that there would be a serious energy penalty in the application of HFC-134a in the order of 5-15%. With an increasing number of efforts to optimize components, especially compressors, it was shown that this decrease in efficiency could be kept moderate; most recent data are even more favourable. Calorimetric and appliance tests have provided data which are only slightly worse -sometimes even better- when comparing HFC-134a and CFC-12 /1, 2, 3/; this is already reviewed in the UNEP Technical Options Report Refrigeration, edited July 1989 /4/. However, it must be stated that favourable results have been obtained using PAG lubricants, which have so far not proven to be a reliable choice in the operation of hermetic stationary equipment. Further lubricant investigations will require extra efforts and may lead to remaining uncertainty in the near future.

The application of a flammable refrigerant with good thermodynamic properties, such as HFC-152a, is still being discussed in literature and by refrigerator manufacturers.
Advantages in energy efficiency in the use of HFC-152a have been reported by several authors /5, 6, 7/; these advantages are in the order of 3 to 10%. Although both refrigerants, HFC-134a and HFC-152a, have a zero ozone depletion potential -ODP-, the residual greenhouse warming potential is in favour of HFC-152a (0.02 compared to 0.34 /8/). Furthermore, the application of HFC-152a in combination with certain known types of lubricant -above 30 C- seems to be a smaller problem. However, the flammability aspect together with the liability of refrigerator manufacturers has not led to a breakthrough in the application of HFC-152a so far.

In order to overcome difficulties as stated above, a mixture, consisting of three chemicals, HCFC-22, -124 and HFC-152a, has been proposed by a chemical manufacturer /9/. Due to the

presence of HCFCs in this mixture, the use of the known reliable alkylbenzene lubricant would be possible. Moreover, since the percentage of HFC-152a applied in this mixture is relatively low (in the order of 20 to 30%) the flammability problem does not have to be addressed.
Without the redesign of components, the application of a certain mixture composition was stated to yield an energy efficiency comparable to CFC-12 /9/.
This mixture or blend would be an ideal candidate as a retrofit refrigerant in existing automotive airconditioning applications. Although the availability of the new substitute HCFC-124 is still uncertain, the latter application may guarantee wide-scale availability in the near future. Next to the use in the automotive sector, application of the blend should certainly be considered in other sectors. The most logical one is the domestic refrigeration sector, where reliability of the compressor operation and energy efficiency -with energy standards becoming more severe- are two very important aspects.

In section 2 a short summary is given of measurement results obtained elsewhere with the three component blend. Sections 3 presents some thermodynamic calculations. Section 4 presents the results of calorimeter measurements, sections 5 and 6 present the results of the appliance measurements performed. Finally some concluding remarks are given.

2. THREE COMPONENT MIXTURES

For use as a substitute -with "drop-in" characteristics- in existing refrigeration installations, one chemical manufacturer proposed two types of blends in the beginning of 1989 /9/. One blend was based on HCFC-22, HFC-152a and CFC-114 (resulting ODP of the blend 0.3). This blend could be used until the other blend, based on HCFC-124 (instead of CFC-114), would be commercially available.
Tests have been reported with the CFC-114 blend, where more or less equal energy consumption compared to CFC-12 could be concluded /10, 11/.

As a replacement refrigerant in domestic equipment, a 50% HCFC-22, 30% HCFC-124 blend should be used in order not to lose too much refrigeration capacity, according to the manufacturer (the resulting ODP of this blend then equals 0.03). Tests have been reported /12/ where the blend was measured on a calorimeter, yielding more or less equal refrigeration capacity and a comparable COP in the standard rating point (-1% compared to CFC-12). In a reviewing presentation /13/ it was mentioned that, above the evaporation temperature of -18 C, the efficiency of this blend gets better than that of CFC-12. In the same presentation /13/ the efficiency of the blend, containing a lower percentage of HCFC-22 (36/40/24% HCFC-22/124/ HFC 152a), was mentioned to be slightly better.
A more severe slope of energy efficiency or COP versus evaporation temperature could be observed in case of both compositions of the blend, compared to CFC-12. In the references above /12, 13/ it was stated that compressors designed for CFC-12 were used, however, no remarks can be found whether the more severe slope of the blend efficiency is due to the design parameters of the compressor and its electric motor, or due to thermodynamical effects.
First appliance tests (refrigerator-freezer combination) in which the HCFC-124 version of the blend was used, were reported by ORNL /14/. Also here marginal losses in energy consumption were reported compared to CFC-12. In this case the refrigeration circuit was not adapted.
In this contribution appliance tests are described using one composition of the blend where particularly the influence of the capillary tubing is being investigated. In selecting the mixture considered in this study, the efficiency aspect and not a possible flammability is seen as the most important criterion.

3. CALCULATIONS

Using a steady state program, obtained from the chemical manufacturer /15/, a number of cycle calculations are made. This for application of CFC-12, HFC-152a and a certain number of different compositions of the blend. In these calculations no superheating or subcooling is assumed. Results are given in Table 1. for two typical evaporation and condensation temperatures (-35/35 C and -30/45 C) as occurring in appliance measurements. In case of application of the blend, there is a temperature glide of 3-7 K both in the condenser and the evaporator; here, the averaged temperatures are taken as the reference evaporation and condensation temperature.

The COP is defined as:

$$COP = \frac{Q_{cool}}{P_{comp}} \quad (1)$$

Condensation/ evaporation temperatures 35/ -35 C

Refrigerant	p_c (MPa)	p_e (MPa)	pressure ratio	temp.glide evap.(K)	capacity (rel.units)	COP
CFC-12	0.847	0.079	10.78	0.00	1.00	2.43
HFC-152a	0.785	0.064	12.22	0.00	0.98	2.60
HCFC-22/HCFC-124/HFC-152a three component blend						
50% - 30% - 20%	0.900	0.073	12.32	4.28	1.07	2.53
36% - 40% - 24%	0.812	0.064	12.78	4.00	0.94	2.54
28% - 32% - 40%	0.786	0.061	12.81	2.39	0.92	2.56
20% - 22% - 58%	0.773	0.060	12.89	1.33	0.91	2.55

Condensation/ evaporation temperatures 45/ -30 C

Refrigerant	p_c (MPa)	p_e (MPa)	pressure ratio	temp.glide evap.(K)	capacity (rel.units)	COP
CFC-12	1.085	0.100	10.77	0.00	1.00	2.21
HFC-152a	1.026	0.083	12.42	0.00	1.00	2.41
HCFC-22/HCFC-124/HFC-152a three component blend						
50% - 30% - 20%	1.169	0.092	12.77	4.06	1.06	2.30
36% - 40% - 24%	1.060	0.080	13.20	3.72	0.94	2.31
28% - 32% - 40%	1.020	0.078	13.16	2.28	0.92	2.34
20% - 22% - 58%	1.007	0.077	13.04	1.28	0.93	2.36

Table 1. Steady state cycle calculations: Calculational results of CFC-12, HFC-152a and different blend compositions concerning refrigeration capacity and COP, using a steady state cycle program (no superheat and subcooling assumed)

The COP for HFC-152a (applied as a pure fluid) is about 8% higher compared to CFC-12. This figure is also confirmed by calculations using the CYCLE-11 program of NIST /16/ where superheat after the evaporator and the use of an intermediate heat exchanger is assumed /5/.
The refrigeration capacities given are relative to the one of CFC-12. In case of HFC-152a there is no direct loss in capacity, however, due to the higher pressure ratios there is a 10% lower mass flow caused by compressor characteristics.
For different compositions of the blend, an average increase in COP can be observed which is roughly 6%. For a composition of 50% HCFC-22 and 30% HCFC-124 the refrigeration capacity increases, which effect, combined with a lower compressor mass flow due to the higher pressure ratio, will roughly result in an equal capacity. This is the reason why this composition of the blend is considered as the "drop-in" for domestic appliances. However, the COP increase observed is not confirmed by appliance measurements performed at ORNL, where a more or less equal energy consumption was measured /14/. This may be due to the way the blend was used there, i.e. without changing the equipment.
With an increasing percentage of HFC-152a (low percentage of HCFC-22) a small further increase in COP can be observed, compared to the 50% HCFC-22 blend. Highest COP is found for 28% HCFC-22/ 40% HFC-152a; this blend would be flammable. Investigation of the COP of this blend for a condensation temperature of 55 C yields the same ratio of 1.06 between the COP of CFC-12 and the one of the blend; this over a broad range of evaporation temperatures (-35 to -10 C). Taking into account the higher pressure ratio, application will result in 20% loss in refrigeration capacity compared to CFC-12. This will require higher compressor capacities.
The 28% HCFC-22 blend composition is used in the measurements described in this paper.

4. COMPRESSOR MEASUREMENTS

For the measurement of the performance of the blend, four freezer appliances are used (see below). Each of these appliances is equipped with a different compressor.
In a first instance, the energy consumption -using CFC-12- of the appliances is determined using AE-L13A18 compressors (150 W capacity in the standard rating point); this is the type of compressor normally used on these appliances. The compressors are all calibrated on a calorimeter; representative values can be found in Table 2. In this table relative COP-values of all compressors are given, which are derived from two typical temperature conditions (-15 and -25C evaporation temperature); these values are relative to the one for the standard combination of compressor and capillary tube for this upright freezer (case 'B').
These relative values are used for scaling the energy consumption values of the different appliances, so that these can be correlated.
In a second instance, the energy consumption of the appliances is again determined, using a 20% higher capacity AE-L16A01 compressor. All compressors are calibrated on the same calorimeter; some typical results and relative COP-values are again given in Table 2.
As a next step, the lubricant in these compressors is changed from mineral to alkylbenzene synthetic oil. The large compressors (AE-L16A01) are again calibrated on the calorimeter in which the blend with composition 28% HCFC-22/ 40% HFC-152a is used. Values for the COP and the relative differences are given in Table 2. Relative values are again derived from the same temperature conditions as applied for CFC-12.

In Table 2 it can be observed that the COP values are more or less alike for the small and large CFC-12 compressor (superiority of about 5% of the small compressor due to higher motor efficiency). A spread of 3-5% around the average is conform production tolerances.
Changing from CFC-12 to the 28% HCFC-22 three component blend, the spread of about 3% in the COP of the different compressors remains. For each of the appliance tests the relative values derived above are used to correlate the energy consumption values.

Compressors AE- L13A18 (CFC-12)				Compressors AE- L16A01 (CFC-12)				Compressors AE- L16A01 (28% HCFC-22 blend)			
COP-values											
no	COP -15/55C	COP -25/55C	COP rel.unit	no	COP -15/55C	COP -25/55C	COP rel.unit	no	COP -15/55C	COP -25/55C	COP rel.unit
A	1.39	1.12	0.98	A	1.42	1.11	1.05	A	1.44	1.14	1.04
B	1.38	1.17	1.00	B	1.35	1.07	1.00	B	1.40	1.08	1.00
C	1.43	1.19	1.03	C	1.41	1.11	1.05	C	1.46	1.17	1.06
D	1.34	1.10	0.96	D	1.37	1.11	1.03	D	1.45	1.12	1.04

Table 2. **COP-values for compressors used in appliance tests, as measured on the calorimeter:** Values are given for two conditions, viz. -15/55 and -25/55C evaporation/condensation temperatures; from these ones, relative values are derived for use as scaling factors to correlate the various appliance measurements. The value applied for superheat, subcooling and ambient temperature is 32 C (note that this is different from the assumptions used in Table 1). It concerns two types of compressors operated with CFC-12 and one of these operated with the three component blend (compressors A, B, C and D are used for appliances with capillary capacities of 4.2, 5.5, 8.0 and 11.0 l N_2/min, respectively).
The L13A18 compressor has the right capacity for normal operation with CFC-12; the L16A01 compressor has a 20% larger capacity as required for the blend.

When the COP values for CFC-12 and the three component blend are compared, it can be observed that the COP measured for the blend is of comparable magnitude for both temperature conditions considered. Taking the average improvement in COP of all the values given, a better performance of 3% can be calculated. This better performance is measured for a 15% lower load of the electric motor; optimization of the motor characteristics would add another 2% to the figure above (this figure is derived from manufacturer data on efficiency versus load).

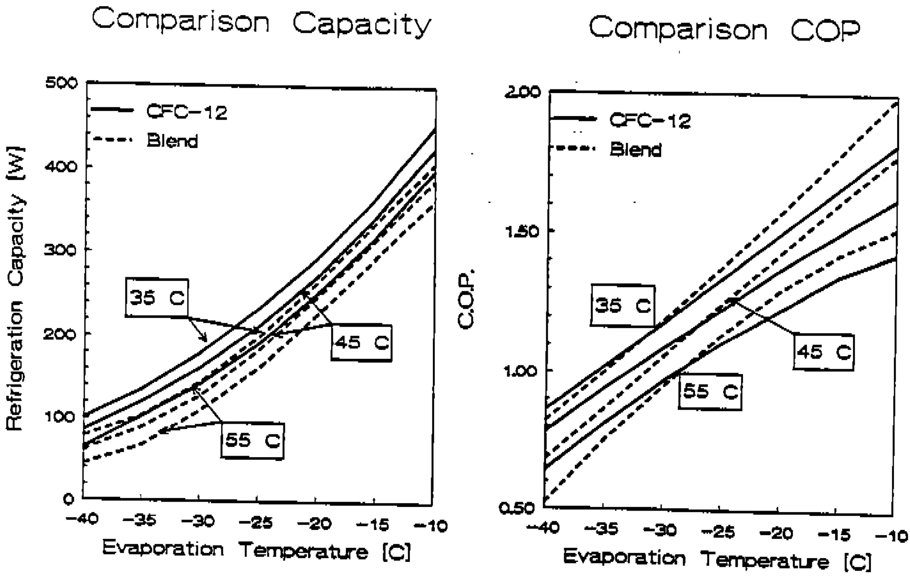

Figure 1. Comparison of the COP and the refrigeration capacity: Comparison of the COP and the refrigeration capacity of the three component blend and CFC-12 versus evaporation temperature (superheat, subcooling and ambient temperature equal to 32 C)

Important conclusion from the compressor measurements, performed at 55 C condensation temperature, is that the average performance of the blend is 5% better than that of CFC-12. This figure is in good agreement with the one calculated for the 55 C condensation temperature.

The dependence of the COP and the refrigeration capacity on the evaporation temperature is illustrated in Figure 1, where average COP values and refrigeration capacities are given. The average has been determined from the values measured for three different AE-L16A01 compressors; average values are given both for CFC-12 and the three component blend.

A more steep character in the COP measured for the blend versus evaporation temperature can clearly be observed. The COP for the blend really falls to low values at low evaporation temperatures; this is due to the extremely low evaporation pressure and the higher pressure ratio which causes a sharp decrease in refrigeration capacity. It also leads to high relative losses. Indication that this character may be caused by compressor characteristics is found in the fact that the decrease in COP is smallest for low condensation temperatures where the refrigeration capacity is relatively high and the pressure ratio moderate (tendency confirmed by calorimetric measurements performed elsewhere /13/).

The lower load of the electric motor in case of the blend, compared to CFC-12, further decreases COP values. As a result, between evaporation temperatures of -35 and -40 C, a 20% lower COP for the blend can be observed.

Above the evaporation temperature of -28 C the COP values measured for the 28% HCFC-22 blend are higher than those determined for CFC-12.

5. APPLIANCE MEASUREMENTS USING CFC-12

Energy consumption measurements are performed on four different static upright freezer appliances. Each of the appliances is equipped with seven evaporator shelves with a total surface area of 2.35 m^2 : the condenser is of the louvre type and has a total surface area of 1.0 m^2 The appliance is normally equipped with an AE-L13A18 compressor, having a refrigeration capacity of 150 W in the standard rating point (-25 C, 55 C evaporation and condensation temperature, respectively).

On each of the appliances a different capillary tube is applied with a small part having heat exchange with the suction tube: capillary tube capacities applied are 4.2 l (A). 5.5 l (B). 8.0 l (C) and 11.0 l N_2/min (D) capacity. The aim of the investigation is to determine the dependence of the energy consumption on the capillary tube capacity and to check whether there exists the same type of influence for the three component blend as measured for CFC-12.

	Compressor AE- L13A18 (CFC-12)					Compressor AE- L16A01 (CFC-12)				
		amb. temperature 25 C		amb. temperature 32 C			amb. temperature 25 C		amb. temperature 32 C	
	charge (g)	energy consump. (kWh/24h)	runn. time perc.	energy consump. (kWh/24h)	runn. time perc.	charge (g)	energy consump. (kWh/24h)	runn. time perc.	energy consump. (kWh/24h)	runn. time perc.
A	157	1.49 (1.52)	52.3	1.82 (1.86)	63.9	180	1.66 (1.60)	44.7	2.08 (2.00)	56.2
B	148	1.42 (1.42)	46.5	1.87 (1.87)	59.5	126	1.54 (1.54)	41.6	1.94 (1.94)	53.2
C	120	1.48 (1.44)	48.4	1.92 (1.87)	61.2	115	1.79 (1.69)	51.9	2.19 (2.07)	58.1
D	120	1.77 (1.84)	65.5	2.20 (2.29)	78.7	124	1.93 (1.86)	54.2	2.63 (2.53)	69.4

Table 3. **Energy consumption values for the appliances equipped with different capillary tubes:** Energy consumption values are given for two ambient temperatures with or without applying scaling factors as given in Table 2 (between brackets the values measured are given). For each of the measurements the running time percentage and the charge applied is given. It concerns the two types of compressors operated with CFC-12 (compressors A, B, C and D are used for appliances with capillary capacities of 4.2, 5.5, 8.0 and 11.0 l N_2/min, respectively). The optimum charge is determined from stationary experiments at 32 C.
The low capacity AE-L13 compressor has an inherent higher efficiency of 5-6%. The tendency in the running time percentages is roughly comparable with the energy consumption values in case of one ambient temperature considered.

Measurements are carried out as follows. First the energy consumption values are determined using the standard compressor and CFC-12 for two ambient temperatures, viz. 25 C and 32 C. The energy consumption is defined as the value measured for an average inner temperature of -21 C for an empty appliance (this is comparable to -18 C warmest package, which is the standard test where load is applied). Energy consumption values are given in Table 3.
Energy consumption values are again determined for the appliances using the 20% higher capacity AE-L16A01 compressor and CFC-12. Values for the four appliances for the two ambient temperatures considered are also given in Table 3.
Observations from Table 3 yield the following. For both the low and high capacity compressor the application of the 5.5 l capillary tube results in lowest consumption values. Values are larger for the other capillary tubes, in the order of 5-15% for capillary tubes of 4.2 and 8.0 l capacity; the large capacity of 11.0 l yields inferior results for both cases (compressor capacities and ambient temperatures).

Using the low capacity compressor, the average scaled consumption value is 6% lower than the one measured using the larger capacity compressor. This will be mainly due to the difference in COP between both types of compressors. Taking the difference in COP for the rating point -25/55 C between both compressors -in case of the "B" compressors, where it concerns the 5.0 l capillary capacity-, the performance of the appliance is in fact equal. Dependence of the energy consumption on the capillary tube is lower for the low capacity compressor (see also Figure 2). Values obtained from the application of the 5.5 l capillary will be directly used when comparing the results using CFC-12 and the three component blend.

6. APPLIANCE MEASUREMENTS USING THE THREE COMPONENT BLEND

Measurements of the energy consumption using the three component blend are given in Table 4 for the two ambient temperature conditions considered.
The charge determination for these measurements is a very critical and important one. Via special procedures the appliances are charged with the blend of the correct composition until the whole evaporator surface area is at evaporation temperature. This is more difficult compared to charging with CFC-12 since a temperature glide occurs in the evaporator. Generally, the ratio between the amounts of blend material and CFC-12 used is between 70 and 75% (this implies a relative reduction in ODP of 98% when switching from CFC-12 to application of the blend).

From Table 4 one conclusion can be drawn already. Both for the ambient temperature of 25 C and that of 32 C, the capillary tube capacities of 5.5 and 8.0 l yield optimum results. It might be concluded that the blend is not sensitive for the capillary tube capacity in this capacity range.

	charge (g)	temp. glide evap.	ambient temperature 25 C energy consump. (kWh/24h)	runn. time perc.	filling degree evap (%)	ambient temperature 32 C energy consump. (kWh/24h)	runn. time perc.	evaporator filling degree (%)
A	98.0	1.3	1.63 (1.57)	48.5	85	2.17 (2.09)	63.2	95
B	92.1	2.1	1.54 (1.54)	48.5	80	2.06 (2.06)	64.5	85
C	85.3	2.9	1.54 (1.46)	45.3	85	2.09 (1.97)	58.7	80
D	88.9	1.3	2.10 (2.02)	63.9	85	2.88 (2.77)	85.0	85

Table 4. **Energy consumption values for the appliances operated with the three component blend:** Energy consumption values are given for two ambient temperatures with or without applying scaling factors as given in Table 2 (between brackets the values measured are given). For each of the measurements the running time percentage and the filling degree of the evaporator is given. All measurements are performed with the AE-L16A01 compressors, as applied on the appliances when using CFC-12. The filling degree of the evaporator is defined as the ratio between the surface area at evaporation temperature and the total surface area; this at the end of the 'on'- period.

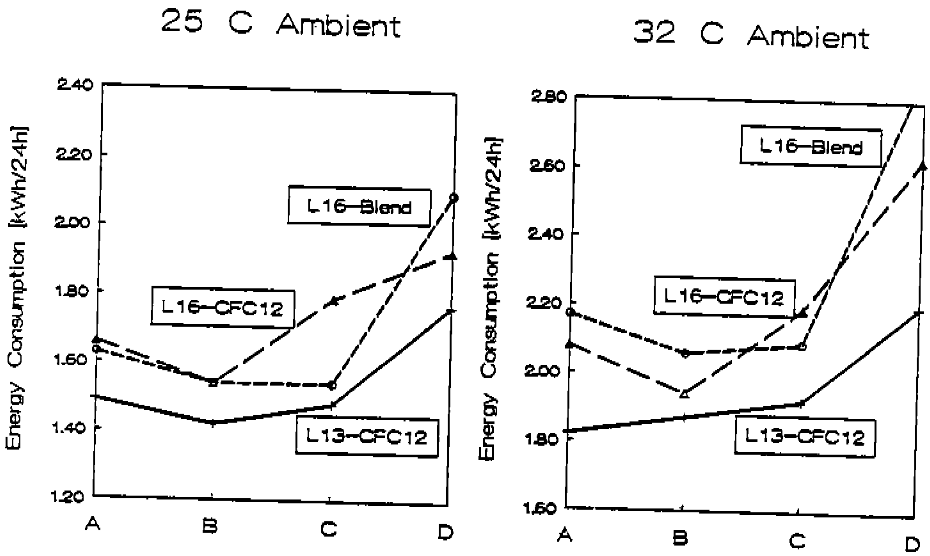

Figure 2. **Comparison of the energy consumption values:** Comparison of the energy consumption values of the three component blend and CFC-12 versus capillary tube capacity (A, B, C and D refer to capacities of 4.2, 5.5, 8.0 and 11.0 l). The energy consumption measurements using CFC-12 and the low capacity compressor are lower, mainly due to the inherent higher efficiency of the compressor.
In the measurements the running time percentage has been varied by time control, not by a thermostat. For both CFC-12 and the blend two cycles per hour are applied; the on-period varies in length with the inner appliance and the ambient temperature. This may lead to small differences compared to thermostat control, especially for low ambient temperatures (high cycling frequency).

However, it may also be that a 25% larger capacity than 5.5 l would yield better results; measurements are lacking.

In Figure 2 the energy consumption results from Table 3 and 4 are once more summarized, for both ambient temperature conditions considered. Following remarks can be made:

- In case of the ambient temperature of 32 C, the energy consumption of the blend is about 5% higher compared to the CFC-12 energy consumption using the same compressor; this holds for the 5.5 l capillary tube (with the capillary tube of 8.0 l the blend has an energy consumption 5% lower than CFC-12). It could indeed be concluded that the consumption of the blend is less sensitive for a change in capillary capacity; it might also be that a capillary capacity between 5.5 and 8.0 l would show a small further decrease in energy consumption (increase of 25% in capacity compared to 5.5 l). The energy consumption when using the low capacity compressor is lower, mainly due to the inherent better compressor efficiency.
  As stated above a 5% increase (5.5 l capillary capacity) in consumption can be concluded for the blend. Since this blend composition should not be considered as a direct "drop-in", the difference in the electric motor efficiency should be taken into account in this figure. From the energy consumption values and running time percentages, given in Tables 3 and 4, an average 12% decrease in motor load can be calculated. According to manufacturer data, this effect results in a 2% lower efficiency. In case of the 5.5 l capillary tube, the performance of the blend can therefore be considered to be 3% worse compared to the application of CFC-12.

- From the results presented in Figure 2, the same kind of comparison can be made for the ambient temperature of 25 C. For both the blend and CFC-12 the application of the 5.5 l capillary tube yields equal results (1.54 kWh/24h); results with the lower capacity compressor are better (see remarks made in section 5 on equal consumption). Resulting, there is no energy penalty in the application of the blend at this ambient temperature, using the CFC-12 refrigeration circuit.
  The dependence of the consumption of the blend on the capillary capicity is not strong, comparable to the dependence observed in case of CFC-12 and the low capacity compressor (a capacity between 5.5. and 8.0 l might also be a better choice here).
  Applying a correction for the difference in motor load the equal energy consumption value can be improved; a decrease in the consumption of about 2% is then calculated.

The better performance of the blend in case of the ambient temperature of 25 C (compared to 32 C) will be caused by the lower pressure ratio and the average higher evaporation temperature which occurs in the shorter running periods necessary to realize the inner appliance temperature of -21 C. In case of the ambient temperature of 25 C, measurements of the blend yield a further improvement; e.g. a value of 5% is measured for an inner appliance temperature of -18 C.

Concluding, a consumption varying between 1.03 and 0.98 of that of CFC-12 can be assumed for the three component blend (dependent on the ambient temperature), supposed the correct capillary tubing is applied. This tendency is confirmed by calorimetric measurements, where the low evaporation temperatures result in worse performance (lower COP values) of the blend.

The above values may be further improved by applying a different evaporator in the static upright freezer, which would make optimum use of the temperature glide of the blend.

In Figure 3 some evaporator temperatures are shown, both for the application of CFC-12 and the blend. A temperature glide (compare the values given in Table 4 for the continuous running condition) can be observed between the beginning and the end of the evaporator, in case of the blend. Since in the evaporator construction used "top-down" flow is applied, the highest evaporation temperature occurs there where the freezer air temperature is lowest (last part of the evaporator). This causes the latter part of the evaporator being somewhat less effective, leading to an average lower evaporation temperature in case of the three component blend. A "bottom-up" flow evaporator would be the appropriate choice for an upright freezer, when applying a blend with a certain temperature glide. It can be concluded that the energy consumption values may be slightly decreased by this measure; however, it is difficult to derive the order of magnitude without any experimental experience so far. This should be subject of further study using different types of appliances (in which different evaporator and condenser constructions are used).

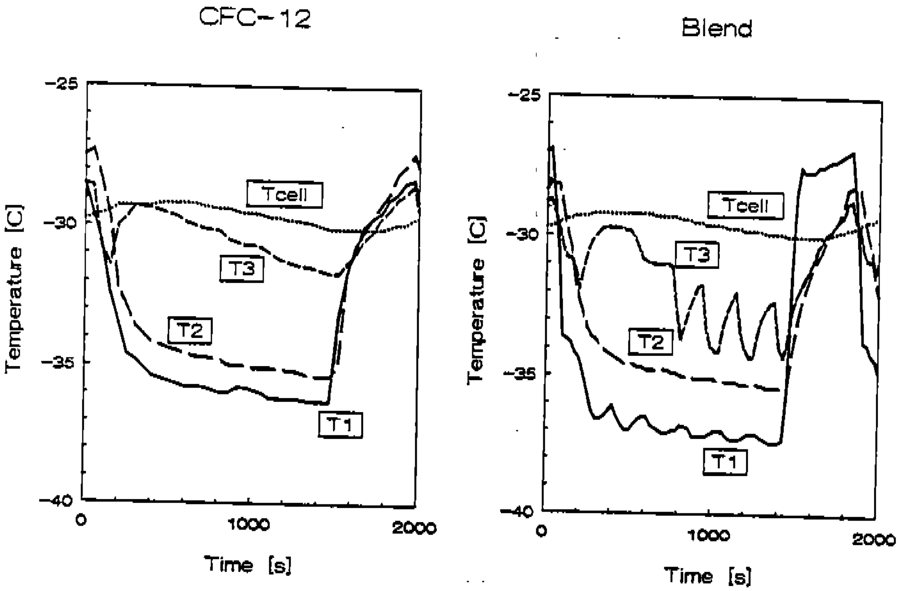

Figure 3. **Time dependent registration of evaporator temperatures during an on/off cycle:** Various temperatures on the evaporator (upper, middle and lower position reffered to as 1, 2 and 3) and the average air temperature (referred to as the cell temperature) are given for measurements using either the three component blend or CFC-12.

7. CONCLUSIONS

Static upright freezers have been studied concerning the energy consumption realizible with a three component blend, consisting of 28% HCFC-22, 40% HFC-152a and 32% HCFC-124. This composition of the blend proved to be the optimum one in steady state calculations.
The following concluding remarks can be made:

- The COP of the blend is calculated to be 6% higher compared to the one of CFC-12. This value is confirmed in calorimetric measurements, using evaporation temperatures between -15 and -25 C.
  It assumes adaptation of the electric motor when changing from CFC-12 to the three component blend (this results in a lower compressor load);
- Superiority of the blend calculated for lower evaporation temperatures cannot be confirmed by calorimetric measurements. Lower values of the COP are generally observed in the range of -30 to -40 C. However, also here the different, lower load of the electric motor influences the results;
- Application of the capillary tube selected for CFC-12 also yields best results in case of the blend. The blend seems to be not sensitive for the capacity of the capillary tube in the range of 5.5 to 8.0 l. Application of a capacity in between might even yield a further improvement, however, measurements are lacking;
- In measurements of the energy consumption of a static upright freezer a consumption varying from 0.98 to 1.03 times that of CFC-12 can be derived, dependent on the ambient temperature. These values assume the adaptation of the electic motor of the compressor (actually it would mean an equal redesign of the electric motor as for HFC-134a /3,4/);
- It can be estimated that a higher decrease in energy consumption than 2% would be feasible for the ambient temperature of 25 C and the inner appliance temperature of -21 C provided an evaporator (and condenser) construction is applied which makes optimum use of the temperature glide of the blend;
- There will be a relatively larger decrease in consumption using the blend compared to CFC-12, when applying a higher air temperature than -21 C (as e.g. is the case in standard US tests).

As a follow-up, a number of studies are recommended:

- measurement of the performance of a different blend composition (e.g. 50% HCFC-22) where the behaviour will not be that much influenced by differences in the electric motor efficiency (equal compressor load);
- measurements of blends in appliances with different heat exchangers designed for making optimum use of the temperature glide occurring when applying the blend;
- measurement of the blend in appliances with a large suction line/ capillary tube heat exchanger;
- determination of the difference of time control versus thermostat control of the evaporator.

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