CALCULATION OF TEWI FOR REFRIGERATED FREIGHT CONTAINERS

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ABSTRACT

The concept of TEWI (total equivalent warming impact) and its importance are summarised. Restrictions and limitations of its applicability are highlighted. A detailed method for TEWI calculation for refrigerated transport containers is presented, including the need for particular equipment tests in addition to those usually carried out for other purposes.

Examples of the use of the method are presented based on typical expected refrigerant unit performance. The sensitivity of the method to assumptions about use pattern, leakage rate and refrigerant choice is examined and discussed.

1. INTRODUCTION

Global warming and the associated climate changes have been recognised as vital environmental issues which have a particular impact on refrigeration, especially since the agreement of the Kyoto Protocol (Heap, 1998). For refrigeration systems, the issues are complicated in that there are two sources of global warming. First, the refrigerant fluid may be a relatively powerful global warming gas, so that any emissions from leaks or during servicing will have an effect. Secondly, operating the system uses electricity, the generation of which emits relatively large quantities of carbon dioxide, which is the major global warming gas by virtue of its quantity. These two sources can be combined in TEWI as a single figure for total carbon dioxide equivalent (British Refrigeration Association, 1996).

The calculation method is straightforward, as follows.

- the type and quantity of refrigerant charge are determined
- the lifetime energy consumption of the system is estimated
- the “direct effect” is calculated from the estimated total lifetime refrigerant emission
- the “indirect effect” is calculated from the estimated energy consumption, using a generation emission factor (kg CO_2 per kWh)
- the two effects are added together to give the TEWI value.

The technique is useful for comparing the environmental impacts of two or more different new systems designed for similar applications.

It must be emphasised that TEWI is a system parameter dependent on an anticipated pattern of system use: it is not a refrigerant parameter. It also has limited precision: uncertainties in global warming potentials of refrigerants and in estimation of use parameters mean that differences in calculated TEWI values of 10% should be regarded as negligible.

2. REFRIGERATED FREIGHT CONTAINERS

The design and operation of refrigerated freight containers have been documented previously (Heap, 1989; Heap and Lawton, 1995). They are standardised within the scope of ISO 1496/II. Present day refrigeration systems may have reciprocating or scroll compressors, and usually operate (for new units) with refrigerant HFC-134a or R-404A. They operate from either 50Hz or 60 Hz electrical supplies from grid mains, or ship’s supply, or from portable diesel generators clipped on to them.

There are two main operation modes. For frozen cargoes (below -10^{o}C) the compressor cycles on and off, with continuous evaporator fan operation. For chilled cargoes (above -2^{o}C) some type of capacity modulation is applied to a continuously running compressor: this could be suction throttling or hot gas bypass, with or without cylinder unloading.

To calculate TEWI for such a unit, the following are required.

- power draw at various ambient temperatures and cargo temperatures, for both 50Hz and 60Hz operation
- generation emission factors for the power supplies to be used
- anticipated use pattern in terms of time running for representative cargo and ambient temperatures and types of power supply
- refrigerant leakage in use and at decommissioning
- global warming potential of the refrigerant fluid.

3. ACQUISITION OF DATA FOR TEWI CALCULATION

3.1 Power draw

Power draw is usually measured under ISO rating conditions (-18°C internal and +38°C external temperatures) with the compressor running continuously against an internal heat load. Generally, power draw for frozen cargo is appreciably less than that for chilled cargo, nevertheless there is a need for measured data for power draw at moderate ambient temperatures. This data is not available at present, and when obtained may need allowance for defrosting or for pull-down of warm cargo. For the calculations below, a figure of 2kW at 20°C ambient will be assumed.

As part of its normal testing regime, CRT investigates control performance of units at chilled set points of 0 or -1°C and of +13°C. Power draw is also recorded. The authors have examined data obtained in commercial testing of 7 different units from 6 manufacturers tested in recent years. These results include those for units using scroll and reciprocating compressors, and using HFC-134a and R-404A refrigerants. Individual results cannot be published as confidentiality must be retained, but the results lie between the upper and lower curves in the two graphs shown as figure 1 (neither of which correspond exactly to any single unit).

There is little difference in power draw between the set points, a consistent difference between 50Hz and 60Hz operation, and a variation in power draw with ambient temperature which is very variable depending on the unit design. For the purpose of illustration, power draws of 4.3 kW and 7.2 kW, corresponding to the lowest and highest measured figures for 60Hz operation in 20°C ambient, will be used.

For TEWI calculation for specific units, measurements for both chilled and frozen operation at a range of ambient temperatures and set points are needed. Such measurements represent a small addition to the normal testing requirements of manufacturers and purchasers of equipment.

3.2 Generation emission factors

For land operation, generation factors may be obtained from local electricity generators. In the UK a figure of 0.53 kg CO_2 per kWh is quoted by BRA (op. cit.). Figures vary from around 0.1 in France (largely nuclear generated) to around 1.0, with an OECD average of 0.58 (Sand et al., 1997). Typical oil-fired plant is quoted at 0.77, and this may be a reasonable figure to assume for shipboard supplies, in the absence of more specific data.

No allowance is made in these figures for the potential contribution to global warming of gases other than CO_2 which may be emitted from generating plant.

3.3 Use pattern

The anticipated use pattern will vary depending on the trades in which the container is expected to operate. At the least, an estimate of the time per year carrying chilled and frozen goods respectively is needed. There will be considerable differences in utilisation between shipping lines, and it may be good to adopt some common assumptions about “typical” use for the specific purpose of TEWI comparisons. This would require data from a number of lines to be integrated into a common average pattern.

For illustration purposes, a simple pattern will be assumed, as follows:

- total time operating equal to 120 days per year
- one third cargo frozen, two thirds chilled.
- for simplicity, all supplies 60Hz and a single average ambient temperature of 20^{o}C.

3.4 Refrigerant leakage

The total future leakage emissions of containers are difficult to assess, for obvious reasons. Figures quoted elsewhere suggest a leakage of up to 10% of charge per year, with a lifetime of 15 years and a charge of around 5 kg. At decommissioning there should be a high degree of recovery of the refrigerant for either re-use or destruction. Increasingly, refrigerant loss will be recorded in the future in order to meet likely legislative requirements.

3.5 Global warming potential

The global warming potential (GWP) of refrigerants is usually quoted relative to CO_2 over a 100 year integration period. These figures are widely available, and for the commoner container refrigerants are as follows.

Refrigerant	GWP
CFC-12	8500
HCFC-22	1700
HFC-134a	1300
R-404A	3750
R-409A	1440
R-413A	1250

It should be noted that these figures are estimates subject to possible errors of up to 20%. and also that the 100 year timescale yields rather higher figures than would a longer period.

4. EXAMPLES OF CALCULATIONS

4.1 Baseline cases

From the above, we have the following assumptions.

- power draw - frozen cargo, 2 kW; chilled 4.3 kW or 7.2 kW
- generation factor 0.77 kg CO_2 / kWh
- use of 40 days frozen, 80 days chilled per year for 15 years
- leakage of 0.5 kg per year overall.

TEWI has been calculated using these assumptions for each of the refrigerants CFC-12, HFC-134a and R-404A. The results are as follows.

"4.3 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	63,750	117,533	35%	181,283
HFC-134a	9,750	117,533	8%	127,283
R-404A	28,125	117,533	19%	145,658

"7.2 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	63,750	181,843	26%	245,593
HFC-134a	9,750	181,843	5%	191,593
R-404A	28,125	181,843	13%	209,968

These results show clearly that the more efficient "4.3 kW" unit, even using CFC-12, has a lower TEWI value than the "7.2 kW" unit on any of the refrigerants. For both units, the direct emission is less than 20% of the total with R-404A and less than 10% of the total for HFC-134a. For the less efficient unit, the difference between TEWI values for these two refrigerants is less than 10% and therefore not significant. Equally, the difference between use of HFC-134a and a zero GWP refrigerant would not be significant.

4.2 Reduced leakage

If we assume a leakage reduction of 50%, the results are as follows.

"4.3 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	31,875	117,533	21%	149,408
HFC-134a	4,875	117,533	4%	122,408
R-404A	14,062	117,533	11%	131,595

"7.2 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	31,875	181,843	15%	213,718
HFC-134a	4,875	181,843	3%	186,718
R-404A	14,062	181,843	7%	195,905

Only in the case of CFC-12 does the reduced leakage affect the calculated TEWI value by more than 10%. Reduced leakage does not compensate for a less efficient unit.

4.3 Different pattern of use

Returning to the baseline case but with a use pattern of 120 days per year with frozen cargo, 40 days with chilled, we get the following.

"4.3 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	63,750	114,206	36%	177,956
HFC-134a	9,750	114,206	8%	123,956
R-404A	28,125	114,206	20%	142,331

"7.2 kW"unit

Refrigerant	Direct emission	Indirect emission	Direct/total	TEWI
	kg CO_2 / kWh			kg CO_2 / kWh
CFC-12	63,750	146,362	30%	210,112
HFC-134a	9,750	146,362	6%	156,112
R-404A	28,125	146,362	15%	184,237

Despite the increased overall utilisation, the reduction in chilled carriage means there is negligible difference from the base case for the "4.3 kW" unit. The reduction in TEWI is more significant for the less efficient unit.

5. CONCLUSIONS

The use of TEWI for refrigerated containers has been illustrated. The results above show clearly that efficiency during the carriage of chilled cargo is likely to be the most important factor determining TEWI for refrigerated containers. For accurate calculations for particular units, additional testing over and above the usual is needed, to determine power draw on frozen operation at various ambient temperatures.

The calculated examples show the extent to which TEWI is reduced in going from CFC to HFC refrigerants.

6. REFERENCES

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CALCUL DU TEWI DES CONTENEURS FRIGORIFIQUES DE MARCHANDISES REFRIGEREES

RESUME: On résume le concept du TEWI (total équivalent de l'impact de réchauffement) et son importance. On souligne les restrictions et les limitations de son applicabilité. On présente une méthode détaillée du calcul du TEWI pour les conteneurs de transport frigorifique, y compris le besoin d'essais particuliers d'équipement en plus de ceux normalement exécutés à d'autres effets.
On présente des exemples d'utilisation de cette méthode basés sur le fonctionnement habituel exigé d'installations frigorifiques. On examine et on analyse la sensibilité de cette méthode et des suppositions sur le modèle d'utilisation, du taux de fuite et du choix de frigorigène.

DISCUSSION

H. CABRERA (Australia) - You have shown that TEWI calculations can be carried out successfully with only a little extra effort but will it be carried out by the shipping companies?

R.D. HEAP - The current emphasis on energy efficiency by equipment manufacturers shows a growing customer interest in energy efficiency. This is important to allow greater numbers of refrigerated containers on a given ship. The use of TEWI as a comparative indicator is therefore likely to become more common.

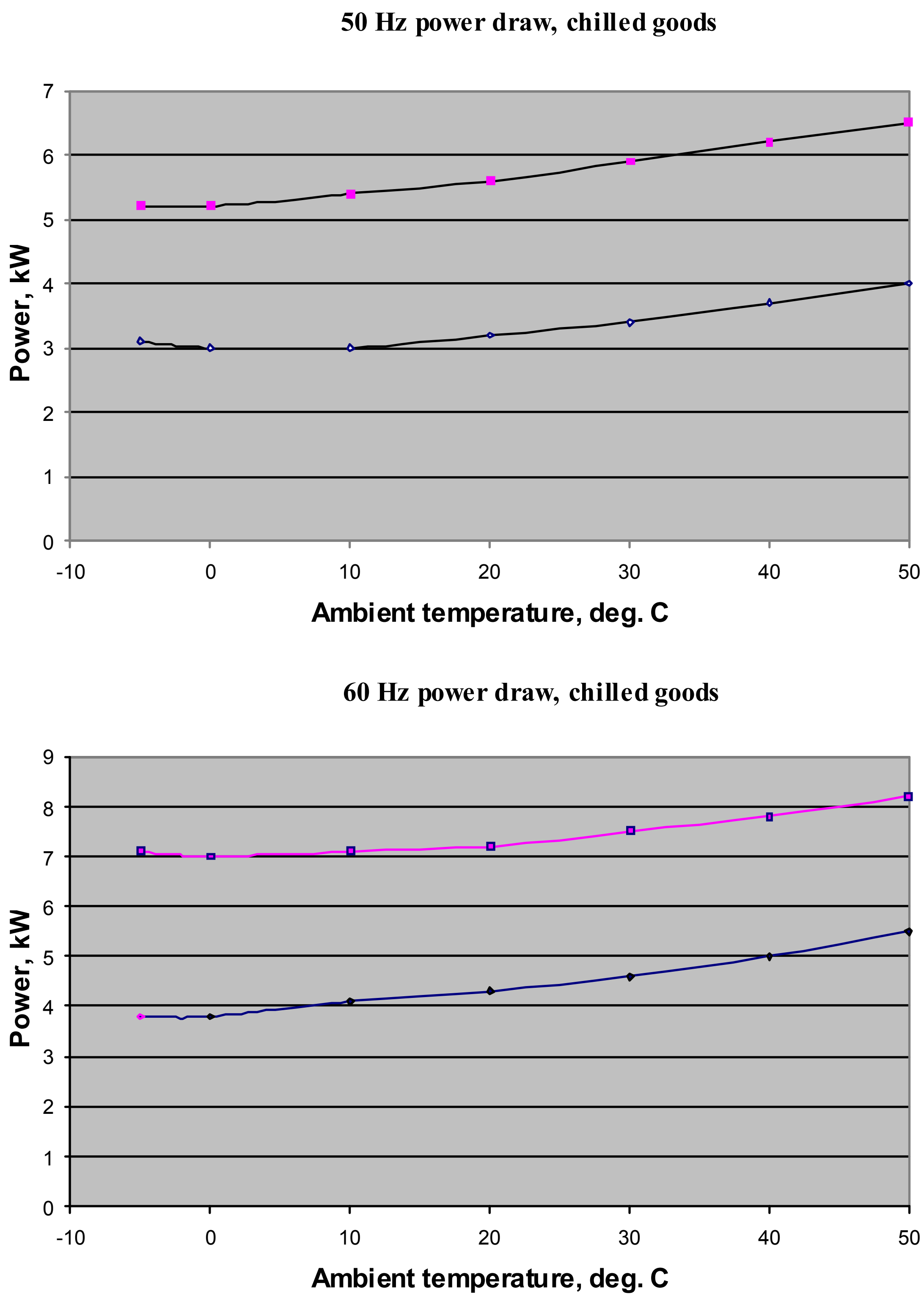

Figure 1. Power draw range for refrigerated containers of various designs at steady temperature conditions, 50 and 60 Hz operation, -1 to +13 °C cargo temperatures.