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Air-Conditioning and Refrigeration's Contribution to Global Warming Gases

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Abstract

This paper utilizes previously-developed methodologies to illustrate the relative contributions to atmospheric global warming gases from today's air-conditioning and refrigeration equipment versus those produced twenty-five years earlier. Equipment included in the comparisons are a low-pressure centrifugal chiller, a low-temperature supermarket rack, a residential split-system air-conditioner, and a household refrigerator. It is illustrated that small variations in efficiencies have a greater impact on greenhouse gas creation than do large variations in a refrigerant's global warming potential.

Introduction

A modern infrastructure is dependent on air-conditioning and refrigeration for many consumer applications (e.g., household cooling and heating, refrigerators, automotive air-conditioners, etc.), commercial applications (e.g., comfort cooling in buildings, supermarket refrigeration, etc.), and industrial applications (e.g., process cooling, train/rail/ship refrigeration, etc.). However, utilization of air-conditioning and refrigeration equipment potentially contributes to global warming gases in two ways:

1). The first method, called the direct effect, occurs if the refrigerant is inadvertently (or purposely) vented from air-conditioning and refrigeration equipment during installation, normal operation, servicing, decommissioning, or eventual disposal. If not recovered, the refrigerant will eventually find its way to the upper atmosphere where its heat trapping strength will add to the radiative greenhouse forcing over the atmospheric lifetime of the compound.

2). The second method, called the indirect effect, relates to the generation of electricity, from the combustion of fossil fuels (e.g., coal, oil, or natural gas), to power the refrigeration equipment. The combustion of fossil fuels produces, among other gases, carbon dioxide -- a dominant greenhouse gas. The extent of the carbon dioxide emissions, for a given carbon content in the fuel and for a given generation efficiency, depends primarily on the energy efficiency of the air-conditioning and refrigeration equipment; the amount of carbon dioxide generated is directly proportional to the amount of energy used.

It is the combination of the <u>direct</u> (release of refrigerant) and <u>indirect</u> (energy consumption) effects that are of interest in evaluating the impact refrigerants have on global warming. The sum of the two terms is known as the "total equivalent warming impact" (TEWI).

Decreases in the release of refrigerants (resulting from new manufacturing techniques and servicing practices) will reduce the direct greenhouse gas contribution. Increases in equipment operating efficiencies will serve to reduce the indirect effect. Therefore, TEWI becomes an important tool for evaluating the overall impact that air-conditioning and refrigeration technologies may have on global warming.

SIMPLIFIED TEWI DEFINITION

TEWI (expressed in terms of equivalent Kg CO_2 emissions) is the sum of both the direct and indirect influences and provides a measure of the total warming impact of comfort conditioning and refrigeration on the environment {Calm 1993, Fischer 1991}.

$$\text{TEWI} = \text{direct } CO_2 \text{ emission equivalent} + \text{indirect } CO_2 \text{ emission equivalent}$$

Direct Effect

The direct TEWI component is determined by converting refrigerant loss from a system into an equivalent CO_2 emission by multiplying the total mass of refrigerant gas emitted by its 100-year integrated GWP.[1]

$$\text{Direct } CO_2 \text{ emission equivalent (Kg } CO_2) = (\text{charge}) * (\text{make-up rate}) * (\text{service life}) * (\text{GWP})$$

where: charge = Kg refrigerant in the system
make-up rate[2] = % refrigerant charge emitted per year
service life = years of system operation
GWP = Kg CO_2/Kg refrigerant for a 100-year integration time horizon

Indirect Effect

The indirect contribution to TEWI is calculated as follows:

$$\text{Indirect } CO_2 \text{ emission equivalent (Kg } CO_2) = (\text{power}) * (\text{operation}) * (\text{service life}) * (CO_2 \text{ emission from electricity generation})$$

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[1] There are arguments for using 500-year integrated GWPs to approximate an infinite time horizon. However, while long-term or full-life impact of greenhouse gases is a concern, there is also a real concern that continued high release rates of greenhouse gases could affect the rate of climate change in the next several decades. For this reason, the current Intergovernmental Panel on Climate Change convention is to utilize global warming values associated with the 100-year iteration time horizon.

[2] Make-up rates are expressed as a percentage of the total system charge that needs to be replenished each year. The make-up rate includes losses from purges (e.g., low-pressure chillers), leakage, servicing (e.g., maintenance), and incomplete recovery upon ultimate equipment retirement. Utilization of make-up rates allow for a linear assessment of the emissions. A more rigorous analysis would treat each component separately on a time-release basis.

where: power = system power requirements, Kw
operation = hours of system operation per year (equivalent full-load)
service life = years of system operation
CO_2 emission from electricity generation = $KgCO_2$ emitted per Kwh generated

APPLICATION DEPENDENCE OF TEWI

The combined TEWI equation is dependent on the specific refrigerant application. Relevant application variables include equipment life, operation duty (factoring in the load profile), system efficiency, system charge, and emission rate(s). Some typical values for representative applications are indicated in Table 1.

Table 1: Typical TEWI-Dependent Values for Specific Applications

	low-pressure centrifugal chiller		low-temperature supermarket rack [a]		residential split-system air conditioner		domestic household refrigerator (18 ft^3) [b]	
	1995	1970	1995	1970	1995	1970	1995	1970
Service Life (yrs)	25 to 30		15-20		13-20		15 - 20	
Operation [c] (hrs/yr)	2190		5200	6500	1200		—	
Refrigerant	R-123	R-11	R-404A	R-502	R-22	R-22	R-134a	R-12
Refrigerant GWP [d]	93	4000	3850	4510	1700	1700	1300	8500
Power [e]	.6 Kw/ton	.82 Kw/ton	2.13 Kw/ton	2.71 Kw/ton	10.6 SEER	7.0 SEER	650 Kwh/yr	1700 Kwh/yr
Charge	2 lb/ton	2 lb/ton	35 lb/ton	18 lb/ton	2.1 lb/ton	2.5 lb/ton	8 oz	10 oz
Make-up rates [f]	0.75%	15%	10%	40%	2%	10%	0.25%	1%

Notes:
- a. 1970 low-temperature values based on a two-compressor (with 100%/50%/0% unloading) remote condenser rack operating at -20° F evaporator/110° F condensing. 1995 values based on a five-compressor (with variable-speed drive) remote condenser rack operating at -20° F evaporator/105° F. Both were actual built-up, multi-case systems. For supermarket applications, system efficiency and refrigerant charges per ton vary significantly based on the number and length of cases and the length of refrigerant piping. {Bittner 1995}
- b. The equivalent CO_2 emission from the refrigerator insulation is ignored.
- c. Approximate equivalent full load operation.
- d. 100-year iteration values. {ARTI Refrigerant Database}
- e. Power requirements and system efficiency terms are consistent with those associated with the specific type of equipment. Values are reflective of median capabilities and not the best available technologies.
- f. As a result of today's regulations, it is expected that equipment manufactured in the future will have dramatically lower make-up requirements due to smaller refrigerant charges, tighter manufacturing tolerances, and revamped field service practices.

A given application's TEWI value is also influenced by geography; the regional fuel mix and the overall efficiency of the power plant impacts the indirect contribution. Varying levels of CO_2 will be emitted based on the carbon content of the fuel and the generation efficiency of the power plant. The electric CO_2 conversion factor is a measure of CO_2 produced in electricity generation and reflects inefficiencies in power generation, distribution processes, and relative impact of different fuels utilized by generating sources (e.g., coal, oil, natural gas, and nuclear).[3] It should be recognized, due to varying carbon content and energy capacity of fuels from different geographic locations, that the

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[3] The conversion factor does not include CO_2 emission equivalents resultant from mining the raw materials, converting the raw materials into fuel, or transporting the fuel to the power plant.

electric to CO_2 conversion factors vary dramatically from one country to the next. Additionally, within large countries, there is still a great deal of regional variability. For the U.S., the 1995 regional conversion factors have been projected as:{Calm 1993}

Location		Electric Conversion Factor
West	-	.497 Kg CO_2/Kwh
West central	-	.672 Kg CO_2/Kwh
East central	-	.939 Kg CO_2/Kwh
Northeast	-	.489 Kg CO_2/Kwh
South central	-	.737 Kg CO_2/Kwh
Southeast	-	.671 Kg CO_2/Kwh
NATIONAL	-	.674 Kg CO_2/Kwh

The 1970 national average for the electric conversion factor was approximately 20-25% greater than the current project 1995 national value of .674 Kg CO_2/Kwh. This decrease in carbon release (per Kwh of electricity generated) results from better power plant efficiencies and increased utilization of lower carbon-content fuels (e.g., natural gas) and non-fossil fuels (e.g., nuclear, solar, hydro, and wind).

AIR-CONDITIONING AND REFRIGERATION EQUIPMENT TEWI TRENDS

Figures 1 through 4 utilize the data presented in Table 1 to calculate TEWIs for several typical systems produced today versus those of 25 years ago. The contribution by air-conditioning and refrigeration equipment has significantly decreased on a unit basis over the twenty-five year period. Energy efficiency improvements have resulted in the reduction of the indirect contribution. Tightening of systems and better service practices have resulted in the reduction of the direct contribution.

Of interest is the observation that the direct contribution is becoming a smaller percentage contributor and the overall equivalent CO_2 release is being reduced.

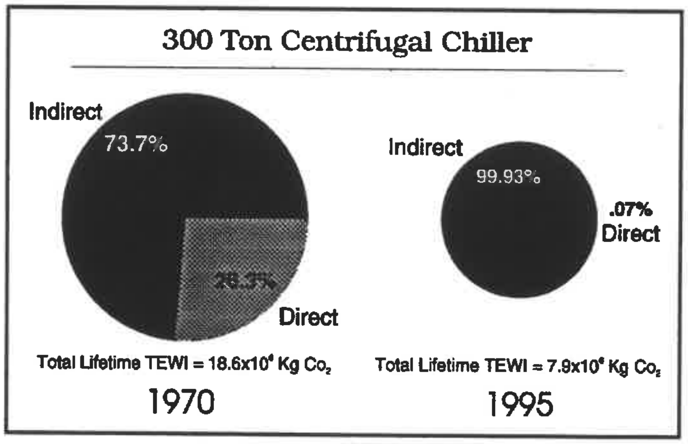

Figure 1.

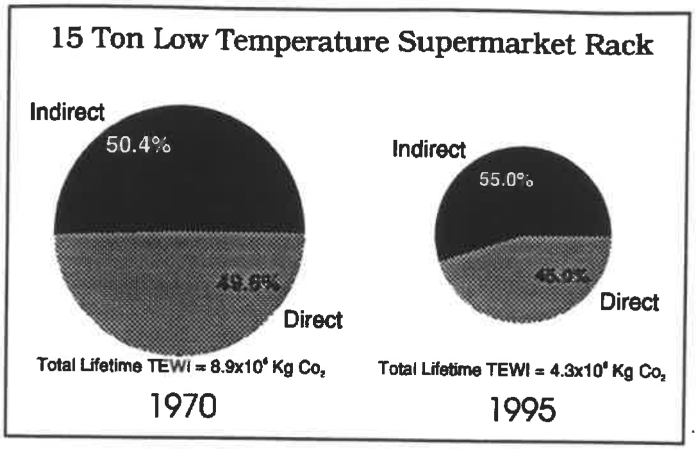

Figure 2.

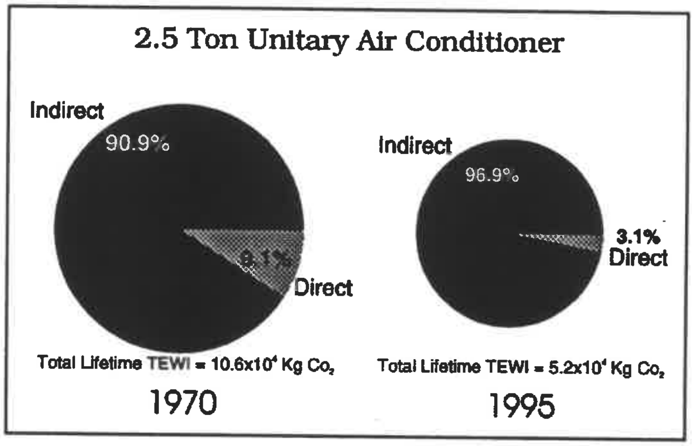

Figure 3.

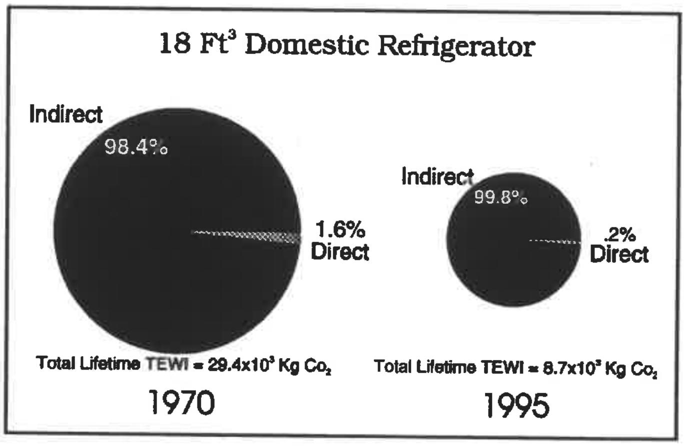

Figure 4.

SENSITIVITY ANALYSIS OF THE TEWI CONCEPT

As illustrated above, indirect and direct contributions have varying impacts on the amount of carbon dioxide added to the atmosphere. We can consider the relative effects of varying both GWP and system efficiency for hypothetical alternatives to HCFC-22. Table 2 illustrates the calculated TEWI for varying GWP (e.g., ±40% that of R-22) with varying assumed efficiencies (e.g., ±5%) with respect to a typical 10-ton unitary R-22 single-package air-conditioning system. The energy efficiency ratios (EERs) presented here are simply meant to demonstrate how TEWI varies as a function of efficiency for the refrigerant/equipment system. As represented in Table 2, a small change in the system efficiency causes a more pronounced effect on TEWI than does a larger change in the GWP value of the refrigerant.

Table 2: TEWI Calculations for Refrigerants with Varying GWP and Efficiencies for a 10-Ton Unitary Single-Package Air-Conditioning System (relative to R-22)[4]

	Relative GWP	Relative EER	Indirect (Kg CO_2)	Direct (Kg CO_2)	Total TEWI (Kg CO_2)	Difference from HCFC-22
HCFC-22	1.00	1.00	258816	5551	264367	----
low GWP/low EER	**0.60**	**0.95**	**272438**	**3331**	**275769**	**+4.3%**
high GWP/low EER	1.40	0.95	272438	7771	280209	+6.0%
low GWP/same EER	0.60	1.00	258816	3331	262147	-0.8%
high GWP/same EER	1.40	1.00	258816	7771	266587	+0.8%
low GWP/high EER	0.60	1.05	246491	3331	249822	-5.5%
high GWP/high EER	**1.40**	**1.05**	**246491**	**7771**	**254263**	**-3.8%**

Variables:
Power (@ 10 EER) = 1.2 Kw per ton of cooling
charge (@ 1.8 lb/ton) = 0.82 Kg of refrig./ton capacity
loss rate = 2.0% of system refrigerant charge
R-22 GWP (reference) = 1700 relative to CO_2 (100yr)
operation = 1600 hrs/yr
elec. conv. = 0.674 kg CO_2/Kwh
capacity = 10 tons cooling
service life = 20 years

As Table 2 indicates, a small decrease in system efficiency will offset the TEWI benefits of a large reduction to a refrigerant's GWP value. Hence, a refrigerant with a high GWP can have a smaller environmental impact if it results in a system that is energy efficient. Figure 5 illustrates this point in a graphical form.

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[4] Several simplifying assumptions shown in the table (e.g., constant refrigerant charge or Kw/ton) are not strictly correct for differing refrigerants, but will only impart a small error into the calculations.

Point (a) on the chart is our example of a 10-ton single-package rooftop unit (EER = 10, GWP = 1700). If the energy efficiency for the unit is maintained at 10 EER, reducing or increasing the refrigerant GWP by 40% (e.g., 1020 and 2380 Kg CO_2/Kg refrigerant, respectively) by moving to points (b) or (c) will lower/increase the overall TEWI by 0.8%. However, going from point (a) to points (d) and (e), a respective decrease and increase of 5% in EER, results in an overall TEWI increase/decrease of 5.1%/4.7%. Hence, a very small EER change overwhelms the impact of a much larger change in GWP.

Another way of viewing Figure 5 is to follow a constant line of TEWI for varying EERs and GWPs. As can be seen, going from point (a) to point (a') -- an EER increase of 5% -- would allow a refrigerant to have a GWP of 5,400 to maintain a constant TEWI value; an increase of 217% over that of R-22's value of 1,700 Kg CO_2/Kg refrigerant.

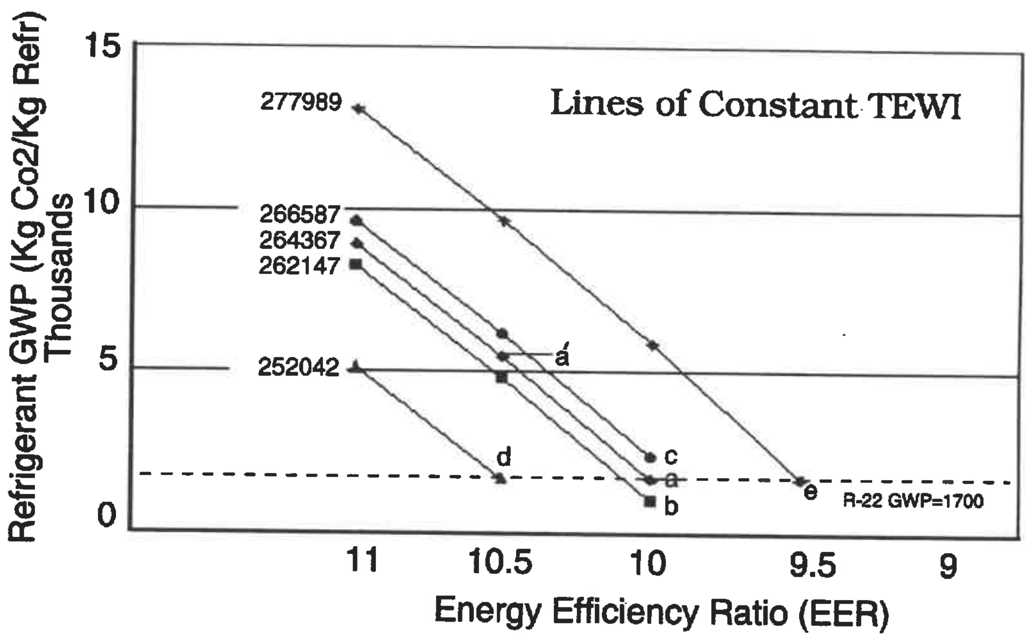

Figure 5. TEWI for varying GWP and efficiencies as compared to HCFC-22

CONCLUSIONS

For air-conditioning and refrigeration applications the direct contribution to TEWI is a small portion of the total; system efficiency is more important than is the GWP of the working fluid. Greenhouse warming contributions from air-conditioning and refrigeration systems are primarily a function of the carbon dioxide emitted during the generation of electricity that drives the equipment.

For today's air-conditioning and household refrigerator applications, over the lifetime of the equipment, 97 - 99^{+}% of the TEWI is due to the release of carbon dioxide formed during generation of power. Hence, focusing only on the working fluid offers little opportunity to reduce greenhouse gas emissions. The steps that manufacturers have taken, and continue to take, to reduce the direct contribution (e.g., system tightening, revamped service practices, etc.) only influence a small portion of the total TEWI.

For today's supermarket applications, where the direct effect is significantly higher, opportunities for reducing the direct emissions exist by reducing charge sizes, further minimizing leaks, and switching to a lower GWP refrigerant. However, these moves cannot be effected at the expense of efficiency.

Overall, small variations in efficiencies have a greater impact on greenhouse gas creation than do large variations in a refrigerant's direct GWP. Therefore, caution must be exercised to ensure that efficient working fluids are not prematurely dismissed from air-conditioning and refrigeration applications just because they have a GWP valuation over some arbitrarily-determined threshold.

REFERENCES

1). R. Bittner, Director of Engineering, Giant Foods Company, telephone interview, 24 August 1995
2). J. M. Calm, **ARTI Refrigerant Database**, Air-Conditioning and Refrigeration Technology Institute (ARTI), Arlington, VA, June 1995 release (updated quarterly)
3). J. M. Calm, *Comparative Global Warming Impacts of Electric Vapor-Compression and Direct-Fired Absorption Equipment*, published by the Electric Power Research Institute (EPRI), EPRI report TR-103297, August 1993
4). S. K. Fischer et. al., *Energy and Global Warming Impacts of CFC Alternative Technologies*, prepared by Oak Ridge National Laboratory and Arthur D. Little Inc. for the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and the U.S. DOE, 1991
5). S. K. Fischer et. al., *Energy and Global Warming Impacts of Not-In-Kind and Next Generation CFC and HCFC Alternatives*, prepared by Oak Ridge National Laboratory for the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) and the U.S. DOE, 1994
6). M. W. Hawley, *Global Warming Impact of HCFC-22 Replacements*, ARI White Paper, May 1994
7). M. Skaer, *Retail Stores Say Venting Not Major Reason for CFC Losses*, Air-Conditioning, Heating & Refrigeration News, 8 May 1995
8). *Summary for Policy Makers, Radiative Forcing of Climate Change: The 1994 Report of the Scientific Assessment Working Group of IPCC*, Published by the Intergovernmental Panel on Climate Change (IPCC) for the United Nations Environmental Programme (UNEP), Table 5, 1994