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Comparison of TEWI for Fluorocarbon Alternative Refrigerants and Technologies in Residential Heat Pumps and Air-Conditioners

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ABSTRACT

A study was conducted to examine the total equivalent warming impacts (TEWI) of unitary residential and commercial space conditioning equipment in North America, Europe, and Japan using refrigerants R-407C, R-410A, and R-290 and alternative heating/cooling technologies. Assumptions and results of this study are presented for U.S. residential applications. Alternative systems are compared with the TEWI of conventional R-22 based vapor compression systems under the same operating conditions. The analysis for North America includes low- and medium-efficiency electric heat pumps and high-efficiency air-to-air and geothermal heat pumps. Alternative space conditioning technologies, such as electric resistance heat, a gas furnace/central air conditioner combination, a gas engine-driven heat pump, and a prototype gas-fired absorption heat pump, are included for residential TEWI comparisons in three U.S. cities with a range of heating and cooling loads. The effects of improving seasonal efficiencies on TEWI are shown, as well as the consequences of replacing R-22 with alternative refrigerants.

TEWI results from previous reports, and those presented here show that the direct global warming potential (GWP) of the refrigerant used for residential heat pump applications contributes less than 7% to the total TEWI for these products and that the direct GWP of the refrigerant is less important than the overall efficiency of the unitary system (Fischer 1991; Fischer 1994; Sand et al. 1997). Clearly, any refrigerant or refrigerant blend proposed as an alternative for R-22 must provide good cycle efficiency in addition to acceptable environmental and operational qualities to be seriously considered in unitary equipment applications.

INTRODUCTION

Residential and light commercial vapor compression air-conditioning systems using the hydrochlorofluorocarbon (HCFC) refrigerant R-22 are common throughout the United States and Japan. These electric heat pumps are used in the mid-latitude regions of both countries where there is a favorable balance between heating and cooling requirements. Air conditioning is also becoming a popular convenience in parts of Europe and the developing countries. Chlorine-containing HCFC refrigerants are scheduled for phaseout under the London and Copenhagen amendments to the Montreal Protocol. Environmental activists are also scrutinizing chlorine-free hydrofluorocarbon (HFC) refrigerant alternatives for possible regulation because of their global warming potentials (GWPs). Systems using these HFCs, however, make a moderate contribution to global warming because of their efficiency and low emission rates. "Natural"[1] refrigerants are being considered by many as inherently superior to "manufactured" working fluids because they have low or zero GWPs.

When the total equivalent warming impact (TEWI) is calculated for unitary and residential air-conditioning systems utilizing alternative technologies or conventional systems operating with HCFC, HFC, or "natural" refrigerants, the environmental benefits of more energy-efficient technologies that decrease CO_2 emissions to the earth's atmosphere become

1. The word "natural" is used to indicate a chemical compound that is naturally occurring in the earth's environment, but it should not connote compounds that are better or safer than those that are "manufactured." In truth, special considerations are often needed to accommodate the flammability and/or toxicity of some "natural" compounds when they are used as refrigerants.

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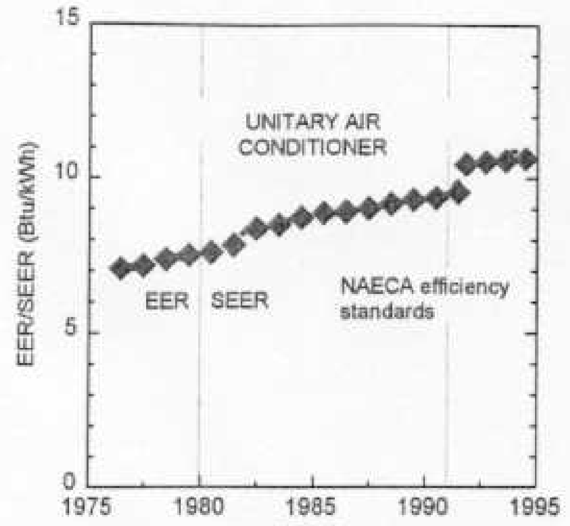

Figure 1 *Efficiency ratings of unitary air conditioners in the U.S. (sales weighted average).*

apparent. The efficiency of unitary equipment has improved steadily, as indicated by Figure 1 (ARI 1996). This trend of improving efficiency, which reduces the indirect contribution to TEWI from CO_2 emissions, will continue even as new refrigerants are adopted due in part to government regulation and to design improvements implemented by equipment manufacturers.

The market for unitary equipment is highly competitive and driven to a large extent by equipment first costs. Alternative refrigerants, such as R-134a, with lower cooling capacities than R-22 are at a disadvantage because any loss in volumetric capacity will necessitate larger compressors and heat exchangers, which translate into a higher cost to the consumer. Additional equipment modifications, manufacturing costs, transportation costs, service expenses, etc., associated with the use of alternative refrigerants will suffer the same disadvantage. Alternative refrigerants such as R-407C and R-410A, which are convenient and safe to handle and deliver the same or greater efficiency and capacity at the lowest cost, have an advantage in the marketplace.

REFRIGERANTS

R-22 is the refrigerant used in virtually all unitary equipment because of its inherent efficiency and high refrigeration capacity. Provisions of the Clean Air Act (CAA) in the United States call for R-22 to be phased out of "new equipment" by 2010 and allow production of smaller amounts of the refrigerant until 2020 for servicing installed equipment. No single-component refrigerant or blend has been identified that can match every desirable characteristic of R-22 in all unitary applications. The Air-Conditioning and Refrigeration Institute (ARI), through its Alternative Refrigerants Evaluation Program (AREP), led an international effort to identify, evaluate, and disseminate data on potential refrigerant alternatives. This effort identified several alternative refrigerants that are blends of two or more compounds, which gave similar or slightly improved performance compared to R-22 (Godwin 1994). AREP also indicated that no single alternative has both a higher efficiency and greater capacity than R-22 in all of its current applications and that several refrigerants or blends of refrigerants may be needed to fill the requirements for servicing older equipment and charging new equipment when R-22 is phased out of production.

R-134a, an HFC, is a commercially available refrigerant initially considered by AREP as an alternative for R-22. It is a single-component refrigerant that has been widely adopted by the domestic refrigeration, automotive air-conditioning, and chiller air-conditioning market segments. As a result of strong domestic and foreign sales, the major refrigerant manufacturers have constructed manufacturing plants to satisfy a projected 2005/2010 demand of 310,000 metric tons a year and have generated extensive product application literature (Billiard 1997). R-134a has a 40% lower refrigeration capacity than R-22 under unitary operating conditions and has shown a 5% decrease in efficiency for typical unitary applications in AREP testing, so it cannot be considered as a "drop-in" replacement. As mentioned before, lower cooling capacities than R-22 are a decided disadvantage because losses in refrigerant volumetric capacity necessitate larger compressors and heat exchangers to maintain system capacity. These result in higher equipment costs for a product that is extremely first-cost sensitive.

Favorable test results with other prospective R-22 alternatives in redesigned and retrofit equipment and the continuing emphasis on more efficient heating and cooling performance make it unlikely that R-134a will be extensively used in unitary air conditioning or heat pumps (UNEP 1995). The most likely replacements for R-22 are binary or ternary HFC mixtures. In addition to being ozone-safe, nonflammable, nontoxic, and efficient, they have performance levels close to or superior to that of R-22.

One of these refrigerants, designated R-407C, is a 23/25/52 mass % blend of the HFCs R-32, R-125, and R-134a that has shown equivalent capacity to R-22 but efficiencies that averaged about 5% lower than R-22 in soft-optimized equipment (Godwin 1994). "Soft optimization" refers to variations in one or more of the following list of system components: lubricant, compressor displacement, refrigerant charge, flow control (i.e., expansion device), motor size, heat exchanger circuiting and/or size, compressor speed, and accumulator size. These changes were made by individual AREP participants to make the equipment more suitable for the refrigerant under test.

R-407C is a zeotropic blend that will fractionate or change composition during evaporation and condensation in vapor compression refrigeration applications and will show about a 5°C (9°F) change in temperature (temperature glide) across the heat exchangers due to this composition change.

This heat exchanger temperature glide and tendency to fractionate make zeotropes less attractive commercially. The use of zeotropes is a departure from the isothermal phase change behavior of pure refrigerants to which the industry has become accustomed. Additionally, system leaks with zeotropes may result in composition changes, making service and repair more difficult.

Tests with R-407C in laboratory breadboard and soft-optimized, commercially produced equipment have established capacity and system efficiency levels relative to R-22 that allow TEWI evaluations for unitary equipment (Hwang 1995; Murphey 1995; Junge 1995; Berglof 1996; Linton 1996). R-407C has an ASHRAE safety classification of A1/A1, which designates it as a commercially available refrigerant with low toxicity and no flame spread as purchased and after a worst-case fraction in a vapor compression system.

Another replacement for R-22, R-410A, is a mixture of R-32 and R-125 with a 50/50 mass % composition. AREP found the blend's capacity was essentially the same as R-22 given compressors appropriately sized for the difference in volumetric capacities of the two refrigerants. The ARI results also indicated that system cooling efficiencies averaged from 1% to 6% higher than R-22 (Godwin 1994). Extensive testing of R-410A has also occurred subsequent to the AREP reports (Hwang 1996; Murphey 1995; Feldman 1995; Linton 1996). The results from these tests indicate that R-410A can be used in redesigned unitary equipment with no decrease in system capacity and a 4% to 7% increase in system efficiency. Most of this system efficiency gain is attributed to improved thermophysical properties of the blend over R-22. System efficiency results from this series of tests were used for the TEWI results presented in Figures 2 through 4.

When used in refrigeration equipment, R-410A is considered a "near azeotrope" in that it does not fractionate during a phase change. One drawback of the mixture is that it has a system operating pressure approximately 50% higher than R-22, so it cannot be considered as a drop-in replacement nor can it be used for retrofit into existing unitary systems. Design changes will be required to accommodate these higher operating pressures. Another more subtle drawback of this HFC mixture is a critical temperature significantly lower than that of R-22 (73.3°C [164°F] for the HFC blend vs. 96.1°C [205°F] for R-22). This could diminish efficiency relative to R-22 at higher condensing and outdoor air temperatures. R-410A has an A1/A1 ASHRAE safety classification.

Propane (R-290) can be a good refrigerant, and it is attracting attention as an alternative to R-22. The major disadvantage with propane, naturally, is that it is flammable. Due to their flammability, hydrocarbon refrigerants such as propane are only seriously considered in low-charge systems such as refrigerators, freezers, and packaged coolers (Stene 1996). The most significant use of hydrocarbons as working fluids is found in the United Kingdom and Germany. Three engineering solutions proposed to mitigate the flammability risk of propane in residential systems are (1) preventing leakage and removing all sources of ignition; (2) addition of a flame suppressant, such as R-227ea or a fluoroiodocompound, to

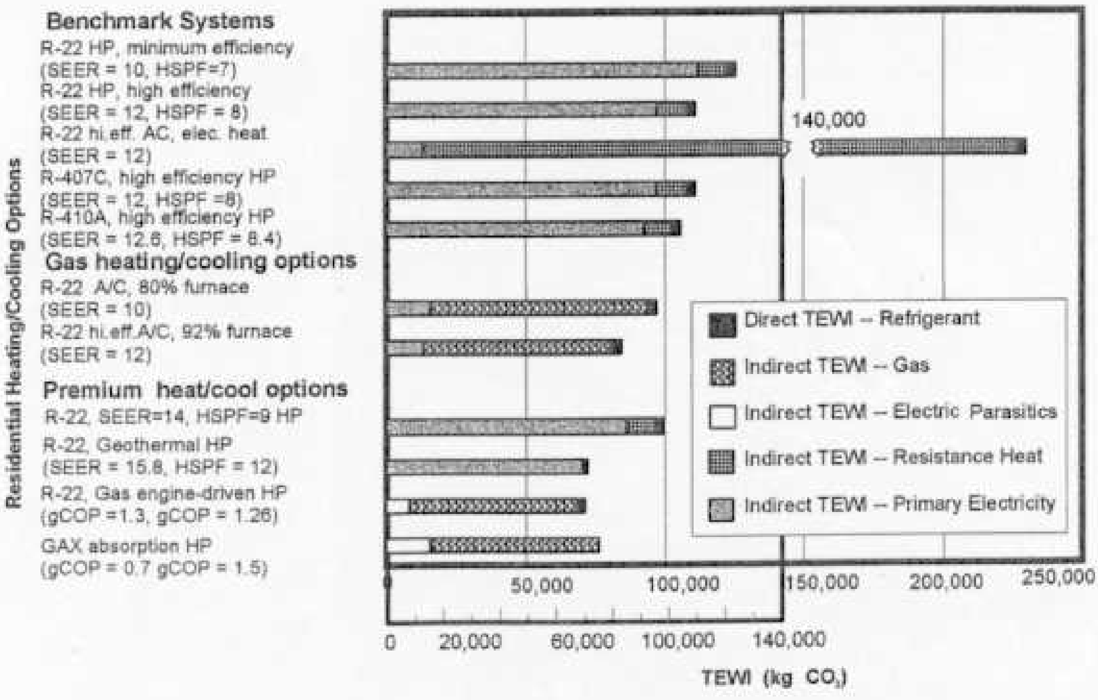

Figure 2 TEWI for residential heating/cooling options: Pittsburgh.

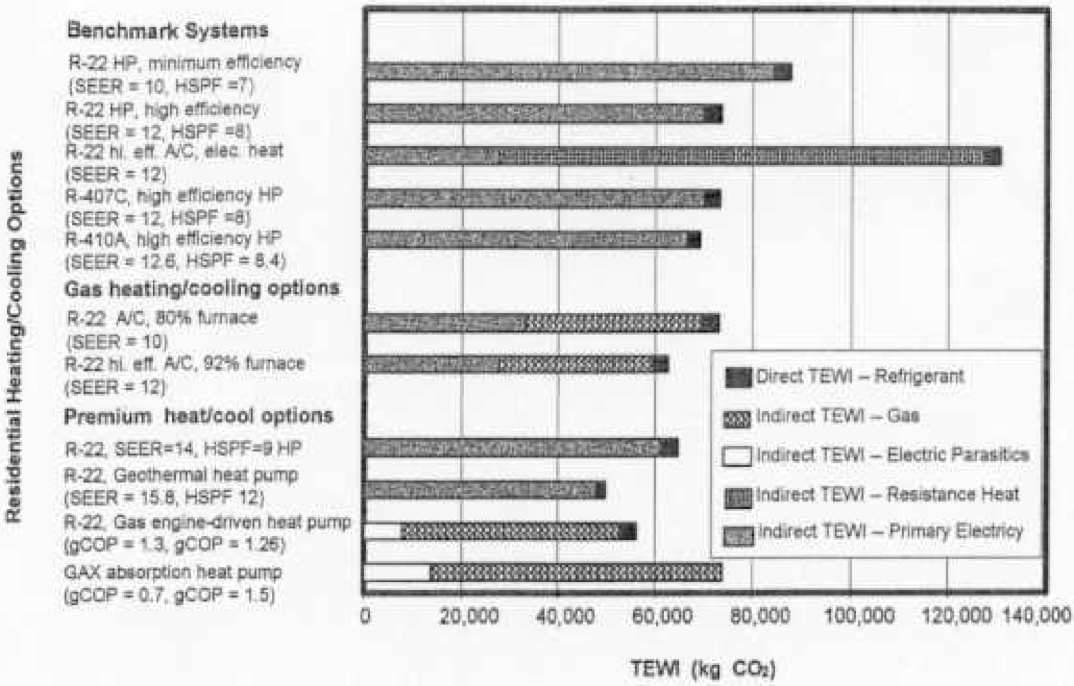

Figure 3 *TEWI for residential heating/cooling options: Atlanta.*

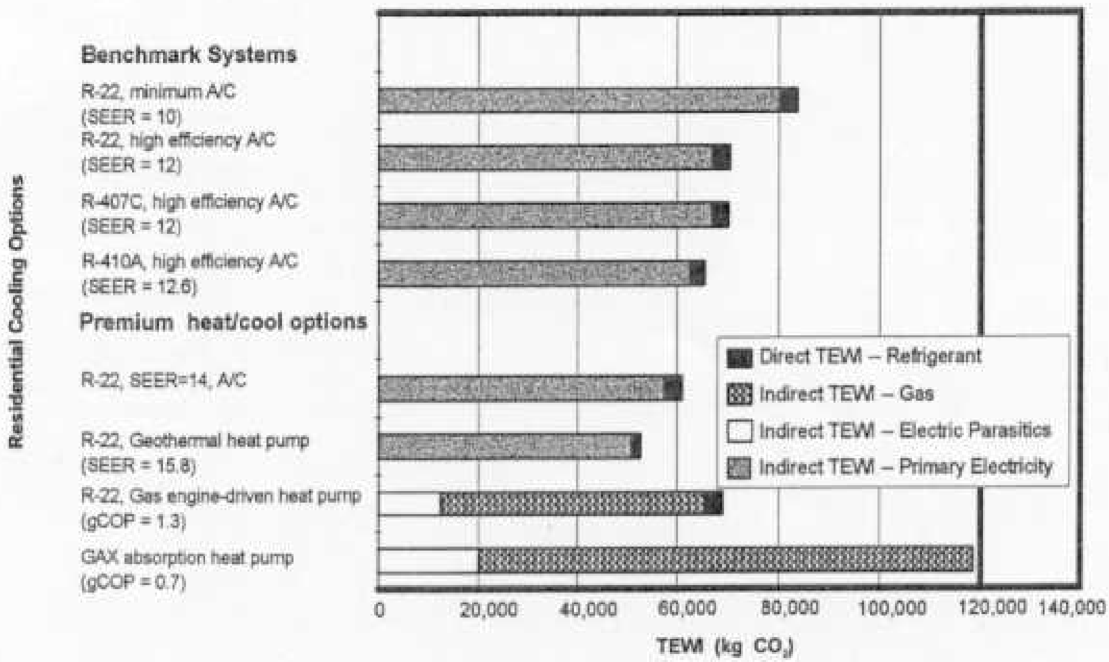

Figure 4 *TEWI for residential cooling options: Miami.*

propane in sufficient quantities to make the mixture nonflammable; or (3) use of a secondary loop to prevent the propane from entering residences (Douglas 1996; Keller et al. 1996). There is a strong reluctance on the part of manufacturers in the United States and Japan to expose customers and employees to the hazards of flammable refrigerants in residential and commercial products, which will make it difficult for propane to gain wide acceptance in these markets. Current industry standards and community building codes prohibit the use of a flammable refrigerant in residential split-system applications (Keller et al. 1997).

One evaluation of propane conducted by an equipment manufacturer reported a slightly better efficiency and capacity for a 9 kW (2½ ton) air conditioner compared to an R-22 system (Treadwell 1994). Part of this work involved a cost estimate for a 12 kW (3½ ton) unitary air conditioner using propane as the refrigerant. This estimate for a propane system came out to be 30% higher than a comparable system using R-22. These increased costs are due to system modifications necessary to safely handle a flammable refrigerant.

More recent evaluations on the feasibility of substituting propane for R-22 in ducted residential air conditioners have also focused on the relative costs vs. environmental benefits, an approach suggested by Kuijpers (1995). Modeling comparisons were performed for 10.5 kW (3 ton) unitary systems designed to use R-22, R-410A, and R-290 as the refrigerants and concluded that the R-290 system would cost 35% more than the baseline R-22 unit when appropriate safety modifications are implemented (Keller et al. 1997). These increases in cost are not required when using a nonflammable refrigerant. In addition, there are higher marginal costs to the manufacturer associated with safe storage, charging, and handling of a flammable refrigerant in the plant compared to R-22. Conclusions from these studies indicate that TEWI could be reduced if propane were used as a refrigerant in leak-tight air conditioner/heat pumps designed to safely accommodate a flammable refrigerant in a ducted, direct-expansion air-to-refrigerant heat exchanger but that applying the additional costs to improve the efficiency of systems using nonflammable refrigerants would be more cost-effective.

Several recent research reports indicated that propane is being substituted for R-22 with slight (≈5%) increases in system efficiency in hydronic, heating-only heat pumps commonly used in Europe (Lystad 1996; Rodecker 1996).

When using a secondary loop/central air ducted configuration, the reductions in direct global warming contribution resulting from use of propane as a refrigerant would not outweigh the increase in indirect global warming associated with the additional heat transfer step inefficiency. Therefore, this option was not included in the TEWI results presented in Figures 2 through 4.

Ammonia (R-717) is a good refrigerant that is likely to experience broader application as CFCs and HCFCs are phased out, but it is not a choice well suited for unitary equipment (Fairchild and Baxter 1995). Residential and light commercial vapor-compression air-conditioning systems are mass produced using copper for refrigerant tubing in both the heat exchangers and connecting components, hermetic compressors that have electric motors with copper windings, and direct heat exchange evaporators. Ammonia is incompatible with copper, and the required design changes needed to ensure acceptable equipment lifetimes would result in material and installation cost increases.

Direct heat transfer evaporators are not considered feasible with ammonia in residential applications. There is a desire to keep ammonia out of the conditioned space because of its toxicity, so a secondary heat transfer loop and fluid would be needed. This additional loop increases the cost and complexity of the system and, as with propane, increases the indirect global warming to TEWI much more than the reduction that would result from using a zero GWP refrigerant. Additionally, ammonia has high discharge temperatures, which would be problematic on small systems but can be handled more economically on the larger refrigeration systems in which it is currently being used.

It is not considered likely that ammonia will be used commercially in unitary equipment as a replacement for R-22. No TEWI calculations are performed for unitary systems using ammonia as a vapor compression refrigerant. Ammonia-water absorption equipment options are considered, however, because commercial ammonia-water absorption systems are currently available for residential cooling applications and because this technology has fuel switching and primary energy consideration features that should be compared to electric vapor compression.

ALTERNATIVE TECHNOLOGIES

Electric resistance is evaluated as a heating option in Pittsburgh and Atlanta to provide a comparison to electric, vapor-compression heat pump results. No heating options are considered in Miami because the heating load is essentially zero for a typical weather year. In regions of the country where gas is available, gas furnaces in combination with a centralized, vapor-compression air conditioner are evaluated in addition to a gas engine-driven heat pump and a gas absorption heat pump under development (the generator absorber heat exchange [GAX] cycle), which utilizes an ammonia-water absorption cycle.

ASSUMPTIONS

National averages are used for electric power plant CO_2 emission rates in these calculations. An annual average electrical power plant emission rate of 0.650 kg CO_2/kWh (1.43 lb CO_2/kWh) is used for the United States. This CO_2/kWh emission rate is compiled from open literature data (EIA 1996) and includes an average 6% transportation and distribution loss factor. The heat content and carbon dioxide emission rate for natural gas used for the gas-powered technologies were 38,200 kJ/m^3 and 51.1 g CO_2/MJ, respectively. A 96.5% distribution efficiency was assumed for natural gas, which raised the CO_2

TABLE 1
Relative Efficiencies for Alternative Refrigerants in Residential Air-Conditioning Equipment (Relative to R-22)

Refrigerant	Components (mass % composition)	Refrigerant Charge Size (kg)	Efficiency Relative to R-22 1996-1997	
			Cooling	Heating
R-22	R-22 (100%)	2.80 (6.27 lb)	100%	100%
R-407C	R-32/R-125/R-134a (23/25/52)	2.80 (6.27 lb)	100%	100%
R-410A	R-32/R-125 (50/50)	2.30 (5.07 lb)	105%	105%

emission rate to 53.0 g CO_2/MJ (55.9 g CO_2/1000 Btu; 0.123 lb CO_2/1000 Btu) at its point of use (EIA 1997).

Published measurements for steady-state COP data relative to R-22 and fixed values for the seasonal energy efficiency ratio (SEER) or heating seasonal performance factor (HSPF) of R-22 were used to calculate SEERs and HSPFs for propane and the R-407C and R-410A mixtures. The relative efficiency values used for these calculations are summarized in Table 1. Refrigerant charge sizes for a 10.5 kW (3 ton) heat pump or central air-conditioning unit are also given. Further development of air conditioners specifically designed to use these alternative refrigerants could lead to more favorable comparisons relative to R-22.

System efficiency data used for calculating TEWI values for electrically driven residential heating/cooling options are shown in Table 2. Unitary equipment is usually designed to meet SEER and HSPF targets with appropriate adjustments of hardware to fit the refrigerant and compressor performance.

The seasonal heating and cooling performance of a gas engine heat pump, available since 1994, is listed at 126% AFUE[2] and 1.28 COP (AGCC 1996). TEWI values were computed for this system using published efficiencies. For the GAX absorption heat pump, TEWI values were calculated using heating and cooling COPs applied in previous AFEAS/DOE TEWI reports (Fischer 1994). The GAX COP values include electrical parasitic loads. No GAX systems are currently in production; however, prototypes are being tested, and initial products are targeted for market entry by 2000 (Fiskum et al. 1996). System efficiency values used in TEWI calculations for residential heating/cooling options that use gas as a primary energy source are given in Table 3.

Fifteen-year lifetimes are assumed for U.S. unitary equipment. Based on information assembled from ARI member companies, the maximum residential heat pump and air conditioner annual leak rates of 4% of the charge for 1996-1997 equipment were used for the direct TEWI calculations (Hourahan 1996). An end-of-life (EOL) charge loss rate of 15% was rationalized for residential units on the basis of recovering 90% of the charge from 95% of the field units but allowing for a 100% charge loss from about 5% of field stock (Hourahan 1996).

TABLE 2
Current Technology (1996 -1997) Efficiency Data

System	Efficiencies Cooling/Heating
Air-to-Air Heat Pumps, R-22:	
Minimum Efficiencies	SEER-10 / HSPF-7
High Efficiencies	SEER-12 / HSPF-8
Premium Technologies:	
Air-to-Air Electric Heat Pump (R-22)	SEER-14 / HSPF-9
Geothermal Heat Pump (R-22)	SEER-15.8 / HSPF-12

TABLE 3
Residential Gas Option Efficiencies

System	Efficiencies Cooling/Heating
Electric A/C and Gas Furnace:	
Minimum Efficiency	SEER — 10/80% Gas Furnace
High Efficiency	SEER—12/92% Gas Furnace
Premium Technologies:	
Electric A/C and Gas Furnace	SEER—14/92% Gas Furnace
Engine-Driven Heat Pump (R-22)	gCOP—1.30/gCOP 1.26
GAX Absorption Heat Pump	gCOP— 0.70/gCOP 1.50

METHODOLOGY

Total equivalent warming impacts were calculated for baseline 10.5 kW (36,000 Btu/h) heat pumps with SEERs of 10, 12, and 14 and corresponding HSPFs of 7, 8, and 9 with a refrigerant charge of 2.8 kg (6.2 lb) of R-22 for three locations in the U.S. In calculations where air conditioning is combined with some other heating technology, a central air conditioner with SEERs of 10 and 12 was used. For "premium" technology residential equipment, the baseline SEER of the heat pump or central air-conditioning unit was increased to 14.

[2] AFUE—annual fuel utilization efficiency—appliance heating efficiency is calculated by assuming 100% of the fuel is converted to thermal energy and then subtracting losses for exhausted sensible and latent heat, cycling effects, infiltration, and pilot losses over the entire year. AFUE does not include electrical energy used for fans, pumps, ignition, exhaust, or blowers.

SEERs and HSPFs for a geothermal heat pump were chosen from information provided by major manufacturers and results of standard rating/certification tests (ARI 1993).

Seasonal energy use is computed based on a "typical" 167 m^2 (1,800 ft^2) residence with a 78.8×10^6 kJ/yr (74.7×10^6 Btu/yr) heating load and 17.0×10^6 kJ/yr (16.1×10^6 Btu/yr) cooling load in Pittsburgh; a 36.7×10^6 kJ/yr (34.8×10^6 Btu/yr) heating load and 35.7×10^6 kJ/yr (33.8×10^6 Btu/yr) cooling load in Atlanta; and a 0 kJ/yr (0 Btu/yr) heating load and 86.7×10^6 kJ/yr (82.2×10^6 Btu/yr) cooling load in Miami (Fischer et al. 1991).

RESULTS AND DISCUSSION

Total equivalent warming impacts for various residential heating/cooling options were calculated for Pittsburgh, Atlanta, and Miami in the United States, and the results are shown in Figures 2 through 4. These results are computed using the efficiency data in Tables 2 and 3. Each figure has two sections: the upper portion shows "benchmark systems," or heating/cooling options that represent baseline cost for a residential system in each of these cities, while the lower indicates a "premium heat/cool options" section, which shows options that are significantly more expensive than the baseline technology. Figures 2 and 3 also contain gas heating/cooling options for Pittsburgh and Atlanta, which have significant heating loads. Results for the GAX absorption heat pump included in the "premium heat/cool options" section are based on projected efficiencies since this technology is not commercially available at this time.

Attaching specific prices to each option is difficult and oftentimes misleading because HVAC manufacturers, dealers, installers, and local utilities can all influence the final price paid by the consumer. While specific prices are problematic, it is assumed that newly developed and more efficient options shown will have higher equipment first costs than conventional systems, and dividing these technology options into standard and premium categories gives some indication of the added investment required to obtain a TEWI benefit (Kuijpers 1995).

Each segment of the bar graphs plotted in these figures indicates TEWI contributions from different sources. The initial, gray section of most bar graphs is the indirect TEWI contribution from electric power used for the vapor compression heating and/or cooling process. The fish-scale pattern section of bars shown in Figures 2 through 4 indicates the indirect TEWI contribution from natural gas combustion. In the Pittsburgh and Atlanta results, Figures 2 and 3, the TEWI contribution from electric resistance heat required to supplement heat pump operation and primary electric resistance heat is shown as a weave pattern section. The white section on some bars for gas-driven heat pump technologies shows the TEWI contribution from auxiliary electric parasitic loads, such as resistance heat, pumps, or fans, that are not included in the SEER or HSPF ratings of the equipment. The darkest section on the ends of most bar graphs is the direct TEWI contribution caused by refrigerant losses.

Using Figure 2 as an example, the advantages of increasing unit efficiencies become quite obvious if the R-22 minimum (SEER=10/HSPF=7), R-22 high-efficiency (SEER=12/HSPF=8), and R-22 (SEER=14/HSPF=9) in the "premium heat/cool options" section are compared. Total TEWI values for these three heat pump options in Pittsburgh are about 126,000; 111,000; and 100,000, respectively. A 10% to 12% improvement in TEWI is indicated for each step of efficiency improvement. Relative TEWI decreases with increased efficiency are greater in climates with a higher cooling/heating ratio.

Figures 2 and 3 also show the benefits in TEWI and relative energy savings associated with the added expense of a geothermal or ground-source heat pump, which are mainly due to increased efficiency rather than a smaller charge size.

Use of propane and ammonia as vapor compression refrigerants with secondary loops is not shown because any reductions in direct global warming resulting from use of these near zero GWP refrigerants would be outweighed by increases in indirect global warming emissions with the secondary loop/central air option. Direct propane systems with all the added safety precautions and increased costs needed to make them safe for the U.S./North American market are not shown but are assumed to perform similarly to the R-22 heat pump/air conditioners with essentially no direct TEWI contribution from the refrigerant (Keller et al. 1996, 1997).

Figures 2 and 3 show the effect of using electric resistance heat on TEWI. Combinations of gas furnaces with an electric, central air conditioner are a popular choice that shows a slightly lower TEWI than electric air-to-air heat pumps under the conditions used for these calculations.

There are TEWI results for the HFC mixtures R-407C and R-410A as well as for R-22 in Figures 2, 3, and 4. In all the cases presented, the direct contribution of refrigerant to the TEWI is no larger than 7% of the total. The average direct TEWI contribution is generally 3% to 4%. Essentially no difference is seen in the TEWIs for R-22 systems and those where R-407C or R-410A are used as substitutes because unit efficiencies are very similar and the 100-year integrated time horizon GWPs are 1700 for R-22, 1530 for R-407C, and 1730 for R-410A. The smaller charge sizes per unit of capacity for R-410A and early indications of system efficiency improvements over R-22 will help reduce TEWI for this option.

In climates with a small cooling load and high heating load, the gas-fired engine and GAX heat pumps have a significantly smaller TEWI than electric heat pumps with average SEER (10-12) and HSPF (7-8) ratings. Comparisons in Figures 2 through 4 are based on published efficiencies for gas engine heat pumps and product introduction performance goals for the GAX absorption system. The GAX has TEWI comparable to conventional electric-driven compression systems in climates with balanced heating and cooling loads and higher TEWI in cooling-dominated climates.

Nearly 80% of the direct TEWI is due to the assumption on annual emissions from leakage, accidents, and maintenance practices. As regulatory procedures requiring conscientious maintenance and repairs of leaks and strict adherence to refrigerant recovery come into common usage and are followed, the direct effect will diminish in significance.

CONCLUSIONS

TEWIs for residential systems using blends of HFCs as alternatives are not significantly different from those calculated for R-22. With optimization of equipment designs, they should continue to show small efficiency improvements. Refrigerant leakage—and the corresponding global warming impact of the refrigerant—from hermetic unitary equipment is small. Future service losses should continue to decrease because maintenance and replacement practices mandating refrigerant recovery and recycling are either in place or under consideration and increasingly accepted in many countries.

The direct contributions to TEWI for all vapor compression systems presented are small fractions of the total in each case considered. These contributions should not be ignored, however. Procedures for handling refrigerants and accounting for refrigerant usage currently being adopted should be effective in reducing the direct TEWI effects from those shown here.

TEWIs of fluorocarbon systems are less than those of a propane or ammonia vapor compression cycle with a secondary heat exchange loop. Arguments against using propane or ammonia in direct systems with adequate safety precautions to prevent fires, explosions, and human/material compatibility problems center on the relative effectiveness of additional investments required.

In climates with appreciable heating loads where gas is a convenient option, gas furnace/electric air conditioning and gas-fired heat pump options show a smaller TEWI than standard air-to-air heat pumps. This advantage decreases as the balance shifts to lower heating and higher cooling loads.

First costs, availability, climate, and projected operational costs, rather than TEWI, are likely to remain the principal criteria for selecting residential heating/cooling systems.

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DISCUSSION:

H. Michael Hughes, Engineering Consultant: One of your slides showed that the TEWI for a 12 SEER system with a high leakage rate was still less than that of a 10 SEER system with zero leakage. This demonstrates that the most effective means of reducing contribution to global warming is to emphasize efficiency rather than legislating the working fluid.

James Sand: Yes, thank you Mike for pointing this out. For most applications where refrigerants are used conscientiously, improving system operating efficiencies is more effective at reducing global warming impacts than using low or zero GWP refrigerants. The slide you refer to compares the TEWI of two electric heat pumps: (1) an SEER 12 / HSPF 8 heat pump and (2) an SEER 10 / HSPF 7 heat pump in the Atlanta area. As you point out, the TEWI for the first system with an annual leak rate of 12% of the system charge is lower than that of the second system with no leakage. It's worth noting that an Ad Hoc committee of ARI determined that under the recovery / recycle / reuse requirements mandated in the U.S. the average annual leak rate for a heat pump is less than 2% of its original charge. Another way of summarizing that particular slide would be to say that a zero ODP refrigerant that is less efficient than R-22 in a heat pump (perhaps as a result of modifications needed to use it safely) has a greater adverse environmental effect than R-22 (or currently considered R-22 alternatives) used in a conscientious manner employing recovery, recycle, and reuse.