NATIONAL ENERGY IMPACTS OF CFC ALTERNATIVES IN HEATING, AIR-CONDITIONING, AND REFRIGERATING EQUIPMENT AND FOAM INSULATION

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ABSTRACT

Chlorofluorocarbons (CFCs) are used extensively throughout modern society as the working fluids in high-efficiency refrigeration equipment and as blowing agents in manufacturing high R-value foam insulations. CFCs contribute to the destruction of stratospheric ozone and are a significant threat to the global environment. Future production and emissions of CFCs will be controlled under the provisions of the Montreal Protocol and the use of these compounds will be phased out. The U.S. Department of Energy is concerned about the energy-efficiency impacts of alternative chemical compounds and technologies that may be used as substitutes for CFC-11 and CFC-12 as refrigerants and blowing agents. This paper discusses the possible increase in national energy use resulting from the replacement of CFCs with alternative compounds. Significant increases in energy use could occur, particularly in refrigerator/freezers, freezers, water heaters, and commercial buildings.

INTRODUCTION

Discoveries about "greenhouse" warming and the depletion of stratospheric ozone have brought concerns about the global environment into the national headlines. Chlorofluorocarbons (CFCs) have been identified as major contributors to these environmental problems and a landmark international treaty, the Montreal Protocol (1987), was drafted to address the threat of unconstrained CFC production and release into the atmosphere. This agreement marked the first time that nations have banded together to address a threat to the global environment before absolute scientific evidence was available (data obtained since the agreement was signed have confirmed the decisions made in Montreal). The U.S. Environmental Protection Agency (EPA) drafted rules to implement the provisions of the Montreal Protocol (*Federal Register* 1987) in the U.S. by reducing production of refrigerants 11, 12, 113, 114, and 115 (referred to as CFC-11, CFC-12, CFC-113, CFC-114, and CFC-115) to 50% of their 1986 levels by 1998. The production of halons 1211 and 1301 is also regulated.

The Montreal Protocol also provided for a reassessment of the scientific data linking CFCs and stratospheric ozone levels. The committees participating in this process submitted their recommendations for revising the Protocol in the fall of 1989 to be voted on by the participating countries in the spring of 1990. It is very likely that the result will be a tightening of the provisions and perhaps even a complete phaseout of these compounds by the year 2000.

A great deal of attention is being focused on developing new alternative refrigerants that can be used in place of CFCs in refrigeration equipment and polymer foam insulations. The most important of these, perhaps, are compounds that can be used in place of CFC-12 and CFC-11 in household refrigerators and freezers, automobile air conditioners, centrifugal chillers, and the polyurethane, polyisocyanurate, and extruded polystyrene insulations for buildings and appliances. The U.S. Department of Energy (DOE) is particularly concerned that the products that use these alternatives are as energy-efficient as those they would be replacing. In July 1987, the DOE requested that Fred Creswick and the author perform a quick evaluation of the possible impacts of the Montreal Protocol on national energy use. This project led to several informal reports to the DOE and eventually to publications in the technical literature (Fischer and Creswick 1988, 1989; Creswick et al. 1988).

The study for the DOE was performed at a time when there was a great deal of uncertainty surrounding the issue of whether alternative refrigerants and foam blowing agents could be developed as close substitutes for CFC-11 and CFC-12. Consequently, it relied on what little data were available at that time to look at four distinct scenarios: one in which near drop-in substitutes were available, a fall-back case based on existing compounds and technology, a worst-case scenario in which no chlorinated compounds could be used in place of CFC-11 or CFC-12, and a long-term advanced technology case. A

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disadvantage of this approach, however, was that it examined discrete options and did not convey much information about how sensitive the results were to the assumptions that had been made. Energy use impacts presented in this paper are shown on a continuum scale based on performance of alternatives relative to the CFCs being replaced.

APPLICATIONS

There are two assumptions that apply uniformly to each of the applications that are evaluated. In each application it has been assumed that (1) there has been a complete replacement of the national inventory of buildings or equipment based on CFC-11 and CFC-12 with alternative refrigerants and blowing agents and (2) CFC-blown foam insulation is replaced by an equal thickness of insulation blown with the alternative chemical. National energy use is then estimated for each application using representative refrigeration efficiencies (e.g., compressor, motor, and ideal refrigerant cycle) and insulation R-values and for 1% to 15% reductions in the efficiencies and R-values.

Refrigerator/Freezers and Domestic Freezers

Refrigerators and freezers will be particularly affected by a phase-out of chlorofluorocarbons because they use both CFC-11 in the insulation and CFC-12 in the refrigeration system. There are approximately 113 million refrigerators in the U.S. and 32 million household freezers. The daily energy use of refrigerators is estimated based on a 20 ft^3 automatic defrost refrigerator using a correlation developed in an earlier project for the DOE (Little 1980). The computations were performed assuming 80 kWh per year for defrosting, a compressor capacity of 675 Btu/h, internal loads of 200 Btu/h, a compressor efficiency of 60% and motor efficiency of 80%, and 30.6 W for fans and heaters for the refrigerator. The freezer calculations were based on a capacity of 450 Btu/h without any energy for defrosting, fans, or internal loads. Heat leakage into the cabinets was estimated for 2 in. of insulation around the fresh food compartment, 2½ in. around the freezer compartment, 38°F inside the fresh food compartment, 5°F in the freezer, and 90°F ambient air.

The assumptions for the refrigerator led to a computed compressor EER of 4.74 Btu/Wh for CFC-12, cabinet heat leakage of 295 Btu/h for CFC-11 blown R-8.3/in. foam (Dietrich and Doerge 1988), and a daily energy use of 2.80 kWh. This is equivalent to 1.33 quads (1 quad = 10^{15} Btu) of primary energy (using 11,500 Btu/kWh to convert from site energy to primary energy) nationwide. Similar computations were performed for an 18 ft^3 manual defrost freezer, resulting in a leakage of 360 Btu/h into the cabinet, 1.82 kWh/day, and a national energy use of 0.24 quads.

Figures 1 and 2 show both the energy use for each refrigerator and freezer and the national energy uses as functions of the base case compressor EER for each of four different R-values for the insulation. The top curve in Figure 1 is the energy use for refrigerators using foam insulation with R-values 85% of those for CFC-11 blown polyurethane. The second curve is for R-values 10% lower, the third 5% lower, and the bottom one for current CFC-11 blown polyurethane (0% change). The EER of the refrigeration system is varied continuously from 85% to 105% of the CFC-12 efficiency to show the impact of increased or decreased refrigeration efficiencies on unit and national energy use. In this analysis it does not matter whether these changes in efficiency are due to the thermodynamic properties of the substitute refrigerant or from changes in compression efficiency. Figure 2 contains the corresponding results for household freezers. The data in each of these figures show that energy use for these applications is fairly sensitive to changes in the EER and insulation R-value (e.g., 5%, 10%, and 15% changes in both parameters result in 6%, 13%, and 22% increases in energy use).

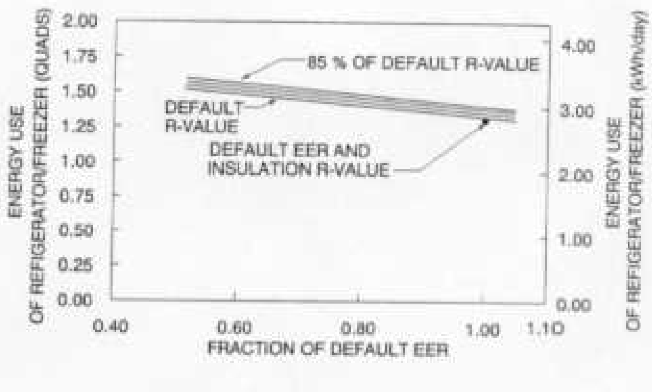

Figure 1 *National energy use for refrigerator/freezers*

Water Heaters

Household water heaters also use CFC-11 blown foam insulation and any alternative blowing agents that form foams with lower R-values will lead to higher national energy use. Currently there are about 86 million water heaters in the U.S. and about half of these use polyurethane insulation and the rest use fiberglass insulation. Those using fiberglass are not considered in these calculations. The analysis was simplified further by examining only the standby losses for the water heaters and avoiding consideration of hot water draw schedules, inlet temperatures, etc. Thus the numbers presented represent energy use only to make up the standby losses and not the total energy use for heating hot water. The calcu-

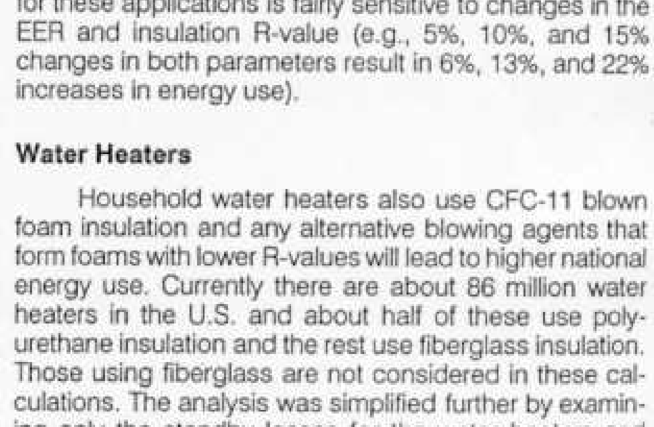

Figure 2 *National energy use for household freezers*

lations are also based on a fixed 80°F temperature difference between the water inside the tank and the surrounding air temperature, comparable to 140°F water and 60°F air, and they do not account for seasonal fluctuations in the air temperature.

This simplified UA-ΔT algorithm was checked against experimental data for a 40-gal water heater (Vasilakis and Gerstmann 1983) before being used to estimate energy use for 50-gal water heaters with two in. of polyurethane insulation. The jacket losses for this base case unit are estimated to be 3825 Btu/day. Changes in these losses are linear with changes in the k-factor of the insulation (neglecting surface effects, R-value of the tank and cabinet, etc.) but nonlinear with changes in R-value. This dependence is illustrated in Figure 3, where the national energy use is presented in quads (based on a 75% heating efficiency for gas units and 11,500 Btu/kWh for electric) as a function of changes in the base case foam thermal conductivity. The total energy use for hot water would change at a lower rate, of course, since the standby losses represent only about 20% to 30% of the water heater energy use (Grot 1978). A 5% increase for standby losses would be more like a 1% to 1.5% increase in overall energy use.

Mobile Air Conditioning

The energy impacts of CFC substitutes on automobile and light truck air conditioning are also twofold but not because of changes in refrigerant and insulation. In this case there is an impact due to using an alternative refrigerant in place of CFC-12 and also a penalty associated with any possible changes in weight for the redesigned system. A lower capacity refrigerant would require a larger compressor and heat exchangers to provide the same degree of comfort as the original equipment. The extra weight of these heavier components will affect fuel use for every mile the vehicle is driven whether the air conditioner is in use or not.

There are approximately 170 million cars and light trucks in the U.S. and about 85% of all new vehicles sold have air-conditioning (Pierce 1975). Thus, using the assumption of a complete replacement of existing equipment with air conditioners using an alternative refrigerant, there would be 144.5 million vehicles affected at some future date. The average car in the U.S. is driven about 10,000 miles/yr, uses about 20 gal of gasoline for air-conditioning per 10,000 miles driven, and requires about 10 gal of gas per 10,000 miles for each 100 lb of weight. A CFC-12-based automotive air conditioner weighing 25 lb would then account for about 22.5 gal out of the typical annual fuel use.

Figure 4 shows the range of impacts that alternative refrigerants could have on national energy use for this application. Each of these five curves reflects the possible effects of heavier air conditioners with changes in the operating efficiency. The effects of changes in air-conditioner efficiency are inversely proportional to the change ($COP_{12}/COP_{alt.}$), while the impacts of increased weight are directly related to the weight of the alternative system. A 10% reduction in efficiency and a 5 lb increase in weight result in an annual fuel use of 25.2 gal for each vehicle for air conditioning ($20/0.90 + 10 \times 30/100$), which overall is a 12% increase from a value of 22.5 gal for the base-case CFC-12 system. This amounts to 0.05 quads/yr nationwide at 42 gallons per barrel of gasoline and 190.4 million barrels/quad.

Centrifugal Chillers

There are 74,000 centrifugal chillers in the U.S. (private communication, Peter Teagan) that use CFC-11, CFC-12, CFC-114, HCFC-22, and HCFC-500 to provide chilled water for space cooling. Although these chillers range in size from 80 to 2500 refrigeration tons for packaged units and up to 10,000 tons for field-assembled machines, the average machine in use has a cooling capacity of about 260 tons. The vast majority of these systems use CFC-11 or CFC-12 and typically use around 0.65 kW/ton (i.e., a COP of 5.41). The national energy use for chillers is the product of the number of machines, the average capacity, energy use per ton, and the number of hours of operation (about 2000 h/yr) (Teagan 1989). This results in a national energy use of 0.29 quads/yr for centrifugal chillers. A 10% increase in kW/ton for each machine due to alternative refrigerants would lead to a 10% increase in national energy use, 0.03 quads.

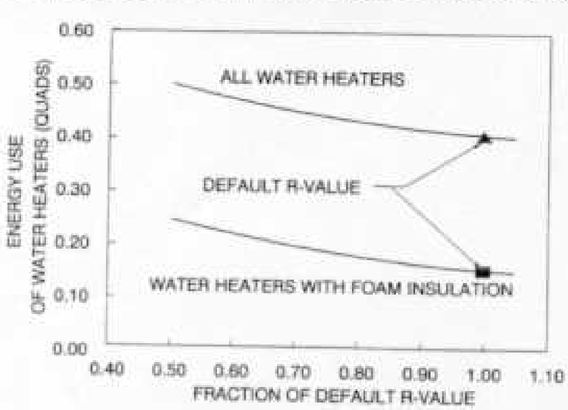

Figure 3 National energy use for water heater standby losses

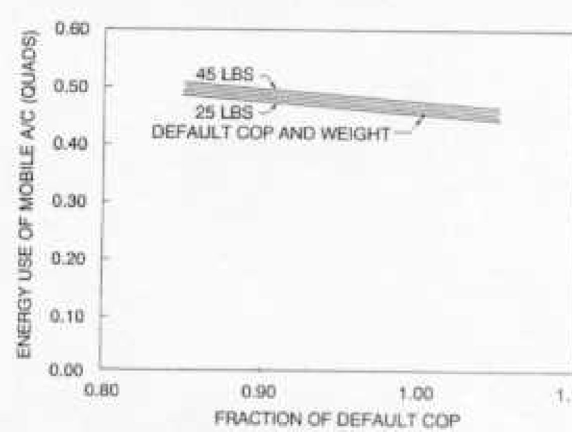

Figure 4 National energy use for automobile air conditioning

Retail Refrigeration

Commercial or retail refrigeration equipment covers a broad spectrum, and it is difficult to generalize about what constitutes a "typical" piece of equipment. This category includes the display cases in supermarkets and convenience stores; it is assumed that the energy use of these units is dominant and that the energy used for refrigeration by cafeterias, restaurants, other retail businesses (e.g., florists, hotel and motel ice makers) is small by comparison. Having reduced the entire category to food display cases, there are three classes of equipment to look at: (1) high-temperature units for fresh fruits and vegetables, (2) medium-temperature units for meats and dairy products, and (3) low-temperature units for frozen foods. HCFC-22 can be substituted for CFC-12 in the high-temperature units without an increase in power requirements so national energy use will not be affected by a phase-out of CFCs in fresh food display cases. The medium- and low-temperature equipment uses HCFC-502 (an azeotropic mixture of HCFC-22 and CFC-115) and they will be affected by the phase-out.

A number of very broad assumptions have been made in order to estimate the national energy impacts of CFC alternatives in these two classes of display cases. These assumptions include estimates of the total number of each kind of unit (710,000 of each), the typical capacity of each one (18,500 Btu/h for a three-shelf dairy case and 4500 Btu/h for a reach-in freezer), and the fraction on-time for each (75%). COPs of 5.81 and 5.20 were computed for the medium- and low-temperature display cases using the thermodynamic properties of HCFC-502, typical operating conditions, and motor and compressor efficiencies of 80% and 62.5%, respectively. Combining all these assumptions results in an estimate of 0.22 quads/yr for commercial refrigeration equipment in the U.S. There is a great deal of uncertainty in this figure, though, because of the generalizations made about the type of equipment and number of units in use. Further refinements are probably not necessary, though, because perturbing these assumptions results in small increases in national energy use; reductions of 5% to 15% in the compressor COPs due to alternative refrigerants result in increases in national energy use of only 0.01 to 0.04 quads.

Refrigerated Transport

There are 178,000 refrigerated trailers in the U.S. used for shipping perishable goods. Typically these are 45 ft trailers with separate refrigeration units driven by a diesel engine. The calculations performed in the earlier work for the DOE focused on the impact of changes in the insulation used in the trailers and did not examine alternative fluids for the refrigeration systems. This simplification was done because of the broad range in the energy use cited for these refrigeration units, 0.25 to 0.65 gal per ton of cooling delivered. It was assumed that there was 4 in. of polyurethane insulation in each wall of the trailer, a 70° F ΔT between the inside and outside air, and that the trailers were in use 50% of the time (on the road continuously but returning empty 50% of the time).

The analysis was further simplified by focusing on the conduction of heat into the trailer and ignoring that part of the refrigeration load from loading and unloading and the infiltration of warm air at highway speeds. An industry rule of thumb was used to increase the loads by 33% to account for heat transmission through the trailer framing members. Combining these numbers (178,000 trailers, 1410 ft^2 of surface area, 70° F ΔT, 133% for framing, 50% use-schedule, 0.65 gal/h per ton refrigeration, and 120,000 Btu/gal for diesel fuel) results in an estimate of less than 0.02 quads/yr nationwide for mobile refrigeration. This number is very small relative to the other applications of CFCs so no effort has been directed toward improving the assumptions or examining the sensitivity of the energy impacts of alternative blowing agents to changes in the assumptions.

Soft Drink Vending Machines

The energy use for refrigerated vending machines, mainly soft drink machines, was estimated using the algorithm that was used for the refrigerator and freezer calculations. No effort was made to account for seasonal temperature differences for machines located outdoors, and the author did not estimate the energy used for bringing down the temperature of a freshly loaded machine. A daily energy use of 7.01 kWh was computed assuming that 1000 Btu/h leaks into the cabinet, that there is a 25 W evaporator fan, 110 W for lighting, 275 W/day for defrosting, and a 2000 Btu/h compressor with a motor efficiency of 80% and compression efficiency of 65% (compressor EER of 6.33 at typical operating conditions) This daily rate corresponds with 0.09 quads for the 3 million machines in use in the country. Although the energy use is very nearly proportional to the thermal conductivity of the insulation (inversely proportional to the R-value), it is not directly proportional to the EER because of the constant auxiliary power for fans, lighting, and defrost. A 15% reduction in R-value combined with a 15% reduction in EER results in an increase in national energy use of only 0.02 quads. Although 0.02 is a large percentage increase from the initial estimate of 0.09 quads, it is insignificant compared with the other impacts of other applications of CFCs.

Residential Construction—Sheathing

More attention and more criticism has been directed toward those sections of the study done for the DOE concerning building insulation than toward all of the other applications combined. This area is composed of three different applications: (1) polyurethane and extruded polystyrene sheathing used in residential construction; (2) polyurethane and extruded polystyrene boards, prefab panels, and spray for commercial buildings; and (3) polyisocyanurate boards for the low-slope roofs of commercial buildings. There is a great diversity of opinion concerning what assumptions should be used in estimating the energy impacts of CFC alternatives for each of these applications.

There are perhaps better data available for analyzing the impacts from changes in materials for residential construction than exist for either of the two areas of commercial construction. Private homes typically use a wood frame construction with 2 × 4 studs on 16 in. centers, 3.5 in. fiberglass batts within the wall cavities, and a heating system using natural gas, fuel oil, electric heat pump, or resistance heat. About 50% of the homes nationwide also have some form of air conditioning. Sheathing material is commonly used on the outside of the frame construction with plywood used where extra reinforcement is needed and either fiberboard, CFC-blown polyurethane or extruded polystyrene foams, or expanded polystyrene foam sheathing elsewhere.

Data are available from a 1986 survey for

- the percentages of homes in the Northeast, Midwest, South, and West that heat with gas, oil, heat pumps, and resistance heat;
- the distribution of homes between the four geographic regions; and
- the percentage of homes in each region that are built using 0.5, 0.625, 0.75, and 1.0 in. sheathing.

The early study for DOE also relied on this survey for the percentage of homes built using polyurethane, polystyrene, and fiberboard sheathing. More general assumptions are used in this study, as mentioned later. The calculations are based on 59.3 million single-family detached homes and 37.3 million attached multi-family homes, and the computations for each home are based on the results of an independent study done for the DOE on this subject (Petersen and Fanney 1988). The computations were repeated for four different scenarios:

- low penetration of CFC foams into residential construction market (i.e., 10% polyurethane, 10% extruded polystyrene, 80% fiberboard),
- medium penetration (20% polyurethane, 20% polystyrene),
- high penetration (30% polyurethane, 30% polystyrene), and
- very high (50% polyurethane, 50% polystyrene).

Table 1 shows the increase in national energy use for each of these cases assuming that equal thicknesses of non-CFC blown sheathings with R-values of 85%, 90%, 95%, and 100% of the CFC-blown foams are substituted for the sheathings using CFC-11 or CFC-12.

TABLE 1
Increased National Energy Use for Single- and Multi-Family Residences Due to Alternative Non-CFC Foam Sheathings (quads)

Fraction of Default R-Values	Low Market Penetration	Medium Market Penetration	High Market Penetration	Very High Market Penetration
0.85	0.01	0.02	0.03	0.03
0.90	0.01	0.01	0.02	0.02
0.95	0.00	0.01	0.01	0.01
1.00	0.00	0.00	0.00	0.00

Clearly, the energy impacts are not particularly large if alternative blowing agents are developed that produce foams with even 85% of the R-value of existing poly-

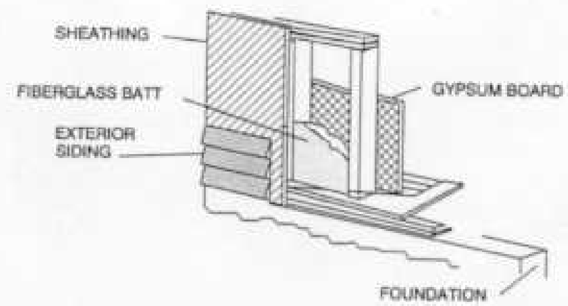

***Figure 5** Cut-away drawing of a residential wall section identifying the layers of insulating materials*

urethane and polystyrene sheathing materials. The reason for this is shown in Figure 5 and Table 2. The cavity wall construction with fiberglass batts is already well insulated and the difference between adding one inch of a CFC-blown polyurethane or polystyrene with a similar product that does not use CFCs is not very large. The impacts would be significant under the very high market penetration assumptions, however, if non-CFC blown products do not become available. There would be a 0.21 quad increase in national energy use if all homes were built using a conventional fiberboard material instead of polyurethane sheathing (0.15 compared to extruded polystyrene). The corresponding changes in national energy use would be 0.13 quads if expanded polystyrene, a non-CFC foam material that is currently available, were used instead of polyurethane in all homes, and 0.04 quads for extruded polystyrene.

TABLE 2
Total Wall R-Values with CFC Alternative Foam Sheathing

Fraction of Default R-Values	R-Value of Wall – 1" Sheathing	
	Polyurethane	Extruded Polystyrene
0.85	19.2	17.3
0.90	19.6	17.5
0.95	20.0	17.8
1.00	20.4	18.1

Commercial Building Wall Insulation

CFC-blown foam insulations are also used in commercial building construction, primarily in masonry cavity walls and in prefabricated panels. Unfortunately, there are no good data on what portion of commercial construction uses these materials or the thicknesses of insulation used. Estimates were made by assuming that:

- 40% of all commercial buildings use CFC-blown foam insulation;
- the total energy use for commercial building space conditioning is 4.73 quads per year;
- somewhere between 25% and 50% of the space-conditioning loads of commercial buildings are due to heat transfer through the walls (the remainder being lost through internal loads, the roof, and the foundation);

- windows comprise 30% of the exterior wall area; and
- masonry construction would use 1 in. of blown foam insulation and 2 in. for panel construction.

The size of the average commercial building is about 14,000 ft^2, which would typically be a one- or two-story building (EIA 1987); for a one-story building the wall area is roughly 25% of the total surface area (walls and roof), while for a two-story building it is about 50% of the surface area.

Figure 6 shows the estimated energy use for commercial building space conditioning due to losses through the walls for the assumptions that the typical building is either one or two stories (i.e., 25% or 50% of building loads from the walls). These curves include the 40% of buildings assumed to use foam insulations and also the 60% that do not. These curves are very flat, due primarily to the assumption that 30% of the wall area is glass. While the R-values of the opaque wall areas are 11.0 and 15.7 for the masonry and panel walls, respectively, the total wall R-values are only 4.1 and 4.5 when the windows are accounted for. Even relatively large decreases in the R-value of the insulation have only a small decremental effect on the losses through the walls. Although there is a 100% difference between the curves in Figure 6, reflecting the uncertainty in the assumptions for the two cases, there is only a 5% to 6% difference between the highest and lowest points on each curve.

Commercial Building Roof Insulation

There are more data to use in evaluating the impacts of changes in polyisocyanurate and extruded polystyrene insulation on low-slope roofs for commercial buildings than there are for the evaluation of wall insulation, but not much more. Approximately 65% of these kinds of roofs are constructed using a CFC-blown foam insulation, mainly polyisocyanurate boards. The cutaway drawing of built-up roofing on a steel deck shown in Figure 7 is fairly typical of this type of construction. Two inches of R-6.38/in. foam boards are used in combination with the other materials to build a roof with an overall R-value of 16 h · ft2 · °F/Btu.

Applying the assumptions used for the calculations for commercial building walls, the energy use due to heat gains and losses through low-slope roofs is approximately 1.18 quads (0.29 quads for the roofs using CFC-blown foam insulation). Data compiled in a university study were used to evaluate the effects of changes in foam R-value on national energy use ranging from 50% to 105% of the base-case R-value of 6.38/in. (Chang and Busching 1983). These results are shown in Figure 8, where the upper curve represents the energy use for all roofs and the lower curve just those roofs using alternative foam blowing agents. These curves show that even a reduction of 15% in the R-value/in. results in a relatively small increase in energy use, 0.04 quads, but that dropping to R-4.0/in. (63% of the base case) would cause a significant 0.13 quad increase.

SUMMARY OF RESULTS

The compounds that are most commonly discussed as substitutes for CFCs in energy-related applications are HCFC-123 for CFC-11 centrifugal chillers, HFC-134a for CFC-12 in refrigerating equipment, and HCFC-123 and HCFC-141b as blowing agents in foam insulation. Experiments conducted at national laboratories and by equipment manufacturers and the chemical producers show that equipment designed to use these chemicals could be almost as efficient as current equipment with efficiency reductions of 5% or less. Thermal losses could be higher than 5%, though, because of growing concerns about global warming and the long-term use of any chlorine containing refrigerants and blowing agents. The total national energy use and the increased energy use assuming a 5% and 15% reductions in refrigeration EER and insulation R-value are sum-

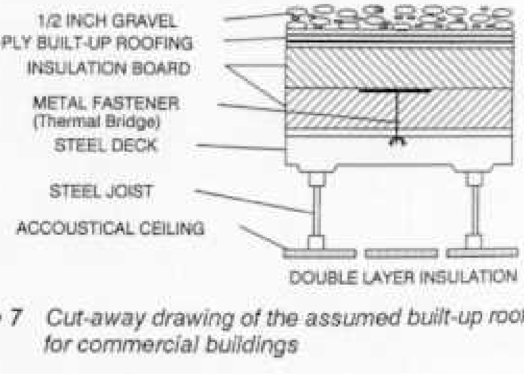

Figure 7 Cut-away drawing of the assumed built-up roofing for commercial buildings

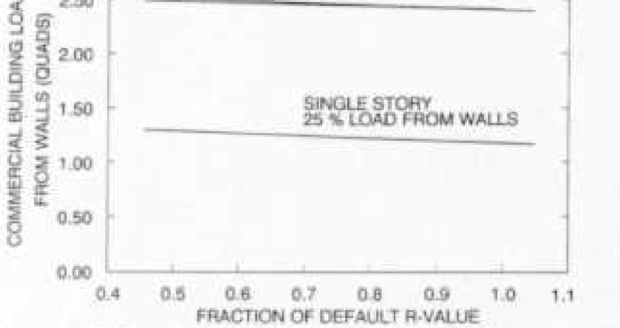

Figure 6 National energy use for heat losses/gains through commercial building walls

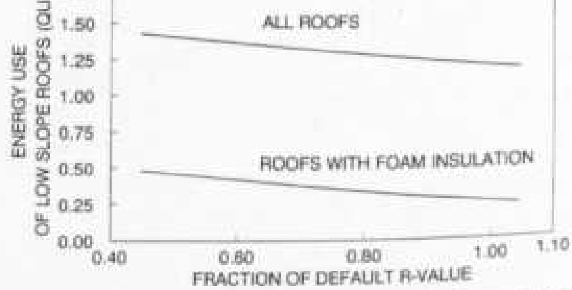

Figure 8 National energy use for heat gains/losses through low-slope roofs on commercial buildings

marized in Table 3. The energy use for those applications that rely on CFCs as refrigerants and also as insulation blowing agents, such as refrigerators and freezers, are much more sensitive to less efficient alternative chemicals than most of the other applications. Residential buildings are particularly insensitive, even under assumptions of significant market penetration, because they use fiberglass batts to provide a major part of the total wall R-value.

TABLE 3
Total Estimated National Energy Use for Each Application and Increased Energy Use with 5% and 15% Reductions in EER and Insulation R-value

Application	Total Energy-Use (Quads)	Energy Impact 5% Reduction (Quads)	Energy Impact 15% Reduction (Quads)
Refrigerator/Freezers	1.33	0.08	0.29
Household Freezers	0.24	0.02	0.06
Domestic Water Heaters	0.36	0.01	0.02
Mobile Air Conditioning	0.41	0.03	0.08
Centrifugal Chillers	0.29	0.02	0.05
Retail Refrigeration	0.22	0.01	0.04
Refrigerated Transport	0.02	*	*
Vending Machines	0.09	<0.01	<0.02
Residential Bldg. Walls	*	<0.01	<0.03
Commercial Bldg. Walls	2.36	<0.01	0.03
Commercial Bldg. Roofs	1.18	0.01	0.04

*not calculated

The uses of blown foam insulation in commercial buildings appear to be insensitive to alternative blowing agents, but it must be remembered that these results are based on very little data. The energy impacts for commercial building walls are low because of the assumptions concerning 40% market penetration and the ratio of window to opaque wall area. The results for roofs are small, relative to the total energy use for roofs, in part because the losses for the roofs without CFC-blown foams are such a large part of the total. There would be significant increases in energy use for both of these applications if non-CFC blowing agents do not become available and existing materials (e.g., fiberglass, expanded polystyrene) had to be used in place of polyurethane and polyisocyanurate foams (assuming equal thicknesses of the foams and existing substitutes).

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DISCUSSION

H.H. Slack, Mechanical Engineer, General Services Administration, Atlanta, GA: What was the basis for the 10% loss in efficiency shown for chillers?

S.K. Fischer: The 10% was chosen somewhat arbitrarily to demonstrate that the changes in national energy use for chillers are directly proportional to changes in the energy use (in kW/ton) of the typical chiller. There is some historical basis to the 10%, in that initial testing of chillers using HCFC-123 showed an 8% to 9% increase in energy use. The machines being built and marketed today, however, show very little difference in energy use compared to chillers using CFC-11.

R.P. Lortie, Senior Staff Engineer, R.J. Reynolds Tobacco Co., Winston-Salem, NC: What is the relative cost differential between R-12 and R-134a and also between R-12 and acceptable blends?

Fischer: I'm not able to answer that. At one time the chemical companies were saying that R-134a would cost 3 to 4 times as much as R-12, but I don't know if that has changed in the last 12 to 18 months. The price differential would certainly be influenced by any changes in the price of R-12 since the production quotas went into effect and by any taxes placed on R-12. I have not heard any comparisons between the cost of R-12 and possible blends.

J. Siemens, Chz. M. Hill Company, Corvallis, OR: Why was the building roof insulation energy impact based on the number of present buildings when that insulation is there to stay? Why wasn't thicker, less "efficient" insulation assumed for new buildings (i.e., *no* building energy impact)?

Fischer: The assumptions throughout this study were made to meet the needs of the Department of Energy in formulating policy and developing programs. DOE has been concerned about how great an impact there will be from CFC alternatives 30, 40, or 50 years from now. In that time frame, it is reasonable to assume there would be a national inventory of equipment using CFC alternatives (e.g., refrigerators, chillers, auto a/c's, etc.) comparable to the number in use today (probably somewhat larger). It is also reasonable to assume there would be substantial new construction of buildings insulated with non-CFC-blown foam insulations. The assumption in this case was that the amount of new construction would equal the number of buildings existing in 1986. It is arbitrary, but that is what was chosen.

The assumption that equal thicknesses of CFC-blown and non-CFC insulation were used was made to get an upper bound on the energy impacts. Equal thermal performance *could* be achieved by using thicker layers of insulation. Whether or not they *would* be used depends on a lot of decisions made by contractors, building owners, regulatory boards, etc. The purpose here was to determine an upper limit on the impact without making a lot of assumptions about what people would actually do. If there is a large impact, then the question needs to be looked at more carefully.