DEVELOPING COST CURVES FOR CONSERVED ENERGY IN NEW REFRIGERATORS AND FREEZERS

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ABSTRACT

Energy consumption in refrigerators can be reduced through the application of a number of conservation measures. These measures may be introduced in many different combinations and in varying orders, each of which will result in a different cost of conserved energy. A microcomputer model is constructed which estimates the impact of specified conservation measures on energy consumption and on initial and lifecycle costs. The model is used to develop cost curves with measures ranked in order of increasing marginal cost. Cost curves are developed for three models of refrigerator/freezers and two freezers. They show potential savings of more than 75% of current energy use at costs that compare favorably with current electricity prices.

This paper begins with a brief description of the model's structure and the calculational algorithms. Next, the cost curves — with measures applied in order of increasing marginal cost — are derived. Measures are described along with their associated incremental first costs, marginal costs of saved energy and net lifecycle cost savings.

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INTRODUCTION AND SUMMARY OF RESULTS

Energy Use and Conservation Potential in Refrigerator and Freezers

Refrigerators are the largest residential end user of electricity in the United States. Department of Energy statistics show 18% of residential electricity consumption going to refrigerators.[1] Freezers consume another approximately 6% of residential energy consumption.

Numerous studies have addressed the feasibility and cost effectiveness of particular energy conservation measures or packages of measures for refrigerators and freezers. But these studies have been limited by their consideration of particular sets of measures, rather than combining all available conservation technologies for refrigerators in a least cost order.

This paper develops a simplified model to account for the sequential addition of a variety of energy conservation measures. The model is used to calculate energy consumption, energy savings, and lifecycle cost, allowing a rank ordering of these conservation options to be made. Measures are ranked both in terms of least cost order and in terms of the extent of technological innovation required to bring energy saving products into mass production.

The results of this evaluation show that it is technically feasible and economically beneficial to reduce the energy consumption of refrigerators and freezers by as much as 80% relative to the energy use of typical American models produced in 1985. The cost of conserved energy from this large reduction is typically between 2 and 2.5 cents per kWh saved. This is equivalent to a simple payback period of about four years at U.S. average energy prices.

This impressive result occurs because many efficiency measures combine in complementary ways that have not been modelled previously. For

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[1] "Supplement to Consumer Products Efficiency Standards Engineering Analysis Document," U.S. Department of Energy, DOE/CE-0045, July 1983, p. 57 (revised).

This impressive result occurs because many efficiency measures combine in complementary ways that have not been modelled previously. For example, improvements in compressor efficiency can still produce cost-effective savings from a refrigerator whose insulation thickness has been optimized. This report analyzes improvements in the efficiency of a number of subsystems of refrigerators and freezers -- the insulation, the door closure, the motor/compresser, and the internal heat transfer -- and finds that simultaneous changes in all of these systems result in cost optimized refrigerators with much lower energy consumption than models currently available.

Background Information

Refrigerator energy consumption has varied widely over the past 40 years as shown in Figure 1.[2] Energy use increased steadily between 1950 and 1972, due to a combination of an increase in size from about 7 ft.[3] to 17 ft.[3], and the addition of extra features, including automatic defrost, a true (5°F) freezer compartment, as well as a 40% decrease in efficiency[3] (not illustrated in the figure).

From 1972 through 1984, the energy consumption of an average refrigerator declined by about 30%, as California established efficiency regulations for refrigerators and as energy prices reversed a decades-long decline and began to increase in real terms.

The bulk of the energy savings were achieved sometime between 1972 and 1981; progress since 1981 has been at a slow 1.5% annual rate of increase in efficiency. California has recently established regulations that will require average refrigerator energy consumption to drop into the mid-600 kWh/yr range by 1992. The expected effect of these regulations is illustrated by the dashed line in Figure 1.

Some progress towards meeting these regulatory goals is apparent. The most efficient large, top-freezer refrigerator widely available in the U.S. in late 1985 consumed about 750 kWh/yr, or almost 35% less energy

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[2] This figure is derived from statistics from the years 1950 to 1975, taken from S. Berman et al. "Electrical Energy Consumption in California: Data Collection and Analysis", Lawrence Berkeley Laboratory, UCID 3847, 1976, combined with figures for 1972, 1978, and 1981-4 taken from the "Written Comments of the Association of Home Appliance Manufacturers to the Northwest Power Planning Council on the Draft 1985 Power Plan", 24 October 1985, Appendix 2.

[3] See Berman et al., ibid.

that the average.[4] Japanese models appear to be significantly more efficient than this[5] and a handmade two-door partial automatic refrigerator designed for use with photovoltaic power systems uses only 250 kWh/yr, based on test ratings.[6]

COMPUTING THE COST CURVE FOR CONSERVATION IN REFRIGERATORS

Methodology

This report examines a wide variety of technologies for improving refrigerator efficiency. It focuses on several of the most promising of these technologies and quantifies the expected costs and savings from incorporating them into the design of refrigerators and freezers. All of these measures are taken from sources whose authors projected them to be technically and commercially feasible for implementation within the next 5-8 years. The measures modelled would result in refrigerators and freezers with greater energy efficiency than current models, but with comparable or better consumer convenience features.

Some of the conservation measures analyzed in this study involve technically straightforward changes in the design of the product. Others require modest technological advance, or the mass-production of measures that may be more difficult to produce in commercial products than in prototypes. As a result of these distinctions, the report categorizes measures with respect to the degree of technical difficulty or innovation required.

All of the individual measures included in this paper have been discussed in the published technical literature. Many of them were carefully reviewed by the appliance industry during proceedings concerning appliance standards.

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[4] Whirpool model ET17HK1M listed in "The Most Energy-Efficient Appliances", American Council for an Energy-Efficient Economy, Washington, DC, Summer 1985.

[5] D.B. Goldstein, "Efficient Refrigerators in Japan: A Comparative Survey of American and Japanese Trends Toward Energy Conserving Refrigerators", Proceedings of the 1984 Summer Study on Energy Efficiency in Buildings, Vol. E, ACEEE, 1984.

[6] See "Photron Inc. Field Test Report - The Sun Frost 17 ft^3 DC Refrigerator" and Sun Frost product literature. Available from Sun Frost, P.O. Box DD, Arcata, CA 95521.

Definition of Measures and Models

This study utilizes the methods employed by the United States Department of Energy (DOE) in its analysis of appliance efficiency standards.[7] The same techniques were employed by the California Energy Commission (CEC) in its recent evaluation of standards.[8]

This method begins with an hypothetical baseline model that represents a particular class of refrigerators or freezers. The baseline model is chosen to embody the typical size, features, energy consumption, and technical description (size, component efficiency, etc.) of a particular model chosen by DOE to be representative of the class. Engineering changes are made to the baseline model, and the cost and energy savings resulting from these changes are calculated. The extra first cost for the changes is estimated on the basis of additional materials, capital, and labor costs, along with markups to projected cost at the retail level.

This analytic method computes the effect of adding discrete energy conservation measures to refrigerators and freezers. A measure involves changing a characteristic of the product, such as increasing the thermal resistance of insulation or improving the efficiency of the compressor. Each measure is independent of all other measures, although the magnitude of energy savings from a measure will depend strongly on the characteristics of the model to which it is applied.

Cost of Saved Energy

This study ranks conservation measures in order of increasing cost of saved energy and decreasing technological feasibility. This leads to a "supply curve" for conserved energy, in which each succeeding measure is more costly than the previous measure and each package of measures is more rapidly available than the following package. When a cost threshold corresponding to the price of the alternative supplies of electricity is reached, the optimum energy conservation level (from a societal viewpoint) is found.

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[7] "Consumer Products Efficiency Standards Engineering Analysis Document," U.S. Department of Energy, DOE/CE-0030, March 1982.

[8] "Technical Analysis of the Energy Conservation Potential for Refrigerators, Refrigerator/Freezers, and Freezers, Docket 84-AES-1", P400-84-013, California Energy Commission, August 1984.

The cost of conserved energy is computed using standard methods.[9] Extra first costs for conservation measures are divided by discounted energy savings over the lifetime of the appliance. We employ a 3% real discount rate, as that is the rate generally used to evaluate the cost of energy supply alternatives.[10]

Classes of Products. Each product class, as defined by industry and DOE, is discussed separately. The top mount automatic defrost refrigerator/freezer accounts for about 70% of total refrigerator sales in the United States.[11] As a consequence, we focus most heavily on this class. The side freezer refrigerator represents some 15% of the market, while partial automatic and manual defrost models share only about 10% of the market.

Industry statistics indicate that some 40% of freezer sales are chest freezers, 55% are manual defrost uprights, and only 5% are automatic defrost uprights.[12] Since chest and upright freezers with manual defrost are relatively similar in characteristics and energy use (the typical upright freezer being sold is about 20% larger and consumes 20% more electricity than the typical chest freezer), they are analyzed together in the next section.

Calculational Methods. The energy consumption levels expected from various combinations of conservation measures are computed using a simplified steady state model developed by Arthur D. Little, Inc.[13] This

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9 A. Meier, J. Wright, and A.H. Rosenfeld, Supplying Energy Through Greater Efficiency - The Potential For Conservation in California's Residential Sector, University of California Press, 1983.

10 See 1986 Northwest Conservation and Electric Power Plan, Ch. 8, Northwest Power Planning Council, 1986, and R. Cavanagh et al, A Model Conservation and Electric Power Plan for the Pacific Northwest. Appendix 1, Northwest Conservation Act Coalition, Seattle, WA 1982.

11 "1983 Energy Consumption and Efficiency Data for Refrigerators, Refrigerator/Freezers, and Freezers," Association of Home Appliance Manufacturers, Chicago, Illinois, submitted to California Energy Commission, Docket No. 84-AES-1, July 1984.

12 Id.

13 Arthur D. Little, Inc., "Development of a High Efficiency Automatic Defrosting Refrigerator/Freezer," ORNL/Sub-7255, 1980, pp. 15-22.

model was found by its developer to duplicate to excellent approximation the results of a much more sophisticated dynamic model.[14]

Comparisons of the predictions of the steady-state model for combinations of features such as those described in this paper were found to agree with more detailed dynamic simulations within 6%.[15] This level of accuracy is appropriate for the purposes of this paper: other sources of error, such as the degree to which the specifications of the "typical" prototype refrigerator actually represent the market, and the extent to which the test procedure properly accounts for the effect of conservation measures, greatly outweigh the potential for errors introduced by the simulation model. Indeed, the use of a more complex model could not be justified in terms of a meaningful improvement in the accuracy of the results.

TECHNOLOGIES FOR ELECTRICITY CONSERVATION: COST AND SAVINGS RESULTS

This section presents the principal options considered, their cost-effectiveness, and the resulting energy demand and savings for the different categories of refrigerators and freezers analyzed. The analyses begin with "baseline" models with efficiencies close to the current average for new sales.[16]

Efficiency measures are drawn from a variety of sources, including DOE's appliance standards evaluation.[17] Additional analysis of more aggressive conservation measures draws heavily on two documents by Arthur D. Little.[18] In addition, some straightforward calculations are made concerning insulation effectiveness.

Top Freezer-Automatic Defrost Refrigerators. The assumed volume for this class is 17 ft^3 and the baseline energy use is 1166 kWh/yr. This

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[14] Arthur D. Little, Inc., "Study of Energy Savings Options for Refrigerators and Water Heaters," Vol. 1, Refrigerators, May 1977, pp. 12, 156-168.

[15] See Addendum to Supplementary Comments of the Natural Resources Defense Council, Inc. of October 5, 1984 to the California Energy Commission, Docket No. 84-AES-1, citing letter from Richard F. Topping to David B. Goldstein, October 9, 1984.

[16] See reference 7.

[17] See references 1, 7, and 8.

[18] See references 13 and 14.

figure closely follows the 1983 average energy use for the top freezer class. The cost and savings of the packages are presented in Table 1.

Conservation options through Measure 5 allows the prototype to conform to the new minimum efficiency standards that go into effect in California in 1992. The average cost of saved energy (CSE) to reach this level of performance is a low 8 mills per kWh.

All measures up to Measure 8 are considered "low technologies," as they include measures that are generally available commercially in some refrigerators, or require small changes in existing processes, or the substitution of commercially available parts for those currently used. The lead time for incorporating these measures into new refrigerators is 18 to 36 months.

The added measures are as follows:

- Increased compressor efficiency. Following DOE's study, the compressor efficiency is first increased from 3.18 EER (Energy Efficiency Ratio) to 3.65; further increases in compressor efficiency are then considered. The low technology measures package includes compressor efficiency increases up to an EER of 4.5. This is the most efficient compressor that was available commercially in 1984. The first compressor improvement saves energy at a cost of 0.3 cents/kWh; the later measure has cost of saved energy of 1.8 cents/kWh.

- Better Insulation. The measures considered in this package of measures are an increase in insulation from the baseline to the intermediate level of 2 inches for the refrigerator compartment and 2.4 inches for the freezer compartment. A second level is also considered, namely 2.5 inches for the refrigerator compartment and 3 inches for the freezer compartment. Both insulation measures have a cost of saved energy of 0.8 cents/kWh.

- Better Gasket. Double gaskets are added to the refrigerator and freezer compartment door closures. The freezer double gasket costs 2.2 cents/kWh of saved energy, while the fresh food compartment double gasket costs 7.1 cents/kWh.

- More efficient evaporator fan and fan motor. The cold evaporator coil in an automatic defrost refrigerator is isolated from the refrigerated food compartments so that it can be heated up for defrosting. The cold is conveyed from the cold coil to the compartments by a small fan. The efficiency of both the motor and the fan blades is low; this measure involves upgrading these efficiencies in straightforward ways. The measure is very cost effective with a cost of saved energy of 1.2 cents/kWh.

The full package of "low technology" measures — Measures 1 through 8 — lowers energy consumption to 460 kWh/yr at an average CSE (i.e., relative to the base model) of 1.4 cents/kWh (see Table 1). The average CSE is based on an annual electricity savings of 703 kWh and an extra first cost of $144.

Next, we look at measures of intermediate technological difficulty. These measures are generally not available commercially in the United States at present, but have been demonstrated in prototypes or in foreign products. We estimate the lead time for incorporating them into commercial production to be 2 to 3 years. Three potentially cost effective measures — Measures 9 and 10 — are presented.

They are:

- External fan motor. At present, the energy used by the evaporator fan is dissipated inside the refrigerated volume, increasing the amount of heat to be removed from the refrigerator. This measure removes the fan motor from the refrigerated volume, placing it outside the insulation on the back of the refrigerator. This measure is already employed in some Japanese refrigerators. However, since some manufacturers have presented potential reliability concerns with it, this measure is included in the intermediate technology category. The cost of conserved energy is less than 1 cent/kWh.

- EER 5 compressor. This measure was included in the 1983 DOE analysis as technically feasible; however, it is not commercially available as a component to manufacturers at present. The improved compressor has been built, tested, and incorporated into prototype models.[19] It appears to be very economical based on the cost of the prototype.

- Dual or Hybrid Evaporator. Current frost free refrigerators use a single evaporator for both the freezer compartment and the refrigerator compartment. The evaporator provides temperatures cold enough for the freezer compartment; "left-over" cold air chills the refrigerated foods compartment. This method wastes energy in dehumidifying the air in the refrigerated food compartment, and then in removing the excess frost produced during dehumidification.

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[19] R. T. Nelson and P.W. MacCarthy, "Research and Development of Energy Efficient Appliance Motor-Compressors," ORNL/Sub-7229, Oak Ridge National Laboratory, Sept. 1980.

The dual or hybrid evaporator uses a separate cold coil in the refrigerated foods compartment. This additional coil defrosts naturally during the off cycle when the temperature rises above 32 °F. This system of two evaporators is currently used in many partial automatic defrost refrigerators and was mass-produced in a frost-free model for several years by Amana. However, since it is more expensive than other measures to achieve a similar level of energy efficiency, it was discontinued by Amana.

This measure has benefits in excess of those reflected in the cost analysis. The higher humidity in the refrigerated foods compartment keeps stored food fresher. Also, the DOE test procedure appears to underestimate the energy savings that this technology produces in the real world.[20] This effect may occur because the test procedure does not include the introduction of moisture from food or door openings.

Using the standard DOE test procedure, this measure, coupled with the EER 5 compressor measure costs 7 cents/kWh saved.

These cost-effective intermediate technologies are included in Table 1. Energy consumption after the application of these measures is 386 kWh/yr. Overall, the intermediate technology model has an average CSE of 1.9 cents/kWh and a marginal CSE compared to Measure 8 of 6.3 cents/kWh.

Next, we look at some more highly advanced or speculative technologies.

- <u>Evacuated panel insulation</u>. Currently, polyurethane foam is the favored insulating material for limiting heat gain through the walls and doors. This measure entails supplementing the foam insulation with evacuated panels to futher supress heat conduction, creating, in effect, a giant thermos bottle. The panels are 1/4" thick and made of sheet steel walls filled with glass balls or expanded mica (for mechanical support). This technology is under development at the Solar Energy Research Institute[21] as well as Arthur D. Little, Inc. It saves energy at a cost of about 4.3 cents/kWh, even after all of the cost-effective measures discussed above have been implemented. This measure is estimated to have a five year lead time for implementation in the U.S., although it is reported that the Japanese are already using evacuated panels in some of their refrigerator models.

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[20] See reference 5.

[21] Personal communication, Peter Miller with Tom Potter, Solar Energy Research Institute, Golden, CO, October 1985.

- o <u>Bottom-mounted condenser</u>. This measure adds additional condenser area to that already located behind the refrigerator. By increasing the heat transfer area, the capacity and efficiency of the refrigeration system are increased. Modelling its effects is more problematic than most of the other technologies and for this reason it is listed along with the "advanced technologies".

The refrigerator with these as well as the previous measures would have an energy consumption of 222 kWh/yr., an 80% reduction from the baseline technology. The average CSE value for the full savings to 222 kWh/yr is 2.4 cents/kWh. The marginal CSE for savings beyond Measure 10 is 5.1 cents/kWh.

<u>Side Freezer Refrigerator</u>. The analysis of side freezer refrigerators follows that for the top freezer class. Table 2 summarizes the energy consumption, energy savings, and cost effectiveness of different packages of measures. The cost-effectiveness of the measures in this case is almost identical to that in the top freezer analysis.

The baseline energy use in this category, 1582 kWh/yr, is close to the average for new models sold in 1985. The energy use required to meet the 1992 California standard is 1000 kWh/yr for this prototype. Incorporation of the measures listed in Option 2 of Table 2 brings this product into compliance with the standard, at 922 kWh/yr, with a CSE of 0.9 cents/kWh.

Incorporating all the low technology measures in Table 2 reduces refrigerator energy consumption to 572 kWh/yr. Consumption of 500 kWh/yr is achieved with the medium technology package. The high technology package, which for this refrigerator class consists only of evacuated powder panels, cuts energy consumption to 300 kWh/yr.

<u>Manual Defrost Refrigerator</u>. The baseline manual refrigerator shown in Table 3 is about 11 cubic feet in capacity and consumes 584 kWh/yr. This approximates the current market average.

The first set of conservation measures reduces energy consumption to 450 kWh/yr, which just satisfies the 1992 California standard. This unit has a somewhat improved compressor and insulation compared to the base model, and it appears to be very cost-effective. Some 10-11 ft^3 manual defrost refrigerators commercially available in 1985 use even less energy according to the standardized test ratings.[22]

The complete package of low technology options brings down energy consumption to 270 kWh/yr at an estimated marginal CSE of 3 cents/kWh.

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[22] "The Most Energy-Efficient Appliances," American Council for an Energy-Efficient Economy, Washington, D.C., Summer 1985.

The advanced technologies option, including a 5.0 EER compressor and evacuated panels, reduces predicted energy consumption to 200 kWh/yr. Once again, this appears to be highly cost-effective based on our estimates of additional production costs.

Freezers

The analysis of freezers follows the methodology used for refrigerators. The measures employed are essentially identical to those described in the earlier section on refrigerators. The costs are taken for the most part from the 1982 DOE evaluation and from the A.D. Little studies.

Manual Defrost Freezer. Table 4 displays the cost and performance values for the various manual defrost freezer designs. The baseline model in this category is a 15 ft^3 freezer with an estimated energy consumption of 760 kWh/yr, close to the 1985 market average. The second option is a model that is close to the 1992 California standard, averaging together the requirements for chest and upright manual defrost freezers. Chest freezers rated at around 500 kWh/yr are already manufactured and commercially available in the U.S.[23]

In the low technology package, insulation is increased from 2.0 inches to 3.5 inches throughout, and a double gasket is added. These two measures cut energy consumption to 327 kWh/yr at a CSE of 2.8 cents/kWh. The intermediate package of measures includes an upgrade in compressor efficiency to 4.5 EER. This single measures reduces energy use to 265 kWh/yr at a marginal CSE of 2.6 cents/kWh.

The advanced technology package, which includes a further upgrade in compressor efficiency and the addition of evacuated panels, cuts predicted energy use to 173 kWh/yr. Based on our first cost estimates, this package is also cost-effective, with a marginal CSE of 5.6 cents/kWh.

Automatic Defrost Freezer. The analysis for automatic defrost freezers parallels that for manual defrost freezers with the inclusion of two additional measures targeted at the defrost system. Table 5 shows the results. The baseline model at 18 cubic feet has an energy consumption of 1080 kWh/yr, slightly better than the current market average. The low technology package of measures, involving better insulation and a better gasket, reduces consumption to 680 kWh/yr. The intermediate technology package contains a 4.5 EER compressor, a more efficient evaporator fan and fan motor and the removal of the fan motor from the refrigerated space. This package reduces consumption to 420 kWh/yr. The advanced technology

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[23] Id.

package further cuts consumption to 280 kWh/yr — an 80% reduction from the base case. All of the options have marginal CSE values of less than $0.04 kWh.

Comparison of Predicted Results with Measured Low Energy Refrigerators

There are a number of commercial refrigerators or prototypes that have been designed or modelled whose performance can be compared with the predictions presented above. Data concerning the correspondence of the design features of these products to those analyzed here are fragmentary; however, there is good agreement between the measured energy consumption of these refrigerators and the performance predicted in this study.[24]

This comparison shows that the ultra-low energy consumption levels predicted by our model are actually achievable. It also illustrates that the range of performance levels currently available is consistent with the approximate performance levels predicted by the model.

Other Measures Potentially Available

This study focuses on measures for which there is published information on technical specifications, performance, and cost. A number of other conservation measures are being developed that may be even more cost-effective than those evaluated above. These measures were omitted from our model due to either greater uncertainties surrounding cost or performances, or our inability to model their effects.

Some of these measure are:

- Improved Conductivity Insulation.
  Japanese refrigerator manufacturers employ a special polyurethane foam insulation material that has a smaller and more uniform cell size and lower conductivity.[25] This measure is not evaluated due to our lack of data on the special foam's conductivity.

- Redesign Evaporator.

[24] H. Geller et al. "Residential Conservation Power Plant Study," Phase I, Technical Potential, American Council for an Energy-Efficient Economy, 1986, pp. 3-25 to 3-29.

[25] See reference 5 and H. Tsuchiya, "Energy Efficiency of Refrigerators in Japan," Research Institute for Systems Technologies, Tokyo, 1982. Also, see Japanese manufacturers' literature on product offerings, 1981-1984.

Unpublished studies by manufacturers have suggested that a redesigned evaporator could have greatly improved heat transfer characteristics, raising the efficiency of the compressor. However, the studies are not available to the public, so neither performance nor cost can be predicted.

- <u>More Efficient Motor-Compressor</u>.
  The analysis above describes motor-compressor efficiencies that are limited to EER 5. This level of performance was achieved in a U.S. prototype using a conventionally controlled 75% efficient motor.[26] It may be possible, however, to increase motor efficiency well beyond 75%, and to control motor speed to reduce startup losses and better match the load. Energy savings would be greater than proportional to the efficiency improvement, because a more-efficient motor produces less waste heat both in the refrigerant circuit and near the cold storage volume. The extent and cost of these improvements could not be quantified, however.

- <u>Use of Different Refrigerants to Improve EER</u>.
  Initial work has suggested that refrigerant mixtures may reduce energy consumption by about 10%.[27] However, this technology is still in the laboratory research stage, and its effects cannot be evaluated with nearly as much confidence as the other measures.

- <u>Two Motors and Two Compressors</u>.
  Several advanced models or prototypes, including the Sun Frost 250 kWh/yr model feature separate motor/compressors, evaporators, and controls for the freezer compartment and the refrigerator. This improves the EER of the refrigerated foods section, as well as providing greater control of temperature. Savings have been estimated at 30%.[28] We found it difficult to quantify precisely the costs and benefits of this measure, so it is not evaluated.

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[26] See reference 19.

[27] W.D. Levins, "An Assessment of the Energy Savings Potential of Nonazeotropic Refrigerant Mixtures," Proceedings of the 1984 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. E, ACEEE, 1984.

[28] H. Geller, "Progress in the Energy Efficiency of Residential Appliances and Space Conditioning Equipment," <u>Energy Sources: Conservation and Renewables</u>. American Institute of Physics, 1985, p. 270-298.

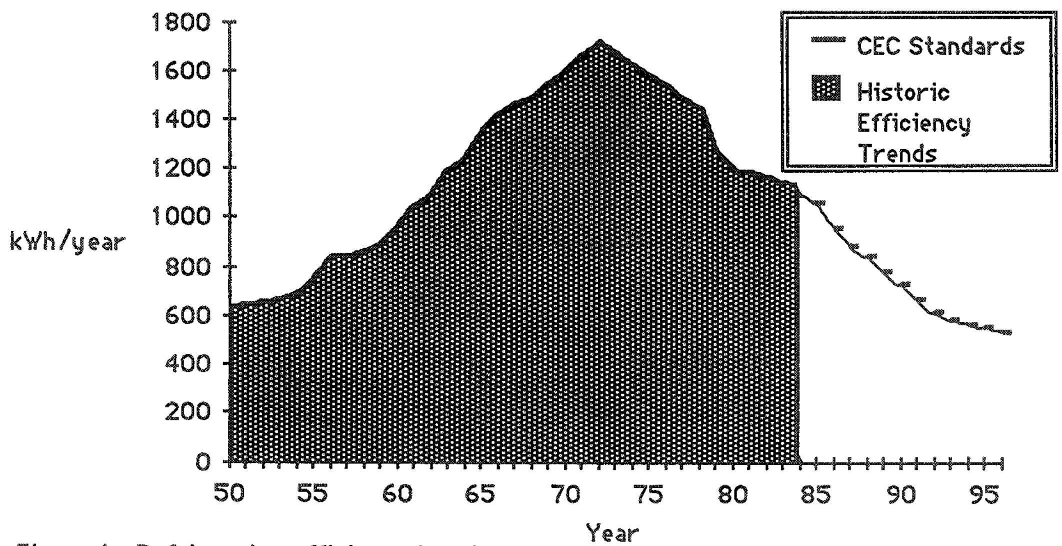

Figure 1. Refrigerator efficiency trends.

Table 1. Top mount auto defrost refrigerator freezer.

Measure	Annual energy use (kwh/yr)	Additional first cost marginal (1985 $)	net (1985 $)	Marginal CSE (¢/kwh)	Average CSE (¢/kwh)
1. Baseline	1166	670.95	----	----	----
2. 3.65 EER compressor	983	7.35	7.35	0.27	0.27
3. Double gasket on freezer compartment	920	20.34	27.70	2.19	0.76
4. 2"/2.4" insulation	752	19.57	47.27	0.78	0.77
5. 2.5"/3" insulation	672	9.33	56.60	0.78	0.77
6. More efficient fan	609	10.98	67.58	1.18	0.82
7. EER 4.5 Compressor	510	27.11	94.69	1.83	0.97
8. Double gasket on fresh food comp.	463	49.76	144.45	7.09	1.38
9. External fan motor	451	1.64	146.09	0.97	1.37
10. EER 5.0 compressor and dual evaporator	386	70.51	216.60	7.23	1.87
11. Evacuated powder panels	268	75.15	291.75	4.29	2.18
12. Bottom mounted condensor	222	40.65	332.39	5.88	2.37

Table II. Side-by-side auto defrost refrgerator/freezer

Measure	Annual energy use (kwh/yr)	Additional first cost marginal (1985 $)	Additional first cost net (1985 $)	Marginal CSE (¢/kwh)	Average CSE (¢/kwh)
1. Baseline	1582	656	----	----	----
2. Anti-sweat switch, dbl. freezer gasket 3.86 EER compressor and 2"/2.5" insulation	922	88.79	88.79	0.90	0.90
3. 2.4"/3" insulation, EER 4.5 comp., fresh food gasket, efficient fan assembly and external fan motor	572	114.06	202.85	2.19	1.35
4. EER 5.0 compressor and dual evaporator	499	70.51	273.36	6.49	1.70
5. Evacuated panels	298	100.56	373.92	3.36	1.96

Costs:

Package 2. Anti-sweat switch: $4.59; 2"/2.4" insulation: 79¢/sq.ft.-in. * 37.44 sq.ft.-in.=$29.58
3.86 EER compressor: $3.68; freezer gasket: 11.37 ft.*$4.48/ft.=$50.94

Package 3. 2.5"/3" insulation: 79¢/sq.ft.-in.*22.24 sq.ft.-in.=$17.57; EER 4.5 compressor: $27.11;
Efficient fan and fan motor: $10.98; fresh food gasket: 12.67 ft.*$4.48/ft.=$56.76
external fan motor: $1.64

Package 4. EER 5.0 compressor: $9.04; dual evaporator: $61.47

Package 5. Evacuated panels: $2.00/ sq.ft. * 50.28 sq.ft. = $100.56

Table III. Manual defrost refrigerator.

Measure	Annual energy use (kwh/yr)	Additional first cost marginal (1985 $)	Additional first cost net (1985 $)	Marginal CSE (¢/kwh)	Average CSE (¢/kwh)
1. Baseline	584	465.00	----	----	----
2. 2" wall insulation and 3.21 EER compressor	449	41.13	41.13	2.05	2.05
3. Double gasket and 4.5 EER compressor	269	100.18	141.31	3.74	3.01
4. 5.0 EER compressor and evacuated panels	203	72.36	213.67	7.34	3.77

Costs:

Package 2) 2" foam walls: $37.85; 3.21 EER compressor: $3.28;

Package 3) 4.5 EER compressor: $27.11; double gasket: $4.48/ft. * 16.31 ft. = $73.07

Package 4) 5.0 EER compressor: $9.04; evacuated panels: $2/sq.ft. * 31.66 sq.ft. = $63.32

Table IV. Manual defrost freezer.

Measure	Annual energy use (kwh/yr)	Additional first cost marginal (1985 $)	Additional first cost net (1985 $)	Marginal CSE (¢/kwh)	Average CSE (¢/kwh)
1. Baseline	760	445	----	----	----
2. 2" walls and doors and 3.65 EER compressor	549	9.68	9.68	0.27	0.27
3. Double gasket and 3.5" insulation	327	103.81	113.49	2.75	1.55
4. 4.5 EER compressor	265	27.11	140.60	2.59	1.68
5. 5.0 EER compressor and evacuated panels	173	86.86	227.46	5.60	2.29

Costs:
Package 2) 2" insulation: 8.05 sq.ft.-in. * $.79/sq.ft.-in. = $6.38; 3.65 EER compressor: $3.30
Package 3) 3.5" insulation: 0.79¢/ft.sq.* 58.37 sq.ft.-in.= $46.11; gasket: 12.88 ft.* $4.48/sq.ft.=$57.70
Package 4) 4.5 EER compressor costs $27.11
Package 5) 5.0 EER compressor: $9.04; evacuated panels: 38.91 sq.ft. 8 $2/sq.ft.=$77.82

Table V. Automatic defrost freezer.

Measure	Annual energy use (kwh/yr)	Additional first cost marginal (1985 $)	Additional first cost net (1985 $)	Marginal CSE (¢/kwh)	Average CSE (¢/kwh)
1. Baseline	1080	656	----	----	----
2. Double gasket and 3.5" insulation	680	101.13	101.13	1.49	1.49
3. External fan motor, more efficient fa and fan motor and EER 4.5 compressor	420	38.09	139.22	0.86	1.24
4. Evacuated panels and EER 5.0 compressor	283	89.04	228.26	3.85	1.69

Costs:
Package 2) 3.5" insulation: 51 sq.ft.-in * 79¢/sq.ft.-in.= $40.29; gasket: $4.48/ft.*13.58 ft. = $60.84
Package 3) 4.5 SEER compressor: $27.11; efficient fan and fan motor: $10.98
Package 4) 5.0 SEER compressor: $9.04; evacuated panels: $2/sq.ft.*40 sq.ft. = $80