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1. SYNOPSIS

This paper discusses the benefits and difficulties of establishing global efficiency standards for residential appliances.

2. ABSTRACT

In most countries, residential electricity consumption typically ranges from 20% to 40% of total electricity consumption. This energy is used for heating, cooling, refrigeration and other end-uses. Significant energy savings are possible if new appliance purchases are for models with higher efficiency than that of existing models. There are several ways to ensure or encourage such an outcome, for example, appliance rebates, innovative procurement, and minimum efficiency standards. This paper focuses on the latter approach.

At the present time, the U.S. is the only country with comprehensive appliance energy efficiency standards. However, many other countries, such as Australia, Canada, the European Community (EC), Japan and Korea, are considering enacting standards. The greatest potential impact of minimum efficiency standards for appliances is in the developing countries (e.g., China and India), where saturations of household appliances are relatively low but growing rapidly.

This paper discusses the potential savings that could be achieved from global appliance efficiency standards for refrigerators and freezers. It also discusses the impediments to establishing common standards for certain appliance types, such as differing test procedures, characteristics, and fuel prices. A methodology for establishing global efficiency standards for refrigerators and freezers is described.

3. INTRODUCTION

In most countries, residential electricity consumption typically ranges from 20 to 40% of total electricity consumption. This energy is used for space heating, cooling and other appliances. Significant energy savings are possible by ensuring that purchases of new appliances are at a higher efficiency than that of existing ones. An example, which indicates the potential savings for one product, refrigerators, follows. Approximately 50 million refrigerators are manufactured and sold each year around the world. Assuming that replaced refrigerators are retired, they require about 3 new 1,000 MW power plants each year. A 30% reduction in refrigerator energy use (equal to the savings from the U.S. 1993 refrigerator standards relative to the existing 1990 standards) worldwide would result in a reduction in construction of about one 1,000 MW power plant each year, and the concomitant reduction in air pollutants (including carbon dioxide) and capital required for power plant construction.

At the present time, only the United States has extensive mandatory national energy efficiency standards for residential appliances. The European Community (EC) is in the process of developing efficiency standards for several residential appliances, especially refrigerators and freezers. The authors do not know of any standards in the developing countries, where the greatest impact on future energy use is possible. A number of steps are necessary before standards can be developed for any nation or group of nations. The efforts in Europe are interesting to watch, in so far as they represent a test case for the world at large. If the EC is successful, that will encourage the development of appliance energy efficiency standards elsewhere in the world. These standards might be either mandatory or voluntary in nature.

Currently, the world markets for 50 million refrigerators and refrigerator-freezers are differentiated by a number of factors: distance from producer to consumer, language differences, and desired product characteristics (e.g., capacity and auto-defrost). However, the bulk of the products are supplied by an increasingly small number of multinational producers. For example, the ties between the European and U.S. markets (e.g., Electrolux purchasing WCI and Whirlpool purchasing the refrigerator division of Philips) have increased over the last few years. Much of the Asian market is influenced by a small number of Japanese manufacturers. The linkages between the Western and Eastern European markets are being developed and strengthened. For many years, compressor manufacturers (e.g., Matsushita and Embraco) have been supplying their products to refrigerator manufacturers throughout the world. Recently, awareness of global environmental issues and the need for global solutions has been increasing. These issues include global climate change and ozone depletion. Refrigerators are becoming more widespread, consume significant quantities of energy, and are tied to the global climate change issue (both through fossil-fuel-generated electricity and CFC usage) and to ozone depletion.

In the last 20 years, first in California, then in the U.S. as a whole, government-initiated mandatory efficiency programs, together with technological change and market forces, have decreased the energy use of refrigerators and freezers by over 100%. Given the importance of the global climate and ozone layer issues, and the global distribution and significant energy consumption of refrigerators, the question arises as to whether it makes sense to consider development of global energy efficiency standards for refrigerators and freezers. The barriers (discussed below) are formidable but the rewards are significant.

Keeping in mind that minimum efficiency standards are intended to eliminate the inefficient designs, while maintaining consumer utility, this paper begins the exploration of the steps required to consider standards applicable to broader geographical regions. This effort may be worthwhile even if ultimately unsuccessful in developing a global standard, provided that it produces a clear set of principles for an analysis process that may lead to regional minimum efficiency standards. These principles could be used to train interested parties, from consumers or consumer groups to manufacturers, utilities and governmental analysts. Success would require data collection (for existing products, technology options, field conditions and usage) and a combination of international meetings and negotiations (technology transfer from developed to developing countries, resolution of trade issues between trading blocks and development of common test procedures).

4. METHODOLOGY FOR STANDARDS SETTING

There are several elements to a well thought out procedure for establishing appliance energy efficiency standards. The first step that must be taken in developing standards is to establish a test procedure by which to measure energy consumption or energy efficiency of an appliance. Secondly, data on the efficiency of all models available for sale need to be collected and analyzed. Labeling of appliances (as to their energy use) is a very useful step, but not absolutely necessary. Once test procedures are in place, minimum efficiency standards can be established through either a statistical or engineering analysis. Finally, an enforcement process must be developed to ensure compliance with minimum efficiency standards.

4.1 Test Procedures

The key element in developing standards is the establishment of test procedures for each product type (e.g., refrigerator-freezers, freezers and clothes washers) of interest. Presently, test procedures often differ from country to country. The United States has its own set of test procedures that have been developed by the Department of Energy (DOE). The Canadian and Australian test procedures are usually very similar, but not exactly the same, to those used in the U.S. As an example of the diversity of test procedures we take refrigerators and freezers. The European Community generally uses the ISO (International Organization for Standards) test procedures for refrigerators and freezers (ISO, 1988). Tests are done at one ambient temperature, with freezer loading, and without door openings. The freezer temperature depends on the rating (number of stars) of the particular refrigerator-freezer. The Japanese have their own test procedure which is quite different than those of other nations (JIS, 1986). In the Japanese test, measurements are taken at two ambient temperatures with a schedule of door openings. The United States test procedure is significantly different from both of the above test procedures (10CFR, 1985). The U.S. test is at one ambient temperature (different than either of the above), with different cabinet temperatures, and without door openings. Table 1 summarizes the main differences among the three test procedures. Because of these notable differences in test procedures for the same product, direct comparison of energy use of refrigerators and freezers tested in different countries under different test procedures is not possible.

For products such as microwave ovens, standards established by the International Electrotechnical Commission (IEC) are widely used. However, not all countries (the U.S. for example, has its own test procedure but intends to change to the IEC standard) have adopted the international standard.

4.2 Technical Analyses

There are several parts to the standards analyses carried out by the Lawrence Berkeley Laboratory (LBL) for the U.S. DOE. First, an engineering analysis is carried out for each product type; it produces manufacturing costs for improving the efficiency of a baseline model. Figure 1 illustrates the results of an engineering analysis for top-mount auto-defrost refrigerator-freezers. Efficiency gains become more expensive as the energy use decreases.

Most of the design options are self-explanatory. The compressor efficiency increases from a COP of 1.32 to 1.48 (or an EER of 4.5 to 5.05). Door insulation is first changed from fiberglass to foam and then its thickness is increased from 3.8 to 5.1 cm. (1.5 to 2.0 inches). The evaporator and condenser fan motors are improved in efficiency so that their power consumptions decrease from 10W and 13.5W, respectively, to 8 W each. After more efficient fans, there is a branch in the choice of the next design option; either increased side insulation or evacuated panels is chosen.

Other components of the standards analyses produce consumer prices for each efficiency improvement studied, life cycle cost curves, national energy savings, a manufacturer impact assessment and an environmental impact assessment.

Figure 2 shows refrigerator-freezer models available in 1989 and the 1993 standard (for this one product class) that resulted from these analyses. The standard is seen to be a function of adjusted volume (AV). Adjusted volume accounts for the different temperatures found in the freezer and refrigerator cabinets. For refrigerator-freezers, AV is equal to refrigerator volume plus some coefficient times the freezer volume. For the U.S. test procedure, the coefficient is 1.63 and for the ISO test procedure it is equal to 2.15 (for 3 and 4 star refrigerator-freezers).

The 1990 U.S. standard was a consensus standard arrived at by consumer groups and manufacturers. It can be seen that the 1990 minimum eficiency standard eliminated the higher energy users from the marketplace. This approach (in 1990) to standards setting could be considered to be a statistical approach; that is, one looks at the models available at a particular time and either performs a regression analysis to determine the dependence of energy use on adjusted volume or visually draws a line through the cloud of points to set the minimum efficiency level for each adjusted volume. Policy makers can decide on the percentage of models they are willing to have eliminated and the desired overall energy savings from standards. The 1993 standard was arrived at through the engineering and economic analyses described above. Both standards are seen to have significant impacts on the range of model offerings. In 1989, when the standards were set, no top-mount reefrigerator-freezer models were available that met the 1993 standard. Such a standard could not be arrived at through a statistical analysis.

5. BARRIERS TO IMPLEMENTATION OF GLOBAL STANDARDS

In general, standards cannot be transferred from one country to another because the methodology used to establish standards involves engineering and economic calculations that differ for each country. For example, the following are some factors that would impact the nature of standards resulting from a typical analysis: (1) characteristics of appliances, (2) test procedures, (3) field energy consumption , (4) manufacturer costs and (5) price of fuel and discount rates. Therefore, resulting cost/efficiency curves differ and all of the above impact life cycle cost, payback periods, and energy use versus volume relationships.

One of the characteristics of appliances that tends to differ most is capacity. For example, U.S. and Canadian refrigerators and clothes washers are mostly larger than European models. For microwave ovens, televisions, and dishwashers, capacity differences are not so great. For refrigerators and freezers, U.S. maximum allowable energy use standards have been established as a function of adjusted volume. Therefore, capacity differences should not present a problem in developing uniform standards; that is, the standards will be a function of capacity when appropriate.

With the coming together of the European Community (EC), harmonization of standards is proceeding at a rapid pace (Galluccio, 1992). It is likely that all European countries (even non EC members) will adopt a set of common test procedures for all appliances. There are efforts to develop standards for appliance testing that are common to all North American nations (Callahan, Grieco, and Schulte, 1992). This effort is being driven by the North American Free Trade Agreement (NAFTA). The above referenced authors state that "we expect to meet over an ISO conference table to discuss the marriage of North American, European and other standards used in the design, certification and installation of gas products." If such large appliance markets develop common test procedures, as seems likely, this will produce great pressure on other nations to employ the same test procedures. The driving force will be trade among countries. Many appliance companies are now multinational and are attempting to increase sales around the world. In order to ship appliances across borders it will be necessary to test them according to new test procedures developed by international bodies such as ISO and IEC.

As mentioned earlier, with the U.S. converting to the IEC test procedure for microwave ovens, it may be possible that all nations testing this product will soon use the same test procedure. The Japanese plan to convert from their own refrigerator and freezer test procedures to the ISO test procedure. This could put pressure on the U.S. to also convert to the ISO test procedure. There are ongoing efforts by the IEC to develop a common test procedure for air conditioners. By the year 2000, it is very likely that all (or almost all) nations will utilize the same test procedure for refrigerators, freezers, air conditoners, and microwave ovens and some gas-fired appliances. Other product types will surely follow.

Another factor that can influence the outcome of a standards analysis is usage of an appliance. Consumers in various countries will tend to use appliances in different ways and with different frequencies. This impacts energy use and therefore, potential energy savings and cost effectiveness of design changes. For some products, such as refrigerators and freezers, this is not much of a problem. Ambient temperatures will affect energy consumption somewhat but usage (door opening) has a very small impact on energy use. However, other appliances such as clothes washers, microwave ovens and especially air conditioners will show greater variation in usage (frequency or hours of use). We will discuss below a method to incorporate different usages in standard setting.

Other factors that impact cost-effectiveness are manufacturer cost for efficiency improvements, fuel prices and discount rates. Discount rates are chosen to calculate the present value of fuel cost savings in future years. All of these may differ among countries. These factors will also be dealt with in the method to be described below.

6. APPROACH TO DEVELOPING GLOBAL STANDARDS

As mentioned earlier, developing countries do not have appliance energy efficiency standards; projected increases in energy use (and carbon dioxide emissions) could be significantly reduced by introduction of such standards. The above discussion could be interpreted as discouraging the development of global standards. However, that is not the intent of the authors who believe that global standards are desirable and feasible. The fastest way to develop uniform standards that could apply worldwide would be for developing countries to use the same test procedures and standards as the EC (EC and developing countries product characteristics are more similar to each other than to U.S. product characteristics). The developing countries could adopt ISO and IEC test procedures and standards, and then apply a time lag to the implementation date to allow local manufacturers time to adapt to new test procedures and manufacturing designs. Financial support would also be necessary because consumers might not be able to afford the higher priced more efficient products and local manufacturers might not have the capital for neeeded investments in tools and plant. Potential sponsors would be the Global Environmental fund (GEF) and the World Bank.

An important issue is whether the U.S., Japan, Canada, and other non-European nations would convert to ISO test procedures and utilize EC standards where appropriate. Japan has already decided to convert their present test procedure for refrigerators to the ISO test. That conversion is expected to be completed by 1997. Additionally, it would have to be decided if EC standards are appropriate for these other countries. We address that issue below. In general, U.S., Australian, and Canadian appliances are larger than their European counterparts so there would be little overlap in the capacities to which the U.S. and EC standards are applicable. Therefore, it would be possible for the U.S. and these other countries to adopt ISO and IEC test procedures and recast their efficiency standards (for larger capacity models) consistent with these test procedures. This would make it possible to compare models manufactured around the world (where there is a capacity overlap) and would facilitate import and export of such appliances. In time, it should be possible to establish one set of test procedures and possibly one set of efficiency standards applicable around the world. In order to accomplish this goal, much international cooperation would be necessary and perhaps some financial subsidy to allow poorer nations to purchase more expensive, but more efficient appliances. The progress being made by the EC is very encouraging to those seeking the goal of uniform appliance test procedures and common energy efficiency standards.

We now present an example as to how various countries can evaluate whether to adopt efficiency standards that are about to be established or already are established in other nations or groups of nations. The methodology employs cost-efficiency data and could be used to examine the sensitivity of payback periods and/or life-cycle costs to the various parameters affecting those two measures of cost-effectiveness. We will use cost-efficiency data developed for the EC refrigerator-freezer rulemaking to illustrate the suggested methodology. Table 2 shows the price-efficiency data for a typical four star European refrigerator-freezer with a volume of 300 liters and a baseline energy use of 566 kWh/yr (Pedersen, 1992).

The design options are as follows: the first is a semi-direct intake compressor with a run capacitor, the second is an increase in wall insulation thickness by 30mm in both the refrigerator and freezer compartments, and the third is a doubling of the evaporator heat capacity. The fourth option is an increase in condenser surface area, the fifth option is a doubling of condenser heat capacity, the sixth option is a change to a two-compressor system, and the seventh option is an increased evaporator surface area. The retail prices are cumulative and are in ECU (European Community Units). When life-cycle costs were calculated using an electricity price of 0.123 ECU/kWh, a discount rate of 7% and a 16 year lifetime, the life-cycle cost minimum occured at the third design option (increased evaporator heat capacity).

In order to examine the impact on life-cycle cost (LCC) of changes in those parameters that enter into its calculation new computer software was utilized to perform a statistical analysis of the location of the LCC minimum. The parameters that impact LCC are the following: (1) lifetime of the appliance, (2) price of fuel, (3) discount rate, (4) initial and incremental prices of the baseline and improved appliance, and (5) baseline energy use and incremental energy savings for the improved appliance. In our analysis we determined the location of the life-cycle cost minimum as a function of several of the above parameters. We chose to observe the sensitivity of LCC location because that is one of the more important pieces of information used in setting standards. Since baseline energy use and baseline price do not impact the location of the minimum LCC, we do not need to evaluate their impact on LCC minimum. Table 3 shows the range of variation chosen for each of the parameters that were allowed to vary. The first three parameters are each allowed to have three discrete values; the baseline values for lifetime, discount rate and electricity price are 16 years, 7%, and 0.123 ECU/kWh, respectively. The range of electricity prices covers most countries throughout the world (IEA 92). The fourth parameter, incremental price, is assumed to have a normal distribution for each associated uncertainty, with a standard deviation of 10% of the estimated incremental price. A Monte Carlo approach is used to generate 100 random variations of incremental price for each combination of the other three parameters. We have chosen to not apply a normal distribution to the incremental energy savings; however, this could be done in future analyses. Usage (e.g., door openings) has not been varied in this analysis; it does not have a strong impact on refrigerator energy use.

Table 4 shows the frequency of occurrence of the LCC minimum at each design option level. Eight cases or scenarios are shown; the first matches the Danish study, with the addition of a normal distribution on uncertainties for incremental prices. For the first case, 99 out of 100, or 99% of the LCC curves generated will have their minimum at design option 3. All subsequent scenarios include the incremental price uncertainties. The first two, vary the lifetime of the refrigerator-freezer. It can be seen that for lifetimes of 13 and 19 years, 91 and 98% respectively, of the LCC curves will still have their minima at design option 3. Therefore, reasonable variations in incremental prices or appliance lifetimes will only slightly impact the location of LCC minima and thus the choice of a standard based on LCC minimum.

The next parameter investigated is discount rate. For 5% and 10% discount rates 96% and 77% respectively, of the LCC curves will still have their minima at design option 3. For the 10% discount rate, all 23 of the LCC minima at level 2 are within 0.2% of the corresponding LCC at level 3. The LCC curves are relatively flat in the region of design options 2 and 3.

The final parameter investigated is electricity price. For a price of 0.06 ECU/kWh, all LCC minima have shifted to design option two. All 100 of the LCC minima at level 2 are within 0.5% of the corresponding LCC at level 3. For an electricity price of 0.15 ECU/kWh, 87% of the LCC minima remain at design option 3 whereas 13% shift to option 4. All 13 of the LCC minima at level 4 are within 0.6% of the corresponding LCC at level 3. Again. the LCC curves are relatively flat in the region between design options 2 and 3.

Finally, one last case was investigated; all three parameters were allowed to change in such a direction as to move the LCC minimum towards the baseline. The result is that 33% of the minima are at option 2 and 67% are at option 1. All 100 of the LCC minima are within 2.4%

of the corresponding LCC at option 3. Figure 3 shows the shape of the LCC curves for the baseline scenario (7%, 16 yrs, 0.123 ECU/kWh) and the two extreme scenarios for typical selections among the 100 LCC curves generated. It can be seen that the LCC curves are all relatively flat in the region between design options 2 and 3.

7. CONCLUSIONS

If common international test procedures are agreed upon for appliances such as refrigerators, freezers and microwave ovens, it may be possible to develop global efficiency standards for such appliances. There are presently international efforts to harmonize test procedures for certain appliances. A methodology is presented that individual countries can use to decide whether existing efficiency standards established elsewhere should be adopted. The starting point is a cost-efficiency curve for each product class under consideration. For cases where a country, or group of countries, has used a statistical approach to develop initial efficiency standards, other countries can simply apply statistical analyses to energy use/adjusted volume data for models sold in their country.

Initial analysis of cost-efficiency data being used by the EC to develop rerfrigerator-freezer energy efficiency standards shows that the location of the LCC minimum under different scenarios (e.g., variable fuel price, lifetime, discount rate and incremental price) is quite stable. Significant deviations from the baseline values of the variables listed above are required to change the location of the LCC minimum. Even for cases where the location does change, the difference in LCC between the new minimum and the previous minimum is small (at worst 2.4% of the LCC). Therefore, the decision as to where (at which design option or efficiency level) to set the standard will usually not be affected by a moderate alteration of the parameters impacting LCC. Each country interested in establishing efficiency standards will need to perform their own analyses to determine whether they should adopt standards set by other countries or regional groups (e.g., the EC). That is, they can determine if local fuel prices, discount rates, appliance lifetimes, usages, and incremental prices will affect the optimal level of standards selected. Technology transfer from countries with experience to those without experience will need to play an important role in carrying out this work. Much cooperation and analysis remains to be done to see if this methodolgy will lead to global or regional efficiency standards.

8. ACKNOWLEDGMENT

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Table 1. Comparison of refrigerator-freezer test procedures

	ISO*	JIS+	U.S.
Ambient Temp (°C)	25.0	15 & 30	32.2
Fresh Food (°C)	5.0	3.0	3.3
Freezer (°C)	-18.0	-18.0	-15.0
Door Openings	No	Yes	No
Loading	Yes	No	No

* Applies to 3 and 4 star refrigerator-freezers.

+ Applies to 3 star refrigerator-freezers.

Table 2. Price-efficiency data for refrigerator-freeezer*

Design Option	Energy Use (kWh/yr)	Price (ECUs)
Baseline	566	856
1. Efficient compressor	482	871
2. Increased Insulation	361	925
3. Increased evap. heat capacity	350	935
4. Increased condenser surface	318	986
5. Increased condenser heat capacity	314	997
6. Dual compressor system	292	1141
7. Increased evaporator surface	281	1160

* Four star refrigerator-freezer with 200 liters fresh food and 100 liters freezer volumes. Auto-defrost in fresh food compartment only.

Table 3 Range of variation of parameters impacting life cycle cost

Parameter	Low Value	High Value
Lifetime	13 yrs	19 yrs
Discount Rate (real)	5%	10%
Electricity Price ECU/kWh	0.06	0.15
Incremental Price (1 std. deviation as % of estimate in Table 2)	90%	110%

Table 4 Location of life-cycle cost minima

DR (real)	Lifetime (years)	Elec. Price ECU/kWh	Design Option 1	2	3	4	5	6	7
0.07	16	0.123			99	1			
0.07	13	0.123		9	91				
0.07	19	0.123			98	2			
0.05	16	0.123			96	4			
0.10	16	0.123		23	77				
0.07	16	0.060		100					
0.07	16	0.150			87	13			
0.10	13	0.060	67	33					

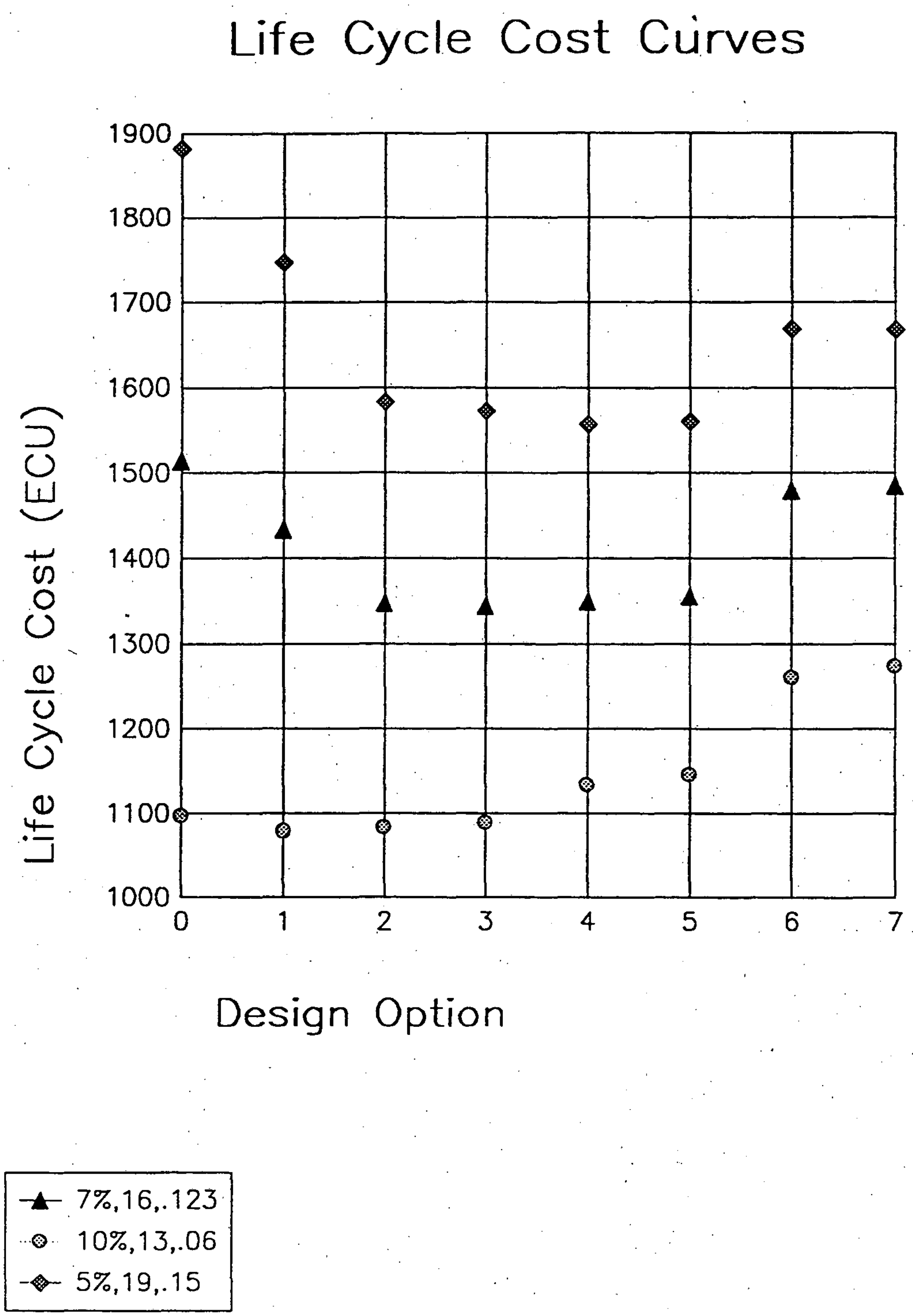

Figure 3: Sensitivity of life-cycle cost to discount rate, lifetime, and fuel price are shown.

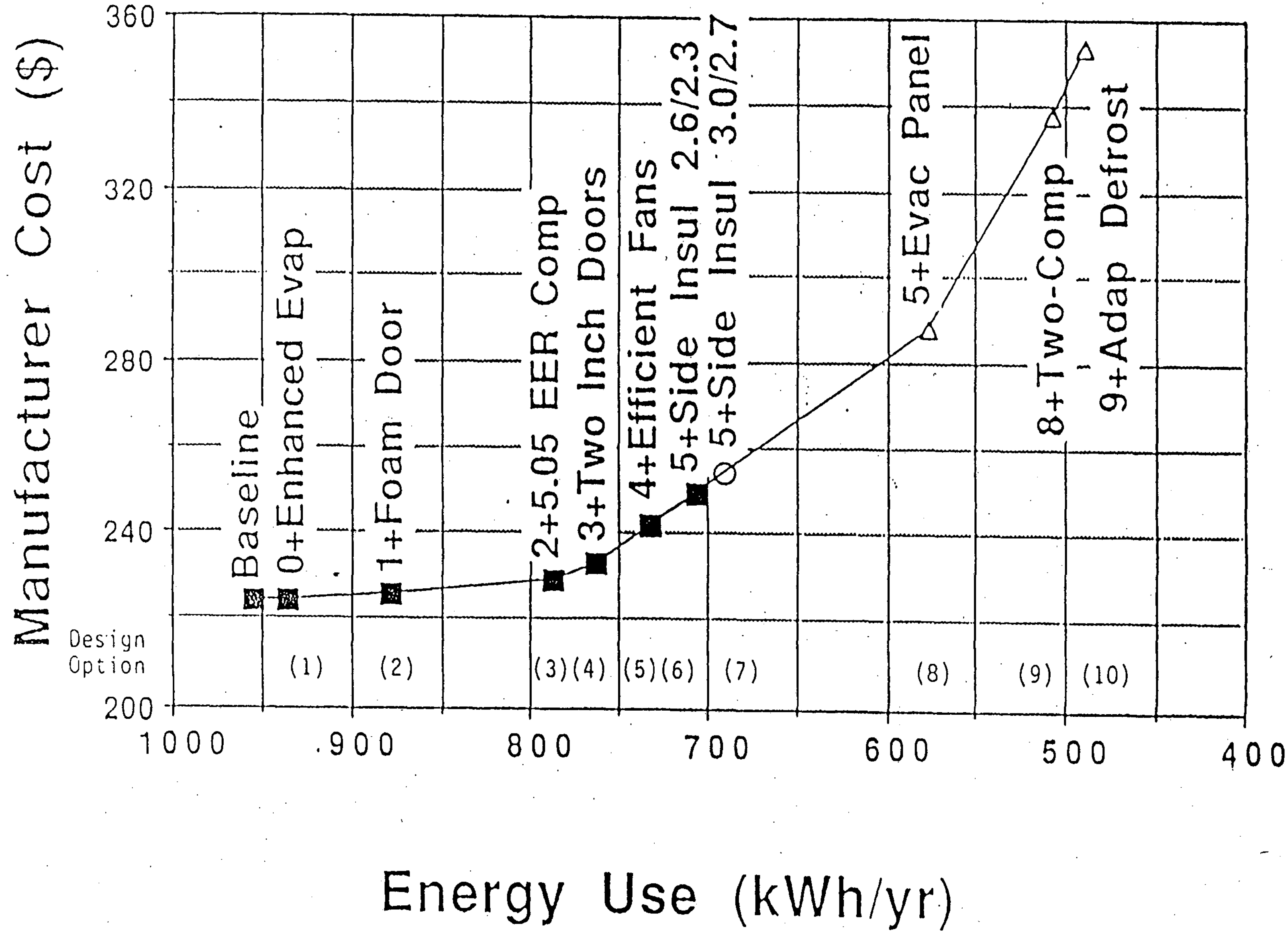

Figure1: Increased manufacturer cost is shown as a function of reduced energy consumption for an 18 ft^3 top-mount auto-defrost refrigerator-freezer.

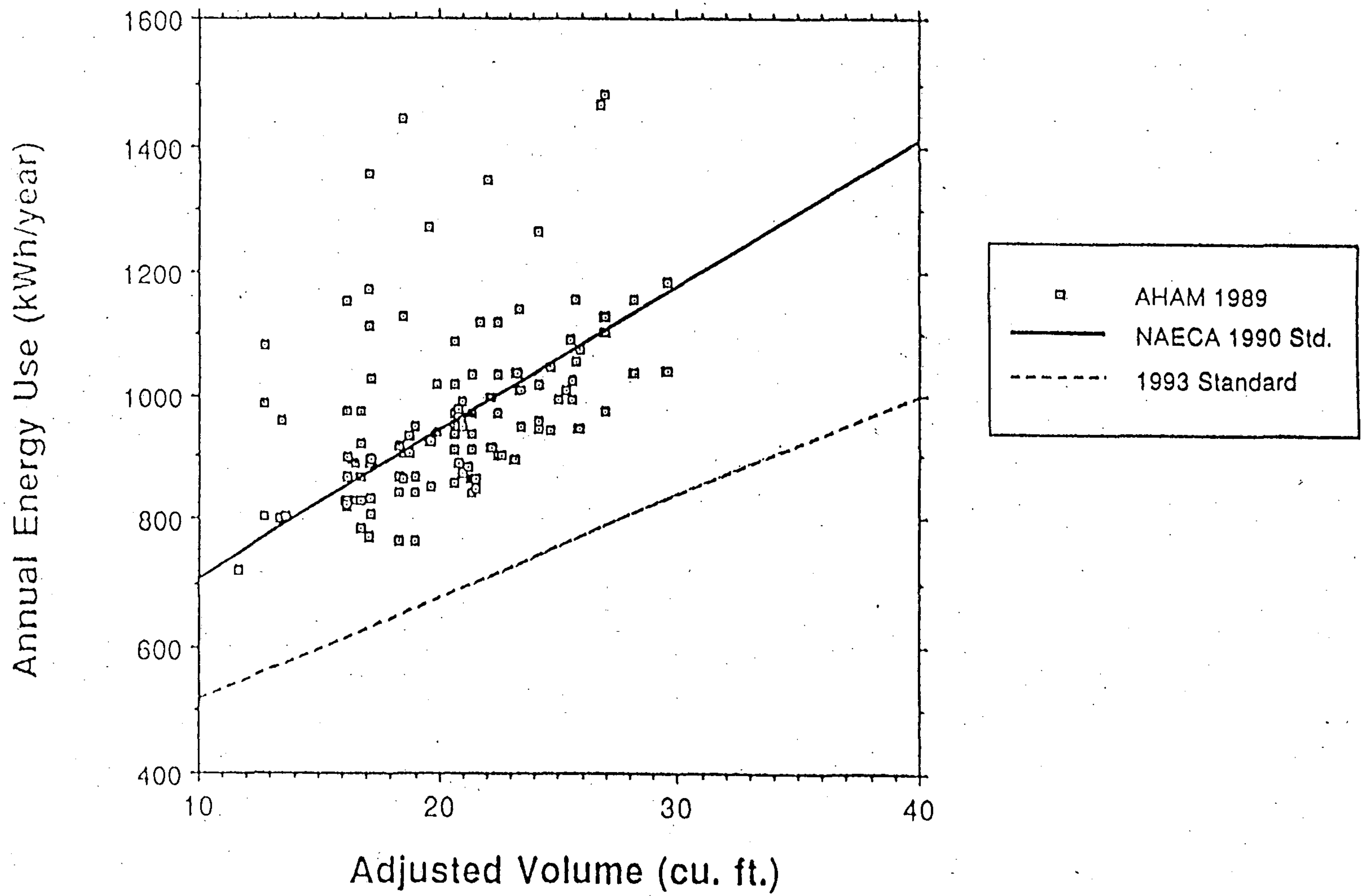

Figure 2: Energy consumption as a function of adjusted volume for 18 ft^3 top-mount auto-defrost refrigerator-freezers available in 1989 and the 1990 and 1993 minimum efficiency standards.