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MORE EFFICIENT HOUSEHOLD ELECTRICITY USE: AN INTERNATIONAL PERSPECTIVE*

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ABSTRACT

The energy efficiency of electric appliances has increased markedly in OECD countries, according to data provided by utilities, appliance associations, appliance manufacturers, and independent analyses of each country we reviewed (U.S., Sweden, Norway, Holland, Japan, Germany, UK). These improvements have, in part, offset increases in electricity demand due to increasing saturation of appliances. However, we see evidence that the efficiency of new devices has hit a temporary plateau: Appliances sold in 1988, while far more efficient than similar ones sold in the early 1970s, may not be significantly more efficient than those sold in 1987. The reason for this plateau, according to manufacturers we interviewed, is that the simple energy-saving features have been incorporated; more sophisticated efficiency improvements are economically justified by five to ten year paybacks, but unattractive to consumers in most countries who appear to demand paybacks of less than three years. Manufacturers see features other than efficiency — such as number of storage compartments and automatic ice-makers — as more likely to boost sales, market share, or profits. If this "efficiency plateau" proves lasting, then electricity use for appliance could begin to grow again as larger and more fancy models appear in households. This means that in every country there is a significant potential for improving the efficiency of electricity use by influencing consumers to choose more efficient devices *and* by coaxing manufacturers to develop more efficient technologies. In a few countries, the latter was achieved through a set of "Gentlemen's Agreements" between government and appliance makers that laid out a set of efficiency goals. In the U.S., minimum efficiency standards were chosen as a way of pushing market choices and technologies even farther. In a few utility districts in Europe (Stockholm, Oslo, parts of Denmark), utilities are engaged in active marketing of electricity efficiency, but in most of Europe information on the results of appliance electricity use testing is the only form of stimulation towards purchase of more efficient appliances. Government authorities and utilities concerned about the costs of meeting growing demands for electricity may wish to examine ways of stimulating the demand for, and supply of, even more efficient electric appliances.

1 INTRODUCTION

Since 1973, the efficiency of most energy uses in homes has improved throughout the OECD.[1] This means that to provide a given amount of energy service (for example, heating, cooling, locomotion or mechanical force), less energy is required today than was needed in the past. These improvements have been introduced through penetration of *new* appliances and, for space heating and cooling, the entrance of new homes with more efficient building shells and the retrofitting of the existing building stock. In this report, we analyze some of the past changes in the efficiency of household appliance electricity use, and discuss prospects for, and barriers to, further increases in the future.

The goal of this analysis is to assist the Scandinavian authorities who have sponsored this work in determining how household electricity demand could develop in the future. Swedish authorities are concerned about the impact of the phase-out of nuclear power in Sweden, and seek better information on how greater efficiency might moderate electricity demand. Norwegian authorities are concerned about the diminishing number of acceptable sites for future hydro projects. This limitation may force Norway to turn to North Sea gas for future expansion of electric power production, which may translate to higher marginal costs. While the mix of energy sources used to generate electricity in Norway and Sweden is almost exclusively non-fossil today, both countries face increased reliance on fossil fuels for incremental electricity generation. On a global scale, however, many authorities are concerned about the impact of increased fossil fuel use on the global climate.[2] Another global concern related to electricity efficiency is the depletion of stratospheric ozone due in part to the release of refrigerants — (CFC) R11 and R12 — into the atmosphere. Virtually all home refrigeration systems rely on these chemicals. Many companies are seeking alternative refrigerants that will neither cause further damage to the ozone nor reduce the efficiency of refrigeration processes. The problems of global climate change and ozone depletion have focused attention on the role of efficiency in providing the most refrigeration for the least expenditure in fossil energy *and* the least ozone-depleting refrigerants. Thus, there are many reasons why Scandinavians should be concerned about electricity efficiency.

Increased electricity-use efficiency is one way of reducing electricity demand and thus, mitigating the problems associated with expanding electricity supplies. In this study, we investigate the prospects for increased efficiency through analysis of electricity use in the major member countries of the Organization for Economic Cooperation and Development (OECD).[3] In the companion report, we made a detailed comparison of electricity use in Scandinavia.[4] The international analysis provides a context for understanding how factors have differentially influenced the development of household electricity use across countries. While there are many notable econometric studies on household electricity demand,[5] these rarely focus on individual end uses, nor address engineering issue that may change future energy demands. The present series of studies, therefore, should be seen as complements and extensions of econometric work. An international approach also illuminates prospects for increased efficiency. Electricity using equipment is increasingly produced by multi-national companies and sold in the international market. Thus, changes in the efficiency of equipment manufactured and/or used in one country may influence developments in other countries.

In this work, we focus on electricity use for cooking, lighting, water heating (only briefly), clothes washing and drying, and food refrigeration. Although space heating dominates household uses in Sweden and Norway, we did not analyze this end-use because it has been comprehensively treated by Scandinavian researchers. And, since Scandinavian homes have the lowest *average* heat losses of any in the world[6] there is not much that an international comparison could contribute to this important subject. We review measures of efficiency, discuss the effect of efficiency on appliance unit consumption over the last 15 years, and postulate how changes in efficiency and other appliance characteristics may influence future electricity demand. We touch briefly on how authorities could accelerate efficiency improvements.

2 SUMMARY FINDINGS

Our basic findings can be summarized in the following statements:

• Most household electricity-using technologies are significantly more efficient today than in 1973, principally because new, more efficient equipment has replaced older equipment. Additionally, some changes in consumer behavior have reduced electricity consumption for some end-uses, while measures applied to homes heated with electricity reduced heat losses and thereby electricity use for heating.

• Although these improvements in appliance efficiency have put downward pressure on unit consumption, unit consumption for most appliances has not declined proportionately. Changes in the frequency/level with which appliances are used, features and options that they possess, and size have generally acted to increase electricity unit consumption. However, in most countries, household electricity use is significantly lower than it would have been without efficiency improvements.

• New appliances and other electricity-using systems are more efficient than older ones that characterize the stock, but the rate of improvement of new appliances has slowed or halted, and consumer indifference to saving electricity is rising.

• A great technical and economic potential exists for increasing electricity use efficiency in future appliances, but policies may be required to provoke the exploitation of that potential by both manufacturers and by consumers. The efficiency improvement in most end-use technologies between 1973 - 1985 was driven mainly by higher electricity prices and a few informal agreements between authorities and the appliance industry, as well as standards in California. Technological changes that resulted in cost reduction (eg., replacement of fiberglass insulation with polyurethane foam in refrigerators and freezers) and automation of production lines were important enabling factors. The slowdown in the improvement of electricity efficiency is due to weakening of public and private interest in saving energy or electricity which in turn, is primarily a result of lower real electricity prices. Thus, accelerating the pace of efficiency improvements requires policies and higher electricity prices.

3 OVERVIEW OF EXPERIENCE SINCE 1973

In this section, we review some recent changes in the way electricity is used in homes. First, however, we define terms that we use frequently throughout this report. Each term denotes an important parameter that determines household electricity use.

Structure is the pattern of overall electricity use, disaggregated by end-uses and by types of dwellings/households.

Saturation is the fraction of homes or household owning or using a particular appliance or having a certain end-use, such as electric heating.

Utilization expresses the behavioral interaction between appliance users and appliances. Generally, utilization refers to indoor (or hot water) temperature, hours heated (or water used), meals cooked, kg. of clothes washed, etc. In this report we often mention the size and features of appliances alongside utilization, since these facets also measure service. For example, a large, frost-free combination refrigerator freezer delivers more service to a home than a small, single-door manual defrost refrigerator.

Household unit consumption means electricity use for a certain end-use per average household that has that end-use.

Appliance unit consumption refers to electricity use per appliance for a specified end-use.

Electricity intensity measures electricity use per unit of energy service for a specified end-use or appliance, such as kWh/(kg of wash), kWh/(liter of refrigeration per day), or kWh/(area heated)x(degree days). Thus, intensity is normalized for of the amount of service an appliance performs. This is the inverse of efficiency.

Efficiency is the ratio of service performed to energy or electricity consumed. Efficiency can refer to a certain product class of appliances (for example, top-mount, auto-defrost refrigerator freezer) or to individual components of an appliance (for example, a compressor, condensor or fan motor). A large refrigerator may be more efficient than a small one, yet require more electricity per year. A refrigerator with automatic defrost may have more efficient components than one without, yet use more electricity because of the defrost feature. Thus, a given improvement in efficiency does not always lead to a similar reduction in unit consumption.

Changes over time in total electricity use are the result of changes in the saturation of appliances, building shell efficiency (for space heating only), appliance utilization, appliance size, appliance features/options, and appliance efficiency. Household unit consumption is a function of the number of appliances per household and last five factors in this list. Appliance unit consumption is a function of the last four factors in this list. Appliance intensity is the inverse of appliance efficiency and is independent of the other factors. Since 1973, all of these factors have changed for almost every OECD country, giving rise to important changes in electricity use per household (3).

3.1 Changes in the Appliance Saturation Since 1973

Saturation of most uses of electricity depends on income, and is sensitive to the price of electricity or alternative fuels where these can substitute for electricity, such as for water heating, space heating, or cooking. In Norway, Canada, and Sweden, the saturation of electric space and water heating equipment increased such that electricity's market share in these two end-use markets grew. Electricity gained market share from oil though substitution because electricity prices were lower relative to oil. In France, electric heating has captured a large share of the new housing market as a result of government and electric utility promotion. In the U.S. and Japan, heat pumps spearheaded the spread of electric heating. In other countries, moderately priced gas and district heating took much of the growth in the heating and water heating market that had once been the dominion of oil. Thus, in these two important markets, the relative price of electricity had an important impact on market share.

Electric cooking gained market share almost everywhere, even where gas was cheap, such as in Holland or Great Britain in the 1980s. In this market, the price of electricity played a minor role in its popularity. In lighting markets and in markets for electric appliances (such as refrigerators, freezers, dishwashers, clothes washers and dryers*), there are no realistic substitutes for electricity except for the heating of water in washers and dishwashers. In these *electric specific* markets, saturation and size of electric appliances grew in all OECD countries and lighting levels increased. By 1987, the differences in electric appliance ownership between households in different OECD countries were much smaller than they were in 1973. As a result, electricity use per household for appliances differed less in 1987 than in 1973. Still, refrigeration appliances in homes in N. America are larger than in Europe, and ownership of dishwashers and clothes dryers still varies significantly. Taken together, the increased penetration of electricity in markets previously held by fuels, and the increased saturation of electric-appliances, could have *doubled* overall OECD electricity use per household between 1973 and 1987. But this doubling did not occur on average, because of changes in efficiency and other offsetting factors.

In the remainder of this paper, we will be discussing electric specific appliances, such as clothes washers and dryers, refrigerators/freezers, as well as lighting, cooking equipment, and briefly, water heaters. We will be considering the factors that determine appliance unit consumption: utilization, features/options, size, and efficiency.

3.2 Changes in Appliance Unit Consumption Since 1973: Utilization of Appliances

For households already possessing an appliance, the level of appliance utilization is influenced by both cost of electricity and other (non-price) behavioral patterns. Some uses are extremely sensitive to operating costs, others depend somewhat less on operating costs, while for some uses, operating costs are either very small or irrelevant. Some applications run independently of utilization, while other applications are totally dependent upon the habits and routines of the members of the household.

* Note: in a few countries, there are gas clothes dryers.

Space and water heating and cooling electricity use is very price sensitive, because the majority of the cost of obtaining this service is the cost of electricity. Thus, the price of electricity has been shown to influence the level of service demanded — such as the set temperature, number of rooms heated, hours heated, and hot water temperature. In Denmark, for example, space and water heating unit consumption fell markedly (4) after electricity prices increased in 1979 and thereafter. Consumption of electricity for space heating did fall somewhat in Sweden during the crisis year of 1974, but rose again when the apparent crisis eased. However, in Sweden, the very low thermal losses of homes in Sweden *reduce* the payoff from sinking temperatures or taking other measures to reduce heating needs. This reduces the incentive for short-term savings measures in these countries unless electricity prices climb significantly, as they did in Denmark. Water heating unit consumption in Sweden and Norway is high: We believe that low electricity prices are one reason, judging by the lower levels of use in Denmark. Electricity use for lighting is also price sensitive because the equipment (light bulbs, lamps) are relatively inexpensive and consumers exert enormous control over use.

The short range price response for other end uses is considerably less. The utilization of electric ranges and ovens in the short run is not as strongly influenced by price as the use of heating and cooling appliances, because there are no alternatives to meeting the needs for cooking. If electricity remains expensive relative to gas in the long run, consumers might replace their equipment with gas ranges and ovens.

For clothes washing, electricity to run the motor is the only real marginal electricity "cost" of using a washing machine vis a vis hand washing, and this cost is small compared with the energy required to heat the water. The same is true for dish washing. It is hard to believe that consumers would radically cut back on the mechanization of their washing for the small savings in electricity. On the other hand, consumers may exercise greater control over the quantities and temperature of water used. For drying, consumers might increase their use of the sun, or of hanging clothes in unused rooms to dry. So, for these "wet goods", consumers can make small but not insignificant reductions in electricity use in response to higher electricity prices and heightened interest in saving electricity.

Electricity use for refrigeration consumes as much as 20% of the household electricity budget. This end use, however, cannot be changed much through changes in utilization. For a given refrigerator, the owner has very little control over the energy use of the appliance — it is either plugged in or not, cooling food or not. (Although, the amount of food contained, and number of door openings do affect appliance unit consumption.) Thus, electricity prices do not influence "utilization" of refrigeration appliances. The level of energy use for the service performed — cooling food in a given volume — is determined by the manufacturer. In the long run, however, manufacturres can reduce the electricity required to cool a given volume, while consumers can choose to buy less electricity-intensive equipment.

For electronics and small motor appliances, variable costs — electricity costs — are a small portion of total costs, and usually invisible to consumers. Thus, the price of electricity does not greatly influence the utilization of these appliances.

For Denmark, Moeller[7] identified some possible changes in utilization that contributed to further reductions in unit consumption, such as changes in cooking, clothes washing, and water heating habits. In the companion report (4) we note other non-price induced historical trends in behavior patterns that have influenced household electricity use. These trends include less time spent at home (affecting all electricity uses), and fewer and simpler meals cooked in the home, both of which have lowered household electricity use slightly since 1973.[8]

3.3 Changes in Appliance Unit Consumption Since 1973: Efficiency of New Appliances

Changes in appliance utilization, features/options and size since 1973 have put upward pressure on appliance unit consumption. Yet, actual appliance unit consumption has not risen commensurately. This is due to the significant downward pressure on appliance unit consumption resulting from improvements in appliance efficiency since the early 1970s. These new, more efficient appliances have become part of the stock through the process of turnover (replacement of old equipment for new) and through stock expansion — increased saturation. As a result, the average efficiency of the stock of appliances increased. Thus, the growth rate of household electricity use fell or turned negative in most countries, except in the countries where space heating grew significantly. In a few countries, such as Denmark or the United States, electricity use per household *for appliances* levelled off or even declined. In other countries, such as Sweden or W. Germany, growth in this indicator slowed by the mid 1980s. In these four countries, the impact of increases in appliance *efficiency* outweighed the impact of greater saturation or size on electricity use per household. In other countries, such as France, Italy, Japan, or Britain, the increase in saturation and sizes/features more than offset the downward pressure of increased efficiencies, thereby raising electricity use per household for appliances.

Since 1973, all electric specific appliances have become more efficient. To illustrate the measures of efficiency, we focus on the refrigerator. A similar type of analysis is applicable for the other five electric specific appliances that we have discussed.

3.3.1 Measures of Efficiency Change

Figure 1 shows the time evolution of an index of electricity-use intensity* for new refrigerators or refrigerator-freezers in 3 countries. Intensity, in kWh per liter of volume per year is indexed to its 1975 value.† The changes in intensity observed reflect different combinations, depending on the country, of changes in size, feature, the efficiency of components (compressor, motor, etc.) and the mix of models sold. Increases in volume decrease the surface to volume ratio which in turn, decreases the heat loss per unit volume, thereby decreasing the intensity (increasing the efficiency) of the refrigerator. Increasing the number and extent of features of the refrigerator tends to increase the intensity. Refrigerator-freezers with fully automatic defrost or icemakers use more electricity than those without, for example. Thus, many factors besides efficiency influence the unit consumption of an appliance.

* For other appliances the units of intensity or its inverse, efficiency, differ.

† The data for W. Germany represent the consumption of a typical 210 liters (7.4 cu. ft.) refrigerator manufactured in the year shown. The data for Japan represent the consumption per liter for a large manufacturer's most popular (varying from year to year) combination refrigerator-freezers (hereafter called "combi"), the size of which grew from under 150 liters capacity in the early 1970s to nearly 400 liters by 1987. The data for the U.S. represent the sales-weighted average consumption for all combis sold in a given year. Since refrigerators are tested differently in each country, *absolute* intensities are not directly comparable. For these reason we present only an index of change.

Curves similar to Fig. 1 could be drawn to represent the evolution of electricity intensity of almost every new appliance over time. How do these changes affect unit consumption for each appliance? To answer this question, we first consider the trends in intensity in each country carefully.

The German data plotted in Figure 1 relates to a "typical" 210L refrigerator-only.[9] The changes in intensity between 1972 and 1987 are due to changes in the efficiency of components only, since the the size remains constant and features have not been added. However, this index does not indicate changes in the intensity of all new refrigerators *entering the stock* because this refrigerator is only one of many models that is purchased. A typical new model is likely to be larger than 210L, and have more features, in particular, it is more often a combi. As stated above, the increased size will increase the efficiency while the increase in features will decrease the efficiency. However, the increased size will increase unit energy consumption (as more space must be cooled). Thus, changes in new appliance size and features might be important enough to increase electricity use compared to existing products, even if the new product is more efficient than an older one.

The Japanese curve represents the performance of one large manufacturer's most popular combi. The decline in intensity over time is the net effect of three concurrent changes: Increasing volume, improvements in component efficiency, and increasing numbers of features. The downward pressure on intensity due to the first two factors outweighed the upward pressure on intensity imposed by additional features. The most recent edition of this model has 3 or 4 doors and an ice-making machine. These additional features account for the slight rise in intensity after 1984. Thus, the Japanese data reflect changes in size, features and components but, still does not reflect changes in the efficiency of new appliances *entering the stock* because this refrigerator is only one of many models that is purchased. We do not know this refrigerator's contribution to new refrigerators sales. Although the electricity intensity of the combi has declined by more than a factor of 4, unit consumption for refrigeration increased due to increases in volume and the shift from single-door models to combis in almost every home in Japan. In other words, the average household in Japan in 1987 used more electricity for its refrigerator than it did in 1970. Thus, efficiency has increased, but unit consumption for household refrigerators has gone *up* in Japan.

The U.S. index largely avoids this latter problem. The U.S. data are based on a "shipment weighted energy factor" (SWEF).* The SWEF captures the impact of changing size, features and component efficiency of all models sold† in a given product class on the efficiency. The US curve in Figure 1 is for the product class of combis with top-mount, auto-defrost freezers, which comprised nearly 50% of sales in 1972 and 67% by 1987. This index represents the *average* intensity of all models sold in this product class in the U.S. in the year indicated. Since 1972, the intensity of these refrigerators have declined. The turn-down in intensity after 1986 is probably the result of the California appliance efficiency standards. (Jim McMahon, LBL researcher, priv. comm.) Since the average size of a new combi in the U.S. has not changed much, and changes in features within this product class are negligible**, that the shape of the U.S. curve represents the

* The SWEF of all models sold in a given product class is tabulated by summing over the tested efficiency (in adjusted cooled volume per kWh) of each model sold times its share of sales. In W. Germany and the U.S., authorities constructed such indicators to keep track of change in efficiency as part of conservation policies. Unfortunately, the German data cover only the period 1978 -1985.

† Assumes that sales are proportional to shipments.

** Through-door access for cold water and ice is the only additional feature included and represents only 2-3% of sales in this product class. Thus, the effects of this change is insignificant.

evolution of electricity intensity *and unit consumption* for all models sold.

By taking the average intensity over all models sold in a product class, we can see changes in the intensity of the refrigerators entering the stock. Features, size, and the efficiency of components all vary from model to model within a product class. Thus, the SWEF reflects the mix of models entering the stock over time, as well as the changes in size, features and components of each model over time. The intensities of different models with otherwise the same features and sizes may vary significantly. Fig. 2, for example, shows the variation in annual electricity use, as a function of size, for combis sold in Sweden in 1987. If consumers buy larger combis, electricity use will increase. But at a given size, consumers may buy ones with high intensities or ones with low intensities. This scatter is caused both by differences in features and differences in the intrinsic efficiencies of the components. If more consumers choose less-efficient rather than more efficient models, the overall efficiency average declines, even if each individual model has been improved. Only by taking into account changes in product mix (size, features, etc.) as well as the actual selection of models by consumers can we get an accurate picture of how electricity use for new appliances sold has changed.

3.3.2 Trends

The shape of Fig. 1 does imply that new refrigerators are less electricity intensive -- more efficient -- than older ones in most countries. This conclusion can be generalized to all electric appliances (3). Fig.3, for example, portrays the average reductions in electricity intensity of a variety of new appliances in Germany, using sales-weighted figures. Fig. 4 portrays the sales-weighted efficiency factor changes for electric and fuel equipment in the United States. In both cases, intensity for these purposes was lower in 1987 than in 1973. Authorities believe that similar improvements have been realized by all new appliances sold in many other countries.* Additionally, powerful evidence for improvement in appliance efficiency comes from individual manufacturers. The efficiency of products that each major manufacturer offers internationally has increased.**

What about other important electricity uses? The thermal integrity of new homes heated with electricity has improved; consumption data from many countries indicate that newer, electrically heated homes use less electricity for heating than older ones. The market share of fluorescent and compact fluorescent lights, which are more efficient than incandescent lamps, has increased in the last 15 years.*** Finally, electronic goods are more efficient than previously. Conversations with manufacturers indicate that the electricity requirements of a large color TV today are far less than those of a small B/W model in the 1960s. The efficiency of stoves/ovens has also improved.

*Schipper *et al.* report estimated improvements in sales-weighted efficiency of 20-50% for new appliances in Holland, Denmark, Sweden, and Japan.

**Based on data and catalogues supplied by Philips (Eindhoven, Paris, Oslo, Stockholm [Asea Skandia]), Cylinda (Stockholm), Thompson (Paris), and Electrolux (Stockholm), representing Europe, as well as National (Tokyo), and Whirlpool (U.S.A.).

***Unfortunately, it is difficult to estimate the quantitative impact of these improvements in efficiency on electricity use for heating or lighting.

Changes in the efficiency of 'wet appliances' -- clotheswashers and dishwashers -- resulted from changes in the factors identified above as well as changes is how much hot water is used and at what temperature the water is required (relevant only for appliances that heat their own water). Reductions in the amount of water used result in less electricity necessary to remove the water from clothes and of course, lower temperatures require less electricity used to heat the water. Fig. 5, for example, shows estimates of electricity and water use in clotheswashers made by Siemens (Siemens AB, Stockholm, priv. comm.) Other manufacturers report similar changes, and display them prominently in their advertising. These changes in water use (amount and temperature) for clotheswashing were made possible by changes in the detergents available and the types of materials that clothes are made of. Also, water requirements were reduced by changes in the way water is injected into the washer drum. Additionally, authorities in every country report that consumers are using high temperature (90C) washes less and lower temperature ones more, perceiving such high temperatures as unnecessary. Taken together, all these changes (which apply to a lesser extent to dish-washing) reduce electricity intensity for washing.

3.4 Many Factors Mean Less Electricity Use: Application to Scandinavia

How do these findings apply to Scandinavia? The companion paper documents improvements in thermal integrity of new housing. In our original report (3), we found that for appliances, efficiency improvements similar to those for Germany and the U.S. were also made in individual models sold in Denmark and Sweden. For Sweden, for example, Mills[10] compared electricity intensity of the most common refrigerator-freezers (combis) sold in Sweden in 1980 and 1987 as a function of size. He found (Figure 6) that virtually every intensity appeared to be lower in 1987 than in 1980. The least intensive 350L combi in Fig. 6 sold in 1987 used only about 450kWh/yr, while the corresponding model in 1980 required over 700kWh. This suggests -- but does not prove -- that the average efficiency of combis sold improved over this period: Unless consumers managed to buy the least intensive models in 1980 and the most intensive ones in 1987, this comparison implies important reductions in the average electricity intensity of new refrigerators. And since the average *size* of combi (or refrigerator, or freezer) has not increased much since 1973, this means that unit consumption must be lower in 1987 than it was in 1973 (however, somewhat larger models were available in 1987 compared with 1980). Without accurate sales-weighted figures, we can only estimate the impact of lower intensity on unit consumption. According to Mills, and the appliance manufacturers in Sweden, this comparison represents most "white" and "wet" goods. Thus, the typical new appliance sold in Sweden is more efficient today than in 1973.

Swedish and Danish experts believe that unit consumption for major appliances has fallen since 1973. Malinen of Vattenfall[11] constructed a detailed model of the Swedish stock of refrigeration equipment based on these kinds of data. He also made similar estimates of the characteristics and electricity use of washing and drying equipment and other household uses, as well as a survey of several hundred homes.[12] His work implies that the intensity of new household appliances significantly declined in Sweden since the mid 1970s. Moeller (7) finds that the same has happened in Denmark. Using information on tested consumption of the most important models of different size, as well as the mix of sizes sold, he estimated the impact of improvements in the efficiency of new appliances sold in Denmark, to arrive at an approximate sales-weighted average for new models. He used this information to estimate how the intensity of the stock evolved. Although neither Moeller nor Malinen had access to detailed sales data that allow calculation of sales weighted efficiencies or intensities, both believe that for most or all products, the average tested consumption of all models sold was less than that of the previous year, and considerably less than the stock in place.*

The foregoing review shows that the unit consumptions of appliances in Scandinavia has decreased, because of greater efficiency. This means that for a considerable time to come, replacement of older appliances by newer ones will likely lower electricity use for appliances, stoves, and in some cases water heaters. But can the pace of technical improvement continue? The next section reviews factors that govern prospects for more efficient appliances.

4 PROSPECTS FOR IMPROVED ELECTRIC APPLIANCE EFFICIENCY

Fig. 7 portrays average unit consumption of household refrigeration equipment in Sweden in 1973, 1978, and 1987. Additionally, the figure shows the estimated unit consumption of the new appliance in each product line with the lowest unit consumption (ie., among models typical of the size of new ones sold), the highest unit consumption of a new appliance, and our projection for a practical "low energy device".† The low energy refrigerator, for example, is the Noergaard design, now marketed by Gram in Denmark (called the LER200). The values for the other "low energy" freezer and combi are derived by scaling results from Geller[13] or the Lawrence Berkeley Laboratory[14] for the U.S. to Swedish sized models.

The spread between "highest" and "lowest" unit consumption in new models is intriguing. The "highest" model consumes about the average of all existing stock, while the "lowest" consumes half as much. The "hypothetical" low energy model consumes half of the "lowest" model. The spread implies that, other things being equal, replacement of all existing models with a random choice of models in the market in Sweden would lower intensity by about 25% if size and features remained constant. There is a 2:1 spread in these unit consumption figures between the 1973 stock and the 1987 new highest unit consumption, without considering size or features. Size is not increasing much, but features are, as more consumers are buying three door combis or models with automatic defrost. Such changes tend to *increase* unit consumption. Our estimate of "lowest possible" implies nearly a 4:1 spread in unit consumption between the models portrayed.

Clearly, then, consumer choice will have a significant impact on future appliance electricity use. Equally important are manufacturers' decisions to develop models with the consumption levels implied by the low energy models depicted. What influences the efficiency of appliances on the market and consumers' choices? Technical potential and economic considerations together influence the efficiency of appliances produced and purchased.

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* Unfortunately, no such data have been assembled in Norway. But conversations with Philipps A/S (O. Sveum, priv. comm.) indicate that Norway experienced similar trends in intensity and efficiency of individual appliances.

† These were selected from Mills' data, using 250l for freezers, 350l for combis, and 400l for refrigerators.

4.1 Electricity-Use Technology: Many Ways to Save Electricity

The first factor that influences future electricity demand for an appliance is technical progress itself. There is no doubt that virtually any type of electric appliance sold today could be made to run on significantly less electricity.[15] This statement is confirmed by the progress and projections for the U.S. (Fig. 8), as made by Geller (13). These projections appear to represent bold reductions, yet they can be traced to detailed estimates or actual prototypes. Noergaard has made similar projections for Danish appliances (see Appendix 1).

A single example for refrigerators will illustrate how these projections are made. Detailed measurements of actual consumption, and engineering models of potential improvements (such as were developed at the Lawrence Berkeley Laboratory in connection with the U.S. Appliance Efficiency Standards mandated by the National Appliance Energy Conservation Act in 1987) show how much electricity use could be reduced if specific technologies were incorporated into typical refrigerators sold today. LBL estimated how electricity use would be reduced by each specified change in appliance technology, as well as by an entire package of changes.[16]

Table 1 shows the step-by-step reduction in electricity use arising from the application of these options. This analysis concludes that technological advances for reducing electricity use in refrigeration have not been exhausted. Other new developments not included in this analysis offer additional opportunities for electricity savings. For example, a Berkeley group has developed a new kind of insulation, so-called SS-Gel, which provides almost three times more thermal resistance than conventional insulation of the same thickness. Thus, technology is not the factor *limiting* future electricity savings.

Some new technologies are slowly making their way into all appliances, such as simple microchip controllers; other technologies, such as rotary compressors, variable speed motors, dual compressor systems, alternative refrigerants, advance seals, are only appearing in a few, usually more expensive, models. One reason that these technologies are not universally being incorporated is due to their relative newness and uncertainty about their performance. For example, there is little experience with evacuated panel insulation for refrigeration. However, LBL studies find that most of the design options in Table 1 are proven, well-developed technical improvements that *could* be implemented today. Why have such options largely been ignored?

Economic conditions and perceptions that guide consumer and producer decisions regarding the purchase/production of more efficient appliances determine the pace with which these improvements are adopted. In the next section, we will identify and discuss these economic conditions and perceptions that affect the rate and degree to which technological changes will be incorporated in standard appliances for the specific purpose of improving efficiency. It is important to note however, that some technological change is likely to occur that will improve efficiency but will be adopted for reasons independent of considerations about electricity savings per se. For example, new ceramic, halogen, and magnetic heating elements for electric cookers promise more rapid cooking and greater user control, which reduces electricity use (Philips Francaise, priv. comm., 1988). Because greater control is a selling point, efficiency will probably increase. Increased costs for water and changes in clothing materials both encourage or permit lower electricity consumption for clothes washing, leading to more careful controls on both chemicals and water use (Bosch-Siemens AG, priv. comm., 1989). Zanussi SA (priv. comm., 1988) suggested that new techniques for food storage which are less reliant on refrigeration are conceivable and may emerge.

4.2 Efficiency: The Role of Consumer and Manufacturer "Choice"

Although technology does not present immediate limits to improving appliance efficiency, the divergence of societal, consumers' and producers' perception of the benefits and costs of increased efficiency are currently prohibiting the realization of these improvements. For consumers, income, the cost of the improvements, the price of electricity, and non-economic factors are all considerations in deciding whether to purchase efficient appliances. For producers, the potential reception by consumers determines the investment in R&D and the commercialization of appliances that embody efficient technologies. According to economic theory, the means of providing a given quantity and quality of service that require the minimum resource inputs (and thus, costs) is the socially optimal one. As we will describe in the following sections, the socially optimal means of providing refrigeration, heating, lighting and other services is not being achieved. Too much energy is being used relative to technological innovation because of market failures that distort consumers' and producers' perspectives and ultimately, their behavior.

4.2.1 The Consumer: Income

Consider first the impact of the level of household income on appliance choice. Higher incomes mean more rapid expansion of appliance ownership and more rapid turnover/replacement of existing models. For the Scandinavian countries, ownership levels of major appliances are high; more appliance purchases means replacement. While new devices are likely larger than those that are retired, the increase in average size is slow.* This replacement will not directly translate into higher electricity use. Indeed, in some markets, like refrigeration and wet goods, the overall impact on electricity demand of replacement is negative, because newer models are so much more efficient than the ones that are scrapped. (If they *are* scrapped: in the U.S. and Sweden, old refrigerators often wind up in basements, garages, or summer homes!)

Higher incomes also permit more luxurious appliances. Luxury can mean better controls and lower energy use for washing and drying equipment. For refrigeration, however, luxury usually means larger and more features, and, recently, the spread of three, four, and even five-door refrigerators. In Scandinavia, the combi is gradually displacing the single-door refrigerator in homes, and slowing the spread of freezers to some extent. Automatic defrost is becoming popular. These changes offset some of the *savings* in electricity from better technology. Such developments occurred in Sweden and Norway as well as in other OECD countries, although the impact of greater luxury on electricity use is far more important in the other countries, where present standards (ie., appliance size, features) are somewhat below those in Scandinavia. In all, we believe that the effect of higher incomes on unit consumption for major appliances in Sweden and Norway should be to reduce unit consumption through replacement more than to increase it due to increasing size or number of features.

* In some markets, increased penetration means larger numbers of smaller washers, dishwashers, or even dryers in households that would not have acquired such equipment a few years ago. These smaller units may have lower consumption per cycle, but, because they have smaller capacity, would tend to have higher consumption per unit of service (dish washed, kg. of clothes washed or dryed).

4.2.2 The Consumer: The Cost of Saving Electricity†

The next fundamental factor governing technology choices is the cost of making efficiency improvements relative to the economic benefits of these savings, the latter of which depend largely on the price of electricity saved. Unfortunately, manufacturers, consumers, and society perceive different costs and benefits.

Consider the actual cost of making specified changes to any appliance and the electricity savings these changes cause. Figure 9 illustrates the energy savings associated with incremental efficiency improvements in a new 18 cu ft. (625 liter) top-mount auto-defrost refrigerator-freezer (this product class represents approximately 70% of sales in the US in 1987). The "base case" reflects the technologies employed in refrigerators currently sold.** Table 1 shows LBL's estimates of the incremental costs associated with these efficiency improvements. With these design options, annual energy use is reduced by 54% while the manufacturing cost is increased by only 34% or $76. Over the operating life of the appliance, the reduced energy use made possible by this additional capital expenditure translates to lower energy costs: The life-cycle cost (LCC) allows one to evaluate the tradeoff between current capital expenditures and future energy expenditures. The LCC is the sum of the purchase cost (the manufacturing cost plus factory, distributor and retail markups) and the discounted operating cost, the latter of which is primarily energy costs. Using an appliance lifetime of 19 years, a 7% real discount rate, and electricity price forecasts that translate to a 0% yearly real increase, LBL estimated the total cost of owning and operating the combi with each additional efficiency option (Figure 10).* LBL has applied analyses such as those illustrated above to a wide variety of household appliances (16), as well as to other aspects of household energy use, such a building energy performance standards.[17]

The results of this type of calculation are very sensitive to the the discount rate and electricity price escalation rate selected. A lower real discount rate shifts the curve up and increases the slope. The base case becomes more expensive relative to the appliance represented by design level 12. Thus, with a lower discount rate, future expenditure is valued more. This means that the difference between the LCC of more efficient appliances that use less electricity and those that use more electricity becomes greater. And the value of an investment in greater efficiency could increase relative to the value of other investments. An economically rational consumer (in a perfectly competitive market) would compare alternative investments such as stocks, bonds, savings and others and will pursue efficiency investments that provide the same or better rates of return as are available from these other investments.

† For further discussion of concepts presented in this section and the following, refer to references 14 and 18.

** Includes 1.9 inches of foam insulation in refrigerator sides, 1.5 inches of fiberglass insulation in refrigerator door, 2.2 inches foam in freezer sides, 1.5 inches foam in freezer door, a compressor with an EER of 4.5, a 10 W evaporator fan and a 13.5 W condenser fan. See reference 14 for more details.

* The possible reduction in electricity use is somewhat less if those options that would increase the use of CFCs (for foam insulation) were not employed. Also, Gel insulation is not considered. Such insulation, which does not use CFCs, is considerably more expensive than foam, but allows the interior of the refrigerator to be a little larger. When all costs and benefits are counted, it appears that this new kind of insulation would reduce costs even more.

Thus, one would expect that those appliances with the lowest LCC at a real discount rate of 7-10% (typical or better than rates of return on private savings) would be most popular. Instead, empirical studies indicate that appliances with the LCC minimum corresponding to a discount rate of 40% to more than 160% are currently being sold in the marketplace.† [18] This indicates that current expenditure is much more highly valued than future expenditure. As will be discussed below, several market and institutional barriers induce this apparently economically irrational behavior.

4.2.3 The Consumer: The Price of Electricity

The initial price of electricity and the electricity price escalation rate are the other variables that influence the absolute LCCs of appliances and the relative differences in LCCs between appliances with varying efficiencies. For a given discount rate, a higher electricity price level will shift the LCC curve up and a higher electricity price escalation rate will increase the slope of the LCC curve. The minimum of the LCC curve is the point where the *additional* efficiency investment cost per kilowatt-hour saved increases the life-cycle cost.

This additional capital cost is combined with the total electricity savings (in kWh) to create an indicator called the cost of conserved energy, or CCE. The CCE is the *additional* capital and maintenance cost amortized over its useful life (at a given discount rate) divided by the total amount of energy saved annually.** Note, this calculation is independent of the price of electricity. Table 2 presents the CCE for the design options on the refrigerator-freezer that we are using to illustrate these concepts. The CCE can then be compared to the price of electricity: efficiency improvements that translate to CCEs which are less than or equal to the price of electricity are attractive investments to an economically rational consumer and from a societal perspective. These investments are not observed in today's markets.

Table 2: Cost of Conserved Energy
Top-mount, Auto-defrost Refrigerator-Freezer[a]
(¢/kWh)

Level 3[b]	Level 4	Level 5	Level 8	Level 12
0.68	0.89	1.23	2.20	3.96

(a) with through-the-door service only.
(b) levels correspond to those in Table 1.
SOURCE: (14)

† The discount rate can be converted into an equivalent payback period. This is the period of time (in years) that it takes to realized energy savings that are equivalent to the purchase price. For this refrigerator example with a lifetime of nearly 20 years, the paypack periods that correspond to the range of discount rates are 3 years to 1 years, respectively. The higher the discount rate, the shorter the payback period the consumer wants, or the shorter his or her time horizon.

** Levelized investment cost in dollars per year divided by energy savings per year results in CCE in units of dollars per kWh.

It is clear from Table 2 that the higher the electricity price, the more efficiency improvements that have a CCE less than or equal to the price of electricity. Thus, more efficiency investments can be justified or the more a consumer gains from investing in greater efficiency. Over the wide range of prices found in the U.S. (or expected over the next 20 years), most of the technical options examined by LBL "pay off." The conclusion: Over this wide ranges of prices, significant increases in the efficiency of most household appliances would save consumers billions of dollars.

The range of household electricity prices in different countries in the OECD varies by more than a factor of three[19] from Norway and Sweden at the low end to Japan, Denmark, and Germany, at the high end. Consumers in Japan, Germany, and Denmark have shown more interest in electricity efficiency than in other countries. The index of unit consumption of combis in Japan fell more than in any other country, as manufacturers developed rotary compressors and other techniques to lower energy costs. Or take consumer choices of products. Extra well-insulated box freezers, for example, cost more than ordinary freezers, but pay back the extra cost through saved electricity in 5 - 7 years (which translate to 22 -14% discount rates). In Germany, the share of these electricity-saving freezers is significant. In Scandinavia, these freezers command only a very small share of the market, although the share in Denmark, where electricity prices are high, is somewhat larger than in Sweden or Norway, where prices are low. Thus, among the countries we have studied, manufacturers innovate faster for "high price" markets (Denmark, W. Germany, Japan), and consumers in "high price" countries *tend* to pay more attention to electricity efficiency (e.g. invest more in saving electricity) than those in relatively lower price countries.

4.2.4 Barriers to Consumer Efficiency Investments*

Why is consumer interest in saving electricity weak? To understand this factor, LBL examined the question of consumer choice in some detail. In the U.S., consumers can choose from similar appliances that differ principally in energy efficiency. Their decisions do not reflect the results of LCC or CCE analyses. Why does consumer behavior diverge from that which would be deemed optimal from both the point of view of an economically "rational" private consumer and a societal perspective. The reasons for this are numerous. First, LBL found that the trade-offs between efficiency and higher first costs were not clear (although less ambiguous for some appliances such as air conditioners that for others, such as refrigerators).[20] Second, the more efficient appliances may not be available in retail stores. Third, the rational consumer may lack the information about costs and benefits of energy efficiency improvements or may not understand how to use the information if it is available. The transaction costs of obtaining this information/understanding may be too high. Fourth, the rational consumer may not have enough capital to invest or may feel too financially unstable to sink scarce resources into investments with payback periods of more than several years. Fifth, the monetary savings are often small both in absolute terms and as a percent if income. Factors one through five are particularly influential for purchases that are motivated by the failure of the consumer's existing equipment, ie., when replacement must be immediate. Sixth, the consumer's appliance purchase decisions are often more heavily influenced by appliance characteristics that do not enter into these costs calculations. An efficient appliance may lack features desired or have other features not wanted

* For further discussion, see reference 18.

by the purchaser. All the appliance manufacturers we interviewed admitted that electricity efficiency was indeed a selling argument; but they also argued that color, noise levels, and other features were more important. And seventh, the consumer using the appliance may not actually purchase the appliance and thus, costs and benefits of efficiency improvements are non-coincident. Rather, the landlord or contractor may purchase the appliances with an incentive to minimize only the purchase cost because he does not pay the operating costs. From conversations with utility experts and manufacturers in every country, it appears that efficiency is a more significant buyer consideration in Denmark and Germany, and less important in Sweden, Norway, France, and the U.S. But in no country does the efficiency of appliances truly play a *dominant* role in consumer decisions. Indeed, manufacturers in France reported that the most important selling argument for the super-insulated freezer was the fact that it can keep food frozen for 48 hours after an interruption of electricity supply. Consequently, this number of hours is displayed prominently in advertising.

This problem — high consumer discount rates, or short consumer investment time horizons — was one of the principal arguments *for* minimum efficiency standards in the U.S. The U.S. standards are defensible on grounds of "cost effectiveness" because the calculations behind the standards use discount rates more favorable to consumers than interest rates offered by banks, for example. The discount rates used — 7 - 10% real — still represent a considerable drop over those revealed by consumers in the LBL studies: *between 40% to more than 160%!* The purpose of standards is to force consumers -- and manufacturers -- to take a somewhat longer time perspective than this discount rate implies!

The conclusion is clear: the market demand for efficiency investments in new appliances is very weak. When electricity prices are rising, consumers express more interest in efficiency than otherwise, but this interest still reflects a very short-term time horizon.

4.2.5 Producers' Perspective

To consider the perspective of producers, or manufacturers, we interviewed nearly a dozen companies and industry associations around the world.* Manufacturer's decisions to invest in research and development on and to commercialize more efficient appliances are primarily influenced by their observation of current consumer behavior, their anticipation of future consumer behavior and technological risks. The manufacturers recognize the extremely high consumer discount rate, and are wary of producing slightly more expensive appliances that will be undercut in the market by cheaper (but more energy-consuming) models. This comprises an economic risk for the manufacturer, when they have to modify their production processes through extra investments (particularly before assembly lines are scheduled to be retired or retooled). In such cases, the manufacturer is uncertain whether he will recoup his extra investments through sales.

Also, manufacturers with a bounded amount of capital, invest this capital in innovations in appliance features that appear to strongly influence consumer purchase decisions. For example, the Japanese company represented in Figure 1 has installed an ice-making feature that makes ice with no air bubbles! American refrigerators feature water and drink dispensers and through-the-door milk cabinets. Three- and four-door refrigerators have now been introduced in Sweden.

* These are listed in an Appendix 2.

These models are not *in*efficient, but manufacturer resources that used to be devoted to efficiency are now being plowed into these other "innovations."

Finally, manufacturers are also concerned about risks associated with technological failure. Technological risks arise when new techniques are introduced (especially at a rapid pace).[21] America's General Electric Co., for example, reportedly lost hundreds of millions of dollars over an assembly line to produce efficient rotary compressors. The assembly line was junked because the product was of poor quality. American firms have not learned how to manufacture rotary compressors. One important electricity saving option for refrigeration — vacuum panel insulation— is seen as a risk from the manufacturers' perspective because its long-term durability is unknown. Similarly, the uncertainties over alternatives to refrigerants R11 and R12 mean that virtually no manufacturer wants to invest in a new line of refrigeration equipment until acceptable alternatives to these refrigerants are found (the particular compressor and insulation level is optimized for any given refrigerant). This means that innovations in compressor and insulation techniques must await decisions by authorities on which refrigerants will be deemed environmentally acceptable.

What elements of the business climate encourage more innovation and private research to save electricity? Certainly, high electricity prices and anticipation of rising prices in the future reduce a manufacturer's risk from investing in efforts to improve efficiency. With higher prices, consumers will be more likely to purchase more efficient appliances even at their low discount rate (the CCE of more appliances fall at or below the price of electricity). With higher prices, undertaking technological risks is more readily justified by potential sales.

5 The Efficiency Plateau?

The net effect of the factors that we reviewed in Section 3.3 was to *decrease* the intensity of new appliances between 1973 and 1985. There is now evidence, however, that the pace of improvements in the efficiency of appliances actually sold is slowing down. Fig. 1, for example, indicates that the intensity of new refrigerators in the three countries has approached a plateau: Models sold in 1987, while far more efficient than similar ones sold in the early 1970s, may not be significantly more efficient than those sold in 1986.

The reason for this plateau, according to manufacturers we interviewed, is that electricity prices ceased to escalate in many countries by the mid-1980s (due to the decline in world oil prices) and therefore, with current consumer discount rates, the justifiable energy-saving features have been employed. More sophisticated efficiency improvements are economically justified at discount rates of 8% to 64% (or ten- to two-year paybacks). Manufacturers see other features as more likely to boost sales, market share, or profits. Manufacturers that we consulted believed that the plateau would persist. They suggest that efficiency of most appliances will continue to improve slowly, by approximately 1%/yr, to the end of the century.[22] This view is supported by the plateau in Fig. 1 and appears to be reflected in the projections made by Vattenfall or Moeller. If this "efficiency plateau" proves lasting, then electricity use for appliance could begin to grow again as larger and fancier models appear in households. Electricity use per appliance may not increase, but it may not decrease at anywhere near the rate of the late 1970s and early 1980s. (However, in the U.S., national appliance energy conservation standards will make 1990 new models more efficient.)

Other observers[23-29] believe that greater improvements are both technically possible and economically defensible. This position follows from CCE analyses and LCC analyses that reflect lower, more socially favorable discount rates. These rates are justified by the need to more strongly value future energy savings and expand consumer decision-making time horizons (particularly with the anticipation of the increasing costs of new electricity supplies) and secondarily, by comparison with other observed market rates of return.

The LBL appliance studies support both the manufacturers' and societal perspective: Potential exists for technical improvement and gains in economic efficiency (both from a social perspective as well at from a consumers point of view, measured in returns on investment); however, left alone, the market will not rapidly push consumers and manufacturers towards greater electricity-use efficiency. The pace of improvements is extremely relevant in that it affects our ability to respond to political and environmental pressures imposed by the expansion of electricity supplies.

5.1 Applicability to Scandinavia

Technology holds promise for more efficient electricity use. The U.S. experience suggests that electricity efficiency plays only a minor role in consumers' appliance purchase decisions, and therefore, consumers do not choose the most efficient models. Is this finding applicable to Scandinavia?

The Scandinavian experience with electric appliances suggests that electricity efficiency is a higher priority in consumer decision-making than in the U.S., but not important enough to become a principal determinant in decisions. The European consumer in general, and the Scandinavian consumer in particular, is probably more concerned with future costs than consumers in the U.S. for three reasons.

First, the U.S. consumer has more disposable income, and therefore is less pressed to consider electricity savings. Second, the U.S. consumer pays lower marginal taxes, and therefore has less incentive to invest today in order to lower consumption costs in the future.* Third, U.S. consumers would appear for the moment to be at less risk than those in Scandinavia of facing increasing electricity prices in the near future. Average prices in the U.S. are already higher than those in Norway and Sweden, and competitive alternatives for new electricity supply (including industrial co-generation and energy conservation in buildings) appear likely to mitigate against dramatic price rises. The future price of electricity in Sweden is much less certain.

As noted in the introduction, interest in electricity saving has been localized in Scandanavia: the nuclear backout in Sweden, concern over the shortage of new hydro sites in Norway, and worry over the environmental impacts of coal-fired electric power plants in Denmark. Yet few policies have been instituted aimed at new electric appliances, particularly in Sweden and Norway. From this study, however, we cannot conclude that under present conditions, Scandinavian consumers will select the most electricity-efficient appliances. While new appliances will be more efficient than older ones, and in most cases have lower unit consumptions, the pace of improvement will be slow under present market conditions. The potentials for more efficient use

* If a Scandinavian in the 75% marginal tax bracket saves one unit of energy cost tomorrow, that savings is equivalent to 4 units of pre-tax income.

will be realized, but only over a very long time period.

Three international concerns have stimulated renewed governments' interest in the dissemination of more efficient electric appliances. The first concern is stratospheric ozone destruction that is caused by the atmospheric release of CFCs from refrigerators and air conditioners. Concern over this problem has unleashed a torrent of R&D to develop ozone-friendly substitutes. The necessary substitution of alternatives for CFC-based refrigerants and foam-blowing agents may lead to slight increases in electricity intensity for these end-uses in the near term, but in the long-term, it is expected that intensity will fall again as manufacturers begin to reoptimize electricity use for new refrigerants. The second concern — the contribution of fossil fuel use to climate change through the greenhouse effect — could lead to international agreements to accelerate improvements in appliance efficiency. These improvements could reduce the need to build new fossil-fuel fired power stations. It is also possible that if nations agree to find substitutes for fossil fuels, the price of the alternatives will be higher, forcing average electricity costs up. Finally, the rapid growth of ownership and use of electric appliances in developing countries[30] is straining electric power systems there. Power plant financiers have begun to realize that improving the efficiency of electricity uses would save enormous capital investments in electricity supplies. This realization may be translated into further pressures on appliance manufacturers to improve *all* their products. All of these international forces will have an impact on improving appliance efficiency in Scandinavia in the long run: Authorities in Sweden and Norway are no longer isolated in their concerns over efficiency.

6 ACCELERATING THE IMPROVEMENT IN ELECTRICITY END-USE EFFICIENCY

In this section, we will briefly review strategies for accelerating the production and dissemination of more efficient appliances.

6.1 Are Policies Necessary?

To capture the potential for efficiency, policies may be necessary to hasten the improvements in efficiency and stimulate consumers to buy more efficient models. National authorities, as well as utilities concerned about the costs of meeting growing demands for electricity may wish to examine ways of stimulating the demand for, and supply of, even more efficient electric appliances. Explicit policies are particularly necessary in an environment of uncertainty: uncertain future energy supplies and costs, and environmental threats. Certain kinds of policies allow planners to reduce future uncertainties. The reduction in uncertainty is in itself of great value to planners.[31] For example, standards that eliminate the most inefficient appliances from the market suppress demand growth that would have resulted from consumers buying these appliances. Where future supplies are uncertain, investments in programs to promote greater efficiency could reduce the need for those supplies and hence, reduce uncertainty further.

Electricity savings policies and programs can be justified for a number of reasons that have been alluded to above. Market barriers - poor information, separation of buyers/users/owners, emergency transactions -- all hinder the selection of electricity efficient appliances. And high consumer discount rates short-circuit the results of whatever marketplace process remains. In this section we review *briefly* some policies and programs worth exploring.

As Wilson *et al.*[32] point out, policies and programs can be aimed to (1) fix the market, (2) change the market and (3) alter the make-up of items on the market. All except the sixth barrier to the purchase of more efficient appliances identified in section 4.2.4 and the barriers to manufacturer production of more efficient appliances discussed in section 4.2.5 could be reduced through policies and programs directed at (1) fixing the market (information programs, regulations for bulk appliance purchase) and (2) altering the products on the market (efficiency standards for buildings and appliances).

While a complete discussion of policies that would promote more efficient appliances — and more generally, energy use — is beyond the scope of this project, we can review a few important policies here:

- In a few countries (W. Germany, Japan), "Gentlemen's Agreements" between government and appliance makers laid out a set of efficiency goals for major appliances (see Wilson *et al.*, 1989). Establishing these goals requires agreement on measuring sticks, wide dissemination of information, and promotion. The German agreements stimulated progress towards greater efficiency in all of Europe.

- In many American States (and now nationally), minimum efficiency standards have been imposed as a way of pushing market choices and technologies even farther than would have occurred as electricity prices increased. [33,34] *The motivation behind state standards has been to reduce the need for expensive new power plants and save consumers money in the long run.*

- In many utility districts in the U.S., utilities actively market efficiency by promoting efficient appliances, offering rebates to purchasers of the most efficient models in any product class. In some cases utilities even buy back old, inefficient refrigeration equipment that otherwise sits in basements or garages and runs for years! *The motivation for such programs has generally been to lower utility investment needs through buying conservation instead. In some cases, such programs were imposed by state regulatory authorities rather than initiated by utilities. Where electricity prices are no longer rising rapidly, utility interest has faded.*

- In a few districts in Europe (Stockholm, Oslo, parts of Denmark), utilities are engaged in active marketing of electricity efficiency. Norwegian and Swedish efforts focused initially on heating efficiency, but now water heating, cooking, lighting, and appliances are being discussed.[35] *Utility involvement is usually motivated by the need to reduce costs that would be incurred through capacity additions. Some utilities have been "urged" to take an active position promoting greater efficiency by political or regulatory bodies, while others appear to act in self interest.*[36]

In most of Europe, however, information on tested electricity use in appliances is the only *nation-wide* form of stimulation towards purchase of more efficient appliances. In Denmark, heavy taxes on electricity (up to 40% of the non-tax price) certainly had a role in boosting consumer interest in efficient appliances, but in no other country have such heavy taxes been applied to household electricity (Wilson *et al.*). If the LBL findings for the U.S. apply to Europe, the European efforts described above will increase interest in electricity use significantly, but they may not be sufficient to move consumers and producers towards significantly greater appliance efficiency.

Experiments with electricity saving policies in Europe are too recent to be able to say which work the best, but the agreements in Germany certainly had an impact on the market in Germany, as well as in other countries, since companies that improved their products to stay competitive there sold the same improved products in other countries, particularly Norway and Sweden, where electricity prices have remained relatively low.

Considering all policy and program initiatives, it is possible to suggest policy measures that could accelerate the improvement of efficiency of electricity-using devices in Scandinavia:

- Minimum efficiency standards for refrigeration equipment, water heaters, cookers, and possibly other equipment;

- Rebates to consumers or builders who purchase the most efficient models. These rebates come from local authorities (utilities, city government, authorities that lend for new construction)[37]

- Changes in rules for lending money for home building, so that only the most efficient appliances and lighting systems qualify for these loans (or, at least, operating costs of these appliances are considered during the loan approval process).

- Stimulation of the development of the next generation of appliances, as Noergaard has undertaken in Denmark and others have done in the U.S.[38]

7 CONCLUSION: UNCERTAINTY

Household electricity use is more efficient in the late 1980s than in the early 1970s. Improvements in the efficiency of new homes, water heaters, electric appliances, and lighting, changes in the use of some existing appliances, altered heating habits, and insulation added to homes and water heaters all contributed to increased efficiency or reductions in electricity use. Higher electricity prices and changed perceptions about the importance of using electricity more efficiently are the most important reasons why these changes occurred, although policies helped in a few important places.

An enormous saving potential remains, compared to the average new system/model/household today: 75% reduction in household lighting (if people buy compact fluorescent bulbs); 30-50% reduction in refrigeration electricity use (if a new generation of appliances is developed); 25% reduction in electricity use for wet goods, 25 - 50% reduction for electric water heating. There is some certainty as to how much electricity -- or rather how little -- could be required in advanced household applications. Current experiments, for example, measure annual electricity use in the Gram LER200 at 85kWh/yr, below the predicted value of 90kWh.

At the same time, there is little certainty as to what consumers will buy, or what manufacturers will offer in the future. The slowdown in the progress of greater efficiency is an important sign of lowered interest in efficiency. Reasons for the slowdown include lower energy and electricity prices, lessened perceptions about importance of electricity savings, consumer ignorance, and manufacturer reluctance to assume the risks of developing the next generation of appliances. Ultimately, then, the future efficiency of the appliance stock depends on consumer and manufacturer choices, as long as a range of alternatives is available to each. Thus, there remains great *uncertainty* over how much electricity will be required to perform a given service in the future, and how much of each service consumers will demand.

There is little doubt that over the very long run, the efficiency of electricity use will continue to improve (23). But policies and programs are needed to re-ignite interest in efficiency that sparked the rapid improvements of the early 1980s. We believe that a variety of policies and programs could be tailored to needs in Sweden and Norway. Such policies could accelerate technical innovation, allow consumers to realize reduced energy costs and thereby diminish the environmental risks of increasing energy use.

REFERENCES

1. Schipper, L. 1987. Energy Conservation Policies in the OECD: Did They Make a Difference? **Energy Policy**, December.

2. Lashof, D. and D. Tirpak, eds. 1989. **Policy Options for Stabilizing Global Climate.** Report to Congress. Washington, DC: U.S. Environmental Protection Agency.

3. Schipper, L., A. Ketoff, S. Meyers, and D. Hawk. 1987. Residential Electricity Consumption in Industrialized Countries: Changes since 1973. **Energy, the International Journal**, Vol. 12, N. 12, 1987. This work was updated for the International Agency and for the present study.

4. Tyler, S. and L. Schipper. 1989. **Residential Electricity Use: A Scandinavian Comparison**. LBL 27276. Berkeley: Lawrence Berkeley Laboratory.

5. Dargay, J. 1980. In **Konsekvensutredning**. Stockholm: Dept. of Industry. See also Blaalid, J., and Olsen, Ø., 1978. **Etterspörselen etter energi: en litteraturstudie.**. Artikler, 111. Oslo: Statistiska Sentralbryaa.

6. Schipper, L., A. Ketoff and A. Kahane. 1985. Explaining Residential Energy Use by International, Bottom Up Comparisons. **Annual Review of Energy** 10. Palo Alto: Annual Reviews, Inc.

7. Moeller, J. 1987. **Elbesparelser i Boligsektorn**. Lyngby: DEFU.

8. Schipper, L., *et al.*, 1989. Linking Energy and Lifestyles: A matter of Time? **Annual Review of Energy** 14. Palo Alto, Ca: Annual Reviews, Inc.

9. These data were taken from Bingman, K., *et al.*,1987. **Stromsparen im Haushalt**. Berlin: Pruefunggemeinnschaft der Elektrizitaetsverke.

10. Mills, E. 1988. priv. comm. LTH. His results are shown in Figs. 7a–c of Bodlund, B., Mills, E., Karlsson, T., and Johansson, T., 1989. The Challenges of Choices: Technology Options for the Swedish Electricity Sector. In Johansson, T., *et al.*, 1989. **Electricity. Efficient End Use and New Generation Technologies, and Their Planning Implications.** Lund: Lund University Press.

11. Malinen, M. 1988. priv. communication. See estimates in Bilaga 4, P. 20 of Anerberg *et al.*, SOU 1987:68.

12. **Maeting av hushaallens elkonsumtion, uppdelad paa ed viktagaste elapparaterna.** Rapport 1 and 2. Vaellingby, Sweden: Vattenfall

13. Geller, H. S. 1988. **Residental Equipment Efficiency: A State–of–the–Art Review.** Washington, D.C.: Office of Technology Assessment.

14. U.S. Department of Energy. 1988. **Technical Support Document: Energy Conservation Standards for Consumer Products.** DOE/CE–0239. Washington, D.C.: DOE. These estimates, which were made by LBL, are the basis for the U.S. appliance standards that will soon take effect.

15. Noergaard, J. 1989. **Low Electricity Appliances: Options for the Future.** In Johansson, T. B., *et al.*, eds., *op cit.*.

16. Turiel, I. 1986. **Design Options for Energy Efficiency. Improvement of Residential Appliances.** The updated estimates were issued by the Department of Energy, reference (14) in 1988.

17. U. S. Department of Energy. 1980. **Economic Analysis: Energy Performance Standards for New Buildings.** DOE/CS-0129. Washington, D.C.: DOE.

18. National Association of Regulatory Utility Commissioners (NARUC) (prepared by Florentin Krause and Joseph Eto, LBL). 1988. **Least–cost Utility Planning Handbook for Public Utility Commissioners, Volume 2 The Demand Side: Conceptual and Methodological Issues.** Washington, D.C: NARUC.

19. International Energy Agency. 1989. **Energy Prices and Taxes.** Third Quarter, 1988. Paris: OECD.

20. Ruderman, H., *et al.* 1987. The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment. **The Energy Journal** Vol. 8, No. 1.

21. New York **Times.** March 4, 1989.

22. Zoellner, J. 1988. **Energy Conservation in Industry and Households during the past 15 Years and the Future Savings Potential.** Paper presented at the Joint Workshop of the German Energy Economics Association and the Norwegian Ass. for Energy Economics in Kiel, Sept. 17,1988. See also Bingman, K., 1987, *op cit.*.

23. Johansson, T.B., *et al.*, eds. 1989. **Electricity.** Lund: University Press.

24. Noergaard, J., and T. Guldbrandsen. 1987. **Potentials for Technical Electricity Savings Using known Technology.** Lyngby: Energy Group, Physics Laboratory III.

25. Noergaard, J., and Pedersen, Preben Buhl, 1987. **Low Electricity Household of the Future.** Lyngby: Energy Group, Physics Laboratory III.

26. Geller., H. 1988. *op.cit.* See also the publication by ACEEE, "The Most Efficient Appliances."

27. Pedersen, P. B., Galster, G., Guldbrandsen, T., and Noergaard, J.S., 1987. **Design and**

Construction of an Efficient US–Type Combined Refrigerator/Freezer. Proc. of XVIIth Int'l. Congress of Refrigeration (Vol. B), Vienna, 1987.

28. Lovins, A., 1986. Lovins manintains a catalogue of efficient electricity–use options through his Competitek Service.

29. I.E.S. also reviewed efficiency studies from Germany (H. Feist) and Italy (Zanussi) for the original study reported to the International Energy Agency. The LBL country reports are available on request.

30. Schipper, L. 1989. **Household Electricity Use and Conservation in Indonesia.** Report to the Household Energy Strategies Program, World Bank. Washington, DC: The World Bank.

31. Hirst, E. and M. Schweitzer. 1988. **Uncertainty in Long–Term Resource Planning** for **Electric Utilities.** ORNL/CON–272. Oak Ridge: Oak Ridge National Lab.

32. Wilson, D., L. Schipper, S. Tyler, and S. Bartlett. 1989. **Policies and Programs for Promoting Energy Conservation in the Residential Sector: Lessons from Five OECD Countries.** LBL–27289. Berkeley: Lawrence Berkeley Laboratory.

33. California Energy Commission. 1983. **"Regulations for Appliance Efficiency Standards Relating to Refrigerators and Freezers, Room Air Conditioners, central Air Conditioners, Gas Space Heaters, Water Heaters, Plumming Fittings, Gas Clothes Dryers, and Gas Cooking Appliances."** P400-83-003.

34. California Energy Commission. 1983. **"California Appliance Standards (an Historical Review) Analysis and Recommendations.** P400-83-020.

35. Blomberg, H. and H. Persson. 1988. **Rabatten paa Watten.** Stockholm: Stockholms Energi AB.

36. Friederichs, M. and Erich Unterwurzacker, ed. 1989. **IEA Workshop on Conservation Programmes for Electric Utilities.** Conference Procedings.

37. Geller, H. S. 1989. **Implementing Electricity Conservation Programs: Progress Towards Least–cost Energy Services Among U.S. Utilities.** In Johansson, T., *et. al.*, 1989, *op. cit.*

38. Noergaard, J. 1989. **Low Electricity Appliance: Options for the Future.** And Geller, H. *et al.* 1988. **The Importance of Government–Supported Research and Development in Advancing Energy Efficiency in the United States Building Sector.** In Johansson, T. *et al.*, eds., 1989, *op. cit.*

FIGURES

1. **Refrigerator Energy Intensity 1972 - 1987.** The figure shows the relative electricity consumption of typical models in each country, reflecting a combination fridge-freezer of 275L in Japan in 1970 (rising to 350L in 1987), a 700 L fridge-freezer in the U.S., and a 300L refrigerator in W. Germany. Absolute values for 1970 are given, but these are not directly intercomparable because test procedures differ in each country.

2. **Electricity Use in Refrigerator-Freezers (Combis): Volume vs. Consumption.** Electricity Use in new combis sold in Sweden in 1987. Test data are from Konsumentverket, as collected and analyzed by Evan Mills, LTH.

3. **New German Electric Appliances.** Electricity savings between 1978 and 1985. For each product, the relative use compared with 1978 = 1 is shown, and the unit over which the SWEF is averaged is given as well. Source: Zentralverband der Elektroindustrie.

4. **Percent Improvements in Efficiency in Major Residential (U.S.) appliances.** Figures are expressed as percentages improvements in the efficiency factors shown in the figure. Included for comparison are important heating appliances as well. The efficiencies represent the *inverse* of those shown in Fig. 1 or Fig. 3.

5. **Water and Electricity Use in Clotherswashers.** New appliances 1974 through 1989 (Sweden) Source: Siemens AB, Stockholm, based on Siemens AG. W. Germany.

6. **Electricity Use: New Fridge/Freezers (Swedem 1980 and 1987).** Adjusted volume versus intensity. Comparison of test data are from Konsumentverket, as collected and analyzed by Evan Mills, LTH. Mills weights the freezer volume at 30% higher in determining the adjusted volume.

7. **Appliance Specific Electricity Use. Sweden.** Unit Consumption of Refrigerators, freezers, and combis in Sweden 1973 - 1987. The averages "avg" are from Vattenfall for the whole stock in that year;; "Highest" and "Lowest" refer to the tested consumption of *new* models on the market, as estimated from Mills' data. "Possible" is our own estimate of unit consumption.

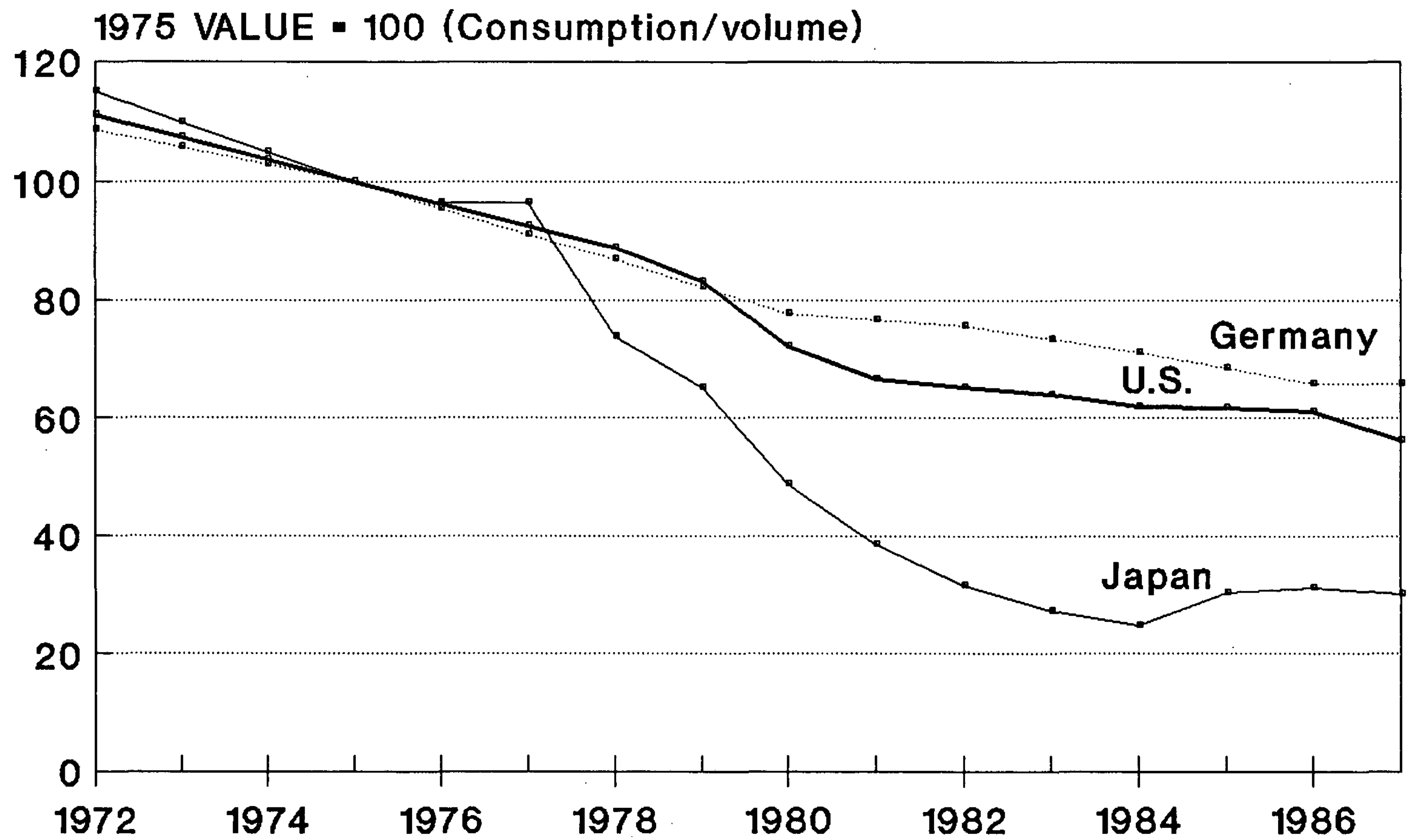
8. **Appliance Electricity Use in the U.S. (Unit Consumption past, present, future).** Unit consumption for U.S. Appliances. Source: Geller (1988), Mills, and LBL.

9. **Energy Use for Design Options of Top Mounted A-D (automatic defrost) Refri-Freezers without TTD (through-the-door) features.** The adjusted volume takes into account the importance of the freezer section; the net volume of the unit is actually 18 cu. ft. in the U.S. The options are listed in Table 1.

10. **Life-Cycle cost for Design Options of Top Mount Automatic Defrost Refrigerators.** The costs refer to Fig. 9 or Table 1. The discount rate is 7% *real.* UEC is "unit consumption". The 1990 Standard for the U.S. is shown for reference. Also, the calculations show estimated cost and energy impacts of keeping the CFC content of the device constant.

FIGURE 1

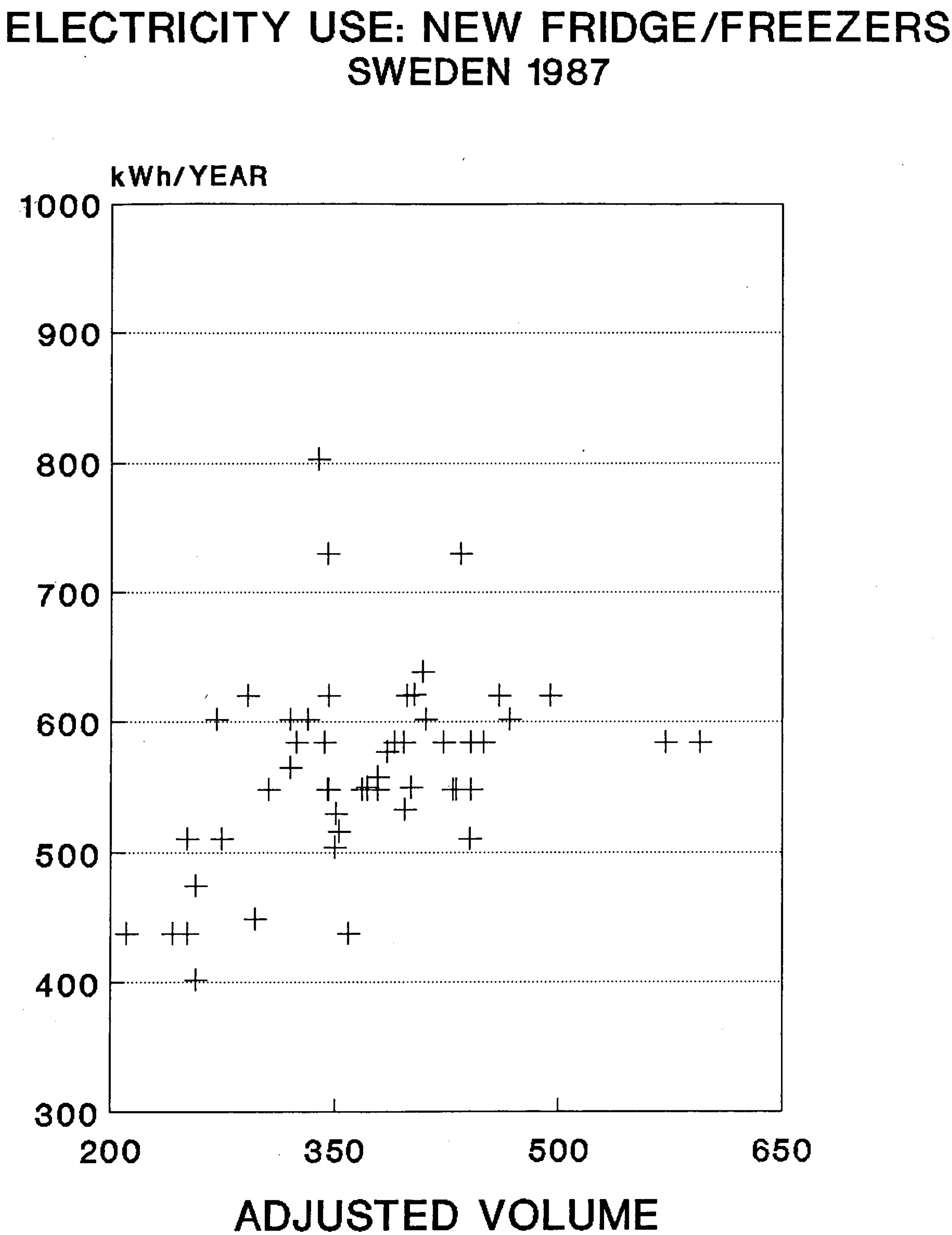
REFRIGERATOR ENERGY INTENSITY NEW MODELS 1972-87



Germany: 1-door, 250 liter
U.S.: combi,top,auto
Japan: combi, 150-330 liter

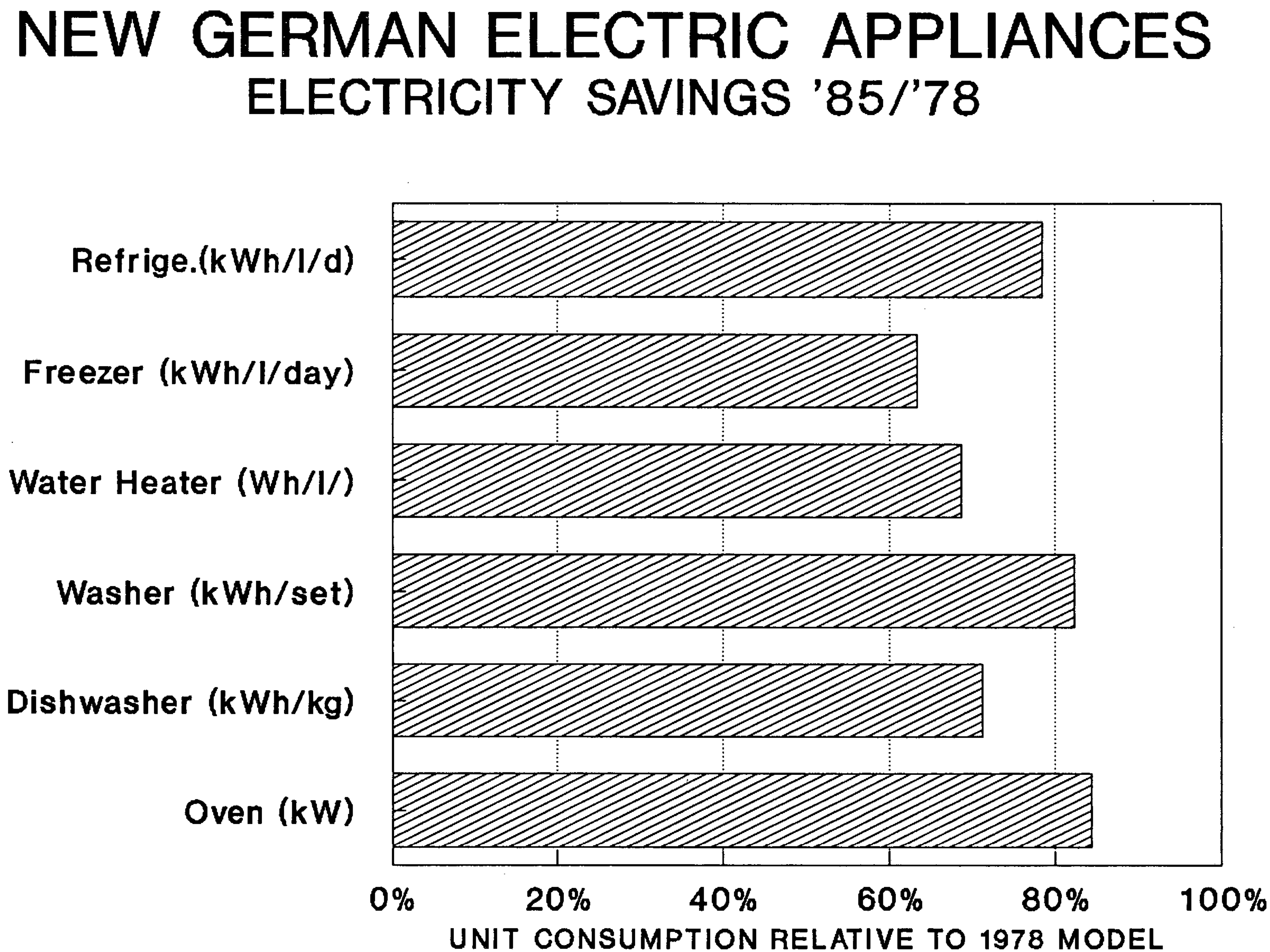
SOURCE: International Energy Studies, LBL

FIGURE 2



Adj. Vol.= refrig. vol.+1.8xfreezer vol
Source: Mills 1989 from Konsumentverket

FIGURE 3

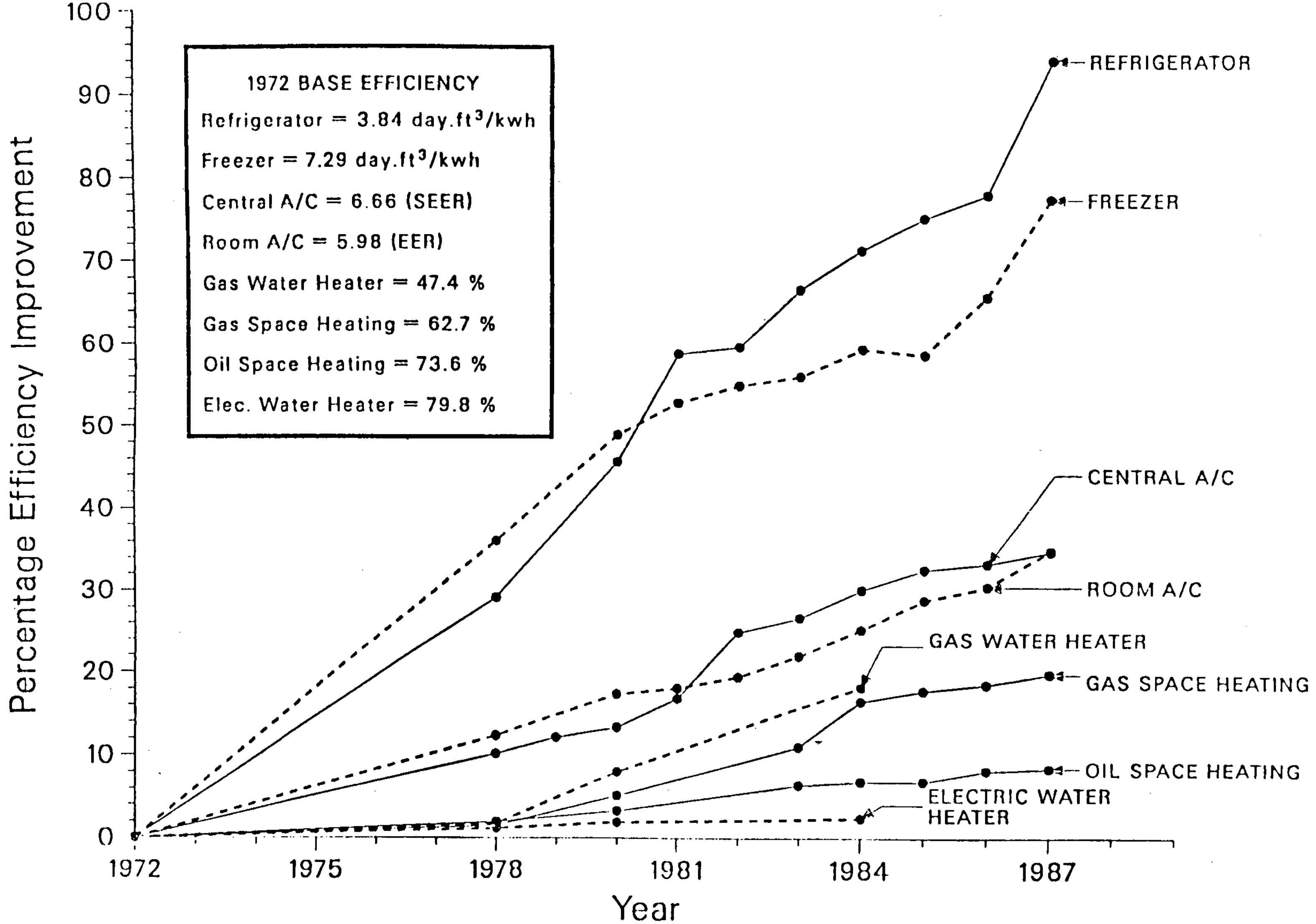


Note: Reductions based on Average
Consumption of all models sold

SOURCE: International Energy Studies, LBL

FIGURE 4

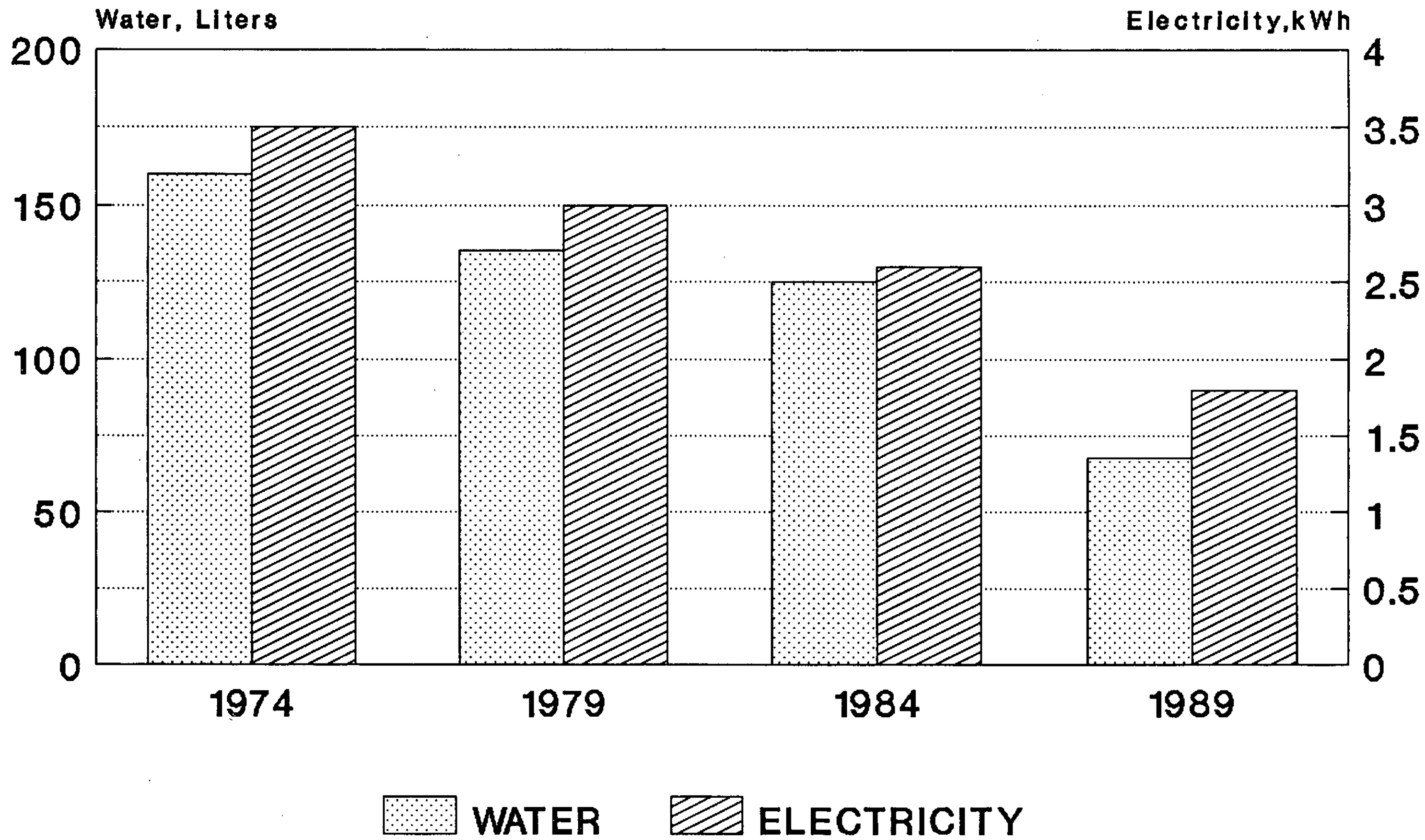
PERCENT IMPROVEMENT IN EFFICIENCY IN MAJOR RESIDENTIAL APPLIANCES



SOURCE: LBL (REF. 14)

FIGURE 5

WATER AND ELECTRICITY IN CLOTHESWASHERS
New Appliances 1974 through 1989



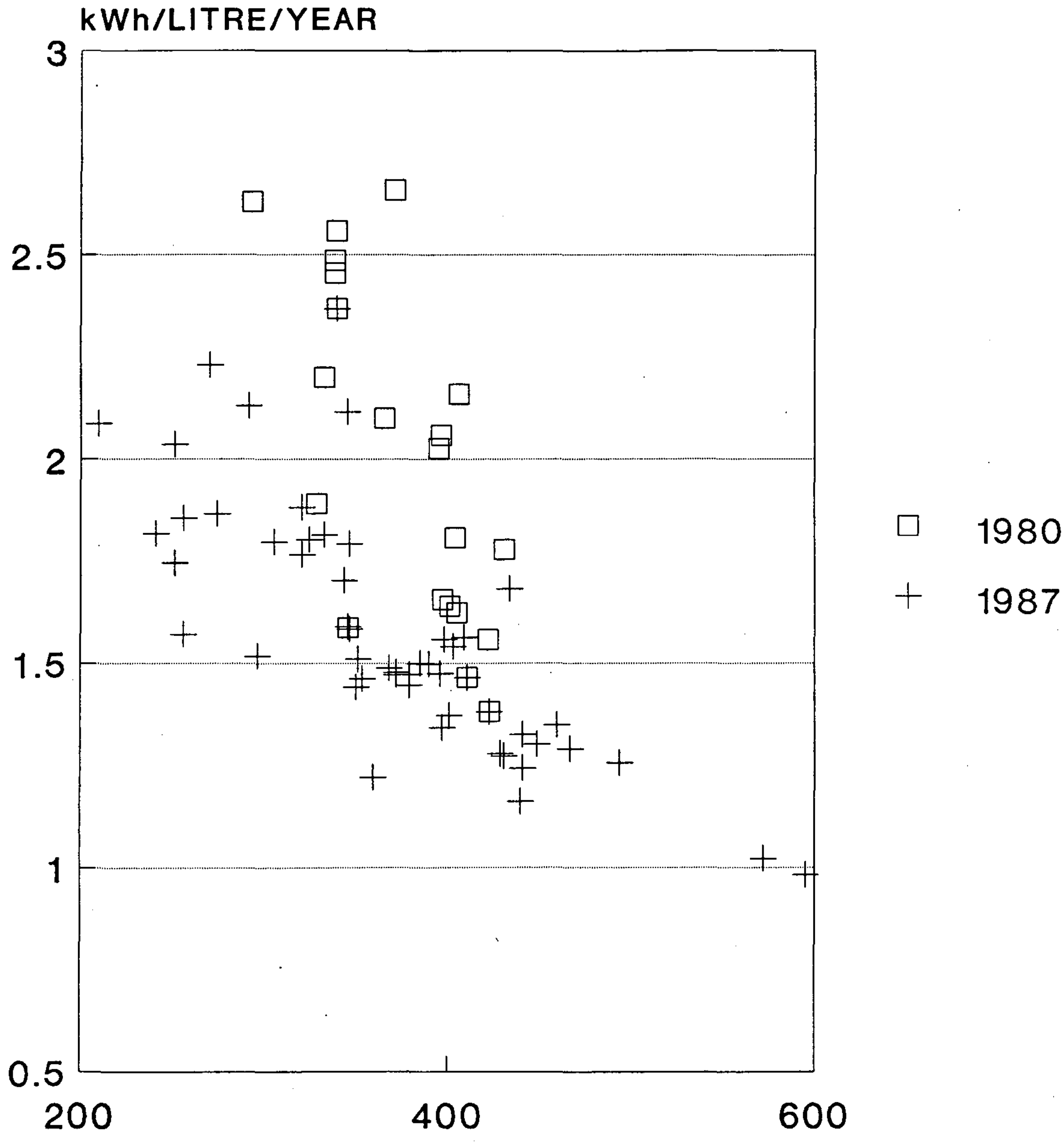
Full Automatic, 95C Cycle

Data from Siemens AB, Stockolm washen

SOURCE: International Energy Studies, LBL

FIGURE 6

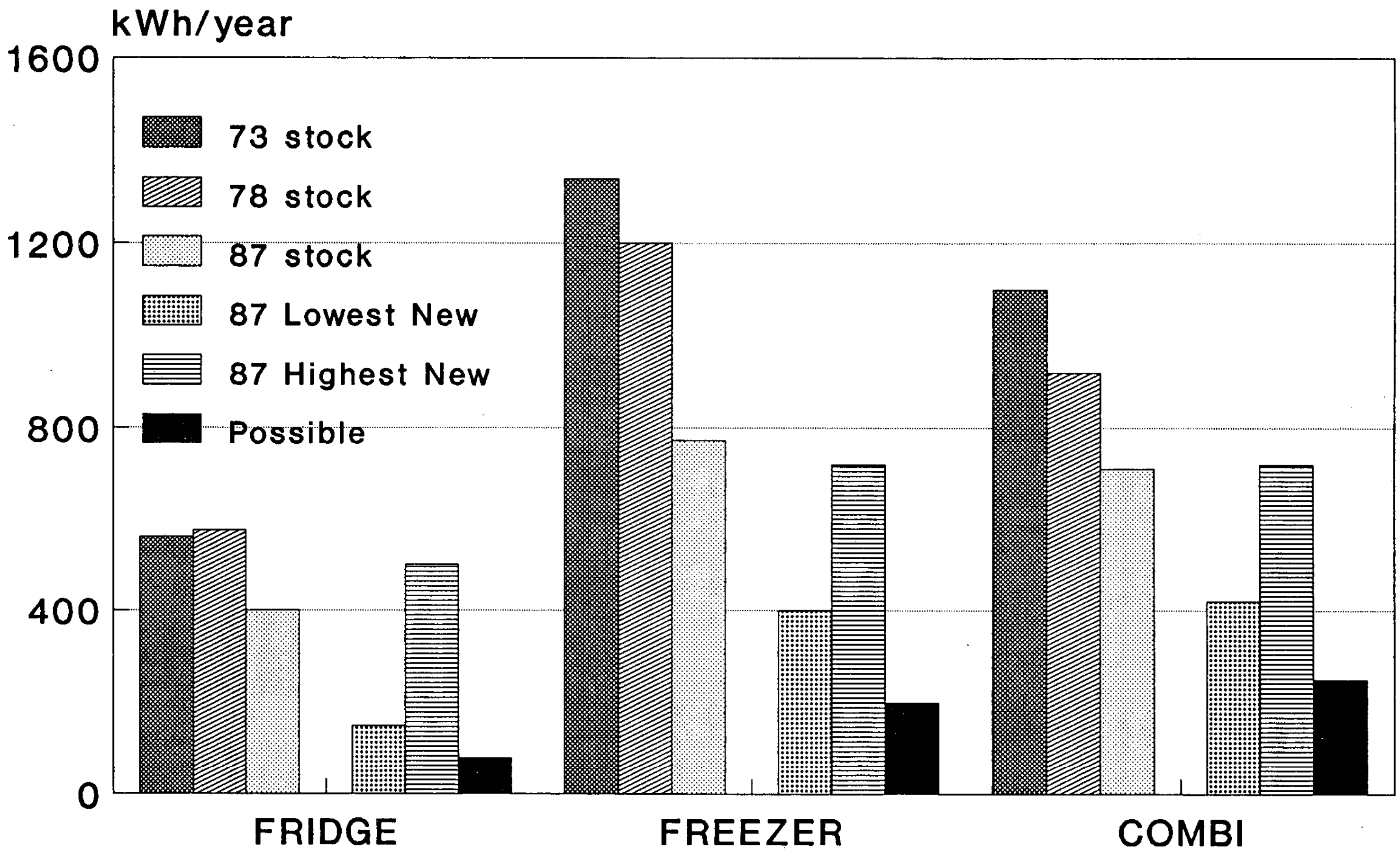
ELECTRICITY USE: NEW FRIDGE/FREEZERS
SWEDEN 1980 and 1987



Adjusted Vol; refrig + 1.8x freezer
Source: K'Verket, and E. Mills 1989

FIGURE 7

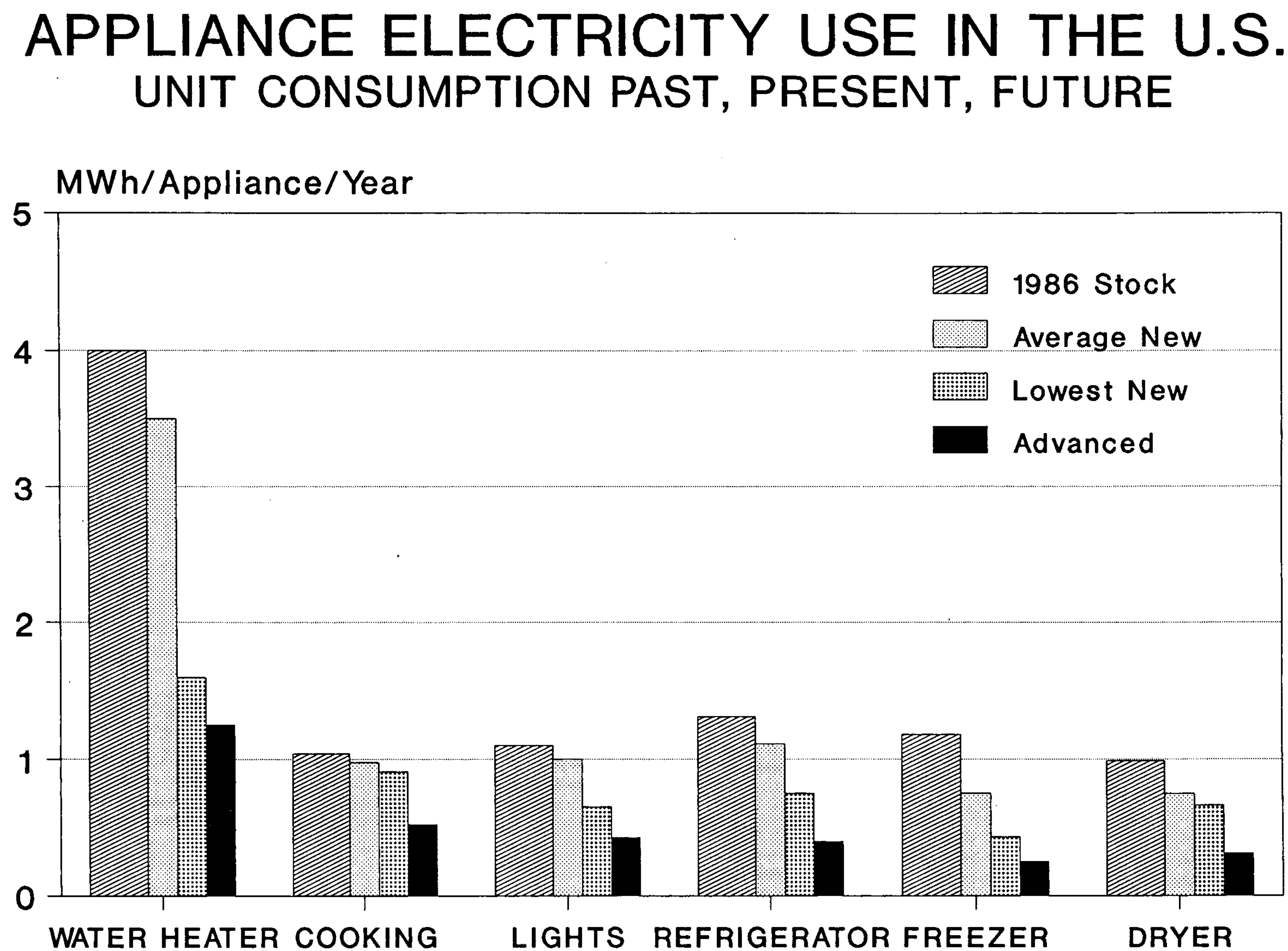
Figure 14. REFRIGERATION - SWEDEN
Appliance-Specific Electricity Use



Sources: Konsumentverket, Vattenfall
Ref:150-200; frez:250-300; comb:350-400

swedapp

FIGURE 8



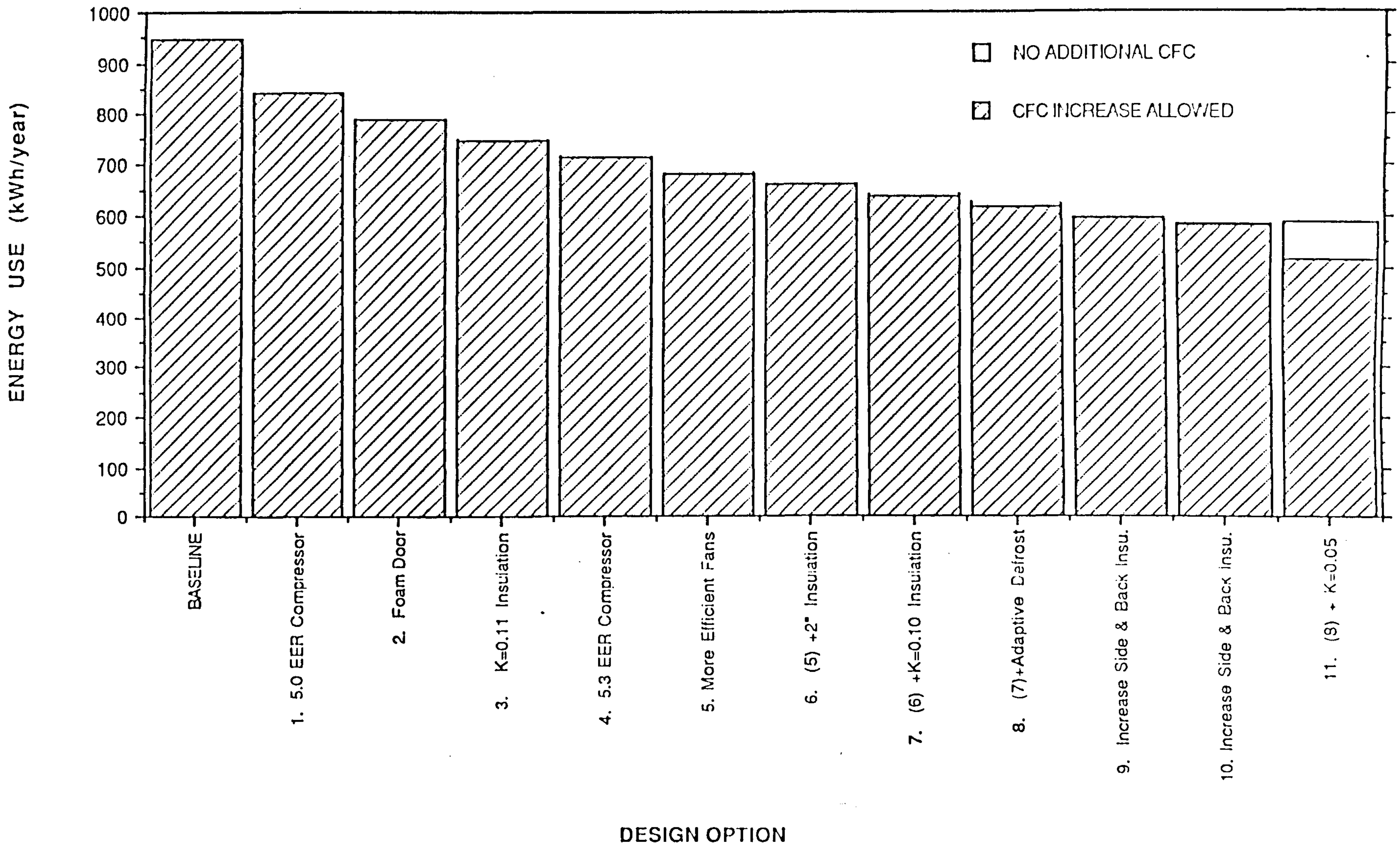
Source: Geller and LBL

appusnew

FIGURE 9

ENERGY USE FOR DESIGN OPTIONS OF TOP MOUNTED A-D REFRI-FREEZERS W/O TTD FEATURES

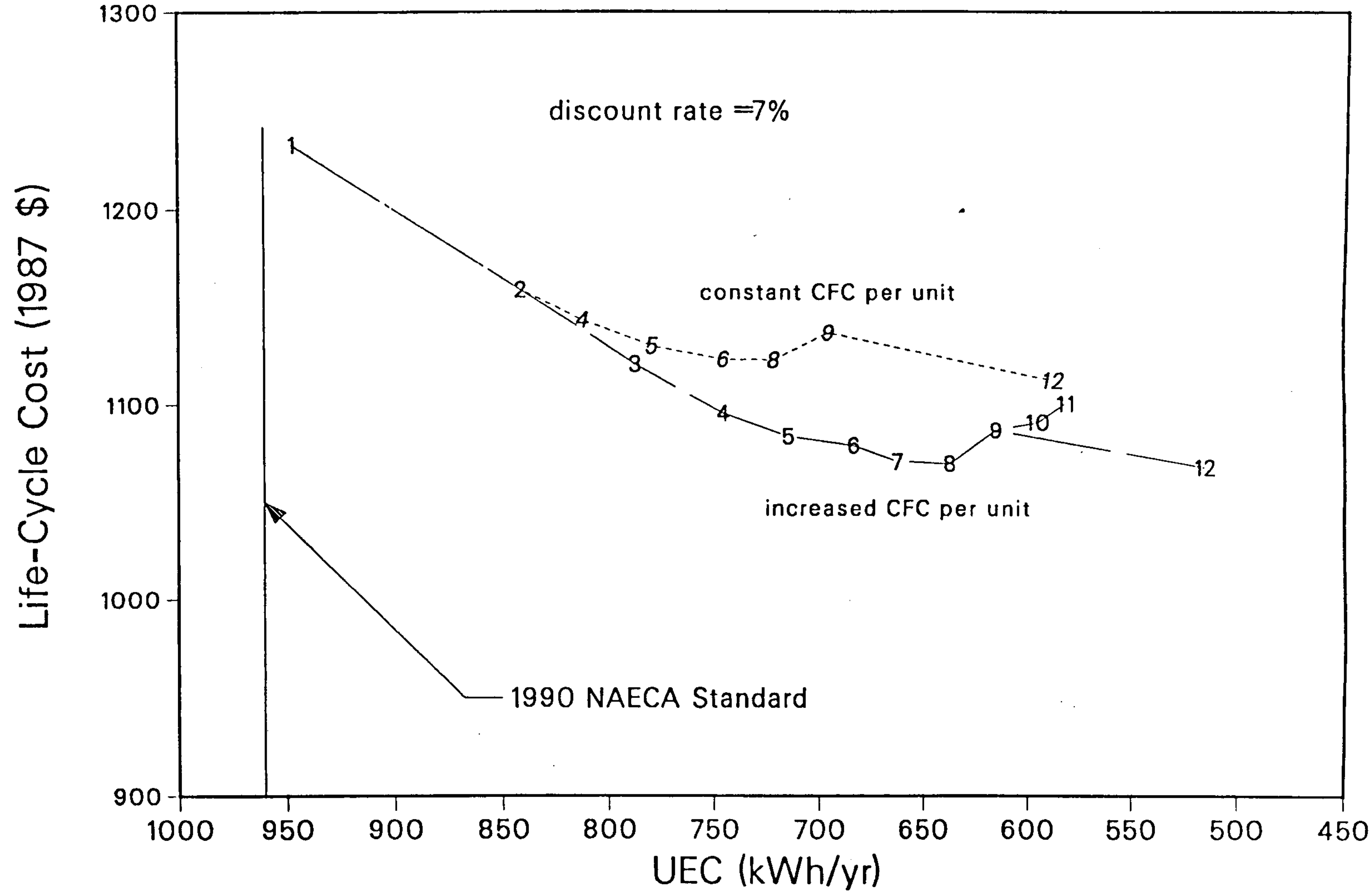
(Adjusted Volume = 20.8 cu.ft.)



SOURCE: LBL (REF. 14)

FIGURE 10

Life-Cycle Cost for Design Options of Top Mount Automatic Defrost Refrigerators
(adj. vol. =20.8 cu. ft.)



SOURCE: LBL (REF. 14)

TABLE 1

Manufacturer Cost and Unit Energy Consumption
Top-Mount Auto-Defrost Refrigerator-Freezer

Level	Design Option	Manufacturer Cost (1987 $)	Energy Consumption (kWh/yr)
0	Baseline	220.0	947
2	Level 0 + 5.0 EER Compressor	223.4	841
3	Level 2 + Foam Door Insulation	224.6	787
4	Level 3 + Improved Foam Insulation (k=0.11)	227.7	745
5	Level 4 + 5.3 EER Compressor	233.2	714
6	Level 5 + More Efficient Fans	242.2	683
7	Level 6 + Door Insulation Increased to 2"	245.7	662
8	Level 7 + Improved Foam Insulation (k=0.10)	253.2	637
9	Level 8 + Adaptive Defrost	269.0	615
10	Level 9 + 2.6"/2.3" Side Insulation, and 2.6" Back Insulation	276.1	595
11	Level 9 + 3"/2.7" Side Insulation, and 3" Back Insulation	283.5	582
12	Level 9 + Evacuated Panel (k=0.05)	296.0	515

Volume = 18.0 cubic feet, Adjusted Volume = 20.8 cubic feet.
Baseline: 4.5 EER Compressor, Side Wall Insulation: 2.2" foam in freezer & 1.9" foam in refrigerator. Door Insulation: 1.5" foam in freezer, 1.5" fiberglass in refrigerator.

SOURCE: LBL (REF. 14)

APPENDIX 1: SUMMARY OF THE DANISH LOW ENERGY REFRIGERATOR LITERATURE AND ANALYSIS OF THE ROLE OF EUROPEAN AND US VERSIONS IN THEIR RESPECTIVE MARKETS

Notes by Dianne Hawk, International Energy Studies

Researchers T. Guldbrandsen, J. Heeboll, K. Mehlsen, and J. Norgard, at Physics Laboratory III at the Technical University of Denmark in Lyngby, have been researching, designing, constructing and testing prototypical, highly energy efficient refrigerators for several years. They have laboratory tested two types of refrigerators: one similar to typical European-style refrigerators (referred to as the LER200) and the other modeled after a typical U.S. refrigerator. The European type refrigerator is not comparable to US refrigerators due to its small size (a little over a third of the size of an average US model) and the fact that it lacks a freezer compartment, a feature of nearly all refrigerators sold in the US. The infrastructure - dwelling size, built-in space in kitchens for refrigerators -- and consumer behavior and preference (frequency of shopping and thus, need for storage space, for example) give rise to these differences. Thus, it is inappropriate to place the European-type refrigerator in the US context, and vice-versa.

In this summary, I will describe the two refrigerators, briefly explain the technical modifications that make them different that the conventional refrigerators they are intended to replace, and relate the energy use and savings that have been found in laboratory testing. Finally, I will discuss the role these highly efficient refrigerators could play in reducing the electricity demand in their respective markets.

The European-Type Refrigerator*

Three complete prototypes of the European type refrigerator have been laboratory tested. With respect to energy use, their target was to produce a refrigerator that used only 40% of the energy used by the best refrigerator on the Danish market: a Gram 215 liter refrigerator which used 245 kWh per year. Design specifications called for the same size, operation and comfort standards of conventional European refrigerators. This refrigerator, without a freezer compartment, has an inner volume of 200 liters or 7.06 cubic feet, a typical European size. It has automatic defrost. Also, an important design criterion was: "Production of the refrigerator must not require new technologies or new techniques in the tooling." Following is a brief description of the major technical changes intended to increase the efficiency, thereby decreasing the unit energy consumption of a refrigerator.

* All information on this refrigerator is from "Development of Energy Efficient Electrical Household Appliances, Part One: Refrigerators," T. Guldbrandensen, J. Heeboll, K. Mehlsen, and J. Norgard, printed by Commission of the European Communities, Report EUR 10449 EN, 1986.

1. Improving the insulation standard from 3 (the Best by Gram) to an average of 6.5 cm of polyurethane foam (used outer steel box of model manufactured by Gram, but required molding of new plastic inner boxes);

2. Improving the compressor: mechanical and electrical improvements increased COP, new motor making use of a new motor system Resistance Start Capacitor Run (RSCR) rather than Resistance Start Induction Run (RSIR);

3. Improved larger heat exchanger; (which increases evaporation temperature and reduces the condenser temperature).

Energy tests on the three prototypes were performed by four laboratories: Danfoss (a compressor manufacturer), Gram (a refrigerator manufacturer), the Danish Government Home Economics Council, and Physics Lab III. These tests were conducted under standard test conditions ISO/R 824(19), DIN8950 (no door openings, empty refrigerator). Physics Lab III found an annual usage to be 102 kWh. Although other lab results varied from Physics Lab III results by ~30% higher, these tests confirmed that the design target for energy use had been met. Under conditions of normal use at Physics Lab III, these same trends prevailed.

Finally, at current Danish electricity prices, assuming "normal use" patterns, the extra investment required by the consumer would pay back within a 3 year period. The economics of the refrigerator was also supported by calculations accounting for extra energy embodied in the extra materials used in the refrigerator. Also, the extra environmental costs of producing this refrigerator (measured by the emission of SO_x, NO_x, C ,and particulates) was found to be insignificant compared to the environment benefits associated with the reduced electricity demand.

This refrigerator appears to represent a *technically* and *economically* viable model for replacing conventional European refrigerators today. It is now being commercially produced by Gram. However, the share of refrigerators, without freezer compartments, in sales has declined in Europe over the last decade. Combination refrigerator/freezers* have dominated refrigerator sales in recent years in most European countries. Thus, European consumers may be beginning to prefer combination refrigerator/freezers to refrigerator-only models (for replacing the existing stock as it turns over or filling the new demand for refrigerators). This trend seems to indicate that this refrigerator can fill an increasingly smaller niche: the single compartment, refrigerator-only market. Currently, however, this group in working on a refrigerator/freezer prototype.

* Also sold in the European market are units called "refrigerators-only" that have one external door but contain several distinct compartments inside. The temperature within the additional compartments vary from the main, largest one. Units of this type that have one of the additional compartments with an internal temperature at freezing, perform a similar function as refrigerator/freezers and thus, are included in the refrigerator/freezer count.

The US-Type Combined Refrigerator/Freezer*

In 1986, a highly efficient US-type combined refrigerator/freezer was constructed at the Physics Lab III. This prototype was designed to provide the same services and comfort level as the best 20 cubic foot US refrigerator available in 1985. The prototype refrigerator has the external dimensions of a 20 cubic foot (567 liter) refrigerator, but the internal dimensions of 18 cubic feet (510 liter) (due to additional insulation). As is typical of US refrigerator/freezers, both compartments have auto-defrost. The freezer is top-mount. Following is a brief description of the major technical changes intended to increase the efficiency, thereby decreasing the unit energy consumption of a refrigerator/freezer.

1. Two separate refrigeration systems, one for the refrigerator and one for the freezer compartment;

2. Condensers for both cooling systems are integrated into the cabinet by fastening the pipes to the inner side of the outer steel sheet;

3. Modifications of the evaporators: the evaporator in the freezer compartment is placed in the rear and the evaporator in the refrigerator compartment is made of aluminum; the evaporators work using natural radiation and convection (no fan).

4. Both cooling systems are equipped with reciprocating compressors with semi-direct intake;

5. Additional polyurethane foam insulation: increased from 51 to 65 mm in the refrigerator compartment and from 63 to 85 in the freezer (compared to 1985 best).

6. A new feature: an electronic controller that controls temperatures in the two compartments and controls the defrost of the freezer evaporator.

The prototype underwent energy testing at both the Physics Lab III and at BR-Laboratory in Huntington Beach, CA. The source report claims that this testing was conducted in accordance with the US DOE 1983 test standard. with one exception. The one major deviation from the procedure they identified was that in neither case was the testing done over one whole defrost period - about 13 days - and thus, the raw data underestimated energy use. Adjusting both lab test results to include energy use for defrosting cycle, energy use was recorded as 520 kWh/year (Physics Lab III) and 536 kWh/year. This compares to 890 kWh/year by the 1985 best available 20 cubic foot refrigerator that the prototype was modeled after (1986 best was 750 kWh/year). However, the temperature the reseachers have identified as the DOE standard for the refrigerator fresh food compartment -- 45 degrees Fahrenheit -- does not agree with DOE test procedure documents for January 1984. The DOE document identifies the proper temperature as 38 degrees Fahrenheit. If the energy test was performed at 45 degrees rather than 38, the energy use results for the prototype underestimate energy use. This would, in part, account for the prototype's lower energy use relative to the best available US-type refrigerators, which were tested at the colder temperature.

* All information on this refrigerator is from "Design and Construction of an Efficient US-Type Combined Refrigerator/Freezer," P. H. Pedersen, G. Galster, T. Guldbrandsen, and J. S. Norgard, pamphlet reprinted from the proceedings from the XCIIth International Congress of Refrigeration, Volume B, pp. 547-554, 1987.

No quantitative analysis has been done on the manufacturing costs associated with these technical modifications. Nor has there been an analysis of the economic viability with regard to the consumer, which depends largely on the additional manufacturing costs to be passed on and electricity prices. The production method is differs greatly from current US production methods. Also, would the consumer accept 18 cuft interior with a 20 cuft exterior? Just as important, the effects of government policy (NAECA and EPA rule-making on clorofluorocarbons (CFCs) currently in progress) have not been evaluated or taken into account in the design of this prototype. Physics Lab III's qualitative summary indicates that changes 1-3 and 5 above will make the prototype more expensive to manufacture than the 1985 best available. On the other side, cost reductions result from: integrated condenser eliminates the requirement for a fan to cool an external condenser,; the freezer fan and evaporator are smaller, and thus, cheaper; and due to separate cooling systems, no special thermostat or air ducts to control the air flow between the two compartments.

The US-type refrigerator/freezer appears to represent an attainable technical potential in the minimization of energy use making use of currently developed technology. Also, the type of refrigerator -- the size range (17-20 cubic feet), combination refrigerator freezer, top-mount freezer -- is in greatest demand in the US, representing 73% of sales in 1986. However, as no quantitative studies have been conducted on it, we have no way of knowing whether it is economically viable to mass produce, from the manufacturer's perspective, or to purchase, from the consumer's perspective (additional first cost, payback period based on US electricity prices...). Therefore, this refrigerator appears to represent a realistic *technical* potential for US-type refrigerators but, it is unknown whether or not it could, economically, have a place in todays US refrigerator market.

APPENDIX 2:
MANUFACTURERS CONTACTED DURING THIS STUDY

1. Electrolux AB, Stockholm. World and Scandinavian Perspectives. Mr. Segerstroem, Mr. Frendin, Mr. Cronelid, Mr. Sunden.

2. Asea Scandia, Stockholm. Scandinavina perspective. Mr. Oehrn.

3. Philips NV, Eindhoven. World Perspective. Mr. Stavast, Mr. Kuypers (refrigeration); Mr. deMol (lighting).

4. A/S Philips, Oslo. Norwegian Perspective. Mr. Sveum.

5. Philips SA, Paris. French Perspective. Mr. Alexendre.

6. ZVEI (Zentralverband der Elektroindustri), Frankfurt. W. German perspective. Hr. Zoellner, Hr. Knaup.

7. HEA, Stockholm (Swedish Perspective). Mr. Jacobsson.

8. AMDEA (Association of Manufacturers and Distributers of Electric Appliances), London. British Perspective. Mr. Collis.

9. Hitachi Corporation, Tokyo. Japanese Perspective. Mr. Matsumura.

10. Matsushita (National), Tokyo. Japanese and World-wide Perspective. Mr. Hino.

11. Whirlpool Corp. (Benton Harbor, Michigan). U.S. Perspective. L. Soorus, S. Pierson.

12. Zanussi SA (Pordenone, Italy). Italian and European Perspective. G. Abbate.

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