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Realized and Prospective Impacts of U.S. Energy Efficiency Standards for Residential Appliances:
2004 Update

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ABSTRACT

This study estimated energy, environmental and consumer economic impacts of U.S. federal residential energy efficiency standards that became effective in the 1988-2001 period or will take effect by the end of 2007. These standards have been the subject of in-depth analyses conducted as part of DOE's standards rulemaking process. This study drew on those analyses, but updated certain data and developed a common framework and assumptions for all of the products in order to estimate realized impacts and to update projected impacts. We estimate that the considered standards will reduce residential primary energy consumption and CO_2 emissions in 2020 by 8% compared to the levels expected without any standards. They will save a cumulative total of 34 quads by 2020, and 54 quads by 2030. The estimated cumulative net present value of consumer benefit amounts to $93 billion by 2020, and grows to $125 billion by 2030. The overall benefit/cost ratio of cumulative consumer impacts is 2.45 to 1. While the results of this study are subject to a fair degree of uncertainty, we believe that the general conclusions – DOE's energy efficiency standards save significant quantities of energy (and associated carbon emissions) and reduce consumers' net costs – are robust.

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ABBREVIATIONS AND ACRONYMS

AAUE	Average annual energy use
AFUE	Average fuel utilization efficiency
AHAM	Association of Home Appliance Manufacturers
ARI	Air-Conditioning and Refrigeration Institute
LBNL	Lawrence Berkeley National Laboratory
NPV	Net Present Value
TSD	Technical Support Document

1. Introduction

The primary purpose of this project was to construct a common analytical framework to estimate energy, environmental, and consumer economic impacts of federal residential energy efficiency standards that became effective in the 1988-2001 period or will take effect by the end of 2007. This study considered initial standards and updates for nine different products (Table 1-1).[1] These standards have been the subject of in-depth analyses conducted by Lawrence Berkeley National Laboratory (LBNL) as part of the standards rulemaking process of the U.S. Department of Energy (DOE). The results of these individual analyses have been published in a number of Technical Support Documents (TSDs), as listed in Appendix 1.

This project differed from the in-depth analyses done for the TSDs in many ways:

1. The TSD analyses estimated prospective impacts only, whereas this study estimated both realized (through 2000) and prospective impacts (through 2050).

- The TSD analyses were performed at different times over the past 13 years and thus considered product installations and impacts over varying periods. For all products, this study considers installations through 2030 and impacts through 2050.[2]

- Each TSD analysis used forecasts of product shipments and energy prices that were current at the time. This study used recent data on actual product shipments and energy prices to calculate realized savings. To estimate prospective impacts, we developed new projections of product shipments based on recent trends and appliance industry near-term forecasts. Each TSD used then current DOE/EIA projections of future energy prices made in different years. Some recent TSDs used marginal energy prices. We used Average Residential Prices from the latest DOE/EIA projections of future energy prices (EIA, 2004).

- The TSD analyses have varied in their specification of a base case efficiency trend against which the impact of standards was evaluated. In some of the analyses in recent years, the base case incorporates an expectation of improvement in energy efficiency without a standard, but in earlier years the base case reflected no change over time in efficiency. This study used a dynamic base case for all products, and adopted the perspective that manufacturers would have made improvements in energy efficiency without standards in most cases.

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[1] We did not analyze the impact of standards for oil furnaces and boilers, kitchen ranges and ovens, direct heating equipment (wall, floor, and room heaters), and swimming pool heaters. Based on limited available data, it appears that these standards had a relatively small impact on the market. This study also did not analyze standards for products in commercial buildings, such as fluorescent lamp ballasts or commercial HVAC.

[2] Appliances have useful lifetimes of 10-20 years. In order to capture the lifetime energy savings of products purchased in the 2020-2030 period, we consider impacts through 2050.

The focus and approach of this report is the same as its predecessor (Meyers et al., 2002). Since that report, however, we have made improvements in the method, updated input data, and revisited various assumptions.

Overview of Methodology

We developed a spreadsheet accounting model to calculate national energy savings and consumer benefits for each product. The analysis tracks the energy use of products sold in each year, beginning in the late 1980s and ending in 2030. The key variables for estimating energy savings from standards are the average annual energy efficiency and energy consumption of a given product sold in each year. The key variable for estimating the additional consumer cost associated with standards is the average product price in each year. For each of the above, we used actual data where available and made (or adopted from the TSDs) projections of future trends.

The approach for estimating impacts of standards involves envisioning a base case scenario for average energy efficiency, energy consumption, and product price that assumes no standards were or will be implemented. In principle, the base case assumes energy efficiency increases over time as a result of the influence of all factors that shape energy efficiency other than federal standards. These include energy prices, labelling programs such as Energy Star, utility and state demand-side programs, government and private R&D, and general technological change in products designed to produce better appliances. In practice, it is impossible to determine whether base case scenarios that we developed for each product accurately reflect the combined influence of these factors.

To estimate the historic energy savings from standards, we used actual data on average energy efficiency and energy consumption where available. Since the base case nominally includes the influence of all factors that shape energy efficiency other than federal standards, we calculated the impact of federal standards as the difference between the base case energy efficiency or energy consumption and the actual values.

For updates effective in 2000 and after, we used a somewhat different approach. Since projecting the actual average energy efficiency or energy use for future years is difficult, we instead used the difference between the minimum average energy efficiency (or maximum average energy use), implied by the standard and the base case values to derive energy savings

We estimate the savings in primary energy consumption using factors for converting site energy to primary energy consumption. We estimate the monetary value to consumers of the energy savings using the average residential price of electricity and natural gas in each year.

In DOE’s analyses of appliance standards, the additional consumer cost for a higher-efficiency appliance is estimated through a detailed analysis of manufacturing costs and markups in the distribution channel. The extent to which the estimated increase in cost to meet a particular standard has in fact occurred has been a matter of some debate.

To be conservative, we have adopted the approach used by DOE and assumed that the standards did cause some additional cost. We utilized the actual price data where available, but we assumed that prices would have been even lower in the absence of standards. Wherever incremental cost estimates were available from the TSDs, we applied the percentage incremental cost as estimated in the TSDs to the appropriate actual prices. Where such estimates were not available, we made estimates for this study.

Each section below further describes the data sources and assumptions used.

Table 1-1
U.S. DOE Energy Efficiency Standards
for Residential Appliances and Equipment

Product	**Effective Date**																			
	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
Refrigerators			X			X								X						
Freezers			X			X								X						
Room Air Conditioners			X										X							
Central ACs and Heat Pumps					X														X	
Clothes Washers	X						X										X			X
Clothes Dryers	X						X													
Dishwashers	X						X													
Water Heaters			X														X			
Gas Furnaces					X															
Oil Furnaces					O															
Ranges and Ovens			O																	
Pool Heaters			O																	
Direct Heating Equipment			O																	

X = Included in this study's estimates
O = Not included in this study's estimates

2. Annual Shipments

The figures at the end of this chapter show actual annual domestic shipments for each product in the 1980-2003 period and projected shipments in the 2004-2030 period.

Historical Data

We used data on annual domestic shipments from the Association of Home Appliance Manufacturers (AHAM) and the Air-Conditioning and Refrigeration Institute (ARI) for all of the considered products for the 1980-2003 period. In the case of central air conditioners, the industry data include single- and three-phase equipment. As the latter are generally not used in residential applications, LBNL estimated the share of single-phase units for the rulemaking analysis (see Appendix 1, #7), and we used those data here.

Projections for 2004-2030

The projections used in LBNL's previous technical analyses for DOE were made during the rulemaking process for each product. For this study, we prepared new projections that take into account the actual shipments data through the year 2003. In most cases, shipments in the 1998-2003 period were greater than had been previously estimated due to the substantial growth in disposable income and housing construction in this period. Given this trend, adjustment to the projections made for the TSDs were necessary for most products.

For the 2004-2006 period, in most cases we adopted forecasts given in *Appliance* magazine in January 2004. These forecasts were made by industry experts.

For 2007-2030, the approach used varied among the products. For most products, we made projections for this study using simple assumptions. For central air conditioners and clothes washers, we applied the annual percentage growth in each year from the most recent TSD projections. For clothes dryers, there were no recent TSD projections, so we used the projected annual growth in clothes washer shipments as a proxy for clothes dryer shipments.

In the TSDs for some products, the projection of shipments is lower with the standard than without, as the analysis predicts that the higher price associated with the standard will lead to either switching among fuel types (e.g., for water heaters) or fewer purchases. The TSD methodology has a module for adjusting energy consumption in the "no standards" case to account for products that would be kept in use if a new product were not purchased. The simpler framework used in this study does not have that capability. Thus, we use the "no standards" (base case) projections in most cases. In the case of water heaters, projected shipments are greater in the 2004 standards case than in the base case for gas water heaters, and lower for electric water heaters in the standards case. We accounted for the impacts of fuel switching due to the 2004 standards using the shipments projections in the water heater TSD.

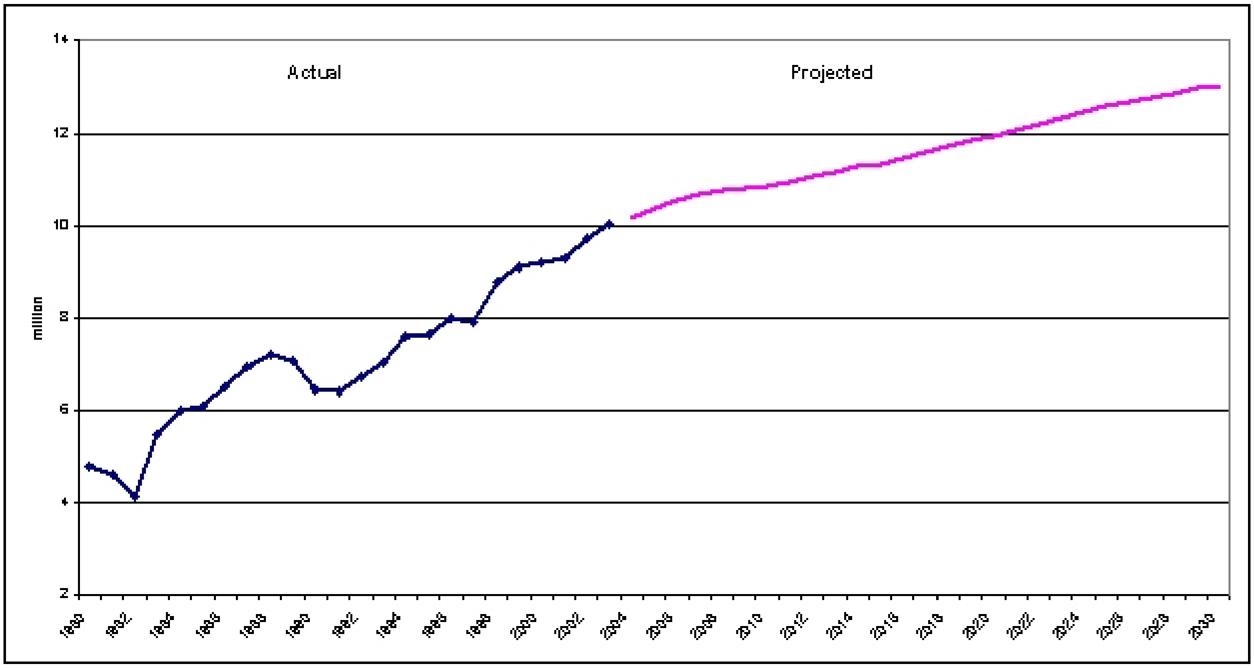

Figure 2.1 New Refrigerators – Annual Shipments, 1980-2030

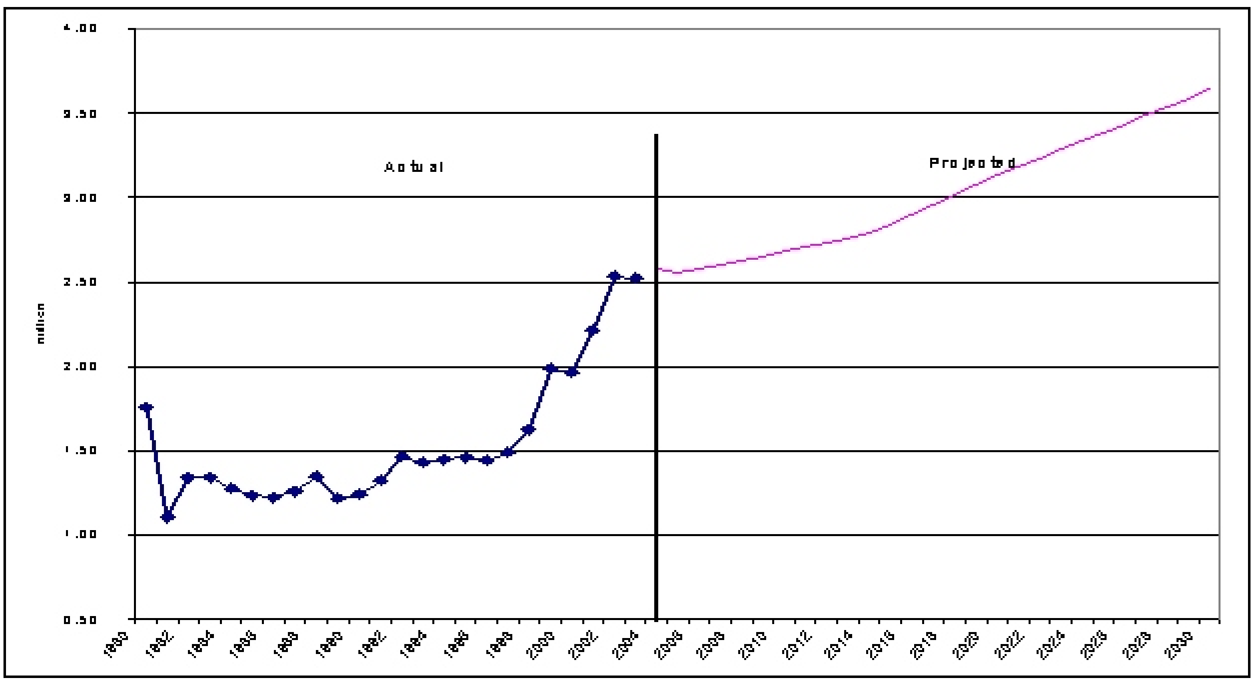

Figure 2.2 New Freezers – Annual Shipments, 1980-2030

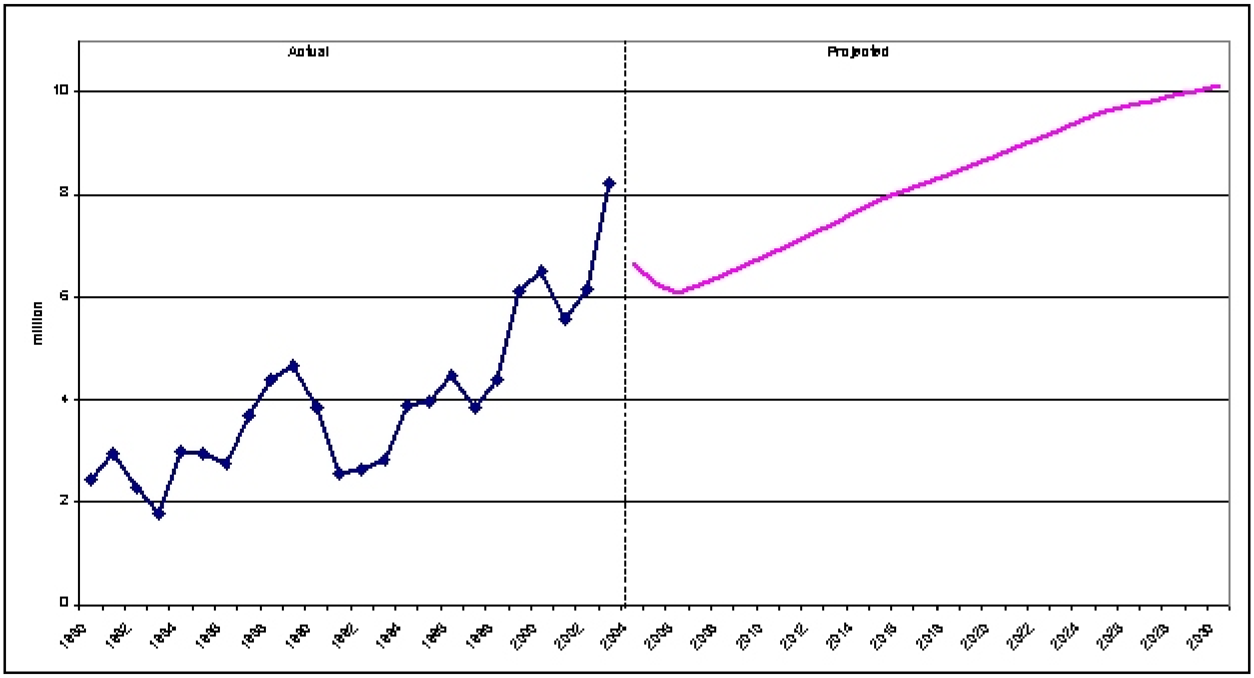

Figure 2.3 New Room Air Conditioners – Annual Shipments, 1980-2030

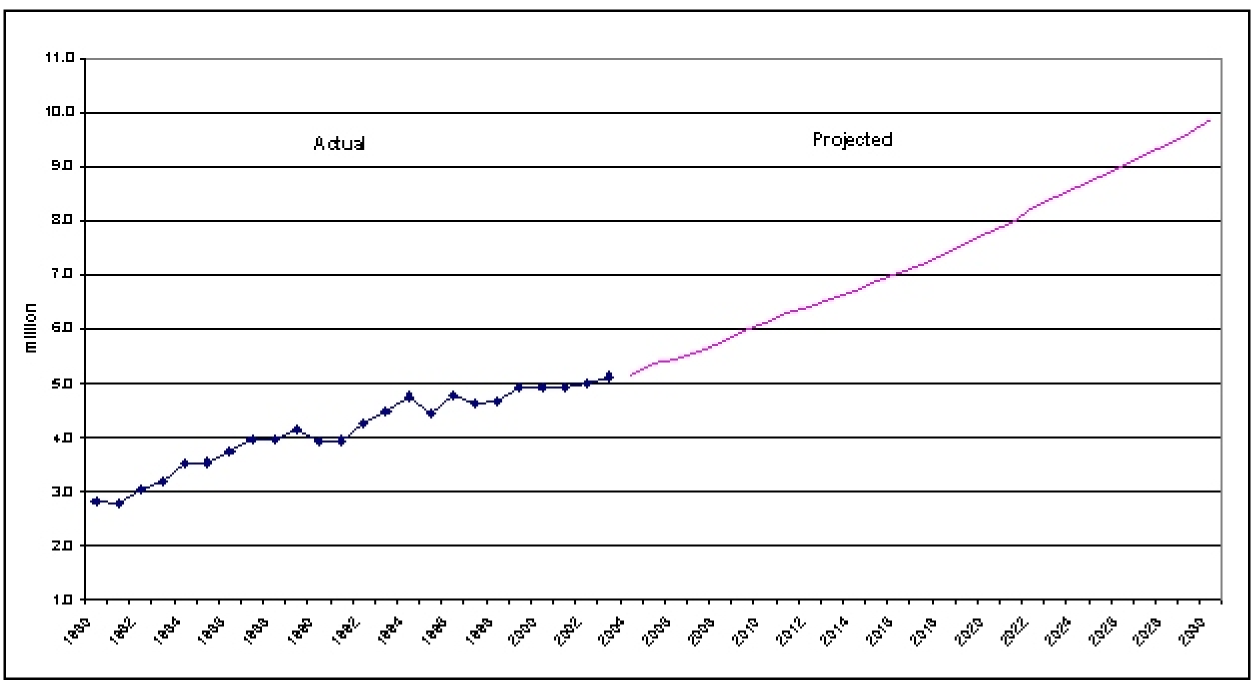

Figure 2.4 New Central Air Conditioners & Heat Pumps – Annual Shipments, 1980-2030

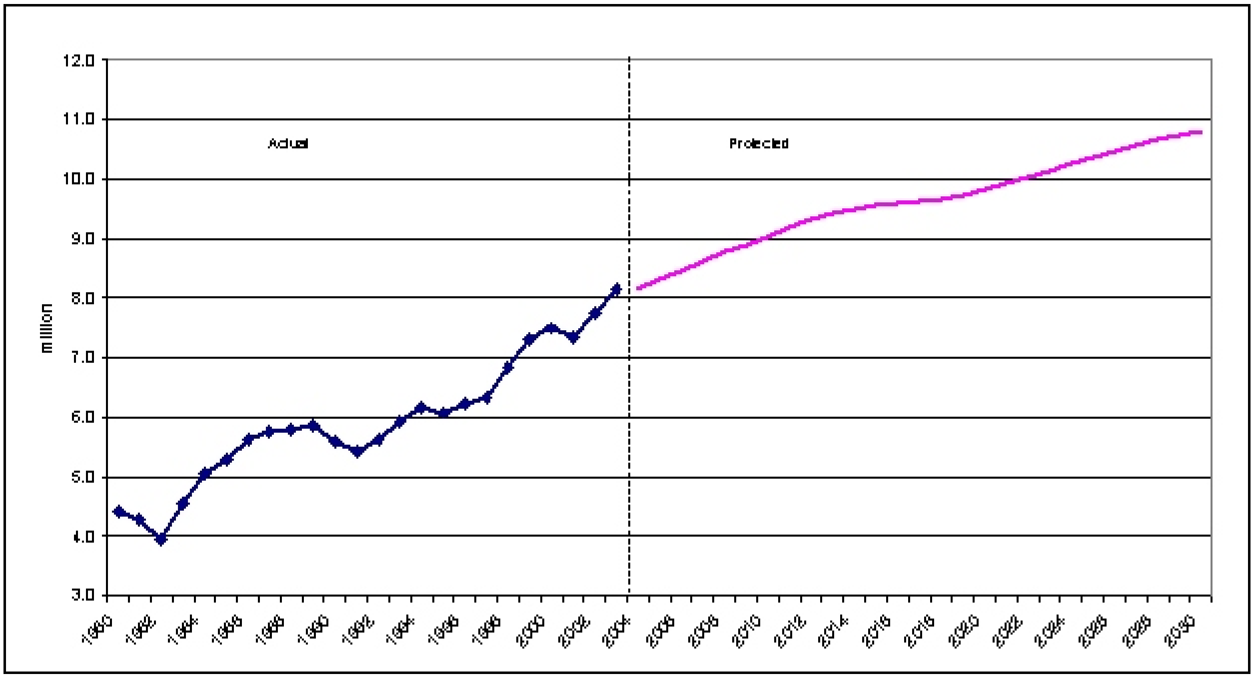

Figure 2.5 New Clothes Washers – Annual Shipments, 1980-2030

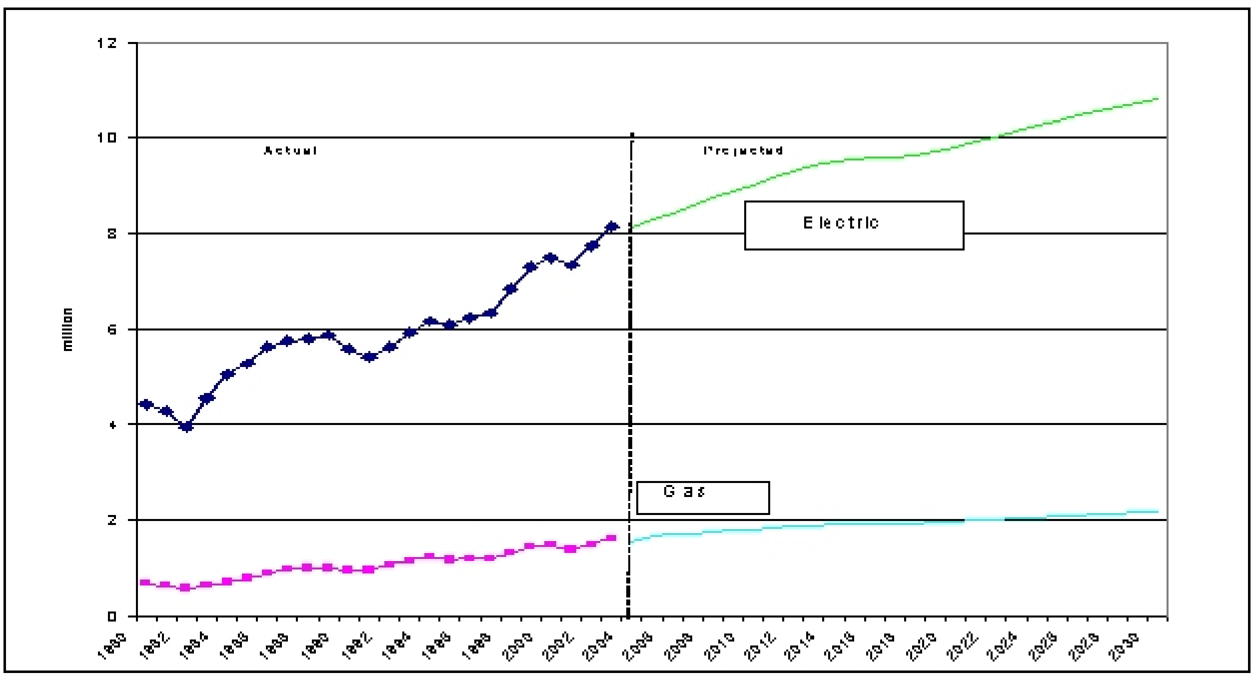

Figure 2.6 New Clothes Dryers - Annual Shipments, 1980-2030

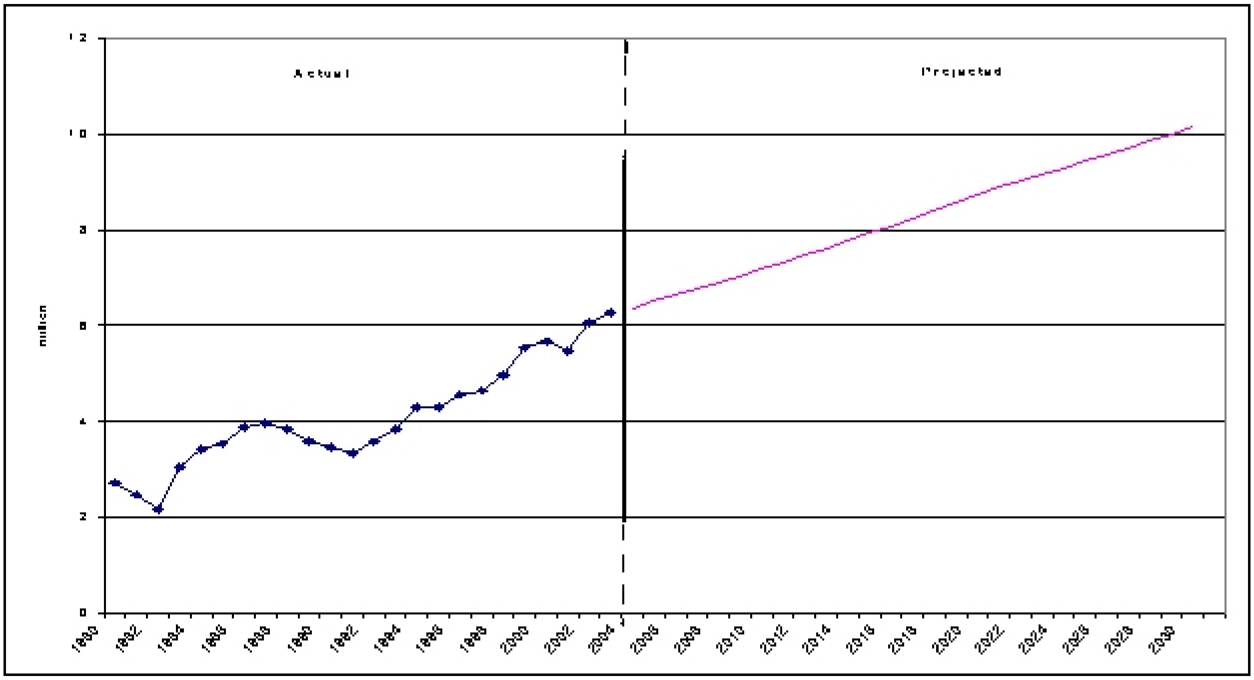

Figure 2.7 New Dishwashers – Annual Shipments, 1980-2030

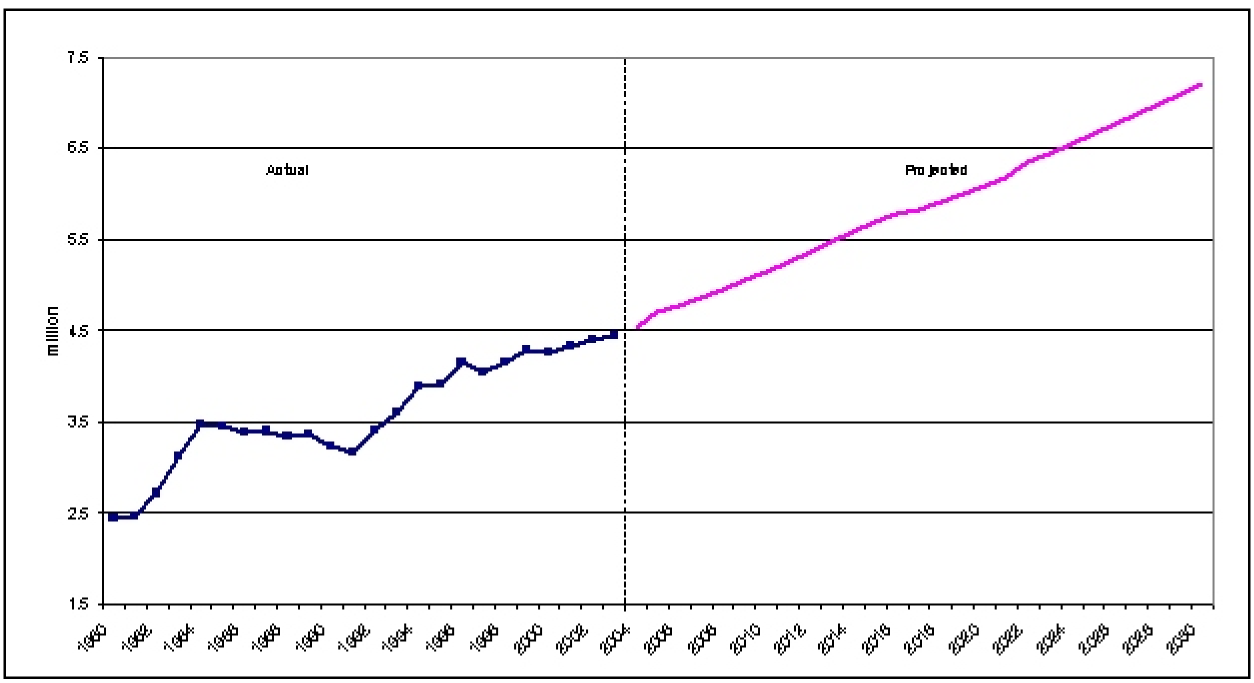

Figure 2.8 New Gas Water Heaters – Annual Shipments, 1980-2030

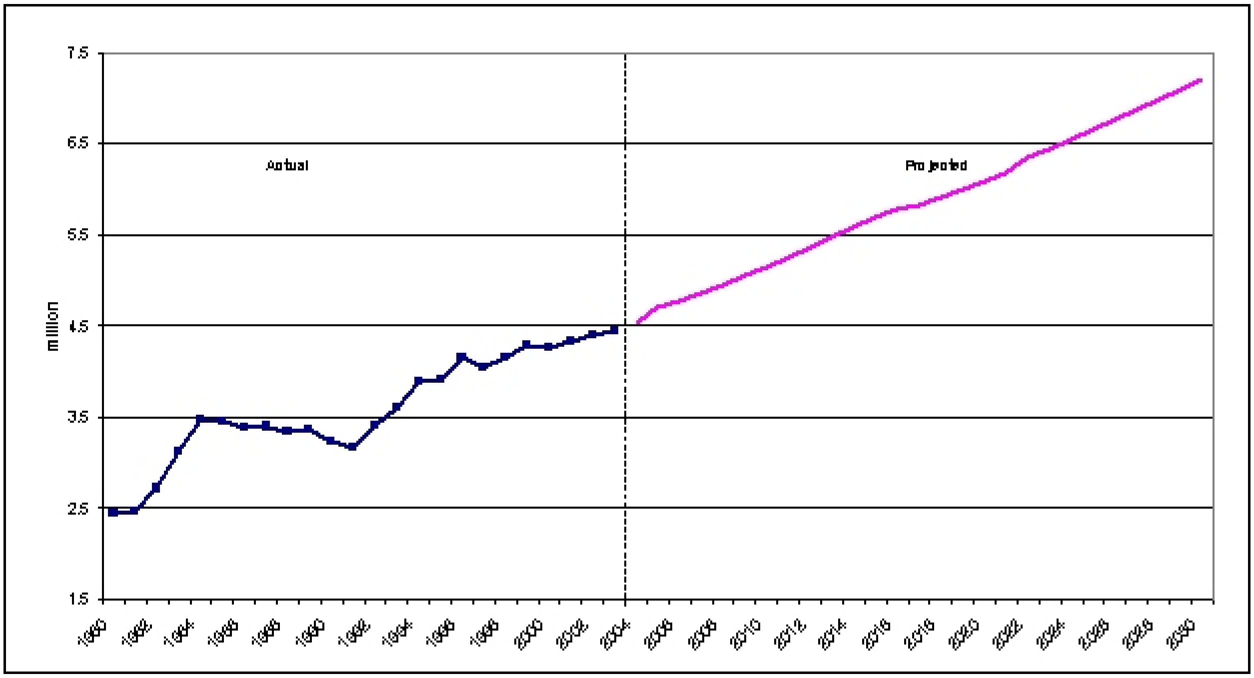

Figure 2.9 New Electric Water Heaters – Annual Shipments, 1980-2030

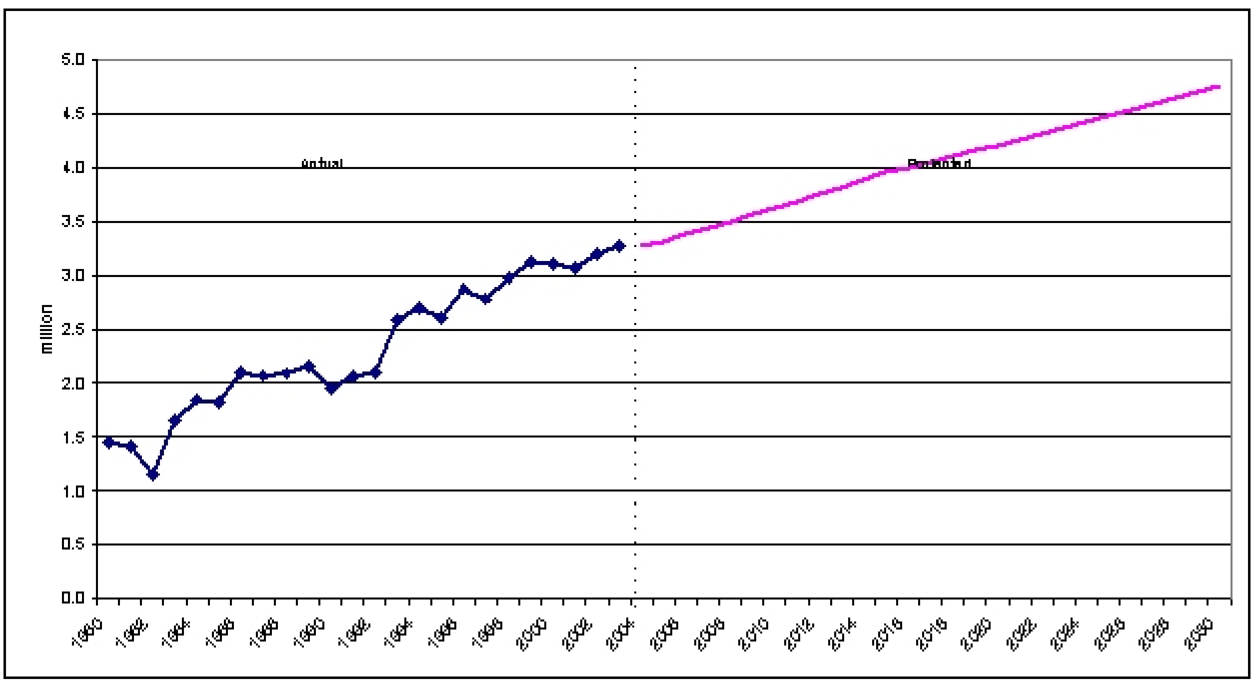

Figure 2.10 New Gas Furnaces – Annual Shipments, 1980-2030

3. Average Annual Energy Efficiency and Energy Consumption

The average annual energy consumption of an appliance is a function of its energy efficiency, which measures the amount of service provided per unit of energy input, and the amount of service provided. Examples of measures of service are adjusted cooled volume (refrigerators), loads of laundry (clothes washers), and heat energy removed (air conditioners).

The energy efficiency is largely a function of the technical features of the appliance. The energy consumption is influenced by the demand on the appliance. For space heating and cooling appliances, the heating and cooling load of the structure is important, in addition to the utilization patterns of the occupants.

In conducting this analysis, we used energy efficiency as the fundamental indicator for some products, and energy consumption as the indicator for others. The choice reflected data availability or specific analytical issues. The reader should be aware that trends in energy consumption do not exactly mirror the trends in efficiency, largely because of changes in average product capacity.

Historical Data

AHAM publishes estimates of average energy efficiency and energy consumption of products sold in a given year in a consistent manner over time for the following products:

Refrigerators
Freezers
Clothes Washers
Dishwashers
Room Air Conditioners

(The AHAM data are based on laboratory measurement.) We made some adjustments to account for performance under field conditions. For clothes washers, we did not use the AHAM data directly because they reflect different assumptions concerning hot water inlet temperature than DOE's TSD analysis, and they do not include energy use for clothes drying. (The energy consumption values that we used include energy use by the clothes washer as well as the estimated energy use for clothes drying and for heating the water for the washer.[3]) Instead, we mainly relied on an estimated time series from the TSD of average energy consumption associated with a washer. The trend in the data from the TSD is similar to the industry estimates.

For room air conditioners, we used the AHAM data on energy efficiency, but not on energy consumption, as the AHAM data reflect a different assumption concerning annual hours of use than DOE's TSD analysis. We calculated energy consumption based on annual data from AHAM

[3] The reason for including dryer energy use is that the 2004 and 2007 standards are based on a modified energy factor that includes the impact of higher spin speed in washers that spin more water out of the clothes and result in less time in the dryer.

on the average cooling capacity, and a fixed value of 533 for annual hours of operation, based on analysis for the TSD.

ARI publishes data on average energy efficiency for:
Central Air Conditioners & Heat Pumps

We estimated average energy consumption for central air conditioners and heat pumps using data on average cooling capacity and average cooling load in the TSD. The available evidence suggests that there has been relatively little change in average capacity since the mid 1980s. Data on change in home size and thermal integrity are insufficient to reliably estimate past and future change in the average cooling load, so we used the TSD value for all years.

For gas furnaces, LBNL estimated historical time series of the average fuel utilization efficiency (AFUE) of new non-weatherized gas furnaces as part of the analysis for DOE's 2004 ANOPR for furnaces and boilers (see Appendix 1, #8). These estimates were based on data from GAMA on the AFUE of models sold in specific years and on the market shares of non-condensing and condensing furnaces. Our calculation of energy consumption uses a constant value of 80 kBtu/hour input capacity and a heating load of 52 million Btu. The available evidence suggests that there has been relatively little change in average capacity since the mid 1980s. The estimate for heating load comes the 2004 furnace ANOPR.

For water heaters and clothes dryers, historical time series data on energy efficiency or energy consumption of products sold in a given year are not available from industry sources or from the TSDs. For these products, we did not use data on historic energy efficiency or energy consumption to estimate energy savings from standards.

Scenarios

For each product, we developed a base case that envisions likely trends without DOE energy efficiency standards. Each base case reflects a subjective estimate as to how energy efficiency and energy consumption might have evolved if no standards had been implemented. Although it is likely that states such as California would have continued their standards programs if DOE had not acted (as California has for products not covered by DOE standards), our base case scenarios do not consider the potential national impact of state energy efficiency standards. Since the DOE standards preempted actual and potential state energy efficiency standards, we credit them with the full impact of standards in general, whether federal or state.

The base case scenarios reflect the historical trend, where available, along with judgement as to changes that might have occurred as a result of market forces.[4] In estimating the latter, we considered the trends in residential energy prices in the 1990s as well as the future trends

[4] For water heaters and clothes dryers, historic data are lacking, so the projected base case trends are relatively uncertain.

projected by EIA. In considering the impact of energy prices on the market demand for product efficiency, we note that real electricity prices continued a downward trend in the 1990s that began in the mid 1980s (Figure 3.1). EIA's projection in *Annual Energy Outlook 2004* shows prices stabilizing in the future. For electric appliances, therefore, electricity prices in the 1990s provided little incentive for consumers to demand higher energy efficiency, and future prices also appear unlikely to stimulate such demand.

Natural gas prices were roughly flat in the 1990s. They spiked in 2001 due to an unusual market situation. EIA's AEO 2004 projection shows a roughly flat trend, though at a higher level than in the 1990s. For gas-using appliances, therefore, natural gas prices provided somewhat more incentive for consumers to demand higher efficiency than was the case with electricity, but the projected future prices do not suggest much stimulus for higher efficiency.

Our base case implicitly includes non-regulatory factors that contribute to efficiency increases, such as utility and state demand-side programs, and consumer information and labelling programs (such as *Energy Guide* and *Energy Star*), and government and private R&D. We assumed that non-price market incentives for higher efficiency in the future will be similar to those currently in effect (i.e., fairly minimal). This implies continuation of Energy Star designation but no resumption of significant utility incentives.

For the standards taking effect in 2000 and later, we estimated the average energy efficiency or energy consumption for products sold in the effective year of the standard. We derived these values using data from the DOE analysis for each standard. In most cases, the average efficiency is higher than the minimum required by the standard, since manufacturers sell a range of products in each product class. We assume that the shares of product classes remain constant, and thus the average values after standards also remain constant over time.[5]

In most cases, we assumed that the impact of a given standard begins in the year corresponding to the legal effective date (as indicated in the charts by when the Base Case begins). In some cases, however, the historic data suggest that manufacturers began to anticipate the standards by marketing more efficient products one or more years in advance of the effective date. In these cases (noted below), we credit the standard for energy savings from "early" introduction of higher-efficiency products.

The value for any given year refers to the energy efficiency or energy consumption of products sold in that year. The calculations assume that the original value for a given annual cohort remains constant for all years in which those units continue to operate.

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[5] In reality, the average minimum energy efficiency for each product may change over time since the market shares of different product classes (which have different minimum efficiency levels in the standard) may change over time. The actual average energy consumption associated with minimum efficiency products may also change due to shifts in the factors that influence energy consumption.

Figures

Figures 3.2 through 3.12 show the actual average energy consumption or efficiency values, the base case scenario, and the value associated with the most recent standard. The notes below describe some pertinent details.

Refrigerators and Freezers

We assume the impact of the NAECA 1990 standard began in 1987. The standard was announced in 1986, and the increase in the actual energy efficiency beginning in 1987 suggests that manufacturers began improving energy efficiency in preparation for the 1990 standard.

The base case average energy consumption declines at a fairly quick pace in the 1987-93 period due to the role of utility demand-side programs in this period.

The energy efficiency values for the 2001 standard for both products are based on the minimum efficiency regulations for various product classes and the estimated share of shipments in each class.

Room Air Conditioners

We assume the impact of the NAECA 1990 standard began in 1987. The standard was announced in 1986, and the increase in the actual Energy Efficiency Ratio (EER) beginning in 1987 suggests that manufacturers began improving energy efficiency in preparation for the NAECA standard.

The base case energy efficiency increases at a fairly quick pace in the 1987-93 period due to the role of utility demand-side programs in this period.

The value for the 2001 update is based on the minimum levels for various product types and the relative distribution of shipments in 1994 (the most recent year for which data are available). We derived average energy consumption from energy efficiency using data from AHAM on average cooling capacity and an estimate of average annual utilization of 533 hours from the TSD. Data do not allow accounting for possible changes in utilization over time.

Central Air Conditioners and Heat Pumps

The calculation of the impact of standards assumes modest increase in actual SEER in the 2003-05 period.

The energy savings include reduction in space heating energy associated with more efficient heat pumps.

Clothes Washers

The historic values are primarily based on the 2000 TSD, supplemented by AHAM data for recent years. The values in Figure 3.5 reflect a clothes dryer and water heater that use electricity, but our energy savings calculations account for the respective market shares of gas dryers and water heaters as well as electric ones.

The initial (1988) NAECA standard had little if any impact on the market, so we include it in the base case.

Clothes Dryers
The values for the first year of the base case and the 1994 standard are based on LBNL technical analyses from the late 1980s, with adjustment to 359 cycles per year to reflect later information on washer usage. The initial (1988) NAECA standard had little if any impact on the market, so we include it in the base case. Given the lack of actual data, the trend for the base case is rather uncertain.

Dishwashers
The values include energy use by the dishwasher itself as well as the estimated energy use for heating the water for the dishwasher. The values in the chart assume that the water heater uses electricity, but our energy savings calculations account for the respective market shares of gas water heaters as well as electric ones. The initial (1988) NAECA standard had little if any impact on the market, so we include it in the base case.

Water Heaters
The values for the 1990 standard and 2004 standard are from the water heater TSD. In the absence of data, we derived the base case value in 1990 by estimating that the 1990 standard caused a 5% reduction in average energy use. Given the lack of actual data, the trend for the base case is rather uncertain.

Note that although we present data on energy use, the TSD analysis uses a constant relationship between energy use and efficiency (Energy Factor) over time. Trends in average household hot water use are uncertain, and factors pushing upward (larger houses with more bathrooms, growing saturation of dishwashers) may be balanced by factors pushing downward (smaller household size, reduced-flow showerheads, cold water wash).

Gas Furnaces
The actual AFUE values for 1980-2000 were estimated by LBNL for the furnace/boiler ANOPR based on industry data for selected years. We assume moderate improvement in efficiency in 1992 in the base case, as the market share of more efficient condensing furnaces was growing in the 1989-92 period. The base case trend after 1992 reflects the leveling off of this growth in the mid and late 1990s.

We used non-weatherized gas furnaces as a proxy for all gas furnaces (including weatherized and manufactured home gas furnaces). They accounted for approx. 85% of total gas furnace sales in 2000. Since non-weatherized gas furnaces in actual use have higher average annual energy use than weatherized and manufactured home gas furnaces, our use of them as a proxy slightly overstates the total energy savings from the DOE standard.

We estimated average energy consumption for gas furnaces by assuming no change in average furnace input capacity or house heating load. We used data derived for the 2004 furnace ANOPR for non-weatherized gas furnaces that give an average capacity of 80 kBtu/hour and an average heating load of 52 million Btu. We did not try to account for possible changes in these variables over time. Growth in the average size of homes would tend to increase the above factors, but improvements in insulation, window glazing, and other structural elements would tend to decrease them.

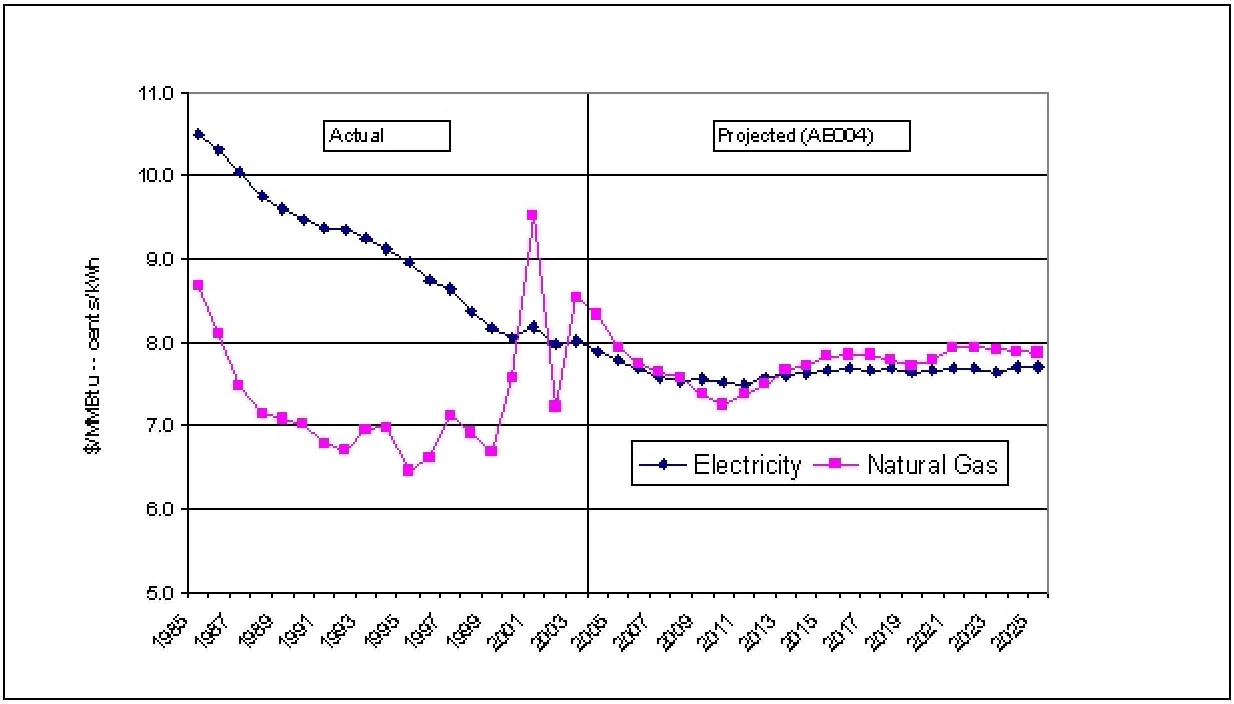

Figure 3.1 Average Residential Energy Prices (real), 1985-2025

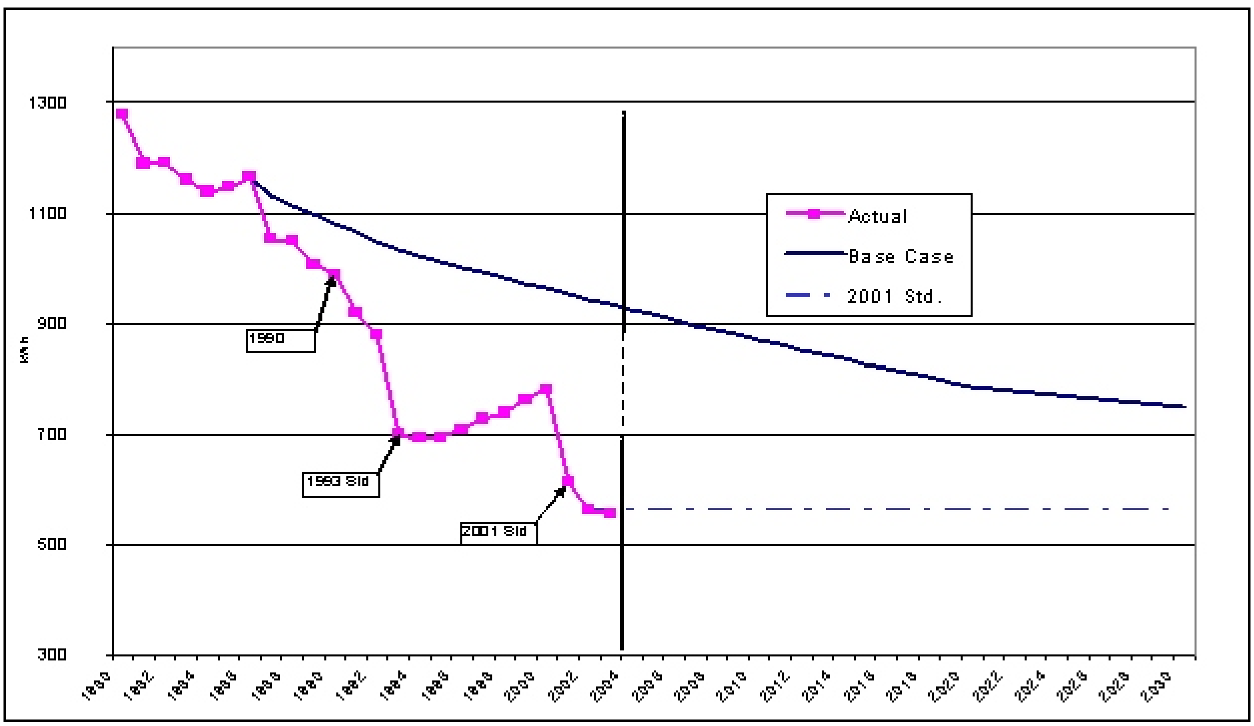

Figure 3.2 New Refrigerators - Average Annual Energy Use, 1980-2030

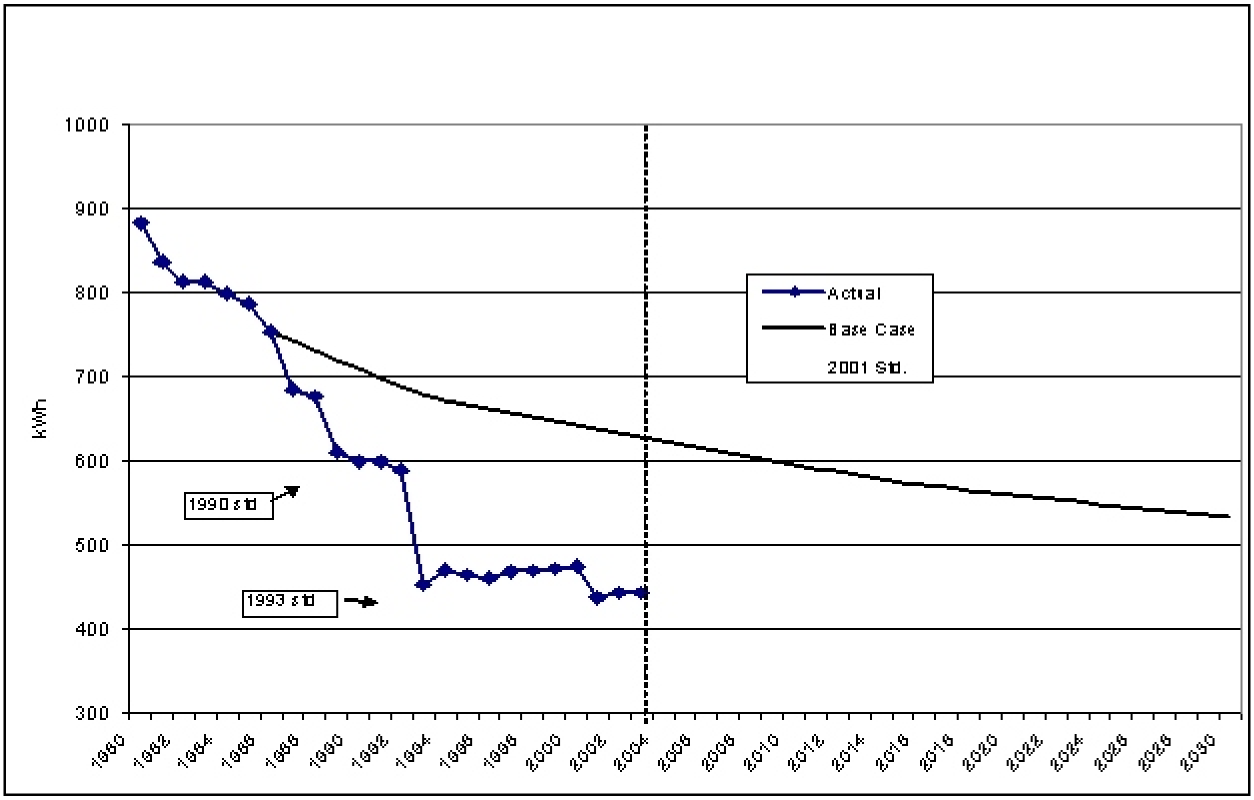

Figure 3.3 New Freezers – Average Annual Energy Use, 1980-2030

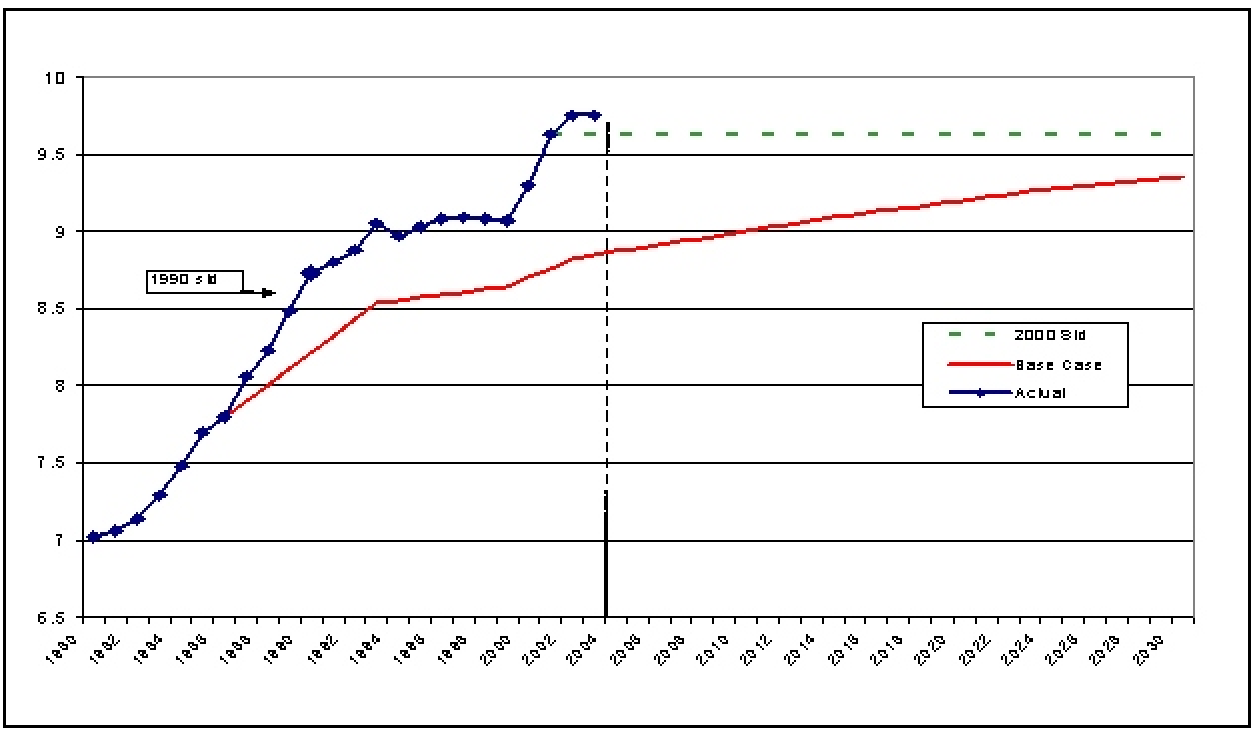

Figure 3.4 New Room Air Conditioners – Average EER, 1980-2030

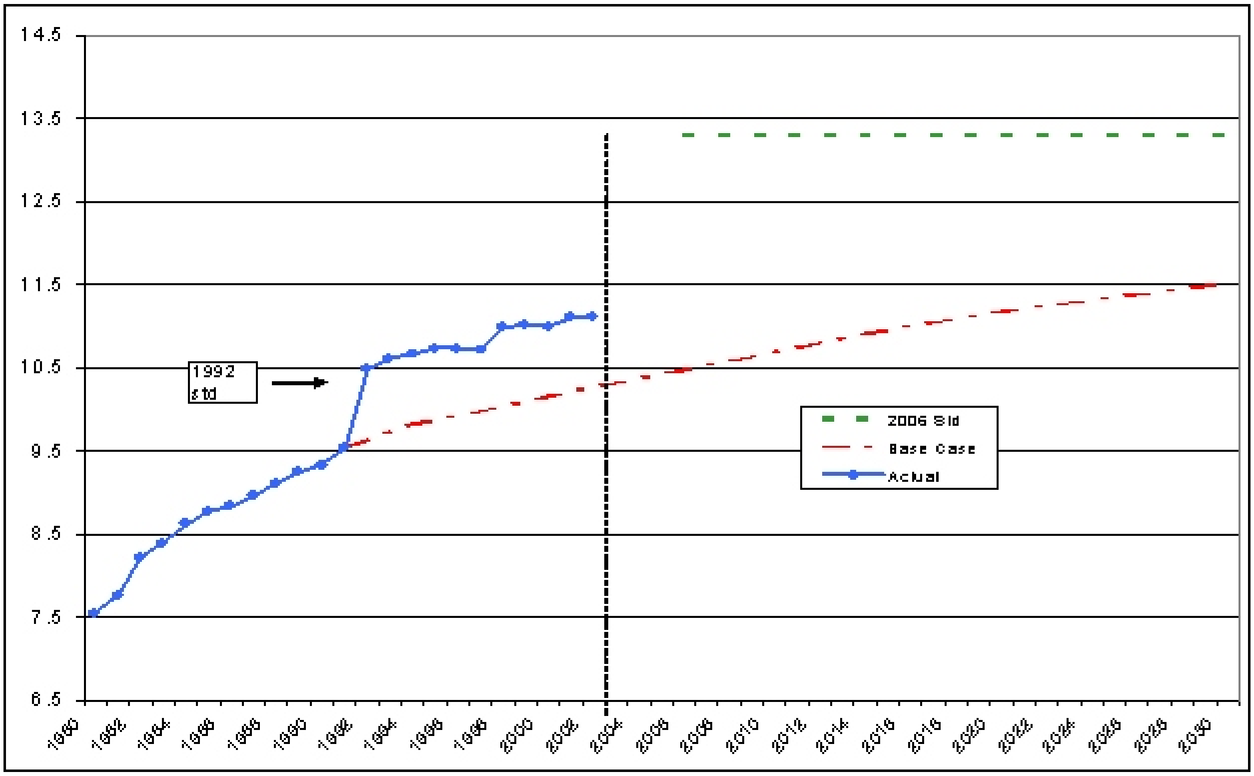

Figure 3.5 New Central Air Conditioners – Average SEER, 1980-2030

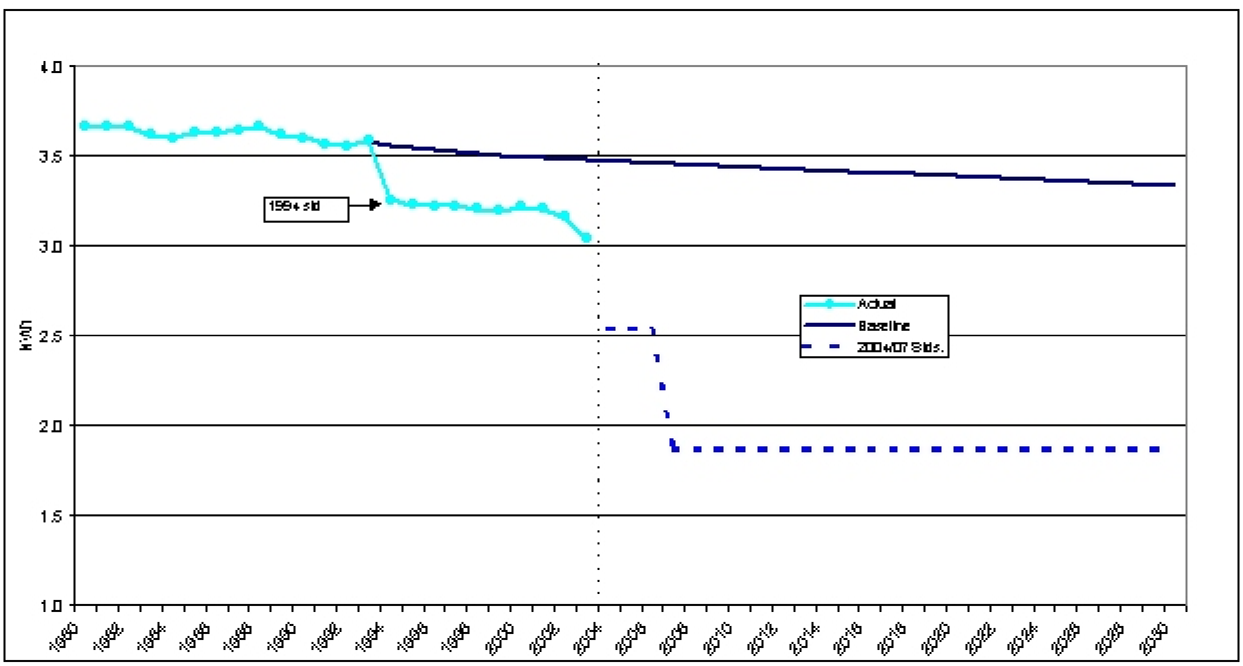

Figure 3.6 New Clothes Washers – Average Energy Use per Cycle (Washer, Dryer, and Water Heater Energy), 1980-2030

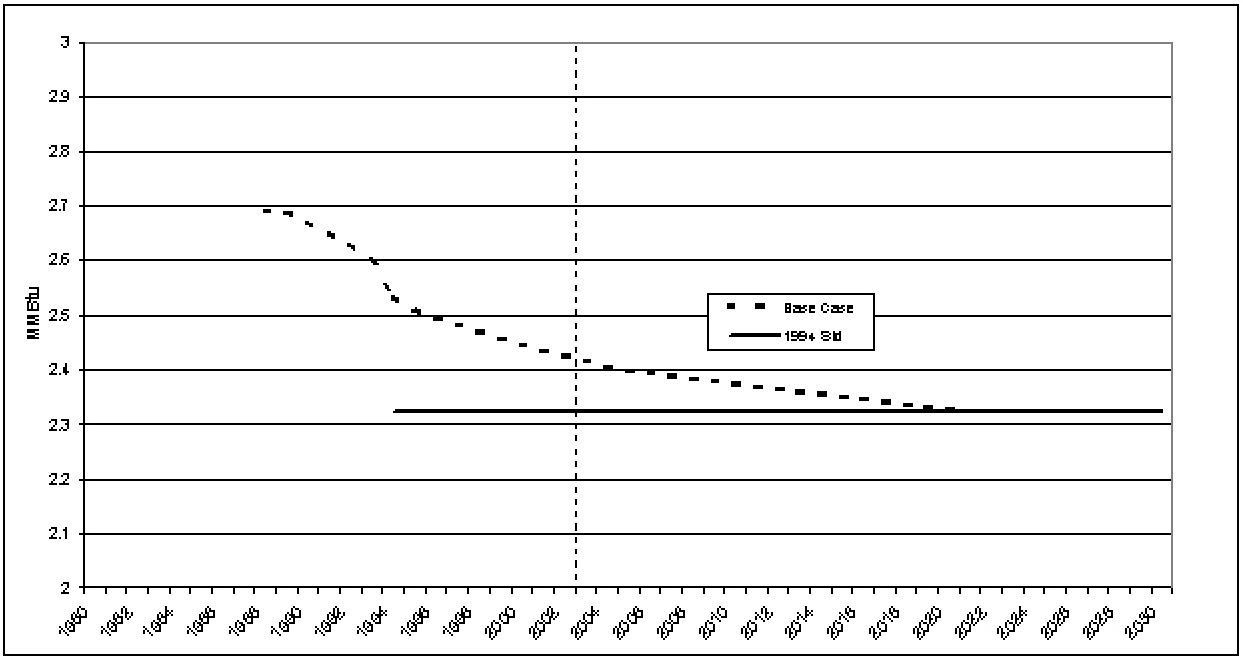

Figure 3.7 New Gas Clothes Dryers – Average Annual Energy Use, 1980-2030

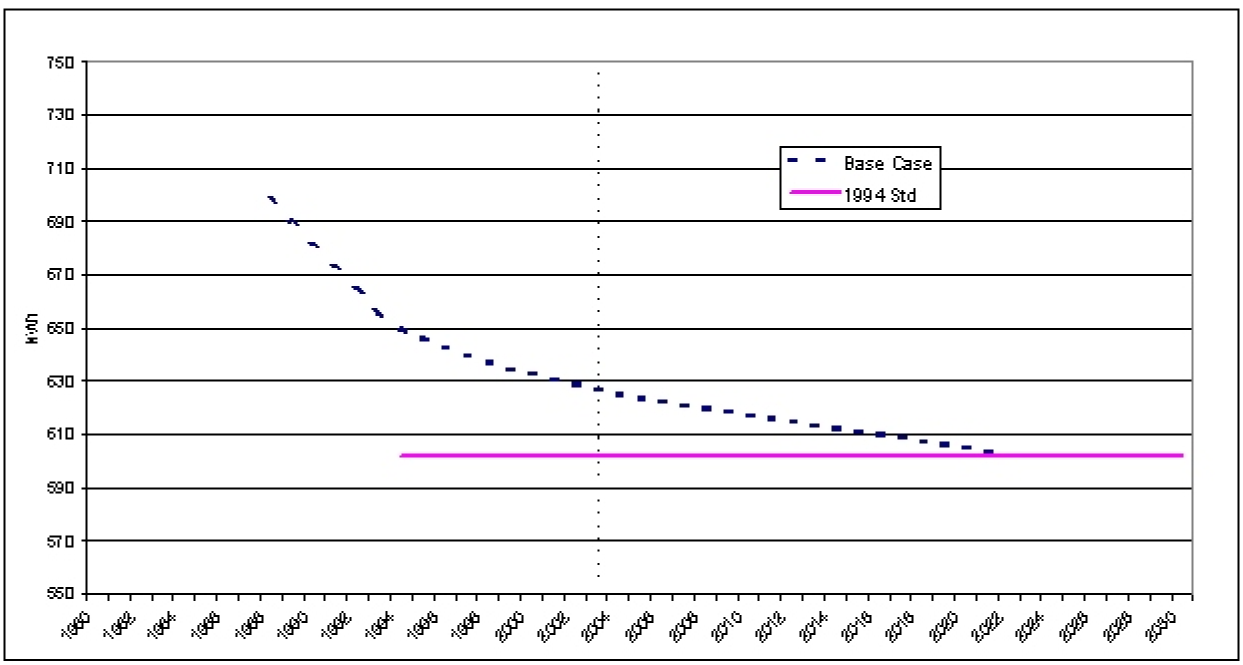

Figure 3.8 New Electric Clothes Dryers – Average Annual Electricity Use, 1980-2030

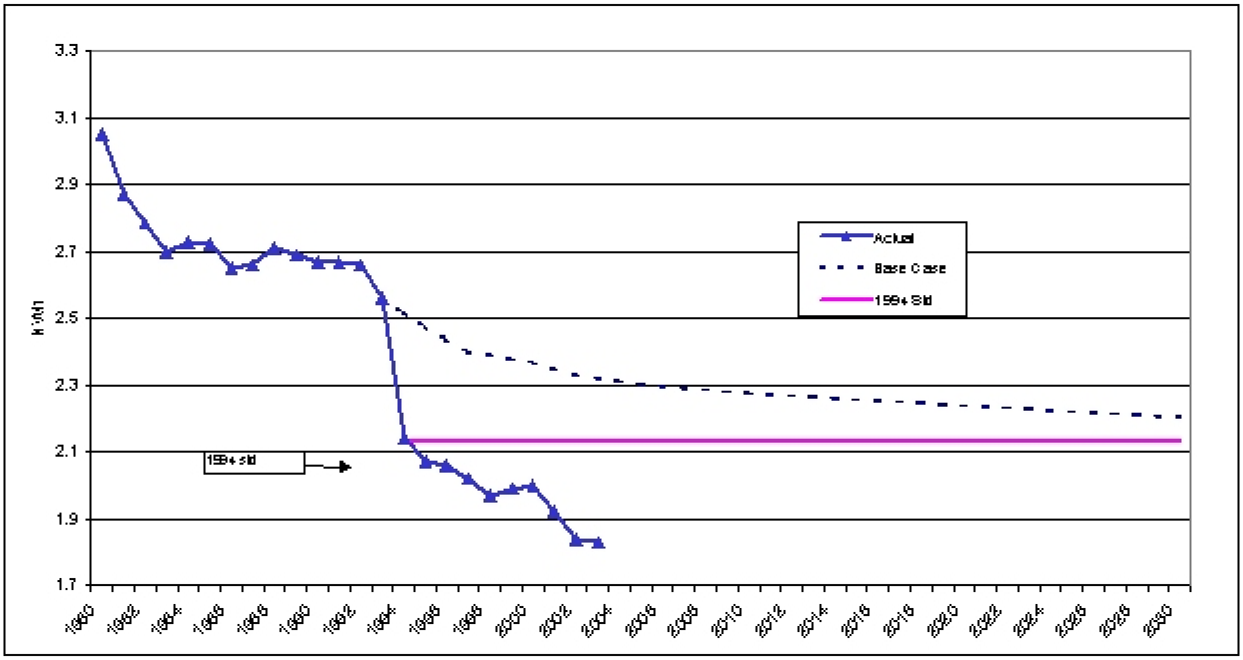

Figure 3.9 New Dishwashers – Average Energy Use per Cycle (Dishwasher and Water Heater Energy), 1980-2030

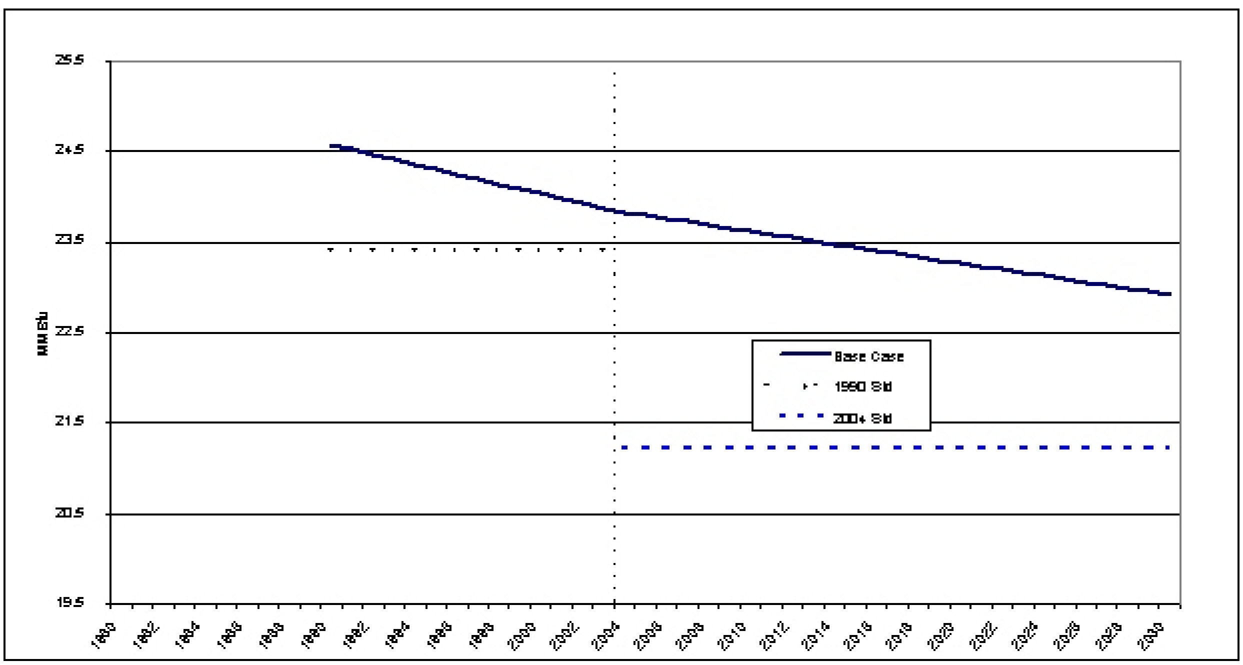

Figure 3.10 New Gas Water Heaters – Average Annual Energy Use, 1980-2030

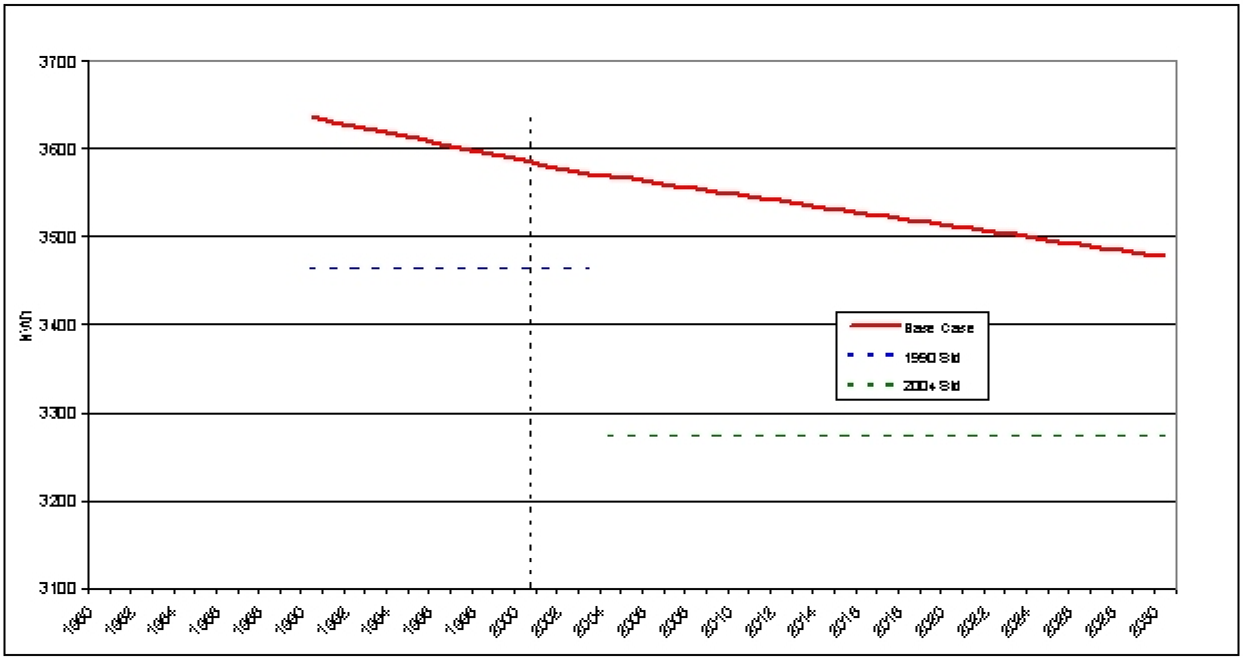

Figure 3.11 New Electric Water Heaters – Average Annual Energy Use, 1980-2030

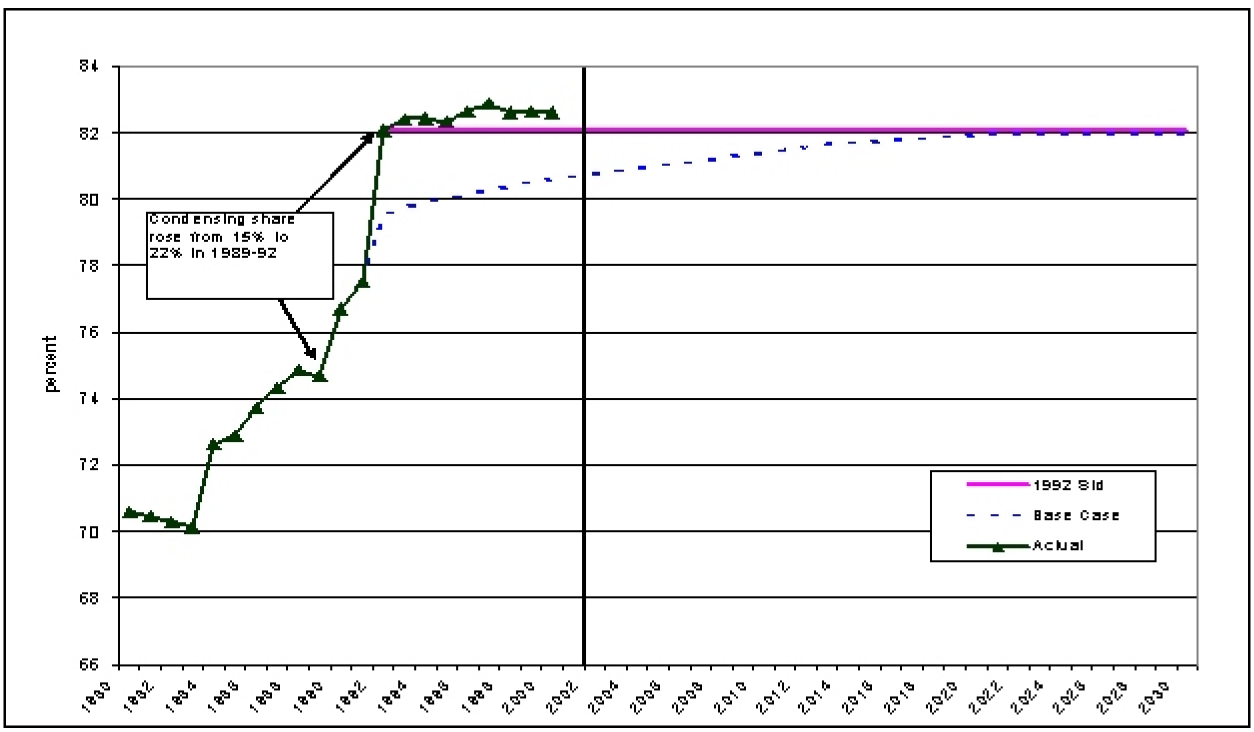

Figure 3.12 New Gas Furnaces – Average Fuel Utilization Efficiency, 1980-2030

4. Incremental Costs of Standards

In DOE's analyses of appliance standards, the additional consumer cost for a higher-efficiency appliance is estimated through a detailed analysis of manufacturing costs and markups in the distribution channel. The extent to which the estimated increase in cost to meet a particular standard has in fact occurred has been a matter of some debate.

AHAM has published data based on market research on the average retail price of products sold in a given year for refrigerators, freezers, room air conditioners, clothes washers, clothes dryers, and dishwashers.[6] The industry data show considerable decline in the average price (adjusted for inflation) between 1985 and the mid 1990s for all of the above products (Figure 4.1). There are a number of factors behind this secular trend operating in manufacturing as well as in distribution.

Looking at the trends, it is difficult to see an impact on price from DOE standards effective in the 1990s. The rise in the average price of refrigerators and freezers in the 1999-2001 period could be partly attributed to the 2001 standard. Since there have been changes in average size and model features in addition to design changes to meet efficiency standards, however, using average prices to assess the effect of standards is problematic.

To be conservative, we have adopted the approach used by DOE and assumed that the standards did cause some additional cost. We utilized the actual price data where available, but we assumed that prices would have been even lower in the absence of standards. Wherever incremental cost estimates were available from the TSDs, we applied the percentage incremental cost as estimated in the TSDs to the appropriate actual prices. Where such estimates were not available, we made estimates for this study.

The incremental cost estimates refer to a standard-level efficiency and a specific baseline technology. Since we use a Base Case in which the average efficiency changes over time, we need to adjust the incremental cost as well.

We utilized the AHAM data and our interpolations for missing years to represent actual average prices in the 1985-2002 period for the products listed above.

For central air conditioners and heat pumps, we relied on cost estimates for different efficiency levels for 1998 new units made for the 2001 TSD. We applied these data to specific years based on the estimated average SEER for each year, interpolating as needed (Figure 4-2). This method does not capture any cost trends independent of efficiency change that have occurred in the past. Thus, the estimated past values may not be accurate in absolute terms, but they should reasonably reflect the percentage change from one efficiency level to the next.

[6] AHAM provides data for 1994 based on market research. The data for 1998 and 2002 were estimated by AHAM.

For water heaters, we utilized the average installed cost estimated for specific efficiency levels in the 2001 TSD. As with central air conditioners, the average cost in any given year is based on the average efficiency in that year.

For gas furnaces, we utilized data on late-1990s prices for furnaces of various specific efficiencies. We then used the average efficiency in each year to derive an appropriate price.

Although the past trend of declining prices may continue to some extent, we have not attempted to estimate the shape of the future decline in average price for any of the products. Rather, we focused on the relative difference in price between the standards scenario and the Base Case, making sure that the price differential corresponds to the efficiency differential. If the secular decline in price continues in the future, our incremental cost estimates, which are calculated as a percentage, would be somewhat too high.

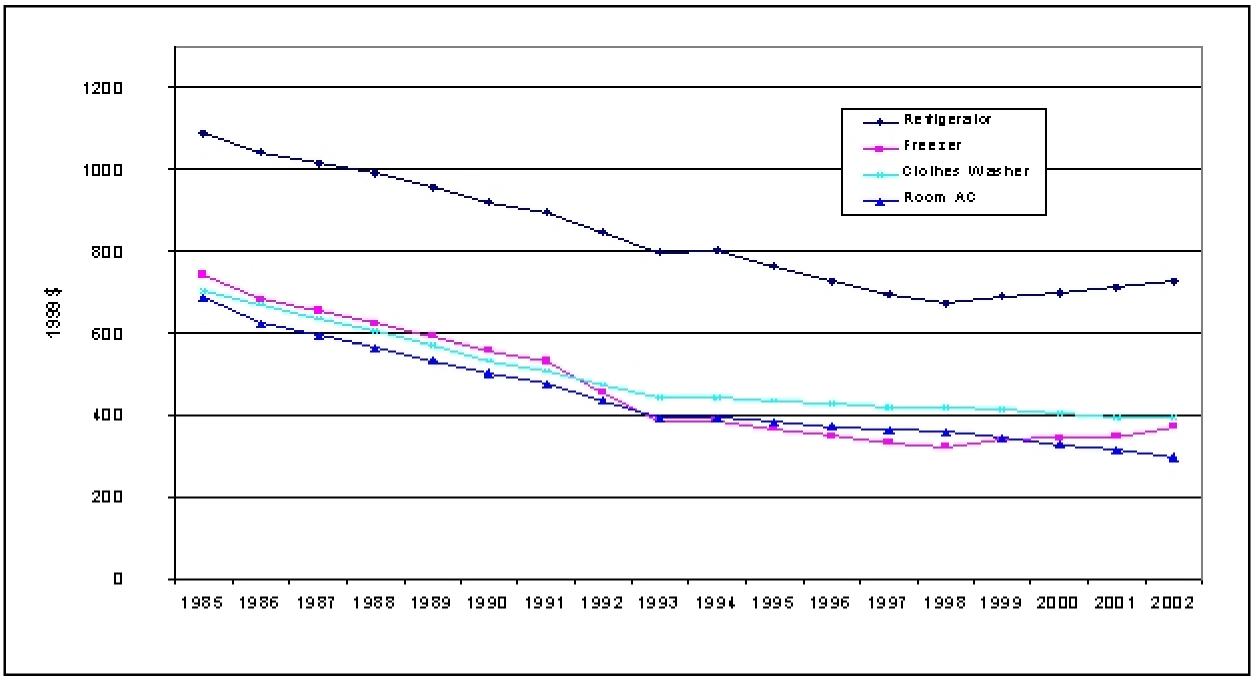

Figure 4.1 Average Retail Price of Selected Appliances (inflation-adjusted), 1985-2002

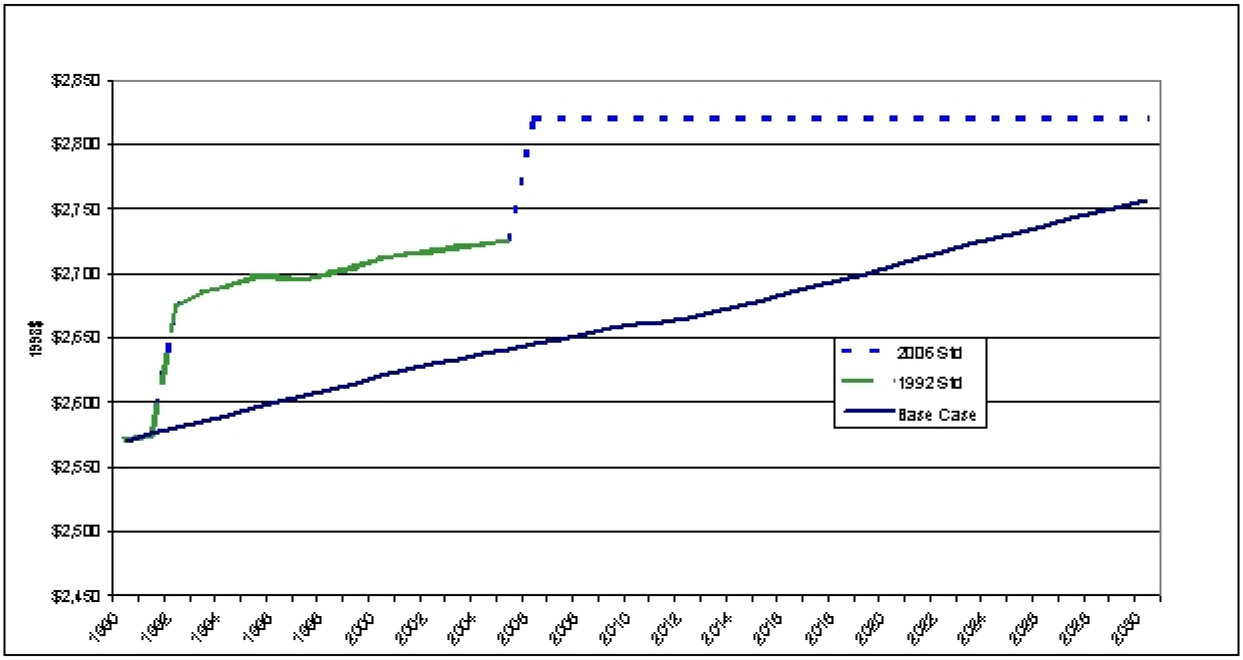

Figure 4.2 New Central Air Conditioners & Heat Pumps – Average Installed Cost (Estimated), 1990-2030

5. Energy Savings Due to Efficiency Standards

Estimating the energy savings due to the federal efficiency standards is inherently uncertain for two basic reasons. First, there is uncertainty regarding what the average efficiency of new appliances would have been in the absence of standards (what we call the Base Case). Second, there is uncertainty about the impact of the standards on the market outcome. At a minimum, a standard removes all models from the market that are below the floor set by the standard. But given the nature of appliance manufacturing and marketing, a standard may also contribute to a greater shift in the market than it nominally requires.

Apart from the difficulties described above, the analyst also faces limitations in the data available. Our approach makes use of historical data that are available on the average efficiency of units sold in various years for a number of appliances. It also makes use of engineering analysis and market data that allow estimation of the minimum efficiency required by each product standard. One must bear in mind that for each product there are actually separate standards for each product class. Thus, estimating the minimum average efficiency required by the standards on a given product calls for estimates of the market shares of each product class in the years in which the standard is effective. Such data are difficult to obtain.

Taking the above into account, as well as the time constraints of this project, we selected a simple method for estimating the energy savings due to efficiency standards. The core of the method is estimation of the impact of standards on the average energy efficiency or energy use for products sold in each year considered. The summing of the per-unit savings over time, done with a stock accounting model, is straightforward, as is the estimation of primary energy savings. These elements are described in the sections below.

Average Energy Savings per New Unit

The approach for estimating the impacts of standards varies among the products. For most products the original standard was followed by one or more updates. In these cases, we used the actual efficiency or energy use data to estimate the energy savings due to the original standard and any updates effective in the 1990s. This approach requires one to place all other factors in the Base Case (as described in chapter 1), which we did in an approximate manner. We then calculated end-use energy savings per unit for each year based on the difference between the actual average energy use or energy efficiency and the value in the Base Case (see, for example, the left-hand side of Figure 3.2).

In all cases, the actual average energy efficiency exceeded the minimum required by the standard, sometimes by a significant amount. Such an outcome is to be expected. Analysis of the characteristics of models on the market before and after the effective date of standards for refrigerators, room air conditioners, and gas furnaces indicates that the standards appear to have stimulated a broader shift in the efficiency of manufacturer offerings, and not merely removal of the least efficient products from the market (Meyers, 2004).

The situation for gas furnaces was somewhat unique. The 1992 standard set a minimum AFUE of 78%, but the average AFUE of furnaces sold in 1992 was 83%. The reason is that roughly 20% of sales were of highly efficient (90-92%) condensing furnaces, while the remainder were at or better than the 78% minimum. The increasing share of condensing furnaces was occurring without the NAECA standard, but the standard increased the average efficiency of the other furnaces in the market.

For updates effective in 2000 and after, we used a somewhat different approach. For the standard-case energy efficiency or energy use, we used either the actual or the projected (in the TSD) market outcome in the effective year. We then took the difference between the standard-case energy efficiency or energy use and the Base Case to derive energy savings (see, for example, the right-hand side of Figure 3.2).

Where actual data are lacking (water heaters and clothes dryers), we used the difference between the maximum average energy use resulting from the standard and the Base Case to derive energy savings.

National End-Use Energy Savings

The calculations use a product retirement function to calculate the number of units in each vintage that are still in operation in a given year. The retirement function assumes that individual appliance lifetime is normally distributed around a mean lifetime. The width of the distribution is such that almost all units retire within a few years of the average lifetime. The mean lifetime for each appliance is shown in the table below.

The model calculates the energy savings for a given standard as the difference in national energy consumption between the Base Case and the standard scenario. It tracks energy savings into the future until all of the units installed in 2030 are retired.

Appliance	Mean Lifetime (years)
Refrigerators	19
Freezers	19
Central Air Conditioners	13
Room Air Conditioners	13
Clothes Washers	14
Dishwashers	13
Water Heaters	10
Gas Furnaces	17

Source: Technical Support Documents (Appendix 1)

National Primary Energy Savings

We calculated the primary energy required for production and delivery of end-use (site) electricity and natural gas in each year using historical data and projections in EIA's *Annual Energy Outlook 2004*. These data yield an average site-to-primary energy multiplier for each year through 2025.[7] We extrapolated the trend for the years after 2025.

Figure 5.1 shows the annual primary energy savings for all products together. A dropoff in savings after 2030 occurs because that is the last year for which we count product shipments. After 2030, as the products purchased in earlier years age, we continue to count savings until all products purchased in 2030 retire. The annual primary energy savings from DOE residential standards in 2020 is 2.1 quads. EIA's *Annual Energy Outlook 2004* has a projection for total residential primary energy consumption of 25 quads in the reference case. As this projection includes the effect of appliance standards, the consumption without the standards would be approximately 27 quads. Thus, we estimate that the standards will reduce energy consumption in 2020 by 8%.

Figure 5.2 presents the cumulative primary energy savings for all products together in selected years. The cumulative savings are 54 quads in 2030, and 67 quads in 2045. Refrigerators claim the greatest savings, followed by clothes washers and central air conditioners.

[7] The analyses done for recent standards rulemakings estimated primary energy savings using "marginal" site-to-primary factors that were derived using DOE's National Energy Modelling System (NEMS). NEMS accounts for the types of power plants that would be used less due to reduced electricity demand from specific standards. The marginal factors differ from the average factors used in the present study.

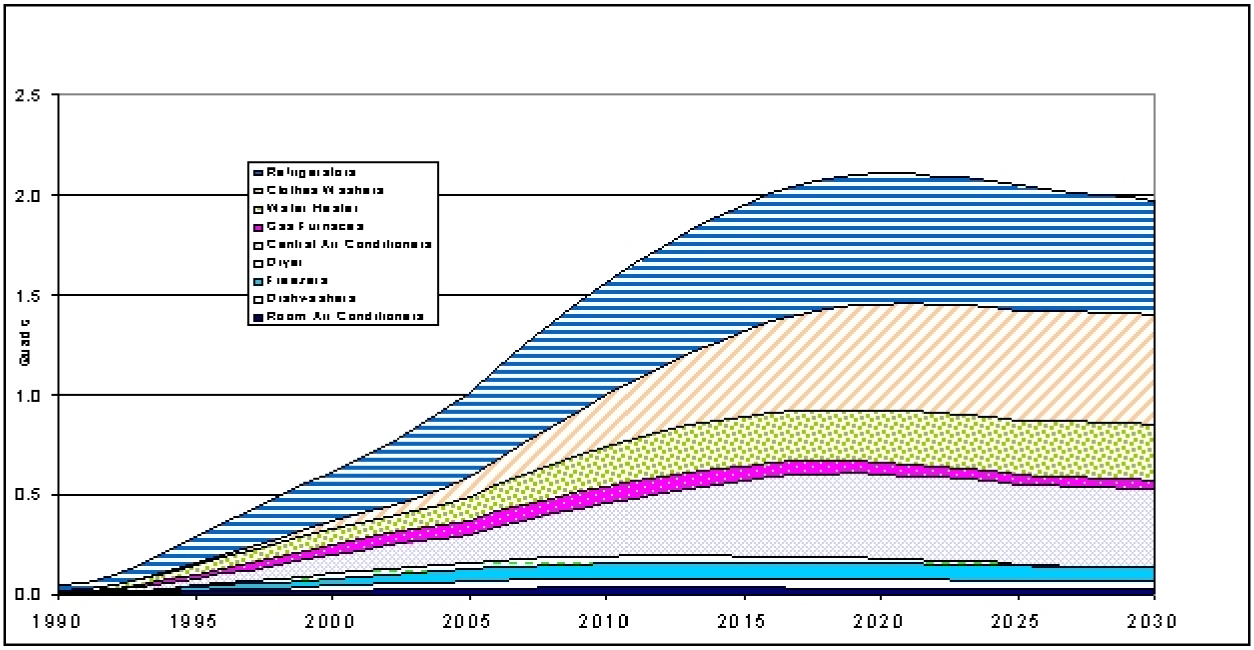

Figure 5.1 Annual Primary Energy Savings from DOE Standards by Product

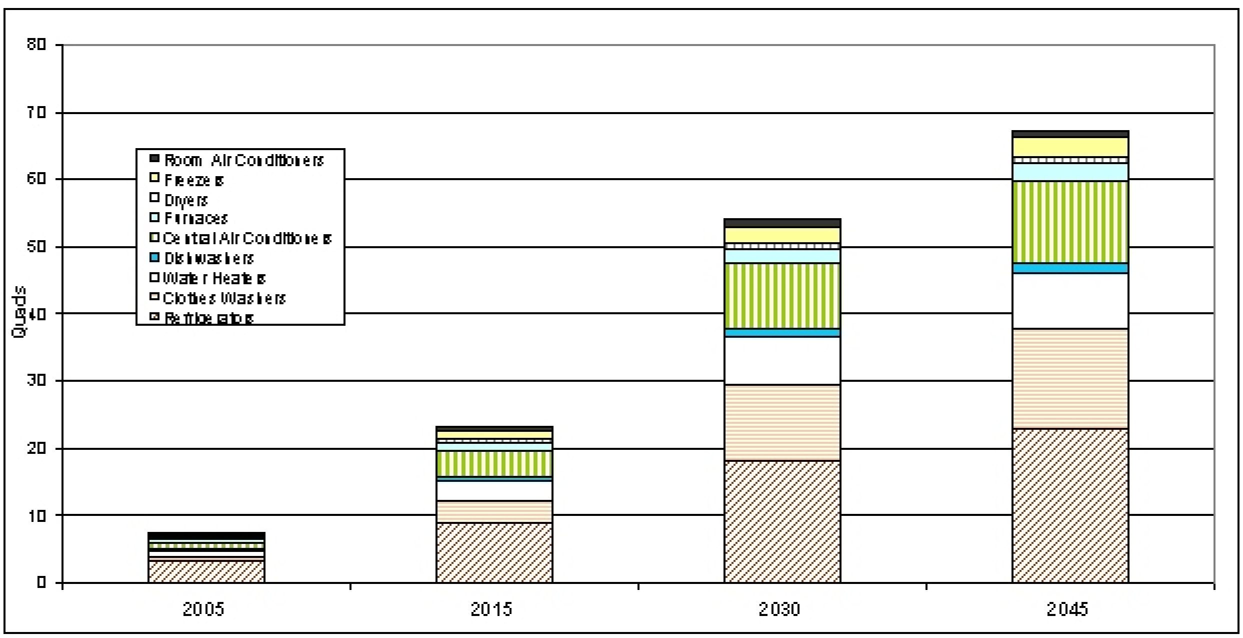

Figure 5.2 Cumulative Primary Energy Savings from DOE Standards by Product, as of Selected Years

6. National Consumer Costs and Benefits Due to Appliance Standards

Figure 6.1 shows the undiscounted annual operating savings, additional product cost, and net benefits for all of the standards together. The additional product cost reflects the estimated incremental purchase price associated with each standard. The operating savings are primarily electricity and natural gas savings valued at the national average residential retail price for each year.[8] For products that reduce water consumption (clothes washers and dishwashers), we include savings on water expenditures in the operating savings. For clothes washers, such savings are a significant fraction of the overall savings. All values are expressed in year 2003 dollars.

We express the benefit of appliance standards to consumers in terms of the Net Present Value (NPV) of costs and benefits over the expected lifetime of products. To calculate the NPV, we discounted future costs and savings in each year to 2003 using a rate of 7% (real), which is the rate used by DOE in its analyses of appliance standards (based on guidance to all federal agencies from the Office of Management and Budget). To express the present value of net savings achieved in the 1987-2003 period, we apply an annual interest rate of 3% (the approximate average return on long-term government bonds) to the net savings in each year, allowing interest to accumulate through 2003.[9]

The discounted operating savings, additional product cost, and net savings are shown for each product in Figure 6.2. The greatest net savings are associated with standards for refrigerators and clothes washers.

Figure 6.3 gives the cumulative net benefits for all products together for various periods. By the end of 2005, the standards will have saved U.S. consumers roughly $30 billion. The present value of projected net savings over the entire 1987-2045 period is $141 billion. The ratio of consumer savings ($239 billion) to additional consumer expenditures ($98 billion) is 2.45 to 1.

The amount of taxpayer funds used to support DOE's residential appliance standards program over the past 20 years is in the range of $200-250 million. Thus, the leveraging effect of the government expenditure on consumer benefit is quite large.

[8] The analyses done for recent standards rulemakings derived and used "marginal" electricity prices to value electricity savings from each standard. Marginal energy prices are the prices consumers pay for the last unit of energy used in a given billing period. The marginal prices differ from the average prices used in the present study.

[9] Interest rates represent the marginal value of savings to society, determining what next year's money is worth today and what today's money will be worth next year. Economists take advantage of this definition and use interest rates to convert future savings into a present value (in which case the interest rate is called a discount rate) and to convert past savings into a present value. Interest rates vary in proportion to the level of risk. Low risk long-term government bonds have yielded roughly 3% (real) in past decades while equity stocks, which face higher risk, yielded over 7%. Consistent with this finding, economists use a low rate to convert low-risk savings into a present value and use a higher rate to convert high-risk savings into a present value. We consider past benefits of energy efficiency standards to be low risk, since there is fairly high confidence that they have occurred. Less certain about the future, we consider future benefits of standards to be higher risk.

The actual consumer benefits achieved to date, as well as the prospective benefits, may be understated in this study. We have relied on engineering estimates to calculate the incremental cost of products that meet efficiency standards. However, both statistical analysis and anecdotal evidence indicate that the actual extra cost faced by consumers has sometimes been less than estimated in the TSDs (Greening et al., 1997). One possibility is that the estimated manufacturing costs were reasonably accurate, but that competitive pressure prevented the manufacturers from passing all of the extra cost onto consumers. Another possibility is that manufacturers responded to the reality of standards by developing less expensive ways of meeting the standards relative to the engineering estimates that were made years in advance.

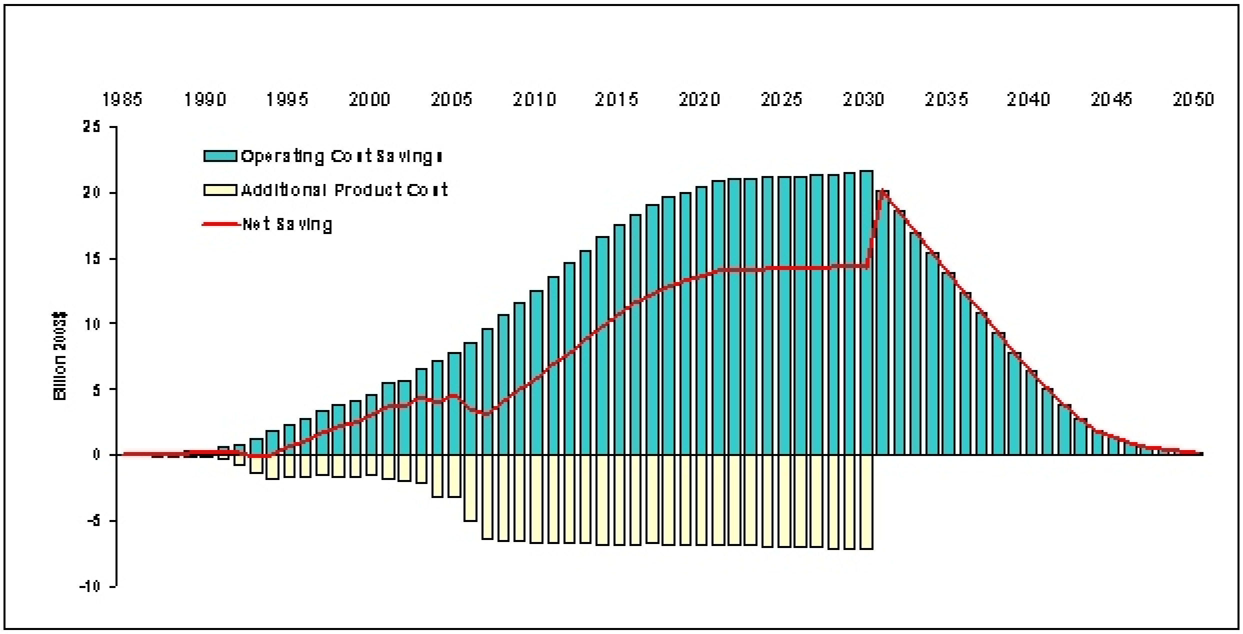

Figure 6.1 **Annual Consumer Impacts of DOE Appliance Standards – All Products (Not Discounted)**

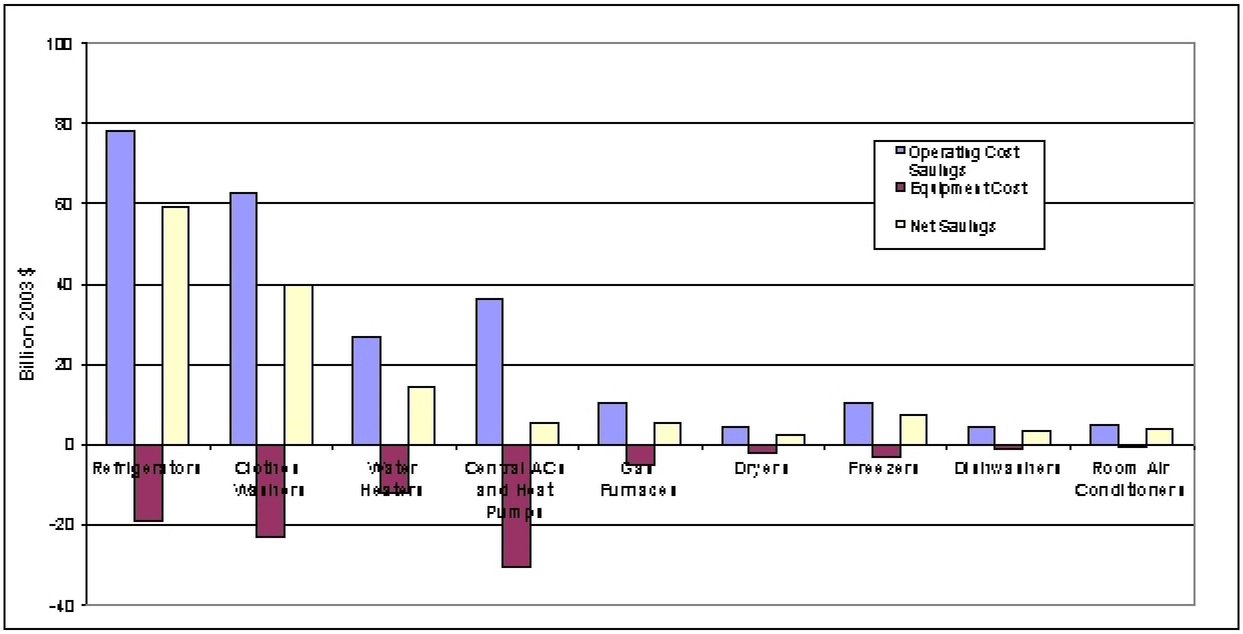

Figure 6.2 **Present Value in 2003 of Cumulative Consumer Costs and Benefits from DOE Appliance Standards, 1987-2050**

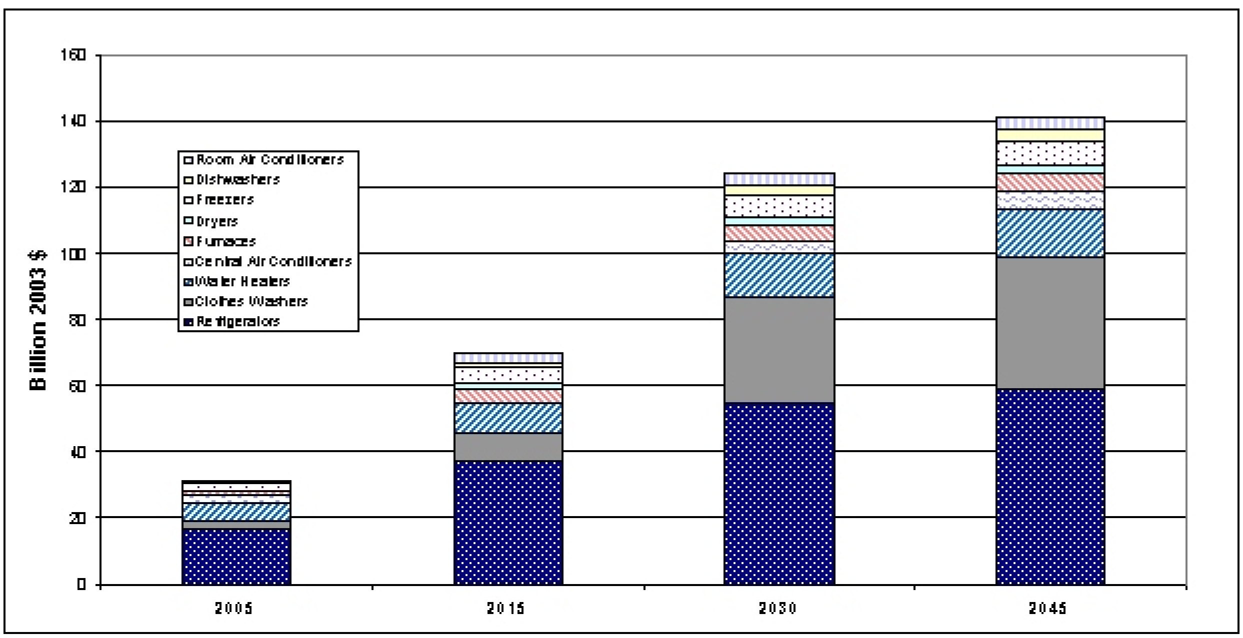

Figure 6.3 **Net Present Value in 2003 of Cumulative Consumer from DOE Appliance Standards from 1987 through Selected Years**

7. Environmental Emissions Reduction Due to Standards

Reductions in carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions due to DOE's appliance standards are based on the estimated savings in primary energy use for electricity generation and primary natural gas consumption. We derived average emissions factors in terms of million metric tons of carbon (MtC) per quad of primary energy consumption for each year in the 1987-2050 period, using historic (EIA, 2003) and projected (EIA, 2004) data on total CO_2 emissions from U.S. electricity generation, along with corresponding data on primary energy consumption by the power sector. We used a similar approach and data for annual NO_x emissions factors.

Because emissions of SO_2 from power plants are capped by clean air legislation, physical emissions of this pollutant from electricity generation will be only minimally affected by appliance standards. The maximum SO_2 allowed by law will most likely still be produced.

Appliance standards also reduce emissions of mercury from coal-fired generation, but we are not aware of reliable emissions factors.

For electricity generation, the use of average emissions factors produces lower values for avoided emissions than would use of marginal factors, which reflect the type of power plants whose production would be cut back due to electricity conservation.

Without DOE's appliance standards, total projected CO_2 emissions from the residential sector (including emissions associated with electricity use) in 2020 are 431 MtC. With the standards, the estimated value is 395 MtC – 8 percent less.[10] The reduction of 36 MtC is equivalent to the CO_2 released by typical annual operation of 28 million of today's average cars.

The annual reduction in NO_x emissions due to standards in 2020 is 0.2 million tons, which is equivalent to around 5% of total current NO_x emissions from U.S. electric utilities.

Table 7-1 presents the cumulative reduction in emissions for all product standards combined.

To place an approximate economic value on the reductions in emissions, we relied on the estimates used by the National Research Council in its recent review of energy research at DOE (NRC, 2001). These ranges are $6 to $11 for a metric ton of carbon and $2,300 to $11,000 for a metric ton of NO_x. For NO_x, we used a range of $2,300-$4,600 to account for the fact that emissions from power plants are less damaging than those from motor vehicles in urban areas. The present value of the cumulative reductions due to appliance standards in the study period (using the same method as for direct consumer benefits) amounts to $2.8-5.1 billion for avoided CO_2 emissions and $7-14 billion for avoided NO_x emissions.

[10] The "with standards" value is the total residential sector emissions in 2020 given in EIA's *Annual Energy Outlook 2004*. We derived the "without standards" value by adding our estimate of carbon reduction due to standards to the EIA projection, which nominally includes the impact of standards.

Table 7-1. Reduction in Cumulative U.S. Emissions due to DOE's Appliance Standards

From 1987 through:	CO_2 (MtC)	NO_x (Mt)
2005	126	1.1
2015	396	2.7
2030	928	5.7
2045	1163	7.1

8. Sources of Uncertainty

A measure of uncertainty applies to all of the variables used in this analysis. For example, future shipments may be higher or lower than projected due to changing economic factors. Energy efficiency has certainly increased for these products.

Perhaps the greatest uncertainty concerns the estimation of the baseline scenarios – what would have occurred in the absence of standards. Both technological and economic factors have contributed to energy efficiency trends in the past. The baseline trends in efficiency improvement developed in this study are not claimed to be precise. Considering historical efficiency trends, expected future residential energy prices, and the intensity of price competition in the appliance market, however, we believe them to be reasonable approximations.

Another large source of uncertainty concerns the incremental cost to consumers of higher efficiency products. Real prices of these goods have tended to trend downward over time and the competitive nature of the market continues to exert downward pressure. As mentioned above, we believe that the future incremental price estimates used in this study (and in the TSDs) are more likely to be overstated than understated. So the costs associated with standards may be overestimated.

The present values of economic impacts are sensitive to assumptions about the rate used to discount future costs and benefits and the rate used to compound past savings to the present.

The benefits of standards may be underestimated in this report if future energy prices increase more than expected or if other factors (such as reduced emissions) are in future assigned some economic value. For some specific appliances, the consumer benefit may be greater than estimated here if peak and off-peak period electricity pricing becomes common.

9. Conclusion

The impact of the U.S. Department of Energy's energy efficiency standards for residential appliances that became effective in the 1988-2001 period or will take effect by the end of 2007 is steadily accumulating as the stock of appliances expands. We estimate that these standards will reduce residential primary energy consumption and CO_2 emissions in 2020 by 8% compared to the levels expected without any standards. They will save a cumulative total of 34 quads by 2020, and 54 quads by 2030.

The estimated cumulative net present value of consumer benefit amounts to $93 billion by 2020, and grows to $125 billion by 2030. The overall benefit/cost ratio of consumer impacts in the 1987-2050 period is 2.45 to 1. The cumulative cost of DOE's program to establish and implement the standards is approximately $170 million.

In addition to consumer financial benefits, the standards will reduce emissions of CO_2 and NO_x by considerable amounts.

Although the estimates made in this study are subject to a fair degree of uncertainty, we believe they provide a reasonable approximation of the national benefits resulting from DOE's appliance efficiency standards.

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Appendix 1 Technical Support Documents for DOE Residential Energy Efficiency Standards

1. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets,* 1993. Washington, DC. Report No. DOE/EE-0009.

2. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, and Freezers, including Environmental Assessment and Regulatory Impact Analysis,* July, 1995. Washington, DC. Report No. DOE/EE-0064. <http://www.osti.gov/bridge/product.biblio.jsp?osti_id=90266>

3. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document For Energy Conservation Standards for Room Air Conditioners,* September, 1997. Washington, DC. Docket Numbers EE-RM-90-201 & EE-RM-93-801-RAC.

4. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps,* 1999. Washington, DC. <http://www.eren.doe.gov/buildings/codes_standards/reports/central_air_tsd/index.htm>

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