Better Appliances: An Analysis of Performance, Features, and Price as Efficiency Has Improved

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Contents

Executive Summary

Efficiency standards have played a major role in saving energy and water and reducing utility bills. In this report, we analyze how the choices available to consumers have changed over time as efficiency standards have taken effect for ten residential, commercial, and lighting products. We found that as products have become more efficient:

- Performance generally stayed the same or improved;
- Manufacturers offered new features to consumers; and
- Prices *declined* or stayed the same for five of the nine products for which we could obtain price data, and for the other four products, observed price increases are outweighed by electricity bill savings.

Using the best available data, we compared products available before and after national efficiency standards took effect and evaluated how three product dimensions—performance, features, and price—have changed over time. For most of the ten products, we examined the current standard (which in three cases was also the first national standard established for the product). However, for refrigerators, clothes washers, and dishwashers, we examined multiple standards that have taken effect over the last 20-25 years. For these three products, sufficient historical data were available to examine how they have changed over time as standards have been established and updated.

Where possible, we examined models available at three points in time: when the standard was established; one year after the standard took effect; and today. Table ES-1 below shows the specific performance attributes and product features that we examined for each of the ten products.

Table ES-1. Products, Performance Attributes, and Features Examined

Refrigerators		Clothes Washers	
	• Temperature performance • Door configuration • Volume • Through-the-door ice • Noise • Additional features • Efficiency • Price		• Washing performance • Method of loading • Tub capacity • Cycle time • Automatic temperature control • Additional features • Efficiency • Price
Dishwashers		**Residential Central Air Conditioners and Heat Pumps**	
	• Washing performance • Cycle time • Tub material • Delayed start feature • Additional features • Efficiency • Price		• Cooling capacity • Size and weight • Dehumidification • Additional features • Efficiency • Price
Toilets		**General Service Light Bulbs**	
	• Flush performance • Bowl cleaning • Style • Efficiency • Price		• Light output • Light color • Dimmability • Lifetime • Efficiency • Price
Incandescent Reflector Lamps		**Fluorescent Lamp Ballasts**	
	• Light output • Light color • Dimmability • Lifetime • Efficiency • Price		• Ballast factor • Lifetime • Additional features • Efficiency • Price

Commercial Rooftop Air Conditioners and Heat Pumps

- Cooling capacity
- Size and weight
- Additional features
- Efficiency
- Price

Refrigerated Beverage Vending Machines

- Machine type
- Volume
- Controls
- Customer interaction features
- Efficiency
- Price

PERFORMANCE

We found that product performance generally stayed the same or improved as efficiency standards took effect. Refrigerator temperature performance has improved and noise levels have dropped over time. Manufacturers have maintained good dishwasher performance even as energy and water use have decreased substantially. General service light bulbs and incandescent reflector lamps that meet new efficiency standards provide the same light output, lifetime, color quality, and dimmability as lamps that were available before standards took effect. Electronic ballasts are quieter and lighter than older less efficient magnetic ballasts and do not produce the visible flicker that is characteristic of magnetic ballasts. And there was no significant difference in the range of available cooling capacities of residential and commercial air conditioners and heat pumps before and after standards took effect.

In just two instances (clothes washers and toilets), an increase in poor performance ratings was reported immediately after the implementation of efficiency standards. However, this effect was temporary. Manufacturers responded by eliminating or re-designing poorly-performing models, and the incidence of poorly-performing models declined. More importantly, over the longer term, performance has improved beyond what was available before the standards. Many clothes washers today do a better job of removing stains and are gentler on clothes than older washers, and today's consumers have enormous choice of toilets with excellent flushing performance.

FEATURES

We found that for each of the ten products we evaluated, manufacturers introduced and expanded the availability of new features as efficiency standards took effect. The average volume of available refrigerator models has increased over time; consumers now have a significantly wider range of options in bottom-freezer units including French-door models; and refrigerators offer a range of new features including new types of water dispensers, in-the-door ice makers, and additional compartments. The availability of clothes washers with large tub capacities has increased dramatically, and new features include electronic controls and displays, steam cycles, and automatic dispensers. Features such as stainless steel tubs and delayed start have become more common on dishwashers, even on low-price-point models. Most central air conditioners now have thermal expansion valves, which can improve both comfort and efficiency and increase equipment reliability. And manufacturers have introduced efficient halogen incandescent and LED light bulbs, which were previously unavailable.

PRICE

We found that prices *declined* or stayed the same as efficiency standards took effect for five of the nine products we evaluated for which we could obtain price data.[1] Between 1987 and 2010, real prices of refrigerators, clothes washers, and dishwashers decreased by 35%, 45%, and 30%, respectively. For toilets and fluorescent lamp ballasts, the incremental cost of the more efficient products at the time the standards were established had disappeared either by the time the standard took effect (in the case of fluorescent lamp ballasts) or within two years after the standard took effect (in the case of toilets). For general service light bulbs and incandescent reflector lamps, prices have increased modestly, but the total cost (purchase price plus operating cost) is lower for the lamps meeting the new standards compared to pre-standard lamps. Finally, for residential and commercial air conditioners and heat pumps, observed price increases are likely attributable at least in part to significant increases in metal prices, which are independent of efficiency standards. However, even if the entire price increases were due to the standards, the payback periods (six years and three years for residential and commercial units, respectively) are significantly shorter than the average lifetimes of this equipment (19 years and 15 years, respectively).

In sum, we found that as efficiency standards have taken effect, product performance generally stayed the same or improved, and manufacturers offered new features to consumers. Prices *declined* or stayed the same for five of the nine products we evaluated for which we could obtain price data, and for the other four products, observed price increases are outweighed by electricity bill savings.

[1] We were unable to evaluate how refrigerated beverage vending machine prices have changed due to a lack of data. However, we found that the manufacturer selling price decreased in the decade before the efficiency standard took effect, while energy use decreased significantly.

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Introduction

Appliance, equipment, and lighting efficiency standards have provided large benefits to both consumers, in the form of lower utility bills, and to the nation, in the form of energy and water savings, emissions reductions, avoided power plants, and increased economic activity. Taking into account products sold from the inception of each national standard through 2035, existing standards will net consumers and businesses more than $1.1 trillion in savings (Lowenberger et al. 2012).

In this report, we analyze how the choices available to consumers have changed over time as efficiency standards have taken effect for ten residential, commercial, and lighting products by addressing three questions:

- How has performance changed?
- How have features changed?
- How have prices changed?

By addressing these questions with the best available data, our goal is to provide a better understanding of how the choices available to consumers have changed over time as efficiency standards have taken effect.

The first section of this report presents our findings from our analysis. The second section discusses some possible explanations for our general findings. The third section summarizes the energy savings, economic benefits, and emissions reductions due to existing efficiency standards. The fourth section provides a brief description of our research methodology. This is followed by sections addressing each of the ten products we examined and our overall conclusions.

Findings

In general, we found that as efficiency standards have taken effect, product performance generally stayed the same or improved, and manufacturers offered new features to consumers. Prices *declined* or stayed the same for five of the nine products we evaluated for which we could obtain price data, and for the other four products, observed price increases are outweighed by electricity bill savings.[2]

Below we describe our key findings for each of the ten products and the specific standards we examined.

REFRIGERATORS—1990, 1993, AND 2001 STANDARDS

Since 1987, refrigerator temperature performance has improved and noise levels have dropped over time as three rounds of efficiency standards have taken effect. The average volume of available refrigerator models has increased, especially among bottom-freezer and side-by-side units, and larger volumes are now available. With the introduction of French-door models, consumers have a significantly wider range of options in bottom-freezer units. And manufacturers have introduced new features including new types of water dispensers, in-the-door ice makers, and additional

[2] We were unable to evaluate how refrigerated beverage vending machine prices have changed due to a lack of data. However, we found that manufacturer selling price decreased in the decade before the efficiency standard took effect, while energy use decreased significantly.

compartments. Between 1987 and 2010, real prices of refrigerators decreased by about 35% while average energy use decreased by more than 50%.

Clothes Washers—1994, 2004, 2007, and 2011 Standards

In 2007, when the current energy efficiency standards took effect for clothes washers, some manufacturers initially had difficulty meeting the standard with some models while maintaining good performance. However, product performance improved very rapidly, and many clothes washers today do a better job of removing stains and are gentler on clothes than older washers. Clothes washer cycle times have largely remained unchanged. In recent years, the availability of clothes washers with large tub capacities has increased dramatically, and consumers have had a significantly wider range of options in front-loaders, which generally provide better washing performance and are gentler on clothes than top-loaders. And manufacturers have introduced new features including electronic controls and displays, steam cycles, and automatic dispensers. Between 1987 and 2010, real prices of clothes washers decreased by about 45% while average energy use decreased by 75%.

Dishwashers—1994 and 2010 Standards

Dishwashers have continued to provide good washing performance using significantly less energy and water, although average cycle times have increased. Over time, features such as stainless steel tubs and delayed start have become more common, even on low-price-point models. And manufacturers have introduced new features including a new type of filter that reduces noise, and bulk dispensers that store and automatically dispense the right amount of detergent. Between 1987 and 2010, real prices of dishwashers decreased by about 30% while average energy use decreased by 50%.

Residential Central Air Conditioners and Heat Pumps—2006 Standard

Since 2001, when the current standards for residential central air conditioners and heat pumps were established, the distribution of available cooling capacities and the dehumidification capability of this equipment have remained unchanged, while the size of units, and in some cases the weight, have increased somewhat. By employing new lightweight heat exchangers in some models, manufacturers have been able to minimize weight increases. Most central air conditioners now have thermal expansion valves, which can improve both comfort and efficiency and increase equipment reliability. While equipment prices increased by about 18% between 2001, when the standard was established, and 2007, one year after the standard took effect, at least a portion of this increase is likely due to the large increase in metal prices (about 300%). Even if the entire price increase were due to the standard, the six-year payback period is significantly shorter than the 19-year average lifetime of this equipment.

Toilets—1994/1997 Standard

Toilets were available with a range of performance, from poor to very good, before and just after the 1994 standards took effect. In the period immediately after the 1994 standards took effect, an increase in poor performance ratings was reported. However, this effect was temporary. Manufacturers responded by eliminating or re-designing poorly-performing models, and the incidence of poorly-performing models declined. The market still offers a range of performance, but today's consumers have enormous choice of toilets with excellent flushing performance. Consumers appear to have the same or greater range of style choices today as compared to just before or after the standards took effect. Even low-profile designs remain in the market and perform well. The incremental cost of the more-efficient toilets at the time the standards were established had disappeared within two years after the standards took effect.

General Service Light Bulbs— 2012-2014 Standard

Efficient halogen incandescent light bulbs provide the same light output, 1,000 hour lifetime, color quality, and dimmability as traditional incandescent lamps, while using approximately 28% less energy. Since the implementation of the standards in California affecting 100W and 75W traditional incandescent lamps, manufacturers have introduced 100W and 75W equivalent LEDs, which were previously unavailable. Over 1,000 hours of operation, efficient halogen incandescent lamps will save consumers $2 and $1.50 in total cost, respectively, for a 100W or 75W equivalent bulb compared to a traditional incandescent lamp. While CFLs and LEDs have higher purchase prices, over 20,000 hours of operation, 100W equivalent CFLs or LEDs will save a consumer about $185 and $140 in total cost, respectively, compared to shorter-lived 100W traditional incandescent lamps.

Incandescent Reflector Lamps—2012 Standard

Incandescent reflector lamps meeting the 2012 standards provide the same light output, lifetimes, color quality, and dimmability as pre-standard lamps, while using approximately 20-25% less energy. LEDs, which are very conducive to directional lighting, are the fastest-growing category of directional lamps, and more than 300 models of LED reflector lamps have been introduced since the 2012 standards took effect. While prices of incandescent reflector lamps have increased since the implementation of the 2012 standard, the total cost (purchase price plus operating cost) is lower for lamps meeting the new standards compared to pre-standard lamps.

Fluorescent Lamp Ballasts—2005/2010 Standard

Electronic ballasts meeting the 2005/2010 standards are quieter and lighter than older, less efficient magnetic ballasts and do not produce the visible flicker that is characteristic of magnetic ballasts. Since the standards took effect, manufacturers have provided a greater range of available ballast factors (permitting better optimization of lighting levels); more ballasts that are parallel-wired (which allows remaining lamps to continue to operate even when one lamp fails); and longer warranties. The incremental cost of electronic ballasts at the time the standards were established had disappeared by the time the initial phase of the standards took effect.

Commercial Rooftop Air Conditioners and Heat Pumps—2010 Standard

Since 2005, when the current standards for commercial rooftop air conditioners and heat pumps were established, the distribution of available cooling capacities has remained unchanged. New units are typically somewhat larger and heavier than models available in 2005, although these increases are usually not a significant issue for this equipment since units are generally located on the roof of a building. Manufacturers have introduced units that have very good part-load performance, and new units often include improved economizers, which can provide large energy savings. Multiple supply fans and hot gas reheat have become more common, which can both reduce energy use and improve dehumidification. While equipment prices have increased by about 10% since the standard was established, at least a portion of this increase is likely due to the large (more than 50%) increase in metal prices. Even if the entire price increase were due to the standard, the three-year payback period is significantly shorter than the 15-year average lifetime of this equipment.

REFRIGERATED BEVERAGE VENDING MACHINES—2012 STANDARD

Since 2009, when the current standards for refrigerated beverage vending machines were established, manufacturers have continued to provide units with a wide range of volumes including very large machines. The market has continued to shift from closed-front to glass-front machines, which can hold more types of beverage products and more easily display products to consumers. In recent years, there has been greater availability of controls that save energy as well as new customer interaction features such as interactive touch screens. While data were unavailable to compare prices of beverage vending machines available before and after the 2012 standards took effect, manufacturer selling price decreased by about 12% between 2002 and 2011, while energy use decreased significantly.

Discussion

Efficiency standards' capacity to deliver large energy and water savings at the same time as product performance stays the same or improves, new features are introduced, and, in many cases, product prices decline results from specific aspects of how standards are established in the United States and competitive markets. We describe some of the factors below that help explain our findings regarding performance, features, and price.

PERFORMANCE

There are several features of efficiency standards in the United States that help to explain our finding that product performance generally stayed the same or improved as efficiency standards took effect. By law, the Department of Energy (DOE) must take into account any product utility or performance impacts in establishing new standard levels. The federal standards law prohibits DOE from adopting standards that would result in the unavailability of performance characteristics or features generally available during a new standard's development.[3] Other efficiency standards have been established by Congress rather than by DOE rulemaking. Standards established by both Congress and DOE are generally developed in close consultation with affected stakeholders and often reflect a consensus. Active stakeholders in both the regulatory and legislative processes, including efficiency proponents and industry stakeholders, share an interest in ensuring that standards do not impair product performance. Efficiency proponents, including consumer advocates, want efficiency improvements that result in products delivering the same or improved service, while using less energy or water. Reduced performance levels not only could harm consumers, but could also potentially result in a backlash against other efficiency improvements. Similarly, industry stakeholders want to ensure that they can continue to offer products that will satisfy their customers. Thus, the regulatory and legislative processes and the interests of the most active stakeholders work together to ensure that product performance is maintained as new efficiency standards take effect.

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[3] See 42 U.S.C. 6295(o).

FEATURES

Our finding that manufacturers introduced and expanded the availability of new features as efficiency standards took effect can be explained by a number of factors. First, the structure of efficiency standards can actually encourage innovation. Efficiency standards are generally performance-based standards, which do not prescribe any specific technology options or design improvements that must be employed to meet the standard. Instead, performance-based standards specify either a minimum efficiency level or a maximum energy (or water) use level. Each manufacturer then determines the lowest-cost way to meet the standard, and different manufacturers may choose different options for meeting the standard. In particular, performance standards can promote innovation in energy-saving technologies (Sachs 2012). Second, efficiency standards are structured so as not to diminish consumer utility. For example, refrigerator efficiency standards are a function of volume such that larger products can use more energy than smaller products; they vary depending on refrigerator configuration (top-freezer, bottom-freezer, or side-by-side); and they allow refrigerators with through-the-door ice service to consume more energy than units without this feature. Third, new energy- or water-consuming features are often not counted in a product's measured energy or water consumption until the efficiency standards are updated to reflect the new features. Fourth, standards are usually set at a level below the maximum achievable, so even if a new feature increases measured energy or water use, the product can still meet a given standard if a manufacturer can make counterbalancing improvements. Finally, when manufacturers redesign products to meet new efficiency standards, they also have an opportunity to incorporate a range of new features unrelated to efficiency and to update product lines, perhaps driving new features and improvements to market sooner than would have been the case absent efficiency standards.

PRICE

Our findings regarding price, and in particular our findings of declining prices over time for some products (including refrigerators, clothes washers, and dishwashers), can be explained at least in part by what is referred to as the "learning" or "experience" curve. Significant work has examined how prices of goods tend to fall in a relatively predictable way as cumulative production increases. For example, for every doubling of cumulative production, prices of refrigerators and central air conditioners have declined by 41% and 18%, respectively (Desroches et al. 2012). Since high-efficiency products tend to incorporate newer technologies than baseline products, it is likely that high-efficiency products that are introduced to meet new efficiency standards will experience even faster declines in cost than what overall historical data would suggest (Desroches et al. 2012). In addition, when manufacturers implement product redesigns to meet new efficiency standards, they also look for opportunities to make the manufacturing process more efficient, which can reduce costs. Two engineers for major appliance manufacturers have noted that "[manufacturers] typically combine improvements in energy efficiency with cost reductions, quality improvements, and new features" (McInerney and Anderson 1997).

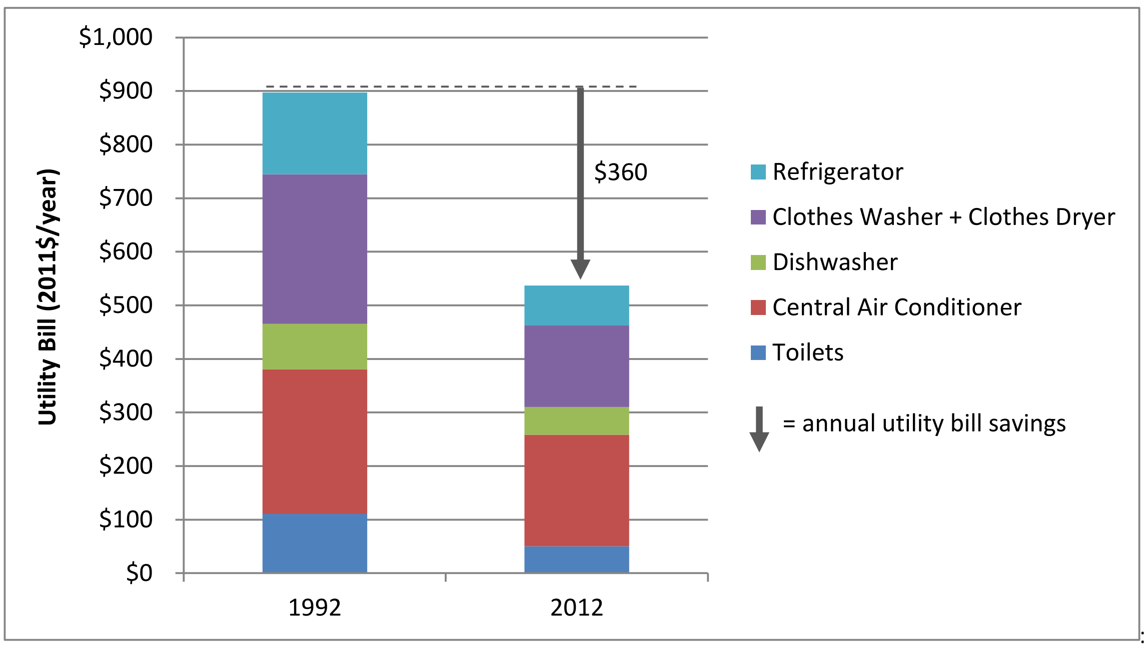
Energy Savings, Economic Benefits, and Emissions Reductions from Existing Efficiency Standards

Existing efficiency standards have yielded large energy savings, economic benefits, and carbon dioxide (CO_2) emissions reductions. In our 2012 report, *The Efficiency Boom: Cashing in on the Savings from*

Appliance Standards, we found that taking into account products sold from the inception of each national standard through 2035, existing standards will net consumers and businesses more than $1.1 trillion in net present value savings. By 2035, cumulative energy savings will reach 200 quads, an amount equal to about two years of total U.S. energy consumption. Net economic savings (taking into account the incremental cost of more efficient products) for consumers and businesses were about $27 billion in 2010 and will increase to more than $60 billion in 2025 (Lowenberger et al. 2012).

Considering six household products evaluated for this report (refrigerator, clothes washer & clothes dryer, dishwasher, central air conditioner, and toilets), a household with products that just meet the current efficiency standards will save $360 on annual utility bills compared to a household with the same products purchased in 1992, or about 40% of the 1992 products' operating cost.[4]

Figure 1. Annual Utility Bill to Operate Six Household Products that Just Meet the Current Efficiency Standards Compared to the Same Products Purchased in 1992



Sources: AHAM (2011) for average clothes washer and dishwasher efficiency in 1992 and average clothes washer volume; DOE (2001a) for central air conditioner energy use; EIA (2012) for electricity price; DOE (2012c) for water and wastewater price.

Notes: Refrigerator bills are based on a weighted average of an 18.1 cu. ft. top-freezer, a 21.9 cu. ft. bottom-freezer, and a 25.1 side-by-side unit; clothes washer bills assume an electric water heater and 295 cycles/ year; dishwasher bills assume an electric water heater and 215 cycles/ year; toilet bills assume 2.6 persons/ household and 4.5 flushes/person/ day.

Existing efficiency standards reduced total U.S. electricity consumption by about 7% in 2011. By 2025, electricity consumption will be about 14% lower than it would be in the absence of existing standards. Reductions in electricity and natural gas consumption in turn reduce CO_2 emissions. Existing standards reduced CO_2 emissions by about 200 million metric tons in 2010, an amount equal to the CO_2 emitted by 51 average coal-fired power plants. By 2035, CO_2 reductions from existing standards

[4] Other appliances that contribute to a household's utility bills that are not included here include space heating equipment (e.g., furnaces), water heaters, light bulbs, and consumer electronics (e.g., TVs).

will reach about 470 million metric tons, equivalent to the CO_2 emissions of 118 average coal-fired power plants (Lowenberger et al. 2012).

In addition to achieving energy and economic savings and reducing CO_2 emissions, efficiency standards have also contributed to increased levels of employment. When consumers and businesses save money on their utility bills as a result of efficiency standards, they have more money to spend and save, resulting in increased economic activity. An ACEEE and ASAP study found that existing standards increased U.S. employment by 340,000 jobs in 2010 (Gold et al. 2011).

Research Methodology

We analyzed how the choices available to consumers have changed over time as national efficiency standards have taken effect for the following ten products, which include residential, commercial, and lighting products. We selected these products because efficiency standards for each of these products have achieved significant energy and/or water savings, and a recent standard has taken effect for most of these products.

- Refrigerators
- Clothes washers
- Dishwashers
- Residential central air conditioners and heat pumps
- Toilets
- General service light bulbs
- Incandescent reflector lamps
- Fluorescent lamp ballasts
- Commercial rooftop air conditioners and heat pumps
- Refrigerated beverage vending machines

For most of the ten products, we examined the current standard (which in three cases was also the first national standard established for the product). However, for refrigerators, clothes washers, and dishwashers, we examined multiple standards that have taken effect over the last 20-25 years. For these three products, sufficient historical data were available to examine how they have changed over time as standards have been established and updated.

For each product, we compared models available before and after the standard(s) took effect. Where possible, we examined models available at three points in time: when the standard was established; one year after the standard took effect; and today. We examined product performance, features, and price. In addition, we also examined major market innovations and their relationship to standards.

To examine product performance and features, we utilized several data sources including historical product databases, *Consumer Reports* ratings, DOE rulemaking documents, and retailer websites. In addition, for each product, we conducted interviews with manufacturers and other industry experts to gain additional insight into product changes and the relationship of any changes to efficiency standards.

To examine price trends, we primarily relied on data from the U.S. Census Current Industrial Reports. The Current Industrial Reports data includes the quantity of shipments and the value of shipments for each year for which data were collected from manufacturers. Dividing the value of shipments by the quantity of shipments yields what is essentially the average manufacturer selling price. To estimate the average retail price, we multiplied the average manufacturer selling price by a product-specific markup that includes any distributor, retailer, and contractor markups and sales tax. We adjusted the retail prices for inflation using the Consumer Price Index (CPI).

Refrigerators

HISTORY AND SCOPE OF REFRIGERATOR STANDARDS

Source: iStockphoto

In 1976, California established the first efficiency standards for refrigerators. The first tier of these state standards took effect in 1977, and a second tier took effect two years later. California subsequently amended the standards for refrigerators, and new standards took effect in 1987. Around the same time, energy efficiency proponents and manufacturers negotiated the first national efficiency standards for refrigerators, which Congress enacted as part of the National Appliance Energy Conservation Act (NAECA) of 1987, signed by President Reagan. NAECA also directed DOE to conduct two cycles of rulemakings to determine whether the initial standards should be amended. DOE completed the first rulemaking cycle in 1989, amending the initial NAECA standards. DOE completed the second rulemaking in 1997, establishing new standards that took effect in 2001. DOE based the revised standards on a joint recommendation submitted by manufacturers, electric utilities, and energy efficiency proponents. Efficiency standards for refrigerators apply to both compact (<7.75 cu. ft.) and standard-size refrigerators, refrigerator-freezers, and freezers. We focus here on standard-size refrigerator-freezers, which represent the largest market segment.

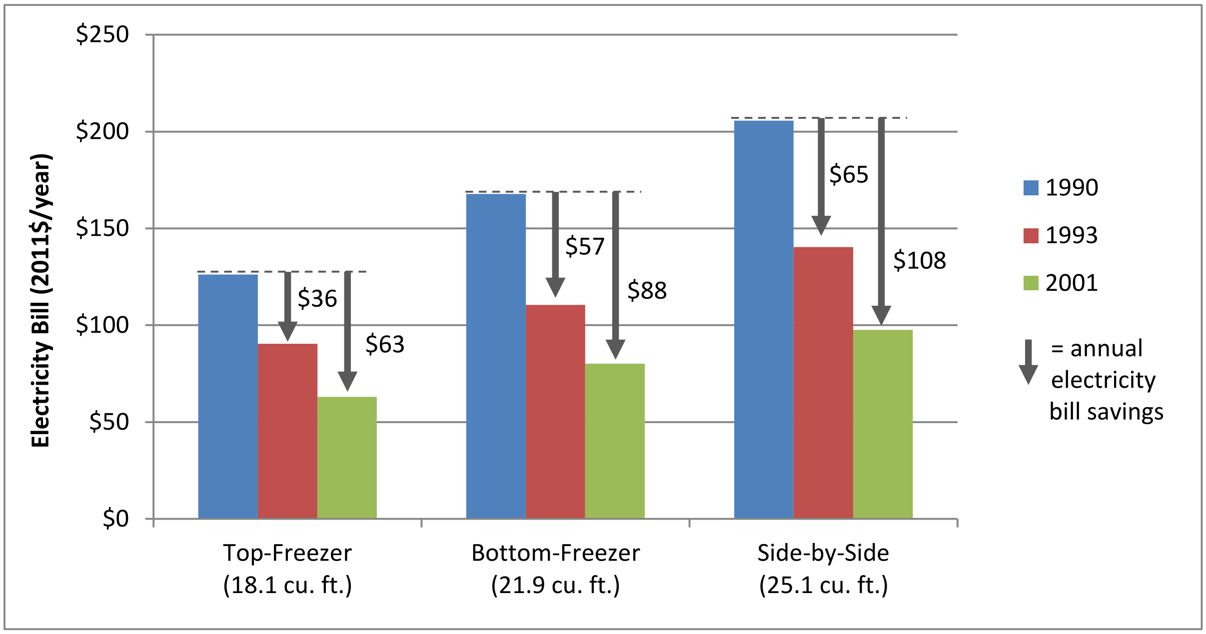
1990, 1993, AND 2001 STANDARDS

The 1987 NAECA standards for refrigerators took effect in 1990. The NAECA standards specified maximum energy consumption levels as a function of adjusted volume[5] such that larger refrigerators could use more energy than smaller units. In addition, the NAECA standards varied based on specific product characteristics and features including door configuration (top-freezer, bottom-freezer, or side-by-side), type of defrost (automatic, partial automatic, or manual), and presence of through-the-door ice. The 1989 DOE final rule, which amended the NAECA standards, took effect in 1993 and required about a 30% reduction in energy use for the major product classes relative to the 1990 standards. The subsequent 1997 DOE final rule, which took effect in 2001, required roughly another 30% reduction in energy use relative to the 1993 standards.

[5] Adjusted volume (fresh-food volume + 1.63*freezer volume) accounts for the greater energy use of a product with a larger freezer compartment compared to a product with the same total volume but a smaller freezer compartment.

Figure 2 shows an average household's annual electricity bill to operate a typical top-freezer, bottom-freezer, or side-by-side unit just meeting the standards in 1990, 1993, and 2001 based on today's electricity prices. A household with a typical top-freezer, bottom-freezer, or side-by-side unit that just meets the current standards will save $63, $88, and $108 on their annual electricity bill, respectively, compared to a household with a refrigerator just meeting the 1990 standards.

Figure 2. Annual Electricity Bill to Operate a Typical Top-Freezer, Bottom-Freezer, and Side-by-Side Unit Just Meeting the 1990, 1993, and 2001 Standards



Source: EIA (2012) for electricity price.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features from 1987-2012 as three rounds of efficiency standards for refrigerators took effect:

- Temperature performance
- Door configuration
- Volume
- Through-the-door ice
- Noise
- Additional features
- Efficiency
- Price

We examined models available in 1987 and 1991 to characterize the market before and after the 1990 standard; models available in 1994 to characterize the market after the 1993 standard; models available in 1998 and 2002 to characterize the market before and after the 2001 standard; and models available in 2012 to characterize the current market.[6]

Temperature Performance

Consumer Reports refers to temperature performance as the ability of a refrigerator to maintain desired temperatures in both the fresh-food and freezer compartments; maintain even temperatures throughout each compartment; and maintain compartment temperatures with changes in room temperature and with high room temperatures (*Consumer Reports* 2013). Several of the industry experts we interviewed noted that refrigerator temperature performance has improved over time, in large part due to the adoption of electronic controls, which is now a common feature. One industry expert noted that actual temperatures on older models with mechanical controls were sometimes far off from design temperatures. Temperature sensors used with electronic controls are more accurate than sensors used with mechanical controls, and electronic controls allow for multiple temperature sensors, enabling independent temperature measurements in different compartments. In addition, electronic controls allow refrigerators to better respond to changes in room temperature.

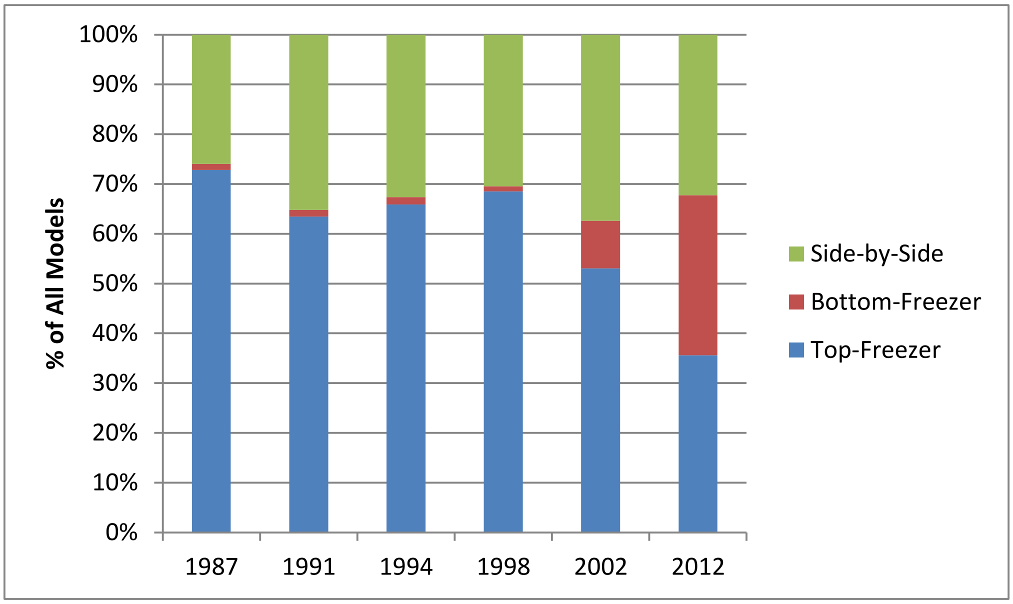
The industry experts we interviewed indicated that manufacturers' adoption of electronic controls has been driven by their ability to provide new features and better performance. Electronic controls allow manufacturers to provide a range of additional features such as measured fill on water dispensers, the ability to measure how much water has gone through the water filter, and door ajar alarms, in addition to better temperature control.

Door Configuration

Figure 3 shows the distribution of refrigerator models by door configuration (top-freezer, bottom-freezer, or side-by-side) from 1987-2012. In 1987, when Congress established the first national refrigerator efficiency standards, the majority of refrigerators available for sale—73%—were basic top-freezer units, while most of the remaining models were side-by-side units. Only 1% of the available models in 1987 were bottom-freezers, and over the next 10 years, the portion of bottom-freezer units remained at less than 2%. However, by 2002, after three rounds of refrigerator efficiency standards had taken effect, bottom-freezers represented 10% of all refrigerator models. In 2012, bottom-freezers represented nearly one-third of all available models.

[6] Data were unavailable to characterize refrigerator models available in 1989, the year the 1993 standards were established.

Figure 3. Distribution of Refrigerator Models by Door Configuration from 1987-2012



Sources: Authors' analysis of AHAM historical refrigerator database for 1987-2002 data; FTC Appliance Energy Data for 2012 data.

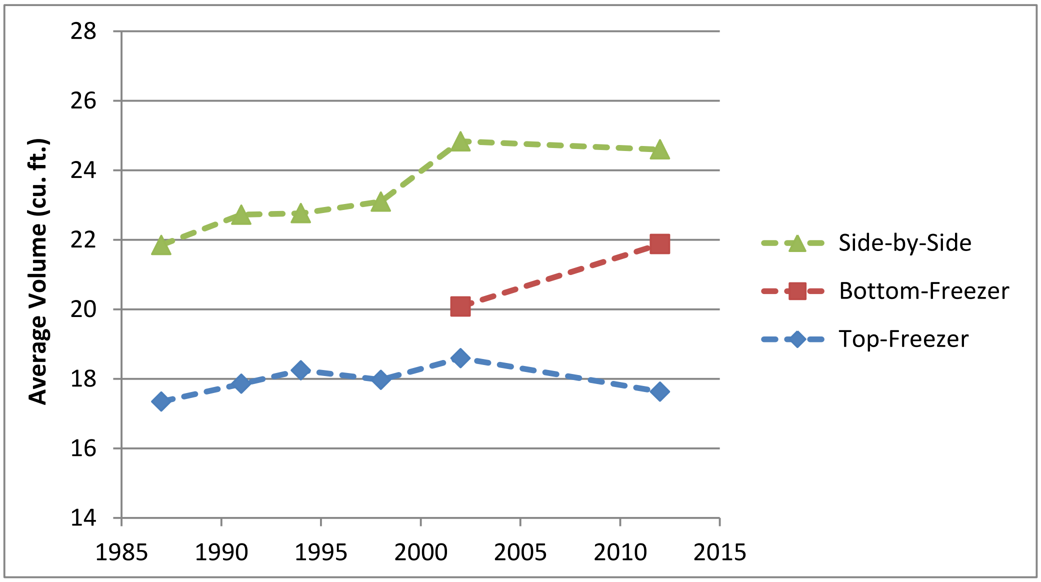
The industry experts we interviewed indicated that the recent growth in the bottom-freezer market has been driven by consumer preferences. One industry expert noted that prior to the late 1990s, bottom-freezer units typically had two doors (one for the fresh-food compartment and one for the freezer compartment); did not incorporate through-the-door ice; and often had smaller volumes than side-by-side units. Subsequently, manufacturers introduced larger models and French-door bottom-freezer units (where the fresh-food compartment has two doors) with through-the-door ice. These French-door units provide the through-the-door ice feature that consumers like, while also providing better accessibility to the fresh-food compartment than side-by-side units.

Volume

Figure 4 shows the average volume of available models of top-freezer, bottom-freezer, and side-by-side units from 1987-2012.[7] Compared with models available in 1987, the average volume of top-freezers in 2012 was almost identical, while the average volume of side-by-side models in 2012 was almost three cubic feet larger than average side-by-side units in 1987. Between 2002 and 2012, the average volume of available bottom-freezer models increased by about two cubic feet.

[7] We exclude data for bottom-freezers from 1987-1998 because during this period, bottom-freezers made up less than 2% of the market.

Figure 4. Average Volume of Refrigerator Models from 1987-2012

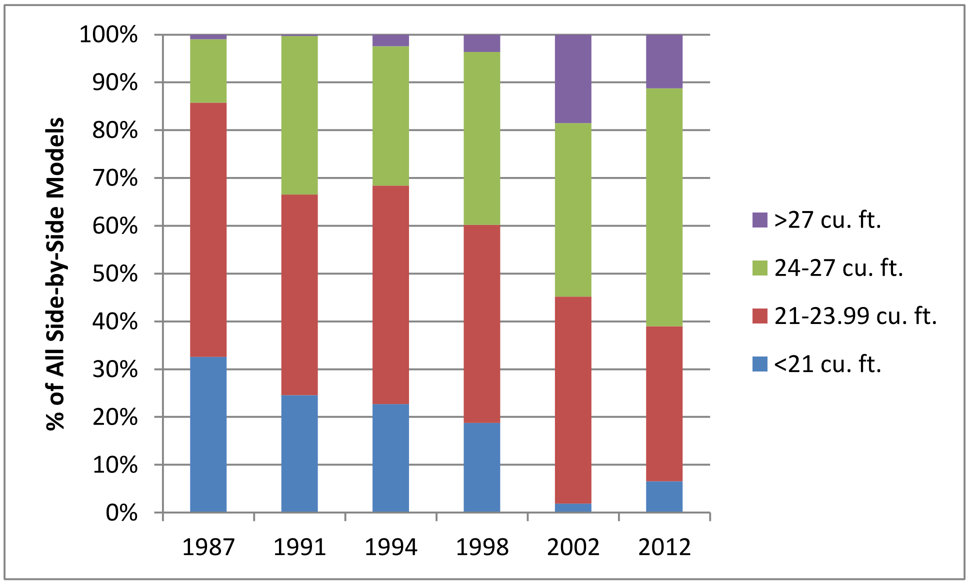


Sources: Authors' analysis of AHAM historical refrigerator database for 1987-2002 data; FTC Appliance Energy Data for 2012 data.

We further examined changes in refrigerator volume over time for side-by-side units, which have held a significant market share since 1987. Figure 5 shows the distribution of side-by-side models by volume from 1987-2012. In 1987, less than 15% of side-by-side models were 24 cubic feet or larger, and only 1% were larger than 27 cubic feet. By 1994, after two rounds of refrigerator efficiency standards had taken effect, more than 30% of side-by-side units were 24 cubic feet or larger. Between 1998, just after the current refrigerator standard was established, and 2002, just after the current standard took effect, the portion of side-by-side models 24 cubic feet or larger increased from 40% to 55%, and the portion of models larger than 27 cubic feet increased from 4% to 19%.

One industry expert we interviewed noted that the relatively constant average volume of top-freezer models over time can be explained in part by the fact that top-freezers are often low-end units that are put into housing units such as apartments, where the purchaser is not the user of the product. In contrast, bottom-freezers and side-by side units are typically purchased by homeowners, who may be looking for larger, higher-end refrigerators. The industry experts we interviewed indicated that the increase in the average volume of bottom-freezer and side-by-side units over time has been driven mostly by consumer preferences. However, several industry experts noted that efficiency standards and ENERGY STAR may have played a small role in the trend toward larger volumes by encouraging the use of better insulation, such as vacuum insulation panels, which can allow manufacturers to increase the interior volume of a refrigerator without increasing the exterior volume.

Figure 5. Distribution of Side-by-Side Models by Volume from 1987-2012



Sources: Authors' analysis of AHAM historical refrigerator database for 1987-2002 data; FTC Appliance Energy Data for 2012 data.

Through-the-Door Ice

Table 1 below shows the portion of bottom-freezer and side-by-side models that incorporated a through-the-door ice dispenser in 1998, 2002, and 2012. (Top-freezers historically have not incorporated through-the-door ice.) Before and after the 2001 standard took effect, there was little change in the portion of bottom-freezer and side-by-side models that offered through-the-door ice. During that time, the majority of side-by-side models (75-81%) included through-the-door ice, while no bottom-freezer models contained this feature. For side-by-side units, there was also little change between 2002 and 2012, with 86% of side-by-side models continuing to include through-the-door ice in 2012. However, a significant change occurred with bottom-freezer units, as more than one-third of bottom-freezer models incorporated through-the-door ice in 2012.

Table 1. Portion of Bottom-Freezer and Side-by-Side Models with Through-the-Door Ice

	1998	2002	2012
Bottom-Freezer	0%	0%	35%
Side-by-Side	75%	81%	86%

Sources: Authors' analysis of AHAM historical refrigerator database for 1998 and 2002 data; FTC Appliance Energy Data for 2012 data.

The increase in bottom-freezer models with through-the-door ice is directly related to the introduction and recent popularity of French-door units. One industry expert also noted that through-the-door ice has grown in popularity with the use of water filters, as through-the-door ice and water dispensers with a filter provide consumers with a similar amenity to bottled water.

Noise

We examined *Consumer Reports*' ratings of refrigerators from 1987-2012 to evaluate how noise has changed over time. Table 2 shows the portion of top-freezers and side-by-side units rated by

Consumer Reports as "good" or better on noise in each year. (We exclude bottom-freezers since there were very few bottom-freezers rated before 2002.) The portion of top-freezers and side-by-side units rated as "good" or better on noise increased between the late 1980s and 1997, with roughly 90-100% of models rated as "good" or better since 1997.

Table 2. Portion of Refrigerators Rated by *Consumer Reports* as "Good" or Better on Noise

	1987	1989	1991	1994	1997	2002	2012
Top-Freezer	--	75%	--	73%	100%	100%	89%
Side-by-Side	54%	--	80%	67%	100%	100%	100%

Sources: Authors' analysis of ratings in *Consumer Reports* (1987, 1989, 1991a, 1994, 1997, 2002, 2012e).

The industry experts we interviewed confirmed that refrigerators have become quieter over time. Manufacturers have developed ways to reduce noise levels as they have realized that noise is an important feature to consumers. These industry experts noted that efficiency standards and ENERGY STAR have played a small role in improving noise levels by encouraging the use of variable-speed compressors, which are both more efficient and quieter than single-speed compressors, although these compressors still make up a very small portion of the market.

Additional Features

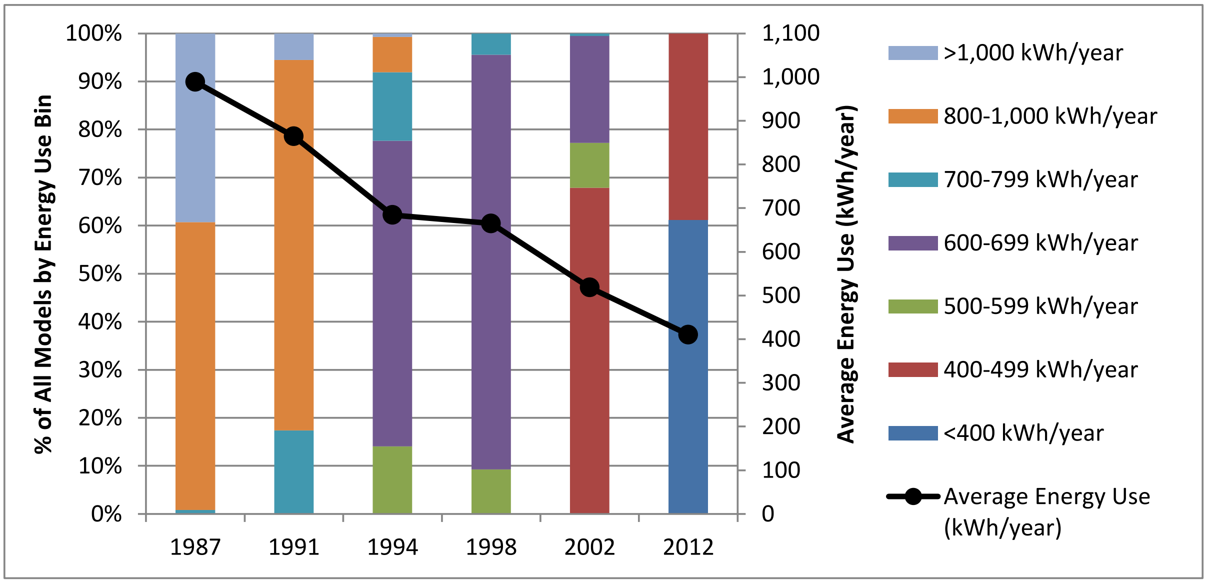
Since 1987, when Congress established the first national refrigerator efficiency standards, manufacturers have added a range of features to their products, and some features that used to be available only on high-end refrigerators have become common even on low-price-point models. New features include dual evaporators, improved water dispensers, in-the-door ice makers, and additional compartments (*Consumer Reports* 2012j). Dual evaporators can help to maintain optimal humidity levels in the fresh-food compartment and prevent the migration of odors between the fresh-food and freezer compartments. Some new refrigerator models offer extra-tall water dispensers, or water dispensers with an auto-stop feature, which automatically fills any container to the top. A new type of ice maker, referred to as "in-the-door," fits within the door panel, which increases storage space in the refrigerator compared to older ice maker designs. Finally, some French-door models now have four doors rather than three and contain either an extra middle drawer, which typically has a different temperature setting, or two separate freezer drawers. In 2012, *Consumer Reports* reported that "high-end features, such as temperature-controlled drawers, adjustable shelves, split shelves, and internal water dispensers, are increasingly available on even the most affordable refrigerators" (*Consumer Reports* 2012f).

Efficiency Levels

Figure 6 shows the distribution of top-freezer models with volumes of 16-20 cubic feet (covering the most common sizes in this product class) by annual energy use from 1987-2012, along with the average energy use of top-freezer models of the same volume. In 1987, about 60% of 16-20 cubic feet top-freezers consumed between 800 and 1,000 kWh/year, while 40% of models consumed more than 1,000 kWh/year. By 1994, after two rounds of national efficiency standards had taken effect, less than

10% of top-freezers consumed 800 kWh/year or more, and about 15% of units consumed less than 600 kWh/year. In 2002, the year after the 2001 standards took effect, about two-thirds of units consumed less than 500 kWh/year, and by 2012, more than half of units consumed less than 400 kWh/year. From 1987-2012, the average energy use of 16-20 cubic feet top-freezer models dropped by almost 60%, from almost 1,000 kWh/year in 1987 to just over 400 kWh/year in 2012.

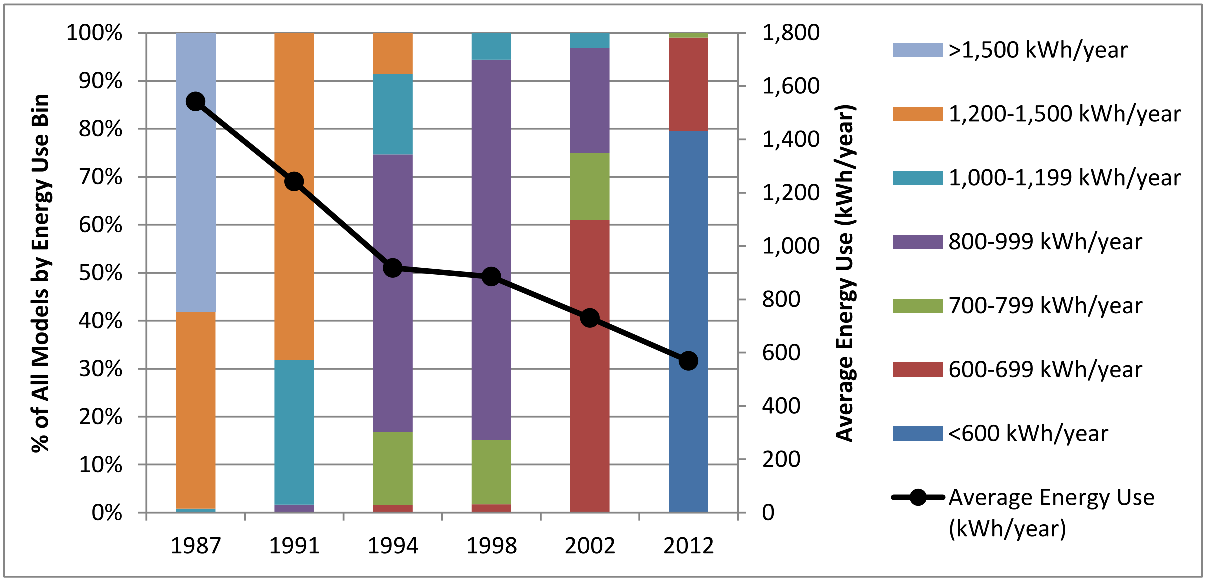
Figure 6. Distribution of Top-Freezer Models with Volumes of 16-20 Cubic Feet by Annual Energy Use from 1987-2012



Sources: Authors' analysis of AHAM historical refrigerator database for 1987-2002 data; FTC Appliance Energy Data for 2012 data.

Figure 7 shows a similar plot for side-by-side models with volumes of 21-25 cubic feet (covering the most common sizes in this product class). In 1987, almost 60% of 21-25 cubic feet side-by-side models consumed more than 1,500 kWh/year, while most of the remaining models consumed between 1,200 and 1,500 kWh/year. By 1994, after two rounds of national efficiency standards had taken effect, less than 10% of side-by-side models consumed 1,200 kWh/year or more, and about 17% of units consumed less than 800 kWh/year. In 2002, the year after the 2001 standards took effect, more than 60% of units consumed less than 700 kWh/year, and by 2012, 80% of units consumed less than 600 kWh/year. From 1987-2012, the average energy use of 21-25 cubic feet side-by-side models dropped by more than 60%, from about 1,500 kWh/year in 1987 to about 570 kWh/year in 2012.

Figure 7. Distribution of Side-by-Side Models with Volumes of 21-25 Cubic Feet by Annual Energy Use from 1987-2012



Sources: Authors' analysis of AHAM historical refrigerator database for 1987-2002 data; FTC Appliance Energy Data for 2012 data.

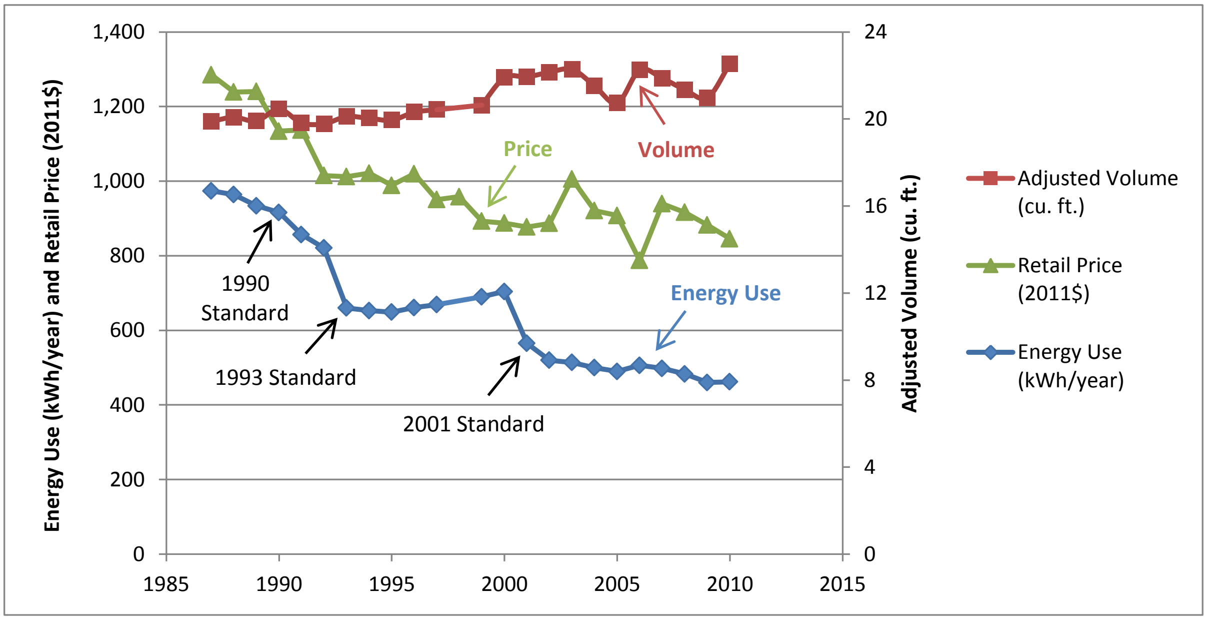
Efficiency standards have played a major role in the huge reductions in refrigerator energy use since 1987. As multiple rounds of efficiency standards for refrigerators took effect, manufacturers continued to offer models that not only met new standards but exceeded the minimum requirements. ENERGY STAR and utility programs have likely played a significant role in continually encouraging the production of refrigerators that exceed the minimum requirements. The industry experts we interviewed also noted that efficiency is a way for manufacturers to differentiate products, and competition encourages manufacturers to produce units that exceed the minimum requirements, even as efficiency standards are updated.

Price

Figure 8 shows the average retail price for refrigerators from 1987 to 2010 (in 2011$) along with average energy use and adjusted volume (refrigerator volume + 1.63 times the freezer volume) over the same period.[8] In 1987, when the first national refrigerator efficiency standards were established, the average retail price of a refrigerator was about $1,300. Between 1987 and 2010, refrigerator prices exhibited a fairly steady downward trend. In 2010, the average price was about $850, or approximately 35% lower than the price in 1987. This decrease in refrigerator prices over time occurred while average energy use decreased by more than 50% and average adjusted volume increased by 13%.

[8] We adjusted retail prices for inflation using the Consumer Price Index.

Figure 8. Refrigerator Energy Use, Volume, and Retail Price from 1987-2010

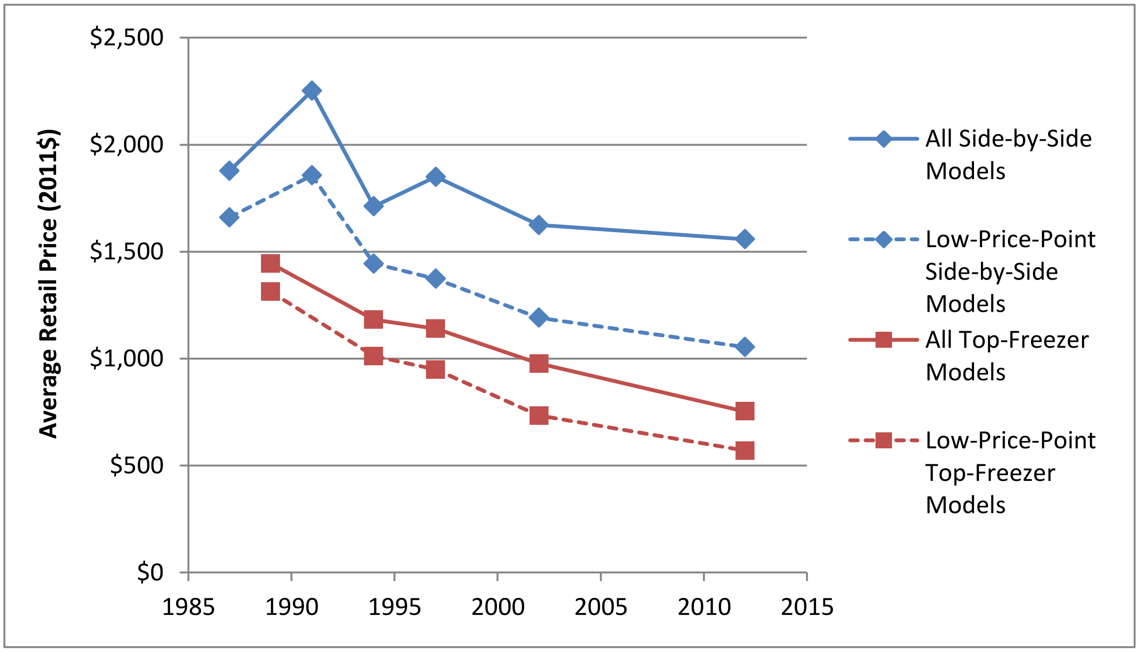


Sources: AHAM (2011) for energy use and volume; authors' analysis of U.S. Census Bureau Current Industrial Reports data for price; DOE (2011d) for markup.

One industry expert we interviewed noted that when manufacturers redesign products to meet new efficiency standards, they also look for opportunities to make the manufacturing process more efficient, which can reduce costs.

We also examined the prices of top-freezers and side-by-side units rated by *Consumer Reports* over time. We examined the average price of all models rated as well as the average price of low-price-point models, which we define as the least-expensive one-third of models rated. Figure 9 shows the average price of all top-freezers and low-price-point top-freezers, and the average price of all side-by-side units and low-price-point side-by-side units rated by *Consumer Reports* from 1987-2012 (in 2011$). In 1989, the average price of all top-freezers rated by *Consumer Reports* was about $1,450, while the average price of low-price-point top-freezers was about $1,300. By 2012, the average price of all top-freezers rated by *Consumer Reports* had dropped by almost half to about $750, while the average price of low-price-point top-freezers had dropped by more than half to about $570. In 1987, the average price of all side-by-side units was just under $1,900, while the average price of low-price-point side-by-side units was about $1,650. By 2012, the average price of all side-by-side units rated by *Consumer Reports* had dropped by about 17% to about $1,550, while the average price of low-price-point side-by-side units had dropped by more than one-third to about $1,050.These data show that refrigerators, especially base-model units, have become substantially more affordable over the past 25 years.

Figure 9. Average Price of Top-Freezers and Side-by-Side Units Rated by *Consumer Reports* from 1987-2012



Sources: Authors' analysis of ratings in *Consumer Reports* (1987, 1989, 1991a, 1994, 1997, 2002, 2012e).

The *Consumer Reports* price data suggest that average prices of both top-freezers and side-by-side units have declined significantly over time, although the decrease was greater for top-freezers. In addition, the divergence between the average price of all units and the average price of low-price-point units over time has been greater for side-by-side models than for top-freezers. Since top-freezers are not considered a high-end product, it is not surprising that there is a relatively small difference between the average price of top-freezers and the average price of low-price-point top-freezers. In contrast, over time, manufacturers have continued to innovate and develop new features for higher-end products including higher-end side-by-side units. The introduction of these feature-laden products helps explain the greater decrease in the average price of low-price-point side-by-side units over time compared to the decrease in the average price of all side-by-side units. Notably, average prices of side-by-side units have declined over time even as energy use has decreased substantially and manufacturers have continued to introduce larger units with more features.

The Next Standard

DOE published a final rule in September 2011 amending the current refrigerator efficiency standards. The new standards, which will take effect in September 2014, require a 25% reduction in energy use for top-freezer and side-by side units and a 20% reduction in energy use for bottom-freezer units. DOE based the new standards on a consensus agreement submitted by energy efficiency proponents and manufacturers. Table 3 shows the portion of models available in 2012 that already meet the 2014 standards for each type of door configuration. About 10% of top-freezer and side-by-side models available in 2012 already meet the 2014 standards, while more than one-third of bottom-freezers meet the 2014 standards.

Table 3. Portion of Refrigerator Models Available in 2012 that Already Meet the 2014 Standards

Door Configuration	% of Models in 2012 that Meet the 2014 Standards
Top-Freezer	10%
Bottom-Freezer	36%
Side-by-Side	9%

Source: Authors' analysis of DOE Compliance Certification Database accessed December 9, 2012.

SUMMARY OF FINDINGS

A household with a typical top-freezer, bottom-freezer, or side-by-side unit that just meets the current standard will save $63, $88, and $108 on the annual electricity bill, respectively, compared to a household with a refrigerator just meeting the 1990 standard. Since 1987, when Congress established the first national refrigerator efficiency standards, real prices have decreased by about 35% while average energy use decreased by more than 50%. Real prices for the most basic units have dropped by more than half. Temperature performance has improved and noise levels have dropped over time, while the range of available products and features has greatly increased. The average volume of refrigerator models has increased, especially among bottom-freezer and side-by-side units, and larger volumes are now available. In recent years, with the introduction of French-door models, consumers have a significantly wider range of options in bottom-freezer units. Manufacturers have also introduced new features including dual evaporators, new types of water dispensers, in-the-door ice makers, and additional compartments. Efficiency standards have played a major role in driving improved efficiency and lowering operating costs without hindering trends toward new features and larger volumes.

Clothes Washers

HISTORY AND SCOPE OF CLOTHES WASHER STANDARDS

In 1987, Congress established the first national energy efficiency standards for residential clothes washers as part of NAECA. The NAECA standard, which was based on a consensus agreement between energy efficiency proponents and manufacturers, required that all washers offer a cold water rinse option. NAECA also directed DOE to conduct two cycles of rulemakings to determine whether the initial clothes washer standards should be amended. DOE completed the first rulemaking cycle in 1991, which established the first performance standards for clothes washers. DOE completed the second rulemaking in 2001, amending the prior standards based on a joint recommendation submitted by manufacturers and energy efficiency proponents. In 2007, Congress passed the Energy Independence and Security Act (EISA), which established the first water efficiency standards for clothes washers. Current efficiency standards for clothes washers apply to both compact (<1.6 cu. ft.) and standard-size clothes washers. We focus here on standard-size clothes washers, which represent the vast majority of the market.

1994, 2004, 2007, AND 2011 STANDARDS

Source: iStockphoto

The 1991 DOE final rule set a minimum energy factor (EF) for clothes washers. EF, expressed as cu. ft./kWh/cycle, captured both machine energy consumption and the energy consumption of a water heater to heat the water used for a wash cycle. The standards in the 1991 DOE final rule, which took effect in 1994, required standard-size top-loading clothes washers to meet a minimum EF of 1.18, while no standard was established for front-loading washers. The 2001 DOE final rule adopted a new metric to measure energy consumption—modified energy factor (MEF). In addition to capturing machine energy and water heating energy consumption, MEF also captures clothes dryer energy consumption based on the remaining moisture content (RMC) of the clothes at the end of the wash cycle. A lower RMC of the clothes coming out of the washer (achieved by using higher spin speeds) can reduce the cycle time of the clothes dryer, resulting in clothes dryer energy savings. The standards in the 2001 DOE final rule took effect in two stages—a first tier in 2004 followed by a second tier in 2007—and applied to both top-loading and front-loading washers. The EISA standards, which took effect in 2011, set a maximum water factor (WF) for clothes washers without changing the energy efficiency requirements. Table 4 below shows the 2004 and 2007 energy efficiency standards along with the 2011 water efficiency standard.

Table 4. 2004/2007 Energy Efficiency Standards and 2011 Water Efficiency Standard

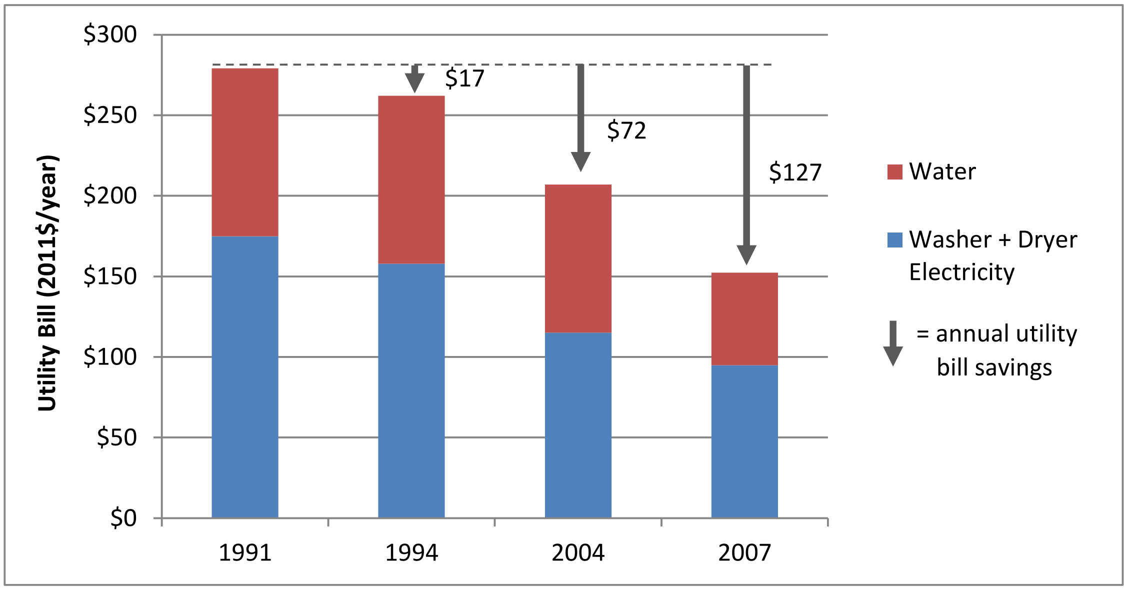
Energy Efficiency Standards		Water Efficiency Standard
2004	2007	2011
1.04 MEF	1.26 MEF	9.5 WF

Notes: MEF is modified energy factor, expressed as cu. ft./kWh/cycle.
WF is water factor, expressed as gallons/cu. ft./cycle.

Since the standard established in 2001 used a different metric for measuring efficiency (MEF) than the earlier metric (EF), it is not possible to directly compare the energy use of washers just meeting the 1994 standard to the energy use of washers just meeting the 2004 and 2007 standards. Most importantly, the EF metric did not capture dryer energy use. However, using the same assumptions that are used in the DOE clothes washer test procedure for calculating dryer energy consumption, we were able to estimate dryer energy consumption for clothes washers rated using the EF metric. The calculation of dryer energy consumption is based in part on the RMC of the clothes at the end of the washer cycle. The average RMC for top-loaders in 2000 was 57% (DOE 2010). We assumed that the average RMC in earlier years was also 57%.

Figure 10 shows an average household's annual utility bill for washing and drying clothes for a typical new clothes washer in 1991 and a washer just meeting the standards in 1994, 2004, and 2007 based on today's electricity and water and wastewater prices.[9] A household with a clothes washer that just meets the current standards will save $127 annually on their utility bills for washing and drying clothes compared to a typical new washer in 1991.

Figure 10. Annual Utility Bill for Washing and Drying Clothes for a Household with a Typical Clothes Washer in 1991 and a Clothes Washer Just Meeting the 1994, 2004, and 2007 standards



Sources: AHAM (2011) for average efficiency in 1991 and average volume; EIA (2012) for electricity price; DOE (2012c) for water and wastewater price.
Note: Assumes an electric water heater and 295 cycles per year.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features from 1991-2012 as four rounds of performance standards for clothes washers took effect:

- Washing performance
- Method of loading
- Tub capacity
- Cycle time
- Automatic temperature control
- Additional features
- Efficiency
- Price

[9] As part of the 2001 rulemaking, DOE collected data from manufacturers on the approximate water use associated with different MEF levels. The water use as estimated by manufacturers to meet the 2007 MEF level was lower than the maximum water usage established by the 2011 water efficiency standard, which suggests that the 2011 water efficiency standard may have had little impact on the water use of typical clothes washers. We were therefore unable to estimate water savings from the 2011 standard. However, we understand that the 2011 standard did eliminate some high-water-using clothes washers from the market, which would yield water and wastewater bill savings for at least a portion of consumers.

Where data were available, we examined models in 1991 and 1995 to characterize the market before and after the 1994 standard; models available in 2001, 2005, and 2008 to characterize the market before and after the 2004/2007 standards; and models available in 2007 and 2012 to characterize the market before and after the 2011 standard.

Washing Performance

As energy efficiency and water efficiency standards have been adopted and (in the case of energy efficiency) updated over the past 20 years, clothes washer manufacturers have had to develop products that maintain (or improve) washing performance using less hot water and less water overall. In 1995, just after the first performance standards for clothes washers took effect, *Consumer Reports* reported that all the machines they tested did a "good or very good job of getting the clothes clean" (*Consumer Reports* 1995c). In *Consumer Reports*' ratings of clothes washers in August 2012, they noted that "good cleaning, high efficiency, and large capacities are common features of the newest washers" (*Consumer Reports* 2012g). *Consumer Reports* has observed that over time, as efficiency standards have become more stringent, washing performance has actually improved. In fact, *Consumer Reports* has had to make their washing performance tests more difficult in recent years in order to be able to continue to differentiate products (*Consumer Reports* 2011a).

However, in 2007, when the current energy efficiency standard took effect, some manufacturers initially had difficulty meeting the standard with some models while maintaining good performance. *Consumer Reports* reported in 2007 that there were significant variations in performance among machines, and that some top-loaders were having a hard time achieving energy savings without sacrificing performance. In addition, the best-performing top-loading machines, as rated by *Consumer Reports*, also had the highest price tags (*Consumer Reports* 2007b). However, product performance improved very rapidly. Less than one year later, in February 2008, *Consumer Reports* reported that their latest tests found "budget-friendly washers, including a $400 top-loader, that cleaned as well as the $1,500 front-loader at the top of [their] Ratings" (*Consumer Reports* 2008).

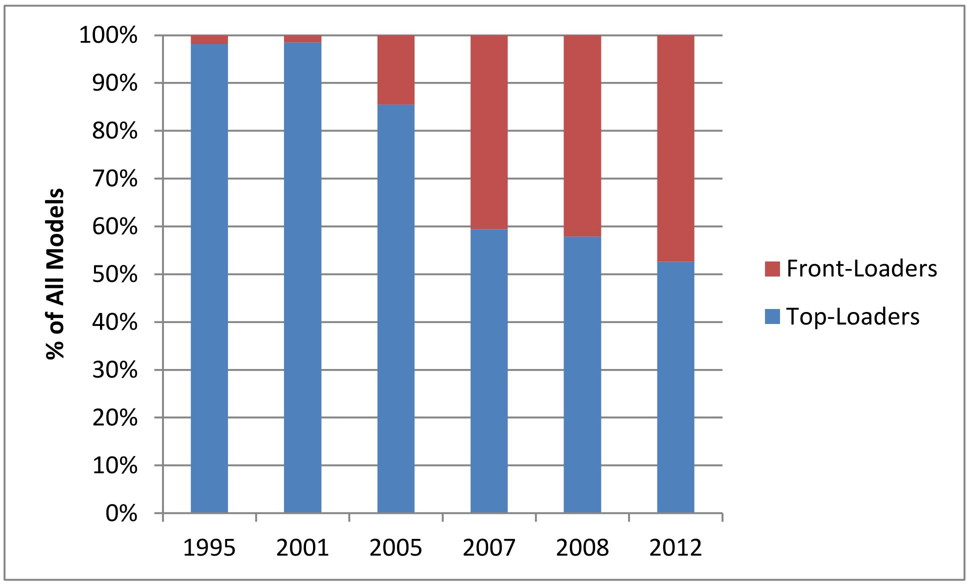
The recent dramatic increase in the market share of front-loaders has contributed to overall improved washing performance. In 2001, *Consumer Reports* noted that front-loaders had "raised the bar for overall washing machine performance" by combining "excellent cleaning ability with unmatched gentleness and efficiency in both water and energy usage" (*Consumer Reports* 2001). As front-loaders gained popularity, manufacturers began to make improvements to top-loaders to try to match front-loader performance. New high-efficiency top-loaders do not use a traditional center-post agitator, which means that they hold more laundry and can be gentler on clothes.

Industry experts we interviewed confirmed that manufacturers have been able to maintain good washing performance, although they noted that providing good performance has become more challenging as energy and water use have decreased. One industry expert we interviewed noted that high-efficiency clothes washers often perform better at soil removal than older washers because high-efficiency washers lift and drop clothes through a detergent-rich solution rather than flooding the clothes with water and detergent. However, as water use has decreased, providing good rinse performance has become a harder task. Industry experts also noted that front-loaders and high-efficiency top-loaders are generally gentler on clothes than traditional center-post agitator top-loaders.

Method of Loading

Figure 11 below shows the distribution of clothes washer models by method of loading from 1995-2012. (Data for 1991 were unavailable.) In 1995 and 2001, only 2% of all available clothes washer models were front-loaders. By 2005, the share of front-loader models had grown to 15%, and by 2012, front-loaders represented almost half of all available models.

Figure 11. Distribution of Clothes Washer Models by Method of Loading from 1995-2012



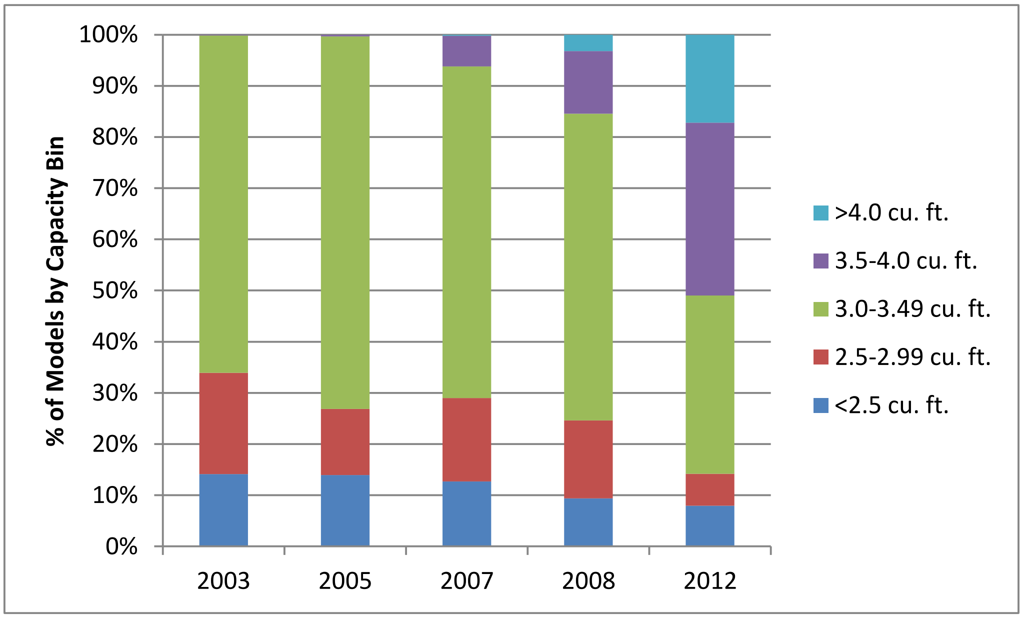
Source: Authors' analysis of California Energy Commission Historical Appliance Database.

Data on actual sales of clothes washers indicate that not only have front-loader models increased significantly as a portion of all available models, but sales of front-loaders have roughly tracked model availability. For example, in 2008, front-loaders represented 36% of all sales (DOE 2012c). The industry experts we interviewed indicated that the huge growth in the front-loader market is likely due to a combination of manufacturers marketing front-loaders as a premium product, often with additional features, and the generally better washing performance and gentleness of front-loaders compared to top-loaders. In addition, one industry expert noted that competition has driven down the price of front-loaders, and that there are now front-loaders at low price points.

Tub Capacity

Figure 12 shows the distribution of clothes washer models by tub capacity from 2003-2012. (Data before 2003 were unavailable.) In 2003, less than 1% of models had a capacity of 3.5 cubic feet or greater, and there were no models larger than 4 cubic feet. From 2007-2012, the share of large-capacity models increased dramatically. By 2012, half of all available models had a capacity of 3.5 cubic feet or greater, and 17% of all models were larger than 4 cubic feet.

Figure 12. Distribution of Clothes Washer Models by Tub Capacity from 2003-2012



Source: Authors' analysis of FTC Appliance Energy Data.

The industry experts we interviewed indicated that the introduction of large-capacity washers has been driven by consumer preferences and by the competitiveness of the market. Washer capacity provides a product differentiator, and large-capacity washers can be a higher-margin product. Efficiency standards do not appear to have hindered the trend towards larger-capacity machines. Since the efficiency metric, MEF, is expressed as cu. ft./kWh/cycle, larger machines can use more energy per cycle than smaller machines. Larger machines can also consume more energy and water per pound of clothes than smaller machines.

Cycle Time

In 1995, *Consumer Reports* reported that typical clothes washer cycle times ranged from 38-50 minutes (*Consumer Reports* 1995c). In 2001, before the 2004/2007 standards took effect, *Consumer Reports* reported that a typical clothes washer had a cycle time of 40-60 minutes (*Consumer Reports* 2001). Table 5 below shows the average and the range of cycle times for the top-loading and front-loading clothes washers rated by *Consumer Reports* from 2005-2012. The average cycle times of both top-loaders and front-loaders have remained relatively constant since 2005. The lower end of the range of cycle times for top-loaders also remained relatively constant since 2005, while for front-loaders, the lower end of the range of cycle times decreased from 60 minutes to 40 minutes from 2005-2012. While the average cycle time of front-loaders in 2012 was 25 minutes longer than that of top-loaders and significantly longer than the range of typical cycle times reported in 1995, the average cycle time for top-loaders (54 minutes) is within the range of typical cycle times in 2001 and similar to the upper range of cycle times in 1995. In addition, two of the top-loaders rated as "CR Best Buys" by *Consumer Reports* in August 2012 with "very good" washing performance and "excellent" energy and water efficiency both have cycle times of only 45 minutes (*Consumer Reports* 2012h).

Table 5. Cycle Times of Clothes Washers rated by *Consumer Reports*

		2005	2007	2008	2012
Top-Loaders	Average	50	47	48	54
	Range	35-80	35-60	30-60	35-80
Front-Loaders	Average	79	79	84	79
	Range	60-120	45-105	50-105	40-105

Sources: Authors' analysis of ratings in *Consumer Reports* (2005, 2007b, 2008, 2012c).

It appears that clothes washer cycle time has been largely unaffected by efficiency standards. One industry expert we interviewed noted that an important factor related to cycle time is how washer cycle time compares to dryer cycle time. In the past, dryer cycle times were typically longer than washer cycle times. While washer cycle times have not changed very much, dryer cycle times are now shorter since washers are doing a better job of removing moisture at the end of the washer cycle. Shorter dryer cycles have meant that the cycle times of washers and dryers are now approaching each other, which is beneficial to consumers when doing sequential loads of laundry.

Automatic Temperature Control

In 1991, *Consumer Reports* noted that "most washers just measure out cold water as it comes into the house or hot water as it comes from the water heater, based on assumptions manufacturers have made about the average water temperature delivered by hot and cold taps" (*Consumer Reports* 1991b). In recent years, automatic temperature control has become a common feature on clothes washers. Automatic temperature control automatically mixes hot and cold water to reach the chosen wash temperature. This feature adjusts the water to the correct temperature based on the cycle selected and ensures that water is not too cold for detergent to work properly.

We examined the portion of models rated by *Consumer Reports* in 2007, 2008, and 2012 that had automatic temperature control. (Earlier data were not available.) Table 6 shows the percentage of top-loaders and front-loaders with automatic temperature control. In addition to examining all models of top-loaders and front-loaders, we also examined the presence of automatic temperature control among low-price-point models by analyzing the least-expensive one-third of models rated by *Consumer Reports* in each of the three years. In 2007, 71% of the top-loaders and 92% of the front-loaders rated by *Consumer Reports* had automatic temperature control—a significant change from 1991. Since 2007, automatic temperature control has become a common feature even on low-price-point models. The percentage of low-price-point top-loaders with automatic temperature control increased from 29% in 2007 to 60% in 2012.

The industry experts we interviewed indicated that the widespread adoption of automatic temperature control was due in large part to efficiency standards since automatic temperature control better regulates the use of hot water. However, automatic temperature control is also a feature that can be marketed to consumers.

Table 6. Portion of Clothes Washers Rated by *Consumer Reports* with Automatic Temperature Control

		2007	2008	2012
Top-Loaders	All Models	71%	77%	85%
	Low-Price-Point Models	29%	43%	60%
Front-Loaders	All Models	92%	90%	89%
	Low-Price-Point Models	78%	86%	78%

Sources: Authors' analysis of ratings in *Consumer Reports* (2007b, 2008, 2012c.)

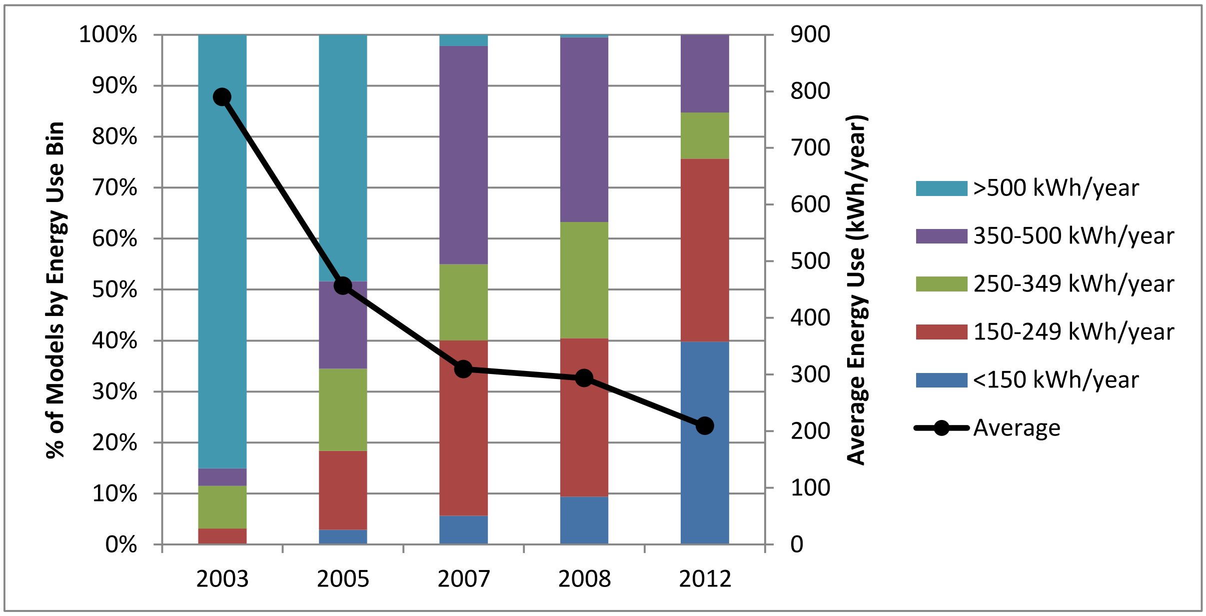
Additional Features

Since 1987, when Congress established the first national clothes washer efficiency standards, manufacturers have added a range of features to their products, and some features that used to be available only on high-end washers have become common even on low-price-point models. New features include electronic controls and displays, steam cycles, and automatic dispensers (*Consumer Reports* 2012i). Electronic controls and displays allow the consumer to save cycle settings and to monitor remaining cycle time and status during the wash cycle. Steam cycles can help to better remove stains. And automatic dispensers can hold and automatically dispense detergent, bleach, and fabric softener at the appropriate times during the cycle.

Efficiency Levels

Figure 13 shows the distribution of clothes washer models by annual energy use from 2003-2012, along with the average energy use of available clothes washer models. (Data before 2003 were unavailable.) The energy use shown in the graph includes machine and water heating energy consumption but excludes dryer energy consumption. In 2003, the year before the 2004 standard took effect, 85% of models consumed more than 500 kWh/year, and only one model was available that consumed less than 150 kWh/year. In 2008, after the 2004 and 2007 standards took effect, more than 60% of models consumed less than 350 kWh/year, and 9% of models consumed less than 150 kWh/year. By 2012, 40% of available models consumed less than 150 kWh/year. From 2003-2012, the average energy use of clothes washer models dropped by more than 70%, from almost 800 kWh/year in 2003 to just over 200 kWh/year in 2012. These data show that over the past 10 years, as three new efficiency standards took effect, manufacturers offered consumers an increasing array of products at efficiency levels exceeding the minimum requirements.

Figure 13. Distribution of Clothes Washer Models by Annual Energy Use from 2003-2012

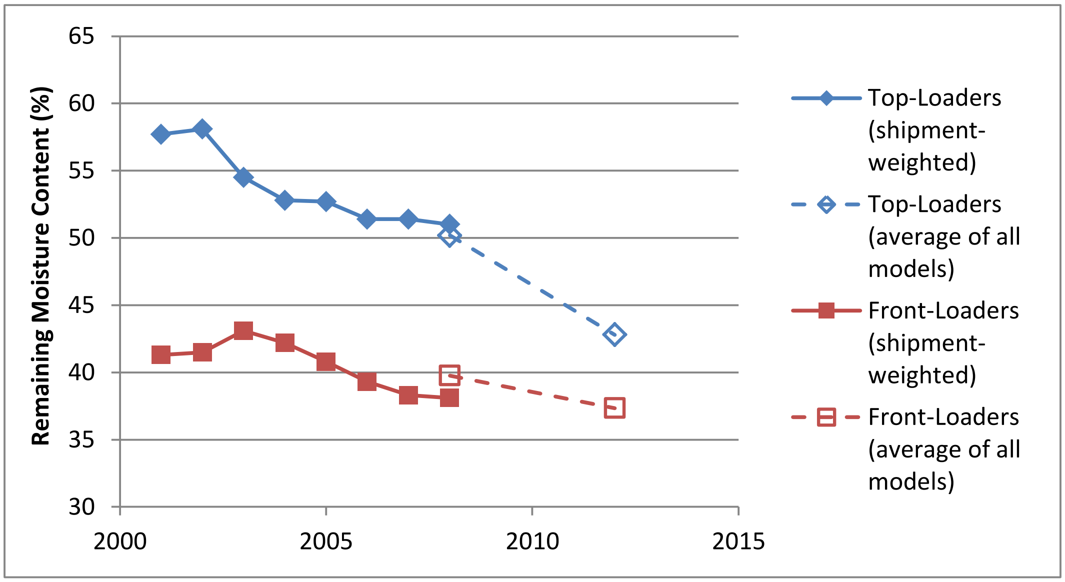


Source: Authors' analysis of FTC Appliance Energy Data.

In addition to significant decreases in machine and water heating energy consumption, new clothes washers do a better job of removing moisture at the end of the cycle, which can reduce dryer cycle times and therefore save energy. The MEF metric, which took effect with the 2004 clothes washer standards, has encouraged manufacturers to utilize higher spin speeds, which has led to significant reductions in remaining moisture content over the past decade, especially among top-loaders. Figure 14 below shows the average RMC of available top-loader and front-loader models from 2001-2008 and the average shipment-weighted RMC of top-loaders and front-loaders in 2008 and 2012. For top-loaders, average RMC decreased from 58% in 2001 to 43% in 2012. The average RMC of front-loaders in 2012 was 37% compared to 41% in 2001. Between 2008 and 2012, the gap between the average RMC of top-loaders and front-loaders narrowed significantly as manufacturers increasingly applied high spin speeds to top-loading machines.

The industry experts we interviewed pointed to efficiency standards as having played a major role in the huge reductions in clothes washer energy and water use since 1987. In addition, they noted that especially in recent years, ENERGY STAR, Consortium for Energy Efficiency (CEE) specifications, and rebates, along with competition among manufacturers to offer high-efficiency products, have contributed to the greater availability of clothes washers with efficiency levels exceeding the minimum requirements.

Figure 14. Average Remaining Moisture Content from 2001-2012

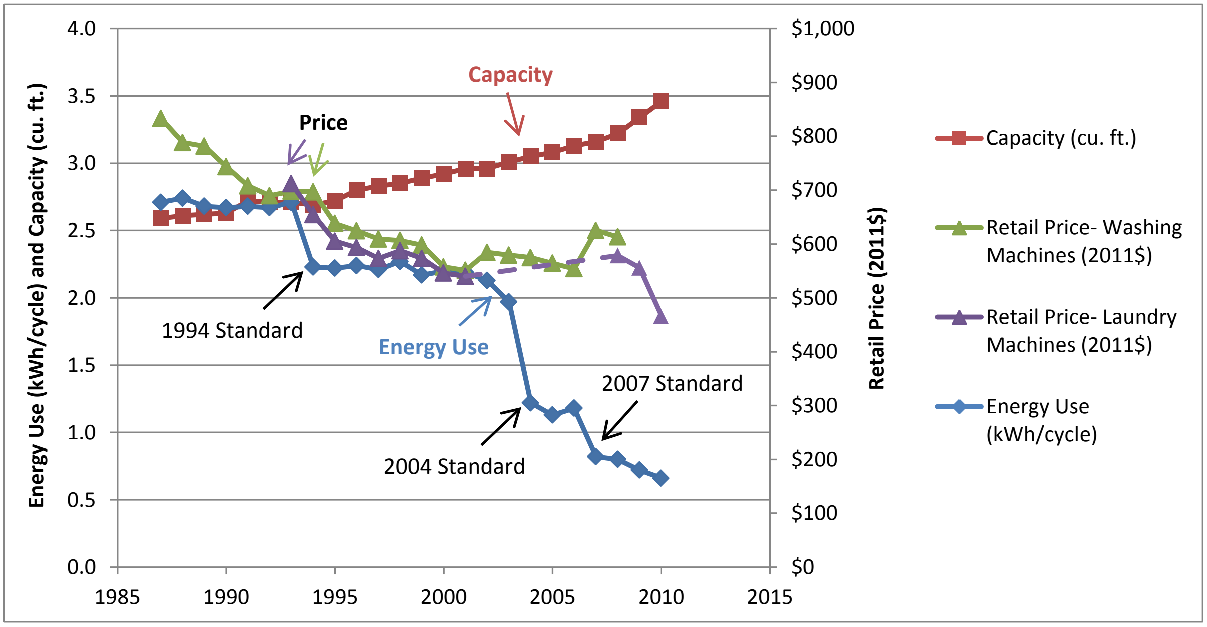


Sources: DOE 2010 for 2001-2008 data; authors' analysis of CEC Appliance Efficiency Database for 2012 data.

Price

Figure 15 shows the average retail price for clothes washers from 1987 to 2010 (in 2011$) along with average energy use per cycle and capacity over the same period. Price data were available from 1987-2008 for washing machines and from 1993-2001 and 2008-2010 for laundry machines (washers and dryers). Both data series are plotted in Figure 15, and the two track each other very closely. Energy use includes machine and water heater energy but excludes dryer energy. In 1987, when the first national prescriptive standard for clothes washers was established, the average retail price of a clothes washer was about $830. Between 1987 and 2010, clothes washer prices exhibited a fairly steady downward trend. In 2010, the average price of laundry machines was about $470, or about 45% lower than the price of clothes washers in 1987 and about 35% lower than the price of laundry machines in 1993. This decrease in clothes washer prices over time occurred while average energy use decreased by 75% and average capacity increased by 33%.

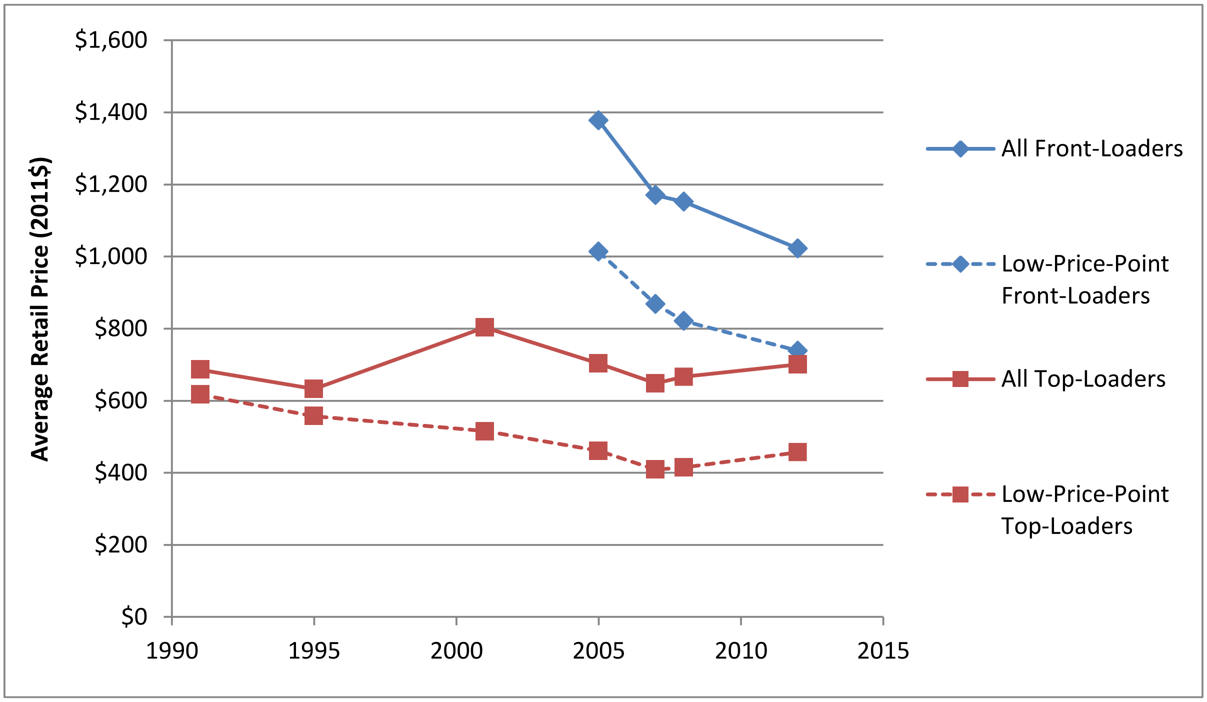
Figure 15. Clothes Washer Energy Use, Volume, and Retail Price from 1987-2010



Sources: AHAM (2011) for energy use and capacity; authors' analysis of U.S. Census Bureau Current Industrial Reports for price; DOE (2012c) for markup.

We also examined the prices of clothes washers rated by *Consumer Reports* over time. We examined both the average price of all models rated as well as the average price of low-price-point models, which we define as the least-expensive one-third of models rated. Figure 16 shows the average price of all top-loaders and low-price-point top-loaders rated by *Consumer Reports* from 1991-2012, and the average price of all front-loaders and low-price-point front-loaders rated by *Consumer Reports* from 2005-2012 (in 2011$). In 1991, the average price of all top-loaders rated by *Consumer Reports* was just under $700, while the average price of low-price-point top-loaders was about $620. In 2012, the average price of all top-loaders rated by *Consumer Reports* was almost the same as it was in 1991—$700. However, over the same period, the average price of low-price-point top-loaders dropped by about 25% to about $460. In 2005, the average price of all front-loaders rated by *Consumer Reports* was about $1,375, while the average price of low-price-point front-loaders was about $1,000. By 2012, the average prices of all front-loaders and low-price-point front-loaders rated by *Consumer Reports* had both dropped by about 25%, to about $1,025 and $740, respectively. By 2012, the average price of low-price-point front-loaders had approached the average price of all top-loaders.

Figure 16. Average Price of Clothes Washers Rated by *Consumer Reports* from 1991-2012



Sources: Authors' analysis of ratings in *Consumer Reports* (1991b, 1995c, 2001, 2005, 2007b, 2008, 2012c).

The divergence over time in the average price of all top-loaders compared to low-price-point top-loaders can likely be explained at least in part by the distinction between low-end models and higher-end products. In recent years, manufacturers have introduced higher-margin products including larger-capacity washers and washers with new features. These higher-end products can claim a price premium and push up the average price of washers. At the same time, manufacturers are clearly finding ways to produce washers at lower cost, as the price of low-price-point washers has decreased over time even as energy and water use have declined substantially. One industry expert we interviewed noted that when manufacturers redesign products to meet new efficiency standards, they also look for opportunities to make the manufacturing process more efficient, which can reduce costs.

The decline in the average price of front-loaders from 2005-2012 is likely due in part to economies of scale. As shown in Figure 11 above, in 2005, only about 15% of available clothes washer models were front-loaders. However, just two years later, 40% of all models were top-loaders, and in 2012, front-loaders represented almost half of available models.

As can be seen in Figures 15 and 16, in recent years the average prices of clothes washers based on U.S. Census Bureau data and estimated markups has been lower than the average prices of clothes washers rated by *Consumer Reports*. While the U.S. Census Bureau data reflects all clothes washers manufactured in the U.S. and is sales-weighted, the *Consumer Reports* data is based on a small sample of clothes washers on the market and is likely weighted towards higher-end products.

The Next Standard

DOE published a final rule in May 2012 amending the current clothes washer standards. DOE based the new standards on a consensus agreement submitted by energy efficiency proponents and manufacturers. The standards for top-loaders will take effect in two stages, with the first tier taking effect in 2015 followed by a second tier in 2018. The standards for front-loaders, which are more stringent than the top-loader standards, include a single tier and take effect in 2015. The 2018 standards for top-loaders will reduce both energy and water use by about 37% compared to the current standards, while the standards for front-loaders will reduce energy use by 18% and water use by 40% compared to baseline front-loader models (which are more efficient than baseline top-loaders).

Table 7 below shows the portion of top-loaders and front-loaders available in 2012 that already meet the 2015/2018 standards. More than half of top-loaders available in 2012 already meet both the 2015 and 2018 standards, while 71% of front-loaders meet the 2015 standard.

Table 7. Portion of Clothes Washer Models in 2012 that Already Meet the 2015/2018 Standards

Product Class	Meet 2015 Standard	Meet 2018 Standard
Top-Loaders	56%	51%
Front-Loaders	71%	

Source: Authors' analysis of DOE's Compliance Certification Database accessed December 7, 2012.

Summary of Findings

An average household with a clothes washer that just meets the current standards will save $127 on the annual utility bills for washing and drying clothes compared to a typical new clothes washer in 1991. Since 1987, when Congress established the first national clothes washer efficiency standards, real prices have decreased by about 45% while average energy use (machine and water heating energy) decreased by 75%. In 2007, when the current energy efficiency standard took effect, some manufacturers initially had difficulty meeting the standard with some models while maintaining good performance. However, product performance improved very rapidly, and many washers today do a better job of removing stains and are gentler on clothes than older washers. Since 1987, average tub capacity has increased by about 33% and larger capacities are now available. In recent years, there has been a dramatic increase in the availability of front-loaders, which generally provide better washing performance and are gentler on clothes than top-loaders. Clothes washer cycle times have largely remained unchanged, while improved moisture removal by washers has narrowed the difference between washer and dryer cycle times. Automatic temperature control has become a common feature, even on low-price-point models. And manufacturers have introduced new features including electronic controls and displays, steam cycles, and automatic dispensers. While efficiency standards lowered the energy and water use of new clothes washers and yielded savings for consumers, they did not inhibit the introduction of new features or consumer preference-driven trends toward front-loaders and large-capacity washers.

Dishwashers

HISTORY AND SCOPE OF DISHWASHER STANDARDS

Source: iStockphoto

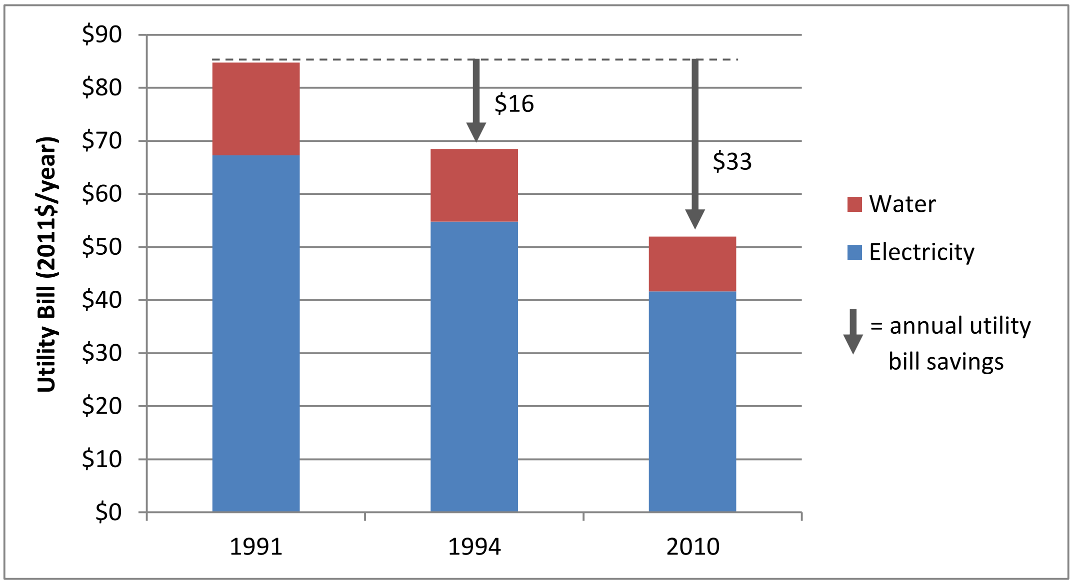
In 1987, Congress established the first national energy efficiency standards for residential dishwashers as part of NAECA. The NAECA dishwasher standards, which took effect in 1988, were based on a consensus agreement between manufacturers and energy efficiency proponents and required that dishwashers be equipped with an option to dry without heat. NAECA also directed DOE to conduct two cycles of rulemakings to determine whether the initial prescriptive standards should be amended. DOE completed the first rulemaking cycle in 1991, which established the first performance standards for dishwashers. DOE initiated a subsequent rulemaking, as directed by NAECA, but the rulemaking was suspended in 1996 and no further rulemaking activity was conducted on dishwashers until a decade later. In 2006, DOE again initiated a rulemaking to complete the second rulemaking cycle as required by NAECA. However, before DOE completed the rulemaking, Congress enacted EISA, which included new energy efficiency standards and the first water efficiency standards for dishwashers. The EISA standards were based on a consensus agreement between energy efficiency proponents and manufacturers. Current efficiency standards for residential dishwashers apply to both compact (<8 place settings) and standard-size (≥ 8 place settings) dishwashers. We focus here on standard-size dishwashers, which represent the vast majority of the market.

1994 AND 2010 STANDARDS

The 1991 DOE final rule set a minimum energy factor (EF) for dishwashers. EF, expressed as cycles/kWh, captures both machine and water heating energy consumption. The standard, which took effect in 1994, required standard-size dishwashers to meet an EF of 0.46. The EISA standards, which took effect on January 1, 2010, specify a maximum annual energy consumption of 355 kWh and a maximum water consumption of 6.5 gallons/cycle for standard-size dishwashers.

Figure 17 shows an average household's annual utility bill to operate a typical dishwasher in 1991, when the first dishwasher performance standard was established, and a dishwasher just meeting the 1994 and 2010 standards based on today's electricity and water & wastewater prices. A household with a dishwasher that just meets the 2010 standard will save about $33 annually on the utility bills compared to a typical new dishwasher in 1991.

Figure 17. Annual Utility Bill for Operating a Dishwasher for a Household with a Typical Dishwasher in 1991 and a Dishwasher Just Meeting the 1994 and 2010 Standards



Sources: AHAM (2011) for average energy use in 1991; *Consumer Reports* (1990a, 1995a) for average water use in 1991 and 1994; EIA (2012) for electricity price; DOE (2012c) for water and wastewater price.
Note: Assumes an electric water heater and 215 cycles per year.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features from 1990-2012 as two rounds of efficiency standards for dishwashers took effect:

- Washing performance
- Cycle time
- Tub material
- Delayed start feature
- Additional features
- Efficiency
- Price

Where data were available, we examined models available in 1990 and 1995 to characterize the market before and after the 1994 standard; models available in 2007 and 2011 to characterize the market before and after the 2010 standard; and models available in 2012 to characterize the current market. We used *Consumer Reports* ratings to analyze several of the product features and performance attributes listed above. We analyzed all models that were rated in each edition of the *Consumer Reports* ratings, and we also analyzed the least-expensive one-third of models rated to represent low-price-point models.

Washing Performance

Table 8 shows the portion of dishwashers that were rated by *Consumer Reports* as having “very good” or “excellent” washing performance. In 1995, 80% of all models rated by *Consumer Reports* and 57%

of low-price-point models were rated as having "very good" or "excellent" washing performance. By 2012, the percentage of models rated as having "very good" or "excellent" washing performance had increased to 92% for both all models and for low-price-point models.

Table 8. Portion of Dishwashers Rated by *Consumer Reports* as Having "Very Good" or "Excellent" Washing Performance

	1995	2007	2011	2012
All Models	80%	94%	84%	92%
Low-Price-Point Models	57%	92%	78%	92%

Sources: Authors' analysis of ratings in *Consumer Reports* (1995a, 2007a, 2011b, 2012b).

A slightly lower percentage of dishwashers were rated as having "very good" or "excellent" washing performance in 2011, the year after the 2010 standard took effect, compared to 2007 or 2012. However, according to *Consumer Reports*, the 2010 standard had no noticeable effect on washing performance, and any decrease in the percentage of models rated "very good" or "excellent" on washing performance between 2007 and 2011 is more likely due to the increasing difficulty of tests conducted by *Consumer Reports* in order to continue to differentiate products (Connelly 2012).

The industry experts we interviewed confirmed that manufacturers have generally maintained good washing performance even as energy use and water use have decreased substantially. However, these industry experts noted that in order to maintain good performance, manufacturers have generally had to increase cycle times.

Cycle Time

Table 9 below shows the average and the range of cycle times for the dishwashers rated by *Consumer Reports* from 1990-2012. Over this period, the average cycle time for all models was similar to that of low-price point models. The average cycle time in 1990 was 87 minutes for all models and 74 minutes for low-price-point models. In 1995, after the 1994 standards took effect, cycle times increased to about 95 minutes for all models and low-price-point models. Between 1995 and 2012, average cycle time increased by about 35 minutes to 130 minutes. However, in July 2012, the dishwasher that received the highest overall rating from *Consumer Reports*, including a rating of "excellent" for both washing performance and energy use, and which was also rated as a "CR Best Buy," had a cycle time of 95 minutes, which is the same as the average cycle time in 1995 (*Consumer Reports* 2012b).

Table 9. Cycle Times of Dishwashers Rated by *Consumer Reports*

		1990	1995	2007	2011	2012
All Models	Average	87	94	124	133	127
	Range	60-115	70-110	105-190	110-205	90-180
Low-Price-Point Models	Average	74	95	117	133	130
	Range	60-85	70-110	105-130	110-170	100-180

Sources: Authors' analysis of ratings in *Consumer Reports* (1990a, 1995a, 2007a, 2011b, 2012b).

Tub Material

Dishwasher tubs are generally made of either plastic or stainless steel. Compared to plastic tubs, stainless steel tubs better resist stains; transmit less sound and more effectively damp vibrations; can withstand higher temperatures; and better retain heat, which can reduce the energy use of the drying cycle. Table 10 below shows the portion of models rated by *Consumer Reports* from 1990-2012 that had a stainless steel tub. In 1990, the year before the first energy efficiency performance standards were established for dishwashers, only one model rated by *Consumer Reports* had a stainless steel tub. In 1995, the year after the 1994 standard took effect, *Consumer Reports* noted that typical dishwashers still had plastic tubs (*Consumer Reports* 1995a). By 2007, roughly 50% of models rated by *Consumer Reports* had stainless steel tubs, although the models with stainless steel tubs did not include any low-price-point models. However, by 2011, the year after the 2010 standard took effect, stainless steel tubs had become a relatively common feature, even on low-price-point models. In 2011, 71% of all models and 22% of low-price-point models rated by *Consumer Reports* had stainless steel tubs.

Table 10. Portion of Dishwashers Rated by *Consumer Reports* with Stainless Steel Tubs

	1990	2007	2011	2012
All Models	5%	53%	71%	71%
Low-Price-Point Models	0%	0%	22%	29%

Sources: Authors' analysis of ratings in *Consumer Reports* (1990a, 2007a, 2011b, 2012b).

The industry experts we interviewed indicated that consumer preferences are driving the trend towards stainless steel tubs. However, as noted above, stainless steel tubs can have a small effect on dishwasher efficiency by reducing the energy use of the drying cycle.

Delayed Start Feature

Table 11 below shows the portion of models rated by *Consumer Reports* from 1990-2012 that incorporated a delayed start feature. Delayed start allows a consumer to set a dishwasher to start the cycle 1-24 hours later. A consumer may use this feature to run the dishwasher overnight, for example. In 1990, 30% of all models and 14% of low-price-point models rated by *Consumer Reports* incorporated a delayed start feature. In 1995, after the 1994 standard took effect, the percentage of all models with delayed start had increased to 60%, although the feature was still less common among low-price-point models compared to all models. However, by 2012, three-quarters of low-price-point models incorporated a delayed start feature, which was similar to the percentage of all models with delayed start (82%).

Table 11. Portion of Dishwashers Rated by *Consumer Reports* with Delayed Start

	1990	1995	2012
All Models	30%	60%	82%
Low-Price-Point Models	14%	29%	75%

Sources: Authors' analysis of ratings in *Consumer Reports* (1990a, 1995a, 2012b).

The industry experts we interviewed indicated that the widespread adoption of delayed start has been driven by consumer preferences. Several industry experts noted that consumers prefer to run their dishwasher overnight or when they are away from home so that the noise from the dishwasher is not disruptive.

Additional Features

In 1995, *Consumer Reports* reported on new "smart" dishwashers that manufacturers had started to introduce, which used "fuzzy logic" to adjust water use and cycle time depending on the soil level of the dishes. *Consumer Reports* noted that these models were more expensive than typical mid-priced models (*Consumer Reports* 1995a). By 2007, *Consumer Reports* noted that the use of soil sensors had become widespread and that sensors were incorporated as a feature on most models including inexpensive models (*Consumer Reports* 2007a). In 2012, nearly 100% of the dishwashers rated by *Consumer Reports* had soil sensors (*Consumer Reports* 2012d). Several industry experts we interviewed indicated that the widespread adoption of soil sensors was mostly due to efficiency standards and ENERGY STAR, since soil sensors can reduce energy and water use.

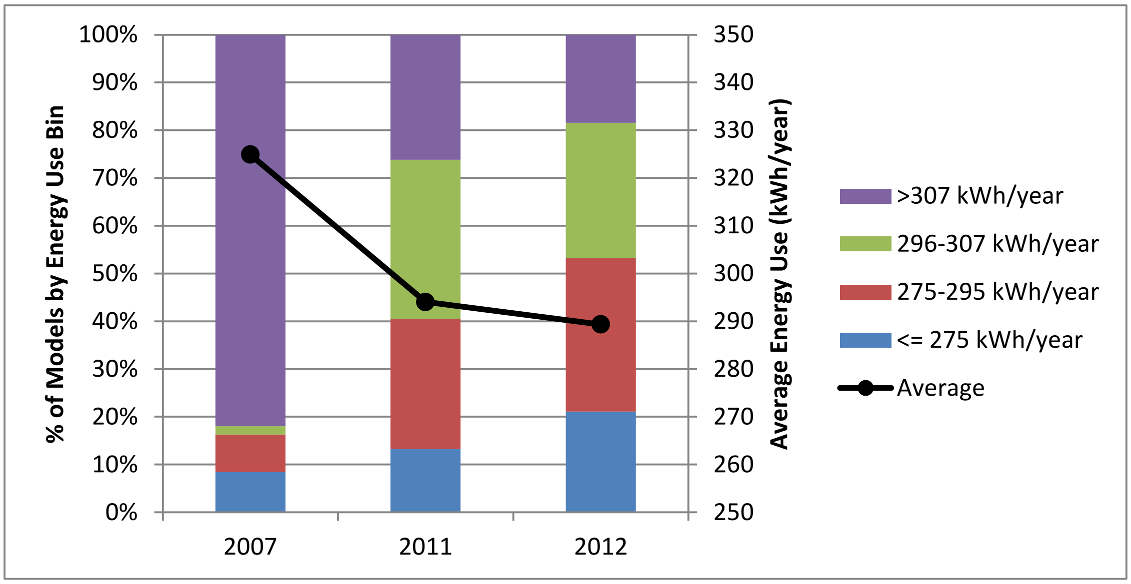
Two new dishwasher features include a new type of filter and automatic bulk detergent dispensers. Traditional dishwasher filters are self-cleaning and have a grinder that pulverizes the debris and flushes it down the drain. Some newer filters are designed to be cleaned manually and do not contain a grinder (*Consumer Reports* 2012a). These manual filters eliminate the noise associated with the grinder. Some new dishwasher models automatically dispense the right amount of detergent and can hold up to 47 ounces of detergent.[10]

Efficiency Levels

Figure 18 shows the distribution of dishwasher models in 2007, 2011, and 2012 by annual energy use, along with the average energy use of available dishwasher models in the same years. (Earlier data were not available.) In 2007, when the current standard was established, more than 80% of available models consumed more than 307 kWh/year, and only 16% of models consumed 295 kWh/year or less, which is equivalent to the 2012 ENERGY STAR specification. In 2011, after the 2010 standard took effect (which specified a maximum energy use of 355 kWh/year), almost three-quarters of models consumed 307 kWh/year or less, and more than 40% of models already met the 2012 ENERGY STAR specification (≤295 kWh/year). By 2012, more than 50% of models met the 2012 ENERGY STAR specification, and 21% of models consumed less than 275 kWh/year (compared to 8% five years earlier). From 2007-2012, the average energy use of available dishwasher models decreased from 325 to 289 kWh/year. These data show that consumers had more choices of dishwashers with efficiency levels exceeding the 2010 standard soon after the standard took effect.

[10] See http://www.monogram.com/dishwasher/performance.htm.

Figure 18. Distribution of Dishwasher Models by Annual Energy Use and Average Energy Use from 2007-2012



Source: Authors' analysis of FTC Appliance Energy Data.

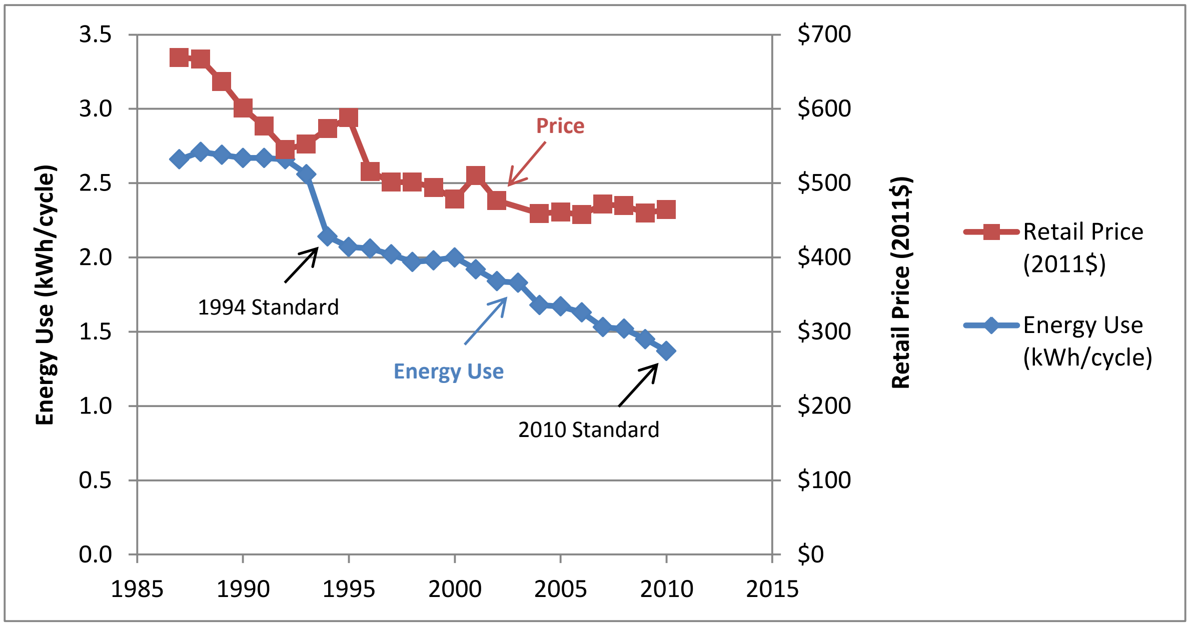
In addition to efficiency standards, in recent years ENERGY STAR has appeared to play a significant role in increasing the availability of high-efficiency dishwashers. For example, ENERGY STAR reported that 96% of dishwasher shipments in 2011 were ENERGY STAR qualified (EPA 2012a).

Price

Figure 19 below shows the average retail price for dishwashers from 1987-2010 (in 2011$) along with average energy use per cycle over the same period. In 1987, when Congress established the first national efficiency standards for dishwashers, the average retail price of a dishwasher was about $670. Between 1987 and 2010, dishwasher prices exhibited a fairly steady downward trend. In 2010, the average price of a dishwasher was about $465, or approximately 30% lower than the price of a dishwasher in 1987. This decrease in dishwasher prices over time occurred while average energy use decreased by 50%.

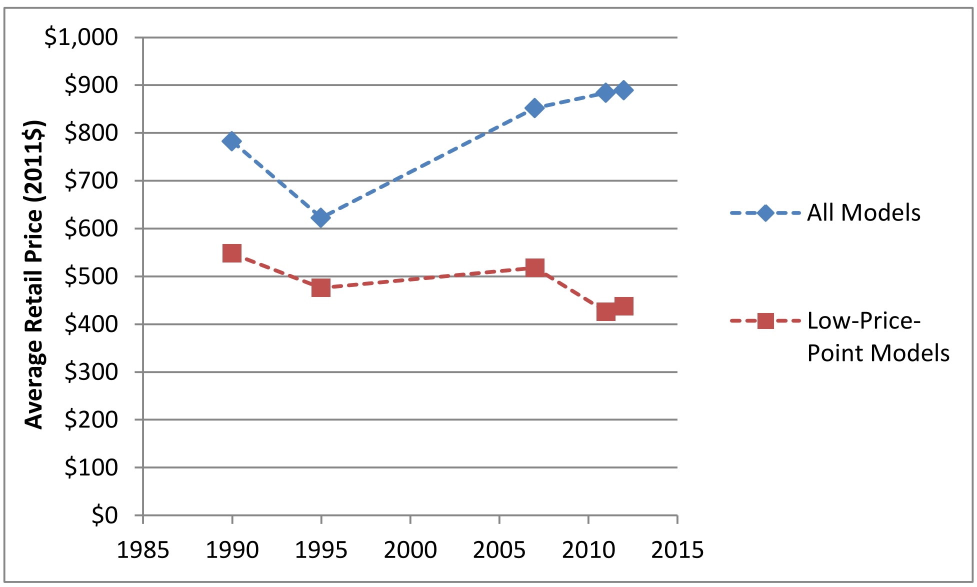
We also examined the prices of dishwashers rated by *Consumer Reports* over time. We examined both the average price of all models rated as well as the average price of low-price-point models. Figure 20 shows the average price of all dishwashers and low-price-point dishwashers rated by *Consumer Reports* from 1990-2012 (in 2011$). In 1990, the average price of all dishwashers rated by *Consumer Reports* was about $780, while the average price of low-price-point dishwashers was about $550. In 2012, the average price of all dishwashers rated by *Consumer Reports* had increased by about 15% to about $890. However, over the same period, the average price of low-price-point dishwashers dropped by 20% to about $440. These data show that base-model dishwashers have become more affordable even as several rounds of efficiency standards have taken effect.

Figure 19. Dishwasher Energy Use and Retail Price from 1987-2010



Sources: AHAM (2011) for energy use; authors' analysis of U.S. Census Bureau Current Industrial Reports for price; DOE (2012d) for markup.

Figure 20. Average Price of Dishwashers Rated by *Consumer Reports* from 1990-2012



Sources: Authors' analysis of ratings in *Consumer Reports* (1990a, 1995a, 2007a, 2011b, 2012b).

As can be seen in Figures 19 and 20, the average prices of dishwashers based on U.S. Census Bureau data and estimated markups have been lower than the average prices of dishwashers rated by *Consumer Reports*, especially in recent years. While the U.S. Census Bureau data reflects all dishwashers manufactured in the United States and is sales-weighted, the *Consumer Reports* data is based on a small sample of dishwashers on the market and is likely weighted towards higher-end products. Part of the difference may also be explained by some dishwashers being sold at lower prices due to discounts, sale prices, and large volume purchases, e.g., by home and apartment developers.

The significant divergence over time in the average price of all dishwashers compared to low-price-point dishwashers can likely be explained at least in part by the distinction between low-end models and higher-end products. In recent years, manufacturers have introduced higher-margin products including fully-integrated models with custom panels and a range of new features. These higher-end products can claim a price premium and push up the average price of dishwashers. At the same time, manufacturers are clearly finding ways to produce dishwashers at lower cost, as the price of low-price-point dishwashers has decreased over time even as energy and water use have declined substantially. One industry expert we interviewed noted that when manufacturers redesign products to meet new efficiency standards, they also look for opportunities to make the manufacturing process more efficient, which can reduce costs.

The Next Standard

DOE published a final rule in May 2012 amending the current dishwasher standards. DOE based the new standards, which will take effect on May 30, 2013, on a consensus agreement submitted by energy efficiency proponents and manufacturers. The standards specify a maximum energy use of 307 kWh/year and a maximum water use of 5 gallons/cycle. The new standards will achieve energy savings of about 14% and water savings of about 23% compared to the current standards. In December 2012, 88% of available models already met the May 2013 standard.

Summary of Findings

An average household with a dishwasher that just meets the current standards will save about $33 on the annual utility bills compared to a typical dishwasher in 1991. Since 1987, when Congress established the first national dishwasher efficiency standards, real prices have decreased by about 30% while average energy use decreased by 50%. Manufacturers have maintained good washing performance using significantly less energy and water, although average cycle times have increased. Over time, features such as stainless steel tubs and delayed start have become more common, even on low-price-point models. In addition, manufacturers have introduced new features including a new type of filter that reduces noise, and bulk dispensers that store and automatically dispense the right amount of detergent. While efficiency standards drove significant energy and water savings and utility bill savings for consumers, they did not inhibit good washing performance or new features.

Residential Central Air Conditioners and Heat Pumps

History and Scope of Central Air Conditioner and Heat Pump Standards

Minimum efficiency standards for residential central air conditioners and heat pumps were first adopted at the state level, beginning with California in 1974. Subsequently, Arizona, Florida, Kansas, Massachusetts, and New York also adopted standards for these products (Nadel and Goldstein 1996). Given the emerging patchwork of state standards, manufacturers and energy efficiency proponents negotiated consensus national standards for central air conditioners and heat pumps. Congress adopted these consensus standards as part of NAECA in 1987. The standards, which required products to meet a minimum Seasonal Energy Efficiency Ratio (SEER) of 10, took effect January 1, 1992 for air conditioners and January 1, 1993 for heat pumps. In addition to the SEER requirement, heat pumps also had to meet a minimum Heating Seasonal Performance Factor (HSPF) of 6.8. SEER represents a unit's cooling output during a typical cooling season divided by the energy input (Btu/watt hours), while HSPF represents a unit's heat output during the heating season divided by the energy input (Btu/watt hours). For both SEER and HSPF, higher numbers indicate higher efficiency and lower energy use. In 2001, DOE published a final rule amending the NAECA standards for central air conditioners and heat pumps. Most central air conditioners and heat pumps are split-system units, where the condensing unit (outdoor unit) is placed outdoors and the evaporator (indoor unit) is placed indoors.

Source: iStockphoto

2006 Standard

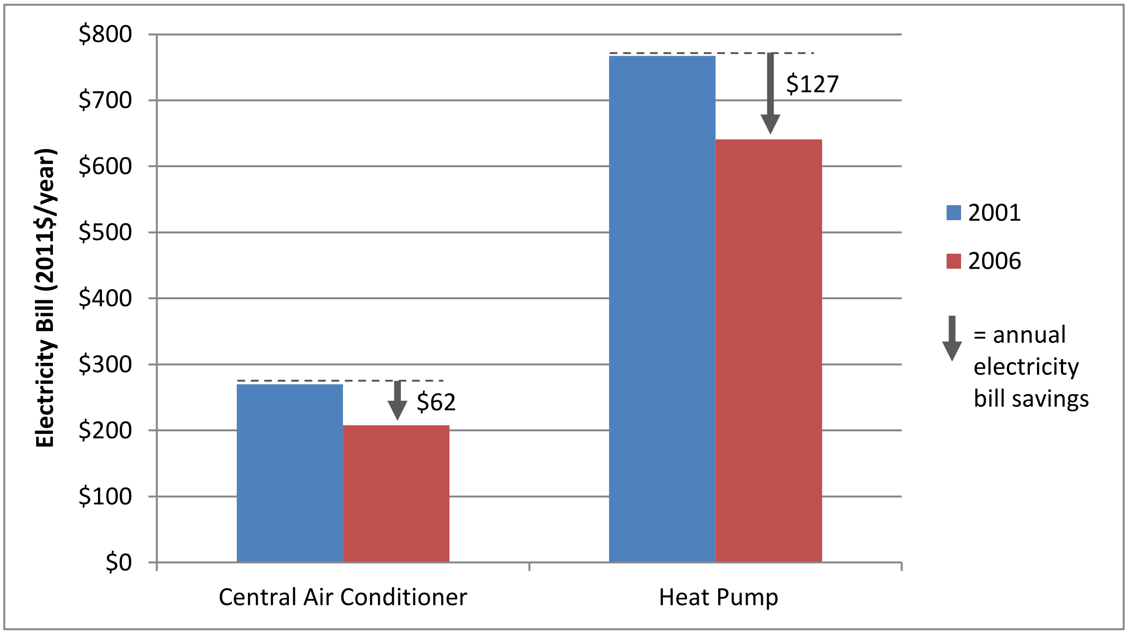
The current standard, established by DOE in 2001, took effect in January 2006 and requires a minimum efficiency of SEER 13.[11] Relative to the 1992/1993 standard, SEER 13 represents a 30% increase in energy efficiency, which corresponds to roughly a 23% decrease in energy consumption.[12] The 2006 standards also raised the minimum HSPF for heat pumps to 7.7.

Figure 21 shows an average household's annual electricity bill to operate a typical central air conditioner or heat pump just meeting the standards in 2001 and 2006 based on today's electricity prices. The 2006 standards reduced a typical household's annual electricity bill by $62 for central air conditioners and $127 for heat pumps. (The savings will vary by climate and hours of operation.)

[11] There are exceptions, with lower standards for a few highly specialized products such as through-the-wall units, space-constrained products, and small-duct high-velocity systems.

[12] (13-10)/13 = 23%.

Figure 21. Annual Electricity Bill for Operating a Central Air Conditioner or Heat Pump for a Household with a Unit Just Meeting the Standards in 2001 and 2006



Sources: DOE (2001a) for energy use; EIA (2012) for electricity price.
Note: The electricity bills for heat pumps include both heating and cooling energy use.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features of central air conditioners and heat pumps available before and after the 2006 standards:

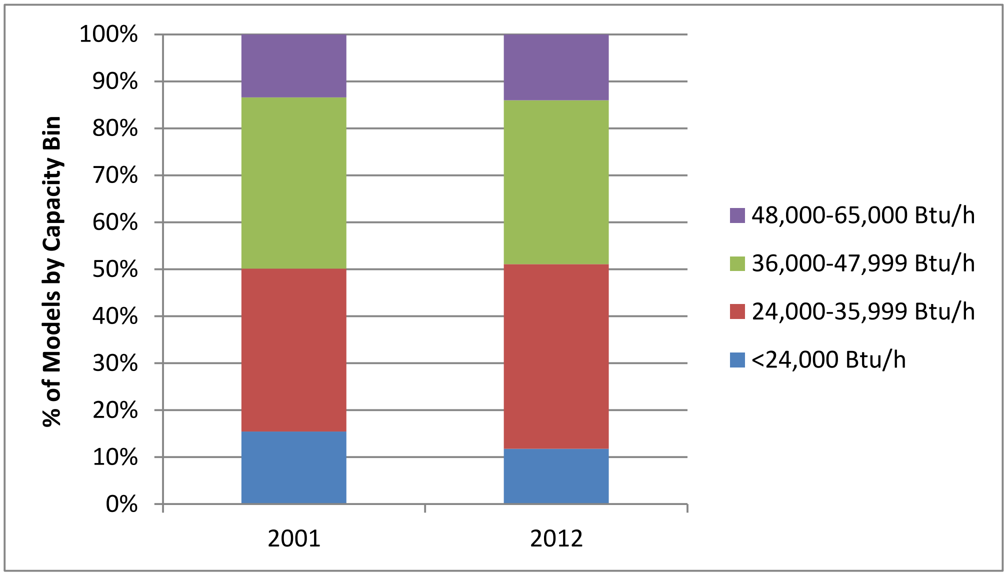
- Cooling capacity
- Size and weight
- Dehumidification
- Additional features
- Efficiency
- Price

We examined models available in 2001 and 2012 to characterize the market before and after the 2006 standards. (We were unable to obtain data on models available in 2007, the year after the standard took effect.)

Cooling Capacity

Cooling capacity, which is measured in Btu/hour, refers to the rate of cooling that a central air conditioner or heat pump can provide under a specific set of conditions. Figure 22 shows the distribution of central air conditioner models by capacity in 2001, the year the 2006 standard was established, and in 2012. There was no significant difference in the distribution of cooling capacities available before and after the 2006 standard took effect. In both 2001 and 2012, roughly 70% of available models had capacities between 24,000 Btu/hour and 47,999 Btu/hour (2-4 tons).

Figure 22. Distribution of Central Air Conditioner Models by Cooling Capacity in 2001 and 2012



Sources: AHRI for 2001 data; authors' analysis of AHRI directory queried on 1/24/13 for 2012 data.

Size and Weight

In order to achieve SEER 13, greater heat exchange area is generally needed compared to the typical heat exchange area necessary to meet lower SEER levels. Adding additional heat exchange area can increase the size and weight of both the indoor and outdoor units of central air conditioners and heat pumps. For example, web research on current and older models indicates that while a 3 ton[13] SEER 10 outdoor unit might require a mounting pad of 24 x 24 inches, a typical SEER 13 outdoor unit might require a 26 x 26 inch pad. For basic 3 ton units produced by Goodman, a SEER 10 unit weighs 142 pounds while a SEER 13 unit weighs 198 pounds. However, such weight gains are not universal as new heat exchanger designs (which often use smaller diameter tubes or aluminum "micro-channels") can increase heat exchange area without increasing weight. For example, Carrier markets a basic 3 ton SEER 13 unit that weighs only 141 pounds.[14] Other major manufacturers such as Trane and York are also using these lighter heat exchangers on some models. All of the industry experts we interviewed agreed that new outdoor units are somewhat larger than baseline outdoor units available prior to the 2006 standard, and that many outdoor units are also heavier. In addition, one industry expert noted that indoor units (evaporators) are now generally larger, and that in order to accommodate these larger evaporator coils, manufacturers have made furnaces shorter, which might increase the energy used by the air handler to circulate heated or cooled air.

Dehumidification

In warm weather, central air conditioners and heat pumps provide dehumidification in addition to cooling. Sensible heat ratio (SHR) describes the fraction of an air conditioner's cooling capacity that is

[13] Cooling capacity is commonly measured in terms of the amount of cooling provided by a ton of ice. A 3 ton unit has a cooling capacity of 36,000 Btu/hour.

[14] Carrier 24ABB3 Comfort 13 air conditioner.

used to remove heat. (The remaining cooling capacity is used to remove moisture.) For the same total cooling capacity, a unit with a lower SHR can remove more moisture than a comparable unit with a higher SHR. We were unable to obtain recent data on the SHRs of central air conditioners and heat pumps. However, an analysis of manufacturer data from 2001 found that there was no correlation between SHR and efficiency for SEER values ranging from 9.5-16.4 (Amrane et al. 2003). All the industry experts we interviewed agreed that the dehumidification capability of central air conditioners and heat pumps has not changed since 2001, when the current standard was established. One manufacturer noted that dehumidification is part of their design specification and that they design products to meet this specification.

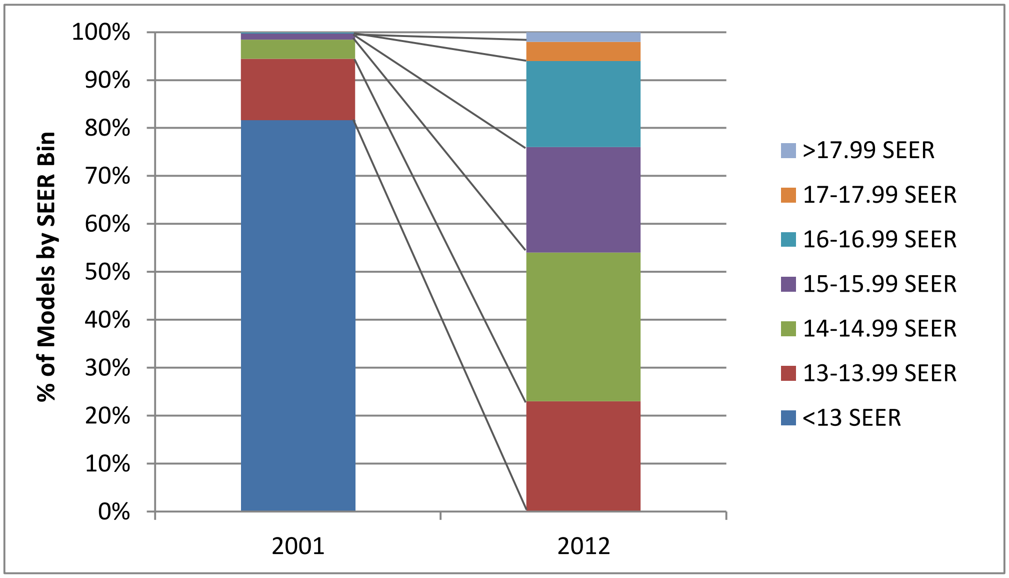
Additional Features

Thermal expansion valves (often abbreviated as TXVs) control the amount of refrigerant flow into the indoor coil of the air conditioner, which helps to optimize the system for different indoor and outdoor conditions. Prior to the 2006 standard, TXVs were only used in some air conditioners, including 60% of SEER 13 units and 100% of units with a SEER rating of 15 or higher (DOE 2001b); the majority of units with efficiency levels below SEER 13 used a less-expensive metering device that is optimized for a single set of operating conditions and performs sub-optimally at other conditions. TXVs reduce the energy use of a central air conditioner by adjusting the flow of refrigerant based on the cooling load. In addition, TXVs can increase the lifetime and reliability of the compressor by preventing liquid refrigerant from reaching the compressor and can improve comfort by helping an air conditioner respond to changes in a home's cooling load (PG&E 2006). According to several industry experts we interviewed, TXVs have become a standard feature since the 2006 standard took effect, as use of a TXV is often part of the lowest-cost technological package that can be used to reach SEER 13.

Efficiency

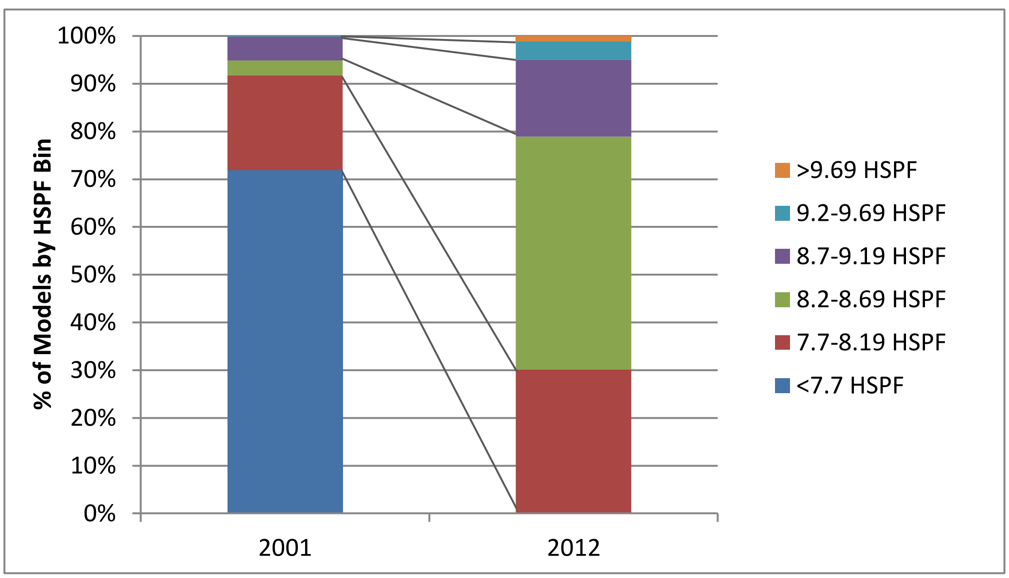
Figure 23 shows the distribution of efficiency levels of central air conditioner models available in 2001, when the current standard was established, and in 2012. In 2001, more than 80% of models had efficiency levels below SEER 13, and only 5% of models had efficiencies of SEER 14 or higher. By 2012, almost 80% of models had efficiency levels of SEER 14 or higher and about one-quarter of models had SEER levels of 16 or higher.

Figure 23. Distribution of Central Air Conditioner Models by SEER Level in 2001 and 2012



Sources: AHRI for 2001 data; authors' analysis of AHRI directory queried on 2/1/13 for 2012 data.

Figure 24. Distribution of Heat Pump Models by HSPF Level in 2001 and 2012



Sources: AHRI for 2001 data; authors' analysis of AHRI directory queried on 2/1/13 for 2012 data.

These data show that the availability of high-efficiency central air conditioners and heat pumps has increased substantially since 2001. Data on actual sales of high-efficiency equipment indicate that not only is high-efficiency equipment available, but consumers are purchasing this equipment. For example, from 2008-2011, between 3% and 13% of equipment sales were at SEER 16, which significantly exceeds the minimum standard (Nadel and Farley 2013). Efficiency standards likely helped to drive the greater availability and sales of high-efficiency equipment by making SEER 13 and

HSPF 7.7 the baseline efficiency levels and spurring manufacturers to develop more higher-efficiency units in order to better compete in the market for value-added products. Other factors also likely contributed to this market shift towards higher-efficiency equipment including ENERGY STAR, which raised its specification for central air conditioners and heat pumps to SEER 14.5 for split systems and SEER 14 for single-package systems as of January 1, 2009; federal tax credits for SEER 16 products, which were particularly lucrative in 2009-2010 (they covered 30% of the cost of a qualifying air conditioner); and utility-sector incentive programs. One industry expert confirmed the importance of federal tax incentives in driving the development and sales of central air conditioners with efficiency levels higher than the minimum standard and noted that sales of high-efficiency units decreased when the tax incentives expired at the end of 2011.

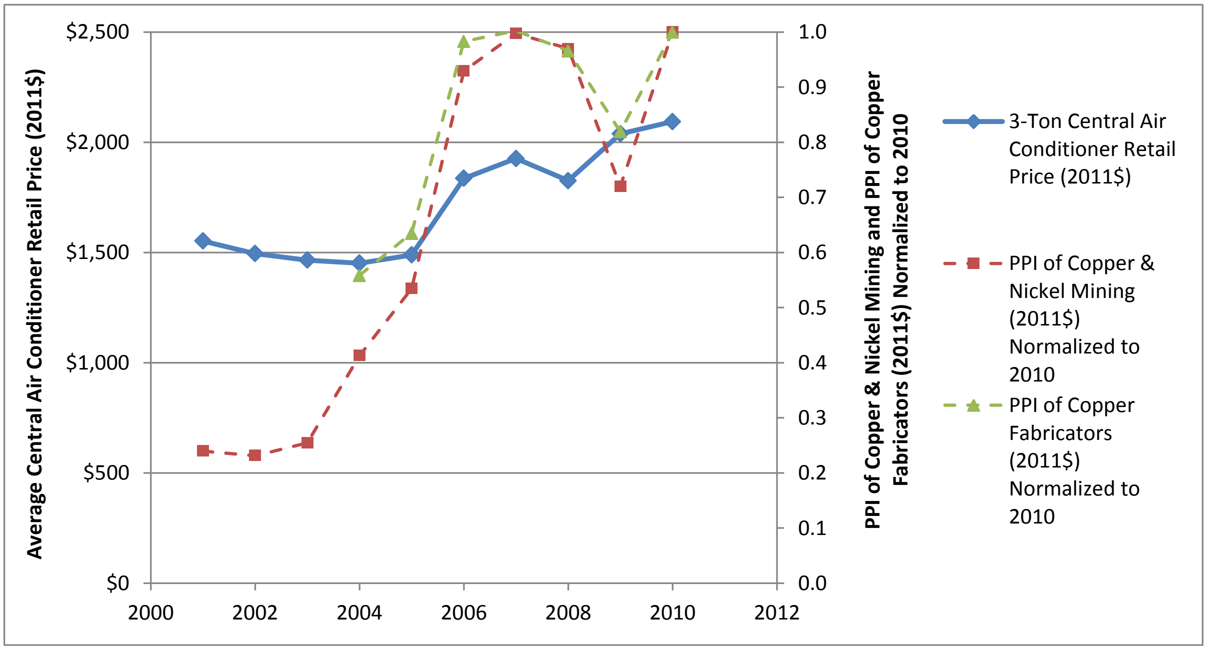
Price

Figure 25 shows the average retail price of 3 ton split-system central air conditioners from 2001-2010, along with the Producer Price Index (PPI) of copper and nickel mining and of copper fabricators normalized to 2010 (all in 2011$).[15] The average price of 3 ton central air conditioners increased from about $1,550 in 2001 to $1,800 in 2006 and to $2,100 in 2010. However, theses price increases are likely not due solely to the efficiency standard. DOE estimates that materials (including copper) make up 85% of the cost of a split-system air conditioner (DOE 2001b). Except for a dip in 2009, from 2006-2010, copper and nickel prices were more than four times higher than they were in 2001. The increase in the price of central air conditioners between 2005 and 2006 occurred at the same time that the price of copper increased by more than 50%. This suggests that the increase in the price of central air conditioners was likely due at least in part to the significant increase in copper prices, which is unrelated to the efficiency standard.

Even if the entire increase in price were due to the efficiency standard, the standard is still cost-effective for consumers. Between 2001, when the standard was established, and 2007, one year after the standard took effect, the retail price of a 3 ton central air conditioner increased by about $375 as shown in Figure 25. As shown in Figure 21, annual electricity bill savings from the standard for a typical household are about $60. Therefore, the simple payback (assuming the entire price increase is due to the standard) is just over six years, which is significantly shorter than the average lifetime of 19 years for a central air conditioner (DOE 2011c). In all likelihood, the actual payback is shorter since the incremental cost of the efficiency standard is likely less than the entire observed price increase.

[15] We show the PPI of copper and nickel mining in addition to the PPI of copper fabricators because the latter only goes back to 2004. As can be seen in Figure 25, the two PPIs track each other closely.

Figure 25. Average Retail Price of 3 ton Residential Central Air Conditioners (2011$) and PPI of Copper and Nickel Mining and of Copper Fabricators (2011$) Normalized to 2010



Sources: Authors' analysis of U.S. Census Bureau Current Industrial Reports data; DOE (2011c) for markup.

THE NEXT STANDARD

In 2011, DOE established new efficiency standards for central air conditioners and heat pumps, which will take effect January 1, 2015. For central air conditioners, the new standards for the first time include separate standards for Northern and Southern states to reflect differences in climate. The new standard will be SEER 14 for the Southern states, while the current SEER 13 standard will remain unchanged for the Northern states. The Southern states are defined as those with less than 5,000 average heating degree days. In addition, for the four Southwest states (California, Arizona, Nevada, and New Mexico), there are additional full-load (EER) requirements to ensure good performance on very hot days. For heat pumps, there will be a single national efficiency standard of SEER 14/HSPF 8.2. As shown in Figures 23 and 24 above, almost 80% of central air conditioner models available in 2012 had efficiency levels of SEER 14 or above, and 70% of heat pump models had heating efficiency levels of HSPF 8.2 or above.

SUMMARY OF FINDINGS

The 2006 standards for residential central air conditioners and heat pumps reduced a typical household's annual electricity bill by $62 for air conditioners and $127 for heat pumps. Since 2001, when the 2006 standard was established, the distribution of available cooling capacities and the dehumidification capability of this equipment have remained unchanged, while the size of units, and in some cases the weight, have increased somewhat. By employing new lightweight heat exchangers in some models, manufacturers have been able to minimize weight increases. Compared to 2001, the availability of high-efficiency units in the current market, including units that significantly exceed the current standards, has increased dramatically. Most central air conditioners now have thermal expansion valves, which can improve both comfort and efficiency and increase equipment reliability. While equipment prices increased by about 18% between 2001, when the standard was established, and 2007, one year after the standard took effect, at least a portion of this increase is likely due to the large increase in metal prices (about 300%). Even if the entire price increase were due to the standard, the six-year payback period is significantly shorter than the 19-year average lifetime of this equipment.

Toilets

HISTORY AND SCOPE OF TOILET STANDARDS

Source: iStockphoto

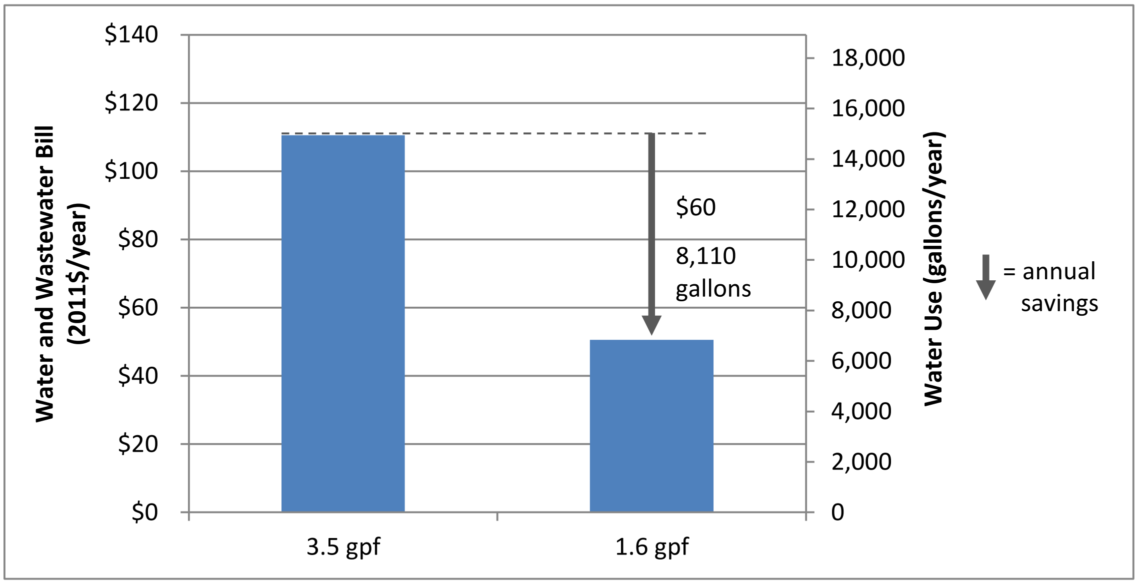
Starting in the 1980s, states and municipalities established the first efficiency standards for plumbing products in response to diverse local and regional water supply and wastewater infrastructure problems. For many cities and states, water conservation proved to be the cheapest and fastest way to address growing demands and to relieve pressure on aging infrastructure. By the early 1990s, 16 states and 6 local jurisdictions had established toilet efficiency standards, all but one at a maximum water use level of 1.6 gallons per flush (gpf) (MaP 2012a). In 1992, toilet manufacturers joined with water and wastewater utilities and environmental organizations to propose national standards in place of the emerging patchwork of state and local regulation. Congress enacted these consensus national water efficiency standards as part of the Energy Policy Act of 1992 (EPAct 1992), signed into law by President George H. W. Bush. The standards apply to all residential and commercial toilets, with some narrow exceptions.

1994/1997 STANDARD

The EPAct 1992 standards set a maximum water use level of 1.6 gpf and took effect in 1994 and 1997 for residential and commercial toilets, respectively. Previously, typical new toilets were rated at 3.5 gpf. Many older toilets used five or even seven gallons per flush.

Figure 26 shows a typical household's annual toilet water use and water and wastewater bill for 3.5 and 1.6 gpf toilets. A household with toilets that just meet the current standards will save more than 8,000 gallons of water per year and $60 on their annual water and wastewater bills compared to a household with typical toilets available before the standards took effect. (Savings vary with flushes per day. A four-person household will save more than 12,000 gallons and $90 per year.)

Figure 26. Annual Water Use and Water and Wastewater Bill for a Household with 3.5 and 1.6 gpf Toilets



Source: DOE (2012c) for water and wastewater price.
Note: Assumes 2.6 persons per household and 4.5 flushes per person per day.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features for the period before the 1994/1997 standards took effect, just after, and in today's market.

- Flush performance
- Bowl cleaning
- Style
- Efficiency
- Price

Flush Performance and Bowl Cleaning

We used three sources to assess toilet performance over time: consumer research conducted for utility program evaluations; *Consumer Reports*' testing; and testing for the Maximum Performance (MaP) program.

Many utilities ran programs in the 1990s incentivizing replacement of installed toilets with 1.6 gpf models. Some utility program evaluations compared the performance of customers' new toilets to that of the toilets replaced. A survey of 1,300 southern California households provides a performance assessment of the thirteen 1.6 gpf toilet models installed by the program compared to the toilets replaced. The survey found that "most customers prefer their new ULF[16] toilets to their old toilets"

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[16] A note on terminology: "low-flow toilets" generally refers to 3.5 gpf products since these toilets, introduced in the 1970s and 80s, generally replaced 5 and 7 gpf models. Thus, manufacturers termed their 1.6 gpf models introduced in the late 1980s and 1990s "ultra-low-flow toilets" or ULF toilets. Toilets that use less than 1.6 gpf are generally called high-efficiency toilets or HETs.

(MWD 1999). In general, consumers found that their new 1.6 gpf toilets clogged less frequently and required less double flushing and brushing than their old toilet. However, consumers reported that three of the thirteen toilet models had inferior performance—they clogged more or required more double flushing or brushing than the toilet replaced.

A study conducted for the San Diego County Water Authority in 1997 assessed consumer satisfaction with their new 1.6 gpf toilets installed under a county program compared to their old toilets that used 3.5 gpf or more. The study found that 93% of consumers said that the new toilets worked as well or better than their old toilets. Just 5% said their new toilet did not work as well as their old one. A similar study from Tampa, FL found that 84-95% of consumers reported that their new toilets performed as well or better than the toilet replaced with respect to double-flushing, bowl cleaning, and mechanical problems. Consumer research from New York City and Los Angeles also found high levels of customer satisfaction. The performance problems reported by a small minority of consumers were associated with particular brands and models (Osann and Young 1998).

Consumer Reports ratings provide another way to assess toilet performance. We reviewed their testing of ultra-low-flow toilets (≤ 1.6 gpf) published in 1990 and 1995 to assess the market before and after the 1994 standard took effect. We used the most recent *Consumer Reports* ratings (September 2012) to assess the current market.

Consumer Reports conducted their first tests of ultra-low-flow toilets in 1990 when they tested 10 products then on the market. Subsequent *Consumer Reports* testing in 1995 and 2012 are not directly comparable to one another or to the 1990 testing because the tests used to assess toilet performance changed. However, a comparison of toilets earning "good" or better marks on key performance attributes provides some sense of the change in performance over time. We compared two attributes assessed by *Consumer Reports* in their 1990, 1995, and 2012 testing: solid waste removal and bowl cleaning. Table 12 below shows that a smaller portion (53%) of tested toilets performed well with respect to solid waste removal immediately after the new standard took effect compared to before the standard (80%). The 1990 testing only assessed ultra-low-flow toilets, but for benchmarking purposes *Consumer Reports* tested a high-sales-volume 5 gpf toilet. *Consumer Reports* found that six of the ten tested ultra-low-flow toilets rated higher than the 5 gpf toilet (*Consumer Reports* 1990b). In the 2012 *Consumer Reports* testing, the portion of tested toilets ranking "good" or better on flush performance and bowl cleaning was about the same as in 1990.

Table 12. Portion of Models Rated by *Consumer Reports* as "Good" or Better on Solid Waste Removal and Bowl Cleaning

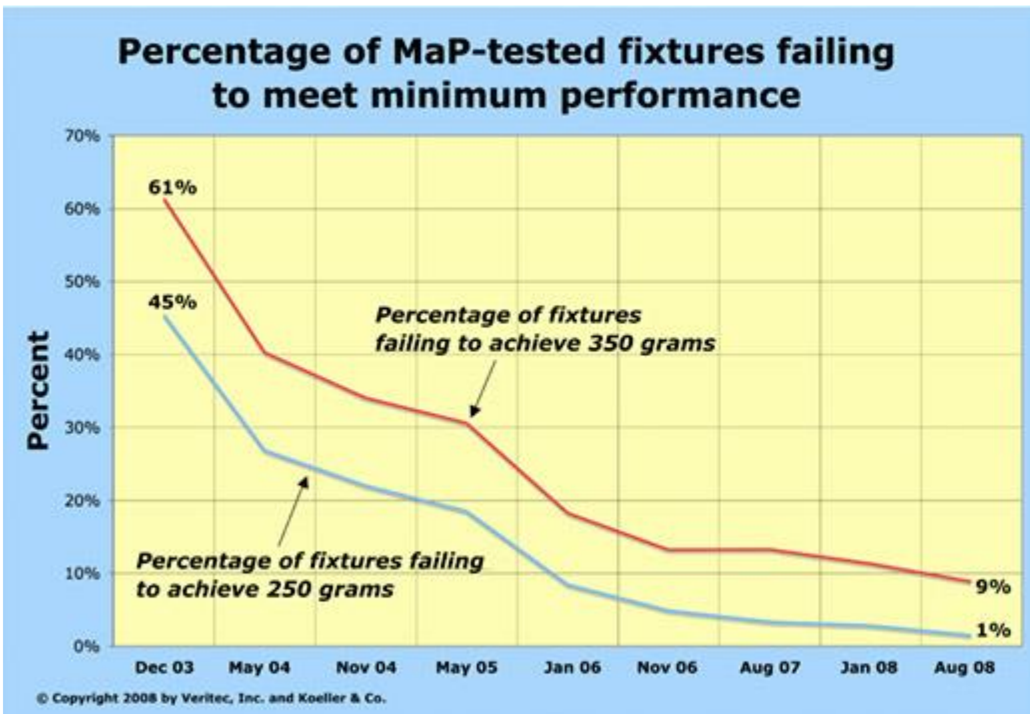
	1990	1995	2012
Solid Waste Removal	80%	53%	81%
Bowl Cleaning	80%	81%	89%

Sources: Authors' analysis of ratings in *Consumer Reports* (1990b, 1995b, 2012g).

The MaP (Maximum Performance) testing data provides a much fuller picture of flush performance in the current market. A consortium led by Canadian and U.S. water and wastewater utilities established the third-party MaP testing program in 2003 to assess toilet performance (MaP 2012a). Under the program, toilet manufacturers voluntarily submit their products for third-party testing for solid waste removal performance. The results are published online and updated on an ongoing basis.[17]

Figure 27 below shows results from the MaP testing over time. Originally, MaP judged products that completely evacuated 250g of test material in a single flush as toilets that would meet consumers' performance expectations. The EPA WaterSense specification set a somewhat more rigorous threshold of 350g. As Figure 27 shows, the portion of tested toilets failing to meet the 250g and 350g thresholds dropped precipitously between 2003 and 2008. By 2008, only 1% of tested toilets did not meet the 250g threshold and only 9% did not meet the 350g threshold.

Figure 27. Portion of Tested Toilets Failing to Meet MaP Thresholds for Flush Performance



Source: MaP

As of 2012, nearly 1,900 toilets had been tested under the MaP program. MaP testing rates each toilet for the amount of waste it can evacuate in a single flush. The average MaP score increased from about 340g when testing began in 2003 to about 800g in 2012 (MaP 2012d). Nearly three-fourths of the MaP certified toilets in late 2012 were rated at 500g or greater and about one-third were rated at 1,000g (MaP 2012c). The MaP data clearly show that today's consumers have an enormous choice of toilets that can more than adequately perform a toilet's basic waste removal function.

[17] See http://www.map-testing.com.

In summary, the data from utility program evaluations and *Consumer Reports* show that many 1.6 gpf toilets performed very well both before and after the 1994/1997 standards took effect. However, a minority of products performed poorly. The *Consumer Reports* testing suggests that the portion of 1.6 gpf products that performed poorly increased somewhat immediately after the standard took effect. Our interviews with industry experts corroborated this increase. Industry experts report that some manufacturers may simply have reduced water use in certain existing models without redesigning their toilets, resulting in poor performance. Others suggest that the lead time provided by the 1992 law (just two years) was inadequate to allow for redesign (MaP 2012a). Although the number of poorly-performing models may have increased temporarily after the new standard took effect, the limited available data suggests that the market has always offered a range of toilets, some with better flushing and bowl cleaning performance than others. For example, *Consumer Reports* evaluated eight toilets rated at 3.5 gpf in 1978 and found a wide range of performance (*Consumer Reports* 1978). In the consumer research conducted in Tampa, a control group that did not install new 1.6 gpf toilets was less satisfied with their toilets' performance than consumers who did, suggesting some performance problems with the higher gpf products. For today's market, the data from MaP demonstrate wide availability of toilets that perform very well at 1.6 gpf and lower levels.

Style

For many consumers, the main choice they consider with respect to toilets concerns bathroom décor. Although many consumers simply want a low-cost, innocuous white toilet, others are looking for models with particular styling and hardware finish. We were unable to systematically assess the range of colors or styles available in toilets over time. However, based on our interviews with industry experts, we found that efficiency performance generally does not impact the styles and features that a manufacturer can offer. One possible exception is toilets with a low-profile design in which the tank is shorter than that of most toilets. The industry experts we interviewed indicated that low-profile designs have always presented a challenge for flush performance, regardless of water consumption.

We examined the availability of single-piece toilets, which is a proxy for low-profile design. Most toilets are manufactured in two pieces: a tank and a bowl that are assembled at installation. Low-profile designs are instead manufactured as a single piece, which eliminates the separation between the tank and the bowl, providing for easier cleaning and a more streamlined appearance. Based on the January 2013 MaP database, 125 single-piece models met the MaP waste removal minimums and 33 of these cleared the maximum test load (1,000g). These data suggest that toilet manufacturers have solved the challenge of low-profile designs, at least for some models. However, single piece designs come with a range of rear tank heights, and models with lower tank heights may have more difficulty generating adequate flushes. Therefore, using online shopping websites, we researched the single-piece toilets listed by MaP. We found a selection of very-low-profile toilets (some with the tank top barely higher than the toilet lid) available from multiple manufacturers that were listed as meeting the minimum MaP performance level; most also met the more demanding WaterSense criteria.

Efficiency

Prior to enactment of the 1994/1997 standard, most new toilets used 3.5 gpf or more and only a few ultra-low-flow toilets (≤ 1.6 gpf) were available. After the efficiency standards took effect, virtually all toilets on the market were certified as exactly compliant with the standard. However, in the late 1990s, toilets with water use lower than the new standard were brought to market. Termed "high-efficiency toilets," these products generally saved about 20% relative to the 1994/1997 standard. Some of these toilets offered a dual flush feature, enabling a light flush (e.g., 0.8 gpf) for liquid waste. In 2004, EPA began to develop a program to promote water-efficient choices modeled on the ENERGY STAR program. EPA launched the WaterSense program in 2006, with toilets as one of the original products. Given the performance issues associated with the introduction of some ultra-low-flow toilets in the previous decade, WaterSense required that toilets bearing the label be both high-efficiency and high-performing. WaterSense certified toilets must save at least 20% compared to toilets just meeting the national standards (i.e., have a maximum water use of 1.28 gpf) and meet a 350g waste removal performance specification using the MaP test protocol.

The number of WaterSense qualified toilets has risen steadily over the past few years. As of December 2012, roughly one-fifth of the toilets certified for sale in California were WaterSense qualified,[18] and the WaterSense website listed more than 1,500 models as compliant with the specification (EPA 2012b). In 2012, 16 out of 26 toilets rated by *Consumer Reports* met WaterSense requirements, including five of the top ten rated products (*Consumer Reports* 2012g). Interestingly, WaterSense certified products perform somewhat better on the MaP flush performance test than other toilets; nearly 50% of WaterSense toilets listed by MaP flushed 1,000g whereas about one-third of all MaP listed toilets flushed 1000g (MaP 2013).

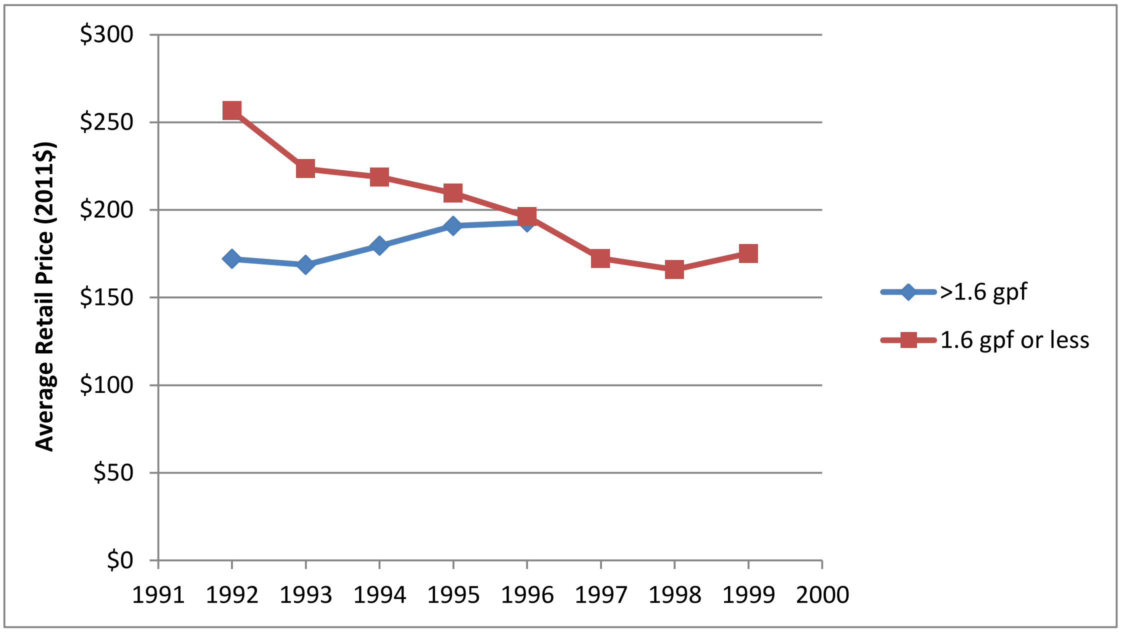
In 2012, the MaP testing program launched a new label, "MaP Premium," to distinguish products with even greater efficiency *and* waste removal performance. At the program's launch in November 2012, 73 toilets representing 22 brands met the MaP Premium maximum flush volume of 1.06 gpf (i.e., approximately 20% and 35% water savings compared to Water Sense and the national minimum standard, respectively) and minimum MaP waste removal of 600g (MaP 2012b).

Price

Figure 28 shows the average retail price of toilets from 1992-1999 (in 2011$). (The U.S. Census Bureau stopped collecting these data in 1999.) The typical new toilet used more than 1.6 gpf prior to the standard taking effect and is represented by the blue line in the figure. In 1992, when Congress established the 1994/1997 standard, the average retail price of a typical toilet was about $170. In 1995, one year after the standard took effect for residential toilets, the average price of a toilet meeting the standard was about $210, or $40 more than a typical toilet in 1992. However, this price increase was not sustained. By 1997, new toilet prices had returned to about the same level as before the standard took effect and remained at that level.

[18] Based on authors' analysis of the CEC Appliance Efficiency Database.

Figure 28. Average Retail Price of Toilets from 1992-1999 (2011$)



Source: Authors' analysis of U.S. Census Bureau Current Industrial Reports data; DOE (2010) for markup.[19]

The data in Figure 28 also show that the price of 1.6 gpf toilets declined from more than $250 in 1992 to about $175 in the late 1990s. These data indicate that 1.6 gpf toilets initially carried a price premium, but that this price premium disappeared soon after the standard took effect.

Current State Standards

Initially, the national toilet efficiency standards preempted state and local requirements. However, preemption of state and local standards subsequently expired and several municipalities (including New York City) and the states of Georgia, Texas, and California have adopted toilet standards based, in part, on EPA's voluntary WaterSense specification (ASAP 2012). These toilets use 20% less water than products that just meet the national standard and must meet flush performance requirements. Based on the information gathered for our assessment of the national standards, it appears that WaterSense qualified toilets offer a similar or better range of consumer choices as non-WaterSense toilets.

Summary of Findings

An average household with toilets that just meet the current standards will save more than 8,000 gallons of water per year and $60 on their annual water and wastewater bills compared to a household with typical toilets available before the standards took effect. Toilets were available with a range of performance, from poor to very good, before and just after the 1994 standards took effect. In the period immediately after the 1994 standards took effect, an increase in poor performance ratings was reported. However, this effect was temporary. Manufacturers responded by eliminating or re-

[19] We assume the markup for toilets is equivalent to the markup for residential electric water heaters since the two distribution channels are similar.

designing poorly-performing models, and the incidence of poorly-performing models declined. Data from today's market show that the market still offers a range of flushing performance, but today's consumers have enormous choice of toilets with excellent flushing performance. The incremental cost of the more-efficient toilets at the time the standards were established had disappeared within two years after the standards took effect. Consumers appear to have the same or greater range of style choices today as compared to just before or after the national standards took effect. Even low-profile designs remain in the market and perform well. Consumers in today's market have more choices in terms of efficiency options than in the 1990s. Consumers can select toilets that use 20-35% less water than allowed by the standard (including dual-flush options) which still provide excellent flushing performance.

General Service Light Bulbs

History and Scope of General Service Lamps Standard

Source: iStockphoto

In 2007, Congress established the first national efficiency standards for general service incandescent lamps (GSILs) as part of EISA. GSILs are the pear-shaped, screw-in light bulbs found in most homes. The standards cover bulbs with a range of light outputs traditionally met by 40-100 watt (W) GSILs.

2012-2014 Standard

The EISA standards divide GSILs into four light output "bins" considered to be equivalent to the four traditional GSIL wattages (40, 60, 75, and 100W) and specify a maximum wattage limit for each bin. To help ensure that efficiency improvements would not come at the expense of poor color quality or shortened lifetime, the standards also require GSILs to have a color rendering index[20] (CRI) greater than or equal to 80 and a minimum rated lifetime of 1,000 hours. The standards are taking effect starting with 100W equivalent lamps over a two-year period (January 2012 – January 2014). EISA exempted 22 types of "specialty" incandescent lamps including appliance, colored, and 3-way lamps. The standard can be met using halogen and halogen infrared technology, which are incandescent technologies that are more efficient than the common incandescent lamps previously sold.

EISA also provides that California may implement the national GSIL standards a year earlier than the national standard effective dates.[21] California adopted all stages of the national standards one year early. Table 13 shows the GSIL standards and the California effective dates.

A lamp that just meets the EISA standards will use about 28% less energy than a traditional incandescent bulb.[22] An average household has about 28 general service lamps, with an average bulb wattage of just over 60W (DOE 2012a). Figure 29 shows an average household's annual electricity bill to operate 28 traditional 60W incandescent lamps compared to 28 replacement

[20] CRI measures the ability of a light source to reproduce the color of various objects faithfully as compared to a natural or ideal light source.

[21] EISA also allowed Nevada to implement the standards earlier, though it opted not to do so.

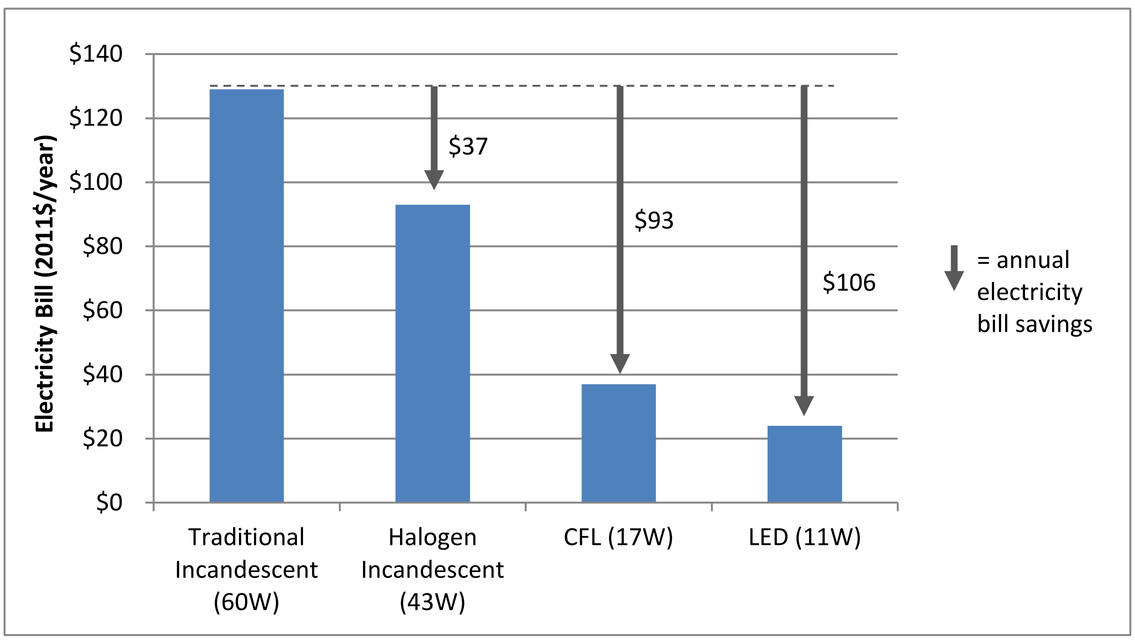
[22] There are interaction effects between lighting energy savings and heating and cooling energy use. However, DOE estimates that these interaction effects in the residential sector are negligible (DOE 2009a).

efficient halogen incandescent lamps just meeting the EISA standard, 28 CFLs, or 28 LEDs. Although the EISA standards do not require CFLs or LEDs, many consumers are choosing these options. A household that replaces 28 traditional incandescent lamps with efficient halogen incandescent lamps just meeting the new standards will save $37 on their annual electricity bill. The annual savings are even greater if a household switches to CFLs ($93) or LEDs ($106).

Table 13. General Service Incandescent Lamp Standards and California Effective Dates

Rated Lumens	Maximum Rated Wattage	Traditional Incandescent Wattage Replaced	Minimum Rated Lifetime	CA Effective Date
1490-2600	72	100	1,000 hrs	1/1/2011
1050-1489	53	75	1,000 hrs	1/1/2012
750-1049	43	60	1,000 hrs	1/1/2013
310-749	29	40	1,000 hrs	1/1/2013

Figure 29. Annual Electricity Bill to Operate 28 60W Traditional Incandescent Lamps Compared to Halogen Incandescent, CFL, and LED Replacements



Source: DOE (2012a) for average daily usage; EIA (2012) for electricity price.

Performance, Features, and Price

Because the national standards are not yet fully implemented, we examined the market reaction to the California standards as an early indication of available replacement lamps. Furthermore, since the California standards affecting 60W and 40W lamps were phased in on January 1, 2013, we focused on 100W and 75W traditional incandescent lamps and replacement lamps. We analyzed the following performance attributes and product features for traditional incandescent lamps and replacement lamps:

- Light output
- Light color
- Dimmability
- Lifetime
- Efficiency
- Price

Traditional incandescent lamps have a lifetime of approximately 1,000 hours and are dimmable. In terms of light color, traditional incandescent lamps are the standard bearer for both lamp color emitted and the color rendered. Light color is measured by Correlated Color Temperature (CCT), which describes the coolness or warmness of the light. General service lamps have CCTs between 2700K (warm) and 6500K (cool), but most consumers are used to 2700-3000K lamps in their homes. Color rendering, measured by the Color Rendering Index (CRI), describes how true colors appear under a light source. A CRI of 100 is the maximum level achievable and indicates that the light source renders colors in the same way as the reference light source (an incandescent lamp). All traditional incandescent lamps and halogen incandescent lamps have a CRI of 100. All ENERGY STAR qualified general service LEDs and CFLs are required to have a CRI of at least 80 and (with only two exceptions as discussed below) all LEDs and CFLs considered in this analysis are ENERGY STAR qualified. A CRI of 80 or higher is considered acceptable for residential lighting. Because of this, in determining color quality of GSIL alternatives, we examined CCT only.

We examined the features and performance attributes of lamp models available as replacements for 100W and 75W traditional incandescent lamps. We define replacement lamps as those with light output levels within ±15% of the average light output of traditional incandescent lamps.[23] Table 14 shows the number of 100W equivalent models by technology type; number of models added since the effective date of the California GSIL standard; number of dimmable bulbs; and other product features. The data represent a conservative estimate of available models that is not presumed to be exhaustive.[24]

We identified 1,121 different 100W equivalent models (i.e., lamps with light output levels within ±15% of the average light output of traditional 100W incandescent lamps), 355 (32%) of which were introduced since the standard took effect in California. Prior to the development of the EISA standards, no 100W equivalent efficient halogen incandescent or LED lamps were available. Since then, major manufacturers such as GE, Philips, and Osram Sylvania have released efficient halogen incandescent alternatives with all the performance attributes of traditional incandescent lamps including 1,000 hour lifetime, excellent color quality, and dimmability. Osram Sylvania and Philips have also introduced 100W equivalent LED lamps since the implementation of the

[23] The average light outputs of 100W and 75W traditional incandescent lamps from the three major manufacturers (GE, Philips, and Osram Sylvania) are 1,667 lumens and 1,173 lumens, respectively.

[24] For example, there are likely CFL or LED lamps that are not ENERGY STAR qualified and were therefore not included in this analysis.

California standard, and GE is expected to release its version in 2013. Overall, the replacement lamps provide a wide range of features and performance attributes. Of the 1,121 lamps we identified, 55 are dimmable (including all the halogen incandescent and LED lamps), efficacy ranges from 21-83 lumens/watt, CCT ranges from 2700-6500K, and lifetime ranges from 1,000 hours (halogen incandescents) up to 25,000 hours (LEDs).

Table 14. Available 100W Equivalent Lamps and Features

	Halogen Incandescents	CFLs	LEDs	Total
100 W Equivalent Lamps (1417-1917 lumens)	6	1,113	2	1,121
Introduced Since January 1, 2011	6	347	2	355
Dimmable	6	47	2	55
Wattage (W)	72	19-26	20-22	19-72
Correlated Color Temperature (K)	2700-3000	2700-6500	2700	2700-6500
Lifetime (hours)	1,000	1,000-20,000	25,000	1,000-25,000
Efficacy (lumens/watt)	21	57-83	80-81	21-83

Sources: CEC Appliance Efficiency Database (queried December 7, 2012), ENERGY STAR Qualified Products List (queried December 7, 2012), Lowe's website (lowes.com), and Home Depot website (homedepot.com)

Table 15 below shows similar data for 75W equivalent models.

Table 15. Available 75W Equivalent Lamps and Features

	Halogen Incandescents	CFLs	LEDs	Total
75 W Equivalent Lamps (997-1349 lumens)	3	664	3	670
Introduced Since January 1, 2012	1	75	3	79
Dimmable	3	20	3	26
Wattage (W)	53	9-20	14-16	9-53
Correlated Color Temperature (K)	2950	2700-6500	2700-3000	2700-6500
Lifetime (hours)	1,000	6,000-15,000	25,000	1,000-25,000
Efficacy (lumens/watt)	20	52-76	69-80	20-80

Sources: CEC Appliance Efficiency Database (queried December 7, 2012), ENERGY STAR Qualified Products List (queried December 7, 2012), and Lowe's website (lowes.com)

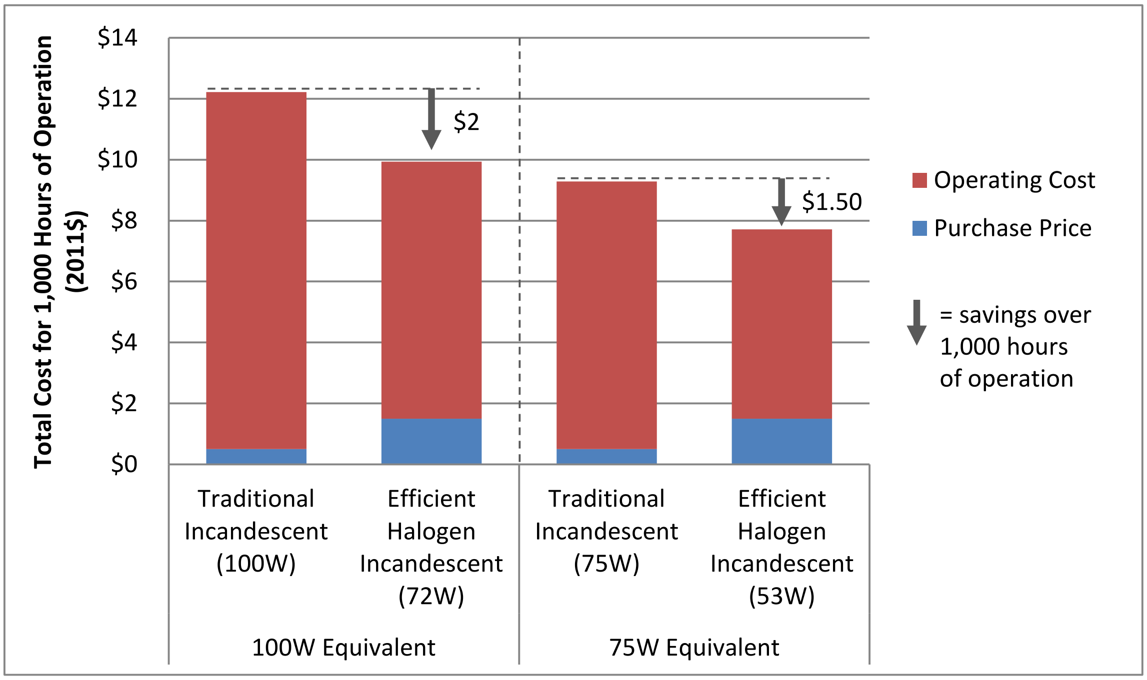
We identified 670 different 75W equivalent models (i.e., lamps with light output levels within ±15% of the average light output of traditional 75W incandescent lamps), 79 (12%) of which were introduced since the 75W standard took effect in California. As in the case of 100W equivalent lamps, 75W equivalent LED lamps were not available until the standard took effect. Three LED lamps are currently available. Of the 670 lamps we identified, 26 are dimmable (including all the halogen incandescent and LED lamps), efficacy ranges from 20-80 lumens/watt, CCT ranges from 2700-6500K, and lifetime ranges from 1,000 hours (halogen incandescents) up to 25,000 hours (LEDs).

The effects of the GSIL standards have been quite dramatic. Efficient halogen incandescent technology has emerged as a direct result of the standards, providing the same light output, 1,000 hour lifetime, color quality, and dimmability previously associated with traditional incandescent lamps, while using approximately 28% less energy. Consumers replacing traditional incandescents with CFLs now have significantly more options than before, with 347 100W equivalent CFL models and 75 75W equivalent CFL models being introduced since the respective standards were implemented. And consumers looking for LED alternatives now have options at the 100W and 75W levels where none existed before. While LEDs contain many attributes that would be appealing to consumers irrespective of efficiency standards (e.g., energy savings and long lifetime), the standards appear to have at the very least hastened the introduction of 100W and 75W equivalent LEDs.

Price

The elimination of 100W and 75W traditional incandescent lamps removed the least expensive bulbs from the U.S. market. Prior to the standards taking effect, incandescent lamps could be purchased for around $0.50 each. In their absence, halogen incandescent lamps just meeting the standards provide the next lowest purchase price option at around $1.50 per lamp. Despite the increase in purchase price, however, the energy savings associated with halogen incandescent replacements more than make up for the additional initial cost. Figure 30 below shows the total cost (purchase price plus operating cost) for 1,000 hours of operation for 100W and 75W traditional incandescent lamps and their respective halogen incandescent replacements. The 1,000 hour total cost for a 100W traditional incandescent lamp is about $12 compared to $10 for the halogen incandescent replacement, or a savings of about $2 per bulb. The savings for a 75W equivalent halogen incandescent replacement are about $1.50 per bulb.

Figure 30. Comparison of Total Cost for 1,000 Hours of Operation for 100W and 75W Equivalent Bulbs



Sources: NRDC (2011) for purchase price; EIA (2012) for electricity price.

Consumers also have the option to purchase highly efficient CFL or LED replacements. These technologies have higher purchase prices but offer significantly longer lifetimes and can use up to 75-80% less energy than traditional incandescent lamps. The price of a CFL is about $3 (NRDC 2011). CFLs sold in multi-packs are often cheaper—as low as about $1.50 per lamp.[25] Average LED prices at the 100W and 75W equivalent levels are currently about $53 and $37, respectively, but according to DOE, LED prices have been declining rapidly and will continue to do so. DOE projects that the price of warm white LED packages ($/lumen) will decrease by 80% between 2011 and 2015 (DOE 2012b). In March 2012, a major LED manufacturer, Cree, announced a 60W equivalent lamp selling at under $13,[26] and multiple manufacturers offer 40W equivalent lamps under $10,[27] suggesting that prices for LEDs are dropping even faster than DOE expected.

Despite the significantly higher purchase price of LEDs, with a lifetime of up to 25,000 hours, LEDs are still a more cost-effective purchase option compared to traditional incandescent and halogen incandescent lamps. Figure 31 below shows the total cost (purchase price plus operating cost) for 20,000 hours of operation for a 100W traditional incandescent lamp and halogen incandescent, CFL, and LED replacements. For 20,000 hours of operation, a consumer would need to purchase 20 traditional incandescent or halogen incandescent lamps versus only two

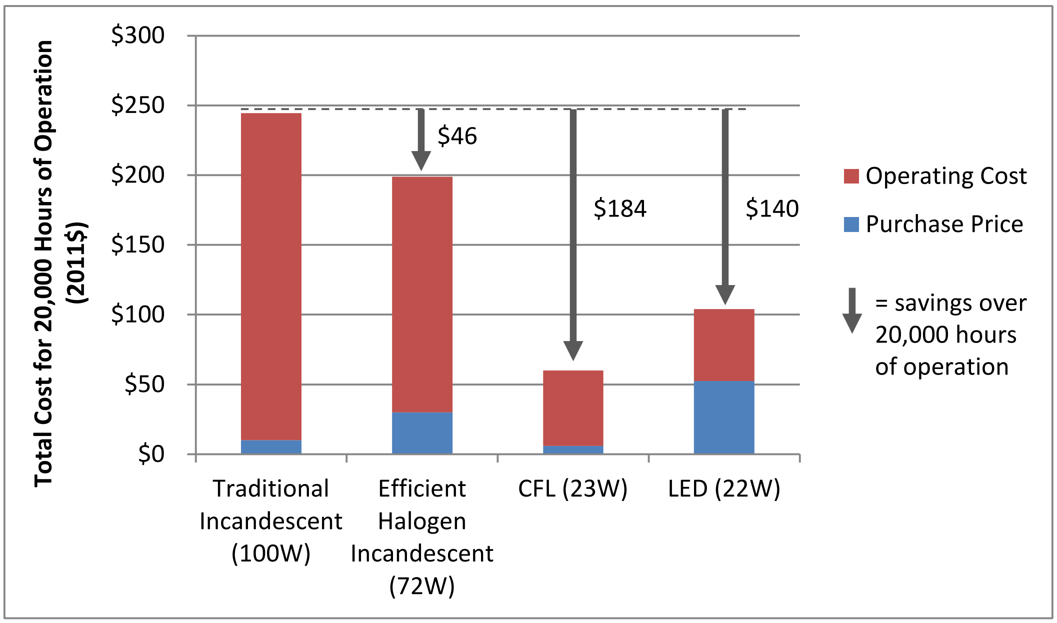
[25] For example, 4-packs of Philips 75W and 100W equivalent CFLs were listed at $6.47 on Home Depot's website in March 2013.

[26] See http://www.cree.com/news-and-events/cree-news/press-releases/2013/march/bulbs.

[27] 40W equivalent LEDs from Cree, Feit Electric, and EcoSmart were all listed at $9.97 on Home Depot's website in March 2013.

CFLs or one LED lamp due to the significantly longer lifetimes of CFLs and LEDs. A consumer would pay a total cost of about $245 for 20,000 hours of operation with traditional incandescent bulbs (purchase price of 20 bulbs plus electricity cost). The total cost for the same 20,000 hours operation with halogen incandescent replacements would be about $200, for a savings of $46. Total savings with CFLs or LEDs are significantly greater—$184 and $140, respectively. These savings represent savings over 20,000 hours of operation from replacement bulbs in just a single socket—total household savings would be much larger.

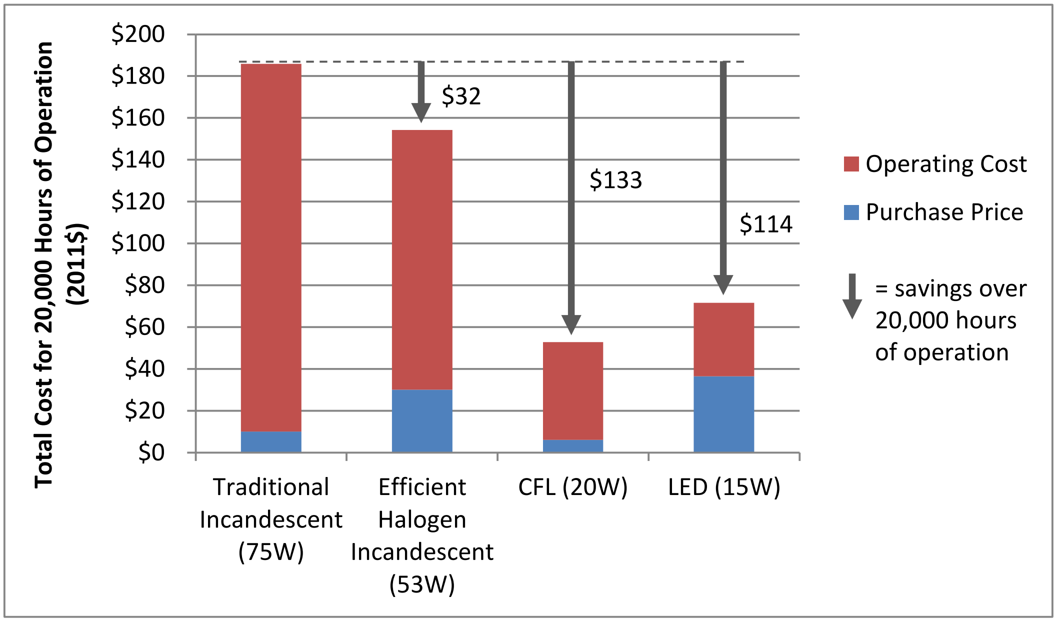
Figure 31. Comparison of Total Cost for 20,000 Hours of Operation for 100W Equivalent Bulbs



Sources: NRDC (2011) for incandescent, halogen, and CFL purchase prices; Lowes.com and Homedepot,com for LED purchase price; EIA (2012) for electricity price.

Figure 32 below shows a similar comparison for 75 W equivalent bulbs. A consumer would pay a total cost of about $185 for 20,000 hours of operation with traditional incandescent bulbs (purchase price of 20 bulbs plus electricity cost). The total cost for the same 20,000 hours operation with halogen incandescent replacements would be about $155, for a savings of $32. Total savings with CFLs or LEDs are significantly greater—$133 and $114, respectively.

Figure 32. Comparison of Total Cost for 20,000 Hours of Operation for 75W Equivalent Bulbs



Sources: NRDC (2011) for incandescent, halogen, and CFL purchase price; Lowes.com and Homedepot,com for LED purchase price; EIA (2012) for electricity price.

The Next Standard

EISA directs DOE to initiate a rulemaking by January 1, 2014 to consider a broader standard for “general service lamps” (GSLs), which include GSILs, CFLs, LEDs, organic LEDs, and any other lamps determined to satisfy lighting applications traditionally served by GSILs. DOE must complete this rulemaking no later than January 1, 2017, with an effective date no earlier than three years after publication of the final rule.

Summary of Findings

A household that replaces 28 traditional 60W incandescent lamps with efficient halogen incandescent lamps just meeting the 2012-2014 standards will save about $37 on their annual electricity bill. The savings are even greater if a household switches to CFLs ($93) or LEDs ($106). Since the implementation of the standards in California affecting 100W and 75W traditional incandescent lamps, consumers appear to have more choices in both 100W and 75W equivalent lamps. Efficient incandescent halogen lamps, which have emerged as a direct result of the standards, have a modest purchase price and provide the same light output, 1,000 hour lifetime, color quality, and dimmability as traditional incandescent lamps, while using approximately 28% less energy. Consumers now have significantly more CFL options, with many models having been introduced since the standards took effect. And manufacturers have introduced 100W and 75W equivalent LEDs, which were previously unavailable. Over 1,000 hours of operation, efficient halogen incandescent lamps will save consumers $2 and $1.50 in total cost, respectively, for a 100W or 75W equivalent bulb compared to a traditional incandescent lamp. While CFLs and LEDs have higher purchase prices, over 20,000 hours of operation, 100W equivalent CFLs or

LEDs will save a consumer $184 and $140 in total cost, respectively, compared to a series of shorter-lived 100W traditional incandescent lamps.

Incandescent Reflector Lamps

HISTORY AND SCOPE OF INCANDESCENT REFLECTOR LAMPS STANDARD

In 1992, Congress established the first national efficiency standards for certain types of incandescent reflector lamps (IRLs) as part of EPAct 1992, which took effect in 1995. IRLs are the cone-shaped light bulbs most typically used in track lighting and "recessed can" light fixtures. The cone is lined with a reflective coating to direct the light. Parabolic aluminized reflector (PAR) lamps are now the most common type of IRL; other common IRLs include "blown" PAR (BPAR) lamps, which are designed to be a low-cost substitute for PAR lamps, and "bulged" reflector (BR) lamps. The EPAct 1992 standards covered IRLs with wattages from 40-205W. The standards excluded lamps with elliptical reflector (ER) and BR bulb shapes and lamps with diameters of 2.75 inches or less. EPAct 1992 also directed DOE to conduct two cycles of rulemakings to determine whether the initial standards should be amended.

Source: Philips Electronics

EISA expanded the definition of IRLs to include lamps with a diameter between 2.25 and 2.75 inches and ER, BR, and bulged parabolic aluminized reflector (BPAR) lamps. EISA applied the 1992 standards to these bulb shapes as of January 1, 2008, and to lamps with diameters between 2.25 and 2.75 inches as of July 15, 2008. However, the EISA standards exempted several types of IRLs including ER30, BR30, BR40, and ER40 lamps[28] rated at 50W or less; BR30, BR40, and ER40 lamps rated at 65W; and R20 lamps rated at 45W or less from the standards.

2012 STANDARD

DOE published a final rule for IRLs in 2009, amending the EPAct 1992 standards and completing the first required rulemaking cycle. The amended standards took effect on July 14, 2012. The 2012 standards include separate minimum efficacy requirements (lumens per watt) depending on lamp spectrum, lamp diameter, and rated voltage. Modified-spectrum lamps produce light color that is often described as replicating natural daylight. To achieve this effect, a portion of the light emission is absorbed by the coating, resulting in a decrease in efficacy. Because of this, the standard distinguishes between standard-spectrum lamps and modified-spectrum lamps and allows modified-spectrum lamps to meet a less stringent efficacy requirement. The standards are further divided based on lamp diameter and rated voltage to account for the impacts of these product features on efficacy. On average, the 2012 IRL standards increased the minimum efficacy requirement from 14 lumens per watt (lpw) to 19 lpw, which represents a 26% reduction in energy use for a given light output.[29]

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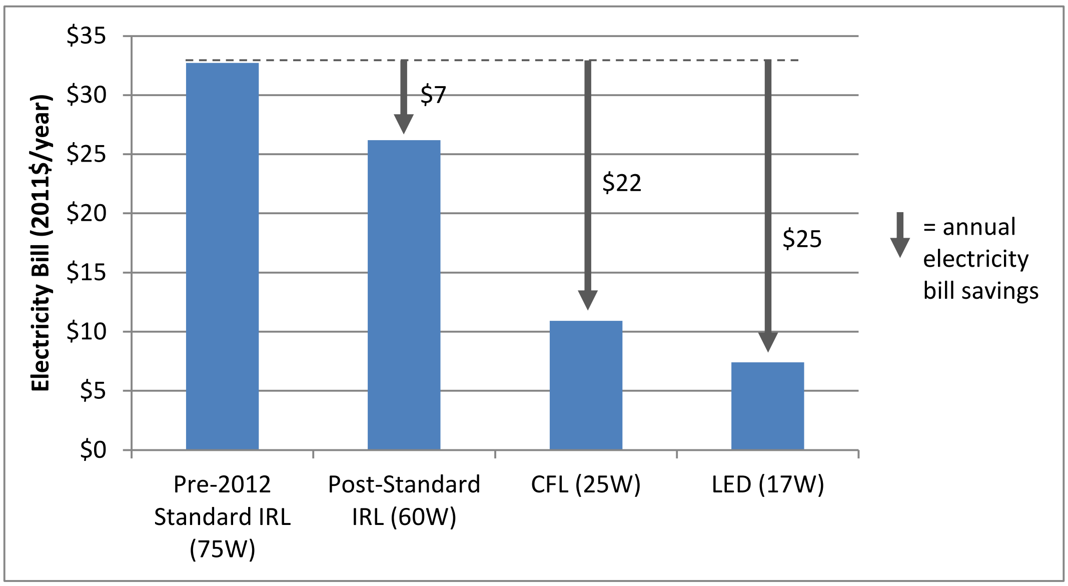
[28] The number after the reflector style is the diameter of the lamp expressed in eighths of an inch. For example, ER30 is 30x1/8" or 3-3/4" in diameter.

[29] There are interaction effects between lighting energy savings and heating and cooling energy use. In the residential sector, DOE estimates that these interaction effects are negligible. In the commercial sector, DOE estimates that reductions in

An average household has about six reflector lamps, with an average bulb wattage of about 69W (DOE 2012a). Figure 33 below shows an average household's annual electricity bill to operate six pre-standard 75W IRLs (closest common IRL wattage to the 69W average) compared to an average household's annual electricity bill to operate six 75W equivalent post-standard IRLs (60W lamps), and 75W equivalent CFL and LED reflector lamps. The standards do not require CFL or LED lamps, but some consumers are choosing to switch to these lamp types. An average household using six pre-standard 75W IRLs would spend approximately $33 on annual electricity costs. A household would save about $7 on their annual electricity bill by replacing these six 75W IRLs with six post-standard 60W IRLs. The annual savings are greater if a household switches to CFLs ($22) or LEDs ($25).

Figure 33. Annual Household Electricity Bill to Operate Six Pre-2012 Standard 75W IRLs Compared to Post-Standard 60W IRLs and CFL and LED Equivalents



Sources: DOE (2012a) for average daily usage; EIA (2012) for electricity price.

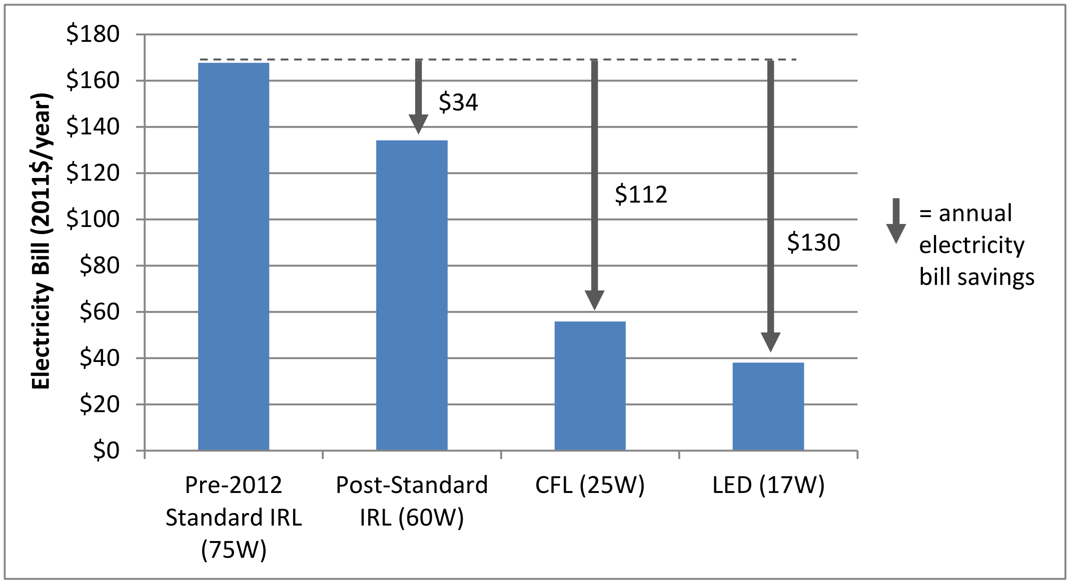
Savings from the 2012 standards for commercial customers are even greater. An average commercial building has 14 reflector lamps, and average operating hours are significantly longer in the commercial sector than in the residential sector (10 hours/day vs. 2 hours/day) (DOE 2012a).

Figure 34 below shows an average annual electricity bill for a commercial customer to operate 14 pre-standard 75W IRLs compared to an average annual electricity bill for a commercial customer to operate 14 75W equivalent post-standard IRLs (60W), and 75W equivalent CFL and LED reflector lamps. Prior to the implementation of the 2012 IRL standard, an average commercial customer using 14 pre-standard 75W IRLs would spend about $170 on annual electricity costs. A commercial customer would save about $34 on their annual electricity bill by replacing these 14 75W IRLs with 14

lighting energy use reduce overall HVAC energy consumption (DOE 2009a). In this analysis, we do not account for these additional HVAC energy savings in the commercial sector.

post-standard 60W IRLs. The annual savings are significantly greater if the replacements are instead CFLs ($112) or LEDs ($130).

Figure 34. Average Electricity Bill for a Commercial Customer to Operate 14 pre-2012 Standard 75W IRLs Compared to Post-Standard 60W IRLs and CFL and LED Equivalents



Sources: DOE (2012a) for average daily usage; EIA (2012) for electricity price.

Performance, Features, and Price

We examined the following performance attributes and product features of IRLs available in 2009, when the 2012 standard was established, and in 2012, when the standard took effect:

- Light output
- Light color
- Dimmability
- Lifetime
- Efficiency
- Price

In their most basic form, IRLs are incandescent lamps with reflective coatings, commonly composed of aluminum applied to the bulb surface. Prior to the 2012 standards, baseline IRLs typically enclosed the filament in a capsule filled with halogen gas; produced about 14 lumens per watt; had a lifetime between 1,500 and 3,000 hours; and were all dimmable (DOE 2009a). To achieve the efficacy levels set by the 2012 standards, IRLs now employ halogen infrared technology that uses special coatings inside the halogen capsule to reflect infrared light back onto the filament. As a result, the operating temperature increases, resulting in greater light output for a given wattage—about 19 lumens per watt with a lifetime of up to 4,000 hours. IRLs that meet the 2012 standards are dimmable and have similar color characteristics as pre-standard IRLs.

We examined the features and performance attributes of IRLs that meet the 2012 standards as well as CFL and LED reflector lamps, which can be used as replacements for pre-standard IRLs. We considered CFLs and LEDs with light outputs within the same range of available light outputs of IRLs. Table 16 below shows the number of reflector lamps by technology type; number of models added since the 2012 standards took effect; number of dimmable bulbs; and other product features. The data represent a conservative estimate of available models that is not presumed to be exhaustive.

Table 16. Available Reflector Lamps and Features

	IRLs	CFLs	LEDs	Total
Reflector Lamps	536	707	916[30]	2,159
Introduced Since July 14, 2012	53	62	323	438
Dimmable	536	61	810	1,407
Light Output (lumens)	420-2210	430-1400	420-1650	420-2210
Correlated Color Temperature (K)	2700-3000[31]	2700-6500	85-4100	85-6500
Lifetime (hours)	1,000-4,000[31]	6,000-20,000	15,000-50,000	1,000-50,000
Efficacy (lumens/watt)	11-24	32-61	50-88	11-88

Sources: Authors' analysis of CEC Appliance Efficiency Database and ENERGY STAR Qualified Product List queried December 19, 2012, manufacturer websites.

We identified 2,159 reflector lamp models that are either certified as meeting the 2012 standards or not currently subject to standards (CFLs and LEDs). More than 40% of these models (916) were LEDs, 707 were CFLs, and 536 were IRLs. Of the 438 models added since the 2012 standards took effect, 323 (74%) were LEDs, 62 (14%) were CFLs, and 53 (12%) were IRLs. Many complying IRLs and CFLs were on the market before the standard was set. With regard to features, all of the IRLs, 61 CFLs, and 810 LEDs are dimmable; light output ranges from 420-2210 lumens; efficacy ranges from 11-88 lumens/watt; CCTs are available from 85-6500K; and lamp lifetimes range from 1,000-50,000 hours. Overall, these available reflector lamps show significant consumer choice with regard to both lighting technology and available features, with light output, CCT, lifetime, and dimmability either comparable to or better than the pre-standard baseline IRLs.

The emergence of LED technology in this lighting category is significant. Based on the reflector lamps we identified, LEDs represent the greatest number of models and are also the fastest-growing technology. Two factors appear to be fostering LED growth in this category. First, LEDs emit light in a specific direction, which makes them very conducive to directional lighting. Second, manufacturers appear to be convinced that LED technology in the directional lighting market will sell and are altering their product offerings accordingly.

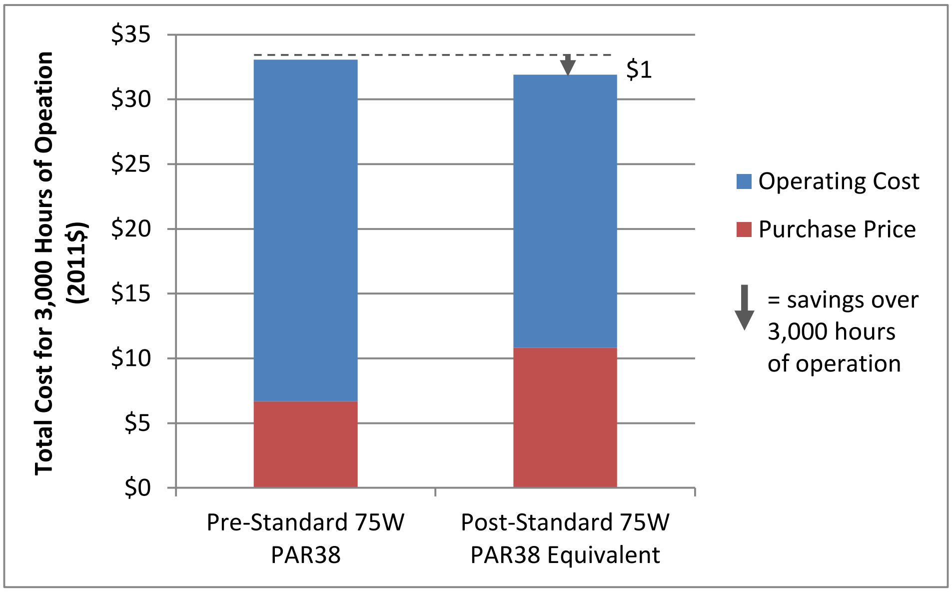
[30] We excluded one LED lamp which appears to be an outlier and is listed as having a rated efficacy of 10 lumens/watt.

[31] CCT and lamp lifetime for IRLs were not listed in the CEC database. However, in general, IRLs listed on various lighting websites have CCTs ranging from 2700-3000K and lifetimes from 1,000-4,000 hours.

Price

Figure 35 below shows the total cost (purchase price plus operating cost) for an average household for 3,000 hours of operation for a pre-standard 75W PAR38 lamp and a post-standard 75W PAR38 equivalent lamp.[32] The post-standard lamp uses 60 watts, but has the same light output (1,100 lumens) as the 75W pre-standard lamp (1,050 lumens). The total cost for the pre-standard lamp is about $33 compared to $32 for the post-standard lamp, or a savings of about $1 per bulb.

Figure 35. Comparison of Total Cost of Pre-Standard and Post-Standard 75W Equivalent PAR38 Lamps for 3,000 Hours of Operation



Sources: DOE (2009a, 2013b) for purchase price and lifetime; EIA (2012) for electricity price.

The Next Standard

DOE initiated a rulemaking in 2011 to consider amending the 2012 IRL standards, which will fulfill the second rulemaking cycle as required by EPAct 1992. DOE must publish a final rule by July 2014.

Summary of Findings

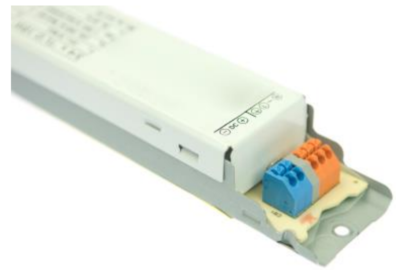
A household that replaces six pre-standard 75W PAR38 IRLs with post-standard IRLs just meeting the 2012 standard will save about $7 on their annual electricity bill. The annual savings are greater if a household switches to CFLs ($22) or LEDs ($25). A typical commercial customer, with 14 IRLs and longer operating hours, will save about $34 on their annual electricity bill by replacing 14 pre-standard 75W IRLs with post-standard lamps. Annual savings for the same commercial customer would be $112 and $130, respectively, by switching to CFLs or LEDs. Post-standard IRLs provide the same light output, lifetimes, color quality, and dimmability as pre-standard IRLs, while using approximately 20-25% less energy. LEDs, which are very conducive to directional lighting, are the fastest-growing category of directional lamps, and more than 300 models of LED reflector lamps have

[32] We used DOE's "medium" price estimates. The post-standard lamp has a longer rated lifetime (3,000 hours) than the pre-standard lamp (2,500 hours). We adjusted the price of the pre-standard lamp by the ratio of the lifetime of the post-standard lamp to that of the pre-standard lamp.

been introduced since the 2012 standards took effect. While prices of IRLs have increased since the implementation of the 2012 standards, the electricity bill savings outweigh the additional initial cost.

Fluorescent Lamp Ballasts

History and Scope of Ballast Standards



Source: iStockphoto

Fluorescent lamp ballasts provide the high voltage necessary to start fluorescent lamps and regulate the current provided to the lamps to produce even light. For many years, ballasts were essentially an electric magnet, with a steel core and wire wound around the core. The original ballasts gave off a lot of heat, resulting in about 5W in power losses per four-foot lamp controlled. In the 1970s, efficient magnetic ballasts were developed with higher-grade steel cores and better and more wire, reducing losses to about 2W per four-foot lamp controlled. In recent decades, ballasts based on electronic semi-conductors have become more common and now dominate the market. These ballasts drive lamps at high frequency (alternating current [AC] power that cycles much more rapidly than normal AC power). Electronic ballasts are inherently more efficient than magnetic ballasts; furthermore, lamps also operate more efficiently at high frequency than at low frequency.

Minimum efficiency standards have played a significant role in the evolution of ballast efficiency. The first ballast efficiency standards were established by states, setting performance levels that could be met by efficient magnetic ballasts. Driven by a patchwork of state standards, manufacturers and energy efficiency proponents developed a consensus recommendation for national ballast efficiency standards. In 1988, these stakeholders went to Congress and a law was quickly enacted (3 months after the initial introduction of the bill) and signed by President Reagan. The law, which took effect in 1990, established initial ballast efficiency standards based on efficient magnetic ballasts. The law also directed DOE to conduct two cycles of rulemakings to consider amending the initial standards and to consider adopting new standards for additional types of ballasts.

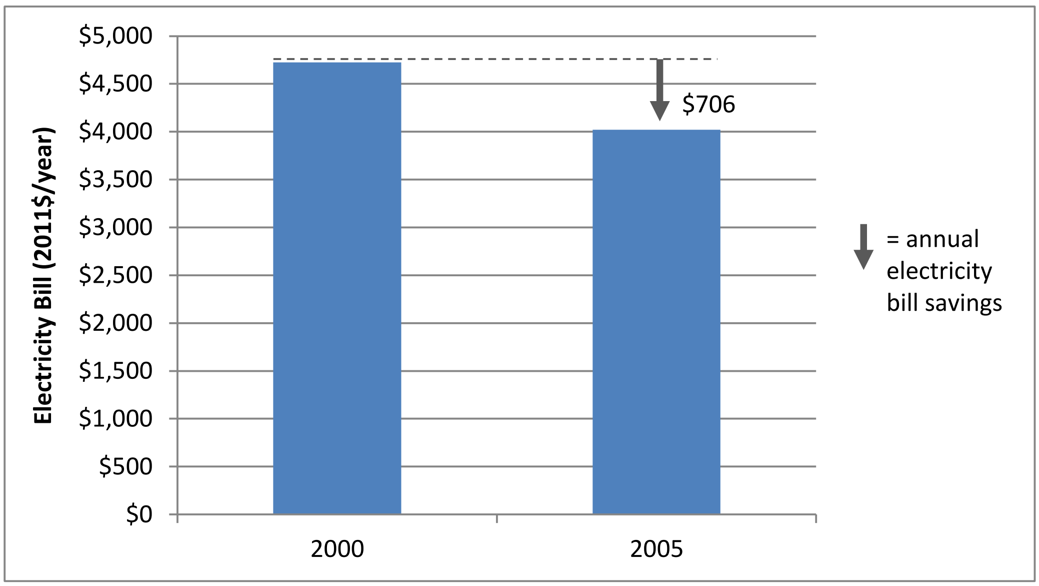
The initial standards covered ballasts that operated the most commonly used lamps in commercial and industrial facilities: 1- and 2-lamp ballasts for four-foot and eight-foot T12 lamps (T12 indicates 12 eighths of an inch in diameter, i.e., 1.5 inches). The initial standards did not cover ballasts designed only for use in residential applications, dimmable ballasts, or ballasts designed to operate at temperatures below 0°F.

2005/2010 Standard

DOE published a final rule in 2000 amending the initial ballast standards based on an agreement negotiated between ballast manufacturers and energy efficiency proponents. The new efficiency standards could be met by most electronic ballasts, but not by magnetic ballasts. The standards applied to ballasts used in new lighting fixtures starting in July 2005, and all ballasts (including replacement ballasts) as of July 2010. The earlier effective date for new fixtures encouraged the use of high-efficiency fixtures that contained T8 ballasts and lamps, helping to accelerate a market shift to the thinner, more efficient T8 lamps. The later effective date for replacement ballasts allowed time so that ballasts could be replaced when the existing T12 lamps reached the end of their life, reducing the incremental cost of these changes.

Commercial buildings have an average of about 300 linear fluorescent lamps (DOE 2012a). Assuming all these lamps are part of two-lamp fixtures, an average commercial building has about 150 lamp-and-ballast systems. Figure 36 below shows an average commercial customer's annual electricity bill to operate 150 lamp-and-ballast systems for two four-foot T12 lamps using ballasts just meeting the standards in 2000 and 2005 based on today's electricity prices. A commercial building owner with 150 lamp-and-ballast systems using ballasts just meeting the current standards would save about $700 on their annual electricity bill compared to ballasts that just meet the 2000 standards.[33]

Figure 36. Annual Electricity Bill for a Commercial Customer to Operate 150 Lamp-and-Ballast Systems for Two Four-Foot T12 Lamps in 2000 and 2005



Sources: McMahon et al. (2000) for energy use; EIA (2012) for electricity price.

In response to the 2005/2010 standards, many customers chose to switch to T8 lamp-and-ballast systems rather than simply replacing their T12 ballasts with more-efficient T12 ballasts. The annual electricity bill savings for these customers would be significantly greater than the savings shown in Figure 36.

Performance, Features, and Price

We examined the following performance attributes and product features of ballasts available before and after the 2005/2010 standards took effect:

- Ballast factor

[33] There are interaction effects between lighting energy savings and heating and cooling energy use. In the commercial sector, DOE estimates that reductions in lighting energy use reduce overall HVAC energy consumption (DOE 2009a). In this analysis, we do not account for these additional HVAC energy savings.

- Lifetime
- Additional features
- Efficiency
- Price

Ballast Factor

Ballast factor indicates the proportion of light that a lamp-ballast combination delivers relative to a lamp's rating. A ballast factor of .88, which is a common level, means that actual light output is 88% of rated output, with power consumption also about 12% lower than rated power. In recent years, manufacturers began to routinely produce ballasts with a range of ballast factors to provide end-users and lighting designers with the ability to fine tune lighting levels by installing ballasts of the appropriate ballast factor. For example, ballast factors of about .77 and .87 are useful for small rooms and other applications where over-lighting can occur, while ballast factors of about 1.18 are useful for applications where more light is needed than the rated light output of the lamp, but not enough to justify adding another fixture. With varying ballast factors, end-users and lighting designers can better match light output to lighting needs while continuing to use the same lamps and fixtures. While standards did not directly cause the increase in available ballast factors, according to one industry expert we interviewed, manufacturers compete in part on energy savings, and with the increase in baseline ballast efficiency due to the standards, manufacturers sought additional ways to offer energy savings; producing a range of ballast factors is one way they do so.

Lifetime

We examined whether there was any difference in ballast lifetime between ballasts available before and after the 2005/2010 standards took effect. It has been suggested that because electronic ballasts give off less heat than magnetic ballasts, they might last longer. DOE looked into this issue as part of a recent ballast rulemaking finalized in 2011, but could not find evidence of any difference in lifetime between magnetic and electronic ballasts. In both the 2000 final rule and the recent 2011 rulemaking, DOE assumed that magnetic and electronic ballasts both have an average lifetime of about 50,000 run-time hours (DOE 2011a). One industry expert we interviewed corroborated DOE's assumption regarding the equivalency of ballast lifetimes before and after the 2005/2010 standards. It appears that manufacturers have selected electronic components that result in a lifetime of about 50,000 hours. Longer lifetimes are technically possible, but would require more expensive components.

Additional Features

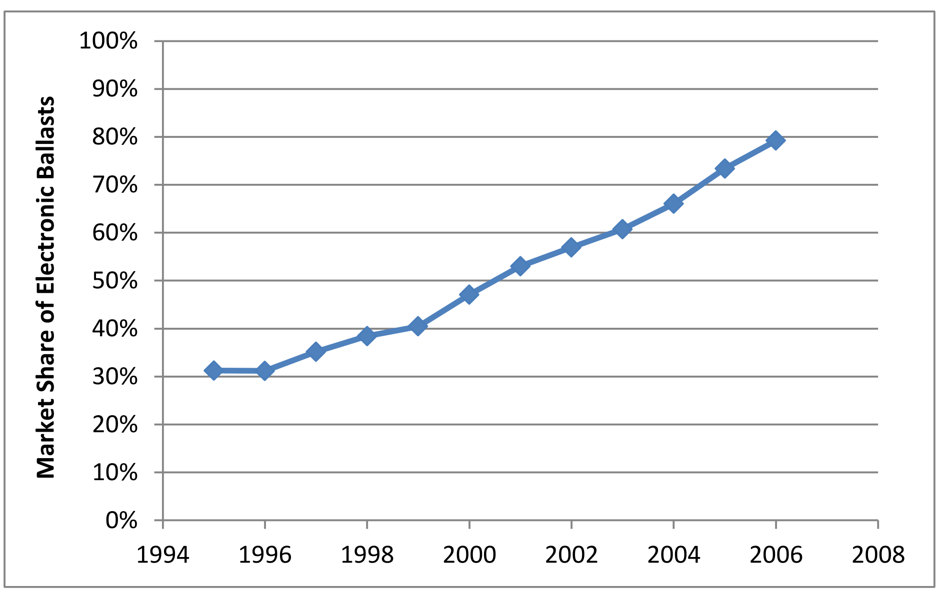
As noted above, the 2005/2010 standards effectively required that ballasts covered by the standard be electronic since magnetic ballasts could not meet the minimum efficiency levels. Electronic ballasts offer at least three advantages to consumers over magnetic ballasts. First, magnetic ballasts operate at 60 cycles per second, producing a flicker that can be visible, while electronic ballasts operate at a much higher frequency (20,000 cycles per second or more) and do not flicker. Second, magnetic ballasts sometimes produce a humming noise due to vibration of the magnetic core, while electronic ballasts are generally much quieter (NLPIP 2000). Finally, magnetic ballasts are somewhat heavier than electronic ballasts; a typical 2-lamp magnetic ballast for four-foot lamps weighs about 2 lbs.,[34] while an equivalent electronic ballasts weighs about 1.7 lbs.[35]

One industry expert we interviewed noted that ballast warranties have increased since 2000, when the current standards were established. Manufacturers used to typically provide a 3-year warranty, while the typical warranty in the current market is 5 years. This industry expert indicated that the change resulted from competition between manufacturers. Another change that has occurred in the market is related to ballast wiring. When the current efficiency standards were established in 2000, most ballasts were series wired, meaning that if one lamp failed, none of the lamps in the fixture would operate. According to one industry expert, in recent years, many more ballasts are now parallel-wired, which allows the remaining lamps to continue to operate even when one lamp fails.

Efficiency

In 2000, when the 2005/2010 standards were established, ballasts essentially came in two efficiency grades—efficient magnetic ballasts that met the 1990 efficiency standards, and electronic ballasts which used about 15% less energy. As shown in Figure 37 below, when the current standards were established in 2000, not quite half the ballasts shipped were electronic and just over half were magnetic. By the first quarter of 2006, shortly after the standards took effect for new fixtures, the market share of electronic ballasts had increased to 79%. (The U.S. Census Bureau stopped collecting ballast data in the first quarter of 2006, so directly comparable data for more recent years are not available.)

Figure 37. Market Share of Electronic Ballasts from 1995-2006



Source: Authors' analysis of U.S. Census Bureau Current Industrial Reports data.
Note: 2006 data is only for the first quarter.

[34] See http://www.iballast.com/546-b-tc-p.html?gclid=CIKJstWXnLMCFRQcnAodP3gAxQ.
[35] See http://ultballastspecs.unvlt.com/pdf/Electronic_Linear_Fluorescent/B132IUNVEL-A.pdf.

In recent years, a variety of more-efficient electronic ballasts have entered the market with efficiency levels that exceed the current standards. For example, as discussed later in this chapter, a new ballast efficiency standard that will take effect in 2014 and is based on the most-efficient commercially-available ballasts is about 5% more stringent than the current standards for the major categories of ballasts covered by the current standards (ballasts that drive one or two four-foot T12 lamps). One industry expert indicated that the 2005/2010 standards influenced utilities to increase qualification levels for rebates, which in turn encouraged manufacturers to develop more high-efficiency ballasts in order to take advantage of the rebates. Another industry expert agreed that there are now more high-efficiency ballasts but attributed this to competition among manufacturers on the basis of providing energy savings.

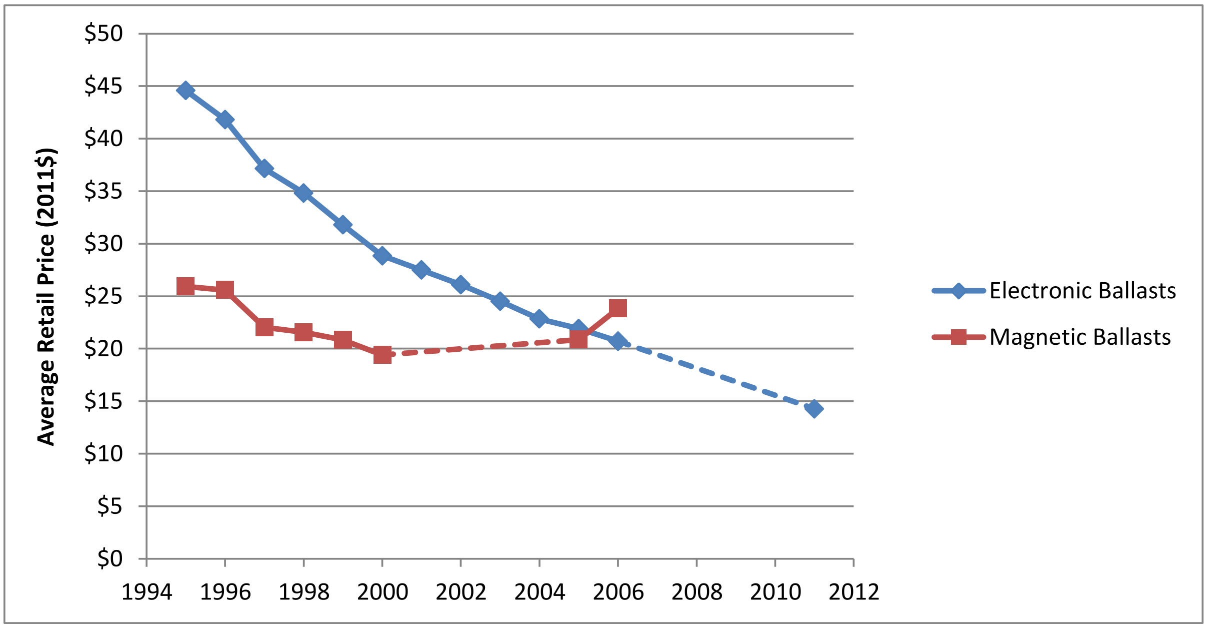
Price

Figure 38 below shows the average retail price of magnetic and electronic ballasts from 1995-2011 (in 2011$).[36] (Data from the U.S. Census Bureau were only available through 2006.) In 2000, when the 2005/2010 standards were established, the average retail price of electronic ballasts was about $29, which was about $10 more than the average price of magnetic ballasts. Between 2000 and the first quarter of 2006, one year after the first stage of the standards took effect, the real price of electronic ballasts declined by about 28%, while the real price of magnetic ballasts increased by about 23%. In the first quarter of 2006, the average price of magnetic ballasts was higher than that of electronic ballasts—$24 for magnetic ballasts versus $21 for electronic ballasts. The decline in electronic ballast prices was likely due to economies of scale, competition between manufacturers, and increased imports, while the increase in magnetic ballast prices can likely be attributed to increases in material prices and reduced economies of scale. As part of DOE's analysis for the recent 2011 rulemaking, DOE estimated an average retail price for a baseline two-lamp T8 electronic ballast of about $14.[37] This indicates that the price of electronic ballasts has continued to decline.

[36] The average prices for magnetic ballasts are based on ballasts that are corrected for power factor because ballasts with power factors below 0.90 and designed and labeled for use in residential applications are not covered by the 2005/2010 standards.

[37] Specifically, a manufacturer cost of $6.94 (in 2009$) times an average markup of 1.96.

Figure 38. Average Retail Price for Magnetic and Electronic Ballasts from 1995-2006 (2011$)



Sources: Authors' analysis of U.S. Census Bureau Current Industrial Reports data for 1995-2006 data; DOE (2011a) for 2011 data and markup.
Note: 2006 data is only for the first quarter; 2011 data for electronic ballasts is for two-lamp T8 ballasts.

The Next Standard

In November 2011, DOE published a final rule amending the current standards for fluorescent lamp ballasts. The new standards will take effect in November 2014. There is variation in efficiency even among electronic ballasts, and the 2014 standards are based on the most-efficient commercially-available electronic ballasts. The new standards also significantly expand the scope of coverage to cover new ballast types including ballasts designed to operate T8 and T5 lamps and ballasts used in outdoor signs. As part of the recent DOE rulemaking, DOE estimated that in 2012, approximately 12% of shipments of ballasts that operate two 4-foot medium bi-pin lamps in the commercial sector met the 2014 standards (DOE 2011b).

Summary of Findings

The 2005/2010 standards for fluorescent lamp ballasts reduced a typical commercial building owner's annual electricity bill by about $700 for 150 lamp-and-ballast systems. Since the standards took effect, manufacturers have introduced a variety of ballasts with efficiency levels that exceed the minimum requirements while also providing a greater range of available ballast factors; more ballasts that are parallel-wired (which allows remaining lamps to continue to operate even when one lamp fails); and longer warranties. The efficiency standards had the effect of eliminating magnetic ballasts from the market for ballast categories covered by the standards. However, with the initial exception of lower first cost, magnetic ballasts provided no advantage to consumers over electronic ballasts. Rather, magnetic ballasts had several disadvantages compared to electronic ballasts including being noisier and heavier and often producing a visible flicker. By the time the initial phase of the standards took effect in 2005, the price difference between magnetic and electronic ballasts had disappeared primarily due to the steady decline in electronic ballast prices.

Commercial Rooftop Air Conditioners and Heat Pumps

History and Scope of Commercial Rooftop Unit Standards

Commercial rooftop air conditioners and heat pumps are the most common type of cooling systems in the commercial sector. These units are relatively inexpensive and can work well for low-rise buildings. They are commonly located on roofs where they are out of sight and do not take up space within the building. Some rooftop units also include a heating section; units that contain a gas furnace are often referred to as "year round" equipment since they provide both heating and cooling. Multiple rooftop units may be employed on the same building, with each serving a different zone.

Source: iStockphoto

In 1992, Congress established the first national mandatory efficiency standards for commercial rooftop units as part of EPAct 1992. EPAct 1992 adopted as a national standard the efficiency requirements for commercial rooftop units contained in a consensus voluntary standard developed in 1989 by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) with substantial manufacturer involvement. The EPAct 1992 standards took effect in 1994 for equipment with a cooling capacity of 65,000-134,999 Btu/hour, and one year later for larger units with a cooling capacity of 135, 000-239,999 Btu/hour.[38] The standards established minimum EER (energy efficiency ratio) levels for both air conditioners and heat pumps as well as COP (coefficient of performance) levels for heat pumps. EER is expressed as cooling capacity (Btu/hour) divided by the power input (in watts), and COP is expressed as heat delivered (in Btu) divided by the energy input (in Btu).

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[38] Three-phase commercial air conditioners and heat pumps with cooling capacities below 65,000 Btu/hour are nearly identical to residential equipment and are therefore rated using SEER and are required to meet separate standards.

2010 STANDARD

DOE began a process to update the EPAct 1992 standards for commercial rooftop air conditioners and heat pumps in 2001. This process led to negotiations between manufacturers and energy efficiency proponents, which resulted in a consensus agreement for new efficiency standards. Congress enacted these consensus standards as part of the Energy Policy Act of 2005 (EPAct 2005) signed by President George W. Bush. The standards, which took effect on January 1, 2010, included amended efficiency levels for units with cooling capacities of 65,000-239,999 Btu/hour as well as the first national standards for units with cooling capacities of 240,000-759,999 Btu/hour. Table 17 below shows the minimum EER requirements for air-cooled air conditioners and heat pumps and the minimum COP requirements for heat pumps for each capacity range.

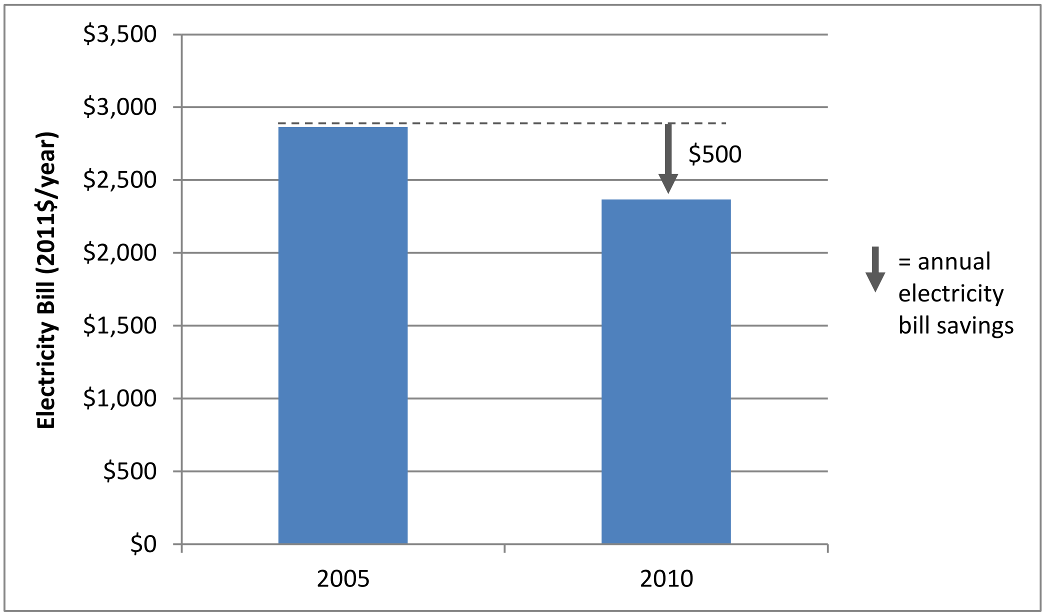
Table 17. 2010 Efficiency Standards for Commercial Rooftop Air Conditioners and Heat Pumps

Cooling Capacity (Btu/hour)	Air Conditioners	Heat Pumps	
	Minimum EER for Cooling	Minimum EER for Cooling	Minimum COP for Heating (47°F)
65,000-134,999	11.2	10.8	3.3
135,000-239,999	11.0	10.6	3.2
240,000-759,999	10.0	9.5	3.2

Note: EER levels for equipment with gas heating modules are 0.2 EER points lower than the values shown in the table.

Figure 39 below shows an average commercial customer's annual electricity bill to operate a 12 ton year-round commercial rooftop air conditioner just meeting the standards in 2005 and 2010 based on today's electricity prices. The 2010 standards reduced a typical commercial customer's annual electricity bill by about $500.

Figure 39. Annual Electricity Bill for a Commercial Customer to Operate a 12 ton Year-Round Commercial Rooftop Air Conditioner for a Unit Just Meeting the Standards in 2005 and 2010



Sources: DOE (2004) for energy use; EIA (2012) for electricity price.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features of commercial rooftop units available before and after the 2010 standards took effect:

- Cooling capacity
- Size and weight
- Additional features
- Efficiency
- Price

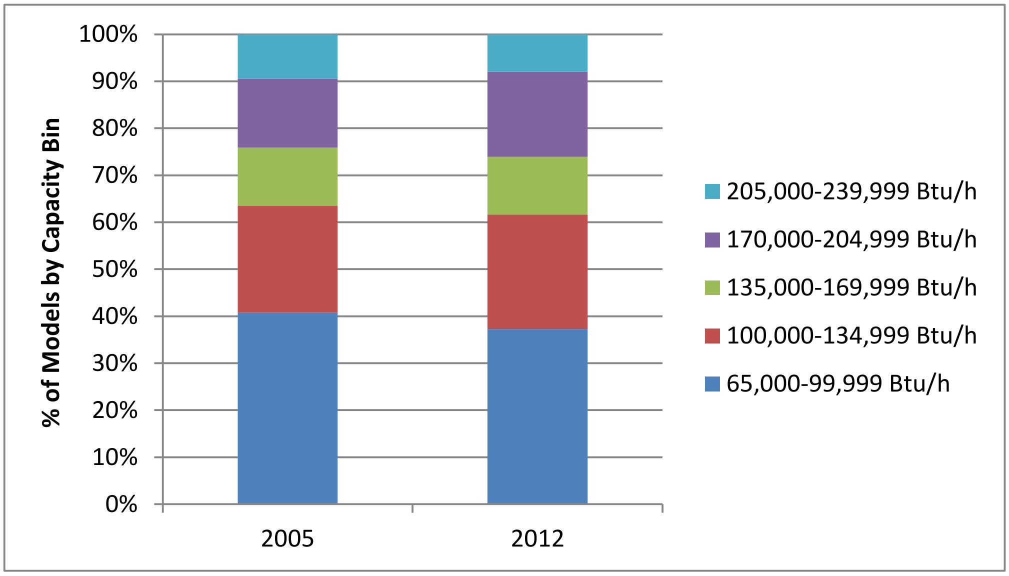
We examined models available in 2005 and 2012 to characterize the market before and after the 2010 standards.

Cooling Capacity

Cooling capacity, which is measured in Btu/hour, refers to the rate of cooling that a rooftop unit can provide under a specific set of conditions. Figure 40 below shows the distribution of rooftop air conditioners and heat pumps by capacity in 2005, the year the 2010 standard was established, and in 2012, for units with capacities from 65,000-239,999 Btu/hour.[39] As seen in Figure 40, there was no significant difference in the distribution of cooling capacities available before and after the 2010 standard took effect. In both 2005 and 2012, roughly 40% of available models had capacities less than 100,000 Btu/hour, and just over 60% of available models had capacities less than 135,000 Btu/hour.

[39] We were unable to compare the distribution of capacities for models with capacities of 240,000 Btu/hour and above because data for 2005 were not available.

Figure 40. Distribution of Rooftop Units with Capacities of 65,000-239,999 Btu/Hour by Cooling Capacity in 2005 and 2012



Sources: AHRI for 2005 data; authors' analysis of the AHRI directory queried on 1/25/13 for 2012 data.

Size and Weight

The size and weight of commercial rooftop air conditioners and heat pumps has increased somewhat as efficiency has improved. According to one industry expert we interviewed, units meeting the 2010 standards are typically 20% larger (primarily taller) and weigh about 12-15% more than units just meeting the prior standards. The weight change is smaller than the size change as most manufacturers redesigned their equipment in 2010 (in response to both the efficiency standard and a change in refrigerant that took effect at the same time) and managed to reduce weight as part of the redesign. In addition, some of the units meeting the 2010 standards use microchannel heat exchangers, which also reduce weight. Since commercial rooftop units are usually located on top of buildings and placed there via cranes, the increases in size and weight are usually not a significant issue for this equipment, although one industry expert noted that in existing buildings, some modifications will be needed if the new unit needs a bigger curb (raised mounting surface for the equipment) and that, infrequently, additional structural steel supports will be needed to accommodate heavier equipment.

Additional Features

The industry experts we interviewed noted that since 2005, many commercial rooftop units have incorporated a variety of improved features and controls. For example, many rooftop units now contain more than one supply fan, which means that when the need for conditioned air is low, one or more fans can be turned off. The ability to turn off one or more fans saves energy and can also improve dehumidification. The shift towards multiple supply fans is being driven in part by the ASHRAE commercial building model energy code, which now requires either multiple air handlers or variable-speed air handlers for equipment with a cooling capacity of 10 tons or more. Hot gas reheat, which improves dehumidification[40] and reduces the use of electric resistance heat, has also become more common in commercial rooftop units. In addition, some units now include alarms to notify building and contractor personnel when the equipment is not working properly.

Another significant change in the market for rooftop units since 2005 has been the wider availability of improved economizers. Economizers sense outdoor temperature and humidity and switch the rooftop unit into fan-only mode when the outdoor air is sufficiently cool and dry to provide cooling. Economizers can reduce energy use by as much as 30-60% in some climates.[41] In the past, economizers often worked poorly (Cherniack and Reichmuth 2008), but recently, manufacturers have improved their economizers by including improved outdoor sensors (NBI 2009), providing tighter dampers on the outside air supply, or switching from less-reliable chain-driven economizers to more-reliable designs that use gears instead of chains. Industry experts noted that improvements to economizers are due in large part to utility efforts and the new 2014 California building code.

Efficiency

Figure 41 below shows the distribution of rooftop air conditioners and heat pumps by efficiency level in 2005, the year the 2010 standard was established, and 2012, for units with capacities of 65,000-239,999 Btu/hour.[42] In 2005, almost 90% of available commercial rooftop air conditioner and heat pump models had EER levels less than 11.0. The majority of units either just met the minimum efficiency standard then in effect (e.g., EER 8.9 for units with capacities of 65,000-134,999 Btu/hour) or the levels specified in the 1999 version of ASHRAE Standard 90.1, a commercial building energy code (EER 10.1-10.3 for 65,000-134,999 Btu/hour units). About 13% of models in 2005 had EER levels between 11.0 and 11.9, while less than 1% had efficiency levels exceeding 11.9 EER. By 2012, 30% of models had EER levels exceeding 11.9, and about 2% of models had EER levels exceeding 12.9.

When the 2010 standards took effect, manufacturers wishing to differentiate their products on the basis of EER needed to further improve efficiency beyond the standard levels. Furthermore, in response to the new efficiency standards, ENERGY STAR and utility incentive programs increased their qualification levels and new versions of building codes were adopted, helping to drive the increase in units with efficiency levels that exceeded the 2010 standards. For example, ENERGY STAR and CEE Tier 1 currently specify EER levels of 11.5-11.7 for equipment with cooling capacities of 65,000-134,999 Btu/hour, while CEE Tier 2 specifies EER levels of 12.0-12.2.

An additional significant change in recent years has been greater interest in Integrated Energy Efficiency Ratio (IEER) for rating commercial rooftop equipment. IEER was developed by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and took effect for equipment rating in 2010. IEER is designed to complement EER as an equipment rating metric. While EER measures the performance of equipment under hot, near-peak conditions (95°F outdoor temperature), IEER is calculated as a weighted average of the performance under different loads (100%, 75%, 50%, and 25%

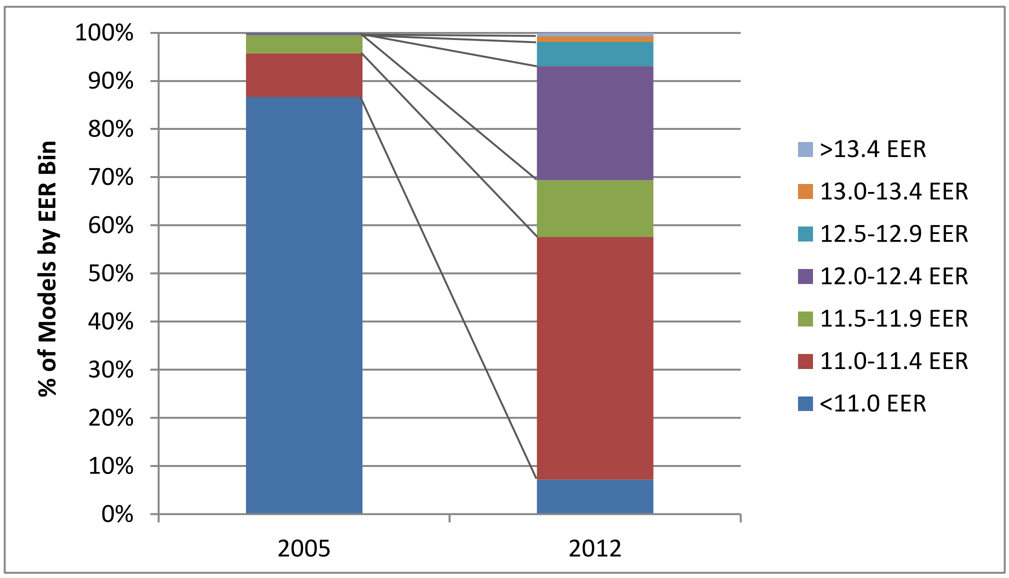
[40] Hot gas reheat recycles exhaust heat energy from the compressor and is intended to reduce indoor humidity while maintaining a comfortable air temperature.

[41] For a few examples, see http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_economizer_airside.

[42] We were unable to compare the distribution of efficiency levels for models with capacities of 240,000 Btu/hour and above because data for 2005 were not available.

of full rated load) and four different outdoor temperature conditions. While EER is important for utilities that need to manage peak loads on their systems and for customers who pay demand charges based on their peak demand, IEER better reflects efficiency over the course of a year. In general, higher IEER levels translate to lower annual energy use. In recent years, manufacturers are increasingly emphasizing higher IEERs in their new products, while continuing to meet or exceed the EER standards. For example, while ASHRAE 90.1 specifies minimum IEER levels of 9.9-11.4 depending on capacity and heating section type, available units have IEERs as high as 19 and 20. One industry expert we interviewed noted that DOE's Commercial Rooftop Air Conditioner Challenge has played a significant role in encouraging and assisting manufacturers to produce units with IEER levels of 18 or higher.

Figure 41. Distribution of Rooftop Units with Capacities of 65,000-239,999 Btu/Hour by EER Level in 2005 and 2012

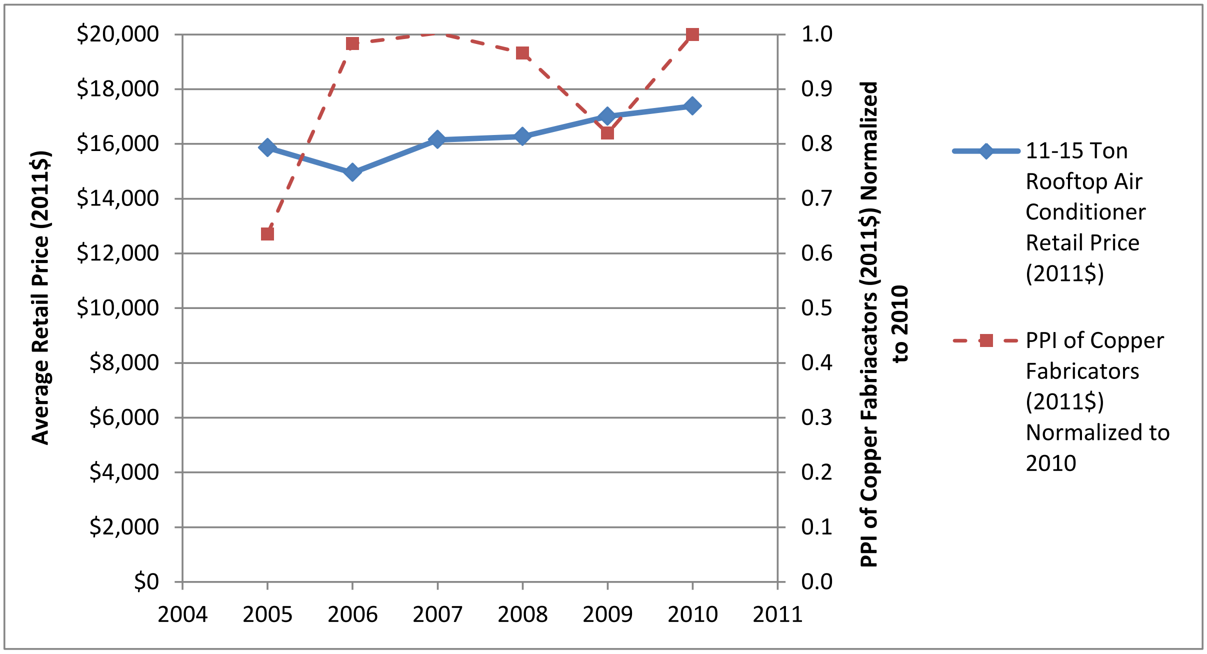


Sources: AHRI for 2005 data; authors' analysis of AHRI directory queried on 1/25/13 for 2012 data.

Price

Figure 42 below shows the average retail price of 11-15 ton year-round commercial rooftop air conditioners from 2005-2010 (in 2011$) along with the PPI of copper fabricators (2011$) normalized to 2010. Over this period, the average price of 11-15 ton units increased from about $15,900 to $17,400, or an increase of about 10%. However, this price increase is likely not due solely to the efficiency standard. Materials, including copper, make up the majority of the cost of a rooftop air conditioner. Except for a dip in 2009, from 2006-2010, copper prices were roughly 80% higher than they were in 2005. This suggests that the increase in the price of rooftop air conditioners was likely due at least in part to the significant increase in copper prices, which is unrelated to the efficiency standard.

Figure 42. Average Retail Price of 11-15 Ton Year-Round Commercial Rooftop Air Conditioners from (2011$) and PPI of Copper Fabricators (2011$) Normalized to 2010



Sources: Authors' analysis of U.S. Census Bureau Current Industrial Reports data; DOE (2004) for markup.

Even if the entire increase in price were due to the efficiency standard, the standard is still cost-effective for customers. Between 2005, when the standard was established, and 2010, the year the standard took effect, the average retail price of 11-15 ton rooftop air conditioners increased by about $1,500 as shown in Figure 42 above. As shown in Figure 39, annual electricity bill savings from the standard for a 12 ton unit for a typical customer are about $500. Therefore, the simple payback (assuming the entire price increase is due to the standard) is about three years, which is significantly shorter than the average lifetime of 15 years for a rooftop air conditioner (DOE 2004). In all likelihood, the actual payback is shorter since the incremental cost of the efficiency standard is likely less than the entire observed price increase.

The Next Standard

The American Energy Manufacturing Technical Corrections Act (AEMTCA) of 2012 requires DOE to consider amending the standards for any commercial equipment for which more than six years have passed since the most recent final rule was published. DOE last issued a final rule for commercial rooftop units in 2005, when the EPAct 2005 standards were codified. As directed by AEMTCA, DOE must publish either a proposed rule or a determination that amendments to the current standards are not warranted by December 31, 2013. In January, 2013, DOE published a Request for Information initiating a rulemaking for commercial rooftop units. DOE has indicated that they are considering replacing the EER metric with IEER (DOE 2013a).

ASHRAE is also considering amending the IEER levels for commercial rooftop units in the ASHRAE 90.1 model building code. ASHRAE has a proposal out for review in 2013 that calls for about 10% energy savings (ranging from 7-13% depending on the product class) relative to the current standards.

If adopted, the new IEER levels will take effect in building codes in 2016. As of October 2012, about 60% of available models met the proposed ASHRAE standards.

SUMMARY OF FINDINGS

The 2010 standards for commercial rooftop air conditioners and heat pumps reduced a typical commercial customer's annual electricity bill by about $500. Since 2005, when the 2010 standard was established, the range of available efficiency levels has increased substantially and new features have been introduced or become more widely available, while the distribution of available cooling capacities has remained unchanged. New units are typically somewhat larger and heavier than models available in 2005, although these increases are usually not a significant issue for this equipment since units are generally located on the roof of a building. Manufacturers have introduced units that have very good part-load performance, and new units often include improved economizers, which can provide large energy savings. Multiple supply fans and hot gas reheat have become more common, which can both reduce energy use and improve dehumidification. While equipment prices have increased by about 10% since the standard was established, at least a portion of this increase is likely due to the large increases in metal prices. Even if the entire price increase were due to the standard, the three-year payback period is significantly shorter than the 15-year average lifetime of this equipment.

Refrigerated Beverage Vending Machines

HISTORY AND SCOPE OF BEVERAGE VENDING MACHINE STANDARDS

EPAct 2005 directed DOE to establish energy efficiency standards for refrigerated beverage vending machines. Beverage vending machines are upright, stand alone, refrigerated cases that hold and dispense cold beverages when money is deposited. DOE published a final rule in 2009 establishing the first national efficiency standards for beverage vending machines. There are two general types of beverage vending machines: Class A machines, which have a glass front and are fully-cooled; and Class B machines, which have a closed, or opaque, front and are zone-cooled (cool air is directed at a fraction of the refrigerated volume so that the next-to-be-vended product is the coolest product in the machine).

Source: Universal Vending

Beverage vending machines include two major systems that require significant inputs of energy: the refrigeration system (including a compressor and evaporator and condenser fans); and the lighting system, which illuminates the front panel. Older machines tended to have limited insulation, inefficient refrigeration components, and old lighting technology. In addition, Class A machines are subject to greater heat gain than Class B machines because the front of Class A machines is generally made of glass.

Beverage vending machines were historically very inefficient, partly due to split incentives. Beverage companies (e.g., Coca Cola Co. and Pepsi Co.) purchase vending machines but do not pay the energy bills to operate the machines. The beverage companies enter into contractual agreements with a building owner where the beverage company places a machine in the building; the building owner pays the energy bill and receives a percentage of the sales revenue; and the beverage company refills the machine. Due to the split incentive, in the past, beverage companies had little motivation to purchase energy-efficient vending machines because the energy bill savings would accrue to the building owner.

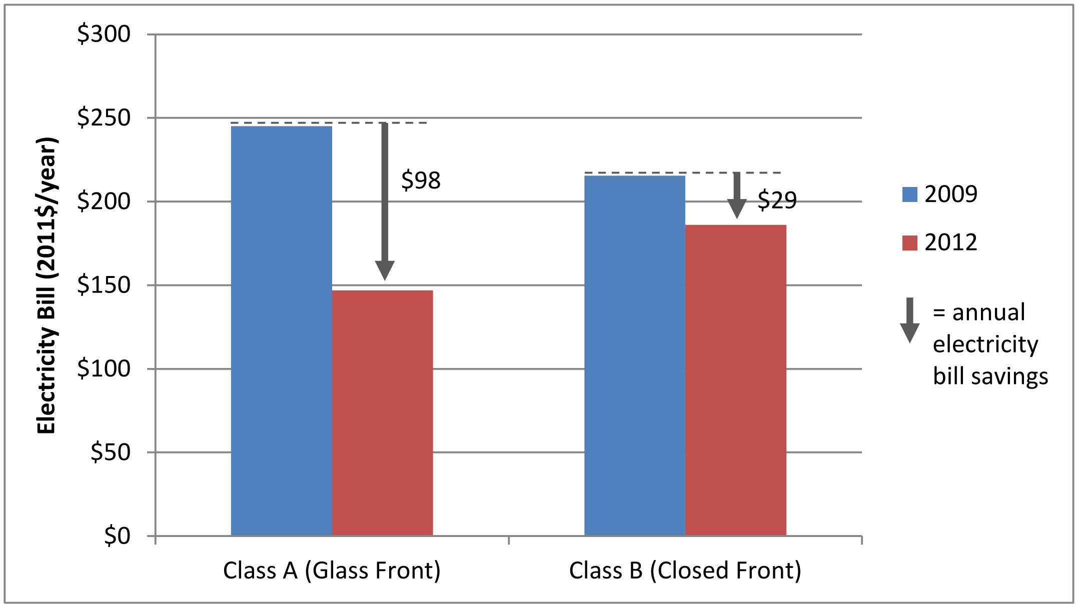
Prior to the first national efficiency standards, the market for beverage vending machines started to shift towards higher-efficiency products for two reasons. First, Coca Cola and Pepsi responded to public criticism by specifying more-efficient units. The vending machine market differs significantly from other markets in that two companies (Coca Cola and Pepsi) purchase the vast majority of vending machines, and product changes are driven in large part by these companies. Vending machine manufacturers responded to the demand for more-efficient machines by introducing products with significantly lower energy consumption. Second, EPA developed an ENERGY STAR specification for beverage vending machines. ENERGY STAR Version 1 addressed new machines and included two tiers, with Tier I taking effect in 2004. Subsequently, ENERGY STAR published a Version II specification, which maintained the same tiers of efficiency requirements but added rebuilt machines as eligible for qualification. (Vending machines are often refurbished, leased, and placed in several different buildings in sequence during their lifetime, and machines can be retrofitted to improve efficiency.) Tier I took effect for rebuilt machines in 2006, and Tier II, which included a more stringent specification, took effect in 2007 for both new and rebuilt machines.

2012 STANDARD

The standards in the 2009 DOE final rule took effect on August 31, 2012. The standards are different for Class A and Class B machines and specify a maximum daily energy consumption (MDEC), in kWh/day, as a function of the volume of the machine such that larger machines can consume more energy than smaller machines.

Figure 43 below shows an average building owner's annual electricity bill to operate baseline 25 cubic foot Class A and Class B beverage vending machines in 2009 compared to machines just meeting the 2012 standards based on today's electricity prices. The 2012 standards reduced a typical building owner's annual electricity bill by $98 for a single Class A (glass front) machine and $29 for a Class B (closed front) machine.

Figure 43. Annual Electricity Bill for a Building Owner to Operate a 25 Cubic Foot Beverage Vending Machine



Sources: DOE (2009b) for energy consumption; EIA (2012) for electricity price.

PERFORMANCE, FEATURES, AND PRICE

We examined the following performance attributes and product features of beverage vending machines available before and after the 2012 standards took effect:

- Machine type
- Volume
- Controls
- Customer interaction features
- Efficiency
- Price

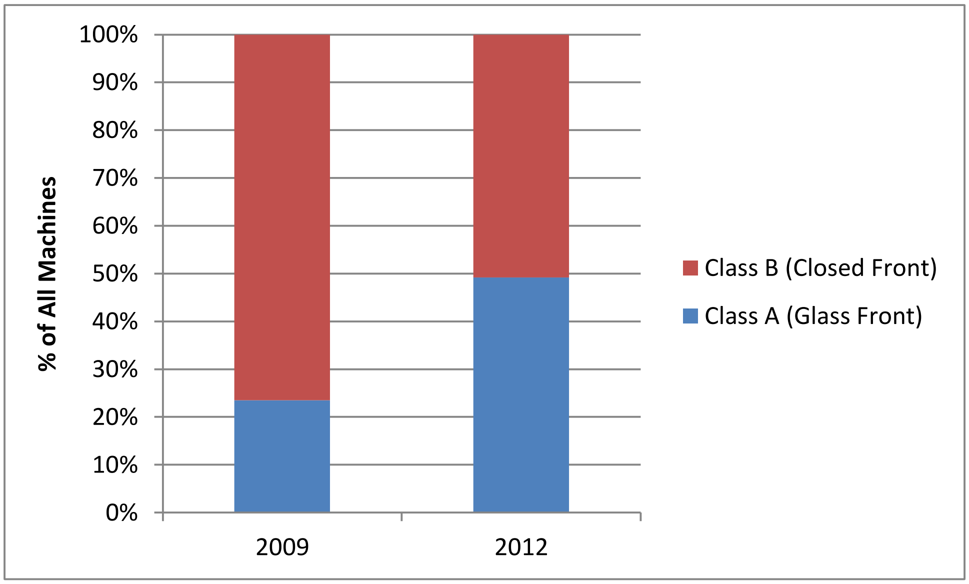
We examined models available in 2009 and late 2012 to characterize the market before and after the 2012 standards.

Machine Type

There is a trend in the vending machine market to move from primarily Class B (closed front) machines to Class A (glass front) machines. Glass-front machines allow beverage companies to sell a wider variety of products. For example, Coca Cola Co. owns several brands of soft drinks (e.g., Coca Cola, Sprite, Fanta, Diet Coke), and they also own branded bottled water, juices, vitamin water, tea, energy drinks, and milk-based beverages. One industry expert we interviewed noted that while closed-front machines can sell a maximum of 13 kinds of beverages, glass-front machines can hold up to 45 types of branded beverage products. In addition, glass-front machines display all the beverage selections to customers, which allows beverage companies to more easily sell all of their beverage brands.

Figure 44 below shows the distribution of beverage vending machines by type (glass front vs. closed front) in 2009, when the standard was established, and in 2012, when the standard took effect. The data for 2009 is based on models certified to ENERGY STAR and does not represent the entire market. However, several industry experts we interviewed indicated that models certified to ENERGY STAR in 2009 were representative of the market as a whole since there is significant demand for ENERGY STAR qualified machines from beverage companies. In 2009, about 25% of all models were glass-front machines. Just three years later, glass-front machines represented about half of all available models.

Figure 44. Distribution of Beverage Vending Machines by Type in 2009 and 2012



Sources: EPA (2009) for 2009 data; DOE (2012) for 2012 data.
Note: 2009 data is based on models certified to ENERGY STAR.

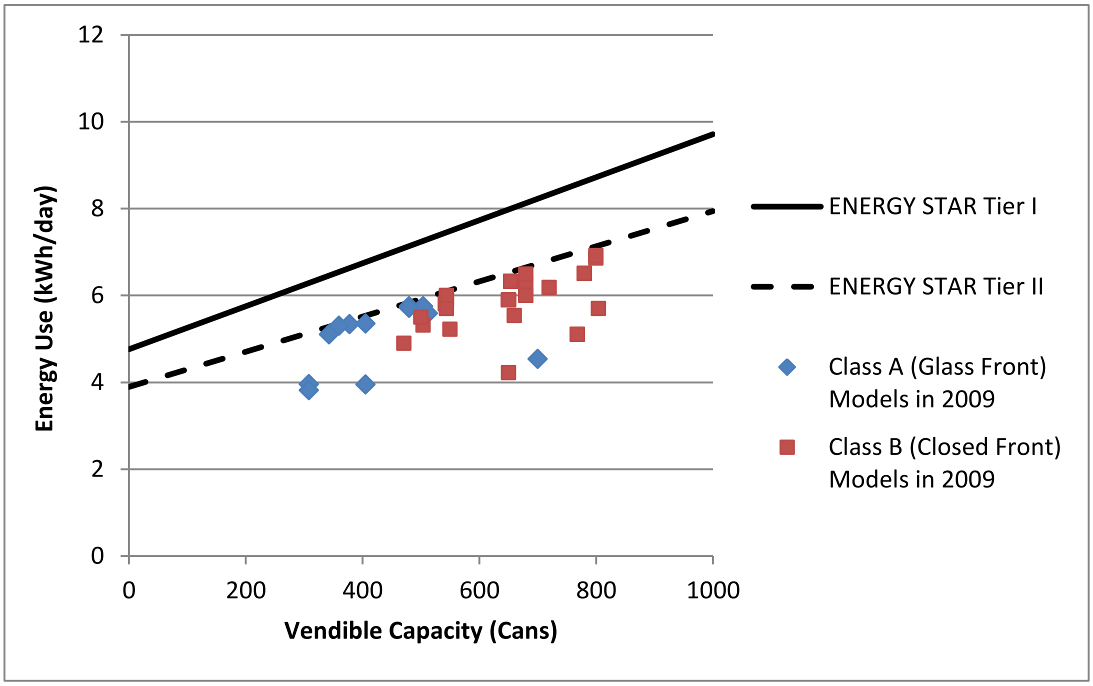
The industry experts we interviewed confirmed that there has been a significant shift in the market from closed-front to glass-front machines.

Volume

Beverage vending machines are available in a wide range of volumes as can be seen in Figures 45 and 46 below. The size of a machine is an important feature for beverage companies and building owners. Larger machines have more advertising space and generally more products, and in large spaces with a lot of traffic it is often beneficial to have a large machine to reduce the frequency of product refilling. On the other hand, for smaller spaces with less frequent visits, it may often make more sense to place a smaller machine. There is also the option of placing multiple smaller machines instead of one larger machine in order for a company to provide an even greater variety of beverage products. The availability of models with a range of volumes provides this flexibility to vending machine buyers.

Figure 45 shows beverage vending machine models certified to ENERGY STAR in 2009 along with the specifications for ENERGY STAR Tier I and Tier II. Although the data in Figure 45 do not represent the entire market, as noted above, several industry experts we interviewed indicated that models certified to ENERGY STAR in 2009 were representative of the market as a whole. Figure 46 shows available beverage vending machine models in 2012 along with the 2012 DOE standards and the ENERGY STAR Tier II specification. (The data labels for Class B models indicate the number of individual models with the same certified volume and energy use.)

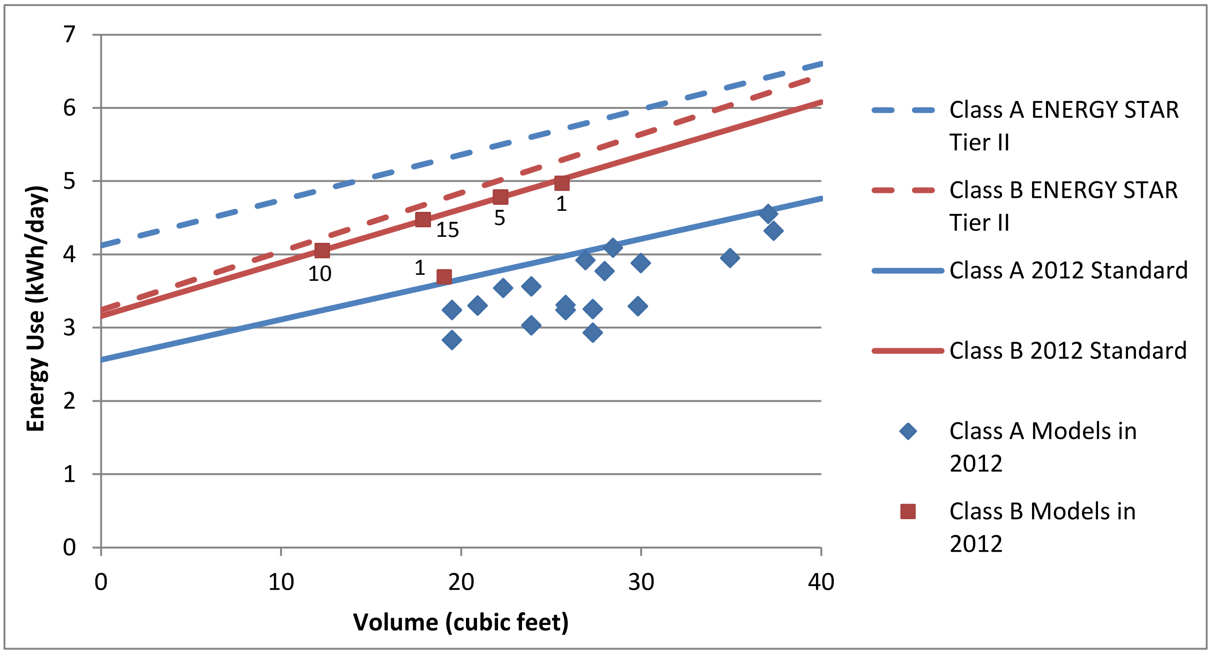
Figure 45. Beverage Vending Machine Models in 2009



Source: EPA (2009).
Note: Models represent models certified to ENERGY STAR in 2009.

The 2012 DOE standard is based on volume expressed in cubic feet, while the previous ENERGY STAR specifications were based on volume expressed in can capacity. Therefore, we cannot directly compare the volumes of beverage vending machines available in 2009 and 2012. However, as seen in Figures 45 and 46 above, in both 2009 and 2012 for both Class A and Class B machines, the largest machines have volumes that are roughly twice as large as those of the smallest machines. It appears that beverage vending machines are available in a wide range of volumes and that the range of available volumes was about the same before and after the 2012 standards took effect. The industry experts we interviewed confirmed that the range of available volumes has not changed significantly since 2009.

Figure 46. Beverage Vending Machine Models in 2012



Sources: DOE's Compliance Certification Database accessed December 10, 2012 for available models; DOE (2009b) for Class A and Class B ENERGY STAR Tier II.
Note: The data labels for Class B models indicate the number of individual models with the same certified volume and energy use; the representations of ENERGY STAR Tier II are based on DOE's approximation of ENERGY STAR Tier II expressed as a function of volume in cubic feet.

Controls

In recent years, there has been an increase in the availability of a variety of controls for beverage vending machines that save energy, which has been driven in large part by ENERGY STAR. To qualify for ENERGY STAR certification, beverage vending machines must include controls that allow the machine to operate in at least one low-power mode during periods of extended inactivity. These controls include sensors or timers that turn off the lights or allow the beverage temperature to rise when machines are not being used (e.g., late at night). Additional controls include occupancy sensors and tracking devices that monitor sales and traffic and learn from use patterns.

Customer Interaction Features

Manufacturers have also introduced new customer interaction features on beverage vending machines. Most new machines now have more complex bill validators, which allow the machines to accept $5, $10, and $20 bills rather than just $1 bills. In addition, many new machines allow for cashless transactions such as the use of credit cards.

Another new customer interaction feature that is becoming popular in the market is the addition of interactive touch screens on closed-front machines. The industry experts we interviewed suggested that these interactive machines are the direction the market is headed. These machines also include hardware that allows the machines to communicate directly with the beverage companies and with other machines. This added interactive capability allows the beverage companies to track sales, monitor the amount of money in the machines, and determine if the machine needs service or needs to be re-filled. The DOE test procedure does not capture the energy use of interactive screens, and as a result, the DOE standard has not impeded the development and adoption of this new feature.

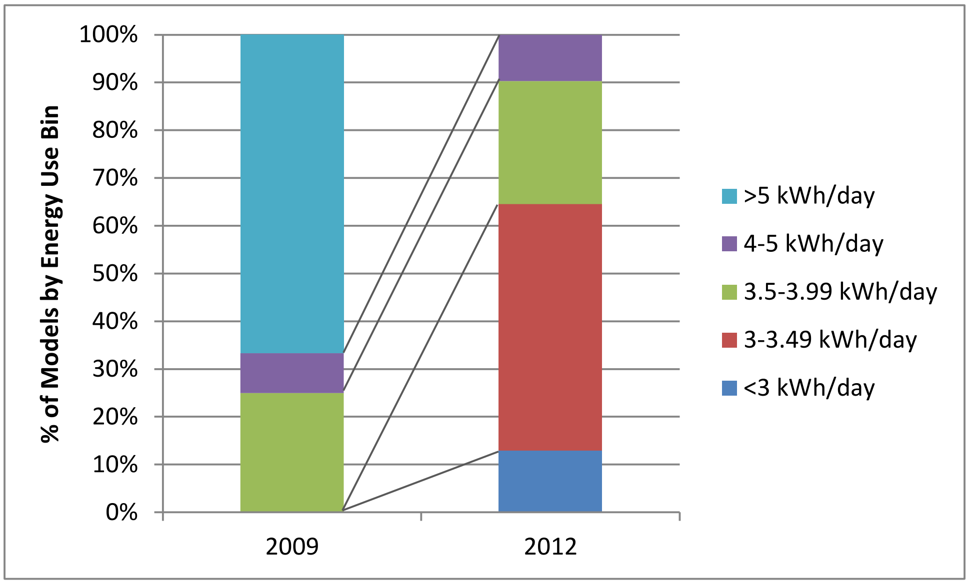
Efficiency

There were significant improvements in the energy efficiency of beverage vending machines prior to the DOE standard due to the ENERGY STAR specifications and the demand from beverage companies for more-efficient machines in response to public pressure. Several industry experts we interviewed indicated that it is nearly impossible to sell machines that are not ENERGY STAR qualified because Coca Cola and Pepsi require the ENERGY STAR label on all machines they purchase. The ENERGY STAR Tier I and Tier II specifications represented energy savings of about 45% and 55%, respectively, compared to a 1996 Canadian Standards Association standard, which reflected a significant shift in the market to more-efficient machines (NRCan 2005).

In 2009, the most-efficient Class A and Class B beverage vending machines consumed 33% and 35% less energy, respectively, than the ENERGY STAR Tier II specification as can be seen in Figure 45 above. The industry experts we interviewed noted that competition among manufacturers to offer high-efficiency beverage vending machines spurred manufacturers to introduce products that not only met ENERGY STAR Tier II but exceeded the ENERGY STAR specification. The most-efficient Class A and Class B beverage vending machines available in 2012 consumed 28% and 19% less energy, respectively, than the 2012 DOE standards as can be seen in Figure 46. These data suggest that just as manufacturers produced machines in 2009 that significantly exceeded the ENERGY STAR Tier II specification, manufacturers are now producing machines that significantly exceed the minimum efficiency standards.

The test method used to determine compliance with the DOE standards specifies a different ambient temperature for testing Class B machines than the test method that was previously used for ENERGY STAR, which means that it is not possible to directly compare the energy use of Class B models before and after the 2012 standard. However, we can compare the energy use of Class A (glass front) models since the test procedure for these products has not changed. Figure 47 below shows the distribution of Class A machines by daily energy use in 2009 and 2012. Larger machines tend to use more energy than smaller machines, and the data in Figure 47 include machines of various volumes. However, as noted above, the industry experts we interviewed indicated that the range of available volumes has not changed significantly since 2009. In 2009, more than 65% of Class A machines consumed more than 5 kWh/day, and there were no Class A machines that consumed less than 3.5 kWh/day. In 2012, 65% of Class A machines consumed less than 3.5 kWh/day, and more than 10% of Class A machines consumed less than 3 kWh/day. These data show that customers now have greater choice in machines with energy use that is significantly lower than the energy use of older machines.

Figure 47. Distribution of Class A Beverage Vending Machines by Daily Energy Use in 2009 and 2012



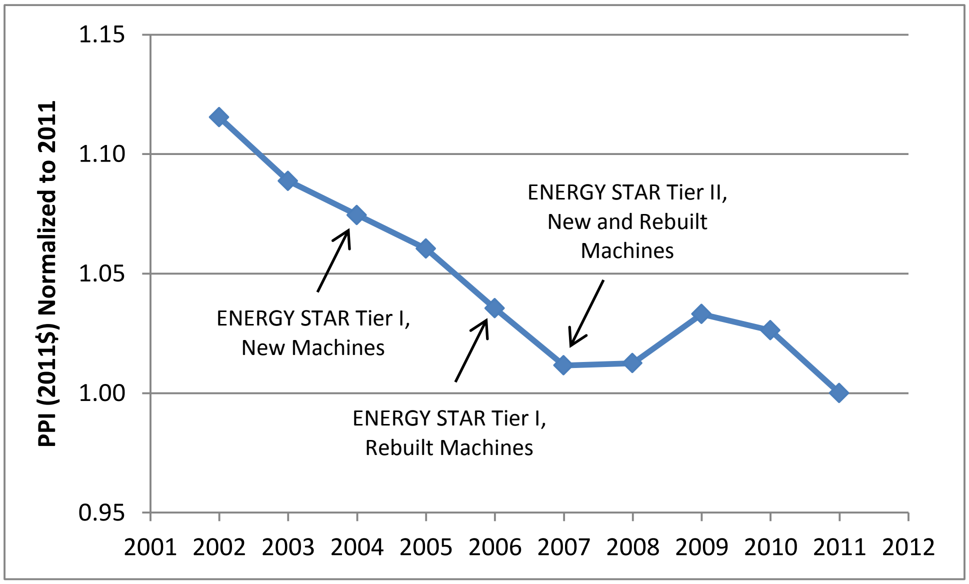
Sources: EPA (2009) for 2009 data; DOE's Compliance Certification Database accessed December 10, 2012 for 2012 data.

Price

Since the beverage vending machine standard only recently took effect (in August 2012), we were unable to compare prices before and after the standard. However, we were able to examine price trends since 2002, when the first ENERGY STAR specification was developed. Figure 48 below shows the PPI of beverage vending machines (in 2011$) normalized to 2011. The PPI reflects manufacturer selling price.[43] Between 2002 and 2011, the average manufacturer selling price of beverage vending machines decreased by about 12% in real terms. The downward trend in manufacturer selling price occurred as two tiers of ENERGY STAR specifications took effect.

[43] We use PPI to examine beverage vending machine prices because U.S. Census data were unavailable for this product.

Figure 48. PPI of Refrigerated Beverage Vending Machines (2011$) Normalized to 2011



Source: Authors' analysis of Bureau of Labor Statistics PPI data.

New ENERGY STAR Specification and The Next Standard

ENERGY STAR finalized Version 3.0 of the beverage vending machine specification in June 2012, and the new specification took effect on February 28, 2013. The new specification applies to both new and rebuilt machines. Relative to the 2012 DOE standards, the new ENERGY STAR specification represents energy savings of 5% and 10% for Class A and Class B machines, respectively. DOE is required to publish a proposed rule to amend the current standards, or a determination that no changes are warranted, by August 2015.

Summary of Findings

The ENERGY STAR Tiers combined with beverage company purchase specifications have improved vending machine efficiency significantly over the past decade. In 2012, efficiency standards took effect which reduced a typical building owner's annual electricity bill by $98 for a single Class A (glass front) machine and $29 for a Class B (closed front) machine. These improvements in efficiency have been achieved while maintaining or increasing the range of vending machine choices available in the market. Since the standard was established, manufacturers have continued to provide beverage vending machines with a wide range of volumes including very large machines. In addition, the market has continued to shift from closed-front to glass-front machines, which can hold more types of beverage products and more easily display products to consumers than closed-front machines. In recent years, there has been greater availability of controls that save energy as well as new customer interaction features such as interactive touch screens. While we were unable to compare prices of beverage vending machines available before and after the 2012 standard took effect, manufacturer selling price decreased by about 12% between 2002 and 2011, while energy use decreased significantly.

Conclusions

We analyzed how the choices available to consumers have changed over time as efficiency standards have taken effect for ten residential, commercial, and lighting products. We examined performance, features, and price of available models before and after each standard.

With respect to performance, we found that product performance generally stayed the same or improved as standards took effect. In just two instances (clothes washers and toilets), an increase in poor performance ratings was reported immediately after the implementation of efficiency standards. However, this effect was temporary. Manufacturers responded by eliminating or re-designing poorly-performing models, and the incidence of poorly-performing models declined. More importantly, over the longer term, performance has improved beyond what was available before the standards. Many clothes washers today do a better job of removing stains and are gentler on clothes than older washers, and today's consumers have enormous choice of toilets with excellent flushing performance.

With respect to features, we found that for each of the ten products we evaluated, manufacturers introduced or expanded the availability of new features after a new standard took effect. In general, these new features have no relationship to the efficiency standards. But, efficiency standards did not inhibit the adoption of these new features. We also found that for each of the ten products we evaluated, a significantly greater range of products that exceeded the new efficiency levels were available after standards took effect compared to when the standards were established.

With respect to price, we found that prices *declined* or stayed the same for five of the nine products we evaluated for which we could obtain price data (refrigerators, clothes washers, dishwashers, toilets, and fluorescent lamp ballasts). For general service light bulbs and incandescent reflector lamps, prices have increased modestly, but the total cost (purchase price plus operating cost) is lower for the lamps meeting the new standards compared to pre-standard lamps. Finally, for residential and commercial air conditioners and heat pumps, price increases are likely attributable at least in part to significant increases in metal prices, which are independent of efficiency standards. However, even if the entire price increases were due to the standards, the payback periods (six years and three years for residential and commercial air conditioners, respectively) are significantly shorter than the average lifetimes of this equipment (19 years and 15 years, respectively).

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