Consumption and Saturation Trends of Residential Miscellaneous End-Use Loads

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ABSTRACT

Recently, the growth of miscellaneous electric loads (MELs) in households has been offsetting some of the efficiency gains made through technology improvements and standards in major end uses such as space conditioning, lighting, and water heating. These end uses, including televisions, personal computers, kitchen appliances, laundry machines, and many other devices, have quickly penetrated into households and now account for almost half of delivered residential electricity consumption. Part of this proliferation of devices and equipment can be attributed to increased service demand for entertainment, computing, and convenience appliances.

Efficiency programs targeting these MELs are particularly challenging as the dynamic market for such products may not be well-suited to traditional approaches such as the slow, methodical analysis required for federal efficiency standards. Also, such products must cross Congressionally legislated thresholds before being considered for federal standards. Voluntary programs such as ENERGY STAR® can be invaluable in reducing consumption; however, not all devices have ENERGY STAR specifications and not all manufacturers participate.

This paper illustrates the correlation between the saturation and penetration of selected MELs and their resulting energy demand per household. The discussion explores the historical context of MELs through analysis of time-series data from EIA's Residential Energy Consumption Surveys and through analysis of projections from integrated energy modeling.

Introduction

Trends in energy consumption from miscellaneous loads have significant implications for residential energy use. In 2011, miscellaneous loads (defined here as electric end uses other than space heating, space cooling, water heating, and lighting), accounted for about half of delivered residential electricity use and about one fifth of delivered residential energy use across all fuels (EIA 2012).

Over the past three decades, the federal appliance standards program has been the primary method for increasing the efficiency of miscellaneous electric loads (MELs), but these standards do not apply to all end uses. State-level standards and the ENERGY STAR program have also increased efficiency for selected products. Some products not currently covered by these programs are either poorly suited to traditional approaches (standards and ENERGY STAR) or do not meet qualifications for inclusion. Indeed, the fastest-growing group of MELs includes those not covered by standards or ENERGY STAR specifications and thus offers little current opportunity for efficiency improvement. This paper identifies different types of MELs, discusses data sources and trends in MELs' energy usage, and presents a new framework for considering the suitability of an appliance standards approach for increasing MELs' efficiency. We also describe major challenges to policy options for increasing efficiency for specific MELs.

Definition of Miscellaneous End-Use Loads

Residential end uses can be divided into two general categories: major and miscellaneous. While there is no universally-defined demarcation, for the purposes of this paper, major end uses consist of space heating, space cooling (air conditioning), water heating, and lighting. All other end uses beyond these four are considered miscellaneous.

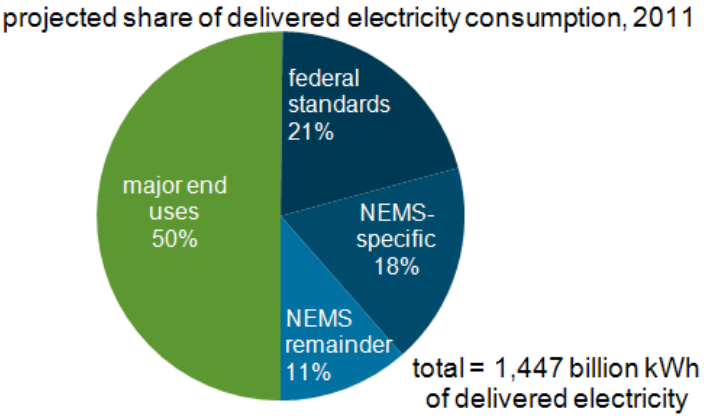
We have limited our discussion to electricity as other fuels, including natural gas, distillate fuel oil, and liquefied petroleum gas (LPG), are used mainly for space heating and water heating. According to 2009 data from the Residential Energy Consumption Survey (RECS), electricity was the only fuel used in every home (EIA 1981-2012). The next most prevalent fuel, natural gas, was used in fewer than two-thirds of households. All other fuels, including propane, fuel oil, wood, and kerosene, were in fewer than half of all homes. Even then, those fuels are seldom used for anything but space heating and water heating. Beyond uses such as natural gas and LPG cooking and natural gas clothes drying, few miscellaneous end uses are powered by anything other than electricity.

Subgroups within MELs

Within MELs we define a few sub-groups of end uses. Most of the larger end uses, including refrigerators, freezers, clothes washers, clothes dryers, and dishwashers, have already been covered by federal standards (DOE 2012b). These uses, as well as some of the remaining end uses, are specifically characterized in the Residential Demand Module (RDM) of the National Energy Modeling System (NEMS), which is the modeling structure used by the U.S. Energy Information Administration (EIA). EIA is the federal agency tasked with developing national energy projections; the end-use characterizations within the residential module of NEMS are important for developing EIA's projections of future energy consumption.

Figure 1 shows that, in EIA's Annual Energy Outlook 2012 Early Release Reference case, MELs covered by federal standards accounted for 21% of residential electricity consumption in 2011 (EIA 2012). That percentage does not include the four major end uses, which were estimated to consume half of all residential electricity in 2011.

Figure 1. Electricity shares of major end uses and sub-groups of MELs



Source: Annual Energy Outlook 2012 Early Release Reference Case (EIA 2012)

Several widespread uses including televisions, personal computers, set-top boxes, microwaves, home audio equipment, DVD and VCR players, video game consoles, security systems, portable spas, rechargeable devices, external power supplies, coffee makers, ceiling fans, and dehumidifiers are specifically characterized in NEMS (EIA 2011c). These end uses are described by unit saturation parameters (i.e., devices per household) as well as unit energy consumption (UEC, or energy consumption per device per year). About 18% of residential delivered electricity in 2011 use was due to this group of MELs (EIA 2012). By including these end uses in NEMS, the model is able to account for virtually all equipment affected by federal standards, state standards, and the ENERGY STAR program, though state standard efficiency levels and ENERGY STAR market share are not explicitly modeled in NEMS (EIA 2011b).

Even after accounting for all of the end uses covered by standards and ENERGY STAR, there are still uses that are not characterized in NEMS. This 'remainder' of MELs is comprised of three general groups:

- **motor-based devices** such as vacuum cleaners, blenders, mixers, electric toothbrushes, garbage disposals, and garage door openers;
- **electric resistance heat-based appliances** such as curling irons, hair dryers, electric blankets, and toaster ovens; and
- a multitude of **electronic devices** such as television and computer peripherals, digital picture frames, and compact audio equipment.

This group is referred to as a 'remainder' as the consumption estimates from the several end uses estimated by RECS and ultimately characterized in NEMS still do not fully encompass residential electricity consumption. Thus the remainder's aggregate consumption is quantified, even if the consumption of each individual end use is not estimated.

Accurate information about the saturation and consumption of this disparate remainder of end uses is comparatively difficult to obtain. Few national surveys have collected data about how often vacuum cleaners or toaster ovens are used in a given year or how many electric toothbrushes are in use in homes. As individual end uses, their consumption is small enough not to warrant much attention; in aggregate, these devices are significant. This 'remainder' of end uses contributed about 11% of all residential electricity use in 2011 (EIA 2012).

Background

History of MELs

Two EIA products can inform the history of residential end-use consumption. RECS has collected data on energy consumption at various points in time. Originally intended as an annual survey when established in the late 1970s, RECS is now conducted on a quadrennial basis. Ten RECS have been conducted in the span from 1980 to 2005. In each survey, EIA uses statistical methods and survey data to estimate end-use consumption for space heating, air conditioning, and water heating. The residual is called "lighting[1] and appliances"—essentially lighting and

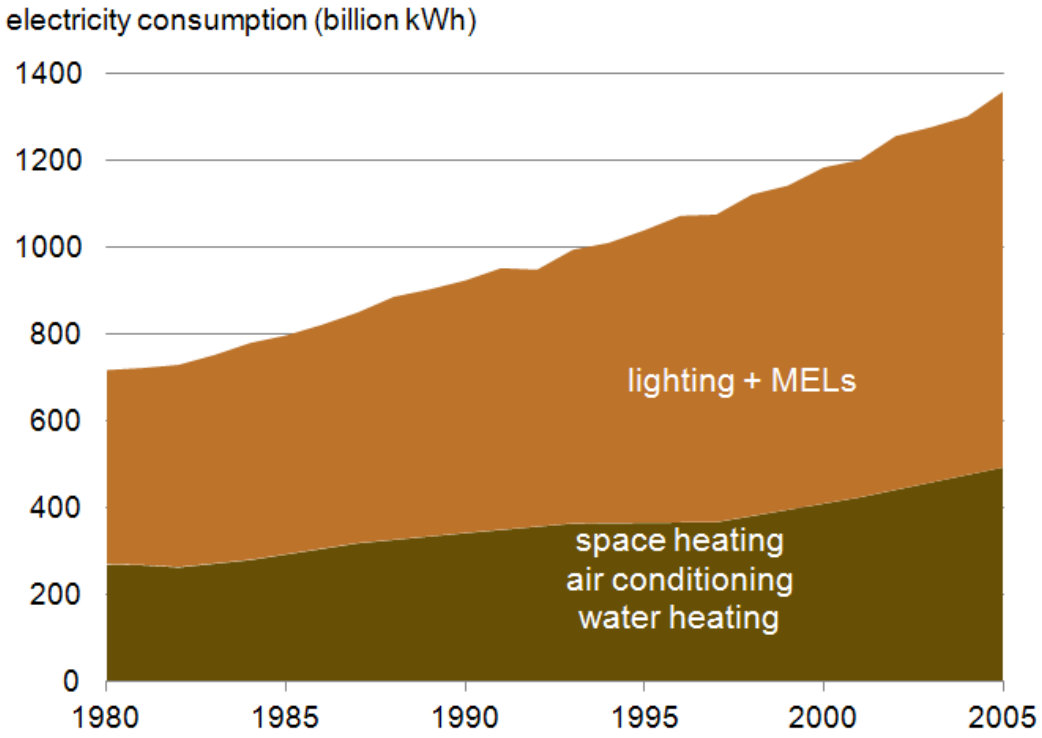
[1] Lighting in particular is difficult to disaggregate based on information collected in a survey. It is relatively easy to count how many refrigerators or cookstoves a house has and how much energy they might consume; it is much more difficult to count the number, type, wattage, and usage pattern data for the various light bulbs in a home.

MELs—and cannot be disaggregated further for the entire RECS series (EIA 1981-2012). Figure 2 shows how these two groups of end uses have grown over time.

Because RECS data is not collected annually, the electricity usage data considered in this analysis comes from EIA's Annual Energy Review (AER) which provides data from energy suppliers. In the RECS years, the end-use shares were adjusted to the AER totals, and intervening years are interpolations of the most proximate RECS years. Since RECS only surveys primary residences and not vacant housing units, second homes, and vacation homes, the RECS consumption data requires adjustment to describe the entire residential sector.

The electric space heating, air conditioning, and water heating category grew at an average annual rate of 2.4%, while lighting and MELs grew 2.7% annually from 1980-2005. Both rates exceed the average annual growth of population (1.1%) and housing stock (1.2%) during that period (EIA 2011a).

Figure 2. Estimates of historical end-use shares of electricity

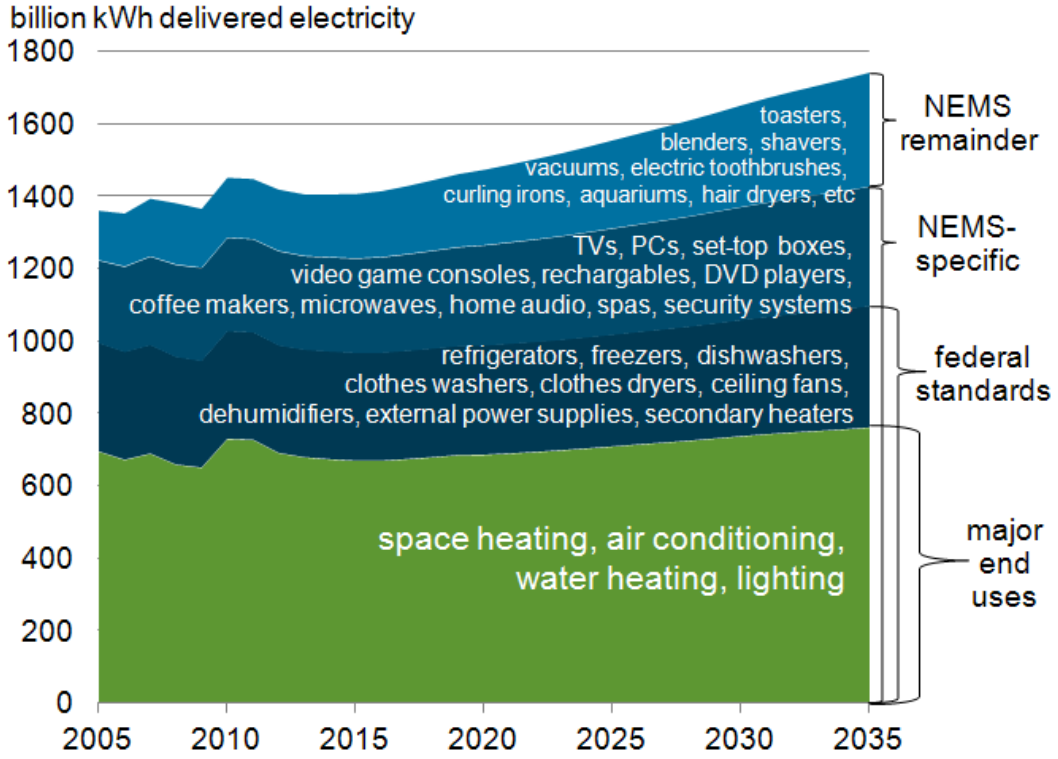


Source: Annual Energy Review 2011 (delivered electricity) (EIA 2011a);
Residential Energy Consumption Surveys 1980-2005 (end-use shares) (EIA 1981-2012)

Projection of MELs Consumption

Current and projected consumption levels are estimated using a third EIA product. The most recent Annual Energy Outlook provides residential consumption estimates for 26 distinct electric end-uses covering about 89% of the electricity delivered to the residential sector in 2011. The remaining 11% is part of "other" electricity use within NEMS and displayed in Figure 3 as the 'NEMS remainder' (EIA 2012).

Figure 3. Projected end-use shares of electricity



Source: Annual Energy Outlook 2012 Early Release Reference Case (EIA 2012)

The year 2005 is the base year for the residential component of NEMS, as that is the most recent year with available consumption and expenditures data from RECS. Within the 2005-2035 projection period, residential-sector delivered electricity is projected to grow at an average annual rate of 1.04%—only slightly faster than the projected growth in population (0.98%) and housing stock (0.91%) over the same timeframe (EIA 2012). Yet the subgroups of electric end uses are projected to grow at very different rates, as Table 1 shows.

The impact of the appliance standards program is easily seen here, as the projected growth rate of the products covered by federal standards (0.46%) is less than one-fourth of the rate of products not covered by federal standards (2.25%). Within the group of non-covered products, though, the group characterized in NEMS grows at only 1.41%, while the remainder grows at a 3.32% (EIA 2012). Thus, the remainder group of MELs is both poorly characterized in the data and contributing the fastest growth in residential electricity usage.

Table 1. Average annual growth rates for groups of electricity end uses, 2005-2035

<table>
<tr><td>NEMS remainder</td><td>3.32%</td><td rowspan="3">1.34%</td><td rowspan="2">2.25%</td><td>3.32%</td><td rowspan="4">1.04%</td></tr>
<tr><td>NEMS-specific</td><td>1.41%</td><td rowspan="3">0.66%</td></tr>
<tr><td>federal standards</td><td>0.53%</td><td rowspan="2">0.46%</td></tr>
<tr><td>major end uses</td><td>0.43%</td><td>0.43%</td></tr>
</table>

Source: Annual Energy Outlook 2012 Early Release Reference Case (EIA 2012)

The growth of the remainder is explained not only by the lack of appliance standards and other efficiency approaches that have been used to moderate end-use growth, but also by growth in the number of end uses within this group. As standards of living rose, technology progressed, and new service demand was essentially created. The number of end uses in this remainder has grown and, as trends continue, is projected to continue growing. Examples of new uses include electric toothbrushes, electronic readers, and plug-in air fresheners—devices that are beginning to replace their equivalent 'analog' precursors that never required electricity.

Efficiency Approaches

There are several ways to encourage energy efficiency in the residential sector, including utility programs (e.g., rebates), voluntary labeling programs (e.g., ENERGY STAR), Congressionally-defined standards (e.g., Energy Independence and Security Act of 2007), and appliance standards instituted at the state or federal level. In this analysis, we focus mainly on federal standards and the two approaches that often precede them: ENERGY STAR specifications and state standards. By virtue of being nationwide and mandatory, federal standards have been a significant means of increasing residential energy efficiency.

ENERGY STAR

Since its inception in the mid-1990s, the ENERGY STAR program has been a way for consumers to identify more efficient, commercially-available products (EPA 2012c). Even as the range of ENERGY STAR products has grown, however, the label is still largely associated with products that are also affected by federal efficiency standards. Only a few products in the ENERGY STAR program are not already covered by federal standards, including televisions, computers and their displays, set-top boxes, room air cleaners, audio/video equipment, and cordless phones (EPA 2012b).

The ENERGY STAR program's selection process is based on guiding principles rather than quantitative thresholds. In general, the most important factor for updating ENERGY STAR specifications is market share. When qualified products surpass 35% of the market share in a particular category, a revision is considered (EPA 2012a). Other factors that may prompt revision include an update of the federal appliance standard, technological changes which allow greater efficiency, and increased product availability.

The Environmental Protection Agency (EPA) often revises their specifications on a more frequent basis than the cycle for updating federal appliance standards (EPA 2012c). For example, ENERGY STAR is in the process of developing its fifth specification for refrigerators since 1996 (EPA 2012b), while only four federal appliance standard levels have been adopted since 1987 (ASAP 2012b). Television specifications and computer display specifications have been revised multiple times since 1998, even in the absence of appliance standards (EPA 2012b).

Recently, ENERGY STAR specifications have been the precursor to federal appliance standards. Many of the difficulties that the EPA may encounter in creating specifications, such as accurate information for market diversity, efficiency opportunities, cost savings realization, and performance and consumption measurability, help inform the approach that the Department of Energy may take in proposing appliance standards.

Appliance standards at the state level. Some states have instituted appliance standards for certain end uses. Due to the way current federal law is written, states are not able to create more stringent standards for products covered by federal standards unless they seek an exemption (ASAP 2012a). Currently, the products that are affected by state standards are those without existing federal standards, including battery chargers, compact audio equipment, DVD players and recorders, pool pumps, portable electric spas, televisions, and wine coolers (ASAP 2012b). In general, these products overlap with ENERGY STAR products, reinforcing the idea that both ENERGY STAR and state-level standards often serve as precursors to federal standards.

Appliance standards at the federal level. Several pieces of Congressional legislation have established the Department of Energy's authority to establish minimum efficiency standards. These laws include the Energy Policy and Conservation Act of 1975 (EPCA), the National Appliance Energy Conservation Acts of 1987 and 1988 (NAECA), the Energy Policy Acts (EPACT 1992 and EPACT 2005), and, more recently, the Energy Independence and Security Act of 2007 (EISA).

Various parts of these Acts have formed the U.S. Code that governs efficiency standards. Generally, products must meet all four key thresholds for products to be included in the federal program (42 U.S.C. §6295 2010):

- average energy use of those products exceeds 150 kilowatt-hours (kWh) in a year in the households that use those products;
- aggregate household energy use exceeds 4.2 billion kWh in a year;
- substantial improvement in energy efficiency is 'technologically feasible'; and
- the standard is 'economically justified'.

Thus the process for determining if a product type or class can have a standard involves two quantitative thresholds (average per-household and aggregate household energy use) and two qualitative thresholds (technological feasibility and economical justification). Both types of thresholds have implications for the potential of policy options to reduce the energy consumption of MELs. Several MELs that cross the quantitative thresholds—i.e., have sufficient per-household and aggregate energy use—may not have demonstrated the opportunity for improved efficiency. These products probably use electric motors or electric resistance heat, which operate at near-ideal efficiency, making further efficiency gains technologically infeasible, except in applications such as pool pumps where multi-speed motors and controllers may be used.

Even if gains are feasible, they must also be economically justified. This qualification requires that the products are in operation long enough for the reduced energy fuel expenditures to justify the additional incremental cost of the more efficient device over its expected lifetime. Depending on the variables (i.e., cost increment, fuel price, equipment lifetime, and efficiency gain), that economic justification may not occur.

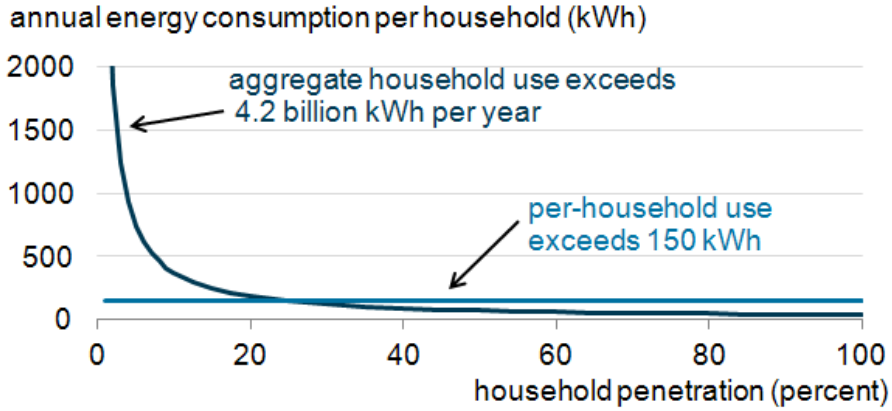
The 'technologically feasible' and 'economically justified' efficiency thresholds likely precludes several kitchen appliances and cosmetic / grooming devices from being covered: toasters, mixers, blenders, coffee grinders, food processors, slow cookers, curling irons, hair dryers, electric toothbrushes, electric shavers, etc. These relatively simple products either do not have enough opportunity for efficiency or their expected lifetimes are not long enough to justify efficiency improvements.

Examining Current Efficiency Levels and Penetration of MELs

The quantitative thresholds for federal standards, as illustrated in Figure 4, provide two useful metrics for understanding current levels of energy consumption and household penetration of several MELs. It is important to make a distinction between terms here: penetration is the percent of households with at least one unit; saturation is the number of units per household.

One requirement is fairly straightforward: the average energy use of those products must exceed 150 kWh per year in the households that use those products. The other requirement is a function of both penetration and household energy use. By plotting household penetration and annual consumption per household (of households with at least one unit), the threshold of 4.2 billion kWh appears as an inverse curve; the more houses that have that product type, the less energy those products have to use to exceed 4.2 billion kWh. As the residential sector grows and the number of households increases, this requirement gets slightly easier to meet.

Figure 4. Visualization of federal standard thresholds

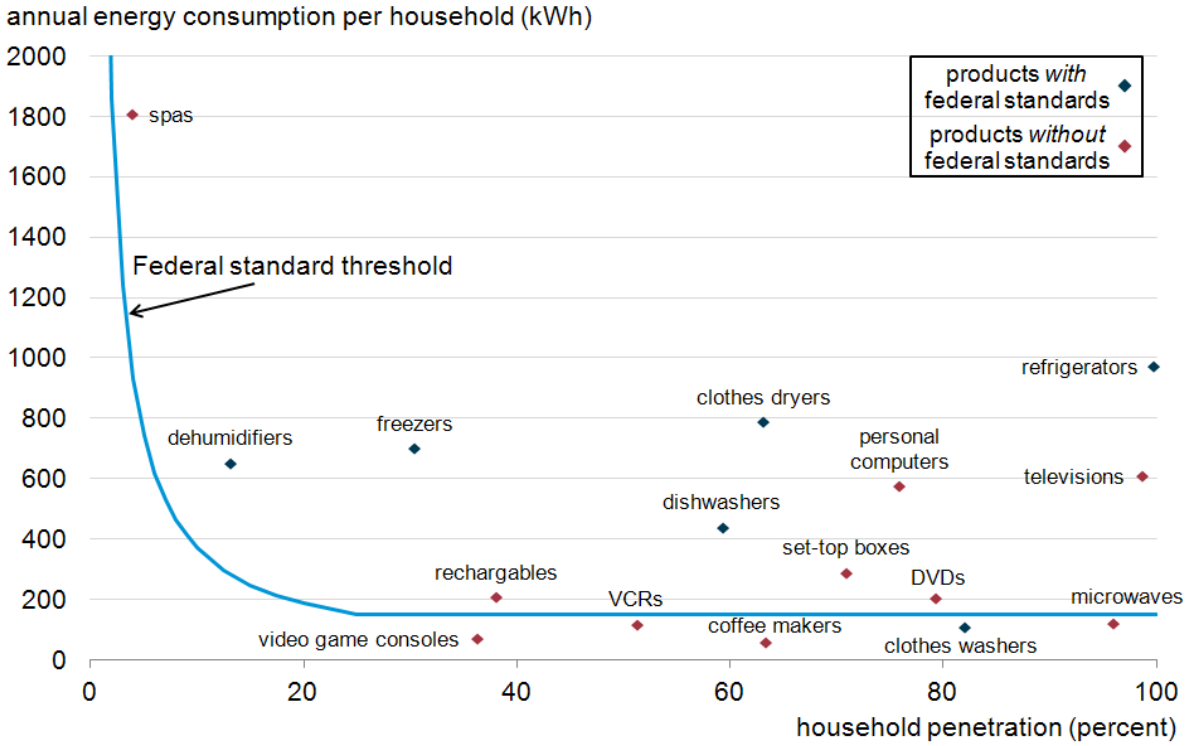


Source: 42 U.S.C. §6295, *Energy Conservation Standards*

Using year-2009 consumption estimates from the AEO and household penetration data from RECS 2009, several MELs can be plotted on this graph, as shown in Figure 5. Blue data points represent end uses that are currently covered by federal standards and red points are products not yet covered. The end uses shown here are not all-inclusive; data for several MELs are insufficient to determine current levels of household penetration or to calculate estimates of annual energy consumption.

Figure 5 depicts several end uses that are already above the threshold for federal standards yet not currently subject to standards. Spas, which have high per-household consumption but relatively low household penetration, are currently subjected to state-level standards in Arizona, California, Oregon, Washington, and Connecticut (ASAP 2012b). There are also a few electronic end uses with relatively high annual consumption per household and high levels of household penetration. DOE recently determined that set-top boxes and network equipment will be covered products with rulemakings scheduled for 2013 (DOE 2011). Although the test procedure for televisions is currently being developed, that does not necessarily imply an efficiency standard will follow. Personal computers have not yet been considered for test procedures or efficiency standards (DOE 2012a).

Figure 5. Household penetration and estimated end-use consumption, 2009



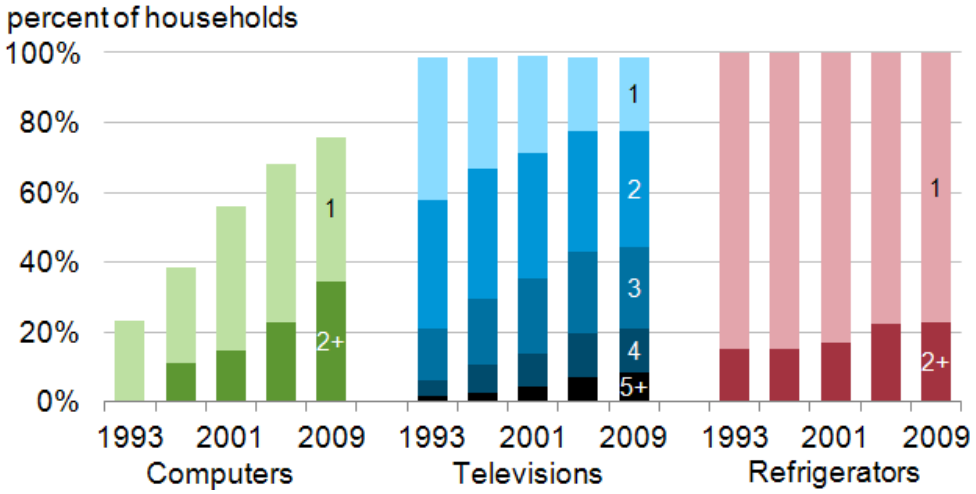
Notes: Clothes washer and dishwasher consumption represents machine use only; energy consumption associated with water heating is not included here. 'Set-top boxes' refers to cable boxes, satellite boxes, digital-to-analog converters, and digital video recorders.
Source: Residential Energy Consumption Survey 2009 (household penetration) (EIA 1981-2012); Annual Energy Outlook 2012 Early Release Reference Case (annual energy consumption, 2009) (EIA 2012)

Opportunities for Change

There are many factors that affect both the penetration and annual energy consumption of MELs. On the axes plotted in Figure 5, movement to the left or right is based purely on household penetration. Over time, penetration tends to increase as standards of living rise and certain technologies become more affordable.

Movement up or down, however, is a function of energy use and several other factors. Increasing saturation plays a key role. In recent years the number of refrigerators, televisions, and computers per household has increased, driving consumption higher than if saturation had remained unchanged. Figure 6 demonstrates the difference between penetration and saturation trends. While the penetration of refrigerators and televisions has remained fairly constant at nearly 100%, saturation of both has been increasing. By comparison, computers are rapidly penetrating and saturating households. In 1997, about 39% of households had at least one computer. Twelve years later, 37% had at least two computers (EIA 1981-2012). Even examining the number of units per household may not convey the full story, as increasing service demand, such as consumer desire for larger monitor sizes, can cause per-unit annual consumption to increase.

Figure 6. Increasing penetration and saturation of select end uses



Note: The 1993 RECS only asked if a computer was used; subsequent surveys captured the number of computers.
Source: Residential Energy Consumption Surveys 1993-2005. (EIA 1981-2012)

On the other side, improved efficiency can cause consumption to decrease, either by consumers choosing more efficient products within a given technology type (i.e., a more efficient clothes washer of similar capacity), or switching to more efficient technology types (i.e., from a cathode-ray tube (CRT) monitor to a liquid crystal display (LCD) monitor). Changes in user behavior or better control mechanisms can affect total consumption, either through better use of 'active' and 'standby' energy modes or through general conservation (i.e., reductions in service demand).

Obsolescence may cause household penetration to decrease for certain devices, though that service demand may still be met by other electric devices. A prime example of this is the replacement of video cassette recorders (VCRs) with DVD players or, more recently, digital video recorders (DVRs).

Examples of Change

The factors mentioned above drive annual energy use for the various miscellaneous electric loads in different ways. The penetration of clothes dryers, for instance, has increased from about 47% of households in 1980 to 63% of households in 2009 (EIA 1981-2012). Comprised primarily of an electric motor and electric resistance heating, clothes dryers in their current form may not have a lot of room for technological advancement. Indeed, there are no ENERGY STAR specifications for clothes dryers. With no major change in saturation or efficiency, changes in consumption in these types of end uses will likely rely on conservation, controls, or some tangential approach (for clothes dryers: increasing clothes washers' spin cycle to reduce moisture content, or encouraging a switch to ambient drying).

Personal computers practically did not exist in the residential sector in 1980, but, as of 2009, are in over 75% of households (EIA 1981-2012). Over this time, computer processors have grown exponentially more powerful as technology advances. Small CRT monitors have given way to larger LCD monitors, while laptops, netbooks, and tablets now offer a reduced-consumption alternative to desktop computers. Tracking the resulting change in energy consumption across these devices can be difficult, as most surveys on personal computing focus

on aspects other than energy use. Increased service demand and saturation have driven growing consumption per household, even as the penetration rate has slowed. Efficiency and technology improvements could moderate or even reverse the growth in personal computing electricity consumption.

For some devices, penetration may not be changing significantly. For instance, the penetration of dehumidifiers has remained virtually unchanged over the past three decades. Other devices may reach high levels of penetration then become obsolete due to advances in technology. In these cases, device penetration reaches a maximum level of households before declining in favor of the newer technology; service demand is not lost but supplanted. For example, in 1997 about 88% of households had a VCR, and a third of those households had more than one recorder. By 2009, the share of households with VCRs had declined to about 51%, while the penetration of DVD players and digital video recorders increased (EIA 1981-2012).

Conclusion

Realized efficiency improvements in the products currently covered by federal standards demonstrate the value of appliance standards. For those products not yet covered, the standards approach may not be well-suited to the technical aspects or market dynamics of many of the remaining end uses. Equipment that relies primarily on motors or electric-resistance heat already operates near ideal efficiency and thus provides little opportunity for improvement. For electronics, rapid changes in the service demand and the variety of equipment that provides it are difficult to address in the comparatively long timeline of the typical rulemaking process. Ultimately, insufficient data at the national level regarding penetration, saturation, and usage of these MELs makes any analysis of efficiency potential difficult.

References

42 U.S.C. §6295. 2010. *Energy Conservation Standards.*

[ASAP] Appliance Standards Awareness Project. 2012a. *National Appliance Standards Laws and Regulations*. http://www.appliance-standards.org/content/appliance-standards-laws-and-regs. Boston, Mass.: Appliance Standards Awareness Project.

___. 2012b. *Products*. Appliance Standards Awareness Project. http://www.appliancestandards.org/products. Boston, Mass.: Appliance Standards Awareness Project.

[DOE] Department of Energy. 2011. *Multi-Year Schedule*. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/multiyear_schedule_aug_2011.pdf. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

___. 2012a. *Energy Conservation Standards Activities*. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/report_to_congress_february_2012.pdf#page=48. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

___. 2012b. *Residential Products*. http://www1.eere.energy.gov/buildings/appliance_standards/residential_products.html. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

[EIA] U.S. Energy Information Administration. 1981-2012. *Residential Energy Consumption Surveys 1980-2009*. 11 vols. http://www.eia.gov/consumption/residential/data/previous.cfm.Washington, D.C.: U.S. Energy Information Administration.

___. 2011a. *Annual Energy Review 2010*. DOE/EIA-0384(2010). http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf. Washington, D.C.: U.S. Energy Information Administration.

___. 2011b. *Assumptions to the Annual Energy Outlook 2011*. DOE/EIA-0554(2011). http://www.eia.gov/forecasts/aeo/assumptions/. Washington, D.C.: U.S. Energy Information Administration.

___. 2011c. *Model Documentation Report: Residential Demand Module of the National Energy Modeling System*. DOE/EIA-M067(2011). http://www.eia.gov/FTPROOT/modeldoc/m067(2011).pdf. Washington, D.C.: U.S. Energy Information Administration.

___. 2012. *Annual Energy Outlook 2012 Early Release*. DOE/EIA-0383ER(2012). http://www.eia.gov/forecasts/aeo/er/pdf/0383er(2012).pdf. Washington, D.C.: U.S. Energy Information Administration.

[EPA] Environmental Protection Agency. 2012a. *ENERGY STAR Products Program Strategic Vision and Guiding Principles*. http://www.energystar.gov/ia/partners/prod_development/downloads/guiding_principles_2012.pdf?fefa-854a. Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

___. 2012b. *Find ENERGY STAR Products.* http://www.energystar.gov/index.cfm?c=products.pr_find_es_products. Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

___. 2012c. *Major Milestones.* http://www.energystar.gov/index.cfm?c=about.ab_milestones. Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.