Energy Impacts of Smart Home Technologies

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Executive Summary

Smart homes use technologies like smart thermostats, appliances, and lighting to enhance residents' comfort and convenience in their homes. These technologies connect to one another through home wireless networks and to the larger world through the Internet. Using software, sensors, and other hardware, they monitor and control the home's systems and allow residents to access them when they are away.

Not only do smart technologies offer comfort and convenience, but they also can save energy. They do so by automatically controlling the equipment and appliances in the home and using energy only where and when it is needed. They can also collect real-time data on energy use and communicate with the electric grid, which can lead to more savings. Service providers can leverage smart home data to offer their customers further energy-saving opportunities.

TECHNOLOGIES

A number of smart home technologies can improve comfort and save energy in the home. Some technologies interact, working together to achieve savings for the same system (e.g., HVAC). Drawing from available studies, we estimate household energy savings relative to average energy consumption for each end-use category. Additional research will validate and improve these estimates.

Appliances and electronics. Smart appliances and electronics automatically optimize their own operation. We can regulate them from anywhere in the home or from afar. For example, smart speakers or hubs can control disparate systems on command, and smart clothes washers and dishwashers can shift their operation to off-peak hours, when energy is less costly. Smart appliances can reduce energy costs for a typical household by 2–9%. Residents who use feedback from these devices to further adjust their energy use can save a modest additional amount of energy (~3%).

Lighting. Smart lighting consists of lamps and switches with advanced controls. Smart lamps are LED bulbs or integrated LED fixtures embedded with a wireless chip. We can control these lights through a smartphone app or smart hub or by using smart switches. Smart lighting incorporates automatic dimming and other advanced functionalities to reduce light levels and operating hours. It has the potential to save 7–27% of a home's lighting energy use.

Outlets and power strips. A home's plug load is the amount of energy drawn by the many types of electronics and small appliances used in the home. Smart outlets, smart plugs, and advanced power strips work with existing wall receptacles and can automate the control of any device with an AC plug. They rely on time scheduling, motion sensing, or load detection to cut off power to devices that are not in use. They can be wirelessly controlled and turned on and off remotely. Because household plug loads can theoretically include an almost infinite number of electronics and electric devices, the potential for plug load energy savings is substantial—up to 50% in some households.

Window coverings. Smart window shades and blinds manage the amount of solar heat and daylight that enters the home. Their wireless motors and sensors enable them to adjust at certain times of the day in response to changes in daylight or according to programmed schedules. Another option, smart window films, adhere to the glass and become transparent only when electrically charged. Smart window coverings can improve a home's thermal comfort, privacy, and security. Their energy savings potential is unique to each home, depending on its design, climate location, and other variables. For a typical home, effective control strategies can yield savings of 11–20% in space heating and cooling and approximately 3% in lighting.

HVAC. Smart heating, ventilation, and air-conditioning (HVAC) systems use multiple sensors for optimizing system operation while improving thermal comfort. They can be controlled remotely through personal devices, and up to 10% savings in home heating and cooling are possible. In a smart HVAC system, room sensors and smart vents relay temperature and occupancy information to a smart thermostat (or other control device) to reduce energy waste in unoccupied areas of the home. Such systems also incorporate local weather data to anticipate heating and cooling needs. Room air-conditioning units and ceiling fans can also be equipped with smart functionality to help save on cooling costs.

Water heating. Conventional gas and electric water heaters can be retrofitted with smart controllers and sensors to optimize home water heating. Some newer models have smart capability built in. Smart controls can shift the time of water heating to take advantage of favorable utility time-of-use rates and demand response programs where available. These controls can actually learn a home's hot water use patterns and avoid heating water when it's not necessary, as when the home is unoccupied. Optimal use can result in savings of 15% of a home's water heating energy consumption.

Smart thermostats. Smart thermostats are the leading smart energy technology installed in US homes, with 11% of households having one. Smart thermostats communicate with other connected devices through the home's wireless network. They use programming algorithms for seamless heating and cooling and autonomously respond to inputs from other systems in the home as well as local weather data. Smart learning thermostats heat or cool the home according to learned household behavior patterns and preferences. Smart thermostats have proved to reduce HVAC energy consumption; average savings of 8% in heating costs and 10% in cooling costs can be expected.

Home energy management systems (HEMS). HEMS are hardware and software systems that can control and monitor one or more energy uses in the home. They continuously collect and analyze data on energy performance and provide feedback through user-friendly interfaces. When used as a central point of control for multiple systems, HEMS potentially achieve more energy savings than could be saved by a collection of individual smart devices. Actual savings depend on which end uses are controlled; savings can range from 5–22% per home.

ENERGY AND NONENERGY BENEFITS

Smart home technologies save energy by optimizing the operation of energy-consuming systems in the home. The data they generate can lead to better energy management and behavior change. Independent studies on smart technologies are limited in scope and size and are available mostly for technologies with high installation rates. One study on five technologies estimates national savings in the range of 0.3–1.1 quads, or 1–5% of the total primary energy consumed by US homes. Other studies indicate that this is a low estimate and that residential sector savings are potentially higher for many smart technologies. An ACEEE analysis estimates that sector savings could reach as much as 17% if every US household adopted smart technology for each of the major end uses—HVAC, water heating, lighting, kitchen and laundry appliances, and home office and entertainment equipment.

Studies that compare the various technologies across different applications will allow us to better understand their energy savings potential. In coming years, we should begin to see results from smart technology field demonstrations that are currently underway. Efforts in data analytics to disaggregate smart technology–generated data into meaningful, actionable findings would also prove useful.

The purchase costs and energy savings of smart technologies vary widely across technology types and applications. For technologies with high up-front costs, control strategies with the greatest savings potential should be used, to prove their cost effectiveness. Many smart home technologies are wireless, making them retrofit friendly. However they have their own energy requirements, to support their sensing, communication, and control capabilities, which are always in *network standby* mode. This could actually diminish any incremental energy savings over conventional technology. It is important to consider this when evaluating the energy performance of any smart technology.

The nonenergy benefits of smart home technologies are the leading reasons for consumer acceptance and adoption. Americans have been quick to equip their homes with smart devices that enhance safety and privacy. Many, too, appreciate the convenience of monitoring and controlling their homes through voice commands or remotely through smartphone apps or cloud-based platforms.

BARRIERS TO ADOPTION

Up-front purchase costs and the perceived complexity of smart technologies are the leading barriers to investment in the smart home. Current adopters tend to be tech-savvy, upper-middle-income households. In addition, most smart homes rely on the Internet for connecting devices to each other and the grid. However people are hesitant to commit to the Internet of Things due to mounting cybersecurity threats and breaches. In order for energy-saving smart technologies to become more prevalent, the many product manufacturers and vendors, energy service providers, and standards-making entities must better understand their benefits, limitations, and value proposition.

SMART HOME TECHNOLOGY INCENTIVES

Utilities offer energy efficiency programs that incentivize smart technologies such as smart thermostats, advanced power strips, and room air-conditioning controls. Incentives are commonly in the form of rebates for purchasing the technology and energy bill credits for participating in demand response programs. Many utilities employ time-of-use rate structures to incentivize customers who voluntarily curb their energy use during peak demand periods.

Utilities have achieved reductions in peak demand through load control devices, and many are expanding on this effort to include smart technologies. Beyond the smart meter, utilities are now incorporating smart thermostats and water heating controls into their programs. Results from smart thermostat programs show average reductions in peak demand ranging from 0.6 to 1.2 kW per thermostat for each event and average savings of 10% and 4% in total household gas and electricity use, respectively. Few programs have reported reductions above 1.2 kW. Programs using smart controls for home water heating are nascent, and findings are not yet available. Some utilities partner with third parties to administer their demand response programs and create customized energy efficiency solutions for their customers.

A smart home may improve on traditional evaluation, measurement, and verification of home performance retrofits and energy-saving measures in new construction. The data generated by smart devices can tell a lot about the performance of a home. These data give contractors and program managers real-time feedback on project performance. They can verify energy savings and identify opportunities for additional energy efficiency measures.

RECOMMENDATIONS

As with many emerging technologies, relatively few completed studies exist for smart home applications. We have limited performance data for most smart home technologies other than smart thermostats; further research is needed. As a result, incentives are still generally lacking for the majority of measures. Best-use cases—especially in existing and older homes—must present validated, predictable, and cost-effective energy savings if smart technologies are to expand into utility program portfolios and the US housing stock at large.

Some utilities are sponsoring pilot projects to shed light on the energy savings potential of smart home technology. Future studies could cover multiple technologies to save on time and administrative costs and to explore their combined savings potential. Projects that generate data from different equipment and across a variety of applications can help to address some of the barriers to market transformation. Such projects might also make it possible to assess behavior change and understand how residents interact with their smart devices.

To realize the full potential of smart technologies, consumer acceptance must evolve beyond early adopters and reach the broader population. We seek ways to increase the uptake of smart technologies that save energy, while acknowledging that some also improve home health and comfort. Incorporating these promising technologies into home performance and low-income programs may help them gain wider acceptance. Utilities could collaborate with contractors to field additional program offerings to their customers. As people become more familiar with smart home technologies and satisfied with the convenience, comfort, and energy benefits they afford, they might be more likely to pursue additional efficiency measures or spread the word to friends and family. Joint exploration of the energy and nonenergy benefits of smart technologies could reveal the full potential of the smart home.

Introduction

Technology is changing how we meet our needs and helping us stay connected to the people, places, and things in our lives. Our increasing interest in technology has played out through the mass adoption of smartphones and tablets, and the global reach of the Internet has brought smart technologies into our homes.

New and existing homes are becoming smarter as the first generation of smart home devices are installed in residences in the United States and around the world. These include lights, thermostats, kitchen and laundry appliances, and security systems.

Smart homes use software, sensors, and other hardware to monitor and control the interior environment. Appliances and devices can communicate with one another and the outside world. Residents can use smartphones to remotely control their smart devices and receive alerts on activity in and around the home when they are away. Alternatively, a smart home can operate with little or no input from its occupants. We are seeing what one researcher describes as a "dynamic redistribution of control between people and things" (Strengers 2013).

Consumers seeking enhanced experiences in their homes are driving the demand for advanced systems. Smart technologies can improve security, comfort, convenience, health monitoring, and entertainment (Wilson, Hargreaves, and Hauxwell-Baldwin 2015). They have another important benefit: saving energy. They do so by automating the control of appliances and equipment and by communicating with one another to optimize home energy use. Smart devices can communicate bidirectionally with the power grid and distributed energy resources for load management purposes. They also generate data that professionals can use to assess the effectiveness of energy efficiency measures and verify savings. Contractors and utilities can leverage these data to educate customers about their energy use and influence their behavior.

Smart technologies can be particularly effective in retrofit programs. A home retrofitted with these technologies performs better than a typical existing home that relies on manual inputs and often goes unmanaged. Such homes may be wasting energy and sacrificing comfort (Hargreaves et al. 2015).

Methodology and Scope of This Study

This report focuses on the energy-saving potential of smart home technologies in utility-sponsored energy efficiency and demand response programs. After describing what makes a home smart, we examine the functionality and energy-saving potential of eight technologies, both individually and as they work in systems. Although a number of barriers may impede the adoption of these technologies, utilities can advance their use and harness their savings potential in energy efficiency programs. We discuss several options for expanding smart home offerings and conclude with a series of action items for program designers.

Our study focuses on existing single-family, owner-occupied homes. Although multifamily buildings are not explicitly included in the scope of this paper, renters can also experience many of the benefits of smart technologies.

Each region of the United States is included in our analysis. The South has the greatest number of single-family homes—approximately 38% of the total—and the Northeast and Midwest represent about 16% and 24%, respectively. The West has the remaining 22%, of which two-thirds are located in Pacific states (EIA 2017a). Regional distinctions are important, as climates, utility rate structures, and efficiency programs are different across regions.

We conducted a literature review and expert interviews in developing the content of this report. We collaborated with professionals in the smart homes space, from academics and energy efficiency advocates to technology manufacturers and energy service providers. The literature review included articles, reports, surveys, and case studies.

We also sent a questionnaire to utility professionals, most of whom administer residential energy efficiency programs. We wanted to find out how familiar they were with smart home technologies and whether they were incentivizing any in their programs. Nine respondents completed the questionnaire in full. The script is included in Appendix A of this report.

Single-Family Homes

Currently, single-family homes consume 80% of US residential energy. These homes hold an enormous potential for home electricity and gas savings through smart energy efficiency retrofits. Electricity serves the majority of residential energy end uses, powering home cooling exclusively and a portion of home space and water heating needs. Natural gas mainly serves home water and space heating, though fuel type varies by region. HVAC and water heating account for approximately half of all energy consumed by US homes (EIA 2017b). Figure 1 shows the energy use breakdown for US single-family homes.

The US residential sector consumes roughly 20 quadrillion Btus (quads) of energy annually. This represents 21% of US primary energy consumption and accounts for 19% of the country's energy-related carbon dioxide emissions. Residential electricity consumption accounts for 38% of all electricity consumed in the United States (EIA 2017b).

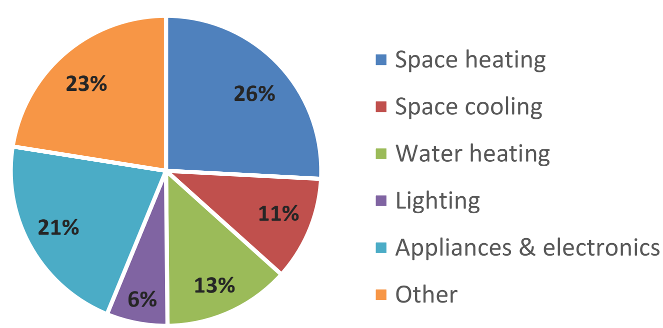

Figure 1. Share of energy end uses in US homes. *Source:* EIA 2017b.

Over the past decade, residential consumption of natural gas and electricity has stayed relatively flat. However recent research using future climate modeling suggests possible increases in home electricity and natural gas use. This is due to forecast warmer summers and colder winters and the attendant increases in cooling and heating demands (EIA 2017b; Schuetter, Debaillie, and Ahl 2014; Meier et al. 2017).

Approximately 66% of the housing units in the United States are single-family, owner-occupied. Homeownership is higher in rural areas, where 81% of homes are owner-occupied, than in urban areas, where the figure is 59% (EIA 2017a; Mazur 2017).

The single-family housing stock is a mix of newer and older homes, with the majority constructed prior to the enactment of a national energy code.[1] The housing stock tends to be newer in rural areas, where 41% of homes were constructed after 1990 and just 15% were built before 1950, as depicted in figure 2. Nationwide, US home construction decreased noticeably between 2010 and 2015 in response to the financial crisis and recession (EIA 2017a).

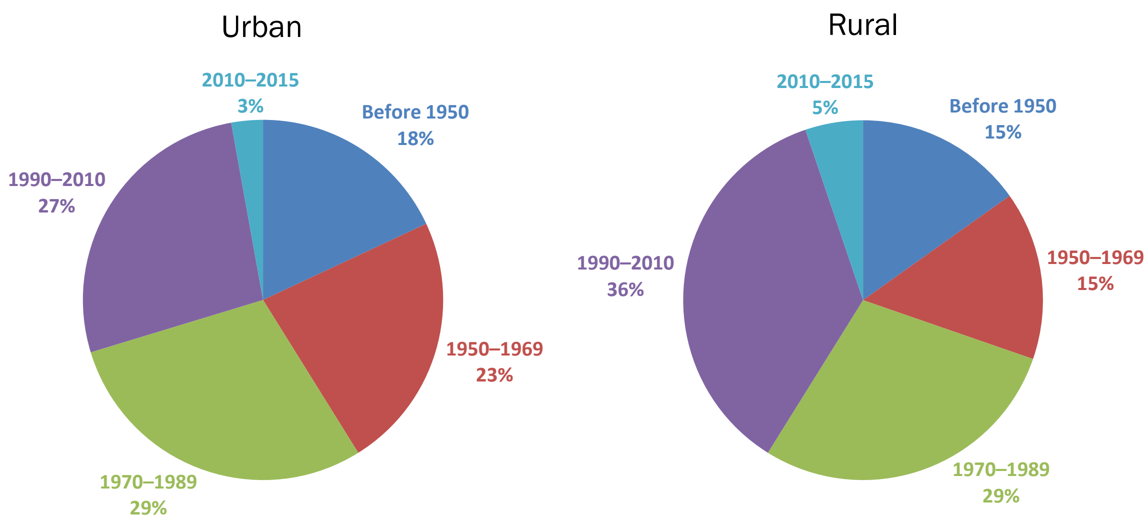

Figure 2. US housing stock by year of construction. *Source:* EIA 2017a.

The Smart Home

Smart homes contain smart technology including appliances, lighting, wall outlets, window coverings, HVAC, water heaters, and thermostats, all of which have advanced features to improve their operation. Smart systems use sensors to monitor variables like temperature and occupancy and adjust settings accordingly. All of these devices have some smart control capability in and of themselves, even without being connected to each other or the outside world. For example, smart lighting can turn on and off or brighten and dim in response to changes in natural light. Figure 3 shows some of the technologies in a smart home.

[1] This was the Energy Conservation and Production Act (ECPA) of 1976.

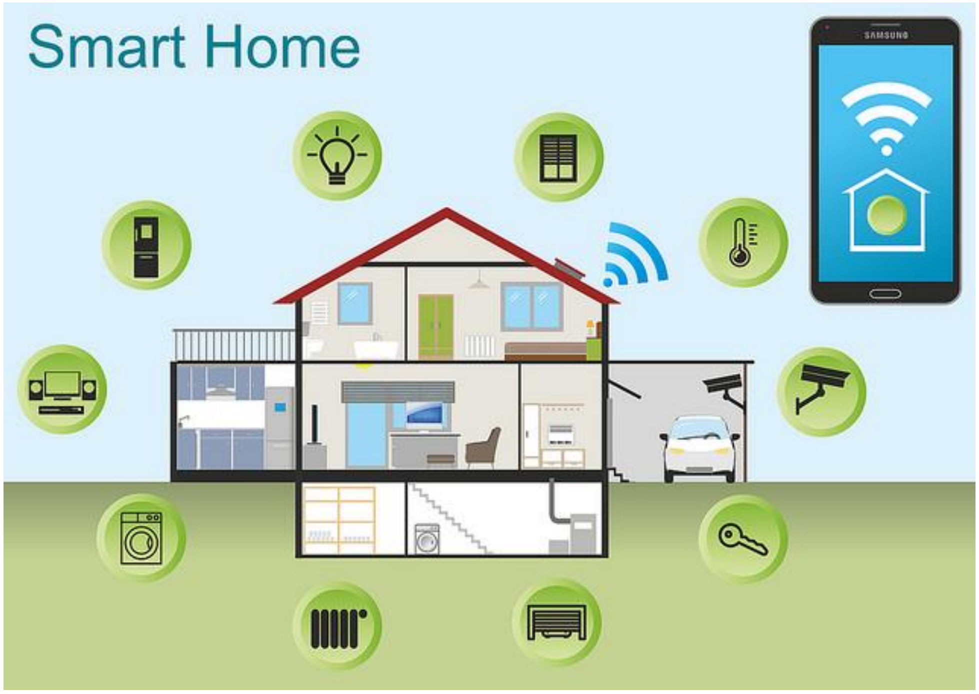

Figure 3. Overview of the connected systems in a smart home. *Source:* Flickr 2017.

Some smart technologies are capable of learning the comfort preferences of a home's residents, for example, temperature settings and lighting levels. They use control algorithms to process information—from inside and outside the home—and respond automatically to changes in occupancy or weather. Smart learning devices recognize household behavior patterns and can turn off systems like HVAC and water heating when occupants are away or asleep, reducing energy waste. Many consumers appreciate these automatic adjustments where they do not have to initiate control themselves (Deutsche Telekom 2015).

Smart homes are less about these individual devices than about their interaction with one another. The key to the smart home is connectivity. Many smart devices are low-powered (and battery-operated) and require some bandwidth to talk to each other. Wireless protocols—Wi-Fi, Bluetooth, Zigbee, Z-Wave, Thread, and others—allow smart devices to share their status and data with one another. For example, a smart thermostat can signal smart window shades to let in more light when the temperature drops in the winter. The shades, in turn, can tell the lighting to dim or turn off in response to the increase in daylighting. In short, smart technologies that target major end uses can change the picture of household energy consumption.

Smart systems can not only optimize their own operation but communicate with distributed energy resources and the power grid. This enables homeowners to save money on their energy bills through load shifting and time-of-use pricing. They can even participate in utility-sponsored programs like demand response directly through their smart devices.[2] Much of a home's energy demand can be reduced at times of peak load.

Devices with analytic capability generate copious amounts of data that can provide insight into a home's activities. These data create new opportunities and mechanisms for identifying equipment inefficiencies and energy-wasting behaviors. Third-party solution providers have entered the smart home space to make sense of the data and engage residents in their energy use. They present information using simple tools like web-based dashboards and graphics. According to a Parks Associates survey, over one-third of US households are willing to pay an additional monthly fee for home energy monitoring and notification services (Parks Associates 2015).

Smart Home Energy Technologies

The true potential for energy savings in the smart home lies in reducing consumption through better management. In this section, we examine the functionality and energy impacts of smart technologies for the following building systems or components:

- Appliances and electronics
- Lighting
- Plug loads
- Window coverings
- HVAC
- Water heating
- Smart thermostats
- Home energy management systems

APPLIANCES AND ELECTRONICS

Smart appliances are typical household appliances with the ability to receive, interpret, and act on signals received remotely. They can self-diagnose mechanical issues and send alerts. Many can automatically adjust their operation in response to real-time signals or preset schedules. Some smart features have been available on appliances for some time. For example, most clothes dryers on the market automatically stop operating when they sense that their load is dry. New technologies and communications protocols are expanding functionality and giving residents new ways to interact with and control their appliances.

[2] The Federal Energy Regulatory Commission (FERC) defines demand response as "Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." See www.ferc.gov/industries/electric/indus-act/demand-response/dem-res-adv-metering.asp.

Once deemed a niche market, smart appliances began to gain greater acceptance in step with other smart home devices in 2014. Researchers estimate that by 2020, more than 220 billion smart appliances will be in homes globally. The United States will account for about 12% of this market, and China nearly 50%. In response to the growing interest, appliance manufacturers are repositioning themselves as technology providers and are finding new channels through which to sell their products. And companies not previously associated with home appliances are entering this market as well; among the players are Google, Apple, Microsoft, and Intel (IHS 2017).

Appliances use 23% of total US residential sector energy (IEA 2016). According to the International Energy Agency's *Energy Efficiency Indicator* report, in 2016 appliances and electronics used nearly 5% more energy than they did in 2000. This is mainly due to the increase of dishwashers, personal computers, TVs, and small electronics in homes.

Sears is partnering with **Amazon** to sell its Kenmore smart appliances through the Amazon website. Sears Kenmore smart appliances will become compatible with Amazon Alexa for voice control capability (Ramakrishnan 2017).

ENERGY STAR® has certified many categories of smart appliances to ensure that those with grid connectivity are also efficient. However the energy draw of smart appliances and electronics may actually increase for features like onboard digital displays and Wi-Fi control. Utilities are encouraging appliance manufacturers to incorporate low-power wireless options into product designs to substitute for the more energy-intensive Wi-Fi. The US Environmental Protection Agency (EPA) is working with the US Department of Energy in establishing test methods for demand response capability in certified appliances.

Smart appliances reduce peak energy demand and generate energy cost reductions through load shifting and demand response. Cost reductions of 2–9% are possible across the major appliance types. One study suggests an additional 3% in cost savings might be possible where feedback leads to efficient appliance use in homes (Sastry et al. 2010).

The EPA's **ENERGY STAR** program began establishing connected criteria for energy-saving features on smart appliances in 2013. Features include the ability of an appliance to report its energy consumption to a home management system (or other interface) and the opportunity for users to manage their appliances remotely—for instance, to receive alerts and put their appliances in vacation mode to save energy.

Dishwashers

Smart dishwashers connect to Wi-Fi for remote control. Residents can schedule and monitor wash cycles and operate lock/unlock controls remotely through their smartphone. The smart dishwasher can send alerts like when the rinse aid is low.

Dishwashers in general have high electric loads due to an onboard electric resistance heater for heated drying and for boosting the supply water temperature. Energy-saving control strategies for smart dishwashers include programming their operation for times of low energy use, as when residents are away or asleep. Smart dishwashers can sense the size of the load and run less energy-intensive wash cycles for small loads. An estimated energy cost savings of 5–9% is achievable through load shifting and demand response (Sastry et al. 2010).

Laundry

Via Wi-Fi, residents can control and monitor their smart clothes washer and dryer remotely. Remote capabilities include initiating wash and dry cycles, monitoring operation, and receiving status alerts. Some models can synchronize with smart thermostats and operate in a quiet mode when residents are home and asleep. A smart dryer may cycle on periodically to freshen clothes that remain in the machine for an extended period.

Smart clothes washers and dryers may reduce energy consumption through control strategies. They can be scheduled to run overnight or during periods of cooler outdoor temperatures to minimize impact on home cooling loads. Similarly, residents can delay their operation until off-peak times or periods of low energy use in the home. Load shifting of smart washers and dryers can result in cost savings of 4–7% (Sastry et al. 2010). Smart laundry machines can also self-diagnose mechanical issues and notify the homeowner of needed repairs. For example, a smart dryer can send an alert if the vent becomes lint-clogged, which inevitably lowers its operational efficiency.

Refrigerators

Like smart dishwashers and laundry appliances, smart refrigerators connect to the Internet. Residents can update a grocery list directly on the refrigerator's LCD screen and then later access the list on their smartphone. Some models go a step further and have built-in cameras that allow users to see the contents of the fridge. A smart refrigerator can promptly notify the homeowner when it has mechanical problems, reducing the time and expense of diagnosing repairs.

Smart refrigerators may reduce energy consumption through demand response. Examples include shifting energy-intensive functions like ice-making and defrost cycling to non-peak times and switching the fridge to vacation mode to suspend those functions while residents are away. An estimated 2–4% in energy cost savings can be achieved by shifting energy-intensive loads to off-peak times of the day (Sastry et al. 2010).

The addition of an LCD screen, camera, and Wi-Fi connectivity on smart refrigerators may increase energy use. At this point, it is hard to know if these features negate potential savings. However some manufacturers note that a camera may result in energy savings by providing quick views into the refrigerator without the need to open the door.

Televisions

Smart TVs can connect to the Internet through Wi-Fi or directly through the home router with an Ethernet cable. They allow viewers to control and stream audio and video content from built-in applications.

Smart TVs often increase energy consumption due to their high standby power needs, which can range from 3 to 30 watts. Most standard TVs use less than 1 watt. Advanced features like ultrahigh definition (UHD) use more energy, although other features like online streaming may reduce the need for set-top boxes, and energy tradeoffs might be possible (D+R International 2016).

Speakers

The smart speaker, commonly referred to as a smart assistant, is a wireless speaker that is hands-free and app-free and responds to voice commands. It connects wirelessly to other smart home devices and can integrate disparate systems in the home. Residents can program their smart assistant to have an away mode, which can be voice activated by saying something like "I'm leaving." This mode can, for example, turn off all lights and any electronics connected to smart plugs, and turn down the thermostat.

More than one-third of Americans who own a smart device also own a smart speaker. It is the fastest-growing smart home device; one model, Amazon's Echo Dot, was the most purchased item during the 2017 holiday shopping season (Weinschenk 2017; Rodriguez 2017).

Smart assistants add to the number of plug loads in our homes. However they may help reduce home energy use by acting as a central point of control for HVAC, lighting, and electronics as they convert voice commands into actions. For example, residents can change the temperature inside their home by telling the smart assistant to raise or lower the setting on their smart thermostat. They can also turn smart lights and electronics on and off by voicing commands as they enter and exit the home. Actual energy savings depend on which end uses are controlled and by how much.

Smart Hubs

Smart hubs are similar to smart speakers in that they can centralize control inside the home. Unlike smart speakers, however, most smart hubs are not voice activated. Instead, they connect smart devices together by relying on command logic, where the operation of devices follows a sequence of events (e.g., if this, then that). People can use apps and cloud-based platforms to manage their devices through the hub. For example, a family on vacation can remotely turn off lights, turn down the thermostat, lock doors equipped with smart locks, and deactivate the defrost cycle on a smart refrigerator. The smart hub can even turn devices on and off based on occupancy.

Smart hubs do not directly reduce household energy consumption. Rather, savings are possible through their ability to control seamlessly the multiple lights, appliances, and electronics in the home.

LIGHTING

Functionality

Smart lighting systems offer several features. Residents can program their lights to turn on and off and dim to preferred light levels. They can also program them to work with the home's security system to enhance safety, for instance turning on the light over the home's entryway when someone rings the doorbell. Residents can control their smart lighting remotely through a personal handheld device or a smart speaker or hub.

> **Smart security technologies** include smart cameras, locks, and doorbells. They monitor activity in and around the home and transmit this information over Wi-Fi or through the cloud to remote devices.
>
> Smart security technology can provide us with greater assurance that our belongings and family members remain safe in the home while we are away.

Smart lighting consists of smart lamps and switches. Smart lamps include LED bulbs and integrated fixtures (e.g., recessed or can lights) and piggyback on the advanced features of LEDs like dimming and color tuning. They connect wirelessly to each other and to other connected devices in the home. Smart bulbs are plug-and-play—that is, they can replace any bulb with a standard screw-in base.

Smart switches can operate both smart and conventional lamps. Also plug-and-play, they replace the standard wall switch. They work well for controlling multiple lamps on a single circuit or bulbs with bases that cannot accommodate smart lamps. People who want smart lighting but do not want to control it through their smartphone or tablet will need to use a smart switch (standard wall switches cannot control smart lamps).

Energy Impacts

Smart lighting has the potential to save energy. Since smart lamps incorporate LEDs, they inherently offer advanced features like dimming and improvements in efficacy over their compact fluorescent and incandescent predecessors. In addition, the remote control and automation features of smart lighting can do better at preventing energy waste than manual controls. Reduced operating hours and light levels show the most promise for energy savings through smart lighting. Savings could range from 7–27% depending on lamp location, with high-use areas in the home potentially yielding greater results (Bonn and Rivest 2016).

Should they become widely adopted, smart lamps present an opportunity to participate in demand response programs. Utilities could dim smart lamps during peak times and especially in winter, when lighting is most used. In aggregate, smart lamps could result in substantial decreases in home energy use through demand response (NEEP 2016).

Smart lamps risk compromising much of the energy they save because of their standby power draw. Unlike conventional lamps that use no power when turned off, smart lamps continue to use power in off mode. They remain in network standby, always connected and waiting for a wireless signal to tell them to turn on. Initial measurements from one laboratory study indicate that standby varies from less than 0.25 watt to more than 2.5 watts per lamp.[3] Lamp efficacy decreases 38% on average when corrected for standby power (Page et al. 2015). Figure 4 represents the annual energy consumption of 11 smart lamp models tested in active and standby mode in the laboratory study.

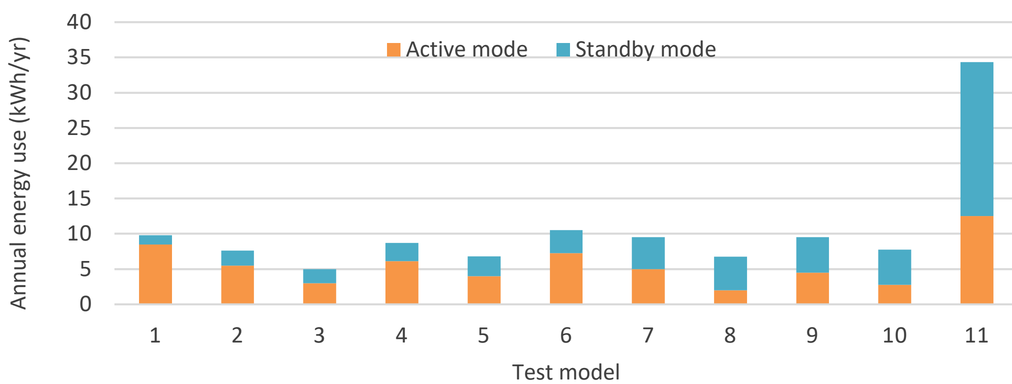

Figure 4. Annual energy consumption of smart lamps in active and standby mode. *Source:* Page et al. 2015.

It is important to consider the energy and cost implications of installing smart lamps in low-use areas of the home. Seldom-used light fixtures with very low energy use can draw standby power around the clock when retrofitted with smart lamps. Non-smart LEDs or CFLs could better serve these fixtures, while smart lamps might be most effective for use in frequently lit locations. Consumers need to become aware of the differences in lighting types and applications so as not to inadvertently waste energy.

OUTLETS AND POWER STRIPS

Functionality

Smart plugs and outlets can automate the control of any device with an AC plug. Smart outlets replace existing wall receptacles and can be controlled remotely using smartphone apps. Most work with whatever is plugged into them, while some are specifically designed for lamps with built-in dimming controls. Smart plugs are simply inserted into existing wall receptacles.

Devices powered through AC outlets are referred to as plug loads. Broadly, they are miscellaneous energy loads—those not serving critical functions in the home—and their energy use often goes unmanaged. They encompass the various electronics and small appliances found in the home today, including computers and printers, DVRs and video

[3] The ENERGY STAR program limits standby power to 0.5–1.5W for certified smart lamps. Lamp operation = 2 hours/day full light output, 22 hours/day standby.

gaming consoles, and small kitchen appliances. Plugs loads account for nearly 20% of the total energy consumed in US homes (Johnson and Bradford 2017).

Some smart plugs and outlets monitor the energy use of their associated devices. They measure loads by sensing actual power usage and can transmit this information to a software platform in time intervals (e.g., every 30 minutes). Users can access their plug load consumption data and identify the energy costs of individual devices.

Advanced power strips (APSs) are similar to standard power strips in providing surge protection, with additional control technology built in. APSs have controllable outlets and can run devices on time schedules or turn them off when the room or home is unoccupied. They are ideal for home offices and entertainment systems. Their outlets are generally designated as primary/master, secondary, and always on. When a device (like a computer or TV) plugged into the primary outlet is turned off, the secondary outlets also turn off so related devices do not continue to draw power. When the TV or computer is turned on again, power is restored to all devices. The always on outlet is for devices that must maintain uninterrupted power, like the home's router.

While many advanced power strips on the market are not technically connected, all have built-in control logic. Recent advancements in APS now incorporate Bluetooth sensors for wireless control. The sensor receives signals from equipment remote controls and recognizes when people are interacting with their electronics. The APS will power down equipment after a period of inactivity.

Energy Impacts

When turned off, many electronics and small appliances in the home enter standby mode in order to maintain LED displays and remote control reception and allow faster startup the next time the device is used. Some power is required to support devices in standby and is commonly referred to as phantom load. Standby mode equates to energy waste. Smart plugs, outlets, and APSs save energy by cutting power to plugged-in devices when they are not in use. They can turn off devices automatically, limiting both standby and active power consumption. In addition, residents can manage them through an app and turn devices on and off, either remotely or by scheduling their use.

Smart plugs, outlets, and tier 1 APSs can reduce standby power loss by shutting down all power to devices after they enter standby mode. Tier 2 APSs go a step further, detecting occupancy in rooms where they are used and turning off all primary and secondary devices when no one is around. They can even power down an entire entertainment system should someone fall asleep with the TV on (sensing a period of inactivity with no use of the remote control or any changes to channel or volume). By cutting both active and standby power, a tier 2 APS may save twice as much energy as a tier 1 model (Mass Save 2017).

Several studies exist on the energy savings potential of advanced power strips. Plug load savings range from 16–20% for tier 1 and 25–50% for tier 2 (Illume 2014; PG&E 2016a). However results from studies can vary according to test method and savings depend on the type and quantity of devices controlled by the APS. Tier 2 APSs rely on user interaction and occupancy detection to achieve savings and some users consider interruption by them unacceptable (Johnson and Bradford 2017). Smart plugs and outlets have low penetration rates and relatively high purchase costs and they lack independent studies as a result (ETCC 2017).

WINDOW COVERINGS

Functionality

Smart window coverings can improve a home's comfort, privacy, and security. They may also lead to improved or extended thermal comfort during demand response events. Smart window coverings consists of wireless motorized shades and blinds that rise and lower (or tilt or rotate) automatically. They adjust at certain times of the day, according to preset schedules, or in response to changes in daylight, such as at sunrise or sunset. Smart shades and blinds include standalone, self-contained units that replace conventional window treatments. Some existing window blinds and shades can be retrofitted with wireless motors.

Another smart window technology is tintable window films that adhere directly to the interior glazing of windows. A Wi-Fi–enabled transformer powers these smart films, which change from tinted to transparent when electrically charged. Residents can control their smart window coverings through their personal devices.

Energy Impacts

Smart window coverings can affect energy use by controlling the amount of solar heat and sunlight that enters our home. Control strategies can lead to reductions in home heating, cooling, and lighting loads when done correctly to target energy performance. However, like smart lamps, smart window controls use some energy in standby mode. One survey of 2,000 US households found that 75% of manual window coverings go unadjusted. A smart, automated system could result in greater energy savings than one that relies on manual control (Bickel, Phan-Gruber, and Christie 2013).

Calculating energy savings from smart window coverings is not straightforward. Potential savings can differ from one home to the next. Savings are dependent on interrelated variables, including climate, window and shading material properties, and building design and orientation. HVAC savings of 11–20% and lighting savings of 3% have been reported (Firlag et al. 2015).

The energy impacts of window coverings may affect other systems in the home. Closing shades and blinds to mitigate solar heat gain may actually increase lighting energy consumption; opening them to optimize for daylight may increase solar heat gain, which can have a positive or negative effect on energy consumption depending on the season. Actual energy savings depend on cost-effective control strategies that account for the variability in individual homes.

HVAC

Functionality

Temperature balancing or zoning is possible with a smart HVAC system. Sensors collect temperature and humidity readings in each room and connect wirelessly to the home's thermostat. A smart HVAC system uses sensor readings and local weather data (obtained from the thermostat or directly through the Internet) to coordinate when and how rooms in the home are heated or cooled.

Smart HVAC may also incorporate smart vents—air supply registers embedded with occupancy sensors—that close when rooms are unoccupied. Some smart vents on the market pair with Nest and ecobee smart thermostats and open or close in response to commands from the thermostat (Keen Home 2017).

Smart HVAC can also help people better understand the efficiency of their homes. Sensors placed in the system can discover deficiencies such as a bad blower, leaky duct, or poorly sealed unit located in the attic. A smart HVAC system can alert the homeowner of routine maintenance items like filter replacements and service tune-ups. Alternatively, homeowners could allow their preferred contractor to monitor the HVAC system remotely. Contractors who perform remote diagnostics can proactively alert homeowners to routine maintenance issues and imminent repairs.

Smart HVAC requires sensors that measure duct pressure and air velocity within the system. These ensure that static pressure and airflow remain within design limits when balancing and zoning. Controls must be capable of responding instantaneously to any changes to maintain safe operation and to avoid hampering fan efficacy. Smart HVAC systems are most common in new construction. Retrofits are more challenging; existing ducts and registers may limit their feasibility. For smart HVAC retrofits to work, the controls must become more sophisticated. Pilot projects addressing this issue are in process (PG&E 2017).

Room air conditioners (ACs) can be equipped with smart controls to monitor room conditions and adjust temperature and humidity settings to save energy and maintain comfort. Retrofit kits add smart controls to existing units. Residents can enable geofences so that the AC automatically turns off when they leave and back on when they return. They can adjust fan speed and temperature settings and create heating and cooling schedules remotely. Smart room AC installations are on the rise; researchers estimate that by 2020 nearly 200 million units will exist globally, mostly in China and the United States (IHS 2017).

Ceiling fans with smart functionality can provide comfort to residents and help cool a home. A combination of embedded sensors—motion, humidity, and temperature—monitor room conditions and adjust the speed of the fan. Smart ceiling fans are wireless and can integrate with other smart devices like smart thermostats and smart speakers for centralized control.

Energy Impacts

Most single-family homes in the United States have central HVAC systems that condition all rooms at one time. However many of these rooms are rarely used or go unoccupied for several days at a time. Smart zoning could result in 10% HVAC energy savings, on average. Homes with isolated rooms might benefit more from smart zoning than those with a few rooms or open floor plans. However leaky ductwork or other issues affecting performance can diminish the savings potential of any system. In these cases, smart zoning may improve comfort but not necessarily energy performance. More studies on smart HVAC would be useful.

Smart room ACs and central systems can connect to the power grid, and utilities can adjust their operation according to daily energy demand. Homeowners can benefit from lower energy costs and utility-sponsored incentives during times of high demand and peak energy pricing. Residents can also receive feedback on their energy use, which can influence consumption behaviors. Energy cost savings of 5–6% are possible (Sastry et al. 2010).

Smart ceiling fans save energy by turning off when rooms are unoccupied and by helping the home's central HVAC maintain indoor comfort. One study demonstrated that with smart ceiling fans, it was possible to increase room temperature by 4°F without sacrificing comfort. The study resulted in average cooling savings of 4–11% (GSA 2016). Ceiling fans may also take the place of air-conditioning units during peak demand periods to save on energy costs.

The EPA's ENERGY STAR program has established optional connected criteria for room ACs and ceiling fans. The program ensures that equipment with smart functionality also has energy-saving features like the ability to turn off remotely or to provide continuous feedback on energy consumption. In June 2017, the EPA released the test method for demand response capabilities for connected room ACs (EPA 2017).

WATER HEATING

Functionality

Domestic water heating is a major end use in the US residential sector. Most of the water heaters installed in single-family homes operate on either natural gas (52%) or electricity (41%). Water heating uses 18% and 34% of total household electricity and natural gas consumption, respectively (EIA 2017a).

Smart water heater controls prevent the unnecessary heating of water. They use analytics to learn household water use patterns and heat water only at times of anticipated need. During periods of inactivity, the water heater idles and the temperature drifts within an acceptable range. Water heaters equipped with smart controls can participate in utility energy efficiency programs that cycle units off during peak demand periods.

Water heaters with storage tanks can be retrofitted with smart capability. Nearly all US single-family households have tank-type water heaters, presenting a large opportunity for smart controls. Both electric and natural gas units (with a digital gas valve) are suitable to retrofit. The smart control consists of a two-part package—a controller and a temperature sensor—installed directly on the unit. The water heater can connect to the home's wireless network, and residents can control and monitor their hot water use through their personal devices.

The communications port CTA-2045, developed by the Electric Power Research Institute, makes it easier to connect existing water heaters to the grid. It uses open communication protocols and can come standard on new units or on aftermarket controls. In one example, the Sears Smart Water Heater Module is equipped with CTA-2045 and can add wireless capability to any Kenmore-brand tank water heater that has an electronic ignition.

Advanced electric water heating technologies like heat pump water heaters (HPWHs) have emerged in recent years as efficient replacements for electric resistance water heaters. HPWHs can also be retrofitted with smart controls. Figure 5 displays the three main attributes of smart water heating controls: they are retrofit friendly, have demand-side management potential, and can perform predictive analytics. It is likely that all new water heaters will eventually have built-in smart functionality.

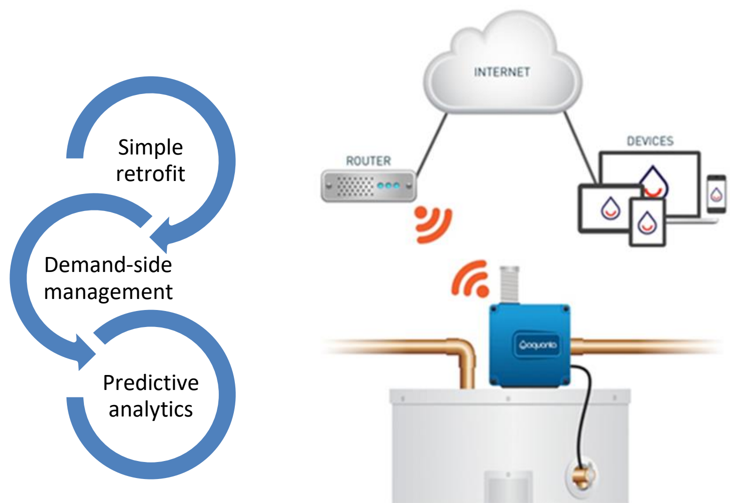

Figure 5. Attributes of smart water heating controls. *Source:* Aquanta 2017.

Energy Impacts

Smart water heating controls can automatically cycle the water heater off during periods of inactivity, as when the home is unoccupied. In general, homes with long periods of inactivity tend to lead to more energy savings than households using hot water consistently throughout the day.

Smart water heaters provide an inexpensive means for energy storage and can serve as a demand-side management resource. They can respond to energy price signals in time-of-use markets. In this case, water is heated during times of low energy pricing (at night) and stored in the tank for use during high-price periods (daytime). There is even an option to superheat (i.e., overheat) the water overnight when a daytime peak is expected, allowing the water heater to be off during that time. Superheating requires the installation of temperature mixing values to guard against scalding. Some utility programs incentivize customers who voluntarily shift their home's water heating to off-peak times.

Smart water heater controls can achieve energy cost savings of $50 to $200 per participant per year depending on energy market conditions. These savings could pay back the incremental cost of a smart control retrofit in one to three years (Hledik et al. 2016).

In addition to time-of-use control, smart water heaters may also communicate with the electric grid and participate in demand response (DR). The utility can automatically turn off or turn down water heaters during peak energy demand. During a DR event, the water heater idles and the hot water stored in the tank serves the home. The temperature returns to the set point following the event.

Heat pump water heaters are highly efficient. As opposed to electric resistance water heaters that rely solely on heating elements, HPWHs require a low level of constant heat and draw it from the surrounding air. They use about half the kWh of electric resistance water heaters. Efforts to combine smart controls and demand response for HPWHs are underway. The Oak Ridge National Laboratory estimates that load shifting of HPWHs and electric resistance water heaters could potentially reduce US daily peak energy demand by 25% (Vineyard, Kuruganti, and Zandi 2017).

Smart water heating is in its nascent stage with a smattering of smart water heater demonstration projects completed or in process. In 2017, Minnesota's Center for Energy and Environment (CEE) completed a smart water heating field study in Minnesota homes. CEE installed smart controls on 34 existing electric resistance and natural gas water heaters and metered the energy use of 10 units for analysis. Overall, the study found a decrease in energy use per gallon of water and a modest increase in operational efficiency. The smart control did better at maintaining water temperature and preventing overheating than the original controllers did (Schoenbauer and Kalensky 2017).

In the CEE study, energy savings from the smart controller proved to be behavior dependent, with some use cases performing better than others. For example, households having longer periods of no hot water use saw savings up to 15%, while homes with frequent hot water use had negligible savings (Schoenbauer and Kalensky 2017).

One laboratory study found 9–18% energy savings for advanced water heating controls on HPWHs (Vineyard, Kuruganti, and Zandi 2017). More case studies could coalesce best-use cases to validate whether smart water heating consistently provides energy savings and an inexpensive means of energy storage. For example, a comparison in energy cost savings for electric and natural gas water heaters would be useful since electricity is generally more expensive than natural gas in most parts of the country.

THERMOSTATS

Functionality

Smart thermostats are a major improvement over programmable thermostats in optimizing HVAC control. They rely on inputs from the local weather station and from wireless sensors that monitor temperature, humidity, and occupancy. A smart thermostat automates the operation of the home's HVAC in response to occupancy, household behavior patterns, and weather conditions and forecasts. It can even communicate with other connected devices throughout the home. Smart thermostats often incorporate remote control features like geofencing or proximity sensing of residents' devices.

Some smart thermostats can learn the comfort preferences of residents and respond accordingly (York et al. 2015). Learning thermostats use programming algorithms to seamlessly heat or cool the home, which can prevent overheating and overcooling and the attendant energy waste. Smart thermostats can also give program administrators and contractors real-time insight into a home's energy performance and can assist them in post-retrofit measurement and verification.

Smart thermostats have evolved over the past five years or so. Like the smart electric meter—a communicating digital meter that replaces the home's conventional analog meter—early-generation smart thermostats came about to enable utilities to communicate with individual homes. Smart meters and thermostats provide utilities with more control over managing peak loads in time-of use-markets. Today's generation of smart thermostats are an improvement over first-generation models. They now communicate bidirectionally with the power grid over the Internet or through a gateway.[4] They also allow utility service providers to automate demand response activities and customize energy services for their customers.

The market for smart thermostats is experiencing significant growth. In 2016, there were 7.8 million smart thermostats in North American homes, a 64% increase over the previous year. By 2021, projections have them in more than 43 million US homes, 40% of the total (Berg Insight 2017). The appeal of smart thermostats could build consumer awareness and lead to increased adoption of additional smart home devices (NYSERDA 2016a).

In the United States, smart thermostats can be found primarily in single-family homes. Approximately 11% of US single-family homes have them (AESP 2017). Some regions have experienced faster adoption of the technology than others; in New York State, for instance, an estimated 14–15% of homes have smart thermostats (NYSERDA 2016a). These are small (but growing) numbers compared with standard programmable thermostats, which make up the largest share of thermostats installed in US homes. Purchase costs for smart thermostats have dropped from roughly $400 for first-generation models to $150–250 for today's leading models (before rebates).

> What percentage of US single-family homes use standard programmable thermostats?
>
> *Answer:* 58% and 49% for heating and cooling, respectively.

Energy Impacts

Smart thermostats save energy by optimizing HVAC operation and reducing run time. The advanced control features of smart thermostats prevent the overheating and overcooling that can occur with non-smart versions. Moreover, third and fourth generations are superior to earlier models. The technology has come a long way in programming and sensing capabilities and can allow cooling and heating temperatures to drift for longer periods without sacrificing comfort. Both home heating and cooling savings are possible with smart thermostats (NEEP 2017a).

Savings are also possible through a smart thermostat's away and sleep modes and through the use of remote temperature sensors placed in any room in the home. With these sensors a

[4] A gateway is essentially a router that regulates wireless communications between two dissimilar networks. In a smart home, the gateway converts the communications protocol of the utility's network to that of the home so that the utility can communicate with the home's smart devices (and vice versa). It also serves as a line of demarcation between utility and customer equipment (Wacks 2017).

smart thermostat can control the HVAC in response to the conditions and occupancy of a specific room. Residents can program temperature settings for these modes and reduce their home's HVAC energy use.

Reported energy savings from smart thermostats vary widely. Many manufacturers report HVAC savings of anywhere from 10–20%. Independent evaluations on smart thermostats tend to be closer to 10% (York et al. 2015).

Savings also vary regionally. One study noted 15% heating savings for homes in very cold climates and 20% cooling savings in mixed-humid climates (Urban, Roth, and Harbor 2016). First-year results of a PG&E study found 4–5% electric savings and 0–4% gas savings on average for smart thermostats in homes across PG&E's California service territory (PG&E 2016b). According to the *Mid-Atlantic Technical Reference Manual*, average heating and cooling savings projections are 6% and 7%, respectively (NEEP 2017b). An Energy Trust of Oregon study on air source heat pumps found 12% average electric heating savings (Apex Analytics 2014). Navigant conducted two impact analyses in Illinois—one for the electric utility ComEd and the other for the three natural gas companies serving the state. Savings estimates averaged 6.7% for heating and 4.8% for cooling (Navigant 2015, 2016). Finally, collective results from two program pilots in Indiana found average heating and cooling savings of 13% and 15%, respectively, relative to a manual thermostat baseline, and 6.5% and 1% when compared with programmable thermostats (CLEAResult 2015).

The EPA has developed an ENERGY STAR specification for connected (i.e., smart) thermostats sold in the United States. This effort marks the first step for manufacturers to self-report on product performance. The specification, released in early 2017, sets energy savings thresholds for thermostats met through testing, measurement, and verification. Savings thresholds are set at 8% for heating and 10% for cooling and normalized across all US climate zones. Manufacturers must report their data to the program every six months for their product to remain certified. Currently, 11 smart thermostat models are ENERGY STAR–certified (table 1).

Table 1. ENERGY STAR–certified connected thermostats

Brand	Model name	Date qualified	Date available to market	Standby power (W)
Bryant	Housewise	4/28/2017	9/1/2014	0.81
Carrier	Côr	4/28/2017	9/1/2014	0.81
ecobee	ecobee3	4/28/2017	9/1/2014	1.06
ecobee	ecobee3 Lite	4/28/2017	9/1/2014	0.81
ecobee	ecobee4	4/28/2017	5/3/2017	1.19
EcoFactor	Simple S100	4/26/2017	1/1/2016	0.55
Honeywell	Lyric Round 2nd Gen	1/12/2018	5/02/2014	0.18
Honeywell	Lyric T5 Pro	12/21/2017	9/22/2016	0.36
Honeywell	Lyric T6 Pro	12/21/2017	9/22/2016	0.34
Nest	Learning Thermostat	2/24/2017	9/1/2015	0.06
Nest	Thermostat E	5/26/2017	8/31/2017	0.04

Source: EPA 2018

Like smart water heaters, smart thermostats can participate in utility demand response programs. Utilities (or authorized third parties) can administer DR events remotely and automatically adjust thermostat settings. Customers can enroll and participate in DR directly through their smart thermostat in some cases. Where applicable, they can voluntarily schedule the cycling of their HVAC unit to benefit from time-of-use rates. When aggregated across many homes, smart thermostats have the potential to reduce energy consumption significantly during peak demand periods (Unger 2017).

Utilities can send price and DR signals directly to smart thermostats using open source communication standards like Open Automated Demand Response (OpenADR).[5] During peak demand, the utility can remotely cycle off HVAC units for 50% or 100% of the time (users typically receive a higher incentive for 100%). Some DR programs cycle AC units off by raising the temperature setting on the smart thermostat. In this instance, the thermostat receives a signal and the set point is automatically raised 2–4°F. States like California are requiring OpenADR-enabled smart thermostats in their energy code to increase participation in utility demand response programs.

Uniquely, the smart thermostat can communicate with the power grid during a DR event. It collects real-time data (e.g., indoor temperature and humidity and HVAC run time) and allows program administrators to better track the event. Thermostat-generated data enable

[5] The OpenADR standard makes it possible for demand response programs to become vendor agnostic. OpenADR is a nonproprietary, open standard for communicating DR signals to devices using a common language protocol. Utilities can automate signals and communicate directly with the device, without needing to interface with the manufacturer's platform (OpenADR 2016).

providers to customize reports and engage with customers around their energy use. Through further data analysis, they have the potential to identify inefficient homes and recognize additional energy efficiency opportunities.

HOME ENERGY MANAGEMENT SYSTEMS

Functionality

Home Energy Management Systems (HEMS) are hardware and software systems that enable advanced control of energy-using systems and devices in the home. They continuously analyze data to provide real-time feedback on home energy performance.[6] HEMS collect key inputs and data streams, ranging from smart meter and smart home technology data to external information like weather, utility price, or demand response signals. They share this information with smart devices in the home so these devices can respond to changing conditions. HEMS may also send alerts when something seems unusual, as when a refrigerator is running overtime because someone left the door open.

HEMS serve as the brain for the smart home. Be it a smart thermostat or smart hub that interfaces with other smart devices, a software platform that sends feedback to the homeowner, or anything in between, the HEMS is the cornerstone of the smart energy home. Figure 6 shows a HEMS with the Amazon Echo smart speaker as the control interface. Several smart devices from various manufacturers are compatible with the Echo.

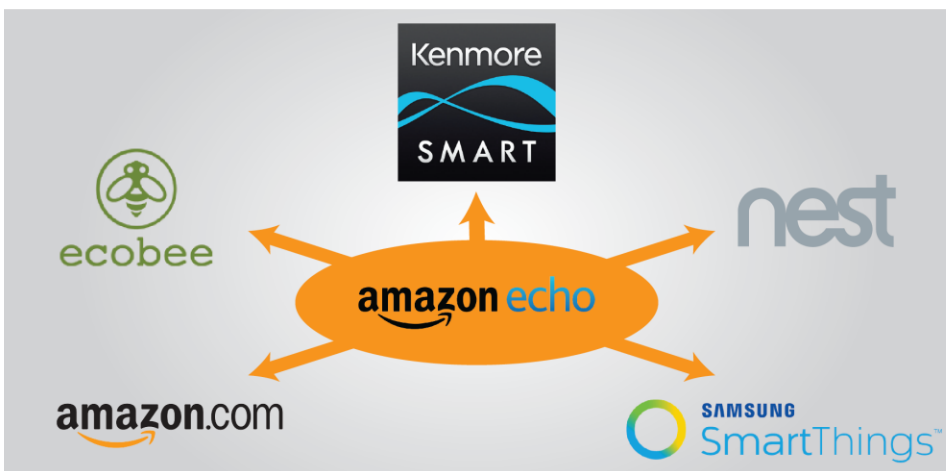

Figure 6. Amazon Echo smart speaker as a home energy management system centralized point of control

Energy Impacts

HEMS enable the energy-efficient operation of smart home devices and potentially achieve more energy savings than each device could reach on its own. As smart technologies begin to incorporate sensing, communication, and automation, they may leverage energy savings

[6] Definition adopted by the HEMS Working Group (NEEP 2018).

by working in synergy and communicating with one another, as opposed to operating in isolation (Ford et al. 2016).

In connecting multiple smart devices, HEMS enable a standardized way for these devices to interact as one system. They can implement one integrated schedule across all devices, as well as switch one device on or off based on data received from another. For example, when the smart thermostat switches to Away mode, HEMS can turn off all smart lights and smart plugs. HEMS can generate average energy savings of 10–13% across multiple systems in the home (NYSERDA 2017).

HEMS affect energy use by accounting for what is happening outside the home. They can use local weather data and utility energy price signals to optimize the operation of energy-consuming systems. As distributed energy resources like solar photovoltaics, battery storage, and electric vehicles become more prevalent in the residential sector, HEMS can interact with and include them in whole-home optimization.[7]

We can interact with and remotely control and monitor our smart home through user-friendly dashboards or in-home displays. HEMS also provide interval data that can be used to evaluate baseline consumption and savings from energy efficiency measures (NEEP 2015).

Energy Savings

The true potential for energy savings in the smart home lies in reducing energy consumption through better management. And better management lies in optimizing our home's energy-consuming systems. We can align their operation to our preferences and reduce unnecessary energy use. Smart technologies can yield higher overall efficiency through better controls, communication, and response.

Another important attribute of the smart home is that it can limit energy use to certain times of the day. Whether or not the grid is calling for demand reductions, we can take advantage of an energy pricing structure (i.e., time-of-use rates) and control our smart systems around peak demand periods.

CHALLENGES IN ESTIMATING ENERGY SAVINGS

Smart energy technologies collect granular energy use data in real time. This makes it possible to measure their energy impacts, verify savings, and establish performance baselines. Smart devices can be integrated and can share their data. On the other hand, several issues make it difficult to derive clear energy savings estimates. For one thing,

[7] A survey of New York homeowners found that 51% of those owning a smart thermostat also have a solar photovoltaic array on their home (NYSERDA 2016a).

energy savings data exist for only some smart home technologies. The degree to which data are available corresponds with a technology's market availability and uptake.

Moreover, the energy savings potential for smart technology is dependent on multiple variables that can vary across device type. These include climate and seasonal impacts; in fact, as much as half of a home's energy use is driven by the weather (Li et al. 2017). As one would expect, smart thermostats can achieve optimal cooling savings in hot-humid climates and heating savings in cold climates. Smart thermostats may also lead to greater savings in homes in temperate climates—those with small differences between indoor and outdoor temperatures. Here, the smart thermostat might allow indoor temperatures to drift for long periods without attracting notice or creating discomfort. This could lead to larger reductions in HVAC run times and a larger savings percentage than for homes in more extreme climates.

Other variables include the age and condition of equipment, and home occupancy patterns. For example, smart water heaters generate greater savings in homes that are unoccupied for long stretches of time.

Another issue making it difficult to estimate savings is the fact that some smart technologies (e.g., HEMS) are completely new to the home and do not replace traditional components. In addition, it can be difficult to isolate savings attributable to smart functionality from savings that a non-smart but otherwise efficient technology would have achieved on its own. Smart home devices require hardware and software for connectivity and communications within the home—features unique to smart technology. Therefore energy savings are not easily distinguishable, especially for devices that are not plug-and-play. Also, multiple smart devices may address the same energy end use—for instance, smart thermostats and smart vents both affect HVAC energy consumption—and their combined savings potential is somewhat less than their sum (Urban, Roth, and Harbor 2016).

In some cases, smart technology may actually use more energy. In general, the EIA forecasts that US household electricity use could increase in the coming years as efficiency improvements only partially offset the increased penetration of miscellaneous devices (including smart ones) (EIA 2017b). In particular, some devices that achieve incremental savings over conventional technology also may use additional electricity for sensing, communication, and control. As discussed earlier in the report, it is important to consider the network standby power consumed by any smart technology when evaluating its savings potential. Net savings *reductions* can range from 8% for some smart thermostats up to 40% for some smart lighting products (Urban, Roth, and Harbor 2016). As product options with lower standby power become more available—and smart technologies become less costly to purchase and implement—we could see improvements in net energy savings and cost-effective solutions.

Consumer behavior also plays a part in energy savings and consumption. Each smart home is as unique as its owner, and the degree to which energy is saved or consumed is dependent on how each of us interacts with our devices. The smart home today is not fully automated; it relies on us to engage and make choices that impact energy savings.

Finally, control strategies can make or break energy savings potential. This is especially true for smart technology with high up-front costs. For instance, purchasing smart shades and blinds for an entire home can be cost prohibitive at $350–500 per window (smart films are slightly less expensive, roughly $320 for a 3x4 window). Cost-effective strategies for smart shades and films might be ideal in certain applications like south- or west-facing windows, where controlling for solar heat gain and daylighting can be most impactful. Investments in smart window coverings might seem more feasible to a household that is already planning to invest in new window treatments than to a household with no such plans.

SAVINGS ESTIMATES

Most savings data for smart home technology come from manufacturer claims and a handful of independent studies on few technologies and applications. Smart thermostats are the most studied of these and new-generation models are superior to earlier versions. Conservative savings estimates range from 6–10% for home heating and cooling. For smart appliances, a 2010 study found 2–9% energy cost savings through load shifting and demand response activities. Recent studies on smart water heating found 15% savings in a best-use case and up to $200 in annual bill savings in time-of-use markets.

A 2016 study on five smart home technologies by the Fraunhofer Center for Sustainable Energy Systems estimated potential savings in the range of 0.3–1.1 quads, or 1–5% of the total primary energy consumed by US homes in 2015. These savings are made up largely of home heating and cooling savings (Urban, Roth, and Harbor 2016).

In May 2017, the New York State Energy Research and Development Authority (NYSERDA) completed a HEMS pilot on 50 New York homes. The study evaluated the energy savings potential of HEMS in controlling HVAC, lighting, and plug loads. The study resulted in 5–22% energy cost savings and 10–13% electricity savings per home, with HVAC control yielding the most savings in the majority of homes (NYSERDA 2017). These results indicate that the savings in the Fraunhofer study are likely a low estimate.

In ACEEE's questionnaire on smart home technologies, program administrators were asked to rank a number of technologies according to low, medium, or high energy savings potential, on the basis of their perceptions. Figures 7, 8, and 9 show their choices.

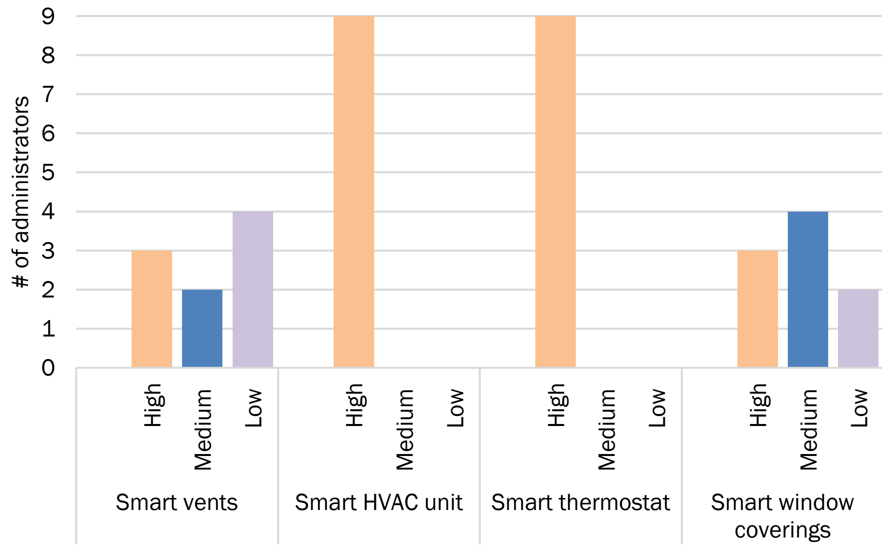

Figure 7. Perceived energy savings of smart HVAC, thermostats, and window coverings

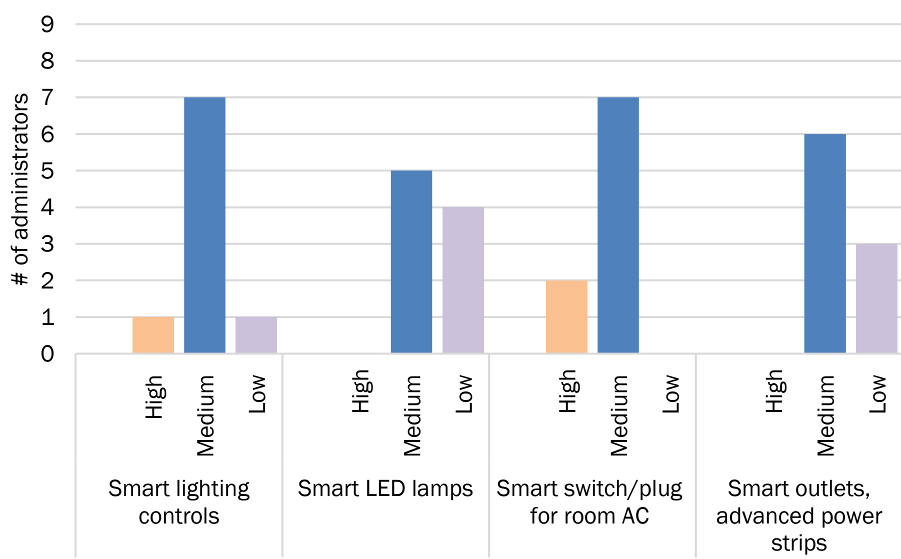

Figure 8. Perceived energy savings of smart lighting and plug load management

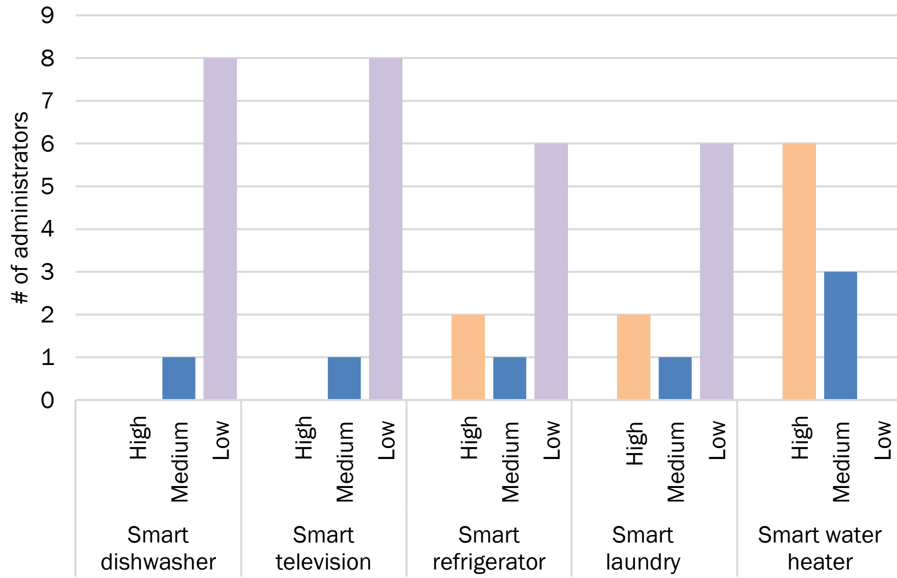

Figure 9. Perceived energy savings of smart appliances

We collected available data on smart home technologies to quantify typical purchase costs and energy savings estimates for each end use or system that the technology controls. Table 2 summarizes technologies that have published savings data (albeit very limited for some). Manufacturer savings claims are omitted. Purchase costs are based on information from big-box retailers or e-commerce sites (Sears, Best Buy, Home Depot, and Amazon).

Table 2. Retail costs and energy savings estimates for smart home technologies

Technology	Description	Affected end use	Retail cost ($US)	Estimated energy savings as % of affected end-use consumption
Smart thermostat	Connected thermostat	HVAC	$150–250/ thermostat	7–10% cooling 6–8% heating
Smart HVAC	Smart vents, zoning sensors (for central HVAC)	HVAC	$150/vent, $30–40/sensor	10% heating and cooling
Smart ceiling fan	Ceiling-mounted fan w/wireless occupancy sensor	HVAC	$600/fan	4–11% cooling
Smart room AC	Window-mounted AC unit with smart capability	HVAC	$350–400/unit	2–3% cost savings*
	Smart control retrofit kit	HVAC	$80–140/kit	
Smart appliances	Smart dishwasher	Major appliances	$900–1,350/unit	5–9% cost savings*
	Smart clothes washer	Major appliances	$1,250–1,800/unit	4–7% cost savings*
	Smart clothes dryer	Major appliances	$1,200–1,900/unit	4–7% cost savings*
	Smart refrigerator	Major appliances	$3,200–4,000/unit	2–4% cost savings*
Smart water heating	Smart controller and sensor retrofit package for tank system	Water heating	$70–150/unit	15%
Home energy management system	User-interfacing device that can monitor and report home energy use, plus additional devices for controlling various end uses	Multiple systems	$50–150/device and software; additional $ for other devices	10–13% from technology, with savings depending on end uses controlled 4–12% through feedback/behavior change
Smart window coverings	Smart shade/blind, controller, sensor	HVAC and lighting	$350–500/window	11–20% heating and cooling, 3% lighting
	Smart film and wireless transformer kit	HVAC and lighting	$27/sq. ft.	

Technology	Description	Affected end use	Retail cost ($US)	Estimated energy savings as % of affected end-use consumption
Advanced power strip (APS)	Tier 1 APS	Plug load	$30–50/strip	16–20%
	Tier II APS	Plug load	$60–100/strip	22–50%
Smart plug or outlet	110-120v, general service, wireless-capable	Plug load	$35–70/unit	Modest savings assumed for plugs/outlets; savings dependent on end use application
Smart lighting	Smart switch, wireless-capable, wall-mounted	Lighting	$25–60/unit	7–27%
	Starter smart lamp kit (4 smart bulbs + hub)	Lighting	$70–200/kit	Negligible savings for ENERGY STAR–certified smart vs. non-smart lighting
	Smart LED bulbs	Lighting	$15–40/bulb	
Smart television	High-definition, wireless-capable	Major electronics	$300+/40" screen $600+/55" screen	Negligible vs. non-smart ENERGY STAR models

*Energy cost savings through load shifting/demand response. *Sources*: Thermostat: NEEP 2017b; York et al. 2015. HVAC: Urban, Roth, and Harbor 2016. Ceiling fan: GSA 2016. Room AC and appliances: Sastry et al. 2010. Water heating: Schoenbauer and Kalensky 2017. HEMS: NYSERDA 2017; Ehrhardt-Martinez, Donnelly, and Laitner 2010. Window coverings: Firlag et al. 2015. APS: Illume 2014; PG&E 2016a; Johnson and Bradford 2017. Plug: ETCC 2017. Lighting: Bonn and Rivest 2016.

On the basis of savings estimates provided in table 2, we attempted to assign potential sector savings for the listed smart technologies. We weighted each item by its percentage of total residential energy consumption. For plug loads, we accounted for only entertainment and home office equipment. As shown in table 3, residential sector savings could reach 17% through the use of smart technologies. Note that this analysis is a maximum savings estimate; it assumes every US household adopts smart technology for all of the end uses in table 3.

Table 3. Maximum savings potential for smart technologies in US residences

Residential end use	% total energy consumption	% energy saved with smart technology*	Estimated savings as % of total energy use
Space heating	25.8%	29.3%[a]	7.6%
Space cooling	10.8%	33.7%[b]	3.7%
Water heating	13.2%	15.0%	2.0%
Dishwashers	1.4%	7.0%	0.1%
Refrigerators and freezers	6.1%	3.0%	0.2%

Residential end use	% total energy consumption	% energy saved with smart technology*	Estimated savings as % of total energy use
Clothes washers and dryers	3.7%	5.5%	0.2%
TVs, computers, and related equipment	5.6%	37.5%	2.1%
Lighting	6.4%	17.0%	1.1%
Total	73.0%		17.0%

These figures do not include HEMS. *Data from table 2; where a savings range existed, we used the midpoint. [a] Space heating includes savings of 10% for smart HVAC, 7% for smart thermostats, and 15.5% for smart window coverings, adjusted to reduce overlap between measures (e.g., the 7% savings from smart thermostats is applied to the remaining 90% of space heating energy use after smart HVAC). [b] Space cooling includes savings of 7.8% for smart HVAC, 8.5% for smart thermostats, 15.5% for smart window coverings, and 7.5% for ceiling fans, all adjusted to reduce overlap between measures as explained above. Smart HVAC cooling savings are based on 10% for central systems and 3% for room units, weighted 71% central, 29% room based on relative % of homes with each, per 2015 RECS. *Sources:* ACEEE analysis; EIA 2017a; EIA 2017b.

Independent studies on smart technologies are currently limited in scope. Studies are available mostly for technologies with higher adoption rates, such as smart thermostats and advanced power strips. However the savings results of a single technology can vary across test methods (Johnson and Bradford 2017). In upcoming years, we should begin to see results from smart technology demonstration projects that are currently underway. As studies become more widespread and we begin to decipher the data they generate, we hope to be able to prioritize which technologies are the most promising for utility energy efficiency programs. These data could guide homeowners and renters in their purchase decisions. As the market continues to mature and energy data undergo further analysis, we will begin to assign cost-effective solutions to the smart home.

Barriers to Adoption of Smart Home Technologies

VALUE PROPOSITION

If smart technologies are to proliferate in the residential market, the industry must do better in establishing and portraying their value proposition. People have been slow to adopt smart home technologies for several reasons. Some are just not aware of them. Even if they are, they may never have used these technologies and may view them as too complex or expensive. In the questionnaire we conducted, five out of nine program administrators said they believe that technology cost is the biggest barrier to adoption. The slow uptake of residential smart window coverings is certainly a case in point.

In a recent survey of smart device owners, 70% of respondents said they believe smart home technologies help reduce energy consumption (Parks Associates 2017). At this point, however, the nonenergy benefits of these technologies, rather than energy savings, seem to be the primary drivers of demand. People are aware that they improve comfort and convenience in a variety of ways. Some people like the autonomous controllability that smart devices afford, while others prefer to control their homes remotely through mobile and cloud-based apps and, increasingly, through voice commands. Voice-activated devices are becoming more prevalent in the smart home, most commonly in the form of a wireless smart speaker (e.g., Amazon Echo, Google Home, and Apple Homepod). Smart home features that enhance home security are very popular, as the majority of Americans put a high value on privacy and safety. Smart security technology has seen the largest growth in the smart homes space. Finally, smart technology may also make it easier for the ill or elderly to stay in their own homes or in assisted living situations longer (Ironpaper 2016).

In contrast, the average consumer places less value on the energy savings potential of smart technologies. A good example is efficient lighting, whose adoption is taking place more slowly in the residential sector than in commercial and industrial applications. US households tend to place a higher value on the up-front costs of lamps rather than their annual operating costs, and they have limited awareness of the savings potential. Homes are poised for retrofits, as incandescent bulbs remain the most common type of lighting installed. According to the EIA's 2015 Residential Energy Consumption Survey, 38 million US homes—approximately one-third of the total—use incandescent bulbs for at least 50% of their lighting. However the 2016 Sylvania Socket Survey found a 17% increase in LED purchases over 2015 (Sylvania 2016). Consumers can take advantage of utility rebates to upgrade their home lighting to LEDs. With the help of federal standards taking effect in 2020, LEDs should gain significant market penetration over the next decade in all sectors (EIA 2017b).

In early 2016, Lockheed Martin prepared a survey for NYSERDA that targeted nontraditional HEMS providers, mainly those offering home security and communication systems. The survey found that sometimes these providers offer devices like smart thermostats and lighting controls secondarily, as an add-on to their premium service package. For example, ADT Security Services offers a Nest learning thermostat or an Amazon Echo smart speaker when customers subscribe to its home monitoring services. ADT's cloud platform supports Nest products, and customers can control their home security and HVAC through their smartphones.

In the survey, nontraditional providers indicated that consumers are twice as interested in the remote monitoring of their homes as in energy savings. Providers actively marketed the energy savings potential of smart thermostats but not of other smart devices due to insufficient data. None of the providers reported participating in energy efficiency programs, and only one in five have participated in a demand response program (NYSERDA 2016b).

DATA SECURITY

With the influx of Internet-connected devices in the home, cybersecurity is now a prominent concern. Many connected devices maintain personal details, such as the home's address and occupant information as well as vacancy and occupancy patterns. Some 64% of Americans have already experienced a major personal data breach in their lifetime (Olmstead and Smith 2017).

Smart devices use security measures like passwords for remote access. Many users admit to setting weak passwords when connecting their devices to the Internet if only for ease in remembering them later. A Pew Research study found that 55% of Internet users are finding it increasingly troublesome to remember the different passwords they use for their many online accounts. Smart home devices with low levels of security can become vulnerable to cybersecurity threats (Anderson 2017).

INTEROPERABILITY

The lack of interoperability and harmonization across connected devices poses a significant barrier to the smart home. In order to achieve an interoperable smart home, all devices within it must connect to and communicate with one other. However most communications protocols are proprietary to each product manufacturer. Their control networks require independent hardware, hubs, and access nodes, all of which must be managed individually. This complexity is a disincentive to the typical homeowner who seeks an easy way to connect his or her devices.

Most smart devices communicate through the home's broadband Internet and Wi-Fi network. The recent advancement of mesh networks (i.e., low-power wireless networks) brings neutral ground on which the different devices in our homes can play. They are less energy-intensive than Wi-Fi and are platform agnostic—compatible across the numerous smart products and manufacturers—and most use open communication protocols for our devices to talk to one another.

Mesh networks can bridge the multiple connected devices in a home. They are referred to as *mesh* because they layer additional wireless networks on top of (or instead of) the home's existing Wi-Fi. A mesh network is a system of multiple wireless hubs that work together to provide a strong connection and minimize dead zones. Unlike stand-alone routers, which lose signal as distance increases, mesh stations piggyback on one another to create a continuous wireless link throughout the home (Chen 2017). Three popular mesh networks go by the names of ZigBee, Z-Wave, and Thread and can vary in operating range, frequency, and speed. For example, Z-Wave and Thread can manage several hundred devices at a range of about 100 feet, while ZigBee can connect thousands of devices across a much shorter span.

The push for increased interoperability is coming from industry players. For example, EPA is encouraging the use of open communications protocols through its ENERGY STAR specifications for connected devices. Along with product manufacturers and utilities, EPA supports the CTA-2045 communications port developed by the Electric Power Research Institute. The port serves as an open communications interface and is built in or retrofitted on appliances and water heaters. It allows manufacturers to develop products that have grid connectivity and are demand response ready. Utilities can deploy these products in programs without needing a separate interface for each appliance type; they can administer their demand response programs through any device equipped with CTA-2045 (Hopkins and Whited 2017).

The Institute of Electrical and Electronics Engineers (IEEE), in conjunction with the US National Institute of Standards and Technology (NIST) and others, is making strides in developing low-power communication standards to address interoperability shortcomings. The IEEE 2030.5, for example, serves as a general-purpose communications standard for smart devices as well as the smart grid. It leverages open communications protocols intended to suit the majority of connected products, regardless of manufacturer. IEEE 2030.5 does not tie to any specific protocol other than TCP/IP, the common language of the Internet (Simpson et al. 2017).

INTERNET ACCESS

Broadband access is required for our homes to realize the potential of smart devices. A high-speed Internet connection is often essential for communication within the home and with the cloud. Limited bandwidth can cause Wi-Fi signals to drop, and it can become a problem for households without reliable and fast Internet service to control their many devices. According to the US Census Bureau, 23% of all US households do not have broadband Internet service. Among owner-occupied, single-family homes, 7% do not have Internet (Ryan and Lewis 2017; EIA 2017a).

Older populations and low-income populations are the least likely to have broadband Internet in their homes. Less than two-thirds of US adults aged 65 years and older have it, compared with 82% of the population under age 65 (USCB 2017). Broadband Internet subscriptions are also proportional to income levels. As shown in figure 10, nearly all households with incomes of $75,000 or greater have an Internet subscription, while less than half of households making less than $20,000 do. Low-income populations have the lowest home Internet use and make up the highest proportion of handheld-only users. These households rely mainly on smartphones with a cellular data plan (Ryan and Lewis 2017).

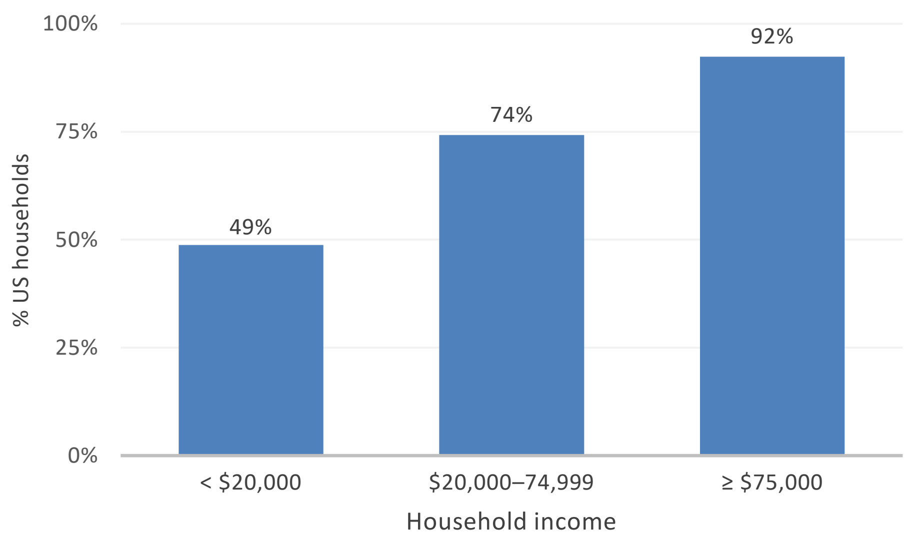

Figure 10. US household Internet subscriptions by income level. *Source:* Census Bureau 2017.

Bluetooth is becoming popular for communicating wirelessly with devices in lieu of the Internet. However it is suitable only for local use; device-to-device communication is limited to very short distances. As described above, open communication protocols are enabling smart devices to communicate directly with the grid without relying on the Internet. They may enable households without Internet access to participate in demand response programs (Utility comments to EPA 2012).

Smart Home Technologies in Demand-Side Management Programs

Energy efficiency and demand response programs can incorporate smart home technologies to reduce energy use and peak demand. Utilities are beginning to understand and appreciate both of these benefits and are considering how best to integrate energy efficiency and DR into their portfolios, either by designing new programs or augmenting existing ones to meet the needs of their customers.

The ACEEE questionnaire asked program administrators if their portfolios offered smart home technologies. Two-thirds of respondents said they incorporate smart technology into their suite of energy efficiency programs to leverage demand-side management. Widget-based (prescriptive) programs were the second-most common type, as shown in figure 11.

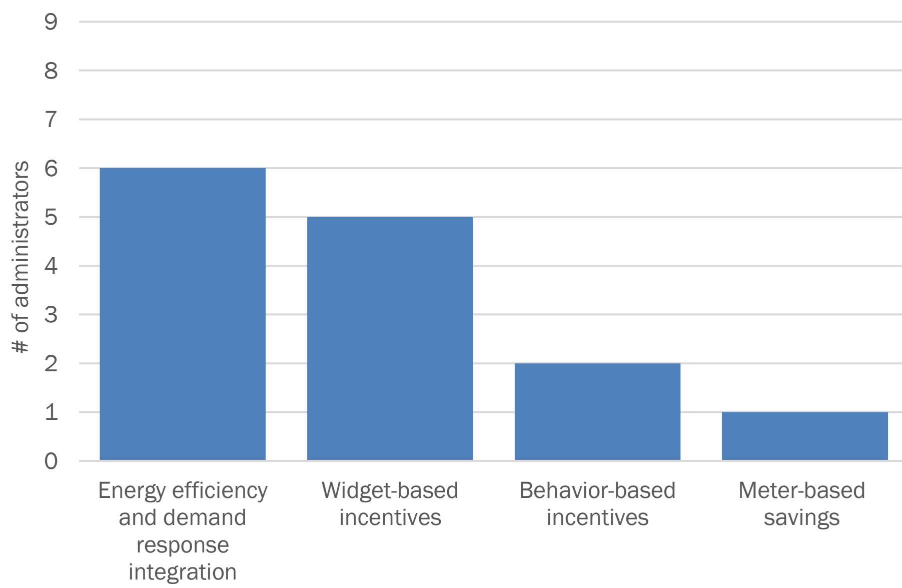

Figure 11. Types of programs involving smart home technologies

This section describes the types of energy efficiency programs currently incorporating smart technology. They include the following:

- Prescriptive rebates
- Demand response
- Thermostat programs
- Water heating programs
- Third-party solutions

PRESCRIPTIVE REBATES

The most common incentive mechanism for residential energy efficiency programs is rebates. They pay back some portion of the purchase cost of replacing traditional home equipment with new, energy-efficient alternatives.

Some utilities have begun offering incentives for a handful of smart technologies. Some offer devices at no cost if the customer enrolls in a demand response program. Table 4 lists representative examples of existing program incentives.

Table 4. Representative program incentives

Smart technology	Rebate amount
Smart thermostat	$50–100/thermostat; up to $25 in energy bill credit for full participation in utility DR program
Smart AC retrofit kit	50–100% off/kit with full participation in utility DR program; additional energy bill credits for participating in DR events
Smart room AC unit	$30–95/unit with full participation in utility DR program; additional energy bill credits for participating in DR events
Advanced power strips	$10–15/strip
Smart refrigerator, dishwasher, clothes washer	$25–$150/each*
Smart LED bulbs	$3–10 or 50% off per bulb*

*Applies to ENERGY STAR-certified products with or without smart functionality

California's Assembly Bill 793 requires the state's utilities to develop programs providing incentives for any device, service, or software that allows customers to better understand and manage their electricity or gas consumption. Its passage has fostered collaboration between utilities and HEMS vendors (Assembly Bill 793 2015; NEEP 2016). Some utilities are sponsoring pilot projects to determine the energy savings potential of smart home technology. Southern California Gas is currently conducting field demonstrations of smart vents to assess their potential in future programs (SoCalGas 2016).

DEMAND RESPONSE

Utilities have achieved reductions in peak demand using automated technologies like advanced metering (i.e., smart meters) and time-of-use rates. Some 64.7 million smart meters are installed in buildings throughout the United States. Of these, 57.1 million (88%) serve the residential sector, though penetration rates vary widely by state (EIA 2017c). Historically, utility demand response programs have focused on large commercial and industrial facilities. Utilities are now looking to the residential sector to help curb peak loads. ACEEE has estimated that utilities can experience 10% reductions in peak demand, on average, through demand response programs (Nadel 2017).

Utilities are incentivizing some smart home technologies for their demand-side management potential, most notably smart thermostats, water heaters, room AC, and heat pump controls. Programs offer rebates for these controls through product manufacturers and retailers to make it easy for customers to acquire the products and participate in demand response. Bring Your Own Device (BYOD) programs are a way to include customers who already own smart devices. In these instances, customers can enroll their devices in demand response and receive incentives for participating in events (or for voluntarily reducing their energy use during peak times of the day). Incentives are built into the electricity rate via time-of-use pricing or show up as credits on participants' monthly bills.

The smart home is helping pave the way for the utility of the future by influencing how utilities manage the grid. In this new model, smart thermostats and smart water heaters are distributed energy resources, much like solar photovoltaics and battery storage. We describe smart thermostat and smart water heating programs in the following sections.

THERMOSTAT PROGRAMS

The recent development of ENERGY STAR criteria for connected (smart) thermostats has helped attach a value to this technology and move it into utility programs. Many residential demand response programs now incorporate load management through smart thermostats. Utilities offer incentives for purchasing these devices and participating in programs. Incentives are usually in the form of rebates, and some utilities cover the cost of installation. In certain direct-install programs, the utility covers the cost of the thermostat and installation as long as the customer participates in a demand response program for a specified length of time. A growing number of utilities sell rebated smart thermostats through specific online marketplaces. One evaluation of smart thermostat programs showed 13–15% average HVAC load reductions per home for each DR event, and 10% and 4% average savings in total household gas and electricity use, respectively. For the utility, a typical DR event resulted in 0.6–1.2 kW average peak load savings per smart thermostat (Colby 2015).

Program administrators deploy demand response mainly in the summer months, when peak electric demand (and pricing) is generally highest. The smart thermostat makes it possible for program administrators to monitor a home's indoor temperature and humidity and HVAC run time. A typical summer DR event might last four hours. At these times, participating customers allow the utility to cycle off their AC unit or raise the temperature setting on their smart thermostat. Utilities can establish a set-point ceiling, a maximum limit when raising indoor temperatures in DR events. Maintaining indoor temperatures below the ceiling prevents homes from overheating, something that can happen in conventional demand response using load control switches (Grant and Keegan 2016). Some summer DR programs incorporate precooling. The utility lowers the thermostat set point and cools down the home just prior to an event to help residents ride through it more comfortably. Customers also have the option to override an event by manually lowering the setting on their smart thermostat.

Some DR programs are coming online to reduce natural gas demand in the heating season (Walton 2017). These programs are referred to as winter demand response. In early 2017, the Southern California Gas Company launched its winter Seasonal Savings program for curtailing natural gas demand on the coldest days of the year. The average participating household can save about 8% on its natural gas space heating (SoCalGas 2017).

Some energy providers partner with thermostat manufacturers in deploying their energy efficiency and demand response programs. Nest and ecobee have developed software platforms that utilities can use in administering demand response. DR-specific platforms collect thermostat data during events and often interface with customers, serving as an engagement tool. In general, customers receive rebates for purchasing a Nest or ecobee thermostat and energy bill credits for participating in demand response.

Approximately 50 energy providers in the United States subscribe to Nest's Rush Hour Rewards program in administering demand response (Business Wire 2016). In this turnkey, scalable program, Nest enrolls customers and administers demand response through its platform. Participants are notified about DR events directly through their Nest thermostat or smartphone app. Kansas City Power and Light offers customers a free Nest thermostat, free installation (or a $50 installation credit), and $25 per year for participating in the program. Commonwealth Edison offers a $100 rebate toward the purchase of a Nest thermostat and up to an additional $40 per summer to participating customers (ComEd 2017). On average, utilities achieve 1.18 kW of demand reduction per thermostat for each event (Tweed 2014).

As mentioned in the previous section of this report, some utilities employ a bring-your-own approach, allowing a range of approved thermostat models to qualify for their programs. For example, Consolidated Edison offers its customers a rebate for purchasing any Con Edison–approved thermostat and participating in demand response events for two consecutive summers. Program designers are beginning to specify the ENERGY STAR criteria for connected thermostats to qualify products for BYO programs. As of April 2018, 30 utilities incentivized only ENERGY STAR–certified thermostats (T. Jantz-Sell, ENERGY STAR program manager, EPA, pers. comm., April 19, 2018).

Southern California Edison (SCE) partners with a third party, EnergyHub, to deliver its Smart Savers program. EnergyHub is responsible for enrolling customers and administering DR signals between SCE and customer thermostats. During an event, EnergyHub collects energy consumption data from each participating thermostat. SCE compensates each customer on a per-kWh basis for actual energy saved during the event in the form of bill credits. One DR event can result in peak load reductions of 1.2–1.5 kW per thermostat (EnergyHub 2016).

Similarly, EcoFactor manages NV Energy's mPowered DR program. The program reports 2.37 kW peak load reductions per thermostat per event. This equates to roughly $100 in annual bill savings per customer (OpenADR Alliance 2014).

Smart thermostats connect to the grid through cloud-based platforms that are proprietary to their manufacturer. Utility program administrators (or authorized third parties) interface with these platforms in delivering demand response programs, and as more grid-connected products come online, utilities have an increasing number of options from which to choose. Managing multiple manufacturer platforms can become burdensome and costly, however. As discussed previously in this report, open communication protocols and the OpenADR standard are allowing programs to become vendor agnostic.

WATER HEATING PROGRAMS

Water heaters have for some time been part of utility demand-side management programs to curtail peak loads. In these programs, water heaters operate at non-peak times of the day. Load shifting sometimes requires superheating water at night when energy demand (and price) is lowest. The tank of the water heater essentially acts as a thermal storage battery by holding hot water for use later, in the daytime. Program participants permit their utility to control their water heater for demand response activities.

For several years, utility demand response programs across the United States have incorporated direct load control.[8] A few examples include PeakRewards from Baltimore Gas and Electric, Duke Energy's EnergyWise program, and OnCall from Florida Power and Light (ClearlyEnergy 2017). Traditionally, water heater demand response programs use one-way switches. The utility initiates direct load control by remotely activating the switch to cycle off the water heater 50%, 75%, or 100% of the time. The switch cannot be overridden during the DR event.

Utilities are just beginning to realize the demand response benefits of smart water heating controls. For example, Green Mountain Power (GMP) now offers customers an Aquanta smart controller through its eSmartwater program. Customers lease the controller by paying a $0.99 monthly fee on their energy bill and allow the utility to control their water heater for demand response. The program, launched in May 2017, pairs the Aquanta controller with the customer's choice of a Nest thermostat or smart lamp starter kit (such as Element Classic) at no additional cost. GMP states that customers who own the Aquanta–Nest package can expect $130 or more in electricity cost savings annually (PLMA 2017).

Arizona Public Service is expanding its Demand Response, Energy Storage, and Load Management *(*DRESLM*)* program in 2018 to include smart thermostats and water heater timers for residential customers who participate in demand response. The utility will also incentivize grid-connected water heaters in new home construction projects (APS 2017).

As smart water heating controls become more common in programs, utilities could initiate preheating through the control, much like precooling a home through the smart thermostat just before a DR event. This ensures that the temperature of the water is at set point going into the event and discourages customers from overriding the event.

Larger water heaters (80+ gallons) provide homes with additional thermal storage capacity. They may reduce the risk of hot water shortages and allow the home to ride out longer DR events. Approximately 67,000 customers with tank sizes of 80–120 gallons participate in Great River Energy's (GRE) thermal storage water heater program. The utility charges water heaters overnight, from 11 p.m. to 7 a.m., and homes are served by hot water stored in the tank for the remainder of the day. The storage capacity afforded to GRE through this program is equivalent to the capacity of one 1-GWh battery (Hopkins and Whited 2017).

The Sacramento Municipal Utility District offers customers a 20-gallon electric resistance water heater as an add-on to their existing electric or gas water heater. These smaller units

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[8] Direct load control programs encompass a variety of high-wattage equipment, most commonly water heaters, air-conditioning units, and pool pumps.

interact with the grid and serve the home's hot water needs during an event when the main water heater is off (Hledek et al. 2016).

THIRD-PARTY SOLUTIONS

Utilities are looking for new ways to engage with their customers to provide them with energy efficiency services. Associating closely with one's utility is an uncommon practice for US households, and just one-third of Americans manage their household utility bills online (Olmstead and Smith 2017).

Utilities are collaborating with third parties to provide customized energy efficiency solutions and to serve as the engagement link between the utility and its customers. Many of these third parties deploy and administer energy efficiency and demand response programs. They often use big data to identify energy efficiency opportunities and provide customized solutions to impact behavior change.

Third-party solution providers can help households recognize how they use energy. They use software and advanced algorithms to analyze home energy data and identify trends and patterns in consumption. Solution providers use data streams to track home performance, even establishing baselines and verifying energy savings for programs. Their solutions may fall under the software-as-a-service model, a growing trend in home and building energy management.

Advanced analytics, when coupled with user-friendly platforms and dashboards, are a valuable tool for customer engagement. Solution providers develop dashboards with graphics and interactive games to report energy use information and engage customers. See examples of solutions in table 5.

Table 5. Examples of third-party solution providers, services, and energy savings

Provider	Solutions	Services	Average energy savings per household
EcoFactor	EcoFactor Platform, Proactive Energy Efficiency, Optimized Demand Response, HVAC Performance Monitoring	Smart thermostat optimization, demand response, HVAC fault detection, customer engagement	11% cooling
EnergyHub	Mercury DERMS Platform, BYOT program	Demand response, grid-edge distributed energy resources management	6–17% cooling
Tendril	Tendril Platform, Home Energy Reports	Demand response, customer engagement	14% heating and cooling
ThinkEco	SmartAC Modlet Platform	Demand response, remote control of room ACs, customer engagement	6–12% cooling

Sources: EcoFactor: OpenADR Alliance 2014. EnergyHub: EnergyHub 2014. Tendril: Business Wire 2017. ThinkEco: ThinkEco 2014.

Recommendations

Utilities are realizing the benefits of incorporating smart technologies into their residential energy efficiency and demand response programs. Offering smart measures can enhance home performance and increase savings across their program portfolios. Program realization rates may improve as customers begin to look to programs as a way to implement smart technologies into their homes.

Program offerings and financial incentives enable smart technologies to become cost effective and enter the market. Some low-cost plug-and-play devices like smart lamps and advanced power strips, as well as popular measures like smart thermostats, might also serve as a gateway for increasing consumer interest and investment in other smart home devices. Introducing energy-saving smart technology into existing programs is a straightforward way to bring these technologies online.

INCENTIVES

Prescriptive programs are simple, low-cost programs that work well for implementing prescribed measures into existing homes. Today's smart home generally consists of devices operating mostly independently, making prescriptive incentives suitable at this time. Rebates help customers offset the purchase cost of technologies and save money on their energy bills. Incentives can increase the uptake of smart devices by making them more affordable and add to the cost effectiveness of the overall program. Current programs cover just a handful of smart home devices. A wider pool of rebates could motivate customers to invest in more smart devices and integrate these devices to work together in the home.

A program could consider smart energy devices in addition to conventional efficiency measures to increase adoption. Existing appliance programs could allow incentives to cover smart appliances. Utilities could promote smart water heater controls for retrofits or new water heater purchases by offering incentives to customers who buy an efficient unit with grid connectivity.

Programs could also offer bonus incentives for the installation of HEMS components that monitor home energy consumption and interface directly with the occupants. HEMS have shown energy savings can be achieved through behavior change (Ehrhardt-Martinez, Donnelly, and Laitner 2010). Their savings potential could increase if coupled with other energy-efficient smart devices.

Some smart measures might not achieve program cost effectiveness because of high up-front costs. One way to integrate such measures and support their growth might be to set a target ($ or %) for them in existing programs. The program could be performance based, paying customers for each kWh or therm saved. Some expensive measures, like smart HVAC systems, are especially suitable to new construction programs. For the existing housing market, it might make sense to implement smart HVAC at the time of home renovations or when an existing system must be modified or replaced.

Most home retrofit programs rely on insulation and other conventional, low-cost measures to achieve cost-effective savings. Programs seeking additional savings could benefit from incorporating smart technologies that are complementary to retrofits, like combining smart thermostats with wall and attic insulation.

DEMAND RESPONSE

Smart thermostats are being integrated into utility demand response programs, along with water heater and AC unit controls. Customers who allow their utility to modulate these energy-consuming systems (or who voluntarily reduce their energy use) during peak demand times receive credits on their energy bill. While smart appliances and smart lamps on their own are not likely to save more energy than non-smart ENERGY STAR–certified models, they have load-shifting potential. Existing residential lighting and appliance programs might look to incentivize smart lamps and smart appliances for their demand response benefit.

CONSUMER RESEARCH AND EDUCATION

Having interconnected devices and systems adds a layer of complexity to the standard home, and utilities should play a role in guiding their customers through the process of adopting these technologies. We need to understand better the energy savings potential that smart technologies afford and to recognize that not everyone will use them in a way that reduces energy consumption. The out-of-the-box approach common to prescriptive programs does not address the specific needs of every household. As smart homes continue to evolve, so will programs that move beyond one-size-fits-all approaches.

DATA FEEDBACK

Smart home devices automate the control and operation of systems to eliminate energy waste. Some smart measures save energy through their optimization, while others promote behavior change through awareness and engagement. These latter devices do not directly save energy; they are enablers and engage users in their home's energy use. For instance, smart hubs and HEMS platforms can help to identify energy savings opportunities by displaying energy use data in easy-to-understand, user-friendly formats.

New approaches to home performance can use data generated by smart technologies like smart thermostats and HEMS. Solution providers can deliver customers personalized reports and engage with them on their energy use. Providing access to these data in real time allows users to see how much energy their home consumes at any given time and for which end uses. This information can encourage them to improve their behavior around consumption and eliminate energy waste.

Advanced analytics can further disaggregate smart technology–generated data to identify patterns of high energy use. Program administrators can then give energy-saving tips and steer customers to specific energy efficiency program offerings through web dashboards or in-home displays (Mackovyak et al. 2017). Efficiency Vermont's Smart Thermostat Analytics Toolkit (STAT) pulls in several data sources from a home's smart thermostat (and smart meter, where applicable). The STAT runs an iterative analysis to evaluate the performance of the thermal envelope and generate savings estimates. Essentially, it helps identify homes that may be a good fit for Efficiency Vermont's home retrofit programs (VEIC 2017). The Fraunhofer Center for Sustainable Energy Systems is leading a similarly focused study in Massachusetts. It is using smart thermostat data to identify homes in need of efficiency measures and to improve the targeting and marketing of energy efficiency upgrades to specific homeowners (NEEP 2017c).

HOME PERFORMANCE PROGRAMS

Typical home retrofit programs lack adequate pre- and post-retrofit energy use data to estimate and verify savings (Cluett and Amann 2016). The data from smart technology can validate post-retrofit energy performance (Rinaldi and Caracino 2017). Smart thermostats can also monitor comfort to see whether retrofitted homes are more comfortable as well as more energy efficient.

Smart technology integrated with efficiency and demand response programs provides a unique opportunity to identify inefficient homes. Through a smart thermostat, utilities have the ability to notice whether a home maintains its temperature over the course of a demand response event. Temperatures that noticeably drift can indicate that a home is performing poorly and needs energy efficiency improvements.

A home with a good thermal envelope (air sealed and well insulated) should be able to maintain a comfortable temperature over the course of a DR event. One study found that tighter homes have deeper energy savings during demand response. These homes saw 95% reductions in HVAC run time and an 86% customer satisfaction rate during DR events (ICF 2017). In contrast, homes with inefficient envelopes can rapidly climb in temperature, making indoor conditions uncomfortable. In most cases, rising indoor temperatures during DR events indicate envelope air leakage.

If a home becomes too warm, an occupant can override the DR event by manually lowering the setting on the smart thermostat. One Southern California utility reports that, for any given DR event, approximately 20% of its customers manually override the thermostat setting. Most overrides occur two hours into the four-hour event (2 p.m. to 6 p.m.). Some program administrators automatically remove customers from an event if their home reaches a temperature limit.

When overrides occur, virtual home energy audits can take place (Rinaldi and Caracino 2017). They provide an opportunity for program administrators to engage with their customers and offer additional energy efficiency measures.

Utilities can partner with home performance contractors to field additional program offerings. Homeowners can permit their utility to directly relay data from their smart thermostat to an approved home performance contractor (Rinaldi, LeBaron, and Caracino 2014). The contractor can then follow up with the homeowner and offer additional energy efficiency services.

OTHER RECOMMENDATIONS

Industry stakeholders should collaborate to advance the smart home market. Technology providers and trade allies could work to educate consumers and offer guidance on smart technologies and applications that save energy. Incorporating these into home performance and low-income programs may help boost market uptake. For starters, consumer acceptance must evolve beyond the tech savvy and early adopters and reach the broader population.

As consumers become more familiar with smart home technologies and satisfied with the comfort, convenience, and energy benefits they afford, they are more likely to pursue additional efficiency measures or spread the word to friends and family. We need to explore ways to increase the uptake of smart technologies that save energy and improve the health and comfort of our homes.

For programs to be successful in implementing smart technology through ratepayer investment, they must prove to be cost effective. Designers are hesitant to include measures in prescriptive programs without predictable energy savings. For now, utility program designers who want to proceed with a smart home project may require more information than is currently available. The Emerging Technologies Coordinating Council created by the major California utilities provides a forum for sharing the results of applied smart technologies research. These and additional efforts to catalog smart technology applications are necessary to gain a better understanding of their benefits and limitations. Such efforts also present an opportunity to learn about consumer preferences and acceptance surrounding the various technology types.

As with any emerging technology, smart home technologies need demonstration projects to document actual energy savings and help policymakers and utility program managers understand their potential. Aside from smart thermostats, most technologies lack documented performance data and extensive demonstrations. Programs implementing smart technology can provide value by measuring actual energy savings following installation. Best-use cases—especially in existing and older homes—must present validated, predictable, and cost-effective energy savings in order to increase the uptake of smart technologies across program portfolios and the population at large.

Going forward, it might make sense to combine smart home technologies together into one project to save on time and administrative costs, and to incorporate technologies that are not typically studied. Joint pilots could generate combined energy savings data at the whole-home level while, at the same time, individually metering each technology. For example, one study might incorporate smart plugs and smart window coverings into a smart lighting project. Pilots and demonstration projects that generate data from different systems and a variety of applications will help us assess the full potential of the smart home, which can lead to a smarter energy future for utilities, policymakers, and, ultimately, all of us.

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Appendix A. Questionnaire Script

Background Questions

1) In which region(s) do you operate?
[ ] Northeast US

[ ] Midwest US

[ ] South US

[ ] West US

[ ] Canada

2) In which US sub-region(s) do you operate?
[ ] New England

[ ] Middle Atlantic

[ ] South Atlantic

[ ] East South Central

[ ] West South Central

[ ] East North Central

[ ] West North Central

[ ] Mountain

[ ] Pacific

3) In which state(s) or province(s) do you operate?
[ ] Alabama

[ ] Alaska

[ ] Arizona

[ ] Arkansas

[ ] California

[ ] Colorado

[ ] Connecticut

[ ] Delaware

[ ] Florida

[ ] Georgia

[ ] Hawaii

[ ] Idaho

[ ] Illinois

[ ] Indiana

[ ] Iowa

[ ] Kansas

[ ] Kentucky

[ ] Louisiana

[ ] Maine

[ ] Maryland

[ ] Massachusetts

[ ] Michigan

[ ] Minnesota

[ ] Mississippi

[ ] Missouri

[ ] Montana

[ ] Nebraska

[ ] Nevada

[ ] New Hampshire

[ ] New Jersey

[ ] New Mexico

[ ] New York

[ ] North Carolina

[ ] North Dakota

[ ] Ohio

[ ] Oklahoma

[ ] Oregon

[ ] Pennsylvania

[ ] Rhode Island

[ ] South Carolina

[ ] South Dakota

[ ] Tennessee

[ ] Texas

[ ] Utah

[ ] Vermont

[ ] Virginia

[ ] Washington

[ ] Washington, D.C.

[ ] West Virginia

[ ] Wisconsin

[ ] Wyoming

[ ] Alberta

[ ] British Columbia

[ ] Manitoba

[ ] New Brunswick

[ ] Newfoundland and Labrador

[ ] Northwest Territories

[ ] Nova Scotia

[ ] Nunavut

[ ] Ontario

[ ] Prince Edward Island

[ ] Quebec

[ ] Saskatchewan

[ ] Yukon

4) Which of the following best describes your role?
( ) Utility/energy efficiency program administrator

( ) Third-party program implementer

( ) Other ____

Technology and Programs Questions

5) If each of the devices listed below were to have smart functionality in the home, what do you believe is their incremental energy saving potential? That is, consider each device as smart and rate it as having high, medium, or low savings potential. Then drag and drop it into the corresponding box.

	Low savings potential	Medium savings potential	High savings potential
HVAC vents/registers			
Lighting controls			
Dishwasher			
Window AC plug/switch			
Power strips and/or wall outlets			
Pool pump			
Thermostat			
Television			
Water heater			
Refrigerator			
Laundry appliances			
LED light bulbs			
HVAC unit			
Window shading			

6) For your smart programs—programs that implement smart technologies—please identify the general program type:
[ ] Widget-based incentives

[ ] Behavior-based incentives

[ ] Energy efficiency and demand-response integration

[ ] Other ____

[ ] Not applicable; we do not currently offer any smart programs.

Standpoint Questions

7) Do you believe the smart home can have the most impact on (multiple answers permitted):
[ ] Energy savings

[ ] Demand response/load shifting

[ ] Behavior change

[ ] None of the above

[ ] Not sure

8) In your opinion, how much do you think a smart home can reduce carbon emissions? Please slide the button to a point on the scale that best matches your opinion.

0 ________________________[__]_____________________________ 100

9) In terms of energy savings potential, do you believe the smart thermostat is underrated, valid, or overrated?

( ) Underrated

( ) Valid

( ) Overrated

( ) Not sure

10) What do you believe to be the biggest barrier to widespread adoption of the smart home?

( ) Technology cost

( ) Data and privacy security concerns

( ) Consumer acceptance

( ) High-speed internet access

( ) Other ____

11) Do you see smart home technology contributing to better and more accurate program EM&V?

( ) Yes

( ) No, never

( ) No, not yet

( ) Not sure

12) Are your programs using smart home technology for EM&V at this time?

( ) Yes

( ) No

13) Do you have any further comments about smart homes? We acknowledge and appreciate your direct involvement in energy efficiency and demand-response programs. We would value any additional comments you'd like to share with us on this topic.

Thank you for taking our survey. Your response is very important to us.

If you have questions regarding this survey or our research in smart homes, please email Jen King, Senior Research Analyst, at jking@aceee.org