Permanent Electrical Loads in New Homes [1]

Alan Meier, Lawrence Berkeley National Laboratory
Quentin Aillot, Ecole Nationale des Travaux Publics de l'Etat

ABSTRACT

Numerous electrical products and components are installed by the builder during construction and prior to occupancy. Some of these components are required by safety codes, such as smoke detectors, others are needed to support the communications infrastructure, and still others provide features that future occupants will find useful, such as remotely controlled garage door openers. We compiled a list of over 50 builder-installed devices that are likely to have continuous power consumption, and measured the power consumptions for a smaller group. A procedure to measure these loads in a home was developed based on readings from the smart meter. A typical American home can easily have 80 W of continuous power – over 650 kWh/year – devoted to these components. New homes are likely to have more of these devices and higher loads. Techniques to reduce this energy use include: selection of lowest-power solutions when a range of power consumptions are available, more efficient circuitry and power management, a separate DC circuit to serve DC-powered appliances, and use of energy-scavenging sensors and controls in place of grid-powered components. A protocol to define and measure builder-installed loads, along with a recommended ceiling, might also stimulate savings.

Introduction: The Rising Significance of Miscellaneous and Electronics Loads

An increasing fraction of residential electricity is consumed by devices that do not fit into core end uses such as refrigeration, water heating, cooling, etc. Several terms are used to described these loads, including "plug loads", "other", and "MELs" (for "Miscellaneous and Electronic Loads"). Studies have identified MELs as an important problem because it continues to grow in both absolute and relative terms (Comstock and Jarzomski 2012). MELs is estimated to account for 26% of electricity use in US homes (EERE 2011). At the same time, the composition is changing because energy consumed by consumer electronics may have begun falling (Roth et al. 2014).

In this paper we examine a subset of MELs, the "builder-installed" electrical products. These are the appliances and components installed by the builder during construction and prior to occupancy. The builder-installed subset is extraordinarily diverse but may nevertheless be susceptible to unique policy tools. We compiled a list of common builder-installed devices, report on their power consumption, and describe approaches to reducing their energy use. Our study focuses on homes and data from the United States; however, many of the devices are similar to those found in Europe, Japan, and elsewhere. We focused on the continuous, or standby loads, from these devices rather than the "active" consumption for three reasons. First, the active energy consumptions may be already regulated by efficiency standards. Second, active-mode consumption depends on behavior and other factors that we could not evaluate and,

[1] An earlier version of this paper was presented at the 2015 EEDAL Conference in Lausanne, Switzerland.

in any event, are outside the builder's control. Finally, the fixed loads often represent the largest fraction of these devices' energy consumption.

Definition of Builder-Installed Products and Loads

"Builder-installed products" are the appliances and components put into a home during the construction process and before people occupy it. Builders typically install appliances and components because they are required by building codes or to make the home more attractive to potential buyers or occupants. Some of the products are "hard-wired", that is, need an electrician to install and cannot be unplugged. They are, in effect, "permanent" loads. The principal categories of builder-installed products with continuous loads are proposed in Table 1.

"Builder-installed loads" are the electrical consumptions of these products. These loads are described in terms of their power (W) because many products draw power continuously, although they may have additional power levels while active.

The set of builder-installed and occupant-installed products overlaps. Some products and appliances may be selected and installed by either the builders or the occupants depending on local conditions. For example, builders now install an increasing number of devices associated with information technology infrastructures that were formerly installed by occupants.

Table 1. Categories of energy-using, builder-installed products

Category	**Examples**
Required by building code for safety	Ground fault circuit interrupters (GFCIs)
Security related	Security system, intercom
Associated with heating, cooling, ventilation, hot water	Heating controls, including thermostat, power supply, logic board
Communications and IT infrastructure	Cable modem, Wi-Fi router
Amenities & Features	Remote control features on blinds, gas fireplace

These categories are only roughly defined because many products provide multiple services. The selection and number of these devices vary widely with the location and home. Expensive homes typically have more of everything.

Earlier Investigations of Builder-Installed Loads

Some builder-installed products have been measured in laboratories and in stores. For example, The Australian Greenhouse Office (Energy Efficiency Strategies 2004) measured power consumptions of smoke alarms. Delforge measured the power of ground fault protection circuits (P. Delforge, Natural Resources Defense Council, pers. comm., April 2014). The standby power consumptions of various builder-installed appliances – dishwashers, tankless water heaters, etc.– are also sometimes reported by manufacturers in their product manuals.

The aggregate electricity consumption of a home at the completion of construction, but prior to occupancy, has not been widely investigated. In 2006, Brown et al. (Brown et al. 2007) surveyed 13 new, but unoccupied, homes in the United States and estimated the loads from builder-installed devices. Through field studies, sub-metering, and measurements of individual devices, they estimated that builder-installed loads were responsible for a continuous power draw of about 50 W (or 440 kWh/year).

Borgeson used data from smart meters to identify the lowest hourly consumption over one year in 5000 existing California homes (Borgeson 2013). Figure 1 shows a cumulative distribution of power use among the homes.

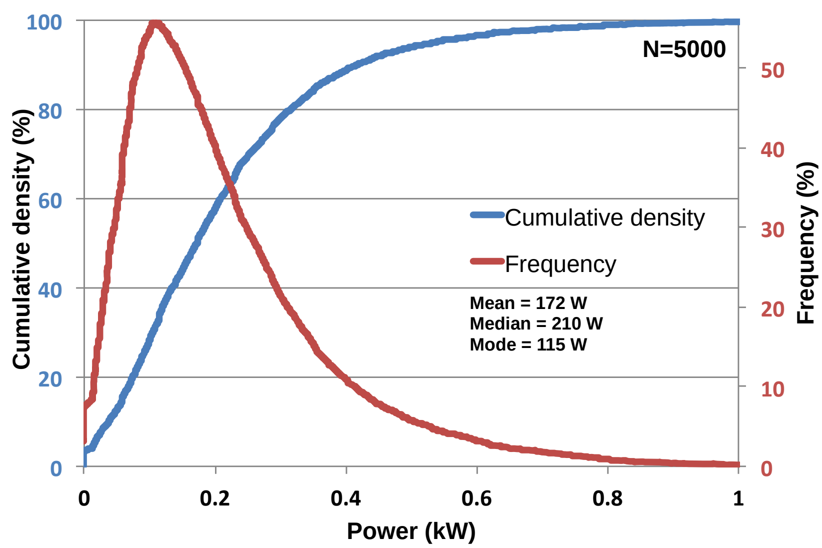

Figure 1. Distribution of minimum power loads – lowest hour during the year—for 5000 California homes. *Source:* Adapted from Borgeson

About half of the homes had a minimum load greater than 0.25 kW, corresponding to roughly 2200 kWh/year. Another California study of 70,000 homes found an average minimum load of 218 W (Delforge, Schmidt, and Schmidt 2015). The minimum observed load in these existing homes does not correspond directly to builder-installed loads but it establishes an upper limit. It is likely that the core end uses (such as refrigerators, water heaters, and lights) are switched off or not operating during the hour that the minimum load occurred, so builder-installed loads could be responsible for a significant fraction of these observed minimum loads.

Delforge et al. (Delforge, Schmidt, and Schmidt 2015) examined in detail the “idle loads” in ten existing homes in Northern California. This study focused on devices that are “always-on", such as audio/video equipment, set-top boxes, computers, aquariums, and hot water recirculation pumps. It differs from our study, which focuses on builder-installed loads, prior to occupation. Nevertheless, they are complementary because they highlight the kinds of continuous loads that will be added after people move into a new home. Our study adds further insights regarding newly-constructed homes because have some appliances and components that are less common in existing homes, such as more GFCI outlets, hard-wired smoke alarms, and tankless water heaters.

Typical Builder-Installed Products with Continuous Electrical Loads

Tables 2a-e list many builder-installed products with continuous electrical loads. The products are divided into the categories proposed in Table 1. No home will have all of these devices and some homes will have more than one of certain devices. Some characteristics of these products are described below. The intent is not to be comprehensive; rather, it is to illustrate the diversity of products.

Table 2a - 2e. Builder-installed devices that draw power continuously

Table 2a. Components required for safety reasons

GFCI outlets	Smoke detector/alarms
GFCI breaker	CO detector
AFCI	

Table 2b. Components installed to provide occupant security

Entryway audio and video systems	Motion/light sensors
Security systems	Electronic door locks
Doorbells	DC exterior lighting power supply
Garage door opener	

Table 2c. Associated with heating, cooling, ventilation, hot water

Demand water heater (gas) controls	Heat pump crankcase heaters
HVAC controls	Mini-split ACs/HPs
Point-of-use water heaters	Ceiling fan remote controls
Ventilation fans	Hot water circulation pumps
Well pumps	Boiler circulation pumps
Motion-activated faucet sensors	

Table 2d. Communications infrastructure

Cable amplifiers	Entryway audio and video
Telephone/Internet boxes	Wi-Fi routers
FIOS boxes	Ethernet hubs

Table 2e. Amenities and features

Irrigation/sprinkler controls	Toilet flush sensor
Vacuum cleaner (built-in)	Smart toilet (“washlet”)
Gas fireplace remote	Dishwasher
Remote controls for blinds and curtains	Heated towel racks
Oven/stovetop	Inverters for photovoltaic systems
USB outlets	Sump pumps
Pool pumps	Electric vehicle chargers
Fountains	

Components Required By Building Codes

An increasing number of electrical devices are required by building codes to ensure the safety of the occupants and the structure. New homes in North America homes are required to be equipped with technologies to prevent accidental electrical shocks, such as ground fault circuit interrupters (GFCIs). Outlets with this safety feature must be installed in kitchens, bathrooms, laundry rooms, and in any location where standing water may occur. Arc-fault circuit interrupters (AFCIs) and other kinds of circuitry are installed at the panel to prevent fires by detecting hazardous short circuits and then disconnecting mains power. These circuits also draw power continuously.

Smoke detectors and alarms have been required in U.S. homes for decades. Traditionally, residential smoke detectors were battery-powered and drew no mains power. However, studies found that many batteries were not replaced and numerous serious fires could have been prevented with functional smoke detectors (Ahrens 2004). As a consequence of these findings, building codes are being revised to require hard-wired smoke detectors to eliminate the problem caused by dead or removed batteries. Fire codes typically require a smoke detector in each bedroom, on each floor, and in several other key locations. Carbon monoxide alarms are also required in houses with combustion appliances. As a result, a large, new home could easily contain over eight smoke and carbon monoxide detectors. Builders may install other kinds of safety-related sensors and alarms in special situations. For example, homes vulnerable to flooding might have special water alarms. All types of sensors are becoming networked so, again, the Wi-Fi router is arguably a necessary component of safety and security systems.

Security-Related Loads

Builders install some products to provide security to the occupants. Door bells and their associated transformers, were among the first continuous loads in homes. Modern homes and apartments, especially those in Japan and Korea, have sophisticated communications systems between persons at the entryway and the occupants. Their features include a “doorbell”, audio and video connections, and entry control. Almost all new U.S. homes with garages are equipped with garage door openers, usually controlled with remote controls. These door openers have child-safety features that remain active even when the garage door is closed. Home security systems are installed both as retrofits and by builders. With the dramatic reduction in cost of video surveillance, new homes are being equipped with a network of video cameras. Some systems are connected to the Internet, thus requiring the builder to install a Wi-Fi router and Internet connection. Most security systems have batteries that must be continuously charged.

Loads Associated With HVAC and Water Heating Equipment

Builders are typically responsible for installation of Heating, Ventilation and Air Conditioning (HVAC) equipment. Nearly every type of HVAC system now includes some sort of continuous load. These loads may be significant; for example, a recent DOE regulation established the maximum allowable “off-mode” consumptions at 30 W for most central air conditioners and heat pumps (U.S. DOE 2013). Many building codes now require continuous mechanical ventilation, which is provided by small fans, drawing around 30 W. Heat pumps have crankcase heaters that, depending on the control strategy, continuously draw up to 50 W(Kneifel et al. 2015). Heating systems based on circulating hot water require a pump that is selected and installed by the builder. If incorrectly commissioned, these pumps can operate all the time. Equipment designed to provide local cooling or heating, such as room air conditioners and ceiling fans, are nearly always installed with remote controls that have small, continuous loads. Thermostats typically operate off low-voltage power supplied through a transformer.

Tankless (or demand) water heaters have electrical controls to regulate water temperature and delivery; these draw about 5 W even when no hot water is called (Bohac et al. 2010). Domestic water heating systems might have a circulating pump to ensure immediate delivery of water to all taps in a building, which would draw a constant electrical load. Builders may find it more convenient – and cheaper—to install small electrical water heaters at remote faucets. Some builders equip kitchens with a means of boosting hot water temperatures to over 90°C for hot beverages. Most designs include a small reservoir of hot water maintained at this temperature.

In addition, many restrooms in commercial buildings are equipped with motion-activated faucets. The sensors and actuators are driven by mains power, ambient light, or batteries. These technologies are now appearing in residential faucets.

Communications and Information Technology Infrastructure

Builders of new homes are adding new communications and information technology products prior to occupancy. Many of the products are also selected by owners after occupancy but the division of responsibility depends on local conditions and the specific requirements of the building. Builders must frequently install a communications network and the associated infrastructure to service the HVAC, safety, and security systems that now rely on wired and wireless communication. Cable and satellite networks each require their own internal infrastructure of energy-using products (Lanzisera, Nordman, and Brown 2012). For example, large parts of the eastern United States gain access to the Internet, video, and telephone service with fiber optic networks (FiOS). These homes use a FIOS converter box, which includes a rechargeable battery to maintain telephone service during power interruptions (Gabel and Burns 2012). Large homes often need cable amplifiers to provide full service; each of these amplifiers draws a couple of watts.

Mains outlets are now being offered with integrated USB and Ethernet connections. To date USB connections provide only power (and contain one power supply in each outlet); however, future designs will integrate power and communications.

Amenities and Features

Builders add features to their homes because customers want them. Many of these features involve energy-using products (some of which have already been discussed earlier). In the kitchen, builders often select and install the cooktop (or stove), in-sink garbage disposal, dishwasher and, less frequently, the refrigerator and oven. Nearly all of these appliances will have continuous—though low—power consumption when not being actively used. In the bathroom, heated towel racks are becoming common, though more so in Europe than in North America. About 75% of Japanese homes have toilets with advanced, electrically operated features ("Toilets in Japan" 2015), including a heated seat, a "shower-wash", and remote control. In Japan, these toilets draw 22 W (Yuasa et al. 2014). Each of those units requires a dedicated GFCI outlet nearby, too. These types of toilets are gradually appearing in North America. New homes throughout the world are employing remote controls for lights, curtains, blinds, gas fireplaces, floor heating, and other amenities, all of which draw power continuously.

Outside the home, in the yard, builders include all sorts of devices to make the yards more attractive and easier to maintain. Automated irrigation systems and low-voltage lighting systems are two common examples, both requiring continuous power for the power supplies and other components. Pumps and other equipment for swimming pools and spas use several kilowatts intermittently while in active modes; however their timers, safety features, and demand controls draw power continuously.

Future homes will almost certainly be equipped with electric vehicle charging facilities (once these become standardized). In-home battery storage may also become common. Both will have fixed loads.

Measured Power Use of Unoccupied New Homes

In order to better understand the aggregate impact of builder-installed loads, we measured the power use of new and existing unoccupied homes. This measurement is easy to perform on homes with advanced smart meters because they display the instantaneous power consumption roughly every 30 seconds. We located new homes that were recently completed by the builder but not yet occupied. We inspected the home (where possible) and confirmed that all lights and other equipment—if any were present—were switched off. We then observed the meter for several minutes to verify that power consumption was constant. The floor areas, ages, and other characteristics were obtained from the builder or from a national real estate listing service (zillow.com).

We surveyed four existing and nine new homes in Northern California. The power consumptions are shown in Figure 2. The observed loads ranged from 25 – 180 W. (Note that 100 W of constant electricity consumption corresponds to ~900 kWh/year.) The lowest value occurred in an existing home built during the 1970s, with no apparent upgrades since then. The highest values occurred in new homes and in an existing home that had recently undergone a complete rehabilitation. Figure 2 also shows the observed loads normalized to their reported floor areas. Most of the homes had loads near 0.04 W/ft^2 (0.4 W/m^2).

This simple measurement protocol is susceptible to two kinds of errors, both of which lead to overestimates of builder-installed loads. First, the measurement will consistently over-estimate builder-installed loads because operating lights or other appliances may be overlooked. For example, in one new home we later identified (though photo-documentation) outdoor lights operating during the measurement period. (We subtracted those loads.) Second, floor areas are consistently under-estimated from public records because owners fail to report home expansions and improvements. Actual builder-installed loads, per unit-area, will be lower than estimated until more reliable floor area data are applied.

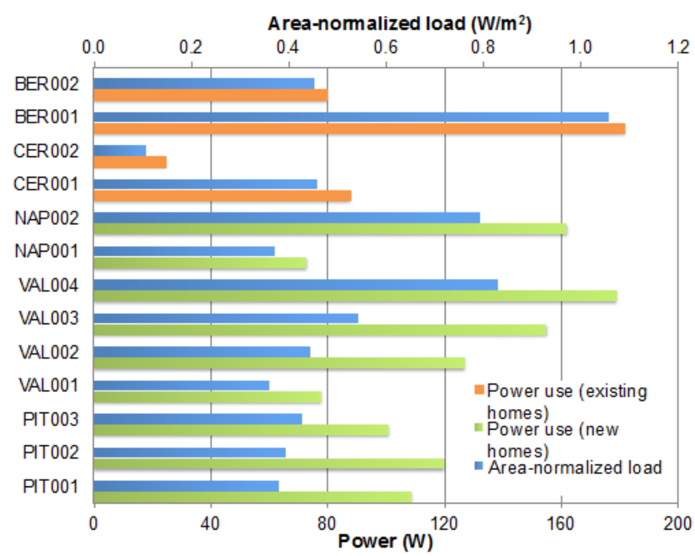

Figure 2. Power measurements of unoccupied homes.

These measurements show that builder-installed loads are responsible for a significant fraction of total electricity use. New homes in our survey had an average of 120 W (1050 kWh/year) of builder-installed loads. This corresponds to about 13% of a single-family home's electricity consumption in California – 7600 kWh/year (Kema, Inc. 2010). We therefore sought to understand the causes of builder-installed loads through measurements of individual builder-installed products.

Power Draw of Builder-Installed Products

We also measured and compiled power measurements of individual builder-installed products. These are summarized in Figure 3. We focus on the lowest continuous power consumption of these products since this draw would occur even when the occupants are absent. For each product, we display the minimum and maximum reported values, along with our own estimate of a "typical" value.

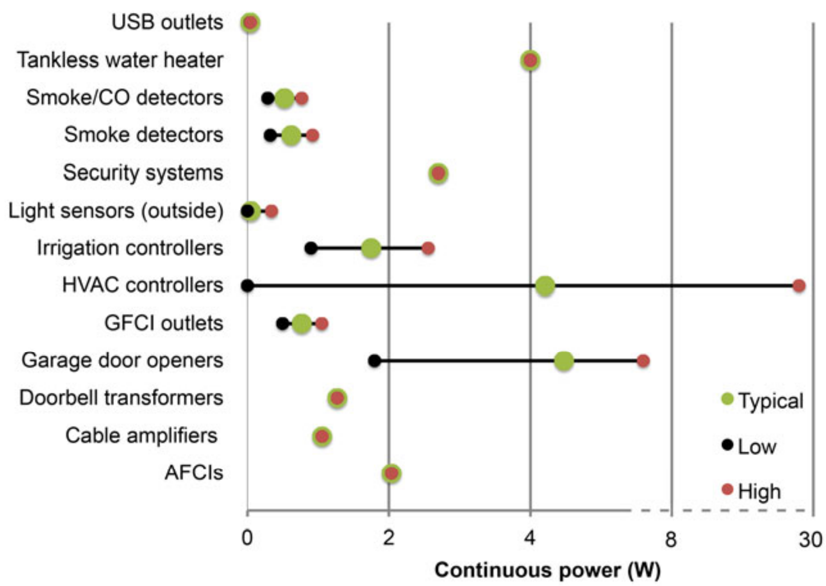

Figure 3. Summary of measurements of builder-installed loads.

These measurements have numerous shortcomings. First, there is no clear definition of builder-installed products, so some products may also be consumer-installed. Second, sample size is small – sometimes only one product – and are therefore not representative. Third, measurement techniques were not standardized; they were typically instantaneous power measurements performed informally rather than based on, say, IEC 62301 (International Electrotechnical Commission 2011). Fourth, the measurements are often imprecise because most metering equipment is not accurate at the very low power consumption of these products (below ~2 W). Finally, the list is incomplete; many other products draw power continuously in homes.

Most of these builder-installed products consume very little power–often less than one watt – which translates into very little annual electricity consumption. (One watt of continuous power use corresponds to 9 kWh per year.) The number of these products present in a home may be quite large, however. A modern American home could easily contain eight GFCI circuits in order to comply with safety codes. Similarly, a new home will require at least five smoke detectors (though this depends on number of rooms and floors). This situation also occurs with respect to various remote-controlled devices and perhaps, in the future, USB outlets. The aggregate load of these products will add up to over 75 W in most new homes. Table 3 is a sample tabulation.

Table 3. Tabulation of builder-installed loads in a typical new U.S. home

Components	Power (W)*
7 AFCIs	14.3
8 GFCI outlets	6.2
4 Smoke detectors	2.5
4 Smoke/CO detectors	2.1
Built-in microwave oven	1.0
Built-in oven	2.0
Built-in dishwasher	1.5
Cable Amplifier	1.1
2 Ceiling fan controllers	2.0
Doorbell transformer	1.3
Garage door opener	4.5
HVAC controller	25.0
Irrigation controller	1.8
2 Light sensors (outside)	0.1
9 Occupancy sensors	3.8
Security system	4.5
Tankless water heater	4.0
USB outlets	0.2
Total	78

*Some values are estimated

This list includes many of the most common devices, but it could easily be much larger if the builder is responsible for more built-in appliances or the home has continuous ventilation, a heat pump crankcase heater, or other small heating devices. Nevertheless, these listed loads alone translate into over 650 kWh/year, or about 9% of the electricity use of an average California single-family home. New categories of products may have significant standby power use. For example, electric vehicle chargers will draw 1 – 13 W, depending on manufacturer and configuration at the time of measurement (Energy Star 2013).

Energy Saving Opportunities

The builder-installed loads described above will persist for decades and possibly for the lifetime of a building. These permanent loads translate into a substantial amount of energy consumption and carbon emissions. Reducing the energy use of builder-installed loads would appear to be difficult because nearly all of these components draw very little power. However, several strategies are possible, including:

- identification of lowest-power solutions when a range of power consumptions are available, notably for products whose efficiency is already regulated (such as tankless water heaters and heating systems);
- "daisy-chaining" GFCIs, allowing one circuit to serve many outlets (this is already done)
- more efficient circuitry and power management;
- a separate DC circuit to serve DC-powered appliances; and
- use of energy-scavenging sensors and controls in place of grid-powered components.

The solutions must be very inexpensive because the value of the savings in each device will be small. It is possible that non-energy benefits, such as safety during power outages, could defray some of the costs.

One way to stimulate attention to builder-installed loads, possibly leading to energy savings, is to establish a protocol to define and measure builder-installed loads. This measurement would be publicized and become a sales feature for new, low-energy homes. In the future, authorities might establish a cap on builder-installed loads.

Conclusion

The miscellaneous loads represent a growing fraction of residential electricity use. They are challenging to define, measure, and reduce. The "builder-installed" loads, and especially those with continuous power draws, make up a special category because they are selected by a single entity and installed at more or less the same time. The builder installs these devices in order to satisfy safety codes, provide security, support basic building services, and provide features that attract potential buyers. A typical home can have 50 builder-installed components that draw power continuously.

Only a few measurements of builder-installed loads in completed homes have been performed but these are sufficient to indicate their power consumption is significant. Measured power consumptions of the individual components are sparse. In addition, the measurements have been performed in variable conditions over the past decade. Nevertheless, it is possible to construct an inventory and estimate total power draw. In even simple cases, the loads approach 80 W of continuous power, or over 650 kWh/year. This corresponds to 6% of an average U.S. home's electricity use, but will become a much higher fraction after the home is equipped with the next generation of efficient appliances.

Reducing builder-installed loads is technically and economically challenging. The appliances and components installed by builders in new homes are extraordinarily diverse; however, they might be addressed by a single comprehensive strategy aimed at contractors and the home-building sector. Furthermore, many regions already have energy codes addressing construction of new homes, so regulatory, informational, and financial pathways already exist to encourage lower builder-installed loads.

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. Q.A. was supported by the Ecole Nationale des Travaux Publics de l'Etat; Ministère de l'Ecologie, du Développement Durable et de l'Energie (France). The authors also thank valuable comments by the reviewers.

References

Ahrens, Marty. 2004. “US Experience with Smoke Alarms and Other Fire Detection/alarm Equipment.” *Quincy, MA: National Fire Protection Association*.

Bohac, Dave, Ben Schoenbauer, Martha Hewett, Mary Sue Lobenstein, and Tom Butcher. 2010. “Actual Savings and Performance of Natural Gas Tankless Water Heaters.” Minneapolis: Center for Energy and Environment.

Borgeson, Samuel. 2013. “Targeted Efficiency: Using Customer Meter Data to Improve Efficiency Program Outcomes.” Ph.D. Dissertation, Berkeley, CA: University of California.

Brown, Richard E., William Rittelman, Danny Parker, and Gregory Homan. 2007. “Appliances, Lighting, Electronics, and Miscellaneous Equipment Electricity Use in New Homes.” LBNL-62440. Berkeley: Lawrence Berkeley National Laboratory. http://escholarship.org/uc/item/1w05f0d1.

Comstock, Owen, and Kevin Jarzomski. 2012. “Consumption and Saturation Trends of Residential Miscellaneous End-Use Loads.” In *2012 ACEEE Summer Study on Energy Efficiency in Buildings*. Pacific Grove: ACEEE.

Delforge, Pierre, Lisa Schmidt, and Steve Schmidt. 2015. “Home Idle Load: Devices Wasting Huge Amounts of Electricity When Not in Active Use.” NRDC Issue Paper IP:15-03-A. San Francisco: Natural Resources Defense Council.

EERE. 2011. *Buildings Energy Data Book*. Washington, D.C.: Energy Efficiency and Renewable Energy Office, U.S. Department of Energy.

Energy Star. 2013. “ENERGY STAR Market and Industry Scoping Report Electric Vehicle Supply Equipment (EVSE).” Washington, D.C.: U.S. Environmental Protection Agency.

Gabel, David, and Steven Burns. 2012. “The Transition from the Legacy Public Switched Telephone Network to Modern Technologies.” Report No. 12 – 12. Silver Spring, Maryland: National Regulatory Research Institute. http://www.nrri.org/.

International Electrotechnical Commission. 2011. “IEC 62301 Household Electrical Appliances Measurement of Standby Power.” *Edition* 2: 94720–136.

Kema, Inc. 2010. “2009 California Residential Appliance Saturation Study.” CEC-200-2010-004-ES. Sacramento, Calif.: California Energy Commission.

Kneifel, Joshua, William V. Payne, Tania Ullah, and Lisa Ng. 2015. “Simulated versus Measured Energy Performance of the NIST Net Zero Energy Residential Test Facility Design.” NIST Special Publication 1182. Gaithersburg, Maryland: National Institute of Standards and Technology. http://dx.doi.org/10.6028/NIST. SP. 1182.

Lanzisera, Steven, Bruce Nordman, and Richard E. Brown. 2012. “Data Network Equipment Energy Use and Savings Potential in Buildings.” *Energy Efficiency* 5 (2): 149–62.

Roth, Kurt, Bryan Urban, Victoria Shmakova, and Brian Lim. 2014. “Residential Consumer Electronics Energy Consumption in 2013.” In *ACEEE Summer Study on Energy Efficiency in Buildings*. Pacific Grove, CA: American Council for An Energy Efficient Economy (Washington, D.C.).

“Toilets in Japan.” 2015. *Wikipedia, the Free Encyclopedia*. https://en.wikipedia.org/w/index.php?title=Toilets_in_Japan&oldid=668276421.

U.S. DOE. 2013. *Standards for Residential Central Air Conditioners and Heat Pumps*. *Federal Register, 78 FR 72533*. http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/75.

Yuasa, Kazuhiro, Mai Yata, Yoichiro Nakano, and Shuji Fujii. 2014. “Reduction in Residential Energy Consumption Owing to Lifestyle Changes—A Survey Research for Meguro Ward in Tokyo, Japan.” *Journal of Asian Architecture and Building Engineering* 13 (3): 665–71.