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In Response to Request for Additional Public Comments

Additional submitted attachment is included below.

BEFORE THE
CALIFORNIA ENERGY COMMISSION

In the matter of: Phase 2 Appliance Efficiency Regulations & Roadmaps	Docket No. 17-AAER-12 Low-Power Mode & Power Factor

COMMENTS OF THE CONSUMER TECHNOLOGY ASSOCIATION

The Consumer Technology Association (CTA)[1] provides these comments in response to the Energy Commission staff's February 12, 2019 Request for Additional Public Comment in this proceeding.

Energy Commission staff stated at the January 24, 2019 webinar that the Energy Commission should exempt a category of equipment from any new low-power test method and possible roadmap if significant additional energy savings were not likely to result from that category being part of the test method.

Equipment already covered by an existing consensus test method should therefore be excluded because duplicative testing would not provide any *new* meaningful information to the Energy Commission. These categories include Audio-visual (AV) Equipment, Computers/Slates and Tablets, Imaging Equipment, Monitors/Displays/Signage Displays, Set-top Boxes, Small Network Equipment (SNE), Smart Thermostats, Telephones, and Televisions. These test methods that are individually tailored for specific products produce more accurate results than a horizontal test method that attempts to cover a wide range of diverse electronics. The Energy Commission's additional questions presented during the January 24th webinar demonstrate the challenge of a one-size-fits-all approach: there is no clear answer to many of these questions because of the variability in technical characteristics and use cases of the nearly limitless range of products that could be covered, as proposed.

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[1] CTA is the trade association representing the $398 billion U.S. consumer technology industry, which supports more than 15 million U.S. jobs. Our membership includes more than 2,200 companies, including manufacturers, retailers, distributors and installers of the consumer technology products that appear to be within the broad scope of this proceeding. Eighty percent of CTA's members are small businesses and startups, and others are among the world's best known manufacturer and retail brands. Our members have long been recognized for their commitment and leadership in innovation and sustainability, often taking measures to exceed regulatory requirements on environmental design and energy efficiency.

Equipment categories already covered by not only a consensus test method but also an effective voluntary energy efficiency program are especially compelling for exemption from any new horizontal test method. Under the voluntary agreements for SNE and set-top boxes, the Energy Commission and public already have access to low-power mode test results (idle-mode for SNE and standby power for set-top boxes) for the vast majority of new units deployed in California since 2015, which are posted at www.energy-efficiency.us. This data is reviewed by an independent auditor and is subject to third-party verification testing. It would serve no useful purpose to require burdensome and duplicative new testing using a second test method that would be less accurate and inconsistent with the existing data available to the Energy Commission.

New testing regimes for products covered by voluntary agreements are also unnecessary because those agreements are already delivering impressive improvements in energy efficiency that would be the focus of an Energy Commission roadmap. The independent auditor found that consumers have saved $3.5 billion, and more than 20 million metric tons of carbon dioxide emissions have been avoided as a result of the set-top box agreement, and that the current SNE agreement levels improved the efficiency of SNE by nearly 20% compared to typical, previously deployed devices. In addition, both agreements are implementing even more rigorous energy commitments beginning in 2020.

In our previous comments, we described a current activity to develop a consensus standard for measuring power consumption for several categories of audio-visual (AV) products, including smart speakers and soundbars. This "CTA-2084" test method standard will support the revision of the EPA's ENERGY STAR Audio/Video Specification Version 4.0, and CTA-2084 ultimately will be an American National Standards Institute (ANSI) consensus standard. The project working group is open to any interested stakeholders per ANSI requirements. Current participants include industry, energy efficiency advocates, testing labs, and regulatory agencies. Contemplated as part of the test method are low-power mode settings such as idle state and sleep mode. Procedures for placing the products in the two low-power modes are specified in CTA-2084. Once in their respective modes, IEC 62301 is referenced to measure the power consumption. As noted previously, the Energy Commission is welcome to participate directly in this effort with other stakeholders if the covered AV product categories are of interest for purposes of the low-power mode proceeding. The new standard is expected to be published later this year.

Lastly, we would like to highlight the availability of comprehensive data on the power consumption trends across all significant categories of consumer technology products. Since 2006, CTA has commissioned and published four peer-reviewed energy use studies, the most recent of which was issued in December 2017 and is attached to these comments.[2] We urge the Energy Commission staff to review the report and would welcome their questions and feedback, including feedback on where additional data may be desired.

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[2] Energy Consumption of Consumer Electronics in U.S. Homes in 2017: Final Report to the Consumer Technology Association, B. Urban, K. Roth, M. Singh, D. Howes, Fraunhofer USA, December 2017.

Respectfully submitted,

CONSUMER TECHNOLOGY ASSOCIATION

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Fraunhofer USA Center for Sustainable Energy Systems

Energy Consumption of Consumer Electronics in. U.S. Homes in 2017

Final Report to the Consumer Technology Association

by Bryan Urban, Kurt Roth, Mahendra Singh, and Duncan Howes

December 2017

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List of Acronyms and Abbreviations

AEC	Annual Electricity Consumption
CE	Consumer Electronics
CEA	Consumer Electronics Association
CT	Consumer Technology
CTA	Consumer Technology Association
CRT	Cathode Ray Tube
DOE	U.S. Department of Energy
DTA	Digital Terminal/Transport/Television Adapter
DVR	Digital Video Recorder
EPA	U.S. Environmental Protection Agency
FhCSE	Fraunhofer Center for Sustainable Energy Systems
GPU	Graphics Processing Unit
IAD	Integrated Access Device
STB	Set-top Box
TEC	Total/Typical Energy Consumption
TV	Television
TWh	Terawatt-hour
UEC	Unit Electricity Consumption
UHD	Ultra High Definition

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We would also like to thank Paul Gagnon with IHS Markit for providing computer monitor data and Ian Olgeirson of SNL Kagan for providing set-top box data.

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EXECUTIVE SUMMARY

The Consumer Technology Association (CTA) commissioned this study to quantify the electricity used by consumer electronics in U.S. households in 2017. Consumer electronics include devices, such as televisions and computers, intended for everyday use in homes. Relative to other energy end uses, electronics tend to have shorter product cycles, varied usage patterns, and rapid adoption. As a result, their characteristics can change dramatically in just a few years, providing a need for up-to-date energy consumption assessments, especially for informing energy policy decisions. This study represents the fourth of its kind, enabling a trend analysis.

We estimate that 3.4 billion consumer electronic devices consumed about 143±9 TWh in 2017. This represents about 10% of residential sector and 4% of total U.S. electricity consumption. Powering these devices costs about $18 billion annually. Per-household, this is about 1,205 kWh or $155 per year. Relative to prior year estimates, the 2017 energy total was less by about 11% (2006), 26% (2010), and 14% (2013). The decreases since 2010 are driven largely by the diminishing installed base of CRT televisions.

Results for individual device categories were based on a bottom-up approach used to estimate the installed base, typical annual usage, and power draw by mode. Thirteen categories studied in-depth account for one third of all installed devices and nearly 80% of the total energy consumption (Figure ES-2). The other devices, studied in less depth, are covered in Section 11 (also Table 3-2). Three U.S. phone surveys were fielded to identify the installed base and usage patterns of computers, televisions and soundbars, and video game consoles. Survey responses served as inputs into more detailed energy use models. Uncertainty estimates, developed for priority categories, were typically within about ±15%.

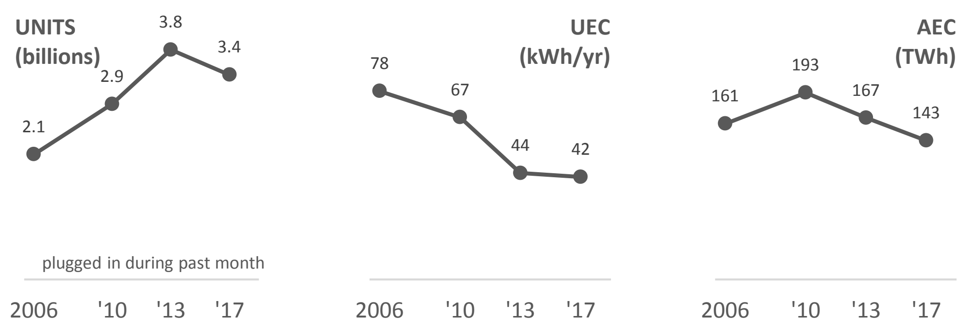

Figure ES-1. Trends in consumer electronics energy use.

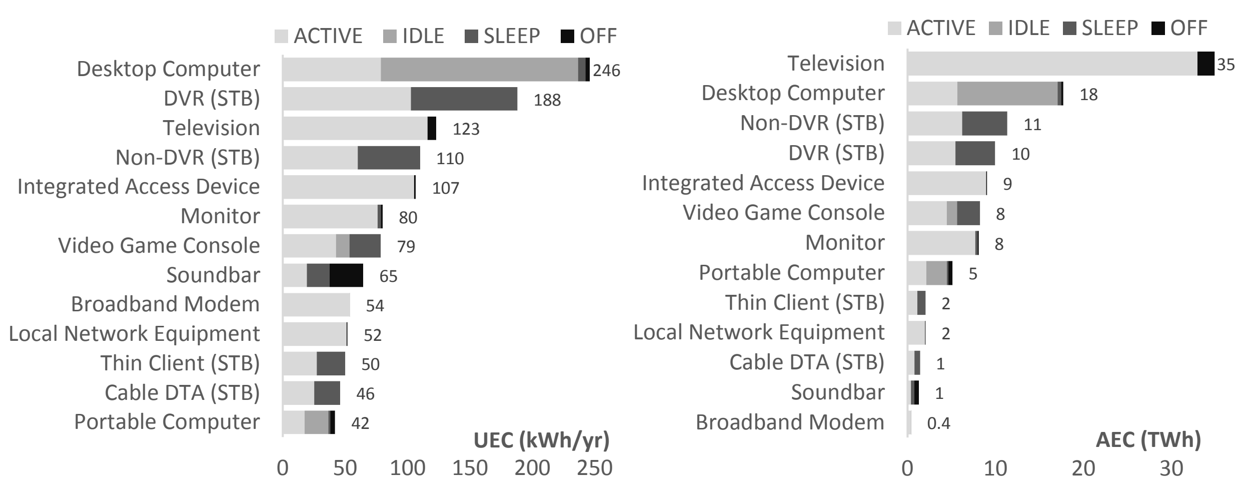

Figure ES-2. Unit energy consumption and annual energy consumption by mode for devices studied in depth.

1 INTRODUCTION

The Consumer Technology Association (CTA) commissioned this study to quantify the electricity consumption of consumer electronics in U.S. households in 2017. This study is the fourth of its kind, characterizing consumer electronics energy use for the years 2006, 2010, and 2013 (TIAX 2007; FhCSE 2011, 2014).

Consumer electronics include a wide array of devices, like computers and televisions, intended for everyday use in homes. They do not include appliances or hardware related to heating, cooling, or lighting end uses. Relative to other end uses, the characteristics of consumer electronics typically change very quickly due to innovation, short product cycles and lifetimes, evolving usage patterns, and rapid technology adoption. As a result, the installed base of many product categories can change dramatically in just a few years and new categories emerge that did not exist in prior studies.

New smart home technologies are blurring the lines between consumer electronics and other end-uses. Devices like digital personal assistants (Amazon Echo and Google Home), smart thermostats, and connected lighting are changing how people use energy in the home. While we did not include these devices in this study, they are growing in importance, and may be included in future editions of this report.

Such rapid changes make it essential to regularly develop up-to-date and accurate energy assessments. For instance, if obsolete data are used to inform energy policymaking, the resulting programs could be less likely to achieve their end goals. Consequently, the Consumer Technology Association commissioned Fraunhofer to perform this study to provide current, high-quality data to inform energy policy decisions.

1.1 Approach

This study followed a similar approach as the three prior studies:

1. Develop preliminary Annual Energy Consumption (AEC) estimates for a long list of devices
2. Select priority device categories to study in depth with a more refined analysis
3. Develop refined AEC estimates for the selected priority categories
4. Compare current energy consumption characteristics with prior estimates
5. Compose a Draft Final Report and undergo peer review
6. Publish a Final Report to the CTA suitable for widespread distribution

1.2 Organization

The report is organized into the following sections:

Section 2	Methodology used to characterize energy consumed by each device category.
Section 3	Results and conclusions.
Sections 4-10	Detailed supporting analysis for the priority device categories studied in depth.
Section 11	Supporting analysis for all remaining “other” device categories studied in less depth.
Appendix A	Consumer Electronics Usage Survey Questions

2 METHODS

2.1 Device Category Selection

While it would be preferable to evaluate the annual energy consumption of all device categories in depth, time and scope constraints led us to focus on a subset of categories where a more refined analysis would yield the greatest value. Consequently, in conjunction with CTA, we selected thirteen categories for in-depth analysis based on the magnitude and uncertainty of preliminary AEC estimates (higher more likely to be selected, see Table 3-1 and Table 3-2). The remaining other categories were studied in less depth in Section 11. Since few categories account for the vast majority of the total energy consumption, this approach has a minor impact on the collective energy estimate accuracy.

2.2 Energy Consumption Analysis

To evaluate device energy consumption, we used a bottom-up approach (Figure 2-1). For each device category, we developed estimates for the average power draw (W) and usage (hours/year) by mode. Multiplying power and usage yields the unit electricity consumption (UEC in kWh/year) by mode. The sum over all modes equals the total UEC. Finally, the product of the UEC and installed base (millions of units) equals the annual energy consumption (AEC in TWh). Prior studies followed similar methods (LBNL 2001; ADL 2002, TIAX 2006). The modes in Figure 2-1 are illustrative and were tailored for each specific category based on their actual power modes. A succinct overview of the model components follows.

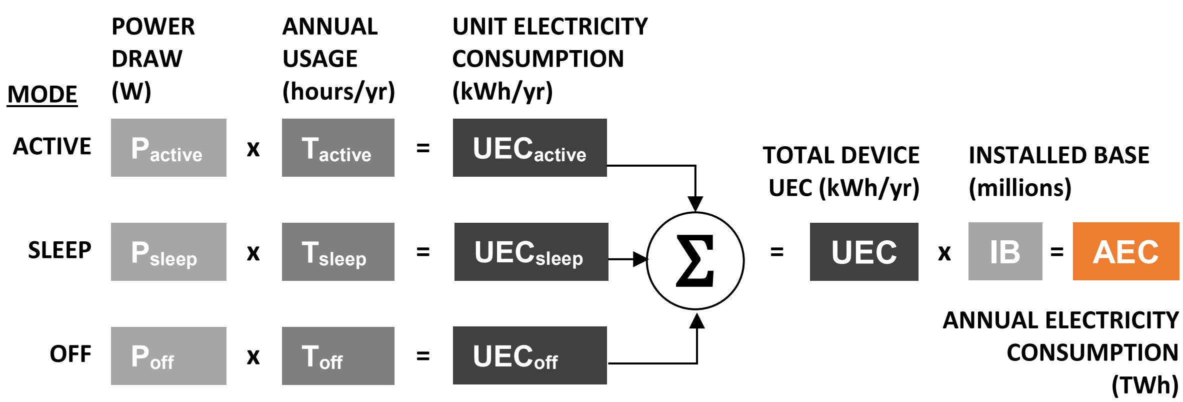

Figure 2-1. Example of device energy use calculation methodology.

2.2.1 Installed Base

The installed base represents the total number of devices in U.S. homes that were plugged in at least once during the past month. Devices that were owned but not plugged in were not counted. Most installed base estimates came from market research studies (most notably ownership and sales reports from CTA), the CE Usage Survey (see Appendix A), and, to a lesser extent, ownership and sales data from other sources. Typically, the installed base estimates have the least uncertainty of any AEC component.

2.2.2 Power Draw by Mode

All consumer electronics have at least two basic operating modes – *on* and *off* – and most have others such as *idle, standby*, *sleep*, *hibernate,* or *charging*. Within a specific power mode, device power draw can vary appreciably due to changes in operation such as variable processor utilization, display brightness, or audio signal. For each device category, we identified the most relevant power modes and developed estimates for the average power draw of its installed base in each mode, attempting to reflect real-world usage scenarios as well as possible.

Ideally, power draw estimates would be identified by taking measurements of actual devices deployed in a large sample (several hundreds) of demographically representative U.S. households. As the cost and effort required was well beyond the scope of this project, we instead relied on several other sources to estimate power draw by mode, including:

- Energy consumption characterization studies
- Field measurement campaigns
- Public product power draw databases (ENERGY STAR, California Energy Commission)
- Measurements by CTA member companies
- Targeted measurements by Fraunhofer

2.2.3 Annual Usage by Mode

For most device categories, identifying the average time spent in different power modes is the most challenging element to estimate accurately.

Ideally, usage estimates would be based on sustained field measurement campaigns that record the time devices spent in different modes. To provide accurate results, such studies would need a sample of at least several hundred demographically representative U.S. households, over the course of weeks or months. Instead, we used other sources to estimate annual usage by mode, including:

- The CE Usage Survey (see Appendix A)
- Data from prior field measurement campaigns[1]
- Data from prior energy consumption characterization studies

The CE Usage Survey responses served as inputs into more refined models used to assess computer, monitor, and video game console usage. We posed more questions for computers and video game consoles because they have substantial AEC values that depend strongly on usage behaviors and power management settings. We also fielded surveys on televisions and soundbars, the latter having not been studied in detail before.

2.3 Uncertainty Analysis

For the first time in this series of studies, we characterized the uncertainty of the AEC estimates for four categories that collectively account for the majority of consumption: Televisions; Desktop Computers; Video Game Consoles; and Set-Top-Boxes. For each of these categories, we identified the major component sources of uncertainty, and estimated their potential impact on the calculated AEC estimates.

While it is often desirable to identify precise confidence intervals for uncertainty, this is not always possible given the many “known unknowns.” Instead, we used a combination of statistical methods, scenario analysis, and professional judgment to assess the likely range of AEC values by varying the most influential modeling assumptions under plausible scenarios.

For the portions of the analysis that relied on survey data, we calculated standard errors to identify approximate 90% confidence intervals of key parameter estimates. Other sources of error may be even more important, including bias in self-reporting and other modeling assumptions. As a result, for each category, we performed a basic sensitivity analysis, calculating AEC in several different ways by varying key assumptions and using different combinations or sources for the input parameters. For inputs that have a range of possible values, we calculated realistic bounding scenarios.

This allowed us to identify key gaps in understanding, set future research priorities, and assess which specific trends are likely to be significant.

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[1] Although useful, prior field measurement campaigns usually fall short of the ideal described due to a limited and biased (i.e., non-random and unrepresentative) sample of households used and devices measured.

3 RESULTS AND CONCLUSIONS

3.1 Results

We estimate that 3.4 billion consumer electronic devices consumed about 143 TWh in 2017. This equals about 10% of residential sector and 4% of total electricity consumption in the U.S. (DOE/EIA 2017). Powering these devices costs about $18 billion annually. Per-household, this is about 1,205 kWh or $155 per year. The 2017 energy estimate is about 14% less than in 2013 (FhCSE 2014).

The thirteen device categories studied in depth account for one third of all devices installed and represent nearly 80% of the total energy consumption (Table 3-1 and Table 3-2). Televisions, set-top boxes, and computers remain the highest consuming categories, collectively representing just over half (56%) of the total. About one quarter of all devices are portable, yet these use less than 5% of the total energy.

Table 3-1. Energy used by consumer electronics in U.S. homes in 2017, devices studied in depth.

CATEGORY	DEVICE	UNITS (millions)	POWER (W)			USAGE (h/yr)			UEC (kWh/yr)	AEC	
			ON	IDLE	OFF	ON	IDLE	OFF		TWh	%
MULTIMEDIA	Television	284	77	-	1.0	1,410	-	7,350	123	35	24%
	Video Game Console	105	63	52	3.2	560	200	8,000	79	8.3	6%
	Soundbar	20	14	9.0	5.0	1,345	2,025	5,390	65	1.3	1%
SET-TOP BOX (subscriber)	DVR	53	22	19	-	-	-	-	188	10	7%
	Non-DVR	103	13	12	-	-	-	-	110	11	8%
	Thin Client	41	7	6	-	-	-	-	50	2.1	1%
	Cable DTA	31	6	6	-	-	-	-	46	1.4	1%
COMPUTER	Desktop Computer	72	65	2.7	1.2	3,635	2,110	3,015	246	18	12%
	Portable Computer	122	14	0.7	0.3	2,585	2,330	3,845	42	5.1	4%
	Monitor	101	31	0.8	0.5	2,455	3,255	3,050	80	8.1	6%
NETWORK	Integrated Access Dev.	85	13.4	-	1.5	7,825	-	935	107	9.1	6%
	Broadband Modem	8	6.8	-	0.1	7,825	-	935	54	0.4	0%
	Local Network Equip.	39	6.6	-	1.0	7,825	-	935	52	2.0	1%
OTHER	Other Devices	2,321	-	-	-	-	-	-	14	32	22%
	TOTAL/Wt.Avg.	**3,385**	**-**	**-**	**-**	**-**	**-**	**-**	**42**	**143**	**100%**

Note: Power modes identified in this summary table are approximate. See individual device sections for more detail.

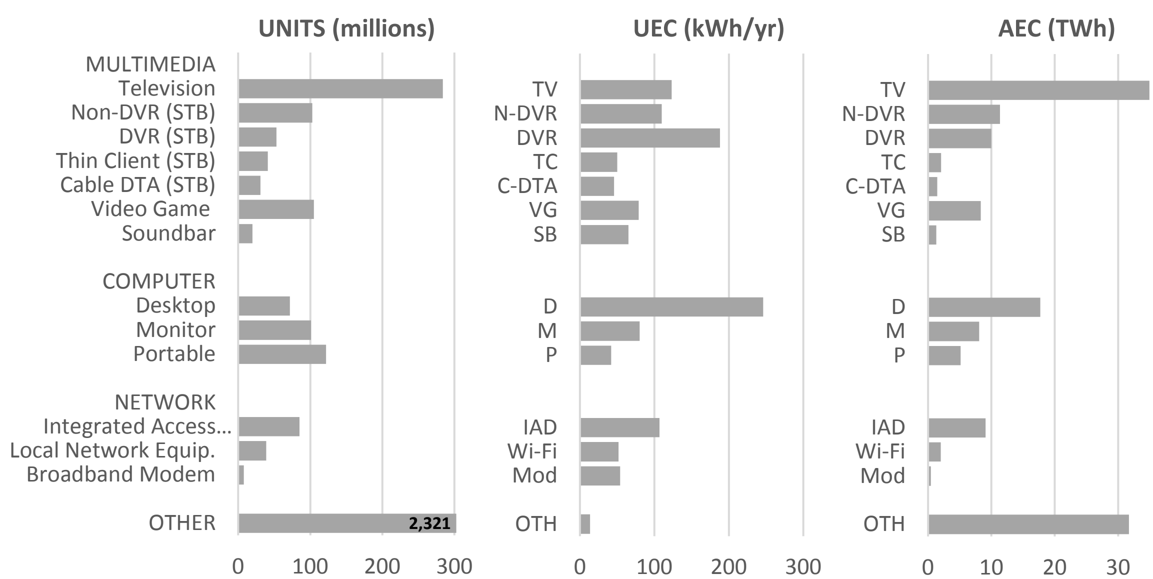

Figure 3-1. Installed base and unit and annual energy consumption of devices studied in depth.

Table 3-2. Energy used by consumer electronics in homes in 2017, all devices.

CATEGORY	DEVICE	UNITS (millions)	UEC (kWh/yr)	AEC (TWh)	AEC (%)
MULTIMEDIA		**1,356**	**67**	**91**	**64%**
VIDEO	Television	284	123	35	24%
	Digital Picture Frame	50	6.5	0.3	0%
	Video Projector	4	55	0.2	0%
SET-TOP	Subscriber DVR	53	188	10	7%
	Subscriber Non-DVR	103	110	11	8%
	Subscriber Thin Client	41	50	2.1	1%
	Subscriber Cable DTA	31	46	1.4	1%
	Standalone DVR	2	275	0.6	0%
	Over-the-air DTA	7	30	0.2	0%
	Digital Media Streaming	77	39	3.0	2%
	Video Cassette Recorder	39	34	1.3	1%
AUDIO	AV Receiver w/ Surround	43	65	2.8	2%
	Computer Speakers	80	44	3.5	2%
	Home Theater In-a-box	20	89	1.8	1%
	Radio + Clock Radio	113	9	1.0	1%
	Shelf Stereo + Compact	30	75	2.2	1%
	Speaker Dock	70	19	1.3	1%
	Sound Bar	20	65	1.3	1%
VG/DISC PLAYER	Video Game Console	105	79	8.3	6%
	Blu-ray Player	48	14	0.7	0%
	CD Player, standalone	42	18	0.7	0%
	DVD Player	94	24	2.2	1%
IT + COMMUNICATIONS		**1,110**	**45**	**50**	**35%**
COMPUTER	Desktop Computer	72	246	18	12%
	Portable Computer	122	42	5.1	4%
PERIPHERAL	Monitor	101	80	8.1	6%
	External Storage Drive	89	17	1.5	1%
	Web Camera	66	22	1.4	1%
	Printer + Multi-function	97	12	1.2	1%
NETWORK	Integrated Access Device	85	107	9.1	6%
	Broadband Modem	8	54	0.4	0%
	Local Network Equipment	39	52	2.0	1%
PHONE	Cordless Phone	104	12	1.3	1%
	Internet-based Phone	12	36	0.4	0%
	Telephone Answering Device	11	14	0.2	0%
	Mobile Non-Smart Phone	66	2.2	0.1	0%
	Mobile Smart Phone	238	4.5	1.1	1%
PORTABLE DEVICES		**920**	**3**	**3**	**2%**
AUDIO	Bluetooth Headset	71	5.9	0.4	0%
	Wireless Speaker	140	1	0.1	0%
VG/DISC PLAYER	Video Game	52	4.3	0.2	0%
	DVD or Blu-ray Player	80	2.7	0.2	0%
	Media Player, MP3 + CD	90	5.6	0.5	0%
INFO TECH	eReader	54	1.8	0.1	0%
	GPS, handheld	68	1.3	0.1	0%
	Smart watch + Wearable	64	0.6	0.04	0%
	Tablet Computer	140	6.1	0.9	1%
VIDEO	Camcorder	54	2.3	0.1	0%
	Digital Camera	107	0.3	0.0	0%
	TOTAL/Wt. Avg.	**3,385**	**42**	**143**	**100%**

Notes: Highlighted categories were studied in depth in the current study.
Categories with borders were studied in depth in FhCSE (2014).

The unit electricity consumption varies across categories by a factor of five (Figure 3-2). Desktop computers use the most energy per device, while televisions use the most energy overall. As in prior studies, active modes accounted for a large majority of the overall annual energy consumption (70%, Figure 3-4).

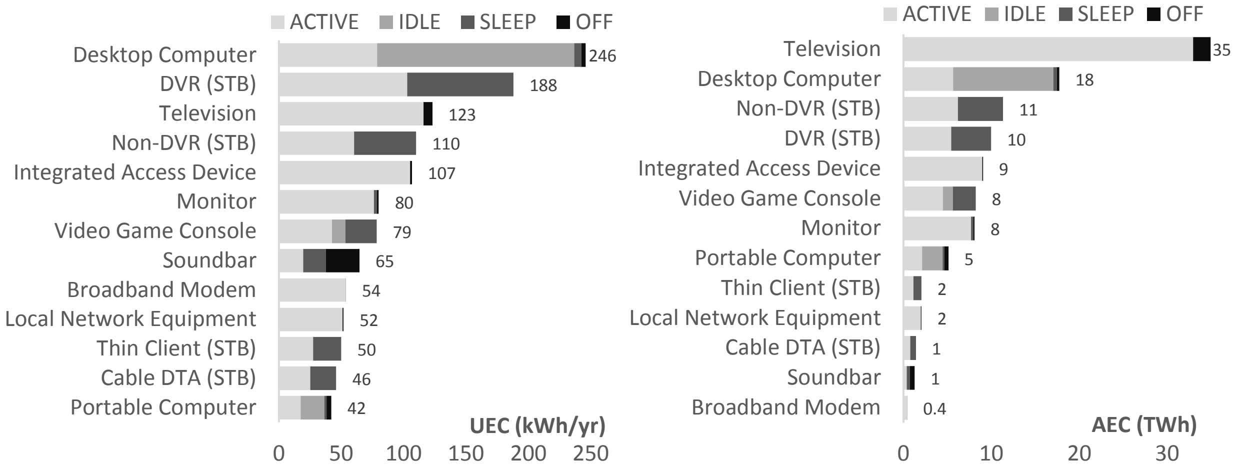

Figure 3-2. Unit and annual energy consumption by mode for devices studied in depth.

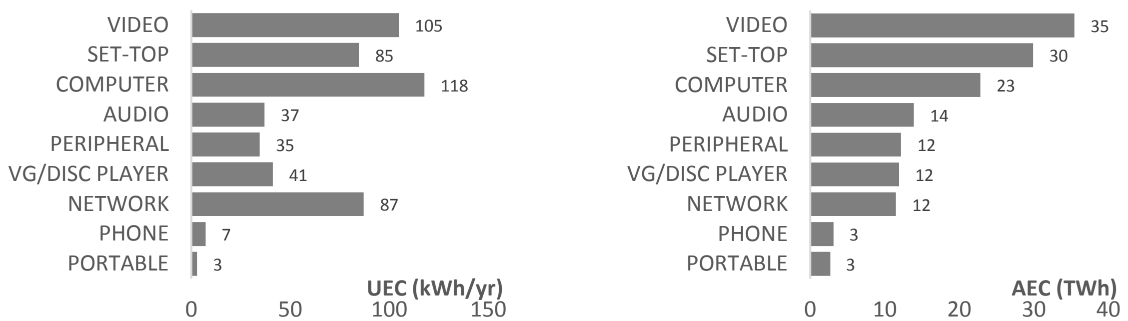

Figure 3-3. Unit and annual energy consumption (all devices, by category).

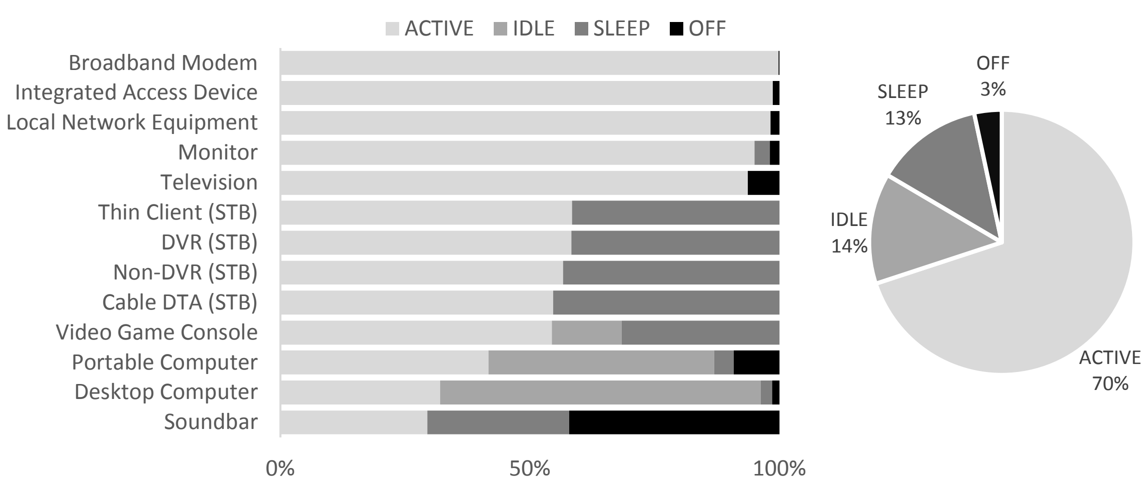

Figure 3-4. Annual energy consumption breakdown by mode for devices studied in depth.

3.2 Trends

The energy consumed by consumer electronics declined about 14% since 2013, continuing the trend that started in 2010. On average, while devices consumed about the same per unit as in 2013, unit energy consumption is nearly half (45%) that of 2006 values.

Meanwhile, the estimated number of devices installed[2] has declined slightly (11%) for the first time since 2006. To a large extent, changes in total AEC are driven primarily by shifts in televisions and computers. These top-level average values, however, mask significant changes within device categories that are addressed below.

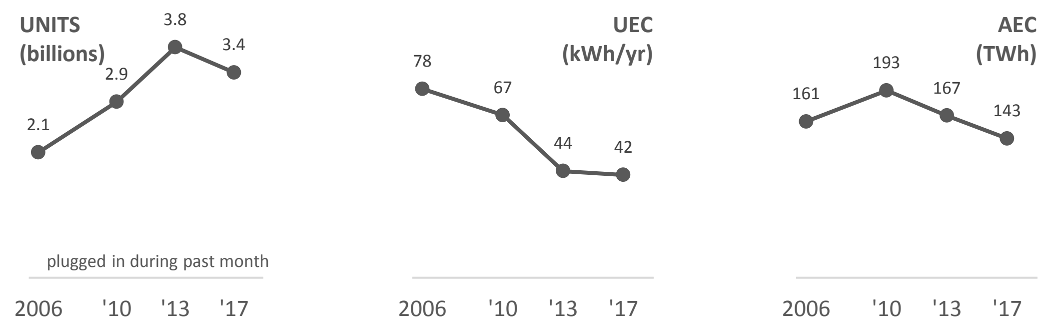

Figure 3-5. Trends in consumer electronics energy use.
Source: Current Study, FhCSE (2014, 2011), TIAX (2007)

3.2.1 Televisions

Televisions still account for the largest share of the total energy consumption. The number of installed televisions had been increasing until about 2010, before starting to decline. More importantly, this decline coincided with a shift from CRT to LCD displays that have far lower power densities. LCDs comprise about 84% of the installed base and CRTs only 7%. With most CRTs out of service, the sharply declining UEC trend may be reaching an end. Usage patterns have remained relatively unchanged. Although screens have gotten larger and resolution continues to improve, the power density and average power draw of LCDs has continued to decline.

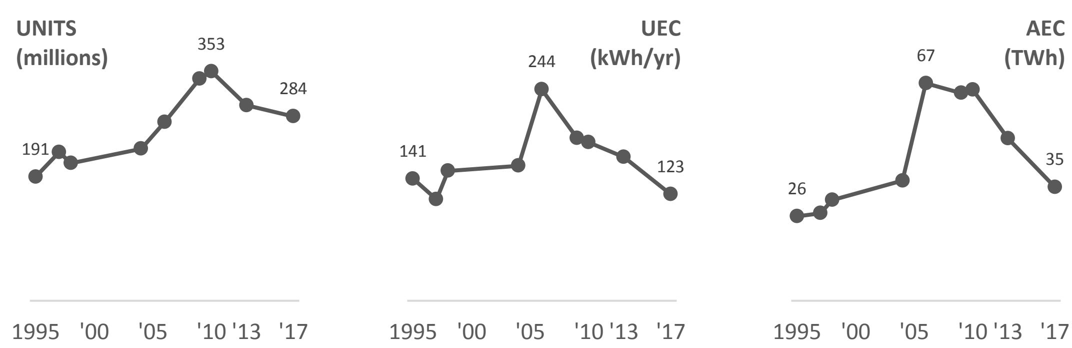

Figure 3-6. Trends in television energy use.

3.2.2 Set-Top Boxes

While the number of set-top boxes (STBs) has remained fairly flat in recent years, we estimate that their AEC has declined by about 22% since 2012 (Figure 3-7). This change is mainly due to a slight decline in

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[2] We focused on devices that are installed (plugged in during the past month), and not simply owned. While the number of devices owned may be increasing, many are not in regular use and do not consume energy.

fully-featured DVR and non-DVR boxes and a slight increase in thin-client boxes. A shift in technology architecture that enables homes to rely on a single DVR unit to serve multiple thin clients in the home. Unit energy consumption estimates in this category are based primarily on the industry's voluntary agreement, which includes third-party reporting of device energy consumption. Since the available reports extend only through 2015, we made projections until the end of 2016. We expect results for 2017 to be similar.

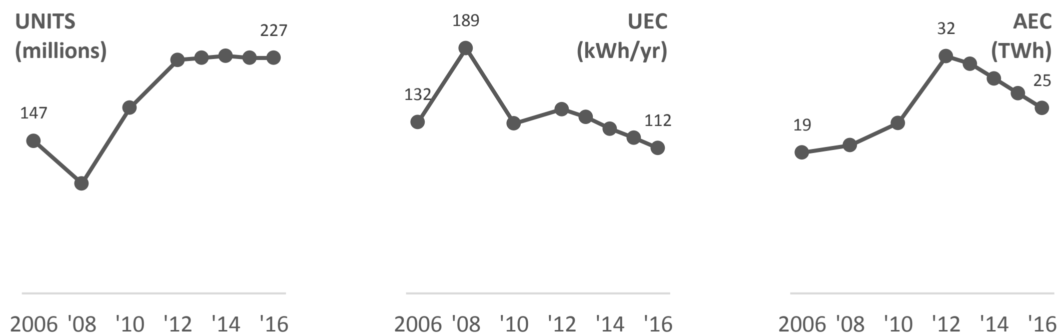

Figure 3-7. Trends in set-top box energy use.

3.2.3 Video Game Consoles

Energy used by video game consoles has continued a steady decline that started around 2008, driven by a recent drop in installed consoles and by shifts in the power draw characteristics. Power draw varies strongly by console type and among different versions of the same console, as hardware and processing capabilities can vary substantially. As consoles evolve rapidly, so do their energy usage patterns. Though consoles are now serving more purposes (e.g., acting as media devices for watching video), the overall usage time per console was similar to that estimated in prior studies. Standby modes account for about one third of video game energy consumption, driven mainly by network-connected standby modes.

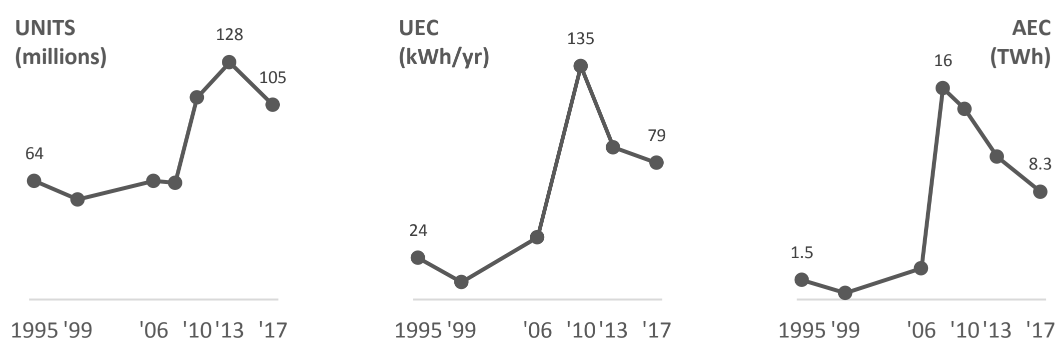

Figure 3-8. Trends in video game console energy use.

3.2.4 Computers

The AEC of portable computers has remained fairly unchanged since 2013, as increases to the installed base have been offset by reductions in unit energy consumption (Figure 3-9). Meanwhile, estimates for desktop AEC have increased, even as their numbers have declined, mainly due to revised usage by mode estimates and refinements to the modeling procedure. Portable computers now significantly outnumber desktops, which have continued to decline. Power draw by mode estimates remained largely unchanged for desktops, while the active-mode power draw for portables has fallen by nearly a factor of two.

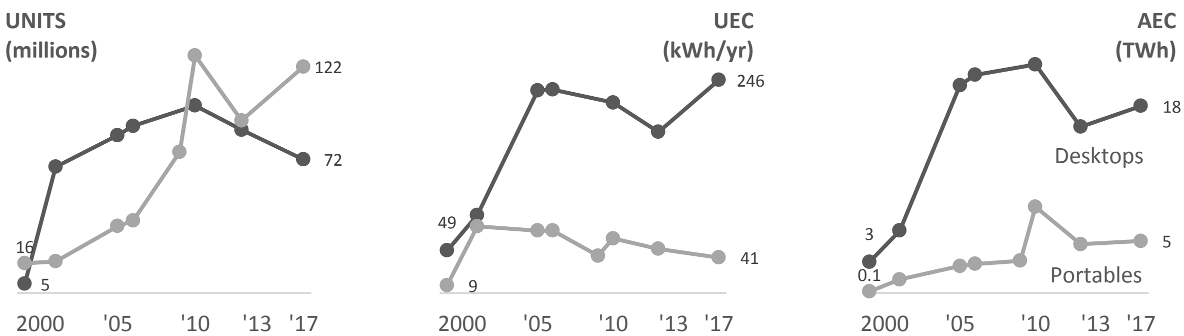

Figure 3-9. Trends in energy use estimates for computers.

3.2.5 Monitors

Even as the number of desktops declined, the number of monitors remained about the same as in 2013. This is mainly because the number of portables increased, while the portion of portables with external monitors remained constant. Overall, the power draw characteristics of the installed base have not changed significantly from 2013, with power draw decreasing slightly in all modes. Most monitors are now LCDs (over 80%). Energy use and UEC remained flat, even as the average screen size continues to increase.

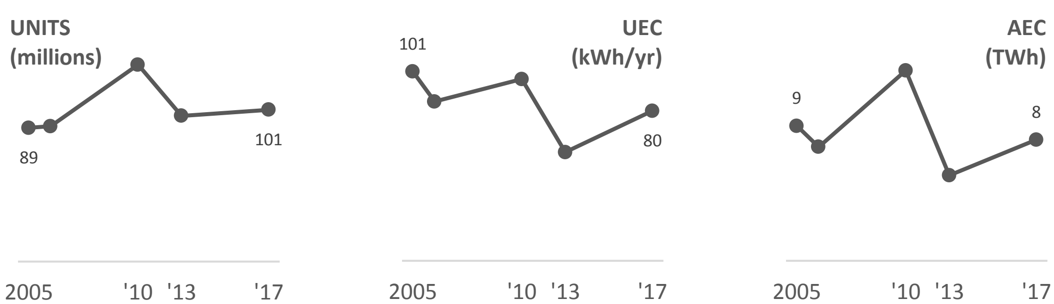

Figure 3-10. Trends in energy use estimates for monitors.

3.2.6 Network Devices

Estimates for network device energy use have changed since 2013, mainly due to the shift towards integrated access devices and away from broadband modems and local network equipment. Reports from the industry's voluntary agreement provided sales-weighted unit energy consumption data, whereas prior studies were based on unweighted power draw averages. Consequently, it possible that the prior UEC estimates were too low. Similarly, prior estimates likely overestimated the number of gateways.

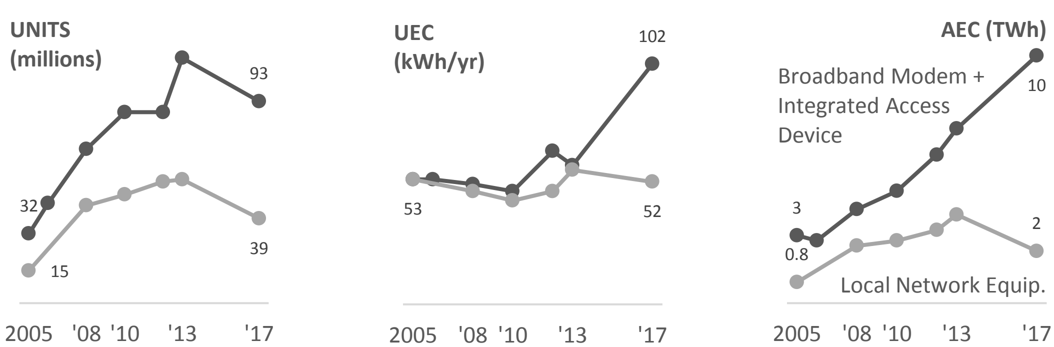

Figure 3-11. Trends in energy use estimates for network devices.

3.3 Uncertainty Analysis

Uncertainty in the AEC estimates for individual categories studied in depth was typically about ±15%. Conservatively assuming that all category estimates were actually within ±20% (±50% for those studied in less depth), we find a 90% confidence interval on the total AEC of about ±6%. This assumes all the estimates are unbiased and that errors are independent and uniformly distributed. We recognize this is a bold assumption that could be refined supported by additional data from future research. Thus, we estimate that in 2017, the consumer electronic devices studied consumed 143±9 TWh.

3.4 Future Research

Based on the uncertainty analyses for specific categories, we identified several key areas that could benefit from additional study or refinements in future work.

Connected standby modes are becoming more common among devices, notably for televisions, soundbars, and video game consoles, and their enable-rates are not well understood. These modes can contribute strongly to energy consumption as they draw power all the time, potentially negating some of the reductions in passive standby power over the years. Since it can be hard to tell if these modes are enabled or not, survey questions about connected standby modes carry greater uncertainty. Field studies or guided surveys could help to better characterize these modes.

Real-world power draw can differ appreciably from values obtained through standardized testing procedures. This is especially important for devices like computers, video game consoles, and televisions, whose power can fluctuate depending on how the device is being used and what content is being displayed. Several studies have developed multipliers to translate as-tested values to more-representative real-world values (Xergy 2016, FhCSE 2013), however, these were based on small samples of devices and limited real-world conditions. Further field research that studied more devices under a wider range of conditions could better quantify these factors and may yield insights for updating the relevant test procedures.

Devices that can be modified after purchase, such as computers, could add uncertainty to the estimates. Gaming computers, and in particular those built or modified by enthusiasts, represent a potential area of additional energy use. Both their usage patterns and components could lead to increased power draw across all modes relative to typical computers (Mills and Mills 2015, Mills et al. 2017). Additional field measurements and surveys could provide further insights.

User settings also play a strong role in some categories. Notably, television and monitor power draw could be strongly influenced by users' brightness settings. Power measurements for this study were typically based on default- or as-tested values, which may not reflect the typical user settings. Similarly, automatic power down (APD) features for devices like computers and video game consoles have a strong influence on the time spent in different modes. Since users may be unaware of these settings, identifying APD enable-rates with surveys carries significant uncertainty. Future studies could use alternative approaches to improve these estimates, for instance using software or guided surveys to explicitly identify specific power management settings.

In all categories that relied on survey data, the installed base and usage estimates carried moderate uncertainty (±5-10%) due to sampling error. This led to higher uncertainty for categories with lower ownership or less frequent usage (e.g., video game consoles). Increasing sample size could improve these estimates. Additional refinements to the surveys could also address potential bias introduced by seasonal or time-of-day effects that could influence usage. Targeted efforts to validate or calibrate sources of self-report bias could further improve estimates, especially those pertaining to usage and behavior.

As consumer behaviors and technology continue to change rapidly, the importance of well-executed sensor-based field monitoring campaigns cannot be understated. Using sensors in the home to nonintrusively monitor device-level power draw and occupant behavior in a statistically significant and demographically representative sample of homes remains a powerful tool for understanding how devices are used and how they consume energy. Studies may eventually be able to leverage the data collection and sensing capabilities of some consumer electronics themselves to provide aggregated insights about user behaviors and time spent in various power modes. Findings from these studies could be used to validate, complement, or improve upon the survey based tools employed in this effort, and to ensure that product test procedures accurately reflect real-world energy performance.

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4 COMPUTERS

Personal computers include both desktops and portables. **Desktops** include those housed in a box or tower with an external monitor (henceforth called Towers), and those with built-in monitors called integrated desktops or All-in-Ones (AIO). **Portables** include laptops, notebooks, and netbooks, but exclude mini and yoga notebooks (displays smaller than 10 inches) and mobile devices such as smart phones and tablets. Those smaller devices typically draw less power and are counted separately in Section 11.

4.1 Installed Base

Installed desktops have declined to 72 million units, down 18% from 2013 (FhCSE 2014). Although the portion of homes with at least one desktop in service remains essentially unchanged from 2013, the number per owner-household has decreased (Table 4-1). Installed portables, meanwhile, have increased to about 122 million units, up 31% from 2013 (FhCSE 2014). This quantity is equal to almost all portable units sold through consumer sales channels from 2012-2016 (CTA 2016). The increase in portables was driven mainly by increased household penetration estimates (60% vs 45% since 2013, FhCSE 2014). Ownership estimates were higher than the installed estimates by about 18% for desktops and 40% for portables, meaning a considerable portion of devices are not in regular use (Table 4-1, CTA 2017).

Table 4-1. Installed base estimates for computers.

COMPUTER	YEAR	BASE	HOUSEHOLD PENETRATION	OWNER-HH (millions)	UNITS per OWNER-HH	UNITS (millions)	SOURCE
DESKTOP	2017	Plugged In	45%	53	1.3	72	Current
	2017	Owned	51%	61	1.4	85	CTA O&M (2017)
	2015	In Use	42%	49	1.2	58	DOE/EIA (2017)
	2013	Plugged In	44%	53	1.7	88	FhCSE (2014)
PORTABLE	2017	Plugged In	60%	72	1.7	122	Current
	2017	Owned	69%	82	2.1	172	CTA O&M (2017)
	2015	In Use	64%	75	1.5	116	DOE/EIA (2017)
	2013	Plugged In	45%	53	1.7	93	FhCSE (2014)

To model usage by computer type, computers in the CE Usage Survey were designated by their usage priority, with respondents answering questions about their most used (primary) and second most used (secondary) desktop and portable computers (Table 4-2). We classified desktops without an external monitor as All-in-One units, and assumed that the AIO portion of tertiary (and higher) desktops equaled the portion of primary and secondary desktops that were AIOs (34%). We validated the AIO installed base estimate against unit sales data from the previous seven years.[3] Assuming most AIOs were sold to consumers and that the U.S. accounts for 90% of North America sales, we summed unit sales data (IHA Markit 2017, DisplaySearch 2011-2013) to obtain an All-in-One installed base of 22 million, about the same as the CE Usage Survey estimate.

Table 4-2. Installed base (millions) for computers.

COMPUTER	FIRST	SECOND	THIRD+	TOTAL	SE
Tower	39	7	5	50	-
All-in-One	15	4	2	22	-
DESKTOP	**54**	**11**	**7**	**72**	7
PORTABLE	**71**	**29**	**22**	**122**	10
TOTAL	**125**	**40**	**29**	**194**	13

Source: CE Usage Survey. SE = standard error of the total.

[3] The average lifetime of a desktop computer is likely about seven years, based on consumer channel desktop sales including AIOs that totaled 66 million units from 2010-2016 (CEA 2103b, CTA 2017) and the current installed base estimate of 72 million desktop PCs.

4.2 Unit Energy Consumption

4.2.1 Power Draw

We analyzed power modes similar to those defined in the ENERGY STAR requirements for computers (v6.0, EPA 2013):

HIGH-ACTIVE	In use (or idle for a short while and awaiting user input); not in a low power mode.
SHORT IDLE	Idle for at least 5 min. and in a low-power mode with the screen still on.
LONG IDLE	Idle for at least 15 min. and in a low-power mode with the screen off.
SLEEP	Sleep mode (entered manually, or automatically after about 30 min.) from which the computer can quickly wake.
OFF/HIBERNATE	Powered down but still plugged in. Hibernate is able to resume the prior session.

Using ENERGY STAR datasets, we developed separate power draw estimates for computers that met or did not meet the standards (Table 4-3). In all cases, we excluded computers identified as mini and business workstations from the analysis. Market penetration of ENERGY STAR computers, ranged from 25-44% for desktops and 74-98% for portables (Table 4-4). Power draw data for about 2,000 ENERGY STAR qualified models from 2013-2017 shows that long- and short-idle mode power did not vary much by year among qualified models (Figure 4-1). Non-qualified models drew about twice as much power in these modes. All-in-One and portable computers had more pronounced differences between short- and long-idle modes, presumably due to their integrated displays.

Table 4-3. Average power draw by mode (W) by ENERGY STAR status and year for computers.

COMPUTER	ENERGY STAR QUALIFIED?	YEAR	ENERGY STAR MEASUREMENTS OFF	SLEEP	LONG IDLE	SHORT IDLE	ADJ. VALUES (REAL-WORLD) LONG IDLE	SHORT IDLE	HIGH-ACTIVE
DESKTOP Tower	YES	2016	0.6	1.5	27	29	28	30	44
	YES	2015	0.6	1.7	25	26	26	28	40
	YES	2014	0.7	1.5	26	27	26	29	42
	YES	2013	0.5	1.5	29	31	30	33	47
	NO	2013-2016	1.2	2.5	68	71	70	75	108
DESKTOP All-in-One	YES	2016	0.7	1.9	17	33	23	39	44
	YES	2015	0.6	1.9	18	34	24	40	45
	YES	2014	0.7	1.8	18	33	25	39	44
	YES	2013	0.7	2.0	19	34	26	40	45
	NO	2013-2016	0.9	2.1	38	68	51	79	90
PORTABLE	YES	2016	0.3	0.7	5.4	8.6	8.1	9.5	18
	YES	2015	0.3	0.8	5.3	8.3	7.9	9.2	17
	YES	2014	0.3	0.7	5.6	8.8	8.4	9.8	19
	YES	2013	0.2	0.6	6.2	9.6	9.3	11	20
	NO	2013-2016	0.5	1.1	13	19	19	21	40

Table 4-4. ENERGY STAR market share for desktop computers.

YEAR	DESKTOP	PORTABLE
2016p	44%	98%
2015	39%	95%
2014	34%	93%
2013	25%	74%

Source: EPA (2012-2015)

Note: Projection for 2016p assumes absolute pct. growth in ENERGY STAR market share from 2015-2016 was the same as 2014-2015.

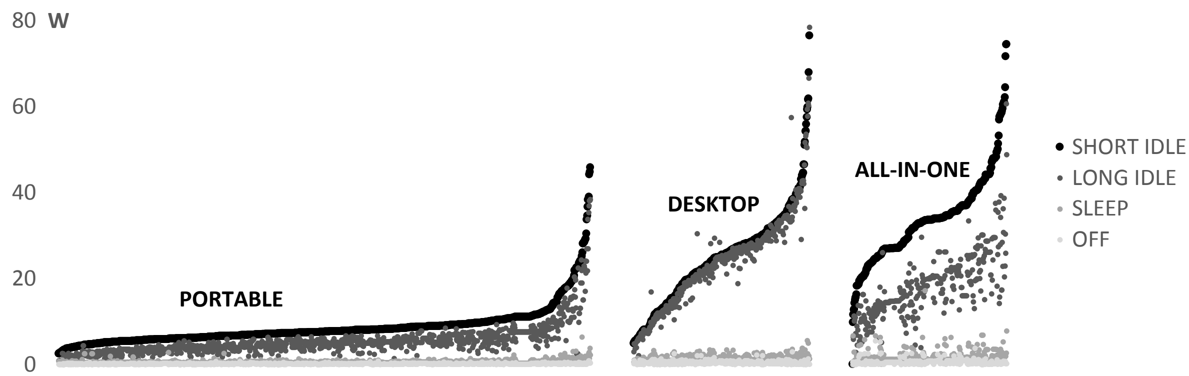


Figure 4-1. Power draw of ENERGY STAR qualified desktop and portable computers available from 2013-2017.
Source: EPA (2017)

Real-world computer power draw can differ from as-tested values. Increased processing, driven by frequently-run programs, such as web browsers, email applications, word processing, and media players, could increase power draw levels relative to the ENERGY STAR test conditions (Xergy 2016). To account for these differences we developed adjustment factors for the idle and active modes (Table 4-5). Given the small number of units tested and the range of potential conditions, the real-world adjustment factors and, hence, power draw values in the active and long-idle modes have large uncertainties.

Table 4-5. Real-world power draw adjustment factors (F) for computers.

REAL-WORLD POWER (W) by MODE		DESKTOP		PORTABLE
		TOWER	AIO	
High Active	= F · Short Idle ENERGY STAR	1.5	1.3	2.1
Short Idle	= F · Short Idle ENERGY STAR	1.07	1.2	1.1
Long Idle	= F · Long Idle ENERGY STAR	1.03	1.3	1.5

Source: Based on Xergy (2016) and FhCSE (2013)
Note: Very small samples (n<5), factors should be considered preliminary.

Measurements on three tower desktops, two All-in-Ones, and three notebooks (Xergy 2016) showed that more processing-intensive activities including streaming video (see also FhCSE 2013), on-line gaming, virus scans, video chat, and, to a lesser extent, streaming audio, could increase active-mode power draw beyond as-tested short-idle power draw values. Desktop factors ranged from 1.2-1.6 for active mode, and 1.0-1.3 for short and long-idle modes. Another study of four desktops that measured web browser influence on power draw found similar average factors (FhCSE 2013). In that study, the average power draw for the most computationally intensive baseline was 1.5 times higher than the short-idle baseline, and the real-world to short-idle ratio was 1.04 with a single browser open to a single web page at a time.[4]

Similarly, test results for three notebooks (Xergy 2016) found real-world adjustment factors that varied by more than a factor of two for active (1.5 to 3.5) and long idle (1.0 to 2.2). Earlier testing of six notebooks (FhCSE 2013) yielded a similar 1.1 ratio for real-world-short-idle to short idle, and a 1.9 factor for active-to-short-idle testing under a more limited range of conditions than Xergy (2016) that were generally similar to high-active mode.[5] Consequently, we used the average values from these two studies, 2.1 and 1.1, for real-world high-active and real-world-short-idle ratios to the ENERGY STAR short-idle values.

[4] Power draw was measured after loading the default home page for ten popular websites individually on three different browsers.

[5] FhCSE (2013) measured the power draw of six notebook PCs while separately running the Fishbowl benchmark and a computer animated film in Flash and then HTML5, in three different browsers. The 1.9 real-world factors equal the average ratio of testing under all those conditions relative to the short idle baseline testing without a browser or other windows open, and anti-virus disabled.

To calculate power draw for ENERGY STAR qualified computers, we took the straight average (by mode, computer type, and year of release) of all models listed in the ENERGY STAR database as of February 2017 (EPA 2017) and multiplied them by the real-world adjustment factors summarized above. To calculate power draw for non-ENERGY STAR qualified computers, we used the dataset that was used to develop the ENERGY STAR v6.0 specification (EPA 2012). Specifically, we identified all models in the dataset that did *not* meet the v6.0 specification for any mode, and we assumed that those computers were representative of non-ENERGY STAR tower desktops sold from 2013-2016.

Next, we weighted the power draw for all computers by type and year sold according the ENERGY STAR qualified market share. Assuming all tower desktops sold from 2013-2016 remained in service, a majority (26 of 47 million units) would have entered service before 2013 (CTA 2017, CEA 2013). We used the tower desktop power draw values from the 2013 study to represent pre-2013 computers (FhCSE 2014), again applying the adjustment factors. Finally, we calculated the sales-weighted average power draw by mode across the entire installed base (Table 4-6).

Table 4-6. Power draw by mode (W) for the installed base of desktop and portable computers.

					REAL-WORLD ADJUSTED		
COMPUTER	**YEAR**	**UNITS (millions)**	**OFF**	**SLEEP**	**IDLE-LONG**	**IDLE-SHORT**	**HIGH-ACTIVE**
DESKTOP	2016	3.9	0.9	2.1	52	56	80
Tower	2015	4.8	1.0	2.2	53	57	82
	2014	5.9	1.0	2.2	55	60	86
	2013	6.5	1.0	2.3	60	65	93
	Pre-2013	26.0	1.6	3.5	58	61	87
		Wtd. Avg.	**1.3**	**2.9**	**57**	**60**	**87**
DESKTOP	2016	2.9	0.8	2.0	38	62	70
All-in-One	2015	3.3	0.8	2.0	40	64	72
	2014	3.8	0.8	2.0	42	66	74
	2013	3.3	0.9	2.1	45	69	78
	Pre-2013	10.7	1.4	2.7	57	88	99
		Wtd. Avg.	**1.0**	**2.2**	**46**	**72**	**81**
PORTABLE	2016	25	0.3	0.7	8.3	9.8	19
	2015	27	0.3	0.8	8.5	9.8	19
	2014	26	0.3	0.7	9.1	11	20
	2013	25	0.3	0.6	12	13	25
	Pre-2013	20	0.5	1.0	14	16	30
		Wtd. Avg.	**0.3**	**0.7**	**10**	**12**	**22**

We followed the same procedure for All-in-Ones (assuming that the portion of ENERGY STAR-qualified units was similar for AIO and towers) and for portable computers (excluding all mini and yoga notebooks). We calculated the average computer power draw by mode for the installed base, using unit sales data (CTA 2017, CEA 2013) to weight different vintages, allocating units to the installed base by vintage starting with recently sold models and working backwards until the totals were reached.[6]

The average power draw values have not changed appreciably for desktops and have decreased slightly for portables relative to 2013. Although the new high-active mode draws more power than the more general active mode defined in the prior study, that represented a mix of time spent in both high-active and real-world short idle modes, so the overall effect on energy consumption estimates is minor.

[6] The installed base, therefore, includes all portable computers sold in 2016, 2015, 2014, and 2013, a portion (19.3 million of 25.1) of units sold in 2012, and none older than 2012. These simplifying assumptions have a minor impact on the average power draw by mode.

4.2.2 Usage

Computers can switch modes based on activity, time between usage sessions, manual power management behavior, and automatic power management settings. We find that both desktops and portables spend a lot of the time in sleep and off modes (>60%). Current usage by mode estimates have changed somewhat since 2013 (Table 4-7), mainly driven by refinements to the modeling methods. The supporting analysis applies power management settings and behaviors, elicited in the CE Usage Survey, to estimate actual usage by mode. Due to limitations of recall, these responses and estimates carry moderate uncertainty. The sensitivities to these estimates are explored in the AEC Uncertainty section.

Table 4-7. Usage by mode (h/day) for computers.

COMPUTER	YEAR	HIGH ACTIVE	SHORT IDLE	LONG IDLE	ACTIVE + IDLE	SLEEP	OFF	SOURCE
DESKTOP	2017	2.4	3.7	3.8	10.0	5.8	8.3	Current
	2016	2.3	6.1	3.6	12.0	1.2	10.8	Xergy (2016)
	2013	3.4	1.3	3.0	7.7	5.7	10.6	FhCSE (2014)
PORTABLE	2017	2.0	2.7	2.4	7.1	6.4	10.5	Current
	2016	2.3	4.9	2.4	9.6	8.4	6.0	Xergy (2016)
	2013	2.9	0.5	1.4	4.8	6.0	11.1	FhCSE (2014)

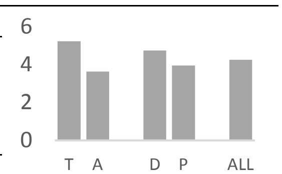
Note: Interpretations of ACTIVE + SHORT-IDLE modes differ among these studies.

4.2.2.1 Active Usage

Active usage includes time people spend actually using each computer. Average daily active usage was about 4.7 hours for desktops and 4 hours for portables (Table 4-8). Towers were used about 30% more than All-in-Ones. Primary and secondary portables differed somewhat in active usage, whereas desktops apparently did not. Computers may spend more time overall in *active modes* when they are left on without being used. Our methods for mapping activity to time by mode are described in the sections that follow.

Table 4-8. Daily time spent actively using computers (h/day) by priority.

COMPUTER	FIRST	SECOND+	ALL
Tower	5.1	5.7	5.2
All-in-One	3.7	3.4	3.6
DESKTOP	**4.7**	**4.8**	**4.7**
PORTABLE	**4.3**	**3.4**	**4.0**
Wt. AVG	**4.5**	**3.8**	**4.2**



Source: Based on CE Usage Survey

The CE Usage Survey asked how long each computer was actively used by anyone "yesterday" during three periods: before noon (AM), from noon to 5PM (PM), and after 5PM (EVENING); as well as for the entire day (ALLDAY). Summing these periods provides a consistency check on reported ALLDAY responses. For the 60% of computers that had responses for all four questions, the sum of the periods exceeds the ALLDAY point response by about 30 minutes. This is not surprising, as respondents tended to round to the nearest half hour, which limits survey precision.

Accordingly, when responses were given for all three periods, we used their sum (maximum of 24 hours) to estimate total daily usage and ignored the ALLDAY response even if provided. When responses for one or more periods were omitted, we used the greater of the sum of the available reported periods and the ALLDAY total. For remaining cases, we used the reported ALLDAY total. Finally, we omitted responses that were missing the ALLDAY total and at least one other time period (17% of computers), since these could deflate the average and are expected to be less reliable. This approach provides a somewhat conservative (high) estimate of active use.

4.2.2.2 Power Management

When computers are not actively being used, power management can reduce their energy consumption. Manual power management (MPM) refers to user routines, like placing the computer to sleep or shutting it down at night. Automatic power management (APM) settings can, when enabled, induce low power modes after a designated period of inactivity. Most computers are influenced by both kinds of PM.

Manual Power Management

To discern manual power management routines, we asked people what happens when someone finishes using a computer for a session during the day and at night (Figure 4-2).[7] Just over one third reported shutting down (always or often) during the daytime, and just over half reported shutting down at night.[8] About one third used standby or sleep modes during the daytime. Desktop computers were left on slightly more than portables, and towers were left on more than AIOs.

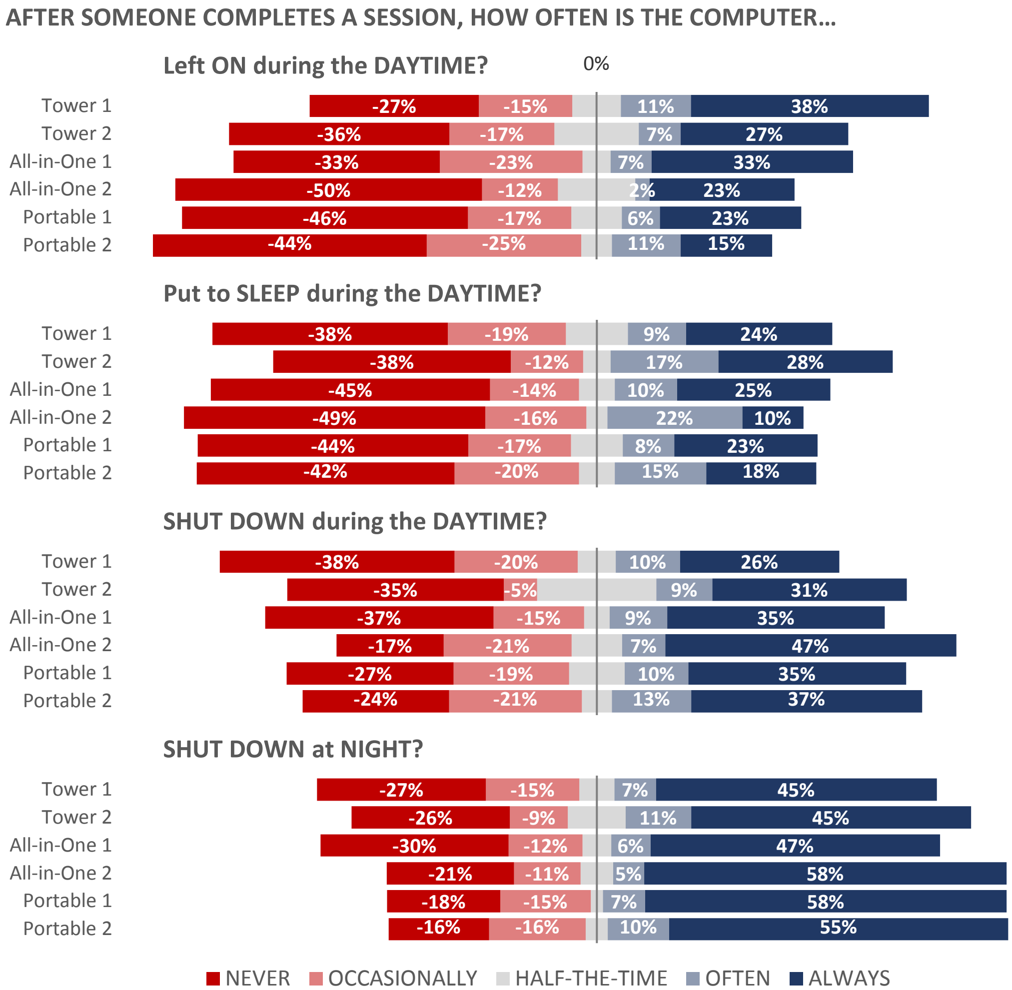


Figure 4-2. Manual power management behaviors of computers.
Source: CE Usage Survey

[7] These questions were asked independently, so values did not always sum to 100% for a given respondent. For instance, even if a computer was left on, and not manually put into sleep mode, it could later enter sleep automatically.

[8] Over half answered daytime and nighttime shutdown questions identically. Most common responses: always/always 26% and never/never 25%.

To convert these qualitative responses into quantitative behaviors, we used the method described in FhCSE (2014). Briefly, we translated the responses from Figure 4-2 into power management probabilities:

NEVER	OCCASIONALLY	HALF-THE-TIME	OFTEN	ALWAYS
0%	25%	50%	75%	100%

Next, for each computer, we normalized the responses for LEFT ON, PUT TO SLEEP, and SHUT DOWN for both daytime and nighttime, such that their sum is 100%. For instance, if someone responded the same way to all three questions about daytime usage, this would result in a 33% chance of each behavior. Likewise, if someone indicated "never" left on, "half-the-time" sleep, and "often" shut down, this would result in 0% left on, 40% = 0.5/(0.5+0.75) sleep, and 60% = 0.75/(0.5+0.75) shut down. Since we only asked if people SHUT DOWN at night, we assumed the nighttime behaviors (LEFT ON and PUT TO SLEEP) were the same as during the daytime. As the resulting probabilities did not vary much between primary and secondary computers, we used these weighted averages for all desktops and for all portables for the subsequent analysis.

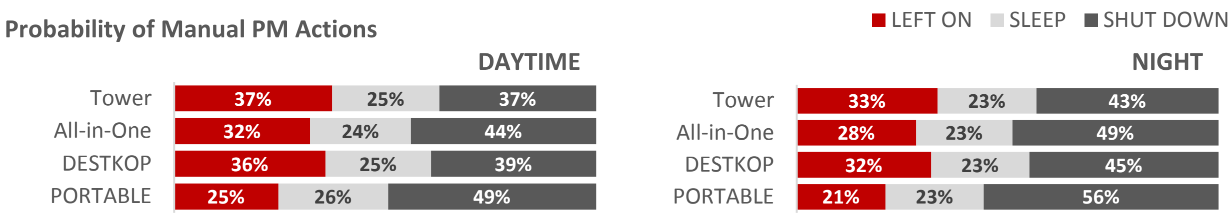


Figure 4-3. Likelihood of manual power management behaviors after a usage session.

Some respondents may have interpreted these questions differently, which could affect the precision of MPM behavior estimates. Of those who ALWAYS put their computer into standby, about 20% said also the computer was ALWAYS left on, while another 60% also said it was NEVER left on after use. This apparent discrepancy could be explained in different ways. First, some may count sleep mode as a specific kind of on-mode, while others may view these modes as mutually exclusive. Alternatively, some said their computer was always put into standby may have said so even if it was done so automatically. Making different assumptions about how to treat these apparent inconsistencies could shift the prevalence of left-on and sleep behaviors, shown in Figure 4-3, by about ±4% absolute. The potential impact of this shift is discussed in the uncertainty section.

Automatic Power Management

To find the prevalence of APM settings, we asked people about what transpired on a recent day when they were the first person in the home to use each computer (Table 4-9). Based on first-use observations, about 67% of desktops and 81% of portables used some kind of computer power management overnight (MPM or APM including standby or off/hibernate, Figure 4-4). When calculating usage, we assumed that computers with auto-hibernate enabled also had auto-sleep enabled, and those with auto-sleep enabled also had auto-screen off enabled.

Table 4-9. Survey questions used to infer overnight power state.

	RESPONSE	STATE
1	The computer and monitor were already ON showing the previous screen image.	Short-Idle
2	The computer was already ON, but the monitor was OFF. You pressed a key or moved the mouse, and INSTANTLY the computer was READY.	Long-Idle
3	You opened the computer lid (for laptops) pressed a key, moved the mouse or pressed a POWER BUTTON, and after a FEW SECONDS the computer was ready to use.	Sleep
4	You pressed the POWER BUTTON on the computer, and WAITED more than 15 seconds until it was ready to use.	Off or Hibernate

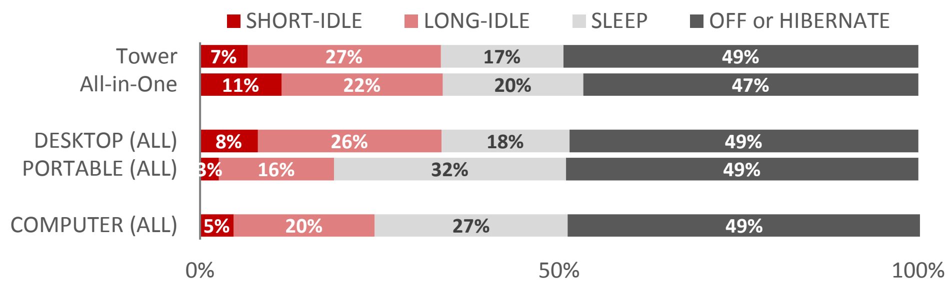


Figure 4-4. Power state of all computers just prior to the first session of the day.

In homes where people do not practice manual PM, the computer's initial state determines its APM settings. Since more than half of computers in the survey were always or frequently turned off manually at night, the first-use condition does not directly reveal their APM status.[9] Therefore, to infer typical APM enable rates, we looked at the subset of computers that were reportedly ALWAYS left on after use and NEVER shut down overnight.[10] Doing so yields APM enable rates (sleep or off/hibernate) of about 23% for desktops and 36% for portables (Figure 4-5). We expect these are likely conservative (low) estimates.

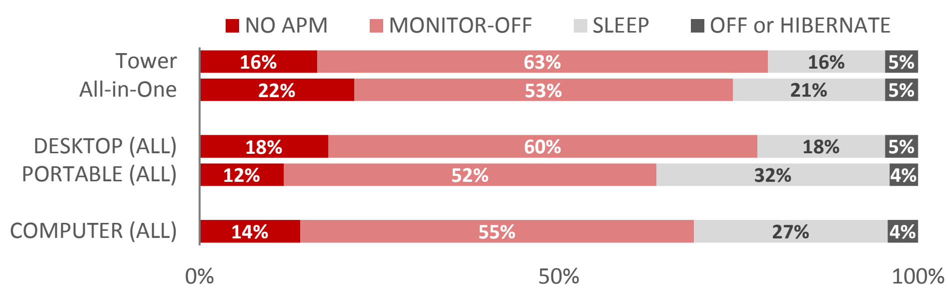


Figure 4-5. Automatic power management setting prevalence of computers.
Based on first-use of computers that were always left on after use and never shut down overnight.

4.2.2.3 Number of Sessions

When usage is spread over many sessions throughout the day, APM may not have enough time to engage or transition into the lowest power modes in between sessions. This tends to increase time spent in intermediate power modes. We asked about typical session duration during the pre- and post- evening periods to estimate the number of usage sessions. On average, usage sessions last for about 1.5-2 hours and are spread over at least 4 sessions throughout the day (Table 4-10).

[9] Manual power management responses were consistent with first-use observations. About 95% of those who reported that they always shut down their computer also reported that their computer took more than 15 seconds (80%) or a few seconds (14%) to start up.
[10] This method may have a limitation. People who always leave their computers on may enable APM less often, meaning the average APM rates could actually be higher. However, APM has the greatest influence on computers that are left on, thus tempering any potential influence on AEC.

Since we asked only about typical session duration, however, it is plausible that there could be more brief sessions interspersed throughout the day. This matters because even a very brief session could interrupt APM and restart the clock. To account for these potentially brief sessions, we rounded up and assigned active usage across three equal duration sessions per time period (daytime and evening). This approach is discussed further in the modeling section that follows, and sensitivity of AEC to number of sessions is explored in the uncertainty analysis.

Table 4-10. Average number and duration of typical usage sessions by time of day.

COMPUTER	AVG. No. SESSIONS			AVG. DUR (h/day)		
	DAY	EVE	TOTAL	DAY	EVE	AVG
DESKTOP	2.8	1.5	4.3	1.5	2.3	1.7
PORTABLE	2.7	1.4	4.0	1.5	2.1	1.7
ALL	**2.7**	**1.4**	**4.1**	**1.5**	**2.1**	**1.7**

Source: CE Usage Survey
Note: Based on subset with nonzero usage.

4.2.2.4 Modeling Usage by Mode

Using a modeling approach to estimate average usage by mode for the computers in the CE Usage Survey, we find that computers spend about one third of the time in active and idle modes (42% for desktops and 29% for portables; Table 4-11).

Table 4-11. Time spent by mode for computers.

COMPUTER	HIGH ACTIVE	SHORT IDLE	LONG IDLE	ACTIVE + IDLE	SLEEP	OFF
Tower	2.7	3.9	4.0	10.6	5.7	7.7
All-in-One	1.9	3.3	3.2	8.4	6.0	9.5
DESKTOP	**2.4**	**3.7**	**3.8**	**10.0**	**5.8**	**8.3**
PORTABLE	**2.0**	**2.7**	**2.4**	**7.1**	**6.4**	**10.5**
ALL	**2.2**	**3.1**	**2.9**	**8.1**	**6.2**	**9.7**

Note: Assumes usage split across three sessions per period (daytime and evening).[11]

To model usage by mode, we split the day into three discrete time periods, or "windows": daytime (7AM-5PM), evening (5PM-10PM), and night (10PM-7AM). For each computer, we assigned its total daily active usage to the daytime and evening periods based on survey responses. If the reported active usage times exceeded the period's prescribed duration, we expand it to accommodate and reduced the duration of the nighttime by an equivalent amount. Night time active usage was always assumed to be zero, corresponding to times when people are usually asleep.

Time spent in inactive modes depends on manual and automatic power management actions. When user activity stops and the computer is left on and left alone, we assume that desktops with fully-enabled APM would progressively spend 5 minutes in **active mode,** 10 minutes in **short-idle**, 15 minute in **long-idle**, 30 minutes in **sleep,** and the remaining time if any in **hibernate** mode until the next usage session. Similarly, we assume that portable computers followed the same process except that the short-idle duration is reduced by five minutes (FhCSE 2014). If APM was disabled and the computer was left on and left alone, we assumed that it would enter short- and then long-idle mode until the next usage session.

Next, we calculated usage by mode under various combinations of MPM and APM settings during all three time periods. Specifically, there are three MPM scenarios (left on, standby, and hibernate/shut down) and

[11] Alternative assumptions for 1 and 10 sessions per period were also considered. With one session per period, the ACTIVE+IDLE time decreases slightly by 0.1 h (1%). With ten sessions per period, and hence more interruptions, ACTIVE+IDLE time increases by 0.4 h (5%).

APM settings apply only when computers are left on. We randomly assigned[12] APM settings to all computers based on the enable rate probabilities identified earlier for towers, AIOs, and portables (from Figure 4-5) and then calculated usage by mode. Next, we combined the resulting usage breakdowns of the three MPM scenarios using a weighted average based on their prevalence (from Figure 4-3).

To allocate time into different modes during each period, we subtracted the active from the total time to find the time available for lower power modes. Next, we assigned times progressively starting with short-idle, long-idle, sleep, and off time following the automatic delays, until all the remaining time in the period was allocated.[13] Since the intensity of computer usage affects power draw, we allocated some active usage time to the high-active mode and the remainder to the short-idle mode. A recent study concluded that desktop and portable computers spent on average 2.3 hours per day on intensive activities corresponding to the high-active mode (Xergy 2016), or about half of their total active time. Therefore, we assume that total daily activity is split equally between high-active and short-idle mode for all computers.

When usage is split across multiple sessions per time period, computers that rely on APM will spend more time transitioning into lower power modes, and may not have time to reach the lowest power mode. We assumed that the total usage during each period was split into three equal duration sessions that were evenly spaced out in each time window. Alternative assumptions (1 and 10 sessions per period) were also considered. With one session per period, the ACTIVE+IDLE time decreases slightly by 0.1 h (1%). With ten sessions per period, and hence more interruptions, ACTIVE+IDLE time increases by 0.4 h (5%).

4.2.3 Unit Energy Consumption

Desktops used about 246 kWh/year and portables 42 kWh/year (Table 4-12). Active and idle modes continue to account for over 90% of unit energy consumption. The power analysis assumed that all portables were plugged in while operating. In reality, due to power supply, charging, and conversion losses, portables can consume additional energy when operated with their battery. To account for these losses, we included an additional 2.6 kWh/year (FhCSE 2014) in the off-mode UEC of all portables.

4.3 Annual Energy Consumption

Computers used an estimated 23 TWh (about 78% desktops and 22% portables; Table 4-12).

Table 4-12. Unit and annual energy consumption for computers.

COMPUTER	UNITS (millions)	UEC (kWh/yr)						AEC (TWh)
		HI-ACTIVE	SHORT-IDLE	LONG-IDLE	SLEEP	OFF	TOTAL	
Tower	50	85	86	83	6	4	264	13.3
All-in-One	22	55	87	54	5	3	205	4.4
DESKTOP	**72**	**76**	**86**	**75**	**6**	**4**	**246**	**17.7**
PORTABLE	**122**	**16**	**12**	**9**	**2**	**4**	**42**	**5.1**
ALL	**194**	**38**	**39**	**33**	**3**	**4**	**118**	**23**

4.3.1 Uncertainty Analysis

Computer AEC estimates carry somewhat higher uncertainty than other categories, mainly due to the high sensitivity to power management settings and behaviors. We analyzed these factors independently, and assuming component uncertainties are independent and uniformly distributed, we estimate the overall AEC is likely between 20 and 28 TWh (Table 4-13).

[12] This randomization approach was used since many respondents did not answer all questions about usage and behavior. To improve precision and ensure convergence, the randomization process was repeated 20 times for all computers in the survey, and results averaged.

[13] Thus, if someone used a computer with APM enabled for 4.5 hours in one session during a 5-hour bin, the computer would go into short-idle, and then long-idle, but there would be no remaining time for sleep or hibernation during that bin.

Table 4-13. Uncertainty estimates for computers.

COMPONENT	AEC IMPACT	
	23 TWh	%
Real-World Power Multiplier	±2.5	±11
Power Management	±2.3	±10
Gaming and Graphics	0 to +2.2	0 to +9
Usage Sampling Error	±1.8	±8
Installed Base Sampling Error	±1.5	±7
Number of Usage Sessions	-0.3 to +1.0	-1 to +4
NET IMPACT	**-3 / +5**	**-13 / +25**

Note: Components are interactive and not additive. Net impact is approximate.

Installed Base and Usage Sampling Errors

Since the installed base and usage estimates were based on a weighted survey (n=1,007), we use the standard error of the mean (SE) to estimate random sampling error at the 90% confidence level. We find the installed base for desktops is 72±7 million (SE=4), for portables 122±10 million (SE=6), and for all computers 194±13 million (SE=8). This uncertainty could affect AEC by up to **±1.5 TWh**.

Similarly, the uncertainty in usage is 4.8±0.7 hours (SE=0.4) for desktops and 4.0±0.6 hours (SE=0.3) for portables. If all uncertainty in the active-mode usage were transposed with off-mode usage (worst case), the overall change could be up to **±1.8 TWh**.

Although there are limited opportunities to compare survey data with field results, a monitoring effort of California homes found that of 45 desktop computers, average daily usage was 7.3 hours in 2012 (LBNL 2014). This compared favorably with the survey-based estimate of 7.7 hours for 2013 (FhCSE 2014).

Real-World Power Multipliers

Empirical factors, or multipliers, used to translate as-tested power draw values into real-world equivalents, carry moderate uncertainty, as they were based on limited measurements of small samples. Generating new estimates with different factors is straightforward, as power draw by mode would simply scale proportionally, though we do not know how far off these factors may be. Assuming, a systematic error of ±20% for each of these multipliers, yields impacts on AEC at the 90% confidence level of ±1.6 TWh (high-active factor), ±1.6 TWh (short-idle factor), and ±1.3 TWh (long-idle factor), for a net effect of up to **±2.5 TWh**.

Other factors, such as aging, could cause computers to draw more power over time. As computers age, they may accumulate software that performs more unseen tasks in the background, potentially increasing standby power. Additionally, fans or heatsinks could become blocked by dust, causing them to run more often. While we lack the empirical data to quantify these effects, they could similarly be modeled using aging multipliers.

Power Management

Assumptions about power management have a pronounced impact on computer energy use. Since power management behaviors may be difficult to recall, there may be appreciable uncertainty in usage by mode. Further study about these behaviors, especially for desktops, could help reduce this uncertainty.

To estimate the impact on AEC, we ran two scenarios adjusting the manual power management rates, supposing that people systematically over- or underestimated how frequently they left their computers on after use. Increasing or decreasing the frequency that people “leave on” by 25% (relative) and transposing this behavior with “turns off” changes AEC by **±2.3 TWh**.

Since automatic power management only influences computers that are left on and are not interrupted by usage sessions, the uncertainty about APM settings contributes less to the overall AEC uncertainty.

When usage is spread out over more sessions throughout the day, computers reliant on APM may spend less time in lower power modes. To examine this sensitivity, we repeated the usage model under different assumptions (1, 3, and 10 sessions per period). Switching from three to one session per period changed AEC by **-0.3 TWh**, and from three to ten by **+1 TWh**.

Gaming and Graphics

Power draw may increase substantially when users are gaming or using intense graphics, especially on computers with dedicated video adapter with graphics processing units (GPU). Additionally, high performance gaming computers may draw more power in all modes, due to hardware (more RAM, more fans, larger power supplies, etc.). Furthermore, gamers may use these high-power computers more often than non-gamers, potentially further increasing energy consumption. To the extent that these effects are not already reflected in the power draw values and real-world factors, power draw and energy use could be appreciably higher for this subset. Here we estimate the approximate impact on AEC.

In California, Mills et al. (2017) found the portion of gaming computers was 15% of desktops and 8% of portables. If applicable to the entire U.S., that implies about 20 million gaming computers in 2017, split roughly equally among desktops and portables. In the CE Usage Survey, discrete graphics cards were reported in 37% of desktops and 16% of portables,[14] implying there were up to 47 million graphics cards in service, fairly consistent with sales data.[15] Since graphics cards are necessary but not sufficient to imply a gaming rig, this seems broadly consistent.

While enthusiasts can install aftermarket graphics cards, many computers ship with a dedicated GPU preinstalled – about 35% as of Q3 2016 (Jon Peddie Research via AnandTech 2016). Accordingly, gaming systems may already be partially factored into in our current power draw estimates. Even so, high-performance gaming modes are not reflected in the adjusted ENERGY STAR measurements we used to estimate typical power draw.

Gaming power draw depends on the graphics adapter and the game. The most common graphics cards among users of a leading online gaming platform were the GTX 970 and GTX 960 (5% and 3.6% of computers, respectively; KitGuru 2016). Measurements of 14 different graphics cards (including the GTX 970) using a desktop rig, found idle mode power draw of 73-99 W (average 82 W, similar to short idle mode for desktops in this study, AnandTech 2014). During a high-performance gaming test, however, the power draw increased to 268-381 W (average 316 W), a factor of 3.8 higher than in idle mode.

We estimate that gaming accounts for about 16% of all active computer use, and about 20% for those computers with a dedicated graphics adapter (Table 4-14, CE Usage Survey). Computers with dedicated graphics also tended to have higher total active usage. For comparison, a study of avid and extreme gamers estimated gaming time among that population at 4.4 hours per day (Mills and Mills 2015); however, some of that time occurs on other platforms.

Table 4-14. Active and gaming time (h/day) and dedicated graphics for computers.

COMPUTER	GAMING TIME		ACTIVELY USED TIME	
	ANY	WITH GRAPHICS ADAPTER	ANY	WITH GRAPHICS ADAPTER
DESKTOP	0.9	1.4	4.8	6.0
PORTABLE	0.6	0.8	4.1	5.1
ALL	**0.7**	**1.1**	**4.5**	**5.6**

Source: CE Usage Survey

Note: Based on the subset who answered about gaming and graphics (n=267 computers from 185 respondents).

[14] About 13% of responders did not know, and we assume these computers did not have graphics adapters.

[15] Globally, 58 million discrete GPUs shipped per year from 2010 to 2016 (Mills et al. 2017).

Assuming that all reported gaming time was high-performance gaming, incremental active mode power draw while gaming is +200 W, and applying this to an estimated 20 million gaming computers, the impact on AEC could be up to +1.8 TWh. Similarly, assuming that for gaming computers, the short- and long- idle modes draw 30% more power than the average computer, and the sleep- and off- modes draw twice as much, this could add another +0.3 TWh, for a net effect of up to **+2.2 TWh**.

4.3.2 Comparison with Prior Estimates

Estimates for computer AEC have increased by about 2 TWh from 2013 to 2017. Changes in estimates occurred because of several factors. First, the installed base declined by 18% for desktops and increased by 31% for portables. Second, although desktop power draw remained fairly consistent, portable power draw in each mode has approximately halved. Third, the time spent in active modes has increased for both desktops (30%) and portables (47%). While the first two factors would tend to reduce AEC, the increase from the third is large enough to result in a net AEC increase.

Although the estimates for active mode usage have changed substantially, these changes may have more to do with modeling assumptions than with actual shifts in behavior. In particular, due to modeling refinements, we found lower estimates for APM rates than before, increasing time spent in active modes. Due to appreciable uncertainty, especially in usage by mode, the AEC changes are unlikely to be statistically significant.

Table 4-15. Current and prior energy consumption estimates for desktop computers.

YEAR	UNITS (millions)	POWER (W) ACTIVE	SLEEP	OFF	USAGE (h/year) ACTIVE	SLEEP	OFF	APM ENABLED	UEC (kWh/yr)	AEC (TWh)	SOURCE
2017	72	65	2.7	1.2	3,635	2,110	3,015	23%	246	18	Current
2013	88	62	3.4	1.6	2,790	2,085	3,885	38%	186	16	FhCSE (2014)
2012	105	66	-	2	2,670	-	-	-	194	20	LBNL (2014)
2010	101	60	4	2	3,420	2,150	3,190	70%	220	22	FhCSE (2011)
2006	90	75	4	2	2,955	350	5,455	20%	235	21	TIAX (2008)
2005	85	75	4	2	2,950	350	5,460	20%	234	20	TIAX (2006)
2005	108	58	-	3	2,115	-	185	15%	151	16	EPA (2005)
2001	68	50	25	1.5	1,495	165	7,100	20%	90	6	LBNL (2004)
1999	5	50	25	2	715	65	7,980	25%	49	3	LBNL (2001)

Notes: ACTIVE includes high-active, short-idle, and long-idle modes. APM indicates estimated automatic power management rates including auto-sleep, hibernate, or shutdown, but excluding auto-screen off.

Table 4-16. Current and prior energy consumption estimates for portable computers.

YEAR	UNITS (millions)	POWER (W) ACTIVE	SLEEP	OFF	USAGE (h/year) ACTIVE	SLEEP	OFF	APM ENABLED	UEC (kWh/yr)	AEC (TWh)	SOURCE
2017	122	14	0.7	0.3	2,585	2,330	3,845	36%	42	5.1	Current
2013	93	30	1.6	1.1	1,760	2,000	3,600	64%	51	4.7	FhCSE (2014)
2010	128	19	2	1	2,915	2,210	3,635	69%	63	8.3	FhCSE (2011)
2009	76	-	-	-	-	-	-	-	43	3.1	EPA (2009)
2006	39	25	2	2	2,370	935	5,460	40%	72	2.8	TIAX (2007)
2005	36	25	2	2	2,370	935	5,460	40%	72	2.6	TIAX (2006)
2001	17	-	-	-	-	-	-	-	77	1.3	DOE/EIA (2001)
2001	17	15	3	0	1,010	650	7,100	-	-	-	LBNL (2004)
1999	16	15	3	2	520	260	7,980	100%	9	0.14	LBNL (2001)

Notes: ACTIVE includes high-active, short-idle, and long-idle modes. APM indicates estimated automatic power management rates including auto-sleep, hibernate, or shutdown, but excluding auto-screen off. Zero power in off mode indicates device was unplugged.

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5 MONITORS

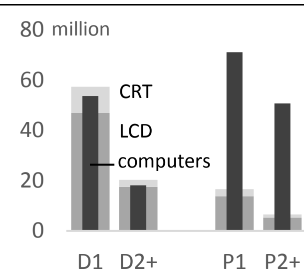
Computer monitors include external displays that are plugged into a desktop or portable computer. They can be used with or without a docking station. Projectors and integrated displays, such as those built into portable or All-in-One computers, are excluded from this category.

5.1 Installed Base

About 101 million external monitors were installed in 2017 (Table 5-1), based on the CE Usage Survey.[16] This represents a negligible change in the total installed base since 2013 (97 million, FhCSE 2014) that masks three trends. First, the number of desktops continued to decline (88 to 72 million) with the installed base of tower desktops decreasing even more precipitously[17] from 70 to 50 million. This is not surprising, given that unit shipments of All-in-One computers stayed relatively flat from 2010-2016 (Display Search 2013, IHS Markit 2017) while desktop unit sales decreased by about 40% (CTA 2016). Second, the number of monitors per desktop computer increased from 0.9 to 1.1, indicating that a larger portion of tower desktops now have multiple monitors (Figure 5-1). Third, the number of portables increased from 93 to 122 million, while the portion with at least one monitor (15%) did not change appreciably since 2013.

Table 5-1. Installed base for monitors.

COMPUTER	COMPUTERS (million)	MONITORS PER COMPUTER	MONITORS (million) LCD	CRT	TOTAL
Desktop 1	54	1.1	47	11	57
Desktop 2+	18	1.1	18	3	20
DESKTOP ALL	**72**	**1.1**	**64**	**13**	**78**
Portable 1	71	0.2	14	3	17
Portable 2+	51	0.1	5	1	10
PORTABLE ALL	**122**	**0.2**	**19**	**4**	**23**
TOTAL/Wt. Avg.	**194**	**0.5**	**83**	**17**	**101**



Source: CE Usage Survey

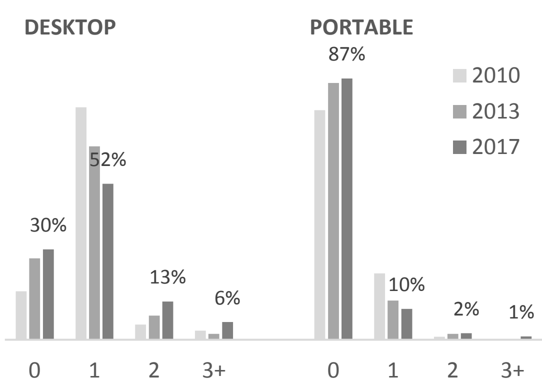


Figure 5-1. Monitors per computer.
Source: CE Usage Survey

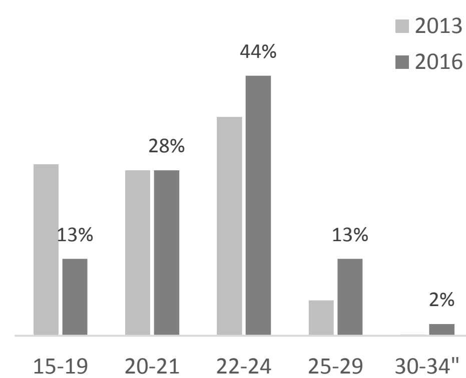


Figure 5-2. Size of LCD monitors sold by year.
Source: IHS Markit (2017), DisplaySearch (2014)

Most installed monitors are LCDs (83%), and surprisingly, the CRT portion (17%) apparently has not changed much since 2010. Screen sizes continued to get larger: from 2013 to 2016, the shipment-weighted average screen has increased from 20.9 to 22.2 inches (Figure 5-2; NPD DisplaySearch 2012, IHS

[16] The CE Usage Survey asked about monitors for up to two desktop and portable computers. We assumed the proportions of LCD and CRTs were the same for less-used computers. To avoid underestimating, computers with "Don't Know" monitor responses (7% of desktops and 13% portables) were excluded before we calculated the number of monitors per computer, and subsequently, the installed base.

[17] Sales data from Display Search (2013) and IHS Markit (2017) show relatively flat sales of AIO PCs.

Markit 2017). As a result, the average LCD monitor in the residential stock is now 21 inches, compared to 18 in 2010 and 17 in 2006 (FhCSE 2011, TIAX 2007).

5.2 Unit Energy Consumption

5.2.1 Power Draw

Monitors have three main power modes: active, sleep, and off. Active mode occurs when the monitor is on and displays an image, and its power draw depends most strongly on display type, screen size, and picture settings (e.g., brightness and contrast). Sleep mode is a low-power state entered after a period of inactivity, typically about 15 minutes, when power management (PM) is enabled. User input from a keyboard or mouse can wake a sleeping monitor into active mode. Off mode, the lowest power mode, is entered when the user manually turns the monitor off or when the computer's power settings are set to automatically turn off the display.

For this study, we divided the installed base into CRTs and LCDs from pre-2011, 2011-2013, and 2014-2016. We allocated LCD monitors into the installed base in different vintage bins starting with newer monitors and working backwards. That is, we first assigned units sold between 2014-2016, then units sold between 2011-2013, and lastly units from 2006-2010 until the total number of LCDs estimated in the installed base was reached. This process yields the installed base distribution by vintage (Table 5-4). About 25 million LCD monitors were shipped to U.S. consumers from 2014-2016 (Table 5-2, based on IHS Markit 2017).[18] Monitors entering service since 2013 have replaced almost half of the 2006-2010 vintage in the 2013 installed base.

For all CRT monitors and pre-2011 LCDs, we used power draw characteristics from the 2010 study (FhCSE 2011). Similarly, estimates for LCDs from 2011-2013 come from FhCSE (2014). We relied on ENERGY STAR databases to calculate the power draw characteristics for LCD monitors entering the installed base in 2014-2016. A new ENERGY STAR specification, version 6.0, came into effect in June 2013 (EPA 2013a). Annual reports by the EPA estimated that 88-92% of computer displays sold in 2014 and 2015, respectively, met the criteria (EPA 2014, 2015), and we linearly extrapolated from those two values to estimate that 96% met the criteria in 2016. Subsequently, we used the database that was used by EPA to develop the ENERGY STAR version 7 specification (EPA 2015) to calculate the average power draw by mode for different screen size bins. For non-ENERGY STAR monitors, we used data from the prior ENERGY STAR specification, v5.1. In 2012, a large majority (83%) of computer displays sold met the ENERGY STAR v5.1 specification (EPA 2012). We assumed that all non-ENERGY STAR monitors sold from 2014-2016 were represented by monitors in the previous ENERGY STAR v5.1 dataset (EPA 2013b) that did *not* meet the new v6.0 specification,[19] averaging power draw by mode for all those monitors in different size bins.

Finally, we calculated the sales-weighted average power draw by screen size for 2014-2016, accounting for the ENERGY STAR qualified fraction of units sold (Table 5-3). Using these values, together with power draw values from FhCSE (2014) for older models, we estimated power draw for the entire installed base of monitors (Table 5-4).

[18] We scaled the total North American unit shipment data (commercial and consumer) by the U.S. population fraction (90%) – based on 35 million people in Canada (Statistics Canada 2013) and 317 million in the U.S. (U.S. Census Bureau 2013) – and by the average consumer fraction (38%, Display Search 2011-2013).

[19] This included monitors that did not meet at least one of the active, sleep, or off-mode criteria required, i.e., some non-ENERGY STAR monitors did meet the power draw by mode criteria for at least one mode.

Table 5-2. Computer monitor sales (millions) in North America by year and size bin.

YEAR	SCREEN SIZE BIN (inches)					TOTAL
	15-19	20-21	22-24	25-29	30-34	
2016	3.3	7.0	11.1	3.2	0.4	**25.1**
2015	5.8	5.6	10.6	2.4	0.2	**24.6**
2014	7.0	5.9	9.9	1.8	0.1	**24.7**
U.S. Res. TOTAL	**5.5**	**6.3**	**10.8**	**2.5**	**0.2**	**25.4**

Source: IHS Markit (2017)

Note: U.S. residential totals estimated by scaling total North American unit shipment data (commercial and consumer) by population (90% U.S., Statistics Canada [2013], U.S. Census Bureau [2013]) and by the average consumer fraction (38%, Display Search [2011-2013]).

Table 5-3. Power draw for monitors by screen size bin for 2014-2016.

MODE	ENERGY STAR?	SCREEN SIZE BIN (inches)					Wt. AVG 21.6 (inches)
		15- 19	20-21	22-24	25-29	30-34	
ACTIVE	YES	12	14	19	26	41	17
	NO	17	19	26	30	85	23
	Wt. AVG	**12**	**15**	**19**	**27**	**44**	**18**
SLEEP	YES	0.3	0.3	0.3	0.3	0.4	0.3
	NO	0.4	0.4	0.5	0.6	0.9	0.5
	Wt. AVG	**0.3**	**0.3**	**0.3**	**0.4**	**0.4**	**0.3**
OFF	YES	0.2	0.2	0.2	0.2	0.3	0.2
	NO	0.3	0.3	0.4	0.5	0.6	0.4
	Wt. AVG	**0.2**	**0.2**	**0.2**	**0.3**	**0.3**	**0.2**

Table 5-4. Power draw for the installed base of monitors.

TYPE	YEAR	AVG. SIZE (inches)	INSTALLED (millions)	%	POWER (W)		
					ACT	SLEEP	OFF
LCD	2014-2016	21.6	25	30%	18	0.3	0.2
LCD	2011-2013	20.9	28	34%	22	0.4	0.3
LCD	2006-2010	19.1	30	36%	33	0.9	0.6
LCD	**Wt. AVG**	**20.5**	**83**	**83%**	**25**	**0.6**	**0.4**
CRT	**Wt. AVG**	**17.0**	**17**	**17%**	**61**	**2.0**	**1.0**
	TOTAL/AVG	**20.0**	**101**	**100%**	**31**	**0.8**	**0.5**

5.2.2 Usage

We estimate monitors are on for about 6.7 hours per day (Table 5-5), slightly longer than computers spend in active and short-idle modes. The remaining time is split about evenly between sleep and off modes. Monitors associated with desktops tend to be used more than those with portables.

Table 5-5. Daily usage of monitors by mode and prior estimates.

YEAR	COMPUTER	USAGE (h/day)			SOURCE
		ACT	SLEEP	OFF	
2017	DESKTOP (Tower)	7.2	9.1	7.7	Current study
2017	PORTABLE	5.0	8.5	10.5	Current study
2017	ALL	6.7	8.9	8.4	Current study
2013	ALL	4.2	12.2	7.7	FhCSE (2014)
2013	ALL	6.6	12.4	5.0	LBNL (2013)
2010	ALL	6.9	9.7	7.4	FhCSE (2011)

To determine monitor usage by mode, we relied primarily on results from the CE Usage Survey. We did not ask about monitor usage behavior directly. Instead, we based the monitor usage on the modeled computer usage by mode, assuming:

1. Computer active or short-idle → the monitor is on
2. Computer long-idle → the monitor is on sometimes (see below)
3. Computer sleep → the monitor is in sleep mode
4. Computer off → the monitor is in off mode
5. For computers with multiple monitors, we assumed identical usage for each monitor.

Monitor state during long-idle mode carries some uncertainty, due to dependence on automatic and manual power management settings. As described in the computer usage analysis (Figure 4-5), we estimate that about 16% of tower desktop and 12% of portable computers had no automatic computer or monitor power management enabled. Based on these findings, we assign time spent in long-idle mode proportionally to on-mode (16% or 12%) and sleep mode (84% or 88%).

Using this method could overestimate active usage for monitors that were connected to a portable computer, since they may only be connected some of the time. However, since the portion of external monitors associated with portables is fairly low, the impact on energy consumption should be minor. Since power draw in sleep and off modes are similar and both small compared to active mode, monitor energy use is most sensitive to estimates of time spent in active mode.

5.2.3 Unit Energy Consumption

Unit energy consumption for monitors was about 64 kWh/yr for LCDs, 159 kWh/yr for CRTs, and 80 kWh/yr on average (Table 5-6). Over 90% of the usage occurred in active mode.

5.3 Annual Energy Consumption

Monitors consumed an estimated 8.1 TWh in 2017, mostly in active mode (Table 5-6). LCDs comprise about 82% of all monitors and account for the majority (66%) of the AEC. Most of the monitor use (82%) was associated with desktop computers.

Table 5-6. Unit and annual energy consumption estimates for monitors.

COMPUTER	TYPE	UNITS (millions)	UEC (kWh/yr) ACT	SLEEP	OFF	TOTAL	AEC (TWh)
-	LCD	83	61	1.8	1.2	64	5.3
-	CRT	17	150	6.5	3.1	159	2.7
DESKTOP (Tower)	-	78	82	2.8	1.4	86	6.7
PORTABLE	-	23	57	2.6	1.9	61	1.4
TOTAL/Wt. AVG		**101**	**76**	**2.7**	**1.5**	**80**	**8.1**

5.3.1 Uncertainty Analysis

We consider two main sources of uncertainty for monitors: the display type (CRT vs. LCD) allocation and sensitivity to usage assumptions. If half the monitors identified as CRTs were actually LCDs, that would reduce AEC by about **0.8 TWh**. Likewise, as there was significant uncertainty in computer usage by mode, we considered the same range of usage values for monitors as we did for computers. The effect of computer usage uncertainty is on the order of **-0.7/+0.8 TWh**. Accordingly, we estimate that the AEC for monitors is between 7 and 9 TWh.

As with televisions, the power draw of monitors depends on the user-selected display settings, and particularly brightness levels. The power draw values we used come from ENERGY STAR measurements, which are taken under as-shipped default monitor settings. If actual brightness levels differ systematically from the test conditions, there could be bias in the average power results. We note this as a potential source of uncertainty, but currently lack supporting data to estimate its magnitude.

5.3.2 Comparison with Prior Estimates

The 2017 AEC estimate for monitors is about 2 TWh higher than in 2013 (FhCSE 2014), driven almost entirely by a higher estimate for the time spent in active mode (Table 5-7). The apparent change in usage is mainly due to refinements to the modeling and assumptions of computer and monitor usage and therefore may not reflect an actual change in behaviors. In contrast, both the installed base and the average power draw by mode values have changed only slightly since 2013.

Table 5-7. Prior energy consumption estimates for monitors.

YEAR	UNITS (millions)	POWER (W)			USAGE (h/yr)			UEC (kWh/yr)	AEC (TWh)	SOURCE
		ACT	SLEEP	OFF	ACT	SLEEP	OFF			
2017	101	31	0.8	0.5	2,455	3,255	3,050	80	8.1	Current
2013	97	33	0.9	0.6	1,535	4,450	2,775	58	5.7	FhCSE (2014)
2013	-	26	1.0	0.0	2,410	4,525	1,825	67	-	LBNL (2013)
2010	131	39	1.2	0.9	2,520	3,540	2,700	97	12.7	FhCSE (2011)
2010	-	43	1.2	-	1,935	6,825	-	84	-	ECW (2010)
2008-CRT	-	71	46	3	-	-	-	-	-	ECOS (2011)
2008-LCD	-	34	6	0.9	-	-	-	-	-	ECOS (2011)
2006	90	42	1	1	1,865	875	6,020	85	7.6	TIAX (2007)
2005	89	45	2	1	1,860	880	6,020	101	9	TIAX (2006)

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6 NETWORK EQUIPMENT

Residential network equipment includes three main categories: **broadband modems** without integrated routers; broadband modems with integrated routers called **integrated access devices (IADs)**; and **local network equipment**. Devices from all categories may support wired connections, wireless connections (Wi-Fi), or both.

Broadband modems and IADs, collectively called broadband access devices, connect subscribers to high-speed Internet service providers (ISPs). Local network equipment includes Wi-Fi and wired routers that establish a local network in the home, allowing communication among devices but do not establish broadband connections.

Recently, the small network equipment industry, including hardware manufacturers and broadband ISPs, adopted a voluntary agreement (VA) designed to improve the energy efficiency of new products.[20] Annual reporting of sales and sales-weighted power draw data formed the basis for this analysis (D+R 2016, 2017).

6.1 Installed Base

The stock of home network equipment has undergone several important changes in the past few years. The total number of installed network devices may have declined by as much as 20% since 2013, owing to a strong shift from broadband modems to IADs that serve multiple functions (Table 6-1). This, in turn, may have reduced the need for separate local network equipment, like Wi-Fi routers, in many homes. Although home internet access has been steady for at least six years (78%), broadband penetration has recently plateaued at about 92 million homes (76%).[21] Meanwhile, home network penetration grew from 61 million homes (51%) in 2013 to 76 million (64%) in 2016, (Figure 6-1, CTA S&F 2016).

Table 6-1. Installed base (millions) for network devices.

DEVICE	UNITS 2013	INSTALLED STOCK in 2017 pre-2016	INSTALLED STOCK in 2017 2016-2017	UNITS 2017	
Broadband Modem	39	5	3	8	6%
Integrated Access Device	50	35	51	85	65%
All Gateway	**89**	**39**	**54**	**93**	**70%**
Local Network Equipment	**57**	**27**	**12**	**39**	**30%**
TOTAL:	**146**	**66**	**66**	**132**	**100%**

Source: Based on D+R (2016, 2017), 2013 stock adjusted from FhCSE (2014).
Notes: Shipments for 2014 and 2017 assumed equal to 2015 and 2016 values, respectively.
Shaded columns indicate 2017 installed stock breakdown by model year (approximate).

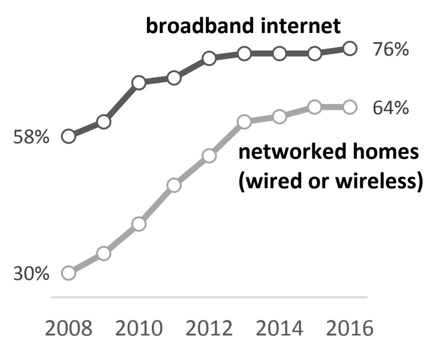

Figure 6-1. Home network and internet penetration.
Source: CTA S&F (2013, 2016)

[20] The signatories serve 79 million residential U.S. subscribers and account for 87% of the market as of 2015.
[21] Pew (2015) reports that broadband adoption was down slightly, at 67% of Americans from 70% in 2013.

We calculated the installed base breakdowns for 2017 based on the following assumptions:

1. Unit shipment data by category for 2014 and 2017 (D+R 2016, 2017) was assumed equal to that of 2015 and 2016, respectively.
2. One gateway (modem or IAD) installed per broadband household,[22] and 93 million residential broadband subscribers (D+R 2017).
3. Integrated access devices represent about 92% of installed gateways and broadband modems represent the remaining 8%.[23]
4. Local network equipment lower includes about 39 million units, the average of two bounding cases. Upper bound: unchanged from 2013 (57 million units). Lower bound: 19% of all installed network equipment (22 million units), consistent with the local network equipment portion of sales from 2014-2015 (D+R 2016, 2017).[24]
5. Devices were then allocated by vintage, starting with the newest models and progressively adding older stock to reach the totals.

IADs remain the most sold network device (Table 6-2, D+R 2016, 2017), increasing markedly from 2013. At the same time, we estimate that the total amount of local network equipment has declined sharply as IADs provide overlapping functionality. Alternate assumptions, where local equipment does not decline so sharply, are discussed in the uncertainty analysis.

Table 6-2. Unit shipments (millions) for network devices.

DEVICE	2014e	2015	2016	2017p	'14-'17	
Broadband Modem	2.6	2.6	1.5	1.5	8	7%
Integrated Access Device	20.7	20.7	25.4	25.4	92	75%
All Gateways	**23.3**	**23.3**	**26.9**	**26.9**	**100**	**81%**
Local Network Equipment	**5.6**	**5.6**	**6.0**	**6.0**	**23**	**19%**
TOTAL:	**28.9**	**28.9**	**32.9**	**32.9**	**124**	**100%**

Source: D+R (2016, 2017)
Note: 2014e and 2017p assumed same as 2015 and 2016, respectively.

Table 6-3. Installed base (millions) for network devices.

DEVICE	2013 FhCSE (2014)	2013 Adjusted		2017	
Broadband Modem	49	39	43%	8	6%
Integrated Access Device	64	50	57%	85	65%
All Gateways	**113**	**89**	**61%**	**93**	**70%**
Local Network Equipment	**57**	**57**	**39%**	**39**	**30%**
TOTAL:	**170**	**146**	**100%**	**132**	**100%**

Note: We adjusted the 2013 estimates from FhCSE (2014) so that the installed base of gateways equals the number of broadband subscribers (89 million in 2013).

6.2 Unit Energy Consumption

6.2.1 Power Draw

The sales-weighted average power draw of network equipment and the power draw of individual products were identified by D+R (2016, 2017). About 90% of equipment sold in 2015 and 98% in 2016 met the

[22] Installed estimates for gateways, based on various sources and projections, may have been inflated in prior studies (FhCSE 2011, 2014). These estimated 1.1-1.3 gateways per subscriber household, which seems unrealistic. We therefore adopt the one-gateway-per subscriber assumption.
[23] IADs comprised about 92% of gateway shipments from 2014-2017 (D+R 2016). This is consistent with an estimate that 90% of global broadband households will have service provider Wi-Fi by 2019 (IHS Markit 2015).
[24] Of broadband households, about 31 million shifted from modems to IADs from 2013 to 2017, potentially displacing as many local network devices. This would explain the number of installed local network equipment to about 26 million from 57 million.

voluntary efficiency requirements. We modeled power draw based on a weighted installed-based, using power data from FhCSE (2014) for the pre-2014 units.

Power draw can vary appreciably among models and by type (Figure 6-2). Today's products have more capabilities to meet consumer demands for higher-speed broadband services and increased Wi-Fi capacity for more devices at higher speeds within the home. While devices that provide increased functionalities to meet these increased consumer demands may sometimes use more energy than less capable devices, signatories are delivering these more advanced functionalities more efficiently (D+R 2017).

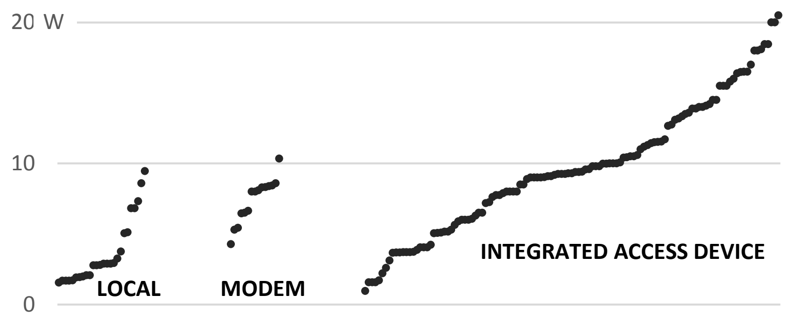

Figure 6-2. Idle mode power draw of network equipment, models shipped in 2015.
Source: D+R (2016)

The ENERGY STAR standard for small network equipment provides a baseline power draw for each device type and allows for additional power adders depending on which features are included (EPA 2013). In this way, devices of a given type can have quite different power draw and still meet the efficiency criteria.

Sales-weighted power draw for the new stock and installed base (Table 6-4) was somewhat higher than the unweighted power draw by model for IADs and local network equipment (unweighted: 9.7 W for IADs, 7.4 W for modems, and 3.6 W for local network equipment; D+R 2016). This suggests that devices with more features and/or higher power draw are more popular than those without, leading to higher average power draw in the installed base.

Overall, on-mode power draw for broadband modems and wireless routers remained about the same, while IAD power draw nearly doubled relative to 2013 estimates. Lacking better data, we retained prior estimates for off-mode power draw (FhCSE 2011). In practice, the off/standby mode has a small impact on network equipment UEC since these devices spend most of their time in on/idle mode.

Table 6-4. Power draw (W) by mode for network equipment.

DEVICE	ACT MODE by VINTAGE		2017 STOCK	
	pre-2016	2016-2017	ACT	OFF
Broadband Modem	6.7	7.1	6.8	0.1
Integrated Access Device	13.3	13.5	13.4	1.5
All Gateway	**12.5**	**13.2**	**12.9**	**1.4**
Local Network Equipment	**7.0**	**5.6**	**6.6**	**1.0**
Wtd. Avg.	**10.3**	**11.8**	**11.0**	**1.3**

Source: D+R (2016, 2017), FhCSE (2014)
Note: Pre-2016 power draw for local network equipment is a weighted average of 7.4 W for pre-2014 and 6.4 W for 2014-2015 models.

6.2.2 Usage

Network devices are normally always on and ready to use. The 2010 CE Usage Survey found that 12% of modems were apparently switched off when not in use. Based on this result, we assumed in prior studies that network equipment spends about 21.4 hours per day in on mode (FhCSE 2011, 2014). While we retain this assumption, we recognize that as the number of connected devices per home increases, people may be less inclined to turn off their networks. Consequently, we also calculated UEC and AEC under the assumption that these devices are always on.

6.2.3 Unit Energy Consumption

Network equipment consumed an estimated 87 kWh/yr per device, with nearly all the usage occurring in active mode (Table 6-5). Modems and local network equipment used comparable energy, while IADs used substantially more due to their double-duty functionality.

Table 6-5. UEC and AEC calculations for network equipment.

DEVICE	UNITS (millions)	UEC (kWh/yr) ACT	OFF	TOTAL	AEC (TWh) ACT	OFF	TOTAL	
Broadband Modem	**8**	54	0.1	**54**	0.4	0.0	0.4	**4%**
Integrated Access Device	**85**	105	1.4	**107**	9.0	0.1	9.1	**79%**
All Gateway	**93**	101	1.3	**102**	9.4	0.1	9.5	**82%**
Local Network Equipment	**39**	51	0.9	**52**	2.0	0.0	2.0	**18%**
TOTAL:	**132**	**86**	**1.2**	**87**	**11.4**	**0.2**	**11.6**	**100%**
	Usage (h/d):	21.4	2.6	**24**				

6.3 Annual Energy Consumption

Network equipment consumed an estimated 12 TWh in 2017. About 82% is attributed to broadband equipment, mostly from IADs. The importance of IADs has grown, in part because of their increased number, but also because their sales-weighted power draw values were higher than previously estimated.

6.3.1 Uncertainty Analysis

Uncertainty in the network equipment AEC estimates depends on several factors, primarily on assumptions about the installed base, power draw characteristics of older devices, and time spent in off mode. We analyzed these factors independently relative to the current AEC estimate. We estimate the actual AEC is likely to be between 10 and 14 TWh (Table 6-6).

Table 6-6. Uncertainty estimates for network devices.

COMPONENT	AEC IMPACT 12 TWh	%
Installed Base Gateways per Subscriber	+2.7	+22
Installed Base of Local Network Equipment	±1.0	±8
Usage 100%	+1.2	+10
NET IMPACT	**-1 to +3**	**-8 to +26**

Note: Components are interactive and not additive. Net impact is approximate.

Installed Base

While the overall number of connected homes is well known, our installed base estimates are based on assumptions about the typical device ownership per household and on unit sales ratios that could influence AEC significantly.

First, we assumed that there was only 1 gateway per subscriber household. Prior studies (FhCSE 2011, 2014) estimated 1.3 gateways per subscriber based on mixed sources. While it is plausible that some homes do use more than one gateway or subscribe to more than one broadband provider at a time, this would imply that about one third of homes have two gateways, which seems unlikely. Under this alternate assumption, there could be up to 25 million more gateways, increasing AEC by up to **+3 TWh**.

Second, we assumed that the portion of local network equipment was about 30% of all network equipment installed. Unit sales of local network equipment, however, comprise only about 19% of devices shipped from 2015-2016. It is unclear how many homes maintain separate or supplemental local networks (in addition to those provided by IADs). Although IADs can theoretically provide many of the same functions of local network equipment, customers may still want or need additional features that go beyond what is provided (e.g., a stronger Wi-Fi antenna or more wired ports). Furthermore, existing networks in the home may be retained, even after adopting broadband with IADs. We estimate the range of possibilities in the bounding cases that local network equipment has not changed from 2013 (57 million units) and in the case that the overall portion of local equipment is the same as its sales fraction (19% of all network equipment, or 22 million units). This yields a range of AEC impact of **±1 TWh.**

Usage

We assumed that all network equipment remains on for about 21.4 hours per day. Alternatively, if devices were never unplugged, the UEC and AEC values could increase by about 10%, or about **+1 TWh.**

6.3.2 Comparison with Prior Estimates

Current energy consumption for gateways grew by about 4 TWh (Table 6-7), primarily due to higher active-mode power draw estimates for IADs. Although the estimated power draw has increased for gateways, the prior values may not have reflected the sales weighted average of products as accurately as the current values do for 2017. At the same time, we estimate a slight decline of -1.4 TWh in local network equipment (Table 6-8), driven mainly by a decreasing installed base.

Table 6-7. Prior energy consumption estimates for broadband gateways (modems and IADs).

YEAR	UNITS	POWER (W)		USAGE (h/yr)		UEC	AEC	SOURCE
	(millions)	ACT	OFF	ACT	OFF	(kWh/yr)	(TWh)	
2017	93	12.9	1.4	7,825	935	102	9.5	Current
2013 adj.	89	7.4	0.9	7,825	935	59	5.2	Current
2013	113	7.4	0.9	7,825	935	59	6.7	FhCSE 2014
2012	88	7.5	-	8,760	0	65	5.7	NRDC 2013
2010	88	6.1	0.8	7,825	935	48	4.3	FhCSE 2011
2010	87	6.0	-	8,760	0	53	4.6	LBNL 2010
2008	71	5.8	-	8,760	0	51	3.6	LBNL 2010
2006	46	6.0	-	8,760	0	53	2.4	TIAX 2007
2005	32	6.0	-	8,760	0	53	2.6	TIAX 2006

Note: For improved comparisons, we adjusted the 2013 values from FhCSE (2014) to correct for a likely overestimate of installed gateways to allow for only one per broadband subscriber.

Table 6-8. Prior energy consumption estimates for local network equipment.

YEAR	UNITS	POWER (W)		USAGE (h/yr)		UEC	AEC	SOURCE
	(millions)	ACT	OFF	ACT	OFF	(kWh/yr)	(TWh)	
2017	39	6.6	1.0	7,825	935	52	2.0	Current
2013	57	7.4	1.0	7,825	935	57	3.4	FhCSE 2014
2012	56	5.5	-	8,760	0	48	2.8	NRDC 2013
2010	49	5.4	1.7	7,825	935	44	2.1	FhCSE 2011
2010	50	5.5	-	8,760	0	48	2.4	LBNL 2010
2008	45	5.5	-	8,760	0	48	2.2	LBNL 2010
2005	15	6.0	-	8,760	0	53	0.8	TIAX 2006

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7 TELEVISIONS

Nearly all homes own at least one television, and their characteristics have changed in recent years due to rapid adoption of new technology. By 2016, about 85-95% of homes had at least one High Definition flat-panel TV, while 20% had a 4K Ultra high-definition set (CTA O&M 2016, Nielsen 2016). About half of all households had at least one internet-capable smart TV (up from just 15% in 2013; CEA O&M 2013, 2016), and about half of those were enabled and connected (Nielsen 2017).

Even with increasing screen sizes, improving resolutions, and added features, TV unit energy consumption has continued to decline as newer, more efficient displays continued to displace the remaining stock of CRT units. As with prior studies, we based TV energy use estimates primarily on usage and ownership data from the CE Usage Survey, public power draw measurement datasets, and industry sales data.

7.1 Installed Base

With about 308 million units owned (CEA O&M 2017) and 284 million units plugged in (2017 CE Usage Survey), televisions remain among the most prevalent consumer electronic devices. Penetration, ownership (Table 7-1), and the distribution of TVs in homes (Table 7-2 and Figure 7-1), have apparently declined slightly since 2013.

Table 7-1. Installed base estimates for televisions.

YEAR	HOUSEHOLDS (millions)	HOUSEHOLD PENETRATION	UNITS per OWNER HH	UNITs (millions)	SOURCE
2017	119	96.5%	2.5[a]	284[a]	CE Usage Survey (2017)
2015	118	97.4%	2.4[b]	276[b]	DOE/EIA (2017)
2013	119	96.8%	2.6[a]	301[a]	FhCSE (2014)
2010	116	99.0%	3.1[a]	353[a]	FhCSE (2011)
2010	116	99.1%	2.9	328	Nielsen (2010)
2009	116	95.8%	2.4[c]	271[c]	FhCSE (2009)
2009	115	99.2%	2.9	335	Nielsen (2010)
2017	119	96.0%	2.7[d]	308[d]	CTA O&M (2017)
2016	119	96.0%	2.8[d]	320[d]	CTA O&M (2016)
2013	119	98.0%	2.9[d]	338[d]	CEA O&M (2013)
2012	119	99.0%	2.9[d]	340[d]	CEA O&M (2012)
2011	119	96.0%	3.0[d]	343[d]	CEA O&M (2011)
2010	114	95.0%	3.0[d]	325[d]	CEA O&M (2010)
2009	114	99.0%	3.0[d]	339[d]	CEA O&M (2009)

Notes: [a] TVs that were plugged in during the past month.
[b-c] TVs that are actively used (b), used to watch TV in the last week (c).
[d] TV ownership, including those not recently plugged in.

Table 7-2. TV ownership distribution.

TVs/hh	CE 2010	CE 2013	DOE/EIA 2015	CE 2017
0	1%	3%	3%	4%
1	19%	29%	25%	27%
2	28%	28%	33%	29%
3	23%	20%	23%	21%
4	14%	11%	10%	12%
5	7%	5%	4%	6%
6	2%	2%	1%	2%
7+	6%	2%	1%	1%

Source: CE Usage Surveys, FhCSE (2011, 2014, 2017) and DOE/EIA (2017)

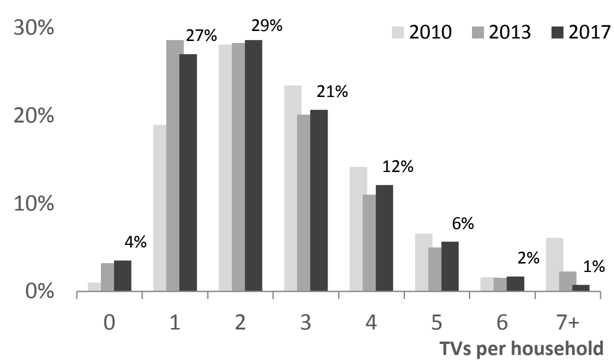

Figure 7-1. TV ownership distribution.
Source: CE Usage Surveys, FhCSE (2011, 2014, 2017)

Survey respondents characterized their four most-watched TVs in the household, in order of most to least used (priority). The first four TVs in homes represent about 95% of all installed TVs. The remaining five percent were assumed to have characteristics identical to the fourth-most watched TVs.

As with prior surveys, respondents sometimes confused display type, so we reclassified responses with invalid combinations of screen size, age, and display type. Specifically, we reclassified Plasma Display Panels (PDPs) smaller than 37 inches as Cathode Ray Tube (CRT) if older than 10 years or as LCDs[25] otherwise. Similarly, we reclassified CRTs less than 10 years old as LCDs. As of 2014, PDP TVs were no longer manufactured for sale in the U.S. (CNN 2014); however, only four people reported PDPs that were less than 3 years old, so rebalancing these models was unnecessary. The net effect of display type rebalancing shifted 15 million PDP and 5 million CRTs to LCDs (Table 7-3 and Figure 7-2).

Table 7-3. Distribution of televisions by display type.

YEAR	SOURCE	LCD	PDP	CRT	Proj.
2017	CE Usage Adjusted	84%	7%	7%	2%
2017	CE Usage Survey Raw	76%	12%	9%	2%
2017	CE O&M Survey	85%	-	15%	-
2015	DOE/EIA (2017)	72%	13%	13%	2%
2013	CE Usage Adjusted	63%	7%	27%	4%
2013	CE Usage Survey Raw	57%	12%	27%	4%
2013	CEA O&M Survey	39%	19%	42%	-
2010	CE Usage Adjusted	33%	7%	54%	6%
2010	CEA O&M Survey	21%	13%	62%	5%
2009	CE Usage Survey	25%	7%	62%	5%

Note: For CE O&M (2017): 85% includes LCD and PDP, and 15% includes all other display types.

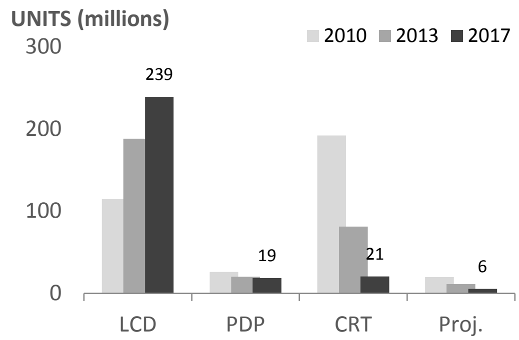

Figure 7-2. Televisions by display type.
Source: CE Usage Surveys, FhCSE (2011, 2014, 2017)

Only about 20 million CRTs remained installed (less than 10% of the installed base), a major decline of about 60 million since 2013. A similarly large decline occurred from 2010 to 2013. As newer LCDs have steadily displaced older CRTs, this shift continues to have the largest impact on total TV energy consumption.

7.1.1 Display Type

Usage strongly affects unit energy consumption, especially since newer, larger televisions tend to be used more than older, smaller ones. We assigned individual TV units from the CE Usage Survey to a "usage priority group" where TV1 is the most used TV in a household, TV2 is the second most used, and so on. These assignments (Table 7-4 and Figure 7-3) show that LCDs are dominant among all usage priorities.

Table 7-4. Installed base by usage priority and display type.

USAGE	UNITS (millions)					
PRIORITY	LCD	PDP	CRT	Proj.	ALL	%
TV1	95	12	5	2	**115**	40%
TV2	71	4	6	1	**83**	29%
TV3	39	2	6	2	**49**	17%
TV4+	33	1	4	1	**38**	13%
TOTAL	**239**	**19**	**21**	**6**	**284**	100%
	84%	7%	7%	2%	100%	

Source: CE Usage Survey, after reclassifying displays

[25] LCD includes LCD, LED, and OLED TVs.

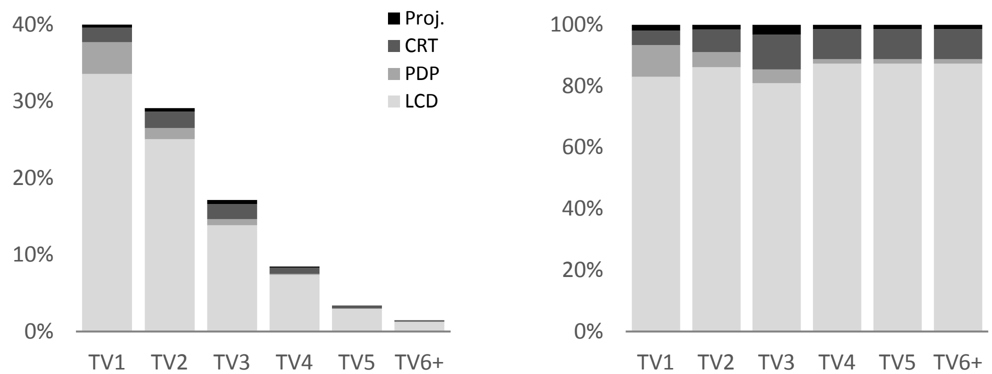

Figure 7-3. Televisions by display type and usage priority.

7.1.2 Screen Size and Age

At about 39 inches, the average screen continues to get larger (Table 7-5 and Figure 7-4), up from 34 in 2013, 29 in 2010 and 26 in 2006 (CE Usage Surveys from FhCSE 2017, 2014, 2011; TIAX 2007). The most-used TVs in a home are also larger than average at 45 inches, and are also growing (compare with 41 in. in 2013, and 28 in. in 2010).

The average age has decreased to about 5 years (5.5 years in 2013, 6 years in 2010). This is consistent with the retirement of older CRTs, which are 17 years old on average, compared with 4 years for LCDs, 5 years for PDPs, and 9 years for Projection displays (Table 7-5 and Figure 7-4).

Table 7-5. Screen size and age by display type and usage priority.

USAGE	SCREEN DIAGONAL (inches)					AGE (years)				
PRIORITY	LCD	PDP	CRT	Proj.	ALL	LCD	PDP	CRT	Proj.	ALL
TV1	45	50	27	49	**45**	4	4	17	8	**4**
TV2	36	52	24	44	**36**	4	4	15	8	**5**
TV3	34	49	25	51	**34**	4	7	19	10	**6**
TV4+	33	47	26	37	**33**	4	4	15	14	**5**
Wt. Avg.	**39**	**50**	**25**	**47**	**39**	**4**	**5**	**17**	**9**	**5**

Source: CE Usage Survey, after reclassifying displays

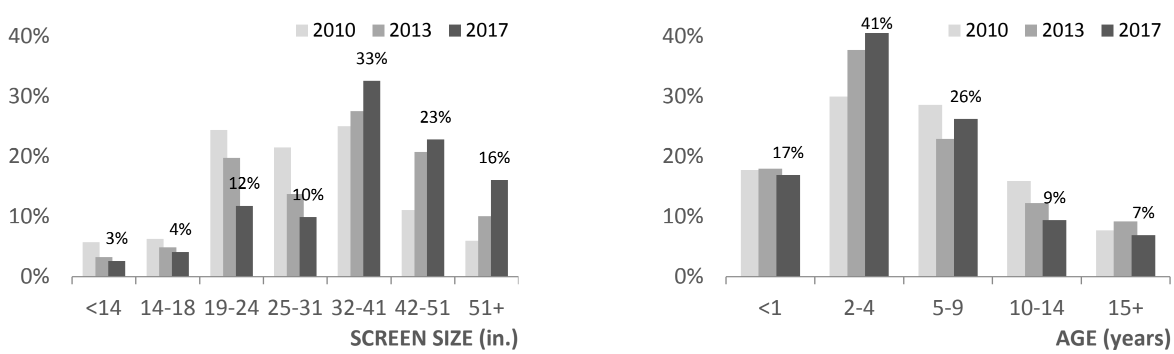

Figure 7-4. Televisions by diagonal screen size and age.

7.2 Unit Energy Consumption

7.2.1 Power Draw

Television power draw depends on display type, screen size, and year. Active mode estimates averaged about 77 W for on mode and 1 W for passive standby mode, with moderate variation according to usage priority and display type (Table 7-6). LCDs drew the least, followed by CRTs, PDPs, and projection displays.

To estimate active-mode power draw, we developed the linear regressions in Table 7-7 based on large measurement datasets from ENERGY STAR and the California Energy Commission Appliance Database (EPA 2016, CEC 2016).[26] We then applied these regressions to the TV models represented in the CE Usage Survey based on user-reported display type, screen size, and production year.

Table 7-6. Power draw estimates for TVs by usage priority and display type.

USAGE	ON MODE (W)					PASSIVE STANDBY (W)				
PRIORITY	LCD	PDP	CRT	Proj.	ALL	LCD	PDP	CRT	Proj.	ALL
TV1	81	129	105	171	**89**	0.6	0.6	4.0	4.0	**0.8**
TV2	64	140	95	166	**72**	0.7	0.6	4.0	4.0	**1.0**
TV3	55	127	100	197	**68**	0.8	2.1	4.0	4.0	**1.3**
TV4+	57	105	103	134	**63**	0.8	0.2	4.0	4.0	**1.2**
Wt. Avg.	**69**	**130**	**100**	**173**	**77**	**0.7**	**0.8**	**4.0**	**4.0**	**1.0**

Source: CE Usage Survey, after reclassifying displays

Table 7-7. Television power regressions by screen area, display type, and year.

DISPLAY	YEAR	ON (W) = $C_1 + C_2 \cdot A$ (in.^{2})			STANDBY (W)		N	SOURCE
		C_1	C_2	R^2	mean	SD		
LCD	2014-2015	8.8	0.062	0.63	0.3	0.1	1,570	EPA, CEC (2016)
	2011-2013	11.8	0.079	0.54	0.3	0.2	6,163	EPA, CEC (2016)
	2008-2010	11.2	0.174	0.83	0.5	0.2	853	EPA, CEC (2016)
	2001-2007	24.2	0.224	0.90	1.7	4.8	138	EPA, CEC (2016)
PDP	2014-2015	20.5	0.074	0.42	0.3	0.1	23	EPA, CEC (2016)
	2011-2013	-53.9	0.163	0.70	0.2	0.2	269	EPA, CEC (2016)
	2008-2010	-3.4	0.239	0.70	0.4	0.2	115	EPA, CEC (2016)
	2003-2007	61.6	0.299	0.57	4.3	8.1	27	EPA, CEC (2016)
Projection	2005-2007	87.5	0.070	0.61	4.0	-	10	EPA, TIAX (2008)
CRT	2006	60.0	0.100	0.91	4.0	-	-	TIAX (2007, 2008)

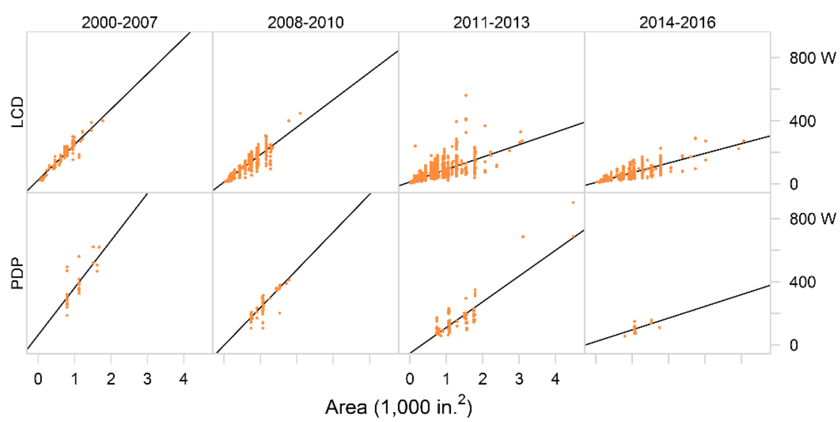

Figure 7-5. On-mode power regressions for LCD and Plasma TVs.

[26] Another source, not considered here due to potential duplication, is DOE's Compliance Certification Database.

The voluntary ENERGY STAR program develops progressively stringent limits for maximum on-mode power draw based on screen area and resolution, and qualified units typically account for more than 80% of total annual shipments (Figure 7-6, EPA 2016). The regressions were based on datasets that included both qualified and non-qualified TVs models. Lacking unit shipment data, we assumed these datasets sufficiently represent the actual installed base.

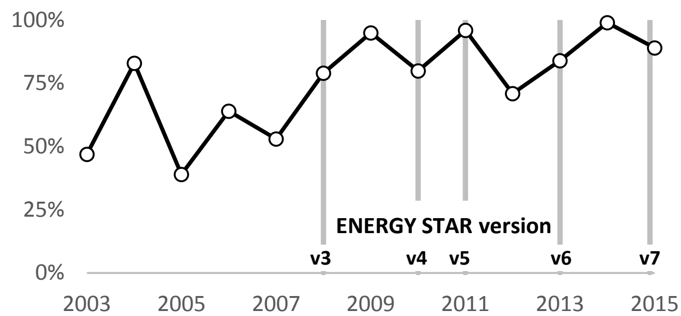

Figure 7-6. Market share of ENERGY STAR qualified televisions by year.

Brightness settings can have a pronounced effect on TV active-mode power draw. Most TVs ship with pre-programmed viewing *modes* that users can select to tailor the viewing experience to specific types of content, such as sports, movies, or games. Users can also enable or disable automatic brightness control, which adjusts screen brightness based on ambient room lighting conditions, or they can manually adjust brightness settings independently. Depending on user selections, power draw could be affected in different ways, yet little is known about what settings are actually used (FhCSE 2017).

Power draw is normally tested in the *default* or *home* mode, but switching from default to maximum brightness could increase power draw by 50% or more (NRDC 2016, FhCSE 2017). ENERGY STAR (since v4.0 in 2010) requires the default brightness must be at least 65% as bright as the brightest preset picture setting (or 228 nits if the brightest setting is 350 nits or more). This should limit potential impacts of brightness variation.

Resolution and content can also affect power draw. A case study of nine models found that UHD TVs drew on average 10% more power when receiving native 4K content relative to FHD-1080p content (NRDC 2015). Most video input sources do not yet provide 4K content, though this will likely become more important as higher definition TVs become more prevalent.

Passive standby power draw was less than 1 W for most models sold since 2008, as this was a limit set by ENERGY STAR (v3.0 in 2008) and California regulations. The newest ENERGY STAR STANDARD (v7.0 in 2015) decreased this limit even further to 0.5 W. Further reductions to passive standby power, if achieved, would likely have only minor impact on overall energy consumption.

Active standby modes allow some internet-enabled smart TVs to remain connected and ready to stream content, download content, or access networks without delay when the TV is powered on. When enabled, these features could increase standby power significantly. Active standby power draw averaged about 11 W (n=35, EPA 2016), which is over 10 times higher than the typical passive standby. To qualify for ENERGY STAR, TVs must be shipped with the lowest power standby mode enabled by default, so users would have to manually enable these features for active standby power to apply. Our current estimates assume active standby is not significantly enabled; however, we evaluate an alternative assumption in the AEC uncertainty section.

7.2.2 Usage

Average per-television on-time was about 3.9 hours per day (6.1 for the primary television; Table 7-8). Usage varies by display type, with the usage of PDPs being substantially higher than other types. This may simply reflect the fact that PDP units tend to be the most-viewed TV in homes that have one.

The 2017 estimate is about 12% less than in 2013 but similar to the 2010 estimate. This could reflect a migration of TV viewing to other platforms, such as tablets, smartphones, and computers. It could also be an artifact of the appreciable uncertainty in the estimated on-time. Implications are discussed in the AEC uncertainty analysis section.

Table 7-8. Time spent in on-mode by usage priority and display type.

USAGE	ON MODE TIME (h/day)				
PRIORITY	LCD	PDP	CRT	Proj.	ALL
TV1	5.9	7.1	6.4	7.1	**6.1**
TV2	2.9	5.8	3.4	2.0	**3.1**
TV3	2.2	4.2	0.9	0.9	**2.1**
TV4+	1.3	2.3	0.7	0.7	**1.2**
Wt. Avg.	**3.7**	**6.3**	**3.0**	**3.6**	**3.9**

Source: CE Usage Survey, after reclassifying displays

7.2.3 Unit Energy Consumption

Television unit energy consumption was about 123 kWh/yr in 2017, a 30% decrease from 2013. At least two-thirds of the decline came from lower average active-mode power draw stemming from CRT retirement. The remainder was due to an apparent decrease in active mode usage.

Table 7-9. Unit energy consumption estimates for TVs by usage priority and display type.

USAGE	ON (kWh/yr)					OFF					TOTAL
PRIORITY	LCD	PDP	CRT	Proj.	ALL	LCD	PDP	CRT	Proj.	ALL	
TV1	175	336	245	446	**197**	4	4	26	25	**5**	**202**
TV2	69	296	117	118	**81**	5	4	30	32	**7**	**88**
TV3	43	195	33	66	**51**	6	15	34	34	**10**	**61**
TV4+	27	86	27	35	**28**	7	2	34	34	**10**	**38**
Wt. Avg.	**101**	**302**	**112**	**226**	**116**	**5**	**5**	**31**	**30**	**7**	**123**

Source: CE Usage Survey, after reclassifying displays.
Note: Higher uncertainty for lesser-used TVs. Proj. = projection.

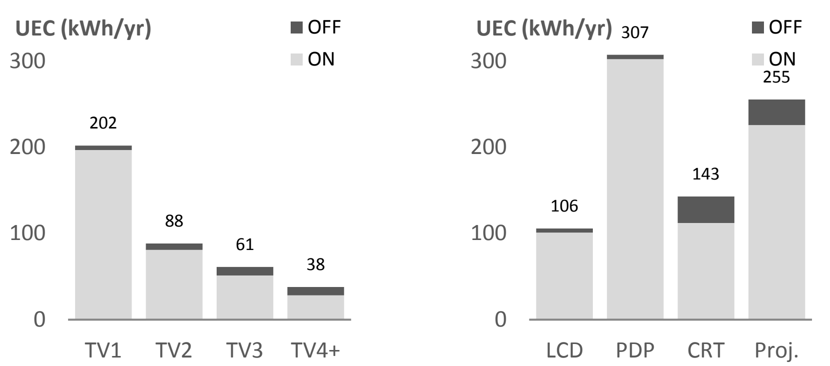

Figure 7-7. Unit energy consumption by usage priority and display type for televisions.

We estimated UEC based on usage and device characteristics from the CE Usage Survey. Respondents answered questions about the first four most-used TVs in a home, accounting for about 95% of installed units. We assumed that the remaining 5% of TVs had characteristics identical to the fourth-most watched

TVs. Since energy consumption depends on complex interactions between usage, screen size, display type, and age, we used a TV-priority model to account for these factors. Specifically, we calculated power draw and usage by mode for each television in the survey, and calculated their survey-weighted averages by display type and usage priority. From these values, we calculated the UEC by mode for each display type and usage priority. Finally, we calculated the overall UEC average by weighting according to installed base.

For comparison, a smaller regional field monitoring study found an average of 0.9 W in standby- and 94 W in on-mode, and on-time of 5.4 hours per day, for a UEC of 238 kWh/yr (n=95 TVs in Northern California homes in 2012, LBNL 2013). Due to the monitoring approach used (up to three devices monitored per home, not all for TVs), these results are biased towards primary TVs.

7.3 Annual Energy Consumption

Televisions consumed an estimated 35 TWh, with primary TVs accounting for two thirds of the total AEC. Although LCDs used the least energy per unit, they now account for about 70% of the total AEC due to their dominance (84%) in the installed base. Nearly all (94%) of the total AEC occurred in active mode, owing to very low (<1 W) standby power of most models sold in the past decade.

Table 7-10. Annual energy consumption breakdown for televisions.

USAGE	UNITS		SIZE	AGE	POWER (W)		USAGE	UEC (kWh/yr)			AEC (TWh)			
PRIORITY	**(millions)**	**%**	**(in.)**	**(yr)**	**ON**	**OFF**	**(h/d)**	**ON**	**OFF**	**TOTAL**	**ON**	**OFF**	**TOTAL**	**%**
TV1	115	40%	45	4.4	89	0.8	6.1	197	5	**202**	23	0.6	**23**	66%
TV2	83	29%	36	5.0	72	1.0	3.1	81	7	**88**	6.7	0.6	**7.3**	21%
TV3	49	17%	34	6.0	68	1.3	2.1	51	10	**61**	2.5	0.5	**3.0**	9%
TV4	24	8%	33	5.4	63	1.2	1.2	28	10	**38**	0.7	0.2	**0.9**	3%
TV5+	14	5%	32	5.2	63	1.2	1.2	28	10	**38**	0.4	0.1	**0.6**	1%
TOTAL/Avg.	**284**	**100%**	**39**	**4.9**	**74**	**1.0**	**3.9**	**116**	**7**	**123**	**33**	**2.1**	**35**	**100%**

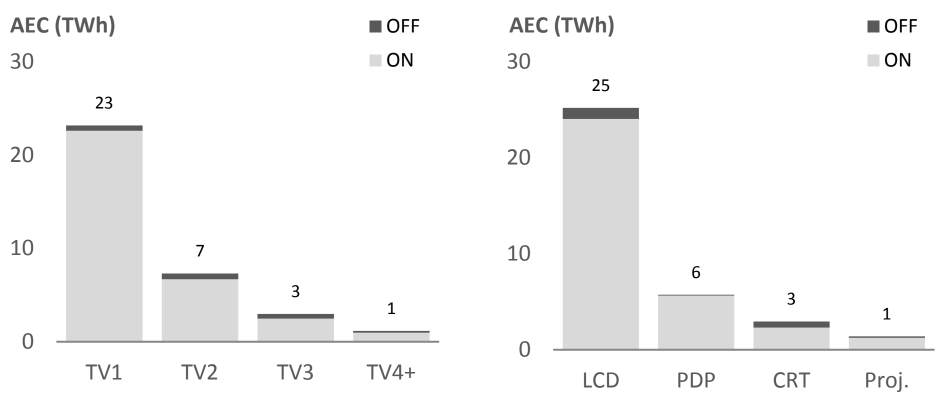

Figure 7-8. Annual energy consumption by TV priority and display type.

7.3.1 Uncertainty Analysis

Several elements contribute to the uncertainty in television AEC, including survey sampling error, the distribution of display types, the influence of user settings on power draw by mode, and active usage. We analyzed these factors independently relative to the current AEC estimate. Their net impact was determined by assigning a uniform probability distribution to each of the component uncertainties, modeling the overall AEC over 10,000 replications, and then reporting the inner 90%. We estimate the actual AEC is likely to be between 32 and 40 TWh (Table 7-11).

Table 7-11. Uncertainty estimates for televisions.

COMPONENT	AEC IMPACT	
	35 TWh	%
Installed Base Survey Sampling Error	±1.2	±4
Display Type Distribution	±2	±6
Active Mode Power Draw	-2 to +5	-5 to +15
Active Standby Power Draw	+1	+3
Usage Survey Time of Year	+2	+5
Usage Survey Day of Week	+1	+3
Usage Survey Sampling Error	±1.6	±5
NET IMPACT	**-3 to +5**	**-9 to +14**

Note: Components are interactive and not additive.

Installed Base and Usage Sampling Error

Since the installed base estimates for televisions were based on a weighted survey (n=1,009), we use the standard error of the mean (SE) to estimate random sampling error. At the 90% confidence level, we find the television installed base is 284±10 million (SE=6). This could affect AEC by about **±1.2 TWh**. Similarly, standard errors for the on-mode estimates of primary TVs were about 0.1 hours per day. At the 90% confidence level, the uncertainty is ±0.2 hours which could affect AEC by up to **±1.6 TWh**.

Display Type Distribution Uncertainty

When asked about their TVs, people were sometimes confused about the display type and answered incorrectly. Bias in these responses could have a pronounced effect on AEC. To partially address this issue, we reallocated TVs that were known to be classified incorrectly based on answers about screen size and age. However, it is likely that some models may still have been misclassified.

PDP units in particular, may be overrepresented in the survey responses, which would tend to increase the AEC. Since PDPs have been discontinued in the U.S., we would expect that their numbers to have declined somewhat in the past three years; however, they have remained stable. Indeed, in prior studies (FhCSE 2011, 2014), PDPs were known to have been overrepresented in the surveys and were appropriately adjusted, because the total number of user-reported PDPs exceeded the total cumulative sales. This suggests that PDPs may remain overrepresented in the current AEC estimates. Based on our current estimate, PDPs consumed 6 TWh. If up to half of these were misclassified and should be shifted to LCDs, the net effect could be up to -2 TWh.[27]

On the other hand, it is also possible that the sharp decline in reported CRT displays could at least partially be due to the fact that some people are unfamiliar with the term CRT or Tube TV and misclassified them as LCDs. This would tend to cancel out the overrepresented PDP effect. Ultimately, however, CRT and PDPs will eventually all be retired, so this is merely a question of when. We conservatively estimate the net uncertainty from display type misclassifications as **±2 TWh**.

Power Draw Brightness Setting Uncertainty

To assess brightness uncertainty, we assume that up to half of TVs had adjusted (non-default) brightness settings, and that these adjustments could reduce power by up to 10% or increase it by up to 30%, relative to the default settings implicit in the regression analysis. Switching from default to maximum brightness, for instance, could double the power draw for some models (NRDC 2016), though on average across many models, the maximum brightness preset power draw was about 18% higher than for the default mode (FhCSE 2017). To qualify for ENERGY STAR, the default mode typically must be at least 65% as bright as the brightest preset picture setting.[28] The actual brightness settings used in homes is not yet well

[27] Since PDP displays tend to be larger on average than LCDs, the effect would actually be slightly less.

[28] Or 228 nits if the brightest setting is 350 nits or more.

understood, and given the potential magnitude of the effect, it remains a topic for future study. Under these assumptions, brightness settings could impact AEC from **-2 to +5 TWh**.

Active Standby Mode Uncertainty

Active standby modes on smart televisions, when enabled, could draw about 10 W more than in passive standby (FhCSE 2017). Smart TVs are currently owned by about half of U.S. homes (CTA 2016), and about 27% of homes had at least one enabled smart TV (as of Q4 2016, Nielsen 2017). Assuming active-standby is only relevant to enabled smart TVs, this could affect standby power for about 32 million TVs. If half of these enabled smart TVs, or 16 million units, also had active standby mode enabled, this could increase their UEC by up to 73 kWh/yr and the total AEC by up to **+1 TWh**.

Usage Uncertainty

Active-mode usage per television estimated from the 2017 CE Usage Survey was about 12% less than in 2013. However, a similar increase (15%) was found from 2010 to 2013. This suggests that the change may not be statistically significant, and could simply reflect limitations of the underlying survey-based methods. For instance, a study of metered television usage (n>12,000, from 2007-2011) found that TVs were used on average for 4.4 hours per day in 2011 (7.1 hours for primary TVs), somewhat higher than self-reported in RECS surveys (Donovan et al. 2014).

Television usage varies with the day of week (more viewing on weekends) and time of year (more viewing during winter months), so depending on when a survey is fielded, its results may be biased bias to the extent that patterns during these days are not representative of the entire year (see also Donovan et al. 2014). The 2017 CE Usage Survey was conducted in May (Q2) over a Thursday through Sunday, and asked about usage “yesterday.” Indeed, quarterly usage data (Figure 7-9, Nielsen 2010-2017) confirm both an apparent decline in per-person viewing (about 5% from 2013 to 2016) and a pronounced seasonal viewing pattern (Q2 and Q3 usage is about 10% lower than Q1 and Q4, each within about ±5% from the annual average). Combined usage of DVD, Blu-ray and Video Game Consoles, which also contributes to total TV on time, has remained relatively unchanged during this period.

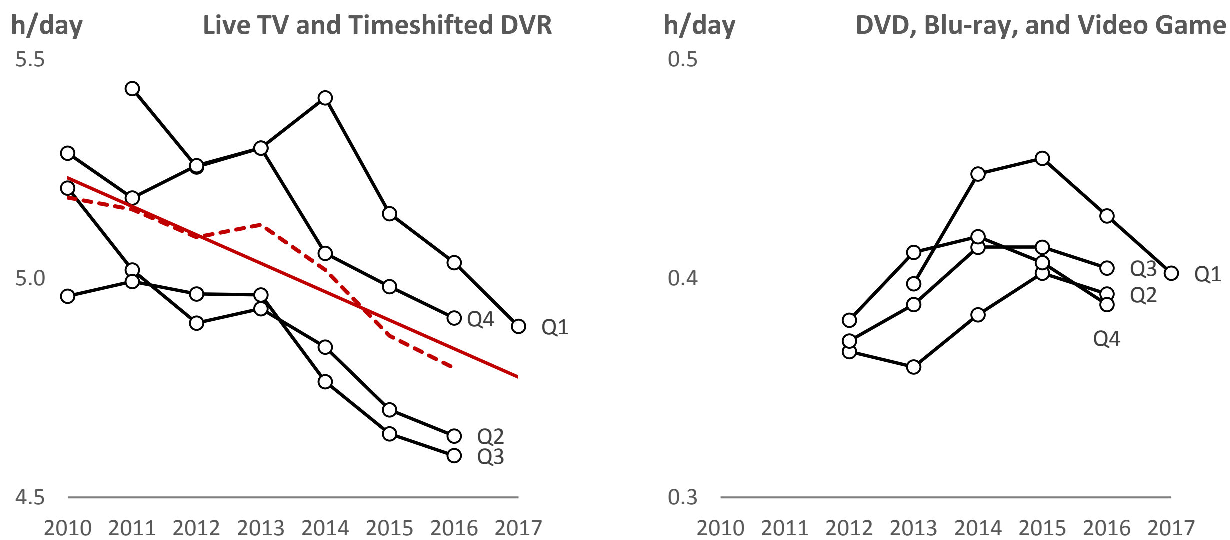

Figure 7-9. Television usage per day per person (age 2+) for several activities.
Based on Nielsen (2010-2017), trendline (solid red line) based on annual average (dashed red line).

Whereas the two prior CE Usage Surveys (FhCSE 2011 and 2014) took place in Q4, the 2017 survey took place in Q2. It is therefore plausible that the prior estimates overstated usage by about 5% and the current estimates understate usage by 5%. Since per-person usage does not map directly to television on-time, especially for homes with more than one TV or resident, it is not possible to directly adjust usage estimates based on these results. Instead, we estimate that usage uncertainty due seasonal variation is generally on the order of ±5%, and specifically here on the order of +5%. This is broadly consistent with fluctuations observed in other prior estimates for active mode usage, ranging from about 1,275 and 1,880 hours per year. Since usage is also proportional to AEC, the overall effect of usage uncertainty on the current installed base is about **+2 TWh**.

Usage also varies by day of the week. The CE Usage Survey was administered from Thursday to Sunday and asked about usage "yesterday", so weekday usage was oversampled (90% of weighted responses were for weekdays, whereas 71% would be ideal). Bin-based estimates from 2015 (DOE/EIA 2017) suggest that compared with weekdays, weekend-day usage is about 15% higher. This could increase current usage estimates by up to 3%, and AEC by up to **+1 TWh**.

7.3.2 Comparison with Prior Estimates

Televisions consumed about one third less energy (15 TWh less) than in 2013, continuing the trend from 2010 to 2013 (Table 7-12). This large decrease is because of two main factors. Most of the effect comes from a precipitous drop in the number of CRTs (60 million units retired) plus a 6% decline in the installed base of TVs generally (from 350 million in 2010 to 284 million in 2017). The remainder is due to an apparent 12% decline in the total active usage relative to the previous 2013 estimate.

It is not clear if this steeply declining AEC trend could continue much longer, since fairly few CRT, PDP, and projection TVs remain in service. And although active-mode LCD TV power draw per screen area has continued to decline, its decreases are smaller in magnitude than in prior years (FhCSE 2017).

Table 7-12. Prior energy consumption estimates for TVs.

YEAR	UNITS (millions)	POWER (W)		USAGE (h/yr)		UEC (kwh/yr)	AEC (TWh)	SOURCE
		ON	OFF	ON	OFF			
2017	284	77	1.0	1,410	7,350	123	35	Current
2013	301	90	1.6	1,605	7,155	166	50	FhCSE (2014)
2011	-	-	-	1,600	7,160	-	-	Donovan et al. (2014)
2010	353	104	3.0	1,390	7,370	183	65	FhCSE (2011)
2009	342	105	3.3	1,390	7,370	188	64	FhCSE (2011)
2006	275	111	4.0	1,880	6,880	244	67	TIAX (2008)
2006*	237	98	4.0	1,880	6,880	222	53	TIAX (2007)
2004*	234	100	3.9	1,275	7,485	156	37	NRDC (2005)
1998*	212	75	4.5	1,445	7,315	150	31	LBNL (1999)
1997*	229	60	4.0	1,460	7,300	117	27	ADL (1998)
1995*	191	77	4.0	1,500	7,260	141	26	LBNL (1998)

Note: * = Analog TVs only.

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8 SOUNDBARS

Soundbars are add-on speaker systems used to enhance the sound output of televisions. They normally include at least one wide horizontal speaker designed to fit above or below a television and may have separate wired or wireless speakers or subwoofers. Some models can connect to other audio sources over wireless connections (Wi-Fi, Bluetooth, etc.) in addition to the usual wired inputs. The main distinction from other kinds of home audio systems, such as audio receivers, home theater in-a-box, or shelf speaker systems, is their slim profile.[29] Soundbar energy use has not yet been evaluated in detail, so limited data were available for their power draw characteristics or usage patterns. To address these gaps, we relied primarily on the CE Usage Survey and in-store power measurements of several units.

8.1 Installed Base

About half of all speakers connected to televisions were soundbars, with about 20 million connected in 2017 (CE Usage Survey 2017). This is consistent with cumulative shipments for 2012-2016 (21 million units, CTA S&F 2016). The category is growing quickly, with sales of 7 million units projected for 2017. Another ownership survey estimated 37 million sound bars (22% of homes, 1.4 units per owner household, CTA O&M 2017), however this is likely an overestimate.[30] Our analysis assumes 20 million soundbars.

Owners indicated the number of speakers and subwoofers connected to their soundbars: about 12 million (61%) soundbars had a subwoofer, and 6 million (32%) had one or more external speakers. Although some reported having more than two external speakers or more than one subwoofer, these options are not common among available models. To simplify the analysis and to correct for unlikely responses, we reclassified speakers with the closest match to a 2.0, 2.1, 5.0, or 5.1-channel system (Table 8-2).

Table 8-1. Installed base estimates for soundbars.

YEAR	BASE	HOUSEHOLD PENETRATION	UNITS per OWNER HH	UNITS (millions)	SOURCE
2017	Plugged in	16%	1.1	**20**	CE Usage Survey (2017)
2017	Ownership	22%	1.4	**37**	CTA O&M (2017)
2017	Ownership	-	-	**21**	CTA S&F (2016)

Table 8-2. Installed base of soundbars (millions) by TV priority and number of speaker channels.

CHANNELS	TV1	TV2	TV3	TV4+	TOTAL	
2.0	5.6	1.2	0.2	0.1	**7.0**	35%
2.1	3.6	0.8	0.1	0.0	**4.6**	23%
5.0	1.1	0.2	0.0	0.0	**1.4**	7%
5.1	5.8	1.3	0.2	0.1	**7.4**	36%
TOTAL:	**16.1**	**3.5**	**0.5**	**0.2**	**20.3**	**100%**

Source: CE Usage Survey

8.2 Unit Energy Consumption

8.2.1 Power Draw

Soundbars can operate in several power modes, including what we define as:

ACTIVE	on and playing audio
IDLE	on, connected, and immediately ready to play audio
CONNECTED STANDBY	off but maintains network connections
SLEEP/OFF	lowest power mode, network connections are disabled

[29] Digital assistant devices, like the Amazon Echo or Google Home, are not considered soundbars and were not included in this study.

[30] The CTA O&M (2017) survey asked about the number of soundbars in the home, without providing a definition. This likely led some people to include non-sound bars in their responses, hence inflating the result. In contrast, the CE Usage Survey (2017) described briefly what a soundbar is and then asked about soundbars specifically connected to TVs, thus providing a more realistic estimate.

The actual modes experienced by products depend on their available features and how they are used. For instance, some can enter different power modes depending on what audio inputs are connected and whether wireless capabilities are available and enabled. Soundbars with wireless speakers or subwoofers require power to establish and maintain communications, and those that accept audio input signals from a wireless source (e.g., Bluetooth or Wi-Fi), must listen for that signal, which also draws power.

Limited power draw measurements were available for soundbars. We relied on data from the ENERGY STAR qualified products database, and we tested nine models in a major electronics retail store.[31]

ENERGY STAR Measurements

To qualify for ENERGY STAR, soundbars must have automatic power down (APD) functionality and sleep mode power draw less than between 1 and 4 W, depending on the configuration. If users can disable APD or set it longer than 2 hours, the audio equipment must also satisfy idle mode power limits. The qualified products database includes about 90 soundbars. For most models, power data were available for sleep, idle, and active modes (Figure 8-1).[32]

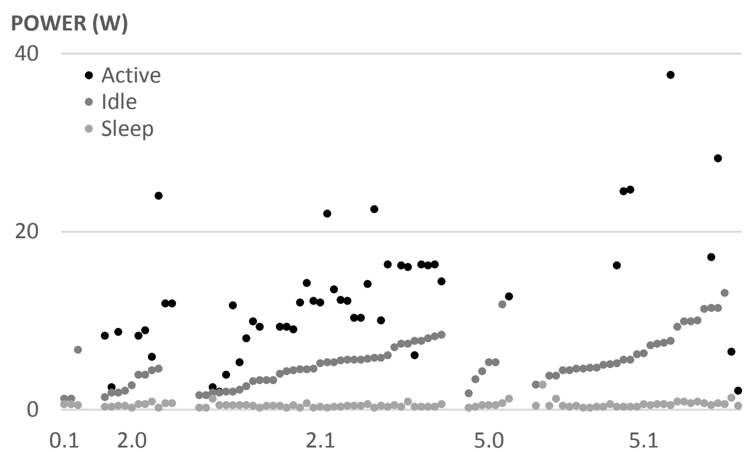

Figure 8-1. Power draw of ENERGY STAR qualified soundbars by number of channels.
Source: EPA (2017)

In-Store Measurements

Models tested in-store included both ENERGY STAR qualified and non-qualified devices. Due to hardware constraints,[33] we were limited in our ability to select different audio inputs and could not test network connected modes. When available, we measured subwoofer and external speaker power draw independently from the main soundbar unit. Using this limited sample, we estimated power draw for the most common soundbar configurations: those with no subwoofers, those with subwoofers, and those with subwoofers and external speakers (Table 8-3 and Table 8-4).

[31] We measured power with handheld loggers (Watt's-up Pro) at one-second resolution.

[32] For consistency, we mapped the number of speaker channels to the nearest of four configurations: (2.0, 2.1, 5.0, 5.1).

[33] The floor models we tested had special lockout features that disabled sleep mode and that limited the selectable audio inputs. As a result, we relied on the in-store audio signals to obtain active mode power draw for most tested devices. These signals were normally sourced through the optical-in channel. When possible, we also tested using a 1 kHz sine wave and an MP3 music audio source using a 3.5mm audio cable.

Table 8-3. Power (W) measurements for nine soundbars.

			SOUNDBAR-ONLY			SUBWOOFER-ONLY			SYSTEM TOTAL		
CH	MAKE	MODEL	ACT	IDLE	OFF	ACT	IDLE	OFF	ACT	IDLE	OFF
2.0	Insignia	NS-SB316	6.0	3.4	<1	-	-	-	6.0	3.4	<1
2.0	VIZIO	SB2920-D6(ES)	3.6	2.1	<1	-	-	-	3.6	2.1	<1
2.1	LG	SH3K	4.8	4.0	<1	5.1	3.9	<1	9.9	7.9	<1
2.1	Klipsch	RSB-11	8.1	7.8	<1	4.3	2.0	<1	12.4	9.8	<1
2.1	Klipsch	RSB-6	5.9	5.7	<1	3.9	2.1	<1	9.8	7.8	<1
2.1	Samsung	HW-M450/ZA(ES)	6.6	5.5	<1	3.8	4.1	<1	10.4	9.6	<1
2.1	Sony	HTCT290	7.7	6.6	<1	4.7	2.7	<1	12.4	9.3	<1
2.1	VIZIO	SB 3621n-E8M(ES)	3.6	2.4	<1	3.8	2.0	<1	7.4	4.4	<1
5.1	Samsung	HW-K950/ZA	-	12.3	4.8*	-	4.5	<1	25.4	25.1	5.8*

Source: In-store measurements

Notes: * = Off mode for this model was likely a connected standby mode. Manufacturer reports off-mode as <0.5 W.

ES = ENERGY STAR qualified

Table 8-4. Power draw (W) by mode estimates for measured soundbars.

SPEAKER	MAIN SOUNDBAR			+ SUBWOOFER			+ EXT SPEAKER (ea.)			= SYSTEM TOTAL		
CHANNELS	ACT	IDLE	OFF	ACT	IDLE	OFF	ACT	IDLE	OFF	ACT	IDLE	OFF
2.0	4.8	2.8	0.5	-	-	-	-	-	-	4.8	2.8	0.5
2.1	6.1	5.3	0.5	4.3	2.8	0.5	-	-	-	10.4	8.1	1.0
5.0	12.4	12.3	0.5	-	-	-	4.3	4.2	0.5	20.9	20.6	1.5
5.1	12.4	12.3	0.5	4.6	4.5	0.5	4.3	4.2	0.5	25.5	25.1	2.0

Source: Based on component average of in-store measurements.

Two models were also listed as ENERGY STAR qualified products. Despite differences in testing procedures, our measured values generally agreed with those reported by ENERGY STAR to within several watts.

For a 5.1-channel soundbar system (two external speakers and one external subwoofer), we tested power draw in stages by component and by power mode, see Figure 8-2. First, we plugged in the main soundbar only, and manually turned it off. Next, we sequentially plugged in the subwoofer, speaker 1 and speaker 2, each time waiting for the power to stabilize for a few minutes. Although the system was ostensibly off, judging by the 5 W draw, it was more than likely in a low power or networked connected mode and not fully in sleep or standby mode. Manufacturer product data specifications for this model claimed standby power draw of <0.5 W.

Next, we manually turned the system on by pressing the power button on the soundbar. With everything still connected (but not playing), the power rose to about 25 W. We then disconnected all but the main soundbar and again added devices back sequentially. This revealed that while on and ready, the main soundbar drew about 12 W, and each additional speaker or subwoofer drew another 4-5 W each.

Finally, with everything connected, we played an audio source and increased the volume to a moderate, loud, and maximum setting. Under normal volume, the power draw increased by less than 1 W from idle mode. At loud volumes, average power increased by about 6 W, and at the maximum volume, power increased by about 13 W, reaching a peak of 38 W.

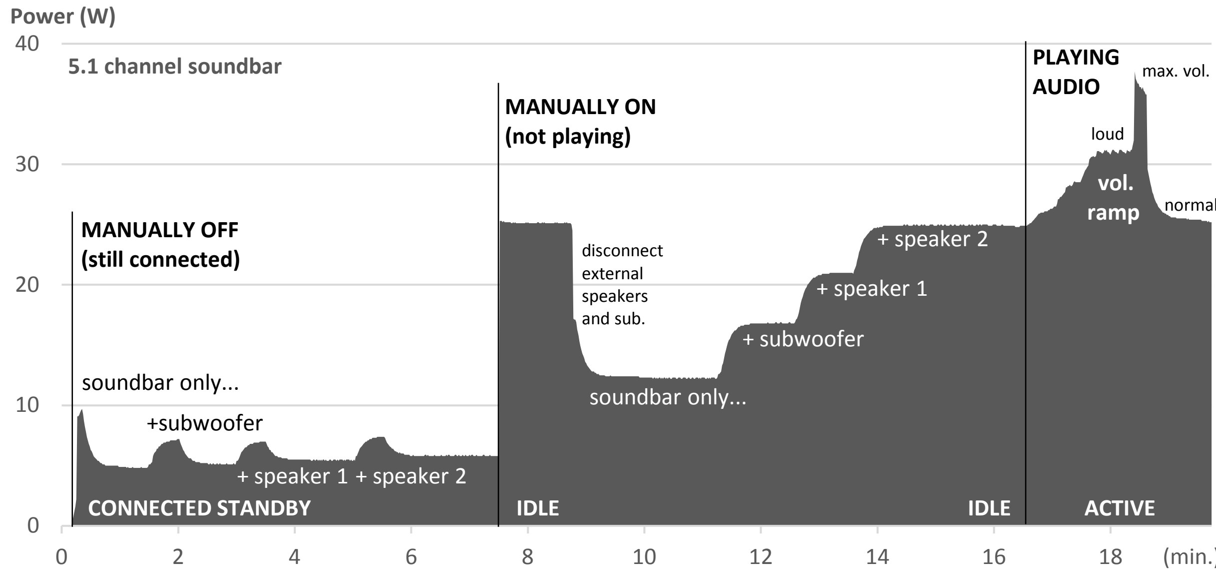

Figure 8-2. Power draw levels measured for a multi-channel soundbar.

Power Draw Estimates

ENERGY STAR qualified soundbars made up a significant but varying portion of the market (33% in 2015, 80% in 2014, and 62% in 2013; EPA 2017). Accordingly, we estimated average power draw as a straight average of the field measurement and ENERGY STAR values (Table 8-5). Due to the small sample of nonqualified units, there remains appreciable uncertainty about their power draw.

Table 8-5. Power draw (W) estimates used to calculate UEC for soundbars.

	ENERGY STAR			FIELD MEAS.			AVERAGE		
CHANNELS	**ACT**	**IDLE**	**OFF**	**ACT**	**IDLE**	**OFF**	**ACT**	**IDLE**	**OFF**
2.0	10.0	3.0	0.5	4.8	2.8	0.5	**7.4**	**2.9**	**0.5**
2.1	11.7	4.8	0.4	10.4	8.1	1.0	**11.1**	**6.5**	**0.7**
5.0	12.7	5.3	0.6	20.9	20.6	1.5	**16.8**	**13.0**	**1.0**
5.1	19.6	6.7	0.6	25.5	25.1	2.0	**22.6**	**15.9**	**1.3**

8.2.2 Usage

We estimate soundbars spent about 4 hours per day playing sound in active mode and about 5.5 hours in idle mode (Table 8-6), with the remainder in off and connected standby modes. Soundbar and television usage are closely related, and about 80% of soundbars were connected to the most-watched television in the home, based on the CE Usage Survey.

Table 8-6. Usage estimates for soundbars.

TV USAGE	UNITS (millions)			USAGE (h/day)		
PRIORITY	**TVs**	**% with SB**	**SBs**	**ACT**	**IDLE**	**OFF**
TV1	115	14%	16.1	4.4	5.7	13.9
TV2+	169	5%	4.2	3.2	5.5	15.4
TOTAL/Wt. Avg.	**284**	**7%**	**20.3**	**3.7**	**5.5**	**14.8**

Source: CE Usage Survey

We estimated active soundbar usage based on survey questions relating to the television, and based on how long people used their soundbar "yesterday." Many soundbars have features that can switch power modes based on what devices are connected. For instance, some turn on automatically whenever the television turns on. Others turn off automatically after a period of inactivity, or when the television is turned off. Automatic power down (APD) takes about 20 minutes on average to engage for ENERGY STAR qualified models (EPA 2014). Still others remain on and ready all the time. Some models continue to draw significant power even after they are apparently turned off. Since there are many combinations of models and settings, it is difficult to characterize precisely how much time soundbars spend in each mode.

We asked people about typical behavior when using their soundbar. About 72% reported their soundbars were turned off manually or with a remote at the end of the day. More than half (58%) indicated that their soundbars turned off automatically after a period of not producing sound. We validated these responses by asking about how the soundbar is normally turned on for the first time of the day. About 62% turned the soundbar on manually or with a remote control, and for a further 31% it turns on automatically with the television. Only 8% said that the soundbar was already on. Together, these responses suggest that most soundbars are turned off when not in use.

8.2.3 Unit Energy Consumption

We estimate that soundbars have an average unit energy consumption of about 65 kWh/yr. Actual values for specific soundbars ranged from 25-110 kWh/yr depending on number of channels. Knowing if a person believes their soundbar is off does not tell us what low power modes were actually being used. Soundbars can appear to be off, but may still be drawing power due to connectivity. Without knowing what portion of soundbars remained in a connected standby mode, we calculated energy use for the supposed off mode under two bounding assumptions (off=off, and off=idle; Table 8-7). As the actual value is likely somewhere in between, we used the average of these cases for both the UEC and AEC calculations.

Table 8-7. UEC and AEC calculation for soundbars.

SPEAKER CHANNELS	UNITS (millions)	POWER (W)			UEC (kWh/yr)				AEC (TWh)			
		ACT	IDLE	OFF	ACT	IDLE	OFF	TOTAL	ACT	IDLE	OFF	TOTAL
2.0	7.0	7	3	1.7	9	6	9	**25**	0.07	0.04	0.06	**0.2**
2.1	4.6	11	7	3.6	15	14	19	**48**	0.07	0.07	0.09	**0.2**
5.0	1.4	17	13	7.0	23	26	38	**87**	0.03	0.04	0.05	**0.1**
5.1	7.4	23	16	8.6	31	32	46	**110**	0.23	0.24	0.34	**0.8**
TOTAL/Wt. Avg.	**20.3**	**14**	**9**	**5.0**	**19**	**19**	**27**	**65**	**0.39**	**0.38**	**0.55**	**1.3**
	h/day:	3.7	5.5	15								

Note: Off-mode includes both fully-off and connected standby modes, assumed to be used in equal proportions.

8.3 Annual Energy Consumption

We estimate that soundbars consumed about 1.3 TWh.

8.3.1 Comparison with Prior Estimates

Since this is a newly studied category, we compared usage and energy consumption estimates with similar home audio categories from prior studies. Usage, UEC, and AEC are all in line with similar product categories such as mini-shelf stereo systems, home theater in a box, and speaker docks (Table 8-8). Active mode power draw for soundbars was about half as high as other stereo systems.

Table 8-8. Prior energy consumption estimates for audio categories.

YEAR	DEVICE	UNITS (millions)	POWER (W) ACT	POWER (W) IDLE	POWER (W) OFF	USAGE (h/yr) ACT	USAGE (h/yr) IDLE	USAGE (h/yr) OFF	UEC (kWh/yr)	AEC (TWh)	SOURCE
2017	Soundbar	20	14	9	5.0	1,345	2,025	5,390	65	1.3	Current
2013	Soundbar*	16	30	12	4.0	1,580	730	6,450	82	1.3	FhCSE (2014)
2013	Mini-shelf Stereo	64	30	12	4.0	1,241	949	6,570	75	4.8	FhCSE (2014)
2013	Home Theater	20	38	34	0.6	1,580	730	6,450	89	1.8	FhCSE (2014)
2013	Speaker Dock	98	5	3	1.3	1,205	2,007	5,548	19	1.9	FhCSE (2014)
2010	Mini-shelf Stereo	63	32	-	4.3	2,482	-	6,278	105	6.6	ECW (2010)

Note: * = Prior preliminary soundbar estimate assumed power draw by mode of mini-shelf stereo and usage of home theater in a box.

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9 SET-TOP BOXES

Set-top boxes (STBs) receive and decode signals for playback on televisions. Features and services vary by service provider, subscription package, and hardware, and may include multiple tuners, video-on-demand, digital video recording (DVR) capabilities, and more.

Subscription STBs are normally leased to consumers by multichannel providers (cable, satellite, and telco). Normally each television in the home must be connected to a STB to receive content. **Standalone** STBs are sold directly to consumers and include digital-media streaming devices, standalone DVRs, and over-the-air digital-to-analog adapters. The following detailed analysis addresses subscription STBs only, which account for the vast majority of STB energy use. Updated estimates for the installed base of standalone STBs are included in the "Other Devices" section of this report.

Among subscription STBs, we analyzed four main device types including: DVR, non-DVR, thin client, and cable DTA. Both **DVR** and **non-DVR** boxes can interface directly with the provider to access content. **Thin client** boxes, in contrast, access content through other gateway or server STBs in the home. Since they rely on other boxes for some core processing functionality, thin client power draw tends to be much lower than DVR and non-DVR boxes. **Cable digital television adaptor (DTA)** boxes are basic STBs that convert digital cable signals for direct viewing on televisions. Within each of these categories, capabilities and power draw can vary substantially.

The set-top box industry adopted a voluntary agreement to drive energy efficiency improvements (NCTA 2014). As part of the agreement, 90% of devices purchased after Jan. 1, 2014 were required to meet ENERGY STAR v3.0 efficiency standards, with the goal of reducing unit energy consumption by 10-45% (depending on box type) by 2017. The voluntary agreement also includes additional energy efficiency provisions, including light sleep capabilities, automatic power down features, and whole-home DVR solutions being made available as an alternative to multiple in-home DVRs for subscribers. Annual reporting includes third-party laboratory and field testing measurements of device power draw, sales-weighted energy use, and procurement data by type, resulting in higher certainty in UEC and AEC estimates than in prior studies.

9.1 Installed Base

The installed base of subscription set-top boxes has remained stable from 2012-2016, at around 230 million units (Table 9-1; D+R 2016). These estimates, provided in the voluntary agreement annual reports, were developed using a stock model and are likely the best available.[34] We used these values and projections for the subsequent energy analysis. While the number of DTAs and DVRs have remained stable, there has been a shift away from non-DVRs towards thin client devices.

Table 9-1. Installed base (millions) estimates by year for subscription set top boxes.

	VOLUNTARY AGREEMENT: D+R (2016)					SNL (2017)		DOE/EIA (2017)
TYPE	**2012**	**2013**	**2014**	**2015**	**2016p**	**2015**	**2016**	**2015**
DVR	54	54	55	54	53	61	62	82+
Non-DVR	136	130	123	113	103	158	157	101+
Thin Client	2	11	20	29	41	3	7	-
Cable DTA	33	32	32	31	31	31	34	-
TOTAL	**225**	**227**	**229**	**227**	**229**	**253**	**260**	**-**

Notes: Voluntary agreement estimates are likely the most accurate.
Projection (2016p) linearly extends D+R 2014-2015 trend for all types and is used in this analysis.
DOE/EIA asked about 0, 1, 2, or 3+ boxes (by type), so their totals assume a max. of three boxes per home.

[34] For a comparison of stock estimates, see Hardy

Other market research estimated a slightly higher overall installed base (253 and 260 million in 2015 and 2016; SNL Kagan 2017) and did not reflect the shift toward thin clients. Prior estimates derived from a consumer survey broadly agreed (237 million in 2013; FhCSE 2014), though thin clients were apparently underrepresented and non-DVRs overrepresented in that study as well. Data from a DOE/EIA survey (2017) generally agreed with the number of non-DVRs, but apparently well-overestimated the number of DVRs, indicating limitations of survey-based methods for identifying the installed base. We estimate the potential implications of these differences on AEC in the uncertainty analysis subsection.

9.2 Unit Energy Consumption

9.2.1 Power Draw

On- and standby-mode power draw by box type and year shipped (Table 9-2 and Figure 9-1 [n=291]; D+R 2014-2016), have decreased slightly for all device types over the past several years. The average power draw values shown in Table 9-2 are straight averages across all models and are not shipment-weighted. For this reason, we did not use these power draw values directly in the energy analysis.

Overall, thin client boxes draw two to three times less power than most fully-featured STBs. The large spread in power draw among models of a given type (Figure 9-1) emphasizes the importance of using sales-weighted data when calculating unit and annual energy consumption. Although standby power was as much as 5 W less than on-mode, the average difference was only 1-3 W. Consequently, UEC remains relatively insensitive to usage patterns.

Table 9-2. Average power draw across models by year shipped for set top boxes.

	ON (W)				STANDBY (W)				
TYPE	**2013**	**2014**	**2015**	**ALL**	**2013**	**2014**	**2015**	**ALL**	**n**
DVR	23	22	20	**22**	21	20	18	**19**	129
Non-DVR	14	13	13	**13**	12	12	11	**12**	107
Thin Client	7	7	7	**7**	6	6	5	**6**	33
Cable DTA	6	6	5	**6**	6	6	5	**6**	22

Source: D+R (2014-2016). Unweighted average across models.

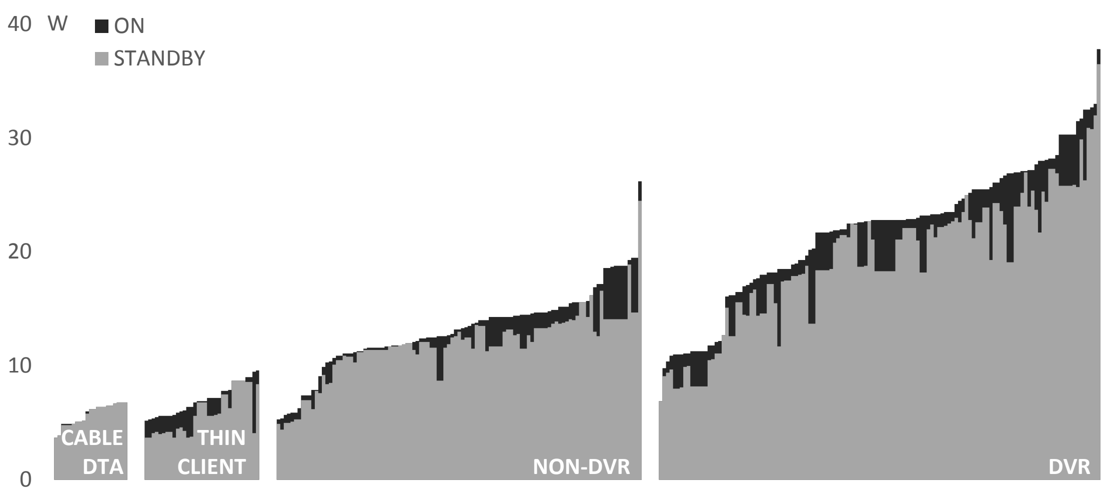

Figure 9-1. Power draw of subscription set-top boxes by type.
Source: D+R (2014-2016)

9.2.2 Usage

Since power draw varies only slightly with mode, the UEC and AEC estimates for STBs are not very sensitive usage-by-mode estimates. DVR and non-DVR boxes are likely to remain on more of the time, since they receive content directly from the provider and may be recording or serving content to other boxes in the home. Thin client and cable DTA boxes have greater potential to enter standby without causing disruption to viewers. However, since these boxes tend to draw far less power than DVR and non-DVR boxes, the relative energy impact of this shift is small.

Unlike other device categories analyzed in this report, we based the energy use estimates of STBs on the weighted UEC values from D+R (2014-2016). The UEC values were based on ENERGY STAR v4.1 usage profiles that depend on default automatic power-down (APD) settings (EPA 2014). When APD features are unavailable or disabled by default, daily usage was 14 hours on and 10 hours sleep. When APD was available and enabled, formulas shifted some time from on- to sleep-mode. If APD modes become more common among devices it may become necessary to evaluate usage by mode in greater detail.

9.2.3 Unit Energy Consumption

On average, we estimate that subscription STBs used about 112 kWh/yr in 2016, about 20% less than in 2012. Since 2013, the UEC of the DVR stock dropped by about 25%, with other types (except DTAs) showing smaller decreases.

Procurement-weighted unit energy consumption values for subscription STBs were included in the voluntary agreement annual reports for all new equipment shipped from 2013-2015 (Table 9-3; D+R 2016). Unit energy consumption data for the 2012 installed base were also provided. Based on the UEC, installed base, and shipment data, we modeled the evolving stock of equipment by vintage to obtain the current UEC values for 2016. For each year, we added the newly shipped stock and retired the oldest remaining stock to reach the target annual installed base totals. This produced the average UEC values by year and equipment type (Table 9-3).

Table 9-3. Unit energy consumption by year for subscription set top boxes.

	UEC of PROCURED STOCK					UEC of INSTALLED BASE (kWh/yr)				
TYPE	**2013**	**2014**	**2015**	**2016p**		**2012**	**2013**	**2014**	**2015**	**2016p**
DVR	195	179	171	162		267	251	230	211	**188**
Non-DVR	109	103	92	83		119	118	116	114	**110**
Thin Client	51	50	49	48		90	57	54	53	**50**
Cable DTA	58	49	47	44		39	40	41	44	**46**
					AVG	**142**	**136**	**127**	**120**	**112**

Source: Installed base UEC modeled based on procured stock (D+R 2016)

9.3 Annual Energy Consumption

Set-top boxes used an estimated 25 TWh (Table 9-4). AEC was calculated by multiplying the UEC by the installed base for each type of STB. Consumption declined steadily from 2012 to 2016, with the largest reductions coming from the improved efficiency of DVR and thin clients, and the shift away from non-DVR units towards thin clients.

Table 9-4. Annual energy consumption (TWh) by year for subscription set top boxes.

TYPE	**2012**	**2013**	**2014**	**2015**	**2016p**
DVR	14	14	13	11	**10**
Non-DVR	16	15	14	13	**11**
Thin Client	0	1	1	2	**2.1**
Cable DTA	1	1	1	1	**1.4**
TOTAL	**32**	**31**	**29**	**27**	**25**

Source: Based on D+R (2016)

9.3.1 Uncertainty Analysis

The installed base represents the greatest source of uncertainty. Overall estimates of the total number of boxes from the voluntary agreement were about 14% less than a separate market research source (SNL

Kagan 2017). Even though the voluntary agreement stock models were based on actual procurement data, and are likely the most accurate estimates available, they still relied on assumptions about the number of boxes installed per subscriber, and carry some uncertainty. Using the difference in these two installed base estimates as a proxy for uncertainty, we estimate that the actual energy use of STBs is between 25 and 28 TWh.

The distribution of box types also differed by source, with SNL Kagan estimating far fewer thin-client boxes installed. However, unless providers have procured many thin-client boxes that are not being used, the voluntary agreement estimates are probably more accurate. As providers change their promotions and offerings, the number and distribution of boxes per subscriber can change with time, making it especially challenging to estimate this with precision.

9.3.2 Comparison with Prior Estimates

Relative to 2013, we estimate that the AEC for subscription STBs has declined by about 6 TWh or about 20%, even as the total number of units remained relatively unchanged (Table 9-5).

Since the methodology for this analysis differs from the survey-based methods used in FhCSE (2014), direct comparisons to those results are less meaningful. Specifically, we now estimate that AEC for 2013 was about 31 TWh, while FhCSE (2014) estimated 28 TWh. This difference highlights the inherent uncertainty in survey-based methods for identifying the installed base, as well as the limitations of using fleet-average power draw instead of sales-weighted values. That said, the results of the two approaches are similar, i.e., within 10% (or 5% if adjusted for the installed base).

Table 9-5. Prior energy consumption estimates for subscription STBs.

YEAR	UNITS (millions)	POWER (W)		USAGE (h/yr)		UEC (kWh/yr)	AEC (TWh/yr)	SOURCE
		ON	SLEEP	ON	SLEEP			
2016	227	13	12	-	-	112	25	Current
2015	227	13	12	-	-	120	27	Current
2014	229	14	12	-	-	127	29	Current
2013	227	14	12	-	-	136	31	Current
2012	225	14	12	-	-	142	32	Current
2013	239	15	13	4,790	3,970	119	28	FhCSE (2014)
2010	179	16	14	4,300	4,460	131	23	FhCSE (2011)
2008	106	-	-	-	-	189	20	LBNL (2010)
2006	147	16	15	2,970	5,790	132	19	TIAX (2007)

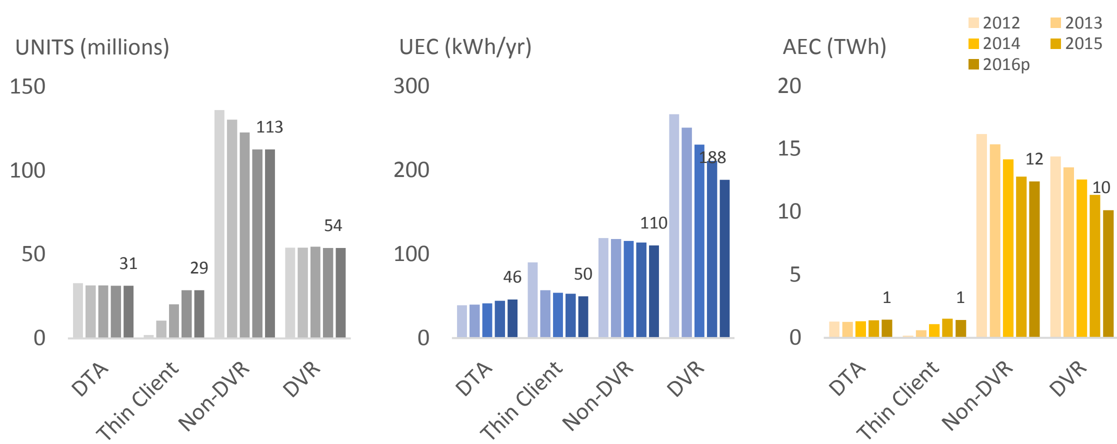

Figure 9-2. Installed base, UEC, and AEC of subscription set-top boxes by type.

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10 VIDEO GAME CONSOLES

Video game consoles include various generations of the Sony PlayStation, Nintendo Wii, and Microsoft Xbox. We excluded the Nintendo Switch from this analysis, as it just launched in Mar. 2017, just prior to the CE Usage Survey. Portable or handheld gaming systems, such as the Sony PlayStation Vita and the Nintendo 3DS, are considered separately in the "other devices" category since their energy characteristics are quite different. Ownership and usage estimates were primarily based on the CE Usage Survey.

10.1 Installed Base

We estimate there were 105 million video game consoles installed in 2017 (see Table 10-1 and Figure 10-1) based on the CE Usage Survey. This represents a nearly 20% decline since 2013 (FhCSE 2014), a trend also noted in CTA (O&M 2016, 2017). The CE Usage Survey specifically asked about the PlayStation 2, 3, and 4, the Nintendo Wii and Wii U, the original Microsoft Xbox, the Xbox 360, the Xbox One, and the most recent Xbox One S. We compared installed base estimates with available U.S. sales data for each console to verify they did not exceeded the total number of units sold.

Seventh-generation consoles (Nintendo Wii, Sony Play Station 3, and Microsoft Xbox 360) accounted for about half of the installed base, while eighth-generation consoles (Xbox One, Xbox One S, PS4 and Wii U) accounted for about 40%. The Xbox 360 was sold in a variety of models from 2005 until it was discontinued in 2016, and at 20% of the installed base, it remains one of the most popular systems.

Table 10-1. Installed base of video game consoles.

DEVICE STATUS	HOUSEHOLD PENETRATION	DEVICES PER OWNER-HH	UNITS (millions)	SOURCE
Installed	36%	2.5	105	Current Study
Owned	39%	2.0	93	CTA O&M (2017)
Owned	40%	1.8	86	CTA O&M (2016)
Owned	48%	-	-	ESA (2017)

Note: Older consoles were likely underrepresented in CTA O&M, as survey questions mentioned only newer consoles as examples.

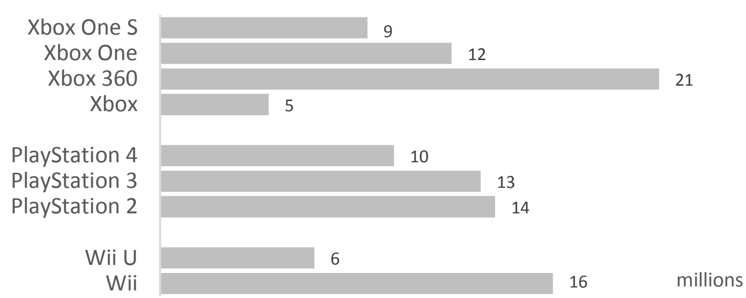

Figure 10-1. Installed base of video game consoles.

10.2 Unit Energy Consumption

Several power modes characterize gaming system energy consumption. Collectively, we refer to gaming, video streaming, and video playback as active modes. This "Active" mode time summed with time in "navigation" mode constitutes the total "on" time for each console.

GAMING	Console is on and a game is being played
VIDEO STREAMING	Console is on and audio/video is being played from a network
VIDEO PLAYBACK	Console is on and audio/video is being played by the DVD/Blu-ray drive
IDLE/NAVIGATION	Console is on is not being actively used
SLEEP/STANDBY	Power has been switched off, but the console remains plugged in

Additionally, many eighth-generation consoles have a semi-off mode referred to as “connected standby” or “networked standby” that keeps the system connected to the internet to automatically perform software updates and to quickly resume use.[35] Each console has different default standby modes and each allows for a range of control from the user. For instance, the Xbox One has an “energy saver” mode that is synonymous with traditional standby or off modes, as well as an “Instant On” mode that keeps the system running at low power. During initial setup, the user can decide what mode the system enters by default when shut off, and this can be changed in the settings.

The power draw for these modes for the most recent model of Xbox One is 10 W in Instant On and 0.4 W in Energy Saver. The original model of Xbox One shipped at release in 2013 had power draw values of 18 W and 0.5 W in Instant On mode and Energy Saver mode respectively. Based on data for a similar feature for the Wii (see FhCSE 2011), we estimate that 70% of eighth-generation system owners keep their system in connected standby modes all the time and 30% have their system shut down completely. This applies to the PS4, Xbox One, Xbox One S, and older Wii systems. The Wii U does allow for a connected standby to continue downloads but draws less than 1W in this mode.

Our assessment considers separate modes for “video streaming” and “video playback”, and the latter refers to any sort of non-internet use of video playback, such as with DVDs and Blu-Ray discs. The energy consumption characteristics of “Navigation” mode used in the previous study (FhCSE 2013) are very similar to those of the “idle” mode as defined in Hittinger et al. (2012) and in EPA’s specification for game consoles (EPA 2013). Consistent with our prior studies, we decided to use only the “navigation” mode in this study to describe time spent “on” but not “actively used.”

10.2.1 Power Draw

Estimates for power draw by mode are provided by console model, release year, and weighted by the installed base (Table 10-2). Values were collected from various sources, including manufacturer provided data (Microsoft, Nintendo) as well as prior studies (FhCSE 2011, 2014; NRDC 2008, 2014).

Video game console manufacturers regularly update their product lines over time. Thus, models with the same name may have different power draw characteristics depending on the year of release. We used the distribution of reported console ownership by year from the CE Usage Survey to estimate the models of each console still in use and weighted the power draw values accordingly.

In general, power draw in each mode has decreased in recent years as newer models of a console are updated and rereleased (Table 10-2). Sony’s release of the PS4 Slim in 2015 drew roughly 30% less power in all modes compared to its original PS4 system. The Xbox One S, while slightly different than the Xbox One, draws roughly 40% less power in gaming modes than its predecessor.

Standby power draw values for consoles equipped with both unconnected and connected standby modes were weighted by ownership distribution. As in FhCSE (2011), we estimated that 70% of these consoles used connected standby, while the other 30% used non-connected standby mode.[36] Sensitivity to this assumption is discussed in the uncertainty section.

The power draw values for most of the seventh and eighth generation consoles were provided by manufacturers (FhCSE 2014, Calland 2017, Jessop 2014, and Boxleitner 2014), and are consistent with measurements from other studies (Desroches et al. 2015, Hittinger et al. 2012, NRDC 2010). In addition, we used the values for the Microsoft Xbox and Sony PlayStation 2 from NRDC (2010). Notably, power draw

[35] We use the term connected standby

[36] This estimate closely matched the distribution of user-reported Xbox One settings (NeoGAF 2014), where 41 of 61 (67%) respondents reported having their console set to Instant On mode. In contrast, NRDC estimated that 10% of users disable connected standby mode.

while gaming varies significantly with gameplay and the product models used in testing (Koomey et al. 2017), so estimations and averages of collected values must be used.

Table 10-2. Installed base and power draw by mode of video game systems.

GEN	CONSOLE	YEARS	UNITS (millions)	%	POWER (W) GAME	VIDEO STREAM	VIDEO PLAYACK	NAV / IDLE	STANDBY AVG	STANDBY (W) NON-CON	CON
	NINTENDO										
8	**Wii U**	**2012-2017**	**6.4**	**6%**	**33**	**31**	**-**	**32**	**0.4**	**0.4**	**0.4**
7	**Wii**	**2006-2013**	**16.3**	**16%**	**16**	**16**	**-**	**14**	**4.8**	**1.0**	**6.5**
	MICROSOFT										
8	Xbox One S	2016-2017	8.6	8%	67	32	39	27	7.8	0.4	11
	Xbox One	2016-2017	-	-	106	63	68	72	11.3	0.5	10
	Xbox One	2013-2015	-	-	110	74	68	72	7.2	0.5	14
8	**All Xbox One**	**Wt. AVG**	**12.1**	**12%**	**108**	**69**	**68**	**72**	**9.2**	**0.5**	**13**
	Xbox 360 S/E	2010-2016	-	-	86	67	67	67	0.4	0.4	-
	Xbox 360	2005-2009	-	-	121	97	96	97	1.8	1.8	-
7	**All Xbox 360**	**Wt. AVG**	**20.7**	**20%**	**83**	**65**	**63**	**64**	**0.7**	**0.7**	**-**
6	**Xbox**	**2001-2008**	**4.5**	**4%**	**64**	**-**	**-**	**60**	**1.7**	**1.7**	**-**
	SONY										
	PS4 Pro	2016-2017	-	-	126	59	54	60	3.1	0.5	4.2
	PS4 Slim	2016-2017	-	-	79	48	44	44	2.3	0.5	3.1
	PS4	2013-2016	-	-	115	82	97	77	2.3	0.5	3.1
8	**All PS4**	**Wt. AVG**	**13.9**	**13%**	**107**	**72**	**79**	**68**	**2.6**	**0.5**	**3.5**
	PS3 Super Slim	2012-2016	-	-	82	62	74	68	0.2	0.2	-
	PS3 Slim	2009-2011	-	-	102	77	94	91	0.7	0.7	-
	PS3	2008	-	-	137	112	126	115	1.3	1.3	-
	PS3	2007	-	-	190	160	178	165	1.4	1.4	-
	PS3	2006	-	-	220	166	209	188	1.5	1.5	-
7	**All PS3**	**Wt. AVG**	**13.3**	**13%**	**104**	**81**	**95**	**88**	**0.5**	**0.5**	**-**
6	**PS2**	**2000-2012**	**9.7**	**9%**	**24**	**24**	**24**	**24**	**1.7**	**1.7**	**-**
		TOTAL/AVG	**105**	**100%**	**71**	**50**	**48**	**52**	**3.2**	**-**	**-**

Note: CON = connected standby, NON-CON = non-connected standby.
STANDBY AVG is a weighted average of connected (70%) and non-connected (30%) standby.

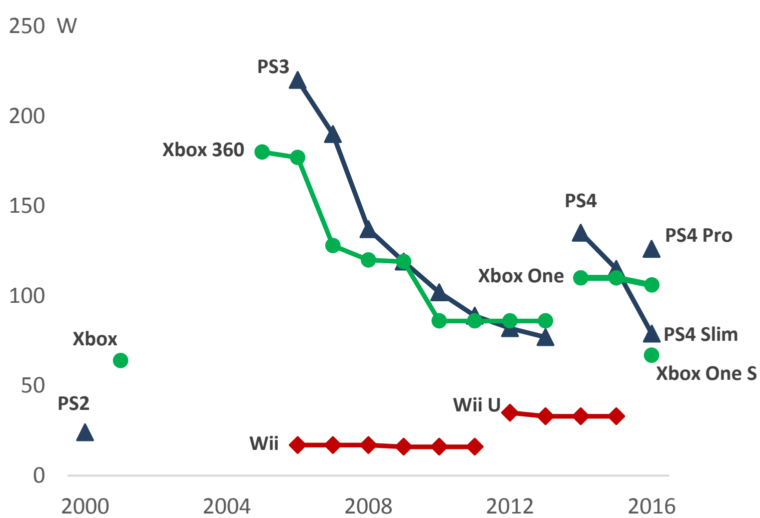

Figure 10-2. Active mode power draw trends of video game consoles over time.

10.2.2 Usage

Annual usage by mode was modeled based on the CE Usage Survey (Table 10-1 and Figure 10-3). Daily usage averaged 1.5 hours in any active mode and 0.5 hours in navigation mode (on but not being used).[37] This compares to values found for 2013 of 1 hour in active modes and 2.4 hours in navigation mode per day (FhCSE 2014). Overall, about one third consoles were used "yesterday." Of those, the average console remained on for 5.7 hours and was actively used for 4.3 hours. Older consoles were used far less for gaming than newer ones, but continued to be used for their video streaming and playback capabilities. The Xbox One S, Xbox One, and PS4 were used the most at over two hours per day.

Table 10-3. Annual usage by mode (hours/year) for video game consoles.

CONSOLE	YEARS	GAME	VIDEO STREAM	VIDEO PLAYBACK	ACTIVE MODES	NAV/ IDLE	STANDBY/ SLEEP
NINTENDO							
Wii U	2012-2017	91	146	-	237	38	8,445
Wii	2006-2013	14	52	-	66	105	8,589
MICROSOFT							
Xbox One S	2016-2017	517	128	236	881	607	7,272
Xbox One	2013-2017	541	252	148	941	421	7,398
Xbox 360	2007-2013	405	274	229	908	100	7,753
Xbox	2001-2008	211	-	-	211	55	8,495
SONY							
PlayStation 4	2013-2017	572	243	43	858	315	7,587
PlayStation 3	2006-2008	123	161	25	309	123	8,328
PlayStation 2	2000-2013	95	64	4	163	34	8,563
TOTAL/Wt. AVG		**300**	**168**	**90**	**558**	**198**	**8,003**

Source: Based on CE Usage Survey
Notes: ACTIVE = GAME + VIDEO
* = higher uncertainty (<10 people reported positive on-time).

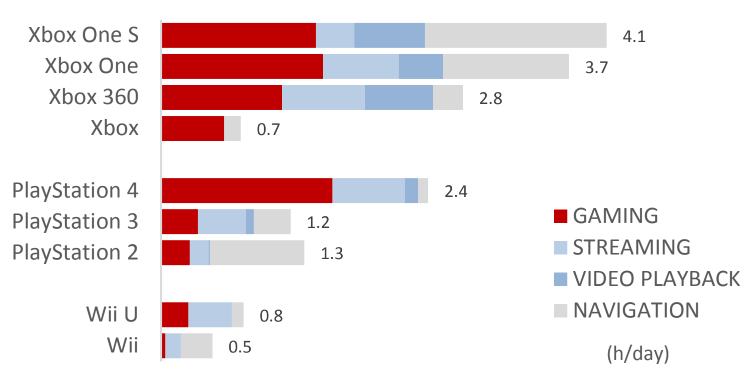

Figure 10-3. Daily time spent in active and navigation modes by console type.

Responses from all console owners were used in calculating both installed base and usage times. From each owner's response, we constructed usage profiles of the time spent in each of the active, idle, and sleep modes. The overall "on time" was adjusted based on the respondent's reported auto power down settings for each console. The time spent in navigation/idle mode, was taken as the difference between total on- and active-times. Remaining time was assigned to standby/sleep mode. For some consoles, few

[37] A meta study estimated that high-definition consoles spent 1.06 h/day in gameplay, 0.71 for video, 0.13 other, 20.9 in standby/off and 1.2 in connected standby (Webb et al. 2013), fairly similar to our current estimates.

respondents reported any usage "yesterday," so the corresponding breakdowns carry greater uncertainty.[38]

About 90% of consoles surveyed were reported to be off before the first use of the day, that is, someone had to actively turn it on before using it. Furthermore, most owners reported newer generation consoles having an auto-off feature enabled, with an estimated time delay of just under two hours on average. Thus, instead of remaining fully on after use, most consoles eventually transition to a standby mode. If a console lacked auto-power down capabilities and was found "already on" before the first use, we assume it was on all the time.

Table 10-4. Power management for video game consoles.

CONSOLE	AUTO OFF?	AUTO OFF DELAY (hr)	USE VOICE-ON FEATURE?	OFF BEFORE FIRST USE?
NINTENDO				
Wii U	56%	1.5	-	92%
Wii	35%	1.4	-	92%
MICROSOFT				
Xbox One S	69%	1.8	12%	86%
Xbox One	77%	1.4	7%	92%
Xbox 360	60%	1.9	-	86%
Xbox	24%	1.3	-	98%
SONY				
PlayStation 4	73%	1.5	-	83%
PlayStation 3	60%	2.4	-	89%
PlayStation 2	38%	2.5	-	88%
Wt. AVG	**57%**	**1.8**	**-**	**89%**

Source: CE Usage Survey
Note: Self-report values may be inconsistent with actual console features.

10.2.3 Unit Energy Consumption

The Unit Energy Consumption for each console is based on the calculated usage profiles, modeled ownership distributions, and weighted average power draw values (Table 10-5 and Figure 10-4). Across all installed consoles, the average UEC was 79 kWh/year. Eighth-generation consoles (PS4, Wii U, Xbox One, Xbox One S) averaged 123 kWh/year. Excluding the Wii U, which has much lower power draw and usage characteristics, the remaining eighth-generation consoles averaged 144 kWh/year.[39]

[38] Notably, the percentage of owners who used their respective consoles "yesterday" was 12% for Wii, 21% for Wii U, and 14% for PS2. For newer consoles, this percentage was 48% for PS4, 46% for Xbox One, and 43% for Xbox One S.
[39] Others estimated a UEC of 102 kWh for high-definition consoles sold between 2005-2011 inclusive (Webb et al. 2014).

Table 10-5. Unit and annual energy consumption for video game systems.

CONSOLE	UNITS (millions)	UEC (kWh/year) GAME	VIDEO STREAM	VIDEO PLAYBACK	ACTIVE MODES	NAV/ IDLE	SLEEP/ STANDBY	TOTAL	AEC (TWh)
NINTENDO									
Wii U	6.4	3	5	-	8	1	3	**12**	**0.1**
Wii	16.3	0	1	-	1	2	41	**44**	**0.7**
MICROSOFT									
Xbox One S	8.6	35	4	9	48	16	57	**121**	**1.0**
Xbox One	12.1	59	17	10	86	30	68	**185**	**2.2**
Xbox 360	20.7	34	18	14	66	6	5	**78**	**1.6**
Xbox	4.5	14	-	-	14	3	14	**31**	**0.1**
SONY									
PlayStation 4	13.9	61	18	3	82	21	20	**123**	**1.7**
PlayStation 3	13.3	13	13	2	28	11	4	**43**	**0.6**
PlayStation 2	9.7	2	2	0	4	1	15	**19**	**0.2**
TOTAL/Wt. Avg.	**105**	**27**	**10**	**6**	**43**	**11**	**25**	**79**	**8.3**

Source: Based on CE Usage Survey

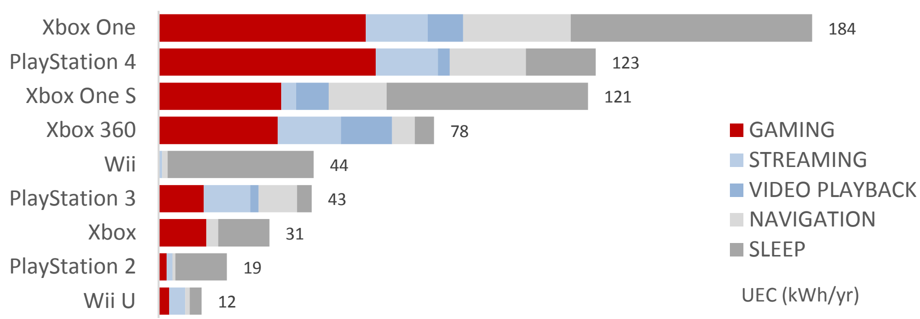

Figure 10-4. Unit energy consumption of video game consoles.

The Xbox One had the highest UEC values due to both higher usage and power draw. Most installed units were early edition models and had higher power draw values, mainly for connected standby mode. Usage among newer generation consoles, and especially the Xbox One and PS4, tended to be more frequent.

On average, eighth-generation consoles (PS4, Wii U, Xbox One, Xbox One S) draw about 80 W while gaming, 50 W in navigation, and 5 W in their combined standby modes. The higher active usage of these consoles, combined with their higher power draw values and longer periods spent in connected standby mode, result in much higher UEC values than prior generation consoles. The Wii U is the outlier of the eighth-generation consoles, as it was used less frequently and had lower power draw values in all active and navigation modes.

10.3 Annual Energy Consumption

Video game consoles in the U.S. consumed an estimated 8.3 TWh in 2017, with the breakdown by console type in Figure 10-5. Newer consoles represented the bulk of the consumption. Nearly half (46%) of the total energy use was attributed to inactive (idle/navigation, or standby modes).

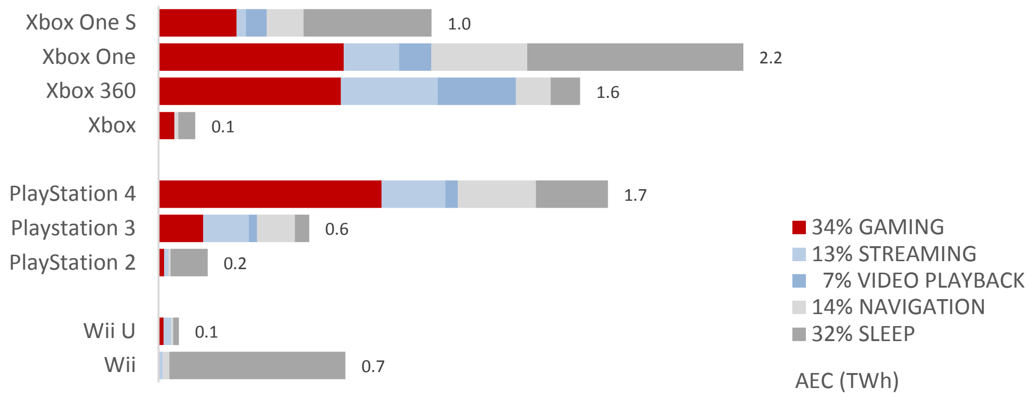

Figure 10-5. Annual energy consumption of video game consoles.

10.3.1 Uncertainty Analysis

Estimates of video game console energy use are sensitive to assumptions about standby modes and auto-power down functions, and to the estimates of usage and installed base. Here we examine the key components of uncertainty and their potential impact on AEC estimates. Based on the following analysis, we estimate the overall uncertainty to be about **±1.3 TWh.**

Table 10-6. Uncertainty estimates for video game consoles.

COMPONENT	AEC IMPACT	
	8 TWh	%
Installed Base Survey Sampling Error	±1.0	±12
Usage Sampling Error	±0.6	±7
Power Draw by Console Version	±0.5	±6
Connected Standby	±0.3	±4
NET IMPACT	**±1.3**	**±16**

Note: Components are interactive and not additive. Net impact is approximate.

Installed Base Sampling Error

Since the installed base estimates for video game consoles were based on a weighted survey (n=1,003), we use the standard error of the mean (SE) to estimate random sampling error. We find the installed base for video game consoles is 105 million (SE=9). At the 90% confidence level, the uncertainty is ±14 million, which could affect AEC by about **±1 TWh**.

Usage Sampling Error

Active mode usage had higher uncertainty than in other categories ±20%. Across all surveyed consoles, the mean daily active time (including zero) was 1.4 hours (SE=0.2). Excluding zero, the mean was 4.6 hours (SE=0.4). This suggests usage uncertainty was on the order of about ±15%. Exchanging 15% of active mode hours with sleep mode across all consoles yields an AEC impact of **±0.6 TWh**.

Power Draw by Console Version

Consoles of the same type but made in different years can vary in their power draw. For instance, the PS4 Slim used about 23% less power in gaming mode than the original PS4. To account for this, we weighted power draw values by console according to the reported ownership distributions from the CE Usage Survey. This assumes that the responses accurately reflect the true distribution of consoles and vintages. If one quarter of respondents mistakenly reported console vintage, AEC could change by up to **±0.5 TWh.**

Connected Standby

For eighth-generation consoles (Xbox One, Xbox One S, PS4) and the original Wii, we assumed a portion of standby time was spent in an internet-connected standby mode that draws more power than in non-connected standby. Of capable devices, we assumed 70% used connected standby mode and 30% used non-connected standby. Changing the distribution of connected to non-connected consoles to 80/20 or 60/40 impacts AEC by **±0.3 TWh**. In the extreme case, assuming no consoles used connected standby, AEC could be reduced by up to 2 TWh.

In the analysis, we included connected standby modes for the Wii, as its WiiConnect24 feature allowed for Internet; however, this feature was discontinued in June of 2013, so it is not clear how many Wii consoles can or do still use that mode. Assuming that the Wii only has a non-connected standby mode would change its AEC by -0.5 TWh.

Automatic Power Down

Doubling or halving the APD time delay (relative to user-responses) has only a minor effect on AEC ±0.1 TWh. More than half reported having APD enabled and most (90%) had to turn on their consoles for the first use, so we expect the sensitivity to APD to be minor. In the extreme case, assuming everyone shuts off their console after use, the AEC could change by up to -0.4 TWh.

10.3.2 Comparison with Prior Estimates

From 2013 to 2017, the installed base declined by about 18%, the average UEC by 10%, and the AEC by 25% (FhCSE 2014, Table 10-7). The change in installed base reflects the decline in the number of older systems, which exceeded the number of new-generation consoles that came into service. Specifically, the installed base for the Wii, Xbox, Xbox 360, PS2, PS3 declined by about 62 million units, while 35 million new Xbox One, Xbox One S, and PS4 units were added. Additionally, Wii U ownership in the U.S. grew from roughly 1.5 to 6 million units over this time.

Table 10-7. Prior energy consumption estimates for video game consoles.

YEAR	UNITS (millions)	POWER (W) ACT	IDLE	SLEEP	USAGE (h/year) ACT	IDLE	SLEEP	UEC (kWh/yr)	AEC (TWh)	SOURCE
2017	105	63	52	3.2	560	200	8,000	79	8.3	Current
2013	128	58	51	2.6	355	885	7,520	88	11	FhCSE (2014)
2013	105	46	-	1	1,705*	-	7,055	68	7.1	Desroches et al. (2013)
2010	75	93	79	3.4	380	2,515	5,865	213	16	Hittinger et al. (2012)
2010	109	85	75	2	1,120	330	7,310	135	14.7	FhCSE (2011)
2008	63	-	-	-	-	-	-	-	16.3	NRDC (2008)
2006	64	36	31	0.8	405	560	7,795	36	2.4	TIAX (2007)
1999	54	8	-	1	175	-	8,585	10	0.5	LBNL (2001)
1995	64	20	-	2	365	-	8,395	24	1.5	LBNL (1998)

Notes: Active includes all active modes (gaming, video streaming and playback). Idle includes navigation mode.
* = Includes active and navigation mode.

The average time spent in active modes increased by about 60% to 560 hours per year. This follows recent trends of video game consoles becoming more multipurpose. Outside of gaming, eighth generation consoles can stream movies and music from apps and their respective online stores, and some can connect to a cable or satellite box for fully integrated TV watching. The average time that consoles spent in idle mode decreased from by nearly 80% to 200 hours per year. This can be attributed to time usage changing from navigation to connected- or unconnected-standby modes due to ubiquitous auto power down functionality in newer consoles replacing older consoles lacking that functionality.

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11 OTHER DEVICES

We estimate that other devices consumed about 32 TWh in 2017, an amount equal to about 22% of the total energy consumption for all consumer electronics. These estimates and their sources, summarized in Table 11-1 through Table 11-3 and Figure 11-1, generally have higher uncertainty than the devices analyzed in previous sections. Several of the "other" device categories, highlighted in the tables, were evaluated in depth in 2013 (FhCSE 2014). For those categories, we assumed the UEC values are not likely to have changed significantly since 2013.

Table 11-1. Installed base, unit and annual energy consumption (AEC) for other devices.

CATEGORY	DEVICE	UNITS (millions)	UEC (kWh/yr)	AEC (TWh)	SOURCE for INSTALLED BASE
MULTIMEDIA					
AUDIO	AV Receiver w/ Surround	43	65	2.8	CTA (2017)
	Computer Speakers	80	44	3.5	CE Usage Survey (2017)
	Home Theater In-a-box	20	89	1.8	FhCSE (2014)
	Radio + Clock Radio	113	9	1.0	CTA (2016b)
	Shelf Stereo + Compact	30	75	2.2	CTA (2016b), FhCSE (2014)
	Speaker Dock	70	19	1.3	CTA (2017)
DISC PLAYER	Blu-ray Player	48	14	0.7	CTA (2016a,b 2017)
	CD Player, standalone	42	18	0.7	CTA (2016b)
	DVD Player	94	24	2.2	CTA (2017), CTA (2016a,b)
SET-TOP BOX	DVR, standalone	2	275	0.6	Fortune (2015), FhCSE (2014)
	Over-the-air DTA	7	30	0.2	FhCSE (2015), assumed 50% reduction
	Digital Media Streaming	77	39	3.0	CTA (2017)
	Video Cassette Recorder	38	34	1.3	CTA (2016a) [a]
VIDEO	Digital Picture Frame	50	7	0.3	CTA (2016b)
	Video Projector	4	55	0.2	Statista (2011), Inferred U.S. values
	Web Camera	66	22	1.4	CTA (2016a)
IT + COMMUNICATIONS					
INFO TECH	External Storage Drive	89	17	1.5	CEA (2013a)
	Printer + Multi-function	97	12	1.2	CTA (2017)
PHONE	Cordless Phone	104	12	1.3	FhCSE (2014), NCHS (2017) [b]
	Internet-based Phone	12	36	0.4	CTA (2016b)
	Telephone Answering Device	11	14	0.2	FhCSE (2014), NCHS (2017)
PORTABLE DEVICES					
AUDIO	Bluetooth Headset	71	5.9	0.4	CTA (2017)
	Wireless Speaker	140	1.0	0.1	CTA (2017)
DISC PLAYER	DVD or Blu-ray Player	80	2.7	0.2	CEA (2013a)
	Media player, MP3 + CD	90	5.6	0.5	CTA (2017) [c]
INFO TECH	eReader	54	1.8	0.1	CTA (2017)
	GPS, handheld	68	1.3	0.1	CTA (2017)
	Smart watch + Wearable	64	0.5	0.04	CTA (2017) [d]
	Tablet Computer	140	6.1	0.9	CTA (2017)
PHONE	Mobile Non-Smart Phone	66	2.2	0.1	CTA (2016a)
	Mobile Smart Phone	238	4.5	1.1	CTA (2017)
VIDEO	Camcorder	54	2.3	0.1	CTA (2017)
	Digital Camera	107	0.3	0.03	CTA (2017)
	Video Game	52	4.3	0.2	CTA (2017)
	TOTAL/Wt. Avg.	**2,321**	**14**	**32**	

Notes: Highlighted categories were studied in depth in FhCSE (2014).

a 77 million VCRs owned (CTA 2016a), 17% of consumers use a VCR (Bank of America 2017); assumed half are plugged in.

b Scaled 2013 estimate (FhCSE 2014) based on ratio of landline subscriptions in 2013 and 2016 (NCHS 2017).

c Source for UEC from Roth and McKenney (2007).

d UEC based on Apple watch, assuming 365 charges per year: 0.205mAh battery x 5 V / 75% efficiency (Apple 2016).

Figure 11-1. AEC, installed base, and UEC of other devices evaluated in less detail.

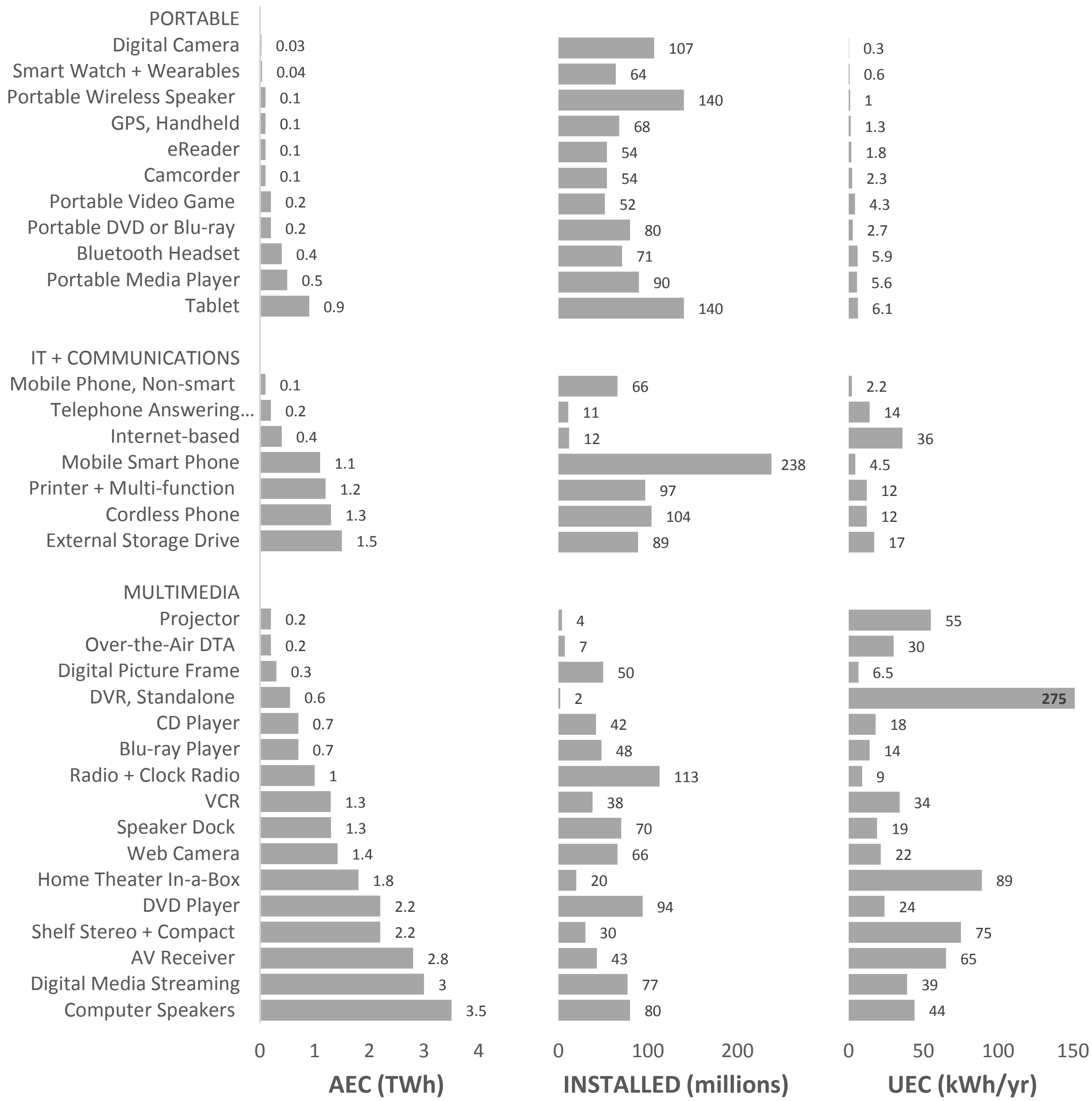

Table 11-2. Average power draw by mode (W) for other devices.

CATEGORY	DEVICE	ACTIVE / CHARGE	IDLE	OFF	SOURCE
MULTIMEDIA					
AUDIO	AV Receiver w/ Surround	52	2	1.0	FhCSE (2011)
	Computer Speakers	21	4	1.4	FhCSE (2014)
	Home Theater In-a-box	38	34	0.6	TIAX (2007)
	Radio + Clock Radio	4.3	-	1.6	ECW (2010)
	Shelf Stereo + Compact	30	12	4.0	FhCSE (2014)
	Speaker Dock	5	3	1.3	FhCSE (2014)
DISC PLAYER	Blu-ray Player	30	16	0.5	FhCSE (2011)
	CD Player, standalone	13	-	1.6	ECW (2010)
	DVD Player	10	0.6	0.6	LBNL (2013)
SET-TOP BOX	DVR, standalone	33	30	-	FhCSE (2014)
	Over-the-air DTA	6.5	0.8	-	FhCSE (2014)
	Digital Media Streaming	4.7	2.5	-	FhCSE (2014)
	Video Cassette Recorder	6.6	-	1.2	ECW (2010)
VIDEO	Digital Picture Frame	3.1	-	0.0	ECW (2010)
	Video Projector	182	10	4.6	Ecos (2011) [a]
	Web Camera	2.5	2.5	1.7	ABI (2015), Nest (2017) [b]
IT + COMMUNICATIONS					
INFO TECH	External Storage Drive	1.2	-	-	ECW (2010)
	Printer + Multi-function	-	-	-	Varied, see FhCSE (2011)
PHONE	Cordless Phone	1.9	-	0.5	ECW (2010)
	Internet-based Phone	6	4	-	YouSustain (2009), TIAX (2006)
	Telephone Answering Device	2	-	-	ECW (2010)
PORTABLE DEVICES					
AUDIO	Bluetooth Headset	2.0 [c]	1.2	0.3	DOE (2012b)
	Wireless Speaker	5.1 [c]	2.3	1.4	DOE (2012b)
DISC PLAYER	DVD or Blu-ray Player	3.2 [c]	1.8	1.0	DOE (2012b)
	Media player, MP3 + CD	5	3	1.7	ECW (2010), SELINA (2010)
INFO TECH	eReader	1.4 [c]	1.2	0.3	DOE (2012b)
	GPS, handheld	1.4 [c]	1.2	0.3	DOE (2012b)
	Smart watch + Wearable	-	-	-	Assumed one charge/day [d]
	Tablet Computer	-	-	0.4 / 0.1	FhCSE (2014) [e]
PHONE	Mobile Non-Smart Phone	4	2.2	0.2	ECW (2010), LBNL (2008)
	Mobile Smart Phone	-	-	0.5 / 0.1	FhCSE (2014) [e]
VIDEO	Camcorder	9.6	0.4	0.4	UCB (2004)
	Digital Camera	4	-	0.3	UCB (2004), Ecos (2006), Wood (2011)
	Video Game	1.8 [c]	1.2	0.3	DOE (2012b)

Notes: Highlighted categories were studied in depth in FhCSE (2014).

a Product of average power draw and usage values does not equal average UEC value reported in Ecos (2011).

b Based on Nest Cam: video-record modes (322-418 mA), off mode (343 mA) x 5 V. Max on-power is 7-9 W.

c Charging power is estimated from battery energy capacity divided by charging efficiency and charge time (DOE 2012a,b)

d UEC based on Apple watch, assuming 365 charges per year: 0.205mAh battery x 5 V / 75% efficiency (Apple 2016).

e Power draw values shown are for a fully charged device plugged in and for the charger without the phone connected.

Table 11-3. Annual usage by mode (hours) for other devices.

CATEGORY	DEVICE	ACTIVE / CHARGE	IDLE	OFF	SOURCE
MULTIMEDIA					
AUDIO	AV Receiver w/ Surround	950	7,610	200	FhCSE (2011)
	Computer Speakers	985	4,125	3,650	FhCSE (2014)
	Home Theater In-a-box	1,580	730	6,450	TIAX (2007)
	Radio + Clock Radio	620	-	8,140	ECW (2010)
	Shelf Stereo + Compact	1,240	950	6,570	FhCSE (2014)
	Speaker Dock	1,200	2,010	5,550	FhCSE (2014)
DISC PLAYER	Blu-ray Player	300	30	8,430	FhCSE (2011)
	CD Player, standalone	660	-	8,100	ECW (2010)
	DVD Player	2,060	1,850	4,850	LBNL (2013)
SET-TOP BOX	DVR, standalone	4,200	4,560	-	FhCSE (2014)
	Over-the-air DTA	3,940	4,820	-	FhCSE (2014)
	Digital Media Streaming	7,880	880	-	FhCSE (2014)
	Video Cassette Recorder	1,500	-	7,260	ECW (2010)
VIDEO	Digital Picture Frame	4,780	-	3,980	ECW (2010)
	Video Projector	530	440	5,610	Ecos (2011)
	Web Camera	8,760	-	-	Upper limit, assumed
IT + COMMUNICATIONS					
INFO TECH	External Storage Drive	8,760	-	-	ECW (2010)
	Printer + Multi-function	-	-	-	Varied, see FhCSE (2011)
PHONE	Cordless Phone	7,040	-	1,720	ECW (2010)
	Internet-based Phone	360	8,400	0	TIAX (2006)
	Telephone Answering Device	8,760	-	-	ECW (2010)
PORTABLE DEVICES					
AUDIO	Bluetooth Headset	310 [a]	4,430 [b]	0 [c] / 4,020 [d]	DOE (2012a,b)
	Wireless Speaker	145 [a]	220 [b]	0 [c] / 8,395 [d]	DOE (2012a)
DISC PLAYER	DVD or Blu-ray Player	60 [a]	1,400 [b]	0 [c] / 7,300 [d]	DOE (2012a)
	Media player, MP3 + CD	660	-	8,100	ECW (2010) for CD players
INFO TECH	eReader	530 [a]	750 [b]	550 [c] / 6,930 [d]	DOE (2012a)
	GPS, handheld	70 [a]	110 [b]	0 [c] / 8,580 [d]	DOE (2012a)
	Smart watch + Wearable	-	-	-	Assumed one charge/day
	Tablet Computer	-	-	-	See FhCSE (2014)
PHONE	Mobile Non-Smart Phone	110	-	8,650	ECW (2010)
	Mobile Smart Phone	-	-	-	Varied, see FhCSE (2014)
VIDEO	Camcorder	-	-	-	-
	Digital Camera	15	-	8,745	TIAX (2007)
	Video Game	205 [a]	2,530 [b]	3,105 [c] / 2,920 [d]	DOE (2012a)

Notes: Highlighted categories were studied in depth in FhCSE (2014).
a Time spent charging. Calculated as a product of charges/year and charge time (DOE 2012a).
b Time spent in maintenance state, i.e. the device is fully charged but still connected to its charger (DOE 2012a).
c Time spent plugged into an electrical socket but without any device connected to it ("No Battery" in DOE spreadsheet 2012a).
d Time the device charger spent unplugged (DOE 2012a).

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APPENDIX A: CE USAGE SURVEYS

As part of this study, the CTA commissioned national phone survey market research. Respondents were asked about devices installed in their home and how those devices were recently used. The questions ultimately posed were developed by Fraunhofer CSE in close consultation with the CTA Market Research Team, which regularly performs surveys on a variety of topics. CTA is a member of the Marketing Research Association (MRA) and adheres to the MRA's Code of Marketing Research Standards. The CTA engaged with Opinion Research Corporation (ORC) to perform the interviews using industry standard random-digit dialing and computer assisted telephone interviewing (CATI).

A total of three surveys were administered via dual-frame telephone interview to a random national sample of U.S. adults. Each survey had a sample size of about 1,000 respondents (half landline and half cell phone), and were conducted over a Thursday-Sunday period:

Televisions	May 11-14, 2017
Video Game Consoles	May 11-14, 2017
Computers (Desktop and Portable)	May 18-21, 2017

As is common practice in survey research, the data were weighted to reflect the known demographics of the population under study. In this survey, weights were applied to cases based on gender, age, race and geographic region. As a result, these data can be generalized to the entire U.S. adult population. All findings presented in this report derived from the surveys were based on weighted data.

Subsequently, we processed the responses to estimate the installed base and usage, following category-specific methods and modeling approaches described in the respective sections.

The complete scripts of the phone surveys are included below.

A.1 Televisions and Soundbars

V1A How many televisions were PLUGGED INTO an electrical outlet in your home at some point during the PAST MONTH? (RECORD NUMBER. RANGE IS 0-20, DON'T KNOW/NOT SURE)

IF TELEVISION WAS PLUGGED IN DURING PAST MONTH, V1A (1-20), CONTINUE. ALL OTHERS SKIP TO NEXT SECTION

IF ONLY ONE TELEVISION, V1A (1), ONLY ASK FOR PRIMARY. IF TWO TELEVISIONS, V1A (2), ASK FOR PRIMARY AND SECONDARY. IF THREE TELEVISIONS, V1A (3-10), ASK FOR PRIMARY, SECONDARY, THIRD, IF FOUR OR MORE TELEVISIONS, V1A (4-20), ASK FOR PRIMARY, SECONDARY, THIRD, AND FOURTH

The next questions are about TELEVISIONS in your household, starting with the PRIMARY, or most-watched TV.

[SHOW IF V1A (2-20)]
For the next few questions, please answer for up to four TVs owned by your household. Please consider the one used the MOST the PRIMARY TV, the one used the SECOND most the SECOND TV, the one used the THIRD most as the THIRD TV and the one used the FOURTH most as the FOURTH TV.

ASK V3-V6B 'A' SERIES BEFORE GOING TO THE 'B' SERIES, ETC.

V3 Is the [INSERT] television that you own a . . .
[READ ENTIRE LIST BEFORE RECORDING ONE ANSWER.]
[DO NOT RANDOMIZE LIST OR ITEMS]

01 LCD or LED Flat-panel TV
02 Plasma Flat-panel TV
03 Tube TV, also known as a direct-view CRT
04 Front or Rear Projection TV
99 DON'T KNOW/NOT SURE

A. Primary
B. Second
C. Third
D. Fourth

V4 What is the approximate screen size IN INCHES of the [INSERT] TV that you own? If you are not sure, please use your best estimate.
(RECORD NUMBER. RANGE IS 5-90, DON'T KNOW/NOT SURE)
(PROBE FOR BEST GUESS BEFORE ACCEPTING DON'T KNOW)

A. Primary
B. Second
C. Third
D. Fourth

V5 What is the age IN YEARS of the [INSERT] TV that you own? If you are not sure, please use your best estimate.
(RECORD NUMBER. RANGE 1-50, DON'T KNOW/NOT SURE)
(IF RESPONDENT SAYS THE TV IS NEW, AS IN LESS THAN ONE YEAR, RECORD AS 1. PROBE FOR BEST GUESS BEFORE ACCEPTING DON'T KNOW)

A. Primary
B. Second
C. Third
D. Fourth

PROGRAMMING NOTE: THIS WORDING SHOULD ONLY BE DISPLAYED DURING THE 'A' SERIES (PRIMARY TELEVISION)

Next, I am going to ask you a couple of questions about how you and those in your household use the TVs you currently have plugged into an electrical outlet. I am going to use two terms that I will define for you.

The first term is ‘turned on’. ‘Turned on’ means that the television’s power is in the ON mode regardless of whether someone is actually using it. For example, a TV is turned on when there is a picture on the screen or sound being emitted, as well as when it has a screen saver on while waiting for users.

The second term is ‘active use’. ‘Active use’ means that the television is on AND being used by someone. For example, when a TV is in active use, someone is using it to watch TV, a movie, play games or is actively listening to the TV.

V6A Now, thinking of the [INSERT] TV that you own, during the PAST 24 HOURS, how much time was it turned on? If you are not sure, please give your best estimate.
(RECORD NUMBER. RANGE FOR HOURS (a) IS 0-24, DON’T KNOW AND RANGE FOR MINUTES (b) IS 0-59, DON’T KNOW)
A. Primary
B. Second
C. Third
D. Fourth

a. Hours
b. Minutes

[ASK FOR EACH V6A A-D ([a (HOURS) IS 1-24] OR [b (MINUTES) IS 1-59)]]
[IF V6A A-D a (0), AUTOPUNCH V6B A-D a AS 0]
V6B And during the PAST 24 HOURS, how much time was the [INSERT] TV in active use? If you are not sure, please give your best estimate.
(RECORD NUMBER. RANGE FOR HOURS (a) IS 0-ANSWER GIVEN IN V6A, DON’T KNOW AND RANGE FOR MINUTES (b) IS 0-59, DON’T KNOW)
A. Primary
B. Second
C. Third
D. Fourth

a. Hours
b. Minutes

The next few questions are concerned with external speakers that may be connected to your TVs. Please answer for each TV.
A ‘Sound Bar’ is a bar-shaped speaker that can be used to boost the sound of your TV. These wired or wireless speakers are often positioned beneath the TV, or mounted directly to the upper or lower edge of the TV.

AS BEFORE V3, IF ONLY ONE TELEVISION, V1A (1), ONLY ASK FOR PRIMARY.
IF TWO TELEVISIONS, V1A (2), ASK FOR PRIMARY AND SECONDARY.
IF THREE TELEVISIONS, V1A (3-10), ASK FOR PRIMARY, SECONDARY, THIRD,
IF FOUR OR MORE TELEVISIONS, V1A (4-20), ASK FOR PRIMARY, SECONDARY, THIRD, AND FOURTH

ASK V15-V21 ‘A’ SERIES BEFORE GOING TO THE ‘B’ SERIES, ETC.

V15 Does the [INSERT] TV have any external speakers connected to it? Would you say…
[READ ENTIRE LIST BEFORE RECORDING ONE ANSWER]
01 No external speakers are connected to it
02 A sound bar (with or without subwoofer) is connected to it
03 Or, another home speaker system, not a sound bar, is connected to it
99 DON’T KNOW

A. Primary
B. Second
C. Third
D. Fourth

IF SOUND BAR CONNECTED TO ASSIGNED TELEVISION [V15 A-D (02)], CONTINUE WITH QUESTION SERIES V16-V21.
ALL OTHERS SKIP TO V15 FOR NEXT TELEVISION IN SEQUENCE, OR SKIP TO NEXT SECTION IF ALL TELEVISIONS HAVE BEEN ASKED FOR

V16 How many of the following external speakers, if any, are connected to the [INSERT] TV's Sound Bar?
(RECORD NUMBER. RANGE IS 0-10 FOR EACH)

a. External subwoofer
b. Other external speakers, excluding subwoofers

A. Primary
B. Second
C. Third
D. Fourth

V18 Please think of the most recent occasion you used the [INSERT] TV's Sound Bar for the FIRST TIME THAT DAY. Did you need to turn ON the Sound Bar, for example, by using a remote control or power switch? Would you say…
[READ LIST. RECORD ONE ANSWER]

01 YES, I turned the Sound Bar on manually or with a remote control
02 NO, the Sound Bar was already on
03 NO, the Sound Bar turns on automatically when I turn on the TV
99 DON'T KNOW

A. Primary
B. Secondary
C. Third
D. Fourth

V19 How long was the [INSERT] TV's Sound Bar used YESTERDAY, by you or anyone else in your household?
(RECORD NUMBER. RANGE FOR HOURS (a) IS 0-24, DON'T KNOW AND RANGE FOR MINUTES (b) IS 0-59, DON'T KNOW)

A. Primary
B. Secondary
C. Third
D. Fourth

a. Hours
b. Minutes

V20 Think of the last time you finished using the [INSERT] TV's Sound Bar for that day. When you finished using it, did you…
[READ LIST. RECORD ONE ANSWER]

01 Turn the Sound Bar off (manually or with remote control)
02 Leave the Sound Bar On
99 DON'T KNOW

A. Primary
B. Secondary
C. Third
D. Fourth

V21 When you finish using the [INSERT] TV's Sound Bar and leave it ON, which best describes its behavior?
[READ ENTIRE LIST BEFORE RECORDING ONE ANSWER]

01 The Sound Bar remains ON and ready to use until I turn it off
02 The Sound Bar turns OFF automatically after a period of not producing sound
99 DON'T KNOW

A. Primary
B. Secondary
C. Third
D. Fourth

A.2 Video Game Consoles

E1A Do you or someone in your household have a VIDEO GAME CONSOLE, such as a Sony PlayStation, Microsoft Xbox, or Nintendo Wii, that was PLUGGED IN at some point in time during the past month? Please do not count ANY HANDHELD VIDEO GAME CONSOLES in your answer.

01 YES
02 NO
99 DON'T KNOW

IF HAVE A VIDEO GAME CONSOLE THAT WAS PLUGGED IN AT SOME POINT DURING THE PAST MONTH, E1A (01), CONTINUE. ALL OTHERS SKIP TO NEXT SECTION

E1 For each of the following VIDEO GAME CONSOLES, please indicate how many you or someone in your household owns.
(RECORD NUMBER FOR EACH. RANGE IS 0-10, DON'T KNOW)
[PROGRAMMER: KEEP A-C & J, D-F, AND H-I AS BLOCKS. RANDOMIZE BLOCKS.
FOR A-C & J, ALWAYS ASK IN J-C-B-A ORDER.
FOR D-F, DO NOT ROTATE WITHIN BLOCK.
FOR H-I, ALWAYS ASK IN I-H ORDER]

A. Microsoft Xbox
B. Microsoft Xbox 360
C. Microsoft Xbox One
J. Microsoft Xbox One S
D. Sony PlayStation 2
E. Sony PlayStation 3
F. Sony PlayStation 4
G. OMITTED
H. Nintendo Wii
I. Nintendo Wii U

E2-E7 PROGRAMMING NOTES: ASK FOR **UP TO 3** CONSOLES, E1A-J (1-10), WITH PRIORITY ON: 1. E1C (MICROSOFT XBOX ONE) 2. E1J (MICROSOFT XBOX ONE S) 3. E1F (SONY PLAYSTATION 4) 4. E1I (NINTENDO WII U) IF NECESSARY, ASK FOR REMAINING ITEMS (A, B, D, E, H) ACCORDING TO LEAST FILL PRIORITY NOTE: MORE THAN ONE OF THE SAME CONSOLE CAN BE ASKED ABOUT IN THIS SEQUENCING, AND SHOULD ALWAYS TAKE GREATER PRIORITY BEFORE A NON-PRIORITY SYSTEM IS CONSIDERED ASK E2-E7 FOR ONE ITEM BEFORE MOVING ONTO E2-E7 FOR THE NEXT ITEM

E2 Please indicate in what year your [INSERT ITEM] was purchased or received as a gift, if you got it BRAND NEW.
(RECORD YEAR. RANGE IS 2005-2017, WAS NOT BRAND NEW, DON'T KNOW)
[RANDOMIZE ITEMS]

A. Microsoft Xbox
B. Microsoft Xbox 360
C. Microsoft Xbox One
J. Microsoft Xbox One S
D. Sony PlayStation 2
E. Sony PlayStation 3
F. Sony PlayStation 4
G. OMITTED

H. Nintendo Wii
I. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

[ONLY DISPLAY BEFORE FIRST SERIES]
The next few questions will be about the USAGE of your video game console.

Next, we will ask you about HOW you and those in your household use your gaming console(s), in one of the following states:

- TURNED ON—the gaming console's power is in the ON mode REGARDLESS of whether someone is actually using it. This includes time when the console is paused.
- ACTIVE USE—the gaming console is ON AND BEING USED by someone, for example, for gaming, streaming media or Internet TV, watching a movie, etc.
- TURNED OFF—the gaming console is OFF. You turned OFF your gaming console manually or by using a voice command.

E3 How much time did your [INSERT ITEM] spend YESTERDAY in each of the following states? Please give your answer in hours and minutes. If you did not use your [INSERT ITEM] yesterday, please say so.
(RECORD A NUMBER. RANGE FOR HOURS IS 0-24, DON'T KNOW; RANGE FOR MINUTES IS 0-59, DON'T KNOW)
[RANDOMIZE ITEMS]

01 Turned on
02 Actively used

A. HOURS
B. MINUTES

a. Microsoft Xbox
b. Microsoft Xbox 360
c. Microsoft Xbox One
j. Microsoft Xbox One S
d. Sony PlayStation 2
e. Sony PlayStation 3
f. Sony PlayStation 4
g. OMITTED
h. Nintendo Wii
i. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

[ASK IF E3 A OR B IS 1 OR MORE FOR 'ACTIVELY USED'- 02]

E4 During the [INSERT E3A] [DISPLAY IF E3A (1-24)] (hours and) [INSERT E3B] [DISPLAY IF E3B (1-59)] (minutes) your [INSERT ITEM] was actively used YESTERDAY, approximately how much of this time was used to do each of the following? If you are not sure, please use your best estimate. Please give your answer in hours and minutes.
(RECORD A NUMBER. RANGE FOR HOURS IS 0-ANSWER FROM E3A (02), DON'T KNOW; RANGE FOR MINUTES IS 0-59, DON'T KNOW)
[RANDOMIZE ITEMS]

01 Play games
02 Stream media from the video game console or internet
03 DVD and/or Blu-Ray playback
04 Watch TV [DISPLAY FOR E4C or E4J ONLY]

A. HOURS
B. MINUTES

a. Microsoft Xbox
b. Microsoft Xbox 360
c. Microsoft Xbox One
j. Microsoft Xbox One S
d. Sony PlayStation 2
e. Sony PlayStation 3
f. Sony PlayStation 4
g. OMITTED
h. Nintendo Wii
i. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

E5 Thinking about the last time when you were the FIRST PERSON to 'actively use' the [INSERT ITEM] on a day, which statement best describes your gaming console?
(READ ENTIRE LIST BEFORE RECORDING ONE ANSWER)

01 It was already turned ON and ready to use
02 It was turned OFF and you needed to turn it on to use it
99 DON'T KNOW

A. Microsoft Xbox
B. Microsoft Xbox 360
C. Microsoft Xbox One
J. Microsoft Xbox One S
D. Sony PlayStation 2
E. Sony PlayStation 3
F. Sony PlayStation 4
G. OMITTED
H. Nintendo Wii
I. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

[ASK IF E5C (02) OR E5J (02)]

E5AA Did you turn your [INSERT ITEM] ON using voice commands?

01 YES
02 NO
99 DON'T KNOW

C. Microsoft Xbox One
J. Microsoft Xbox One S

i. First console
ii. Second console
iii. Third console
iv. OMITTED

E6 Does your [INSERT ITEM] automatically turn off after a sustained period of inactivity?
[RANDOMIZE ITEMS]

01 YES
02 NO
99 DON'T KNOW

A. Microsoft Xbox
B. Microsoft Xbox 360
C. Microsoft Xbox One
J. Microsoft Xbox One S
D. Sony PlayStation 2
E. Sony PlayStation 3
F. Sony PlayStation 4
G. OMITTED
H. Nintendo Wii
I. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

[ASK FOR EACH MENTION E6A-J (01)]
E7 After approximately how much time does the [INSERT ITEM] automatically turn off? Please give your answer in hours and minutes.
(RECORD A NUMBER. RANGE FOR HOURS IS 0-24, DON'T KNOW; RANGE FOR MINUTES IS 0-59, DON'T KNOW)
[RANDOMIZE ITEMS]

A. HOURS
B. MINUTES

a. Microsoft Xbox
b. Microsoft Xbox 360
c. Microsoft Xbox One
j. Microsoft Xbox One S
d. Sony PlayStation 2
e. Sony PlayStation 3
f. Sony PlayStation 4
g. OMITTED
h. Nintendo Wii
i. Nintendo Wii U

i. First console
ii. Second console
iii. Third console
iv. OMITTED

A3. Computers

C1 Thinking about the following COMPUTER products you may have in your home, please indicate how many were PLUGGED INTO an electrical outlet in YOUR HOME at some point during the PAST MONTH. If you do not have this product, please tell me.
(RECORD A NUMBER FOR EACH. RANGE IS 0-10, DON'T KNOW/NOT SURE, DO NOT HAVE THIS PRODUCT)

A. Personal desktop computer
B. Personal portable computer, such as notebooks, laptops or netbook computers; do NOT include tablet computers, such as iPads

IF ANY COMPUTER WAS PLUGGED IN, C1A OR B (1-10), CONTINUE.
ALL OTHERS SKIP TO NEXT SECTION.

IF C1A (1-10), ASK 'A' (PRIMARY DESKTOP) SERIES.

IF C1A (2-10), ASK 'B' (SECONDARY DESKTOP) SERIES.

IF C1B (1-10), ASK 'C' (PRIMARY PORTABLE) SERIES.

IF C1B (2-10), ASK 'D' (SECONDARY PORTABLE) SERIES.

C2-C7 PROGRAMMING NOTE:

ASK 'A' (PRIMARY DESKTOP) SERIES BEFORE MOVING ON TO 'B' (SECONDARY DESKTOP) SERIES, ETC.

[DISPLAY IF C1A (1-10)]
The next set of questions are about DESKTOP COMPUTERS in your household, including those used in home offices [DISPLAY IF C1A (2-20)] (starting with the PRIMARY or MOST USED DESKTOP COMPUTER).

[DISPLAY IF C1A (2-10) BEFORE 'B' SERIES]
Now, for the next set of questions, please think about the SECONDARY DESKTOP COMPUTER in your household.

[DISPLAY IF C1B (1-10) BEFORE 'C' SERIES]
The next set of questions are related to PORTABLE COMPUTERS, such as notebooks, laptops or netbook computers in your household [DISPLAY IF C1B (2-20)] (starting with the PRIMARY or MOST USED PORTABLE COMPUTER). Please do not include tablet computers, such as iPads.

[DISPLAY IF C1B (2-10) BEFORE 'D' SERIES]
Now, for the next set of questions, please think about the SECONDARY PORTABLE COMPUTER, such as notebooks, laptops or netbook computers in your household. Again, please do not include tablet computers, such as iPads.

C2 I'd like to ask you about how long the [INSERT] computer is used by YOU OR OTHERS in your household. Please consider all activities such as email, searching the Internet, watching videos, gaming, playing music, etc. Also please include time when the computer is doing any of these activities even if no one is at the computer.

How much time was the [INSERT] computer used YESTERDAY during the following times? Please answer in hours and minutes.
(RECORD A NUMBER. RANGE FOR A IS 0-24, DON'T KNOW; RANGE FOR B IS 0-59, DON'T KNOW. SEPARATE PUNCH FOR EACH FOR 'NOT USED')

01 During the MORNING hours, before 12:00 noon
02 During the AFTERNOON hours, between 12:00 and 5:00 pm
03 During the EVENING hours, between 5:00 pm and when you go to sleep at night
04 In ONE SESSION OR SITTING of use, BEFORE the EVENING
05 In ONE SESSION OR SITTING of use, in the EVENING
06 Over the whole day

A. HOURS
B. MINUTES

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable

C3 After you or someone in your household finishes a session or sitting, that is, one instance of use, how often is the [INSERT] computer…
(READ ENTIRE LIST BEFORE RECORDING ONE ANSWER)

01 Always
02 Often
03 About half of the time
04 Occasionally
05 Or, never
99 DON'T KNOW

A. Left ON, during the DAYTIME
B. Put into STANDBY or SLEEP, during the DAYTIME
C. TURNED OFF or SHUT DOWN, during the DAYTIME
D. TURNED OFF or SHUT DOWN, OVERNIGHT

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable

C4 Think of a time you were the FIRST person of the day to use the [INSERT] computer. What did you do to begin using it? (READ LIST UNTIL STOPPED. RECORD ONE ANSWER)

01 The computer and monitor were already ON showing the previous screen image
02 The computer was already ON, but the monitor was off. You pressed a key or moved the mouse, and INSTANTLY the computer was READY
03 You [DISPLAY FOR C-D SERIES ONLY] (opened the computer lid,) pressed a key, moved the mouse or pressed a POWER BUTTON, and after a FEW SECONDS the computer was ready to use
04 You pressed the POWER BUTTON on the computer, and WAITED more than 15 seconds until it was ready to use
99 DON'T KNOW

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable

C5 How many of the following devices, if any, does the [INSERT] computer have connected to it? (RECORD A NUMBER. RANGE IS 0-30, DON'T KNOW)

A. LCD flat monitors including LED. DO NOT COUNT displays that are built in to the computer, such as the screen on a laptop, netbook or all-in-one desktop
B. CRT or Tube monitors
C. Computer speaker systems without Subwoofer
D. Computer speaker systems with Subwoofer

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable

C6 A dedicated graphics card or graphics adapter can improve video playback or gaming performance. Does the [INSERT] computer have a dedicated graphics card or graphics adapter?

01 YES
02 NO
99 DON'T KNOW

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable

C7 How much time was the [INSERT] computer used YESTERDAY FOR PLAYING COMPUTER GAMES? Please answer in hours and minutes.
(RECORD A NUMBER. RANGE FOR A IS 0-24, DON'T KNOW; RANGE FOR B IS 0-59, DON'T KNOW. SEPARATE PUNCH FOR 'NOT USED')

A. HOURS
B. MINUTES

a. Primary desktop
b. Secondary desktop
c. Primary portable
d. Secondary portable