



Fraunhofer USA Center for Sustainable Energy Systems

# **LCD Television Power Draw Trends from 2003 to 2015**

Final Report to the Consumer Technology Association

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## EXECUTIVE SUMMARY

Televisions in U.S. homes consumed about 50 billion kWh per year in 2013, or about 4% of the total U.S. residential electricity consumption. Flat-panel displays, first widely available in the mid-1990s, transformed the TV market as LCD, plasma, and most recently OLED displays replaced the incumbent energy-intensive cathode ray tube (CRT).

Since flat panel TVs were introduced, their average on-mode power draw has declined significantly. Meanwhile, screen size, screen resolution, and picture quality, have improved dramatically and added features, like internet connectivity, have become widespread. Typically, over 80% of units sold in the U.S. have satisfied the increasingly stringent regulatory and voluntary standards for energy efficiency.

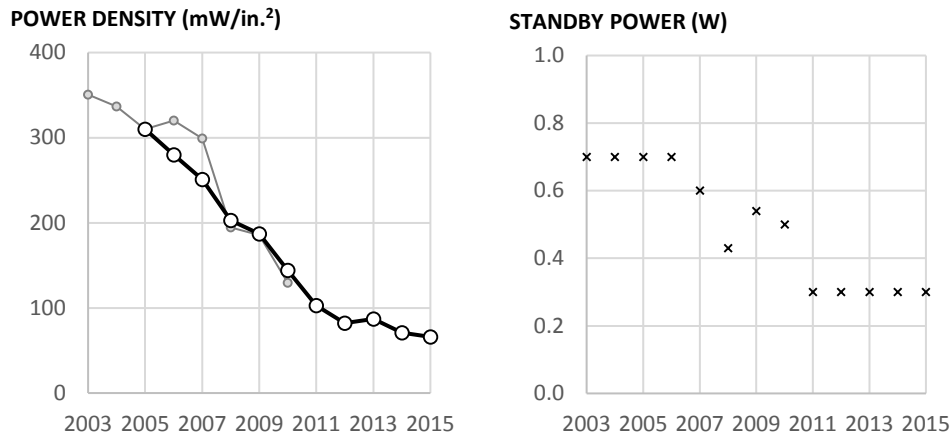
This study characterizes power draw trends of flat-panel LCD TVs from 2003-2015 using power measurements from more than 9,000 TV models. Energy efficiency and capabilities both continue to improve amid rapid product evolution.

Key trends in features and capabilities include:

1. Average screen size increased by 20% from 33 to 40 inches (2010-2016).
2. Screen resolution capabilities increased 6-fold from HD to UHD 8K. 4K TV market share increased from 0% to 50% of units shipped (2012-2016).
3. Internet-capable smart TV penetration has increased from 9% to 50% (2012-2016).
4. Automatic brightness control was present in about half of larger TVs (42+ inches) since 2008.

At the same time, LCD TV power draw has decreased substantially:

1. Average **On-mode** power density decreased four-fold from 300 to 70 mW/in.<sup>2</sup> from 2003 to 2015.
2. Average **Passive Standby** power draw decreased from about 0.8 W to 0.3 W from 2003 to 2015.
3. **Active Standby** power draw must be less than 3 W to satisfy the current ENERGY STAR version 7.0 requirements, however limited data preclude a trend analysis of this mode.



**Figure E-1.** Declining on-mode power density (power per screen area, LEFT). Median passive standby power for LCD TV models 20-70 inches (RIGHT).

User selected settings can have a strong impact on real-world power draw. Values analyzed in this report represent power draw measurements made according to standard testing procedures. Several factors, such as brightness settings, video signal content and resolution, have been shown to influence on-mode power draw, in some cases by 50% or more. Further study is required to better understand the typical TV operating conditions and their impact on real-world power draw.

## 1 INTRODUCTION

Televisions use about 50 billion kWh of electricity per year, about 4% of total U.S. residential electricity consumption, costing households about \$6.0 billion per year (Urban et al. 2015). The average home spends just over \$50 per year to power 2.5 TVs. Because televisions consume more energy than other consumer electronics, it is important to study trends in device power draw, especially as TV display technologies and TV features continue to evolve rapidly.

TV power-draw trends from 2003 to 2010 were previously characterized based on an industry survey of best-selling models (King and Ponoum 2011). This study extends these results through 2015 using public power draw data for over 6,000 qualified TV models from the California Energy Commission appliance efficiency database (CEC 2016), the ENERGY STAR standard development archives (EPA 2016), and industry survey data from King and Ponoum (2011).

Other recent studies characterized TV energy consumption in homes over time (Urban et al. 2015 and 2011; Roth and McKenney 2007); however, these emphasize the distribution and usage of the entire installed base of TVs *in homes*, and so include a mixture of newer and older models. In contrast, this study focuses on the power trends of TV *models* over time.

Flat-panel displays encompass a vast combination of technologies and features, with significant power draw variation across models. To identify important trends, we focus on the key driving factors. On-mode power draw depends primarily on display technology, screen size and resolution, brightness settings, and processing power. Standby power, in contrast, depends primarily on electronic design, networking capabilities, and power supply efficiency.

Amid trends of increasing screen size, higher resolution, and added features, digital flat-panel TV on-mode power draw has progressively declined. From 2010 to 2013, annual TV *energy consumption* fell by about 25% from 65 to 50 billion kWh per year, primarily as digital flat-panel displays displaced older, less-efficient CRT TVs (Urban et al. 2015). High definition liquid crystal displays (LCDs) now dominate the market. Plasma display panels (PDP), once popular, are no longer manufactured for the U.S. market (CNN 2014). For completeness, we provide some PDP trend assessment, but our analysis focuses on LCD TVs.

### 1.1 Power Modes

TVs have two main power modes: *on-mode* and *standby-mode*. New features, such as internet capabilities, have recently introduced active standby power modes. Our standby analysis focuses primarily on *standby-passive* power draw since it is the most well represented in the available datasets.

*On-mode* power draw typically depends strongly on screen area and user-adjustable brightness settings. Datasets typically report power measurements corresponding to one or more brightness settings, as defined in relevant test standards. Brightness settings can be defined using preset modes (e.g., home, movie, game, vivid, eco, automatic brightness control), and users can normally adjust brightness independently of these modes.

*Standby-mode* power draw occurs when the TV is plugged in but produces neither sound nor picture. Simplified definitions of specific standby modes described by EPA (2016) include:

*Off mode*: the TV can only be switched into another mode manually.

*Standby-passive*: the TV can only be switched into another mode manually or with a remote.

*Standby-active low*: the same as standby-passive, but the mode can be switched by an external signal (e.g., from a network).

*Standby-active high*: the same as *standby-active low*, but the TV is exchanging/receiving data with an external source (e.g., to download firmware updates, messaging, or listing information).

## 1.2 Data Sources

Three main sources provide power data and characteristics for over 9,000 TV models to support the following trend analysis. These include the California Energy Commission appliance efficiency database (CEC 2016), the ENERGY STAR standard development archives (EPA 2016), and data extracted from King and Ponoum (2011).

California regulates TV power draw by mode and maintains a database of over 6,000 qualified TV models from 2010 to 2016 (CEC 2016). These regulations limit active and standby power draw, based in part on early ENERGY STAR standards. Since California comprises a significant portion of the U.S. TV market, the vast majority of TV models are likely to meet the CEC requirements, even though they are not mandatory in other states. By definition, the CEC database excludes TVs that draw more than 1 W in standby mode.

The vast majority of TV manufacturers participate in the voluntary ENERGY STAR program that promotes increasingly stringent energy efficiency standards for TVs. Periodically, newer versions are developed to reflect changes in the product landscape. In this process, TV power draw datasets are developed and published using data submitted by manufacturers, providing a historical record of flat-panel displays dating back to 2006. Some records from the ENERGY STAR archive are sourced directly from the CEC database. When analyzing the combined CEC and ENERGY STAR data set, we removed overlapping records when the data source was indicated to reduce double-counting. Since 2008, about 80% of TVs shipped have met or exceeded the then-current ENERGY STAR requirements, making this a representative data source.

An industry survey of bestselling TV models was used to describe power draw trends from 2003-2010 (King and Ponoum 2011). We extracted TV model power data from the charts in this report to characterize older TVs not well represented by the other datasets. Data were present for over 200 models from 2003-2010 in coarse screen size bins. Unfortunately, the authors did not report the fraction of the market represented by the sampled models, nor did they mention if or how weighting was applied to the analysis. Consequently, values from that study may be indicative only.

To identify long-term trends, we characterized TV power draw by year, inferred from the public datasets. The CEC database includes for each TV model the date it was added to the database. We use this to identify the first year the model was known to be available. The ENERGY STAR datasets often included the date the TV was manufactured or tested. When multiple dates were given, we used the earliest available date. When no date was given, we assigned a year based on the most common year of other models from the same dataset. Since each dataset contained only a few years at most, we expect this to have a minor, if any, impact on the power-draw trend analysis. Finally, a given TV model may be sold for multiple years, and different versions of the same model may be sold over time, making the average power draw for a given year somewhat imprecise. Accordingly, this analysis should be used as an indication of the progress of available TV technology.

## 1.3 Organization

The remainder of this report is organized into sections, including EFFICIENCY STANDARDS, ON-MODE POWER, STANDBY-POWER, OTHER FACTORS, CONCLUSIONS, REFERENCES, and SUMMARY TABLES.

## 2 EFFICIENCY STANDARDS

ENERGY STAR, a voluntary program administered by the U.S. Environmental Protection Agency (EPA), develops voluntary energy efficiency standards for a wide range of products including televisions. Because TV technology and efficiency have advanced rapidly, ENERGY STAR has issued five increasingly stringent standards for flat-panel TVs in the seven years spanning 2008-2015. These requirements, shown in Table 1 and Figure 2, set upper limits for both on- and standby-mode power draw for TVs based on screen size and resolution. Version 7.0 additionally limits networked standby modes to a maximum of 3 W. The portion of televisions sold that qualify for ENERGY STAR has exceeded 80% in most years (see Figure 1, EPA 2016).

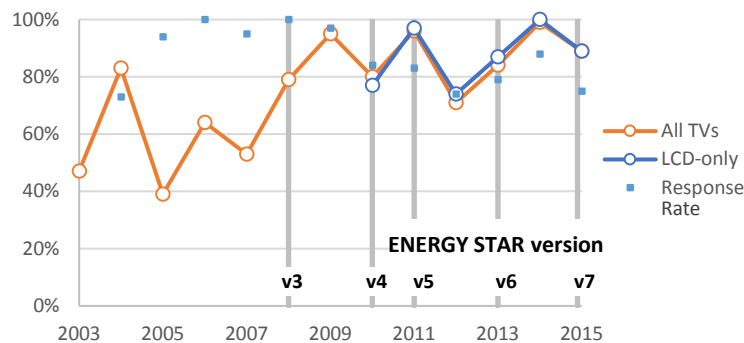
Under version 7.0 (2015), televisions were permitted to use only about one fifth the power allotted under version 3.0 (2008), see Figure 3. High definition TVs, those with at least 2,160 horizontal lines of resolution, were allowed expanded limits that are similar to the version 6.0 (2013) levels.

Mandatory regulations for TVs sold in California, developed by the California Energy Commission (CEC), took effect in several tiers in 2006, 2011, and 2013, with power requirements similar to ENERGY STAR versions 3.0 and 4.0 (CEC 2010). The CEC maintains a public database of qualifying TV models and their power draw characteristics. While these regulations are not mandatory in other states, the vast majority of TVs sold in the U.S. since at least 2010 have met the CEC requirements. Accordingly, the CEC data are likely to be representative of most TVs sold since 2011.

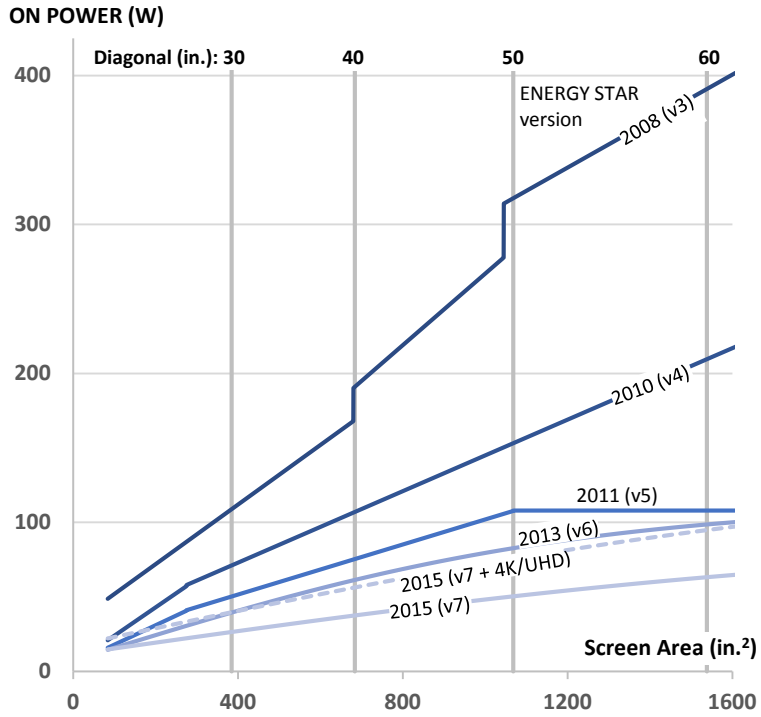
**Table 1.** Maximum TV power draw by ENERGY STAR standard version.

Eff. Date	Ver.	Area and Res.	On-mode (W)	Standby-Passive (W)
2015-10-30	v7.0	$res \geq 2160$ lines	$1.5 \cdot (14 + 78.5 \cdot \tanh(0.00050 \cdot (area - 140) + 0.038))$	0.5
	v7.0	$res < 2160$ lines	$14 + 78.5 \cdot \tanh(0.00050 \cdot (area - 140) + 0.038)$	
2013-06-01	v6.0	any $res$ and $area$	$14.1 + 100 \cdot \tanh(0.00085 \cdot (area - 140) + 0.052)$	1.0
2011-09-30	v5.3	$1068 \text{ in.}^2 < area$	108	1.0
		$275 \leq area \leq 1068$	$0.084 \cdot area$	
		$area < 275$	$0.130 \cdot area + 5$	
2010-05-01	v4.0	$275 \text{ in.}^2 \leq area$	$0.120 \cdot area + 25$	1.0
		$area < 275$	$0.190 \cdot area + 5$	
2008-11-01	v3.0	$1045 \leq area$	$0.156 \cdot area + 151$	1.0
		$680 \leq area < 1045$	$0.240 \cdot area + 27$	
		$area < 680$	$0.200 \cdot area + 32$	
		$res \leq 480$ lines and any $area$	$0.120 \cdot area + 25$	

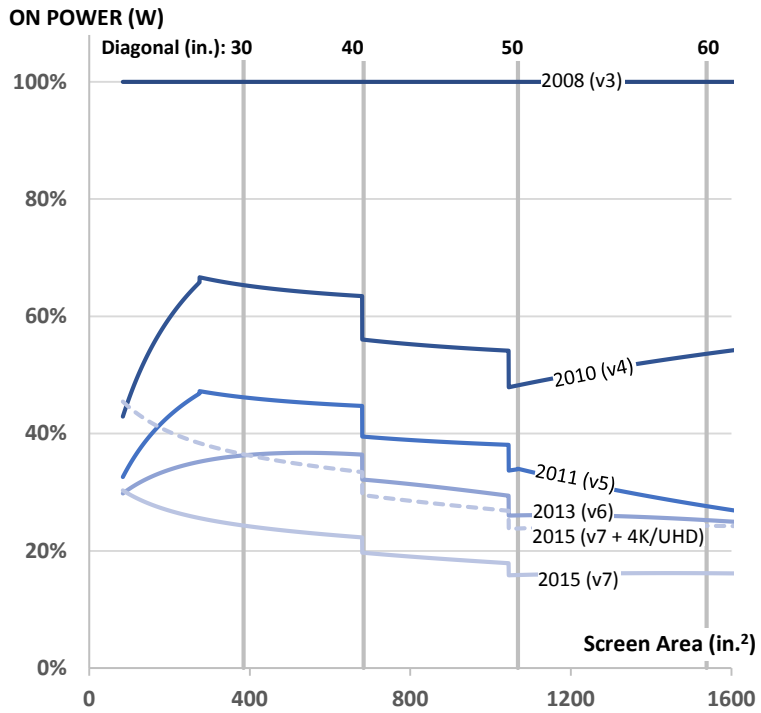
Viewable  $area$  (in.<sup>2</sup>), vertical native  $resolution$  (lines),  $\tanh$  = hyperbolic tangent function.



**Figure 1.** Market penetration of ENERGY STAR qualified TVs.



**Figure 2.** On-mode power limits by ENERGY STAR standard version.

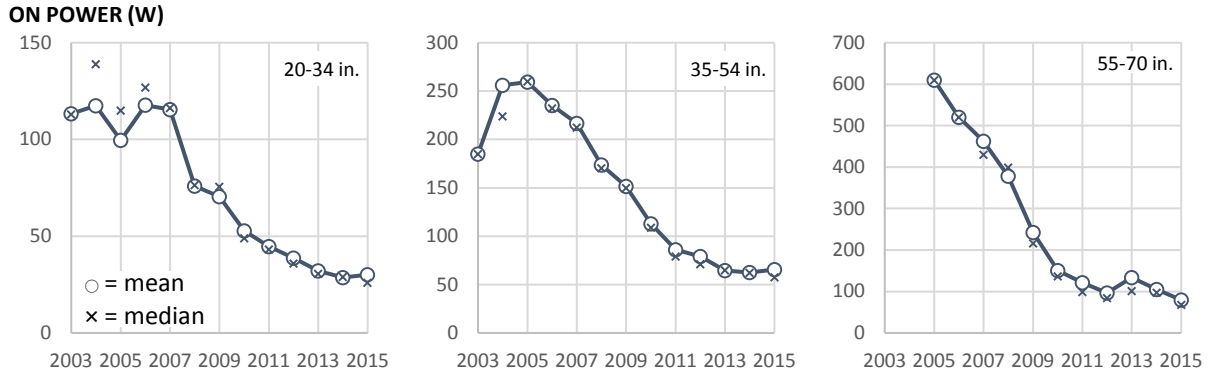


**Figure 3.** Ratio of on-mode power limits to ENERGY STAR standard version 3.



### 3 ON-MODE POWER

LCD TV on-mode power draw, averaged across similarly sized models in Figure 4, has more than halved for all screen size categories during the past decade. The steepest absolute decrease in power draw took place from about 2006 to 2011.



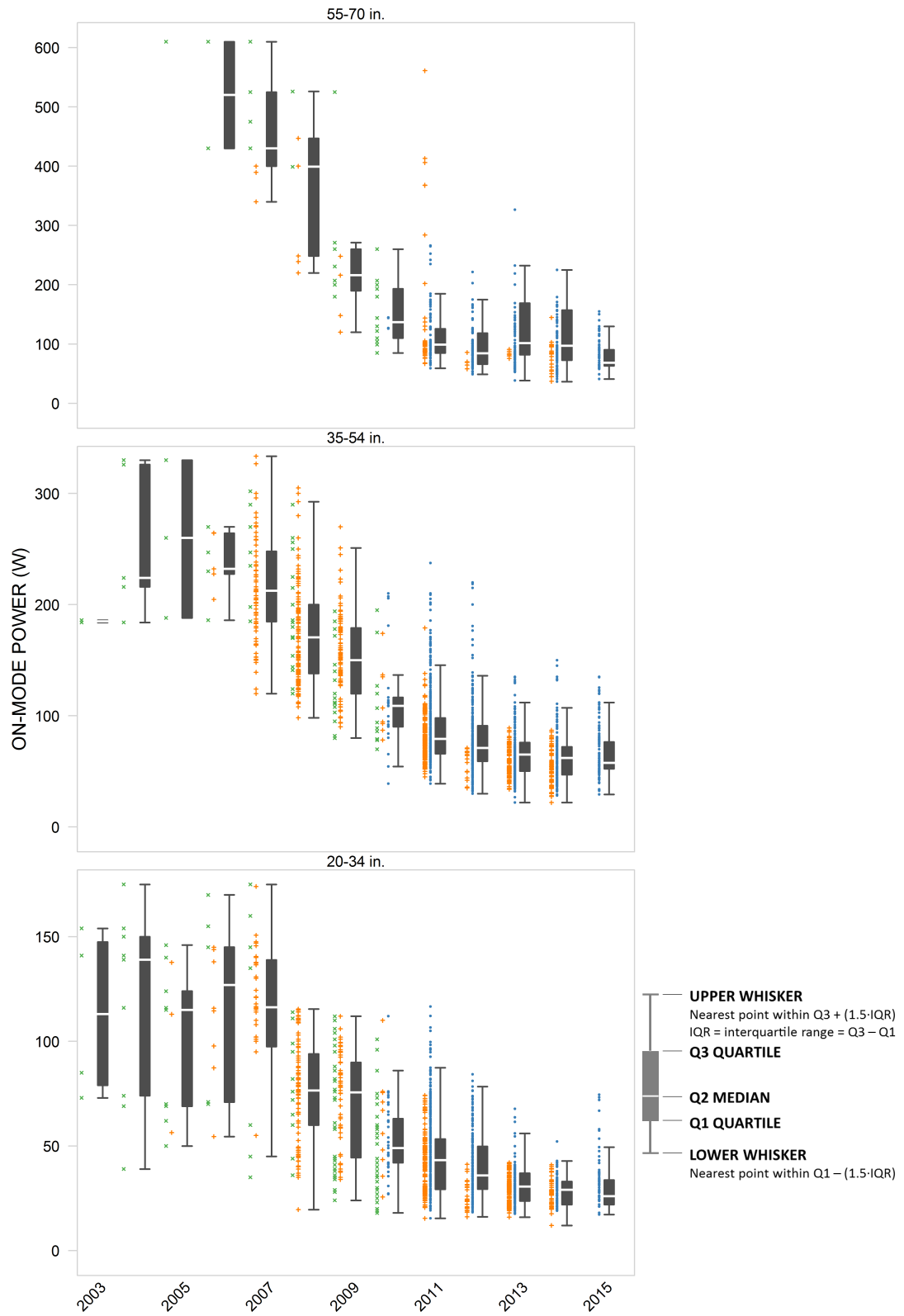
**Figure 4.** On-mode power trends of LCD TVs by screen size and year.

Sources: King and Ponoum (2011), CEC (2016), EPA (2016).

The underlying data for each screen size category, Figure 5, shows substantial variation among models of similar size. Relative to models in the CEC database, ENERGY STAR models had lower power draw, likely because its criteria have become more stringent since version 5.3 in 2011.

Screen size bins were chosen to match those from King and Ponoum (2011) to permit longer term comparisons. Because these bins are fairly wide, and because televisions have different components and features, there is appreciable spread in power draw among models even during a given year.

Tables in Section 8 at the end of this report summarize the CEC power data for finer screen size bins for the years 2011-2015. The following subsections analyze TV power draw in two other ways: normalized by viewable screen area and by brightness.



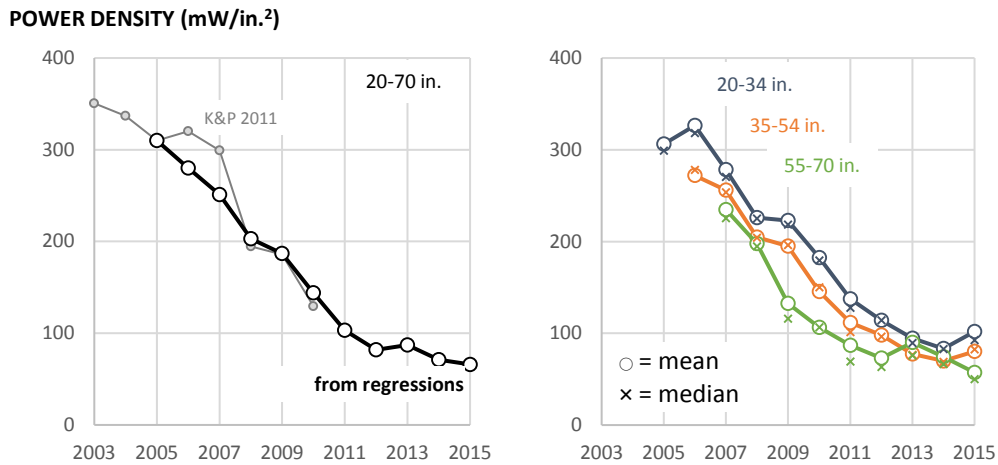
**Figure 5.** On-mode power distribution of LCD TVs by screen size and year.  
Sources: King and Ponoum 2011 (x), EPA 2016 (+), CEC 2016 (•).

### 3.1 Screen Size

Larger screens have gained popularity, with the average LCD screen size increasing from about 33 to 40 in. from 2010 to 2016 (NPD 2012, CTA 2016). Meanwhile, on-mode power *density*, power per viewable area, has declined for all screen size categories (Urban et al. 2015, Park 2011). To date, power density has decreased faster than screen area has increased, so that the overall trend is toward lower power displays.

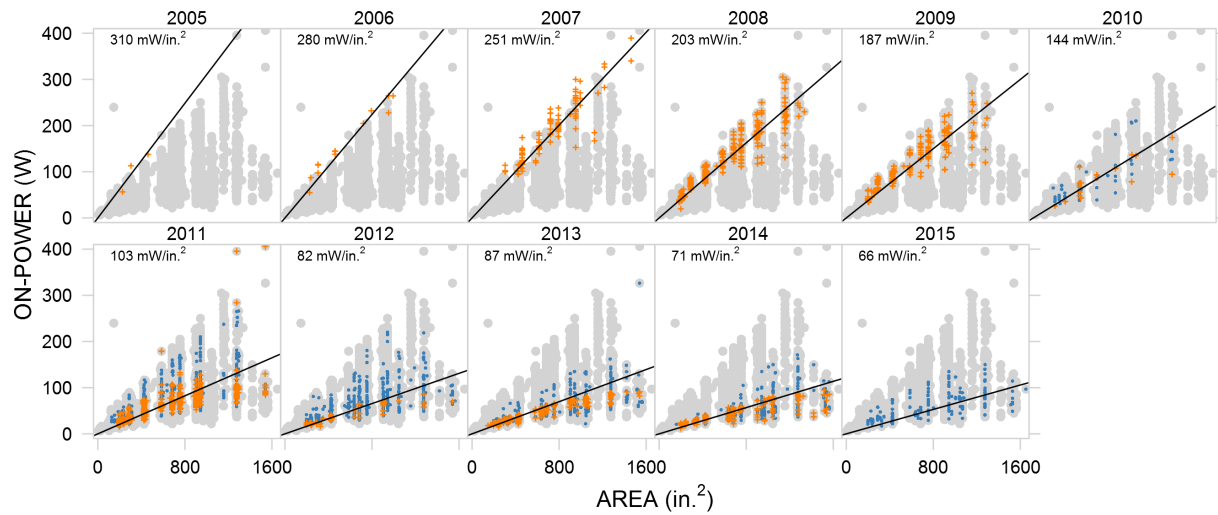
Prior to 2006, LCD TVs drew over 300 mW/in.<sup>2</sup> on average. By 2010, power density fell by 60% (Ponoum and King 2013). From 2010 to 2015, it halved again to about 70 mW/in.<sup>2</sup> The declining progression of on-mode power density was consistent among screen sizes and appears to have tapered in the last few years.

Power density was calculated two ways, both yielding similar trends. First, by plotting power vs. screen area in Figure 7, we fit a line through the origin<sup>1</sup> for each year, with the slope indicating the average power density across all screen sizes in Figure 6 (LEFT). Second, we normalized on-mode power by screen area for all models individually, and for three screen size bins, found the mean and median for each year, Figure 6 (RIGHT).



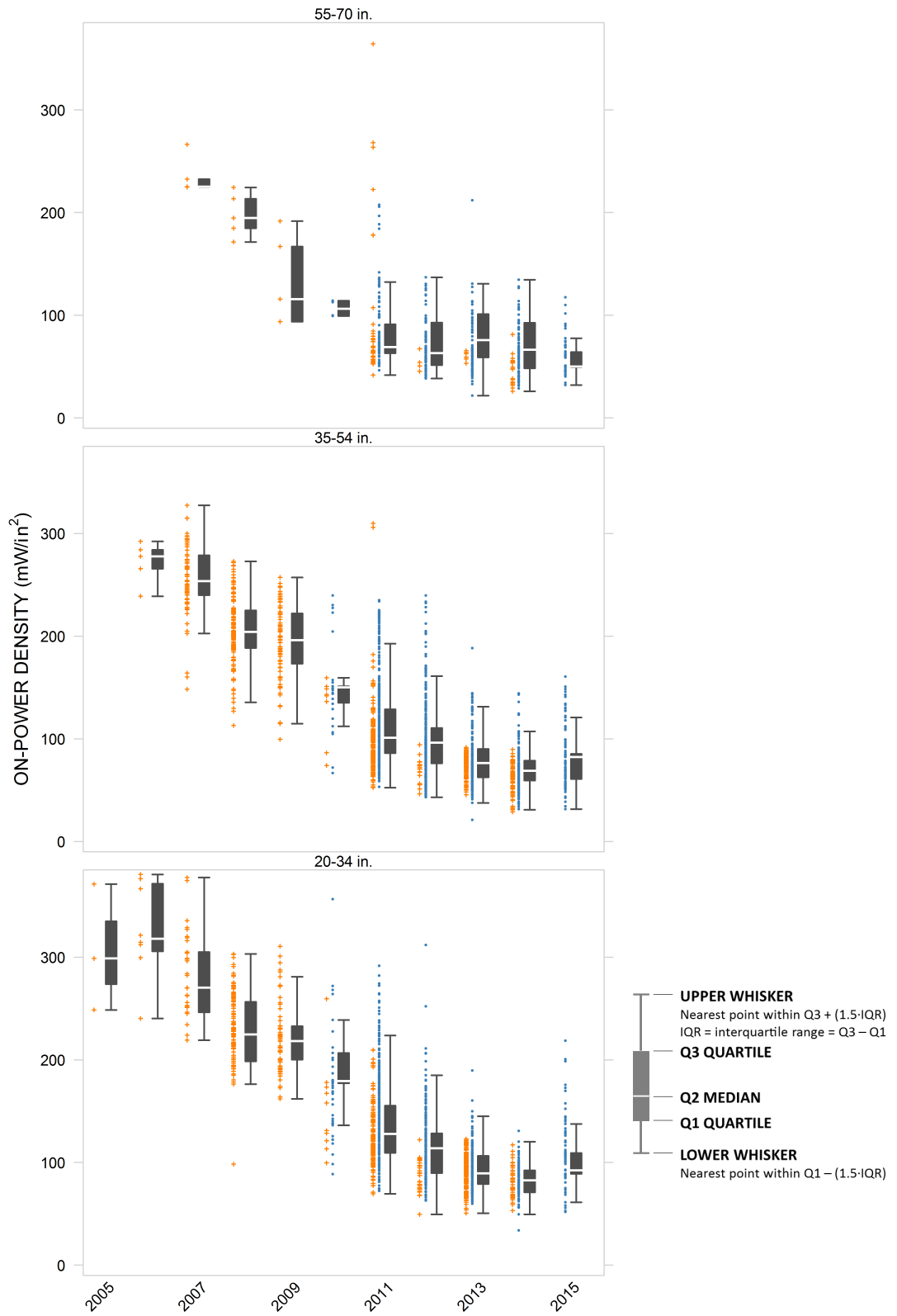
**Figure 6.** On-mode power density trends of LCD TVs by year.  
 LEFT: based on slope by year from Figure 7, historic values from K&P.  
 RIGHT: calculated for each model and then averaged by year.  
 Sources: King and Ponoum (2011), CEC (2016), EPA (2016).

<sup>1</sup> TV power is not exactly proportional to screen area. Other factors, like video processing, require some baseline power, suggesting a fit with an intercept. Including an intercept term did not significantly improve the fit and there was no discernable trend in the intercept term. Excluding the intercept allowed direct comparisons with King and Ponoum results for older models.



**Figure 7.** On-mode power vs. area of LCD TVs by year, with slope of fit through origin.  
Sources: EPA 2016 (+), CEC 2016 (•). All points (•).

On-mode power density, shown in Figure 8, has decreased similarly for the three screen size bins considered. Since we did not have access to TV shipment data by screen size and year, it was not possible to assess the absolute power draw trend for all models together. The number of available models of a given screen size is not necessarily proportional to the number of units sold, so actual shipment data would be needed to perform a meaningful weighted analysis. For historical power draw and energy use trends of televisions that account for the changing screen size distribution in homes, see Urban et al. (2011, 2015).



**Figure 8.** On-mode power density per area of LCD TVs by screen size and year.  
Sources: EPA 2016 (+), CEC 2016 (•).

## **3.2 Brightness**

Screen brightness influences TV power draw, sometimes in complex ways. Brightness can vary in time with the video signal, and often, spatially across the screen or in response to ambient light levels. It also depends on user settings. This section discusses brightness factors and their potential impact on on-mode power draw.

### **3.2.1 Lighting Technology and Dimming**

Declining on-mode power draw stems largely from improvements to lighting technology and its operation. Backlight dimming can, in particular, greatly reduce the power needed to display a picture while improving image quality, especially when displaying darker scenes. The extent and benefits of dimming depend on how displays are lit and how granularly the lights can be controlled.

Edge-lit displays, by far the most common, use light guides to spread light from one or more lamps evenly across the display (Lin 2014). Direct-lit displays, in contrast, place LEDs in a flat array behind the light guide plate, enabling local dimming by screen region. While direct-lit displays can be more energy efficient and provide higher contrast pictures, they require a deeper housing to accommodate the lighting components and are more expensive to manufacture than edge-lit displays (Park et al. 2011). Emissive displays, such as OLEDs, produce light directly by each pixel, eliminating the backlight and LCD entirely. This enables the highest possible dimming resolution and, potentially, the highest efficiency.

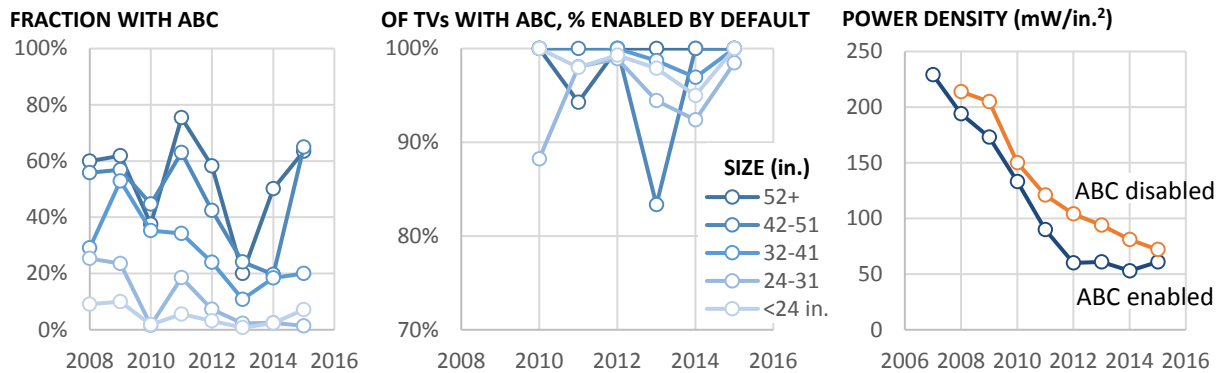
Different lighting configurations offer various levels of granularity in backlight dimming. The least efficient early flat-panel TVs maintained a constant backlight output based on user-chosen brightness settings, with the LCDs absorbing any unwanted light. Later models included zero-dimensional dimming that modulates the entire lamp output based on the desired picture brightness. Televisions with strips of lights (LEDs or CCFLs) can provide 1-D dimming, by dimming rows or columns of lamps independently. TVs using an array of lights (LEDs) can provide 2-D dimming, by dimming LEDs individually (Giamello 2010). Newer emissive displays, such as OLEDs, can modulate brightness at the pixel level, providing superior image quality while further improving efficiency.

Display power draw also depends on lighting efficiency, panel optical transmittance, driver circuit efficiency, and many other factors. Since 2010, cold cathode fluorescent (CCFL) backlights for LCDs have been largely replaced by more efficient LEDs, whose efficacy has continued to improve over time (Park et al. 2011).

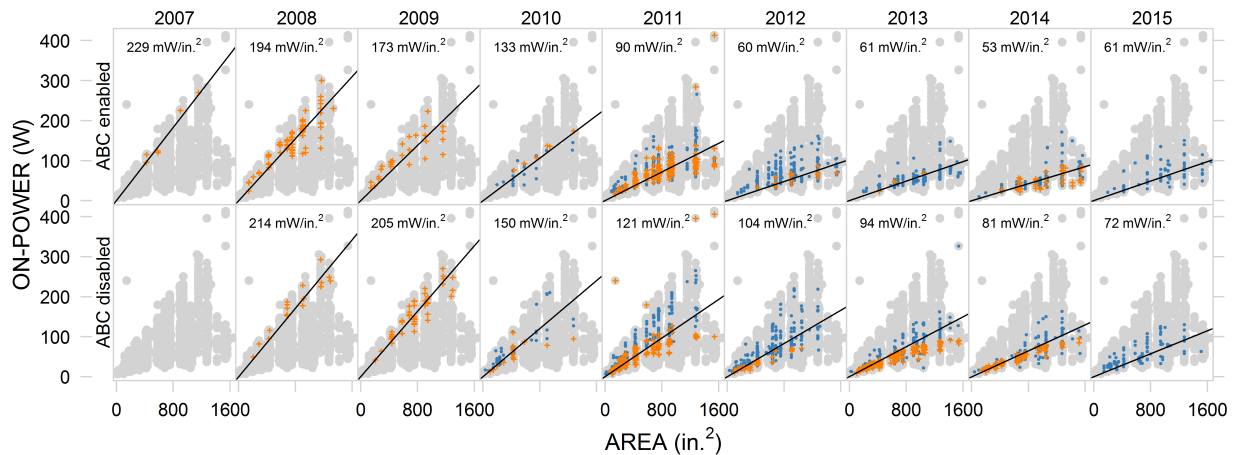
### 3.2.2 Automatic Brightness Control

Automatic Brightness Control (ABC), which dynamically adjusts screen brightness in response to indoor lighting conditions, can reduce TV power draw by about half when enabled (Horowitz et al. 2015). TV models with ABC enabled by default tend to have tested power density that is about 25% less than those without, Figure 9 and Figure 10. Regardless of ABC status, the average tested power draw of TVs has declined steadily.

More common with larger TVs, ABC is present among half of models above 42 inches, see Figure 9. For TVs that ship with ABC enabled by default, their on-mode power was measured with the light sensor exposed to specified ambient light conditions, and a weighted average of these measurements was used to calculate the on-mode power. Of models supporting ABC, almost all now ship with this setting enabled by default; however, it is not clear what portion of viewers keep this feature enabled. For some models, users could easily override these settings without knowing it, in some cases by switching modes or adjusting the brightness or contrast (Horowitz et al. 2016). Further study is needed to assess the actual persistence of automatic brightness control features.



**Figure 9.** Automatic brightness control prevalence among LCD TV models (LEFT) and power density (RIGHT). Sources: CEC and EPA (2016).

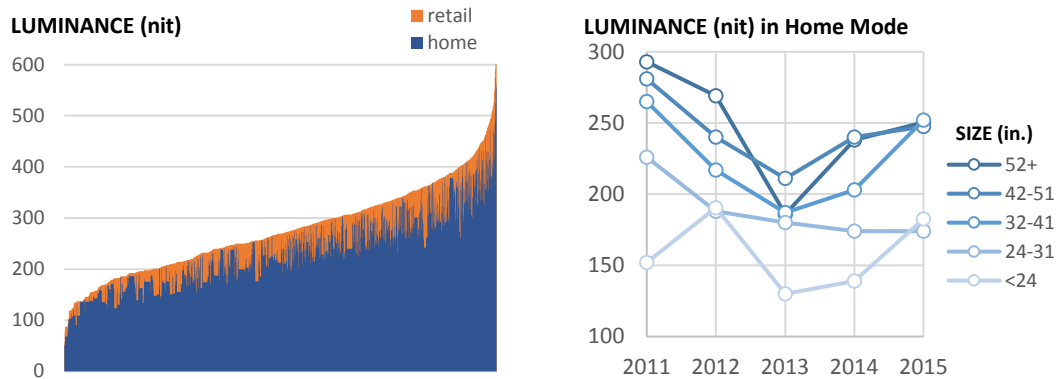


**Figure 10.** On-mode power vs. area of LCD TVs by year for TVs with ABC enabled and disabled. Slope (mW/in.²) found by least squares fit through origin. Sources: EPA 2016 (+), CEC 2016 (•). All data points (•).

### 3.2.3 Brightness Levels

Television manufacturers characterize screen brightness by *luminance*, with units of candela per square meter ( $\text{cd}/\text{m}^2$ ) or *nit*. Typical luminance values, shown in Figure 11, range from 200-500 nits. Some newer models, like those with high dynamic range (HDR), can output 1,000 nit or more. Median default luminance values among models do not indicate a clear trend over time, though larger displays tend to be capable of higher luminance than smaller displays.

Luminance measurements for ENERGY STAR qualification are taken during static image display, whereas power measurements are made during different and dynamic video signals (CFR 10 2016). These testing variables preclude a meaningful brightness-normalized power draw characterization in this study.



**Figure 11.** Home and retail mode luminance (LEFT) and median luminance by screen size (RIGHT) for LCD TVs. Source: CEC (2016).



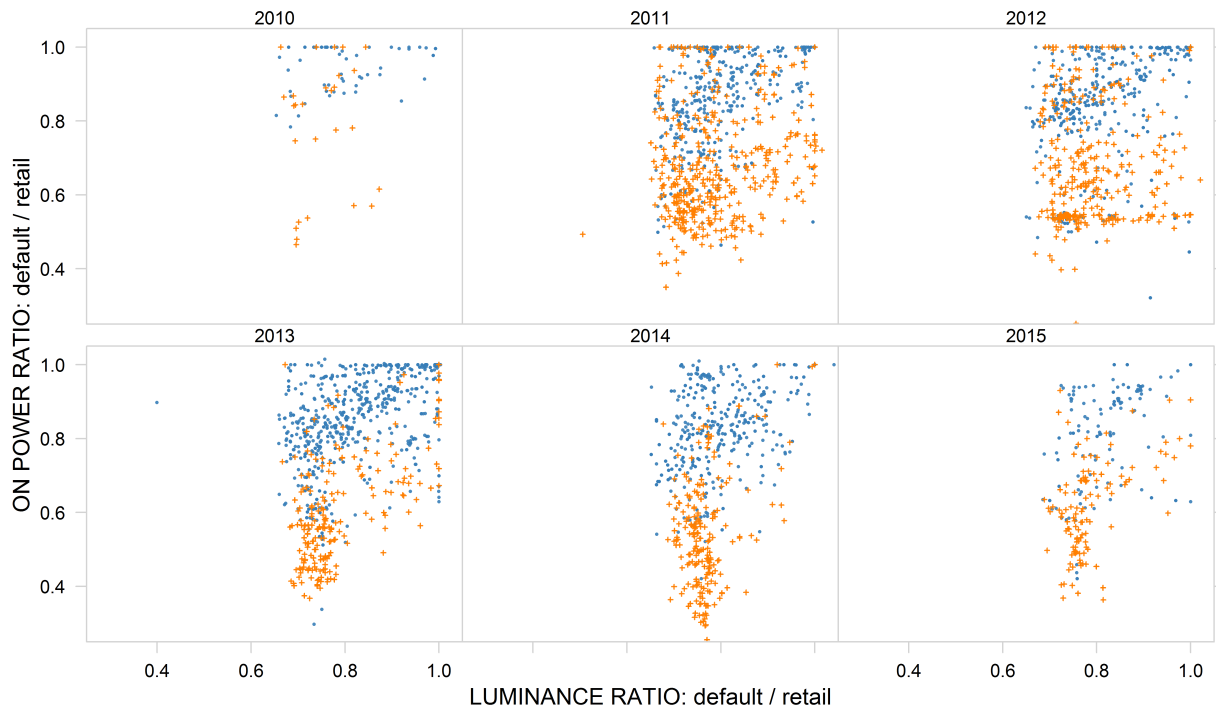
### 3.2.4 Brightness Modes

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. In turn, these modes alter the picture brightness, contrast, and color settings. Depending on selections made by the user, power draw could be affected in different ways. Understanding this impact is important when considering how well power draw measurements represent actual viewing conditions.

Power draw is normally tested in the *default* or *home* mode. Since ENERGY STAR version 4.0 (2010), the brightness in the default mode 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). Aside from three outliers, all the models from the CEC dataset met this requirement.

Measurements from the CEC database indicate power draw and luminance values for both *default* and high brightness *retail* modes, allowing a trend analysis, Figure 12. Consistent with Horowitz et al. (2016), switching from default to maximum brightness could double power draw in some cases, though the mean power ratio (default/retail) was about 85%. The effect was more pronounced among models with automatic brightness control.

While it is unlikely that most viewers would use maximum brightness settings at home, it is unclear which measured power draw figures best represent actual on-mode power draw. Further study of user preferences may be warranted given the potential scale of this effect.

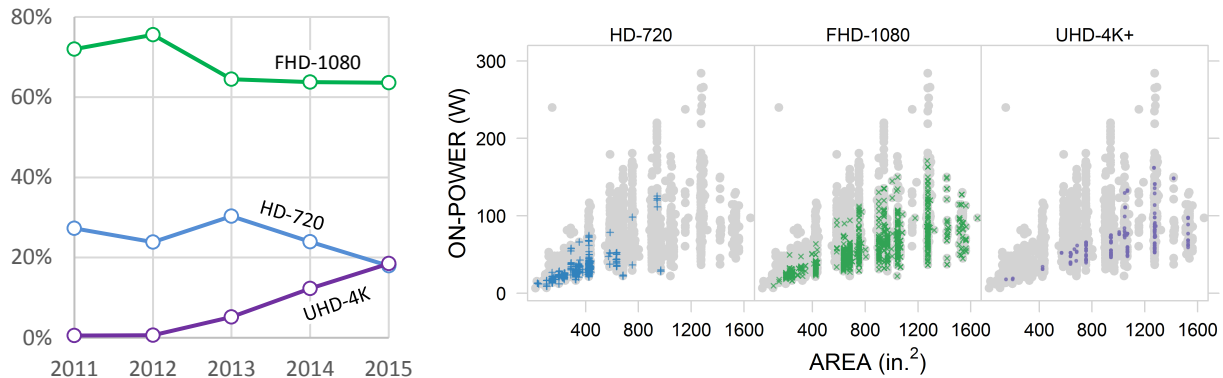


**Figure 12.** Ratios (default/retail) of power and luminance for LCD TV models 2010-2015. Automatic Brightness Control: WITH ABC (+), WITHOUT ABC (•). Source: CEC (2016).

### 3.3 Resolution

TV picture quality has increased over time, in part through higher screen resolution. Early flat-panel displays had a native vertical resolution of 480 rows of pixels called standard definition (SD). Resolution increased with high definition (HD-720), full high definition (FHD-1080), and recently ultra-high definition UHD, (4K) 2160 and (8K) 4320. A recent 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 (Horowitz et al. 2015). Most video sources do not yet provide 4K content, though this will likely change as higher definition TVs become more prevalent.

The distribution of screen resolution in the power datasets used in this report, shown Figure 13, highlights the steep decline of SD models since at least 2011 and the recent introduction and growth of UHD models. From 2011-2015, basic HD models were available primarily for smaller screen sizes, whereas FHD models were common for all sizes. Market share of UHD TVs comprises a new, but rapidly growing portion of the market. About half of TVs sold in the U.S. already support 4K resolution as of 2016, and this is expected to increase (CTA 2016).



**Figure 13.** Screen resolution (fraction of models) by year added to CEC database (LEFT) and on-mode power draw vs. area by screen resolution (RIGHT) for LCD TV models 2011-2015.

Resolution: HD (+), FHD (x), UHD (•). All data points (•).

## 4 STANDBY POWER

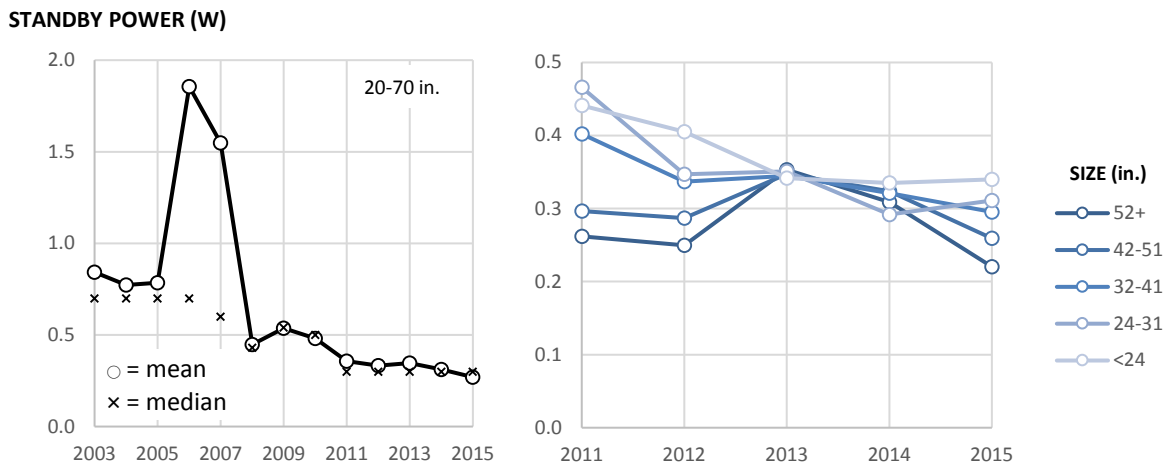
TVs spend most of the *time* in standby mode, even though most *energy consumption* occurs in active mode. Standby energy use of newer TV models represents only about 5% of the overall TV energy use (Urban et al. 2015).

### 4.1 Passive Standby

Early ENERGY STAR standards (v3.0 in 2008) and California regulations limit passive standby power to 1 W, while the newest ENERGY STAR standard (v7.0 in 2015) decreased this limit to 0.5 W. Televisions that draw 1 W in standby mode consume about 7 kWh, or about \$1, per year.<sup>2</sup>

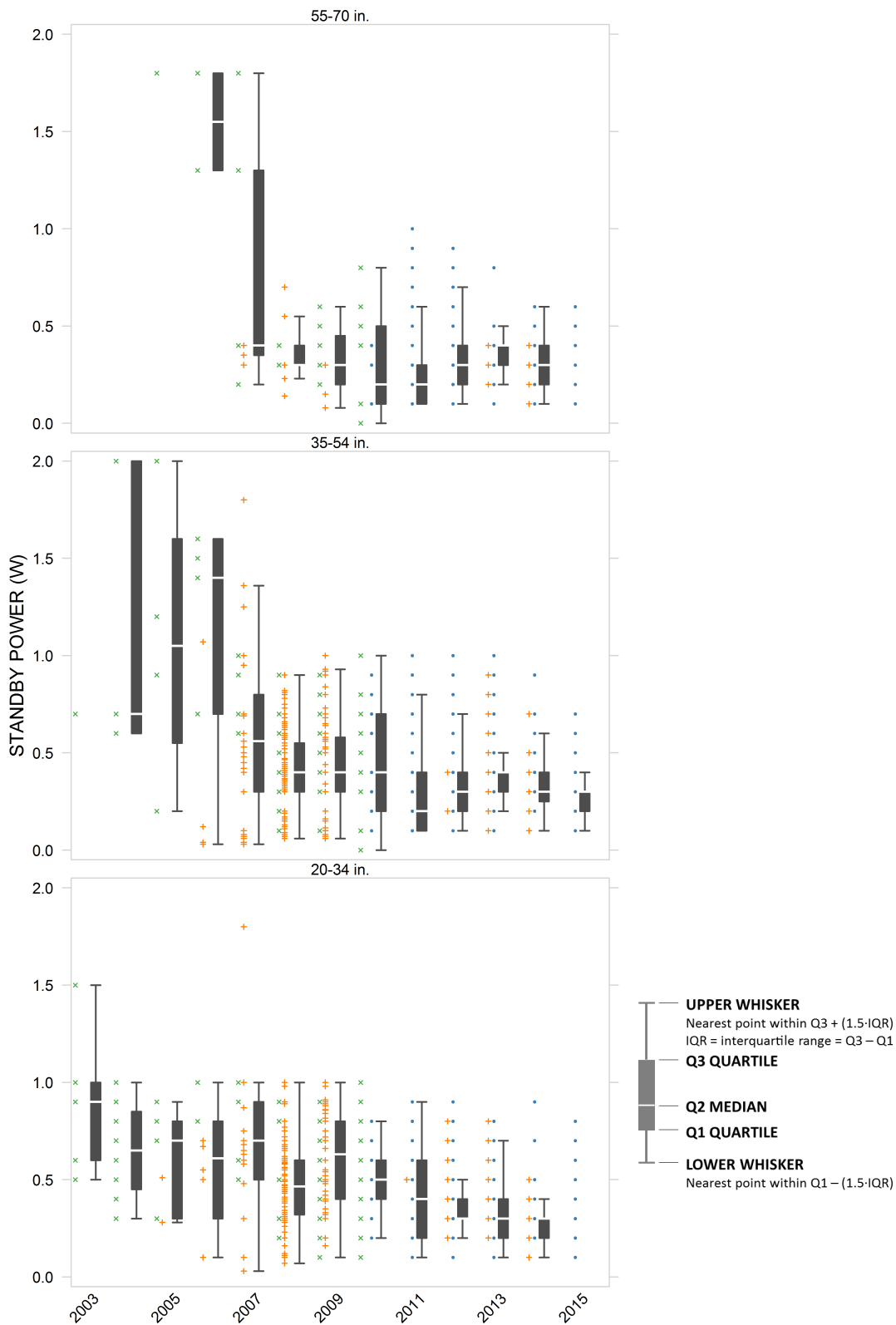
Most flat-panel TVs shipped since 2008 use less than 1 W in passive standby (King and Ponoum 2011), and at least 95% of LCD models since 2014 have met the new 0.5 W limit (CEC 2016). Further reductions to passive standby power, if achieved, would have only minor impact on overall energy consumption.

Trends in average passive standby, shown in Figure 15, indicate a decrease from 0.4 to 0.3 W from 2011-2015. Early models used somewhat more power in standby, but aside from ten outliers in 2006-2007 (15-30 W, not shown), virtually all models drew less than 2 W. Data for years prior to 2008 are comparatively sparse. The apparent spike in the 2006-2007 mean values were unduly influenced by outliers and do not indicate a trend. Consistent with King and Ponoum (2011), screen size did not impact standby power significantly.



**Figure 14.** Passive standby-mode power trends of LCD TVs.  
LEFT: all screen sizes. RIGHT: by screen size bin.  
Sources: King and Ponoum (2011), CEC (2016), EPA (2016).

<sup>2</sup> Based on 19 hours per day in standby and \$0.12/kWh (FTC 2015).



**Figure 15.** Passive standby power distribution by screen size and year for LCD TVs.  
Sources: King and Ponoum 2011 (x), EPA 2016 (+), CEC 2016 (•).

## 4.2 Active Standby

Active standby modes are relatively new and becoming increasingly common.

Internet-capable smart TVs, currently owned by about half of U.S. homes, include features that could yield higher standby power draw when enabled (CTA 2016). For instance, many models take time to recover from standby mode as software boots up and network connections are established. To address this delay, many models offer a quick start mode that allows users to begin watching internet content rapidly after the TV is turned on. In contrast, some models can quickly recover from standby mode (in under 10 seconds) reducing the need for quick start modes. Other active standby modes can temporarily use higher power, for instance, to download software updates, digital content, or program guides.

Active standby power data were available for only 35 models in the datasets considered, with a mean value of about 11 W, which is over 10 times higher than the typical passive standby (EPA 2016). Software can limit the daily time spent in active standby modes, but this varies by model.

To qualify for ENERGY STAR, TVs must be shipped with the lowest power standby mode enabled by default; however, it is unclear what fraction of viewers use the internet features of their connected TVs or enable active standby modes. Actual standby behavior depends on both software and user settings. While initial data suggest active standby power draw may be important, we do not yet have enough data to make a meaningful trend analysis of this mode.

## 5 OTHER FACTORS

### 5.1 Future Improvements

Further gains in TV energy efficiency could be realized through advances in “LED efficacy, reflective polarizing films, power supply improvements, lower screen reflectance, improved backplanes (Low Temperature Polysilicon and Indium Gallium Zinc Oxide), quantum dot technology, and next generation Organic LEDs” (EPA 2016). For a review of display technologies and their potential impact on TV power draw, see Park et al. (2011).

### 5.2 Study Limitations

Similar to Automatic Brightness Control (ABC), Motion Detection Dimming (MDD) dims the screen during periods of rapid on-screen motion and can also reduce power draw when enabled. This feature was not reported in the power datasets, and was therefore not considered in our analysis. Testing of three recent models found that MDD could decrease power draw by 25 to 58% with ABC disabled and 13 to 15% with ABC enabled (Horowitz et al. 2016). These MDD effects were highly sensitive to the test video clip used.

While actual on-mode power draw depends on picture settings and the video signal that is displayed, testing is performed with a standard video clip. There is some concern (Horowitz et al. 2016) that the standard clip may no longer be representative of typical video output, and, in particular, that it features rapid scene changes that could cause MDD to save more energy than it would in ordinary operation. Additionally, since UHD and HDR displays can use more power when displaying high-resolution content, the video clips may fail to capture these effects. Such a determination is outside the scope of this study; however further study appears to be warranted to better characterize these impacts on TV power draw.

Presently, it is not well known what portion of users actually maintain energy-efficient settings, such as ABC and MDD. Although ABC is enabled by default for most TVs that have the feature, for some models it is easy to disable this feature inadvertently by switching display modes or by manually adjusting the brightness or contrast (Horowitz et al. 2016).

Finally, while this study focuses on the power draw and features of TV models, it does not weight the results by actual shipment data. Given that the unit sales of all available TV models are not equal, unit sales weights could be used to calculate representative average power draw values. In an effort to weight TV power data by model, we solicited sales data from TV manufacturers for all models in the CEC database. Unfortunately, the industry responses represented only about 20 percent of the total units shipped during this period, precluding a meaningful weighted analysis. Consequently, this analysis evaluates the historical progression of efficiency among available TV models. Omitting weights could bias average TV power draw estimates; however, since the vast majority of units shipped are ENERGY STAR qualified, the magnitude of this bias is likely to be minor.

## 6 CONCLUSIONS

Amid a rapidly evolving product landscape, LCD television on-mode power draw has decreased progressively from 2003-2015. Typically, over 80% of units sold in the U.S. have satisfied the increasingly stringent regulatory and voluntary standards for energy efficiency.

Over this timeframe, a lot has changed with LCD TV features:

1. Average screen size increased by 20% from 33 to 40 inches (2010-2016).
2. Screen resolution capabilities increased 6-fold from HD to UHD 8K.  
4K TV market share increased from 0% to 50% of units shipped (2012-2016).
3. Internet-capable smart TV penetration has increased from 9% to 50% (2012-2016).
4. Automatic brightness control was present in about half of larger TVs (42+ inches) since 2008.

At the same time, LCD TV power draw has decreased substantially:

1. Average **On-mode** power density decreased four-fold from 300 to 70 W/in.<sup>2</sup> from 2003 to 2015.
2. Average **Passive Standby** power draw decreased from about 0.8 W to 0.3 W from 2003 to 2015.
3. **Active Standby** power draw must be less than 3 W to satisfy the current ENERGY STAR version 7.0 requirements, however limited data preclude a trend analysis of this mode.

Actual television power draw, as with many technologies, depends on user behavior and preferences. Less is known about the persistence and use of energy-efficient display settings and features, which could impact real-world on-mode power draw by 50% or more. As higher definition content becomes mainstream, it may become necessary to reevaluate the testing procedures to ensure they accurately represent actual viewing conditions and content.

Similarly, while internet-enabled TVs can draw more power in active standby modes, it is unclear what fraction are connected to the internet and use higher power-draw modes, and for how long. Further study is warranted to shed light on real-world settings and viewing conditions.

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## 8 SUMMARY TABLES

**Table 2.** LCD TV power draw by screen size and year added to CEC database.

YEAR	SCREEN SIZE (in.)			LUM (nits)		MODELS (% by...)			ON (W)		STANDBY (W)		ON POWER per AREA (mW/in. <sup>2</sup> )	
	group	mean	SD	mean	SD	n	year	all	mean	SD	mean	SD	mean	SD
2011	<24	19	3	194	55	177	17%	3%	26	9	0.4	0.2	183	100
2012	<24	20	2	181	33	170	11%	3%	22	4	0.4	0.1	141	39
2013	<24	20	3	132	34	198	10%	3%	20	3	0.3	0.1	126	66
2014	<24	20	3	174	54	74	7%	1%	18	3	0.3	0.1	112	34
2015	<24	21	2	192	35	14	4%	0%	27	8	0.3	0.1	141	31
2011	24-31	26	2	250	58	124	12%	2%	44	14	0.4	0.2	163	44
2012	24-31	25	2	183	49	177	12%	3%	33	8	0.4	0.1	125	30
2013	24-31	26	2	180	40	164	8%	3%	27	6	0.3	0.1	96	17
2014	24-31	25	2	181	30	87	8%	1%	24	4	0.3	0.0	90	10
2015	24-31	25	2	185	36	73	20%	1%	27	8	0.3	0.1	101	22
2011	32-41	35	3	279	66	398	38%	7%	78	27	0.4	0.2	151	43
2012	32-41	35	4	222	72	533	35%	9%	57	23	0.3	0.2	108	31
2013	32-41	35	4	194	65	661	34%	11%	44	14	0.4	0.1	87	26
2014	32-41	35	4	201	49	319	30%	5%	38	9	0.3	0.1	73	12
2015	32-41	37	4	243	34	85	23%	1%	49	15	0.3	0.1	86	26
2011	42-51	45	2	295	86	247	23%	4%	97	35	0.3	0.2	115	42
2012	42-51	46	3	249	91	419	27%	7%	86	31	0.3	0.1	95	32
2013	42-51	47	2	217	82	480	24%	8%	73	18	0.3	0.1	77	18
2014	42-51	48	3	236	48	373	35%	6%	70	19	0.3	0.1	72	18
2015	42-51	46	3	262	63	100	27%	2%	71	26	0.3	0.1	79	30
2011	52+	55	2	301	67	115	11%	2%	114	45	0.3	0.2	88	35
2012	52+	56	4	268	72	228	15%	4%	99	38	0.3	0.1	73	28
2013	52+	59	5	218	85	457	23%	8%	136	75	0.4	0.1	91	44
2014	52+	59	6	250	50	198	19%	3%	112	47	0.3	0.1	78	31
2015	52+	59	9	258	69	96	26%	2%	87	41	0.2	0.1	58	17

**Table 3.** PDP TV power draw by screen size and year added to CEC database.

YEAR	SCREEN SIZE (in.)			LUM (nits)		MODELS (% by...)			ON (W)		STANDBY (W)		ON POWER per AREA (mW/in. <sup>2</sup> )	
	group	mean	SD	mean	SD	n	year	all	mean	SD	mean	SD	mean	SD
2011	42-51	48	4	77	16	74	85%	33%	134	44	0.2	0.2	138	42
2012	42-51	48	4	68	11	37	65%	17%	102	17	0.3	0.2	101	15
2013	42-51	48	4	96	82	17	30%	8%	105	31	0.2	0.1	108	30
2014	42-51	49	3	64	14	8	62%	4%	85	17	0.3	0.0	82	13
2015	42-51	50	0	63	8	7	70%	3%	113	28	0.2	0.1	106	26
2011	52+	59	3	68	7	13	15%	6%	169	39	0.2	0.0	112	15
2012	52+	60	3	62	10	20	35%	9%	134	27	0.1	0.1	90	11
2013	52+	65	11	70	23	40	70%	18%	242	181	0.3	0.1	122	43
2014	52+	61	2	57	9	5	38%	2%	136	17	0.3	0.0	87	15
2015	52+	60	0	53	0	3	30%	1%	140	2	0.3	0.0	91	2