ANALYSIS OF ROOM ILLUMINANCE AND TELEVISIONS WITH AUTOMATIC BRIGHTNESS CONTROL: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS:

Television Sets

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1.1 INTRODUCTION

This report provides a comparison of three recent U.S.-based studies on typical room illuminance levels during television viewing events. The purpose of these investigations was to determine the appropriate room illuminance levels at which to test the effectiveness of automatic brightness control (ABC), an energy-saving feature increasingly found in new TVs. A TV with ABC enabled will reduce its screen luminance[a] automatically in response to lower ambient lighting conditions (termed room illuminance). Currently, ENERGY STAR requires TVs with ABC to be tested at 0 and 300 lux, and often times the variation in screen luminance occurs in a single step; therefore TVs viewed at 10 lux could be at the same brightness as those in a 300 lux room. A Japanese study[b] which included room illumanince measurements in Japanese homes provided some indications that 0 and 300 lux were extreme conditions, though television viewing preferences may be different in Japan than in the U.S. Anecdotal evidence indicated that 0 lux, i.e. total darkness, was unusual in the U.S. as well. These studies were initiated in order to obtain a better understanding of actual room illuminance conditions in the U.S.

The first study[c] was conducted by the Lawrence Berkeley National Laboratory (LBL) in 9 homes, 5 in Colorado and 4 in the San Francisco Bay area of California, during May and June of 2011. An initial set of one-time room illuminance measurements were taken at 5 points: the center of the room, the viewing location, the top of the TV cabinet, the center of the TV screen, and at the location of the ABC sensor[d]. This was done in order to establish the variance in illuminance within a TV viewing room. Then a power meter was attached to the TV and an illuminance meter placed at the center of the bottom bezel of the TV for up to 2 weeks, and a simultaneous measurement of TV power and room illuminance recorded every 10 minutes in order to monitor room illuminance during actual TV viewing. Although a useful pilot study, the measurements were limited by the sample size, length of data collection, time of year (e.g., seasonality), geography, and the use of multiple measurers.

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[a] The terms "luminance" and "illuminance" are potentially confusing. Luminance, typically measured in cd/m^2, is a measure of light intensity; it is used to measure the amount of light emitted from a source such as a TV screen. Illuminance, typically measured in lux, is a measure of the intensity of incident light from all directions; it is used to measure the level of ambient lighting in, e.g., a room.

[b] Matsumoto et al., 2011, Appropriate Luminance of LCD-TV Screens under Actual Viewing Conditions at Home, Journal of the Society for Information Display, Volume 19, Issue 11, pp. 813-820.

[c] The full report on this study may be found under the current test procedure rulemaking activity at http://www1.eere.energy.gov/buildings/appliance_standards/residential/tv_sets.html.

[d] If the TV was not ABC-enabled, the measurement was taken from either bottom corner of the TV.

The second study[e], by the Consumer Electronics Association (CEA), took measurements in 234 homes between September and December 2011. Of these measurements, 101 were collected by a consultant while 133 were collected by volunteers. The measurements were more geographically diverse, although the majority (62%) were in California. This study only took a single measurement at the center of the bottom bezel of the TV, asking participants to set up the room as they would during typical television viewing (i.e., whether the blinds would be drawn and what artificial lights would be on). This study therefore did not capture any variation in room illuminance while the TV was being viewed at different times of day. Also, due to various considerations, 35 of the measurements were deemed unreliable by the CEA and excluded from the analysis.

The third study[f] was conducted by the Collaborative Labeling and Standards Program (CLASP), and took measurements in 60 homes evenly split between Sacramento, California and Washington, D.C., during October and November 2011. The television-viewing environment was sketched and photographed to document natural and artificial light sources and other major physical characteristics. Similar to the LBL study, the five point illuminance measurements were taken and these were also mapped on to the sketch of the room. The TV was then fitted with an illuminance meter and a power meter. The illuminance meter was located in the middle of the bottom bezel of the TV. Data were recorded at 5-minute intervals for approximately 7 days.

CLASP worked with Shugoll Research to select a diverse sample of homes in order to obtain a broad range of lighting conditions. A screening criterion was used to achieve a demographic mix of household size, age, gender and income, as well as a variety of housing types including single-family homes, apartments and row houses. However, the sampling was still limited geographically and seasonally. Note that CLASP excluded 6 of the households from the final dataset, due to either faulty metering equipment or the household failing to view television during the data collection period.

In addition, to determine the appropriate room illuminance levels at which TVs with automatic brightness control should be tested, this report also examines how current TVs respond to different lighting levels. Testing the current implementation of ABC by manufacturers demonstrates both what type of response is technically possible and at what lighting levels TVs adjust their brightness and therefore their power consumption. Because the majority of TV power is associated with producing light, ABC is a key method used for decreasing reported power. There is a close relationship between luminance and power, as shown in more detail in the later sections of this report. Examining a TV's luminance at various lighting levels can reveal if a TV is too dim, meaning it is over-utilizing ABC to save power, or too bright, meaning it is under-utilizing ABC and missing energy savings opportunities.

Section 1.2 describes the comparative analysis of the 3 recent room illuminance studies. Section 1.3 discusses testing performed on televisions with ABC enabled. Section 1.4 provides some discussion on the results, and Section 1.5 summarizes the main results in this report.

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[e] See comments submitted by the CEA to the Department of Energy, Docket No. EERE-2010-BT-TP-0026.

[f] The full report on the CLASP study is available for download at http://www.clasponline.org/en/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2011/Background-Illuminance-Levels

1.2 COMPARISION OF ROOM ILLUMINANCE STUDIES

1.2.1 Time of Day

In order to determine the comparability of the three studies it was important to consider the time of day at which measurements were recorded, due to the expected influence of bright sunlight on room illuminance. The distribution of time of day at which measurements were recorded is illustrated in Figure 1.2.1, Figure 1.2.2, and Figure 1.2.3. As can be seen from these figures, the majority of viewing events occur in the evening. However, the CLASP data has some more significant values in the earlier part of the day. Deeper investigation revealed that this was specific to measurements recorded in Washington, D.C., as shown in Table 1.2.1, and does not appear to be representative of average behavior. Further comparison with the American Time Use Survey[g], which surveys a representative cross-section of the population, indicates more significant TV viewing in the evening (see Figure 1.2.4). The three studies are therefore considered reasonably representative.

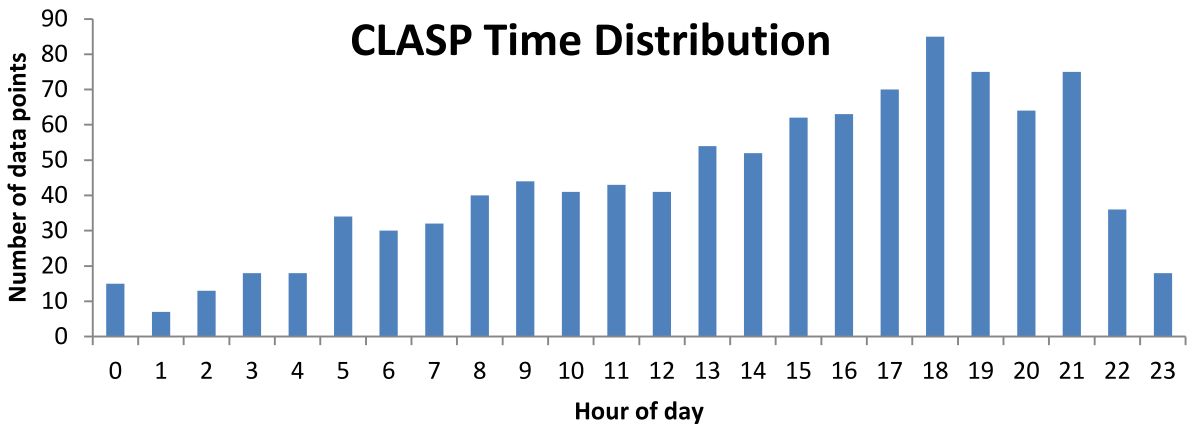

Figure 1.2.1 Time of day distribution in the CLASP data

[g] The Bureau of Labor Statistics' American Time Use Surveys are available to download at http://www.bls.gov/tus/ going back to 2003. Last accessed 1/30/2012.

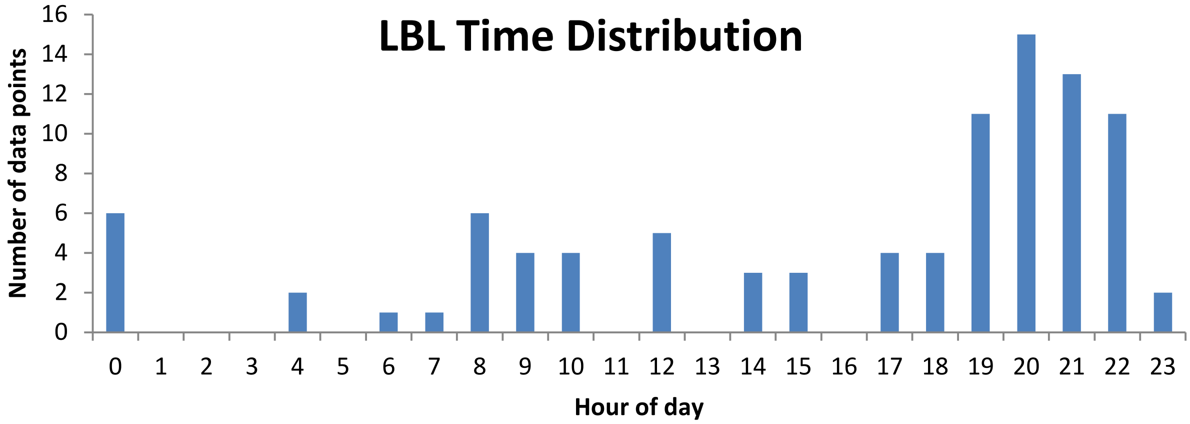

Figure 1.2.2 Time of day distribution in the LBL data

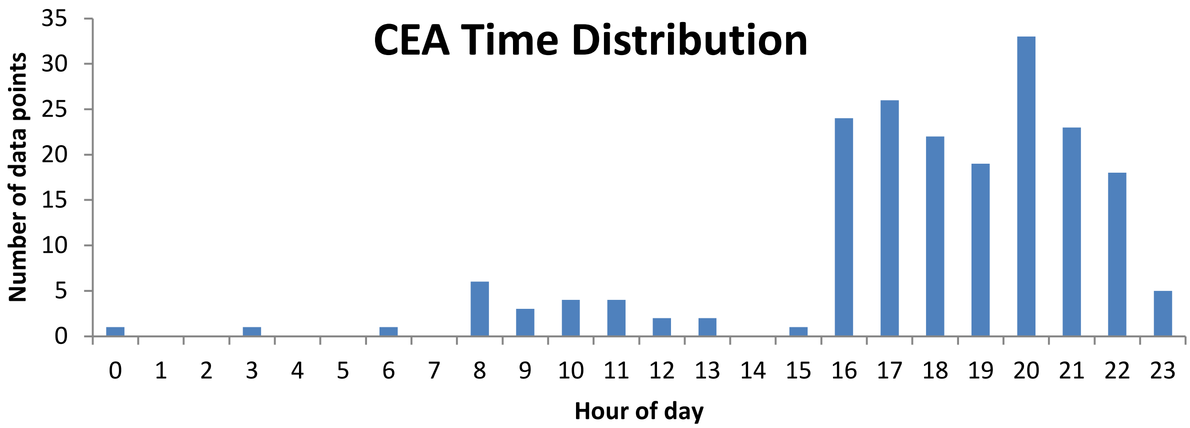

Figure 1.2.3 Time of day distribution in the CEA data

Table 1.2.1 Day and night time hours in the CLASP study by location

	Daytime	Nighttime	**Total hours**
D.C.	951	615	**1566**
Sacramento	662	747	**1409**
Total	**1613**	**1362**	2975

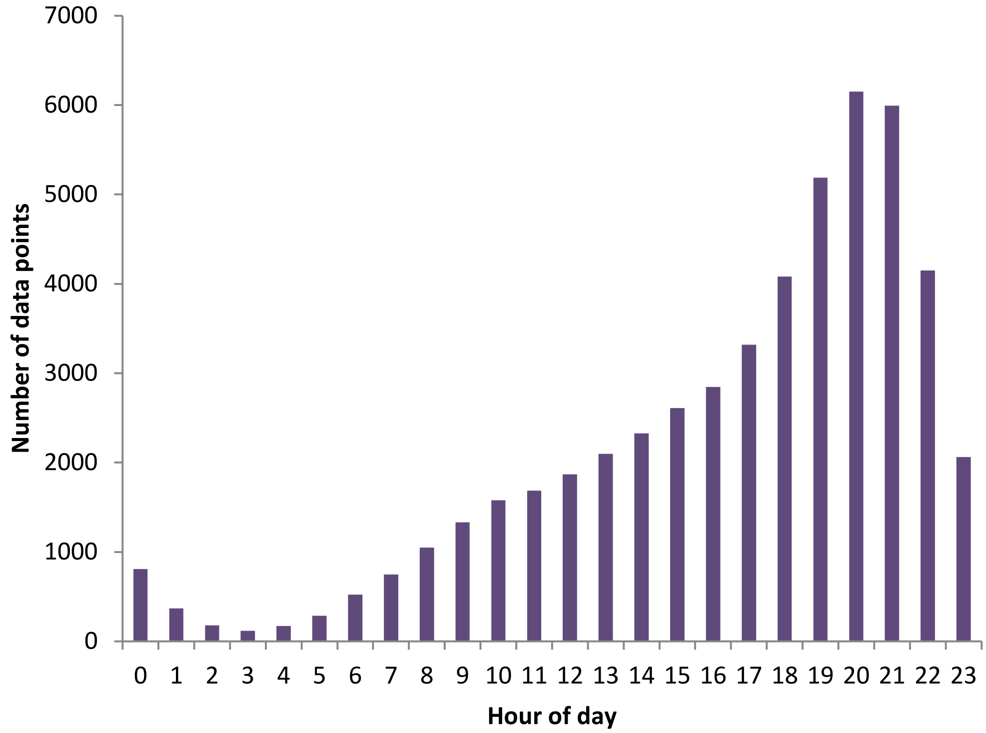

Figure 1.2.4 Distribution of television viewing times from the 2010 'American Time Use Survey'

1.2.2 Range of Illuminance Measurements per Event

A comparison of the range of room illuminance measurements is shown in Figure 1.2.5 below. The x-axis indicates mean room illuminance for each measured viewing event (defined as a time period during which the TV was continuously on), for the CLASP and LBL studies, and each single measurement in the CEA study. The y-axis indicates the cumulative fraction of the measurements at or below that illuminance level.

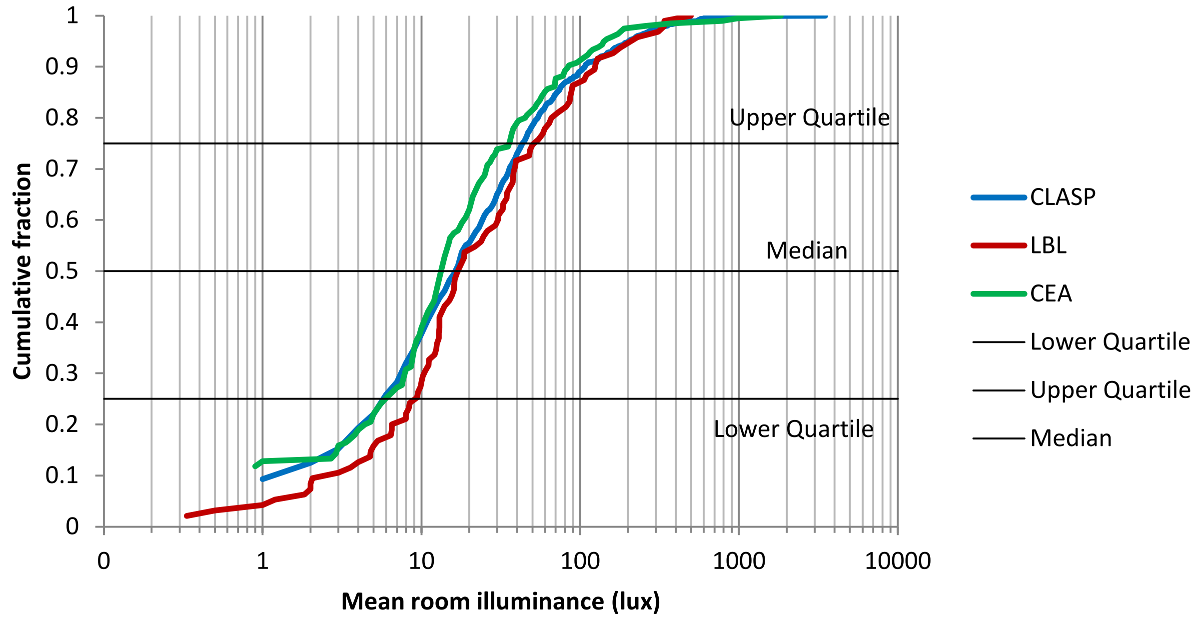

Figure 1.2.5 **Comparison of room illuminance cumulative distributions of the 3 sets of data. Data are averaged over viewing events.**

The y-axis is also divided into even quartiles, and Table 1.2.2 shows the mean room illuminance in the middle of each quartile as well as at each quartile boundary. Interestingly, the CEA and CLASP results are closely related at lower lux levels, with almost identical distributions below the median point (50% of cumulative events). Above the median point, the CLASP and LBL results are more similar.

Table 1.2.2 **Mean room illuminance vs. cumulative event fraction**

	Cumulative events (%)						
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**
Study	*Room illuminance (lux)*						
CEA	1.0	5.9	9.7	13.3	20.2	35.6	69.9
CLASP	2.0	5.8	9.9	16.4	27.5	43.4	85.8
LBL	3.9	9.2	12.9	16.9	32.7	50.4	107.8

The CEA study generally found lower lux levels than the other two studies, with 75% of measurements below 36 lux. The LBL dataset consistently found the highest lux values in all quartiles, only coming close to the CLASP study at the median point. This result is unusual given that more daytime viewing events were recorded in the CLASP study; however, some of the viewing events in this survey were very long, spanning daylight hours into the evening. (For example, one home in the D.C. area explained that they keep the TV on for most of the day for background noise, and the lux level in the room varied considerably during that time). Averaging over individual viewing events may therefore lead to reduced accuracy, but was necessary in order to directly compare the continuous measurements of the LBL and CLASP studies with the one-time measurements of the CEA study.

1.2.3 Range of Illuminance Measurements per Hour

Given the above observations, the mean lux per hour (while viewing TV) may be a more representative measurement than the mean lux per viewing event. The LBL and CLASP data were therefore reanalyzed using the mean lux per hour, shown in Figure 1.2.6. The CEA did not continuously record room illuminance during viewing events; those data are therefore included on the same one-time measurement basis as above, for comparison.

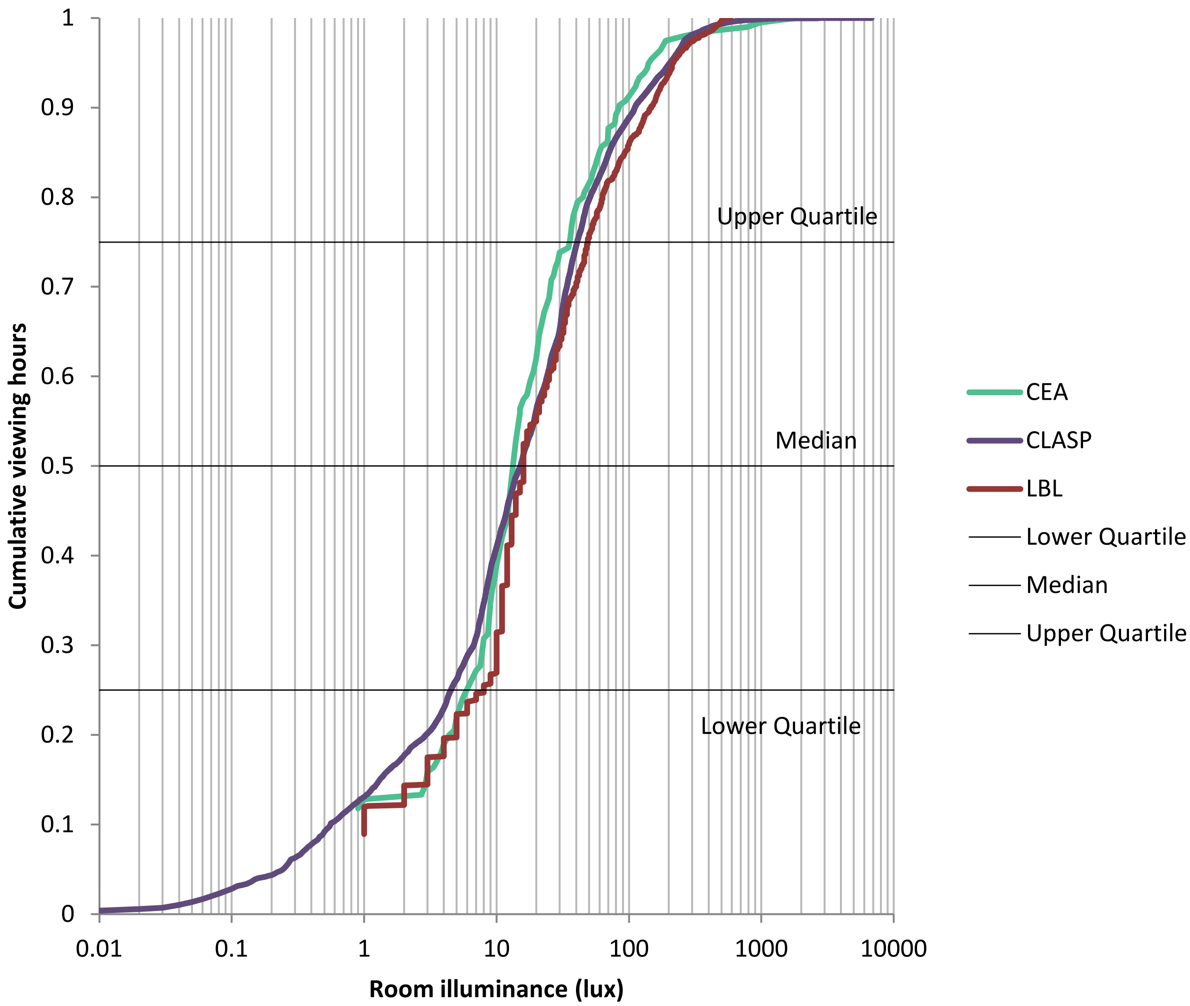

Figure 1.2.6 Room illuminance per hour of TV viewing

Table 1.2.3 shows the room illuminance measurements in each quartile. The CLASP study still shows significantly lower lux levels than the LBL study in a given quartile. This may just be a reflection of the difference in dataset size: only 9 homes were measured for the LBL survey, and data were only recorded for 7-14 days. A few viewing events in bright conditions might therefore easily skew the data towards higher values, even though the majority took place at more commonly-found low lux levels.

Another factor that may explain the difference is seasonality. The LBL survey took place in late spring when daylight hours are longer and conditions brighter, while the CLASP study took place in late autumn, when hours of daylight are shorter. Collection of room illuminance data over a several-month period in the same locations would be helpful to resolve how much seasonality affects average lux levels.

All 3 datasets indicate that the majority (more than 75%) of viewing occurs at less than 50 lux, which is much lower than 300 lux, the upper illuminance level currently required by the ENERGY STAR program. In addition, these studies confirm that while a significant fraction of viewing occurs in low-lux conditions, 0 lux is extremely rare. The CLASP study is the most comprehensive and recorded lux levels to two decimal points, and less than 0.2% of measurements were at exactly 0 lux.

Table 1.2.3 Mean room illuminance vs. cumulative viewing hours

	Cumulative viewing hours (%)						
	12.5	**25**	**37.5**	**50**	**62.5**	**75**	**87.5**
Study	***Room illuminance (lux)***						
CLASP	0.9	4.5	8.8	15.1	26.4	40.6	87.4
LBL	2	8	12	16	28	49	119.5

1.2.4 Comparison Between Weekday and Weekend

An interesting consideration was how TV viewing habits vary on the weekend compared to weekdays, and in particular, whether more viewing occurs in daylight hours on the weekend, and therefore if viewing occurs at higher room illuminance levels. Figure 1.2.7 shows the number of data points that were recorded separated by weekday and weekend for the CLASP study. A very clear preference for evening viewing is obvious, and weekday and weekend follow very similar patterns in relation to the time of day at which the television is viewed.

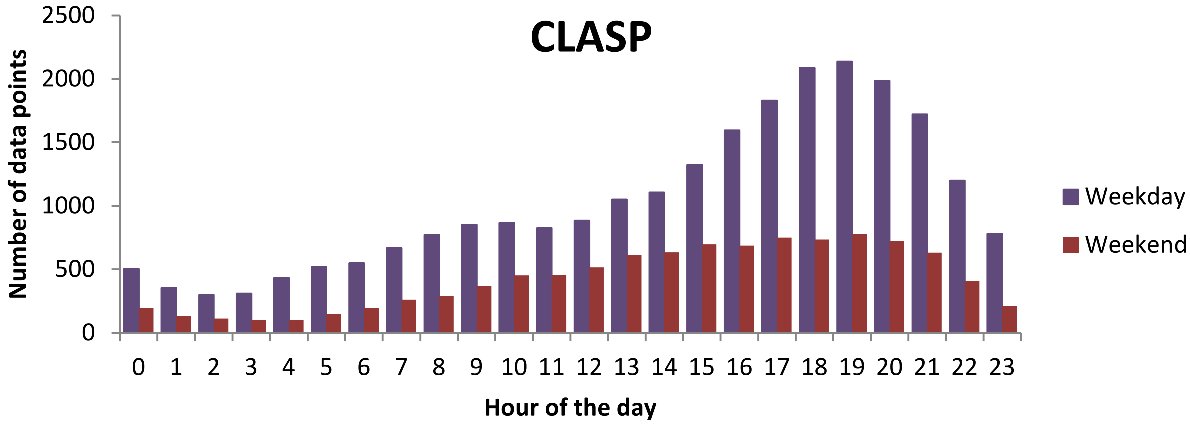

Figure 1.2.7 CLASP study data points by type of day

In order to determine whether there was a preference for watching TV during the daytime on the weekend, the two subsets of data were normalized to a single day, by dividing the weekday data by 5 and the weekend data by 2. The result, shown in Figure 1.2.8, indicates that viewing is greater on weekends between 9 am and 5 pm, but that viewing is greater on weekdays at all other times. Overall, total weekend viewing time is equivalent to an average of 7.1 hours per household, only slightly greater than the total weekday viewing time of 6.8 hours. These viewing hours are close to those for a primary TV as derived from Nielsen metered viewing data for an average U.S. household in 2010.[h]

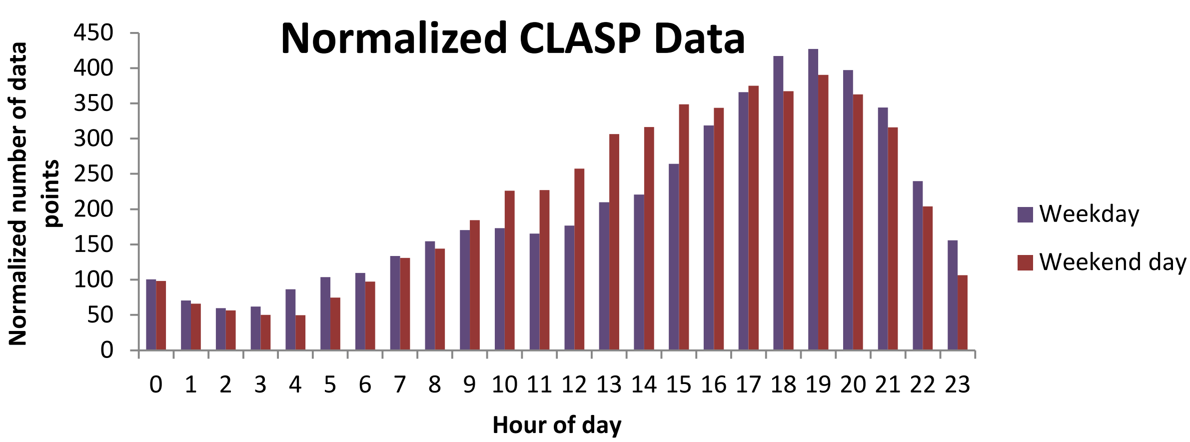

Figure 1.2.8 Normalized CLASP study data points by type of day

The LBL data are shown in Figure 1.2.9, and also demonstrate more viewing during the evening than the day. The data normalized to a single day are shown in Figure 1.2.10. The daytime weekend peak is more pronounced, especially from 11am to 4pm. Overall, total weekend viewing time is equivalent to 3.6 hours per household, while weekday viewing time is

[h] Average monthly viewing time (in minutes) from up to 21,000 households was collected by The Nielsen Company from May 2007 to May 2011. The last full calendar year available (2010) was used in comparing to the room illuminance data presented here.

equivalent to 2.6 hours per household. The overall viewing hours here are much lower than those derived in the CLASP study, and the national average derived from the Nielsen data. It is important to note, however, that only 9 homes participated in the LBL study, and as such there was less significant variation in demographics.

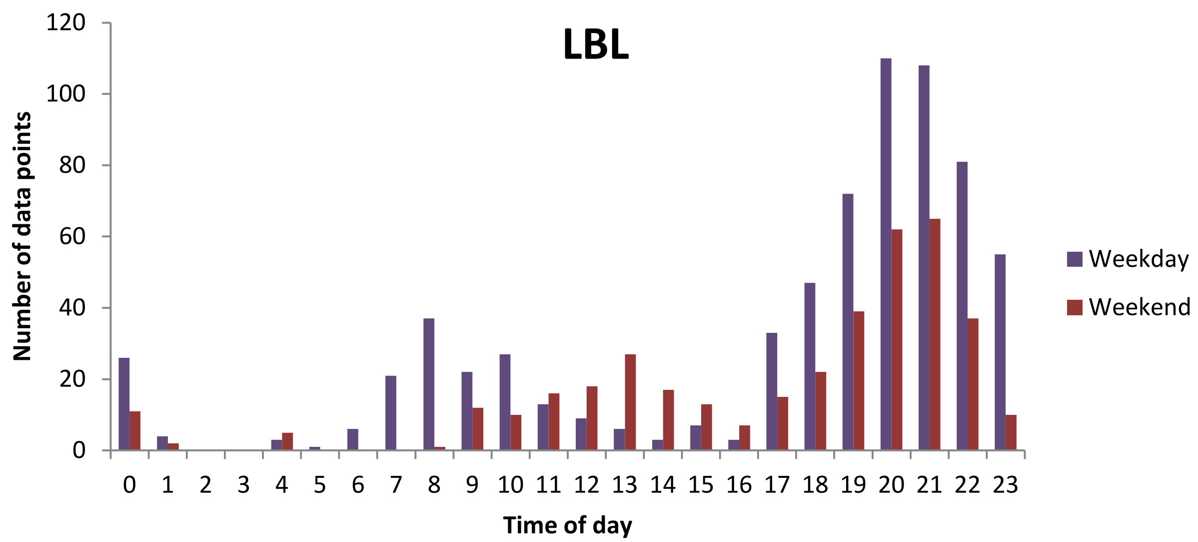

Figure 1.2.9 LBL data points by type of day

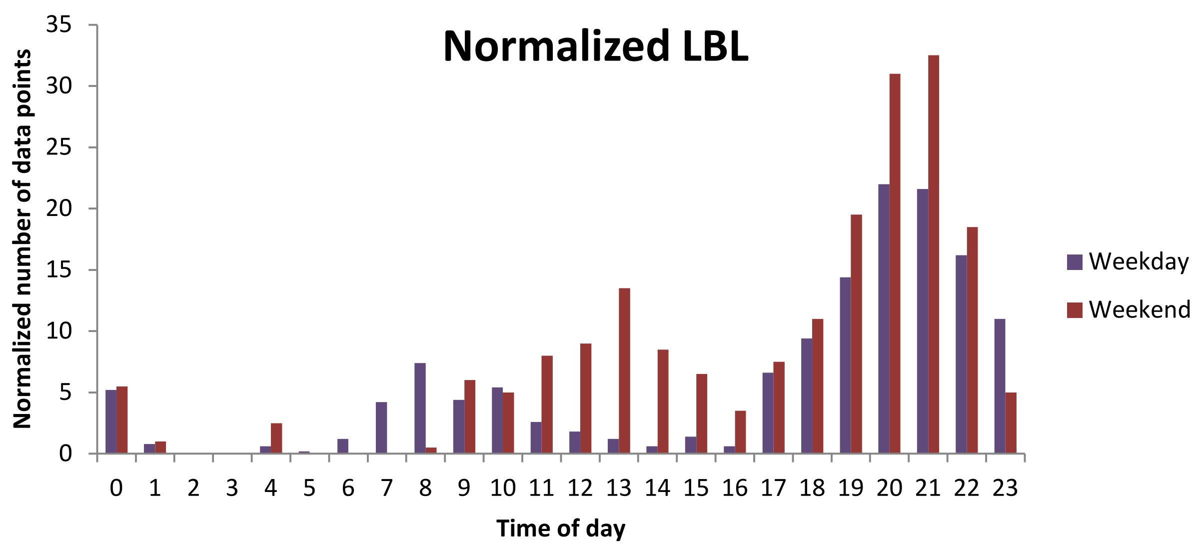

Figure 1.2.10 Normalized LBL data points by type of day

Figure 1.2.11 and Figure 1.2.12 show the average room illuminance by time of day while the TV was on, separated by weekday and weekend. The CLASP data show a clear relationship between lux and time of day, peaking at approximately midday and being darkest before 6 am and after 6 pm. At 6 am and 8 am on the weekend, however, there are spikes in lux levels that are not evident elsewhere in the distribution. The cause of these spikes is unknown at this time.

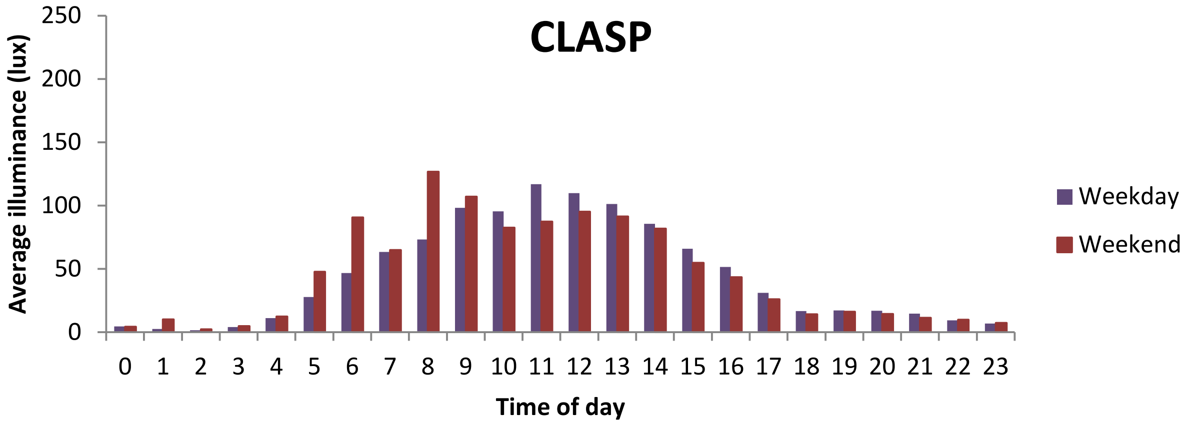

Figure 1.2.11 CLASP lux by time and type of day when TV was on

The LBL study exhibits a clear decrease in lux from 3 pm onward during the week, and from 4 pm onward on the weekend. There is significant variability in the distribution, however, due to the fewer number of data points recorded at other times.

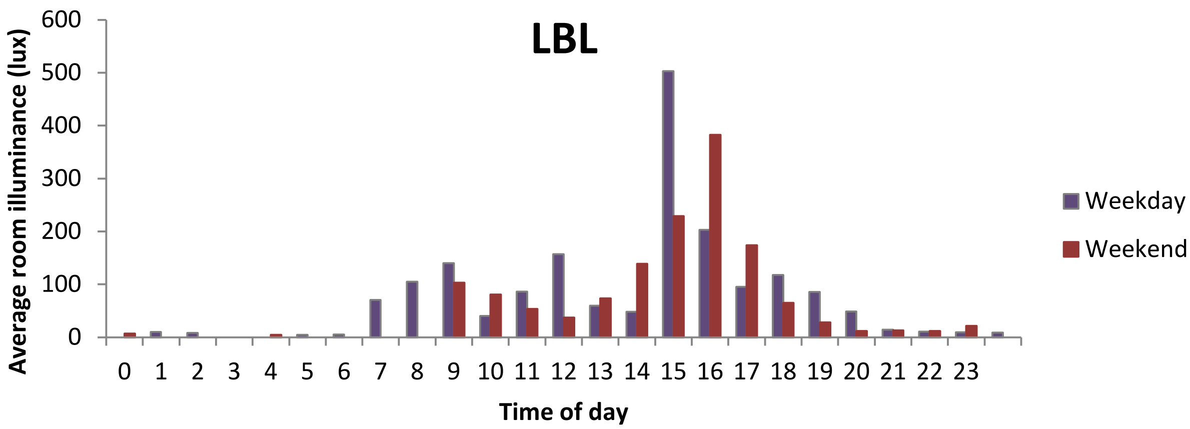

Figure 1.2.12 LBL lux by time and type of day when TV was on

Comparing the two figures, the LBL study shows higher lux levels than the CLASP study. It is difficult, however, to draw any significant conclusions from this due to the small number of homes that were measured in the LBL study. The most important thing to note is that the majority of viewing, consistently across all three major studies, whether per event or per hour, occurs at room illuminance levels of 50 lux or less.

1.2.5 Room Illuminance with the TV On or Off

Another interesting consideration is whether people typically alter room illuminance conditions in order to watch TV (e.g., using blinds or artificial lighting). To provide an indication of this, the illuminance values measured by CLASP were divided into TV-on or TV-off and are presented in Figure 1.2.13. In general, the room illuminance is higher while the TV is on, indicating the probable use of artificial lighting, with the exception of the hours from 8 am to noon. The difference between the illuminance with the TV-on or TV-off is most pronounced for the hours of 8 am to 10 am, indicating the possible use of window shades during TV viewing at this time of day. The exact cause of this significant change in room illuminance is not known at this time, but may be a result of the majority of rooms having east-facing windows.

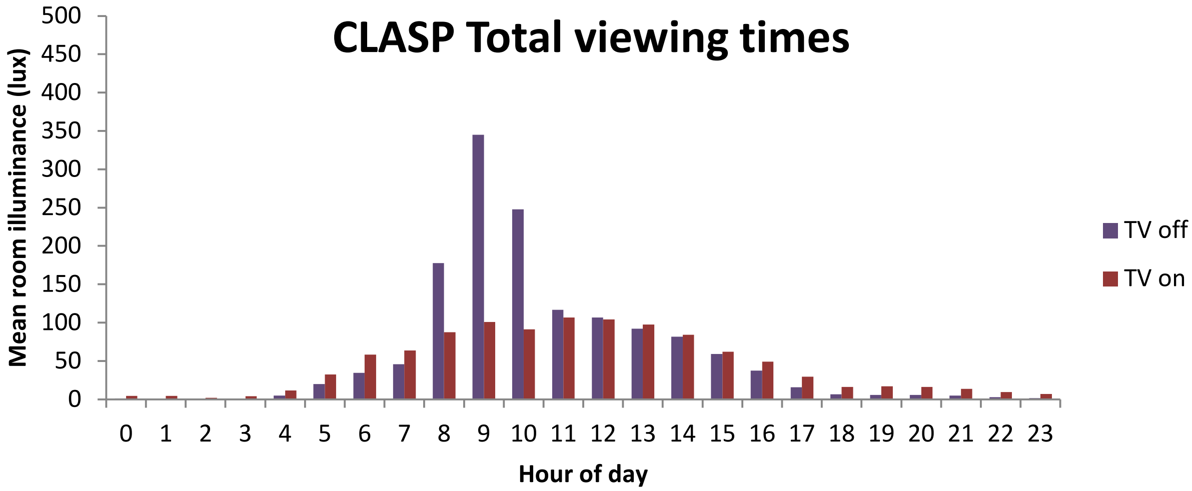

Figure 1.2.13 Room illuminance when TV is on or off

The data were further divided into weekday and weekend day, to see if this affected the room illuminance while the TV was on or off. Figure 1.2.14 shows the weekday results, and it can be seen that room illuminance is higher while the TV is on with the exception of 8 to 10 am, similar to above. Figure 1.2.15 shows the weekend day results. In this case, the room illuminance is higher with the TV on from 9 am to about 4 pm, indicating the probable use of window shades during daytime viewing.

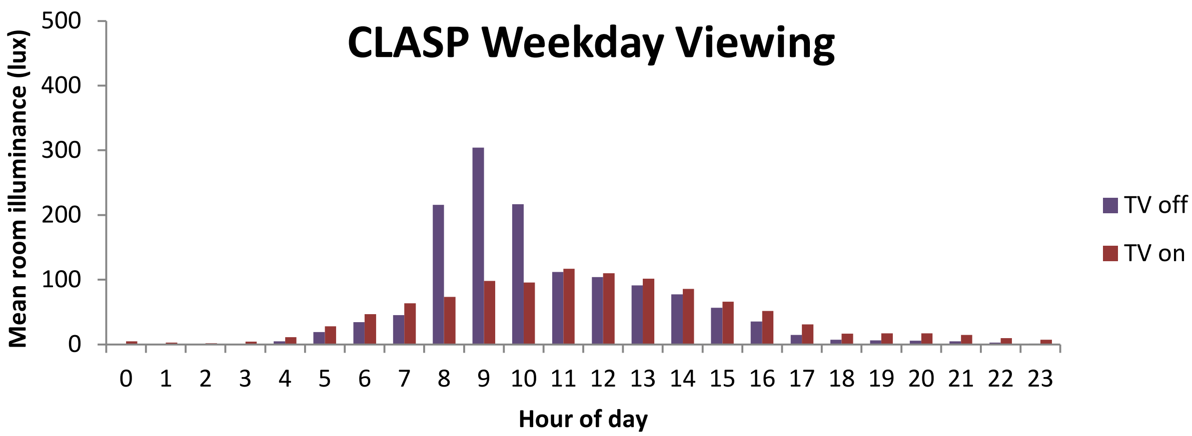

Figure 1.2.14 CLASP Room illuminance when TV is on or off on Weekdays

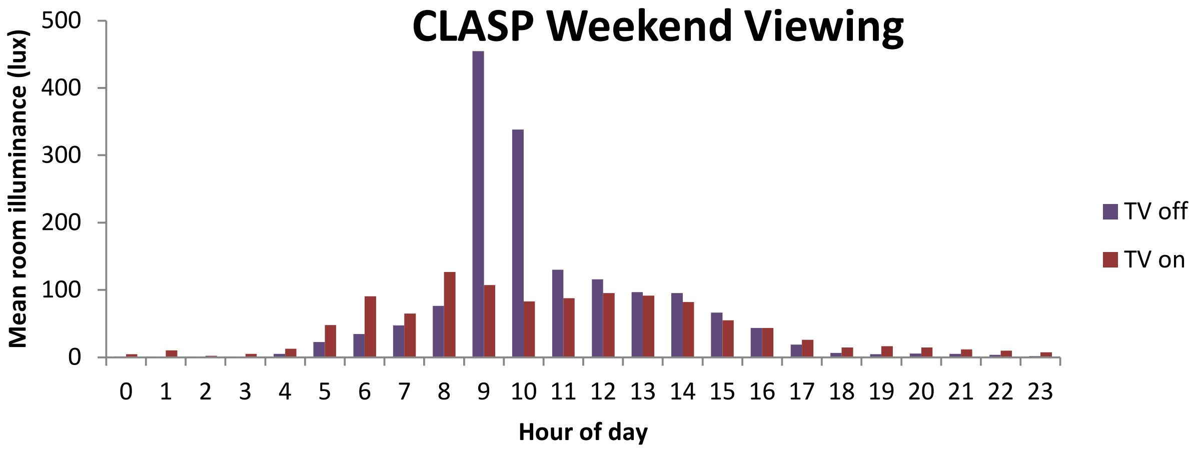

Figure 1.2.15 CLASP Room illuminance when TV is on or off on weekends

The LBL data were also divided into TV on or off subsets, as shown in Figure 1.2.16. The data are more scattered than the CLASP data due to the smaller number of households sampled. The distributions suggest the probable use of artificial lighting in the evening and early morning, and lower room illuminance during the day likely indicates the probable use of window shades while watching TV. While there are generally lower room illuminance levels during the day, however, indicating the probable use of window shades, there are other periods (e.g., between 2 pm and 7 pm) that do not seem to follow any easily-explained pattern.

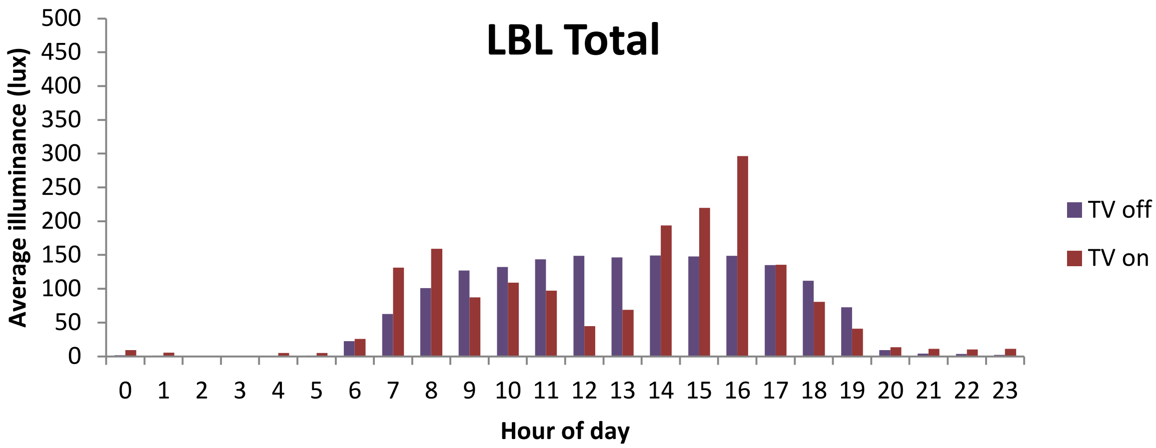

Figure 1.2.16 LBL average room illuminance while TV on and off

The data were also separated into weekday and weekend as shown in Figure 1.2.17 and Figure 1.2.18 respectively. The TV-off curves clearly follow daylight hours. The pattern is, however, is less smooth during the weekday, indicating the possible use of window shades during the day.

The weekday TV-on room illuminance is brighter than the TV-off in the early morning and late evening, indicating the probable use of artificial lighting at these times, while between 9 am and 7 pm the reverse is true, indicating the possible use of window shades during viewing at these times.

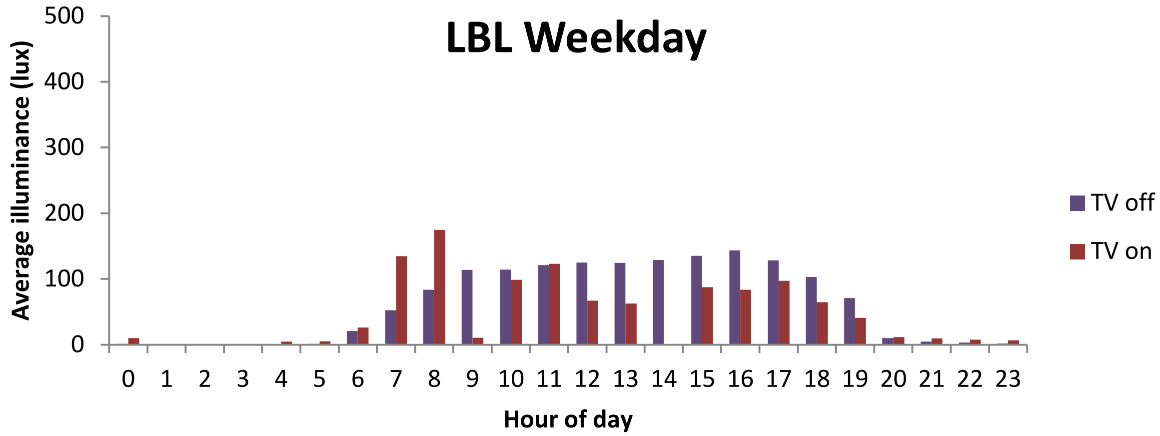

Figure 1.2.17 LBL average room illuminance on a weekday while TV on and off

The weekend TV-on room illuminance is lower than the TV-off during the morning from 8 am to 2pm, and then the reverse is true for the rest of the day. This indicates the probable use of window shades during morning viewing, and artificial lighting the rest of the day. The very high room illuminance during TV viewing at 3 pm and 4 pm is likely due to the small dataset and the result of a single viewing session.

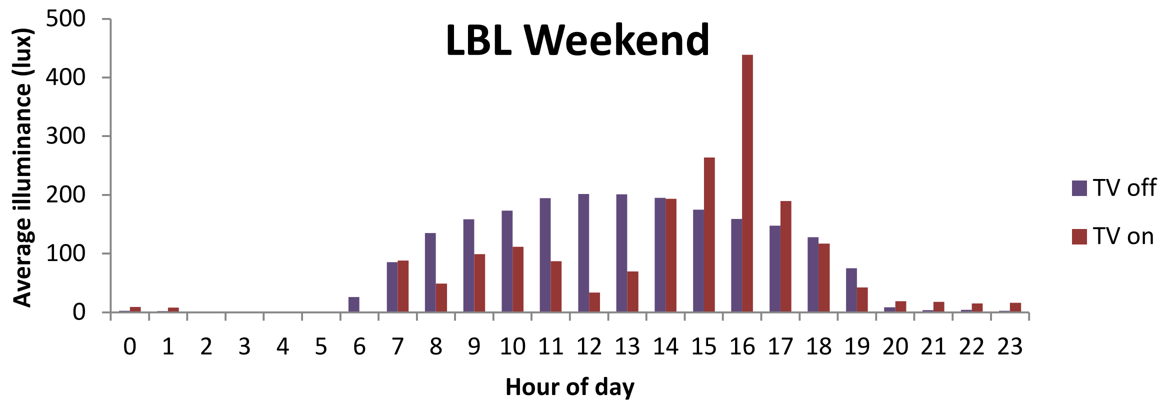

Figure 1.2.18 LBL average room illuminance on a weekend while TV on and off

In general, all of these results indicate that many people adjust lighting levels while watching TV (both up and down), although there is no way of knowing whether the room was used for other activities when the TV was off, or was empty with room illumance levels simply depending on the time of day.

One last consideration is whether, when the TV is on, the room illuminance can actually be 0, given that the TV itself generates light which is reflected off surfaces and walls back to the ABC sensor. The LBL study used meters that recorded integer lux values, which are not precise enough to answer this question. The CLASP study recorded lux levels to 2 decimal places (with tolerances on the accuracy of the meter). Of the 34827 measurements with the TV on, only 58 are recorded as 0. This is less than 0.2% of the measurements. This suggests that 0 lux levels, while possible, are highly unlikely in actual TV-viewing conditions.

1.3 TESTING TELEVISIONS WITH ABC

1.3.1 Ideal Behavior

The human eye perceives light logarithmically. That is, it perceives every doubling of brightness as a subjectively similar degree of increase in lighting levels. Therefore, an increase from 10 to 20 lux seems the same as an increase from 100 to 200 lux, for example. As the light levels increase, it takes more and more of an increase for the human eye to notice. For TVs, this means that ABC needs to be more responsive to room lighting at lower levels to maintain the contrast between the room illuminance and the TV brightness for our eyes to more comfortably watch TV. Figure 1.3.1 shows this ideal relationship. Generally speaking, TVs with ABC responses close to this pattern (example also included in Figure 1.3.1) are more comfortable to watch than ones which maintain the same luminance at lower room illuminance levels. It has been shown in the previous section that most TV viewing occurs at these lower illuminance levels. The ideal TV luminance levels for dark room conditions in Figure 1.3.1 are based on Imaging Science Foundation's (ISF) recommended brightness level for TVs in a dark room setting[i], while the luminance levels for brighter conditions are based on a 2010 study[j] on appropriate luminance levels, which found that at 100 lux, subjects preferred a TV brightness range from 160 to 248 cd/m^2.

[i] Personal communication, Joel Silver, Imaging Science Foundation, March 17, 2010.
[j] Matsumoto et al., 2011, Appropriate Luminance of LCD-TV Screens under Actual Viewing Conditions at Home, Journal of the Society for Information Display, Volume 19, Issue 11, pp. 813-820.

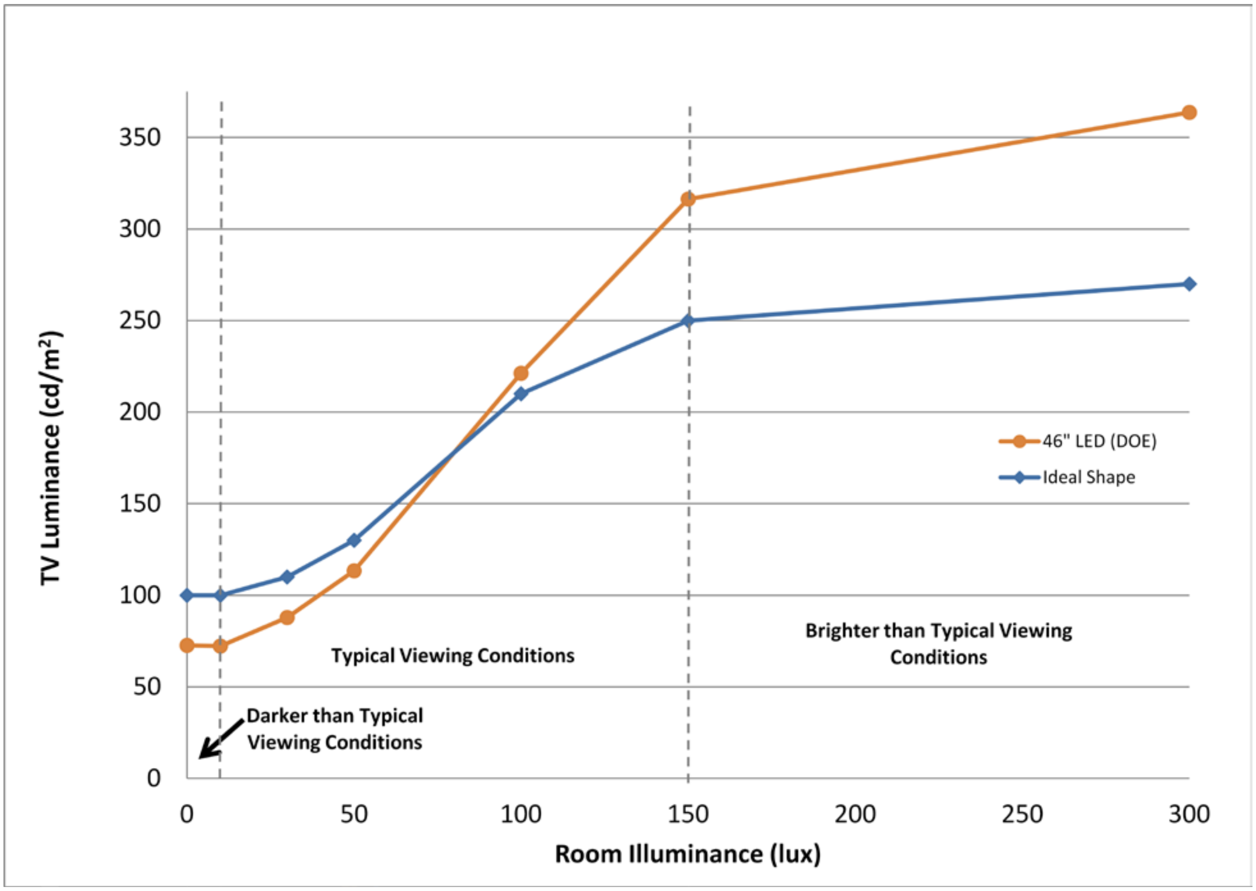

Figure 1.3.1 Ideal TV ABC curves show an "S-shaped" change in luminance as room illuminance increases.

1.3.2 Testing Results

DOE, ENERGY STAR, and CLASP[k] have conducted TV luminance and power testing at various lighting levels between 0 and 300 lux (Table 1.3.1). All power measurements were taken using the 10 minute IEC video test clip referenced in IEC 62087. DOE and ENERGY STAR luminance measurements were conducted using the 3-Bar test pattern specified in ENERGY STAR's current (5.3) test method. Luminance measurements for TVs tested by CLASP were made using the 9-Point test pattern (highlighted in green in Table 1.3.1).

For 8 of the 21 DOE TVs, no luminance measurements were taken and power measurements at 30 and 50 lux were not taken (see Table 1.3.1). CLASP TVs were measured at 10, 50, 150 and 300 lux only for both power and luminance. Because of the incomplete (and varied) luminance measurements and methodologies, this report concentrates on power measurements, though as shown below, there is a clear relationship between television luminance and power. In the figures below, dotted lines are used to connect measurement points,

[k] The full CLASP report is available for download at: http://www.clasponline.org/en/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2011/Analysis-of-tv-luminance-and-power-consumption

but are not meant to represent any interpolation. No assumptions are made about the ABC response in between measurement points.

Table 1.3.1 Summary table of DOE, ENERGY STAR and CLASP TV power and luminance testing. No color: Power measured at 0, 10, 100, 150, and 300 lux, no luminance measurements; Blue: Power and luminance measured at 0, 10, 30, 50, 100, 150, and 300 lux; Green: Power and luminance measured at 10, 50, 150 and 300 lux.

ID	Year	Size/Tech	Power (W)							Luminance (cd/m2)						
			0 lux	10 lux	30 lux	50 lux	100 lux	150 lux	300 lux	0 lux	10 lux	30 lux	50 lux	100 lux	150 lux	300 lux
DOE 1	2010	23" LED	19	19	-	-	27	27	27	-	-	-	-	-	-	-
DOE 2	2010	32" LED	42	83	84	84	83	83	83	41	297	296	296	297	298	299
DOE 3	2010	32" LED	29	29	30	39	43	43	47	128	128	142	203	238	247	259
DOE 4	2010	40" LED	59	113	-	-	113	113	113	-	-	-	-	-	-	-
DOE 5	2010	42" LED	62	63	63	74	87	91	90	94	98	130	159	231	248	234
DOE 6	2010	42" LED	46	56	-	-	101	101	101	-	-	-	-	-	-	-
DOE 7	2010	46" CCFL	104	104	108	110	130	130	130	232	234	241	247	283	300	299
DOE 8	2010	46" LED	28	66	66	66	66	66	66	29	236	236	236	236	236	236
DOE 9	2011	46" LED	44	46	54	62	76	86	86	73	72	88	113	221	316	364
DOE 10	2010	46" CCFL	65	70	-	-	126	124	124	-	-	-	-	-	-	-
DOE 11	2011	47" LED	37	79	79	80	80	79	79	18	286	282	283	285	284	284
DOE 12	2010	47" LED	71	74	-	-	113	126	126	-	-	-	-	-	-	-
DOE 13	2010	52" CCFL	115	116	122	137	166	166	166	165	169	187	227	301	301	302
DOE 14	2010	52" LED	71	92	93	93	92	120	128	93	267	266	266	267	267	267
DOE 15	2010	54" Plasma	111	198	199	200	199	199	188	23	79	80	80	79	79	79
DOE 16	2011	55" Plasma	89	144	137	144	137	142	138	27	64	64	63	64	63	63
DOE 17	2010	55" LED	59	60	78	86	98	98	98	92	92	152	188	236	236	237
DOE 18	2010	55" LED	71	121	-	-	151	151	151	-	-	-	-	-	-	-
DOE 19	2010	60" Plasma	246	435	433	433	435	434	435	68	75	80	81	80	80	80
DOE 20	2010	60" LED	60	61	-	-	91	106	113	-	-	-	-	-	-	-
DOE 21	2010	63" Plasma	163	246	-	-	246	247	247	-	-	-	-	-	-	-
ES 1	2011	46" LED 1	61	81	82	81	82	82	82	158	278	278	278	278	278	277
ES 2	2011	60" LED	49	116	116	116	116	116	116	116	407	408	407	407	408	409
ES 3	2011	46" LED 2	55	60	76	83	95	95	55	95	155	233	269	302	302	94
ES 4	2011	51" Plasma	85	123	123	123	123	124	123	38	63	63	63	63	63	63
CLASP 1	2010	42" Plasma	-	48	-	63	-	86	102	-	29	-	42	-	111	172
CLASP 2	2010	42" Plasma	-	112	-	122	-	122	122	-	78	-	79	-	79	79
CLASP 3	2010	46" LED	-	67	-	82	-	83	83	-	194	-	275	-	278	279
CLASP 4	2010	40" LED	-	88	-	109	-	123	123	-	126	-	177	-	202	205
CLASP 5	2010	55" LED	-	81	-	164	-	165	165	-	49	-	426	-	427	427
CLASP 6	2010	42" LED	-	52	-	54	-	113	114	-	38	-	44	-	326	326
CLASP 7	2010	37" LED	-	43	-	47	-	110	110	-	56	-	122	-	528	528
CLASP 8	2010	40" LED	-	38	-	47	-	61	61	-	68	-	130	-	207	208
CLASP 9	2010	40" LED	-	51	-	67	-	87	88	-	92	-	143	-	277	278
CLASP 10	2010	52" LED	-	47	-	56	-	84	84	-	82	-	123	-	217	218
CLASP 11	2010	32" LED	-	45	-	46	-	46	46	-	120	-	120	-	121	194

Upon reviewing testing completed by DOE, ENERGY STAR and CLASP, several patterns emerge. First, there are two ways in which TVs respond to a range of room iluminances – with a gradual or incremental increase in luminance and power as the room brightness increases (Figure 1.3.2), or in a single step from low to high brightness (Figure 1.3.3). This second response largely negates the viewing benefits of ABC by operating at a fixed screen luminance under most ambient light conditions. Because the current ENERGY STAR eligibility criteria (v5.3) uses the weighted average of measured TV power consumption at 0 lux (45%) and 300 lux (55%) room illuminance with ABC enabled, the single step response results in an unrealistically low value for average TV power consumption. A variation on these response patterns is found in Figure 1.3.4. Here, a TV reduced its brightness at some point after the room illuminance reached 150 lux.

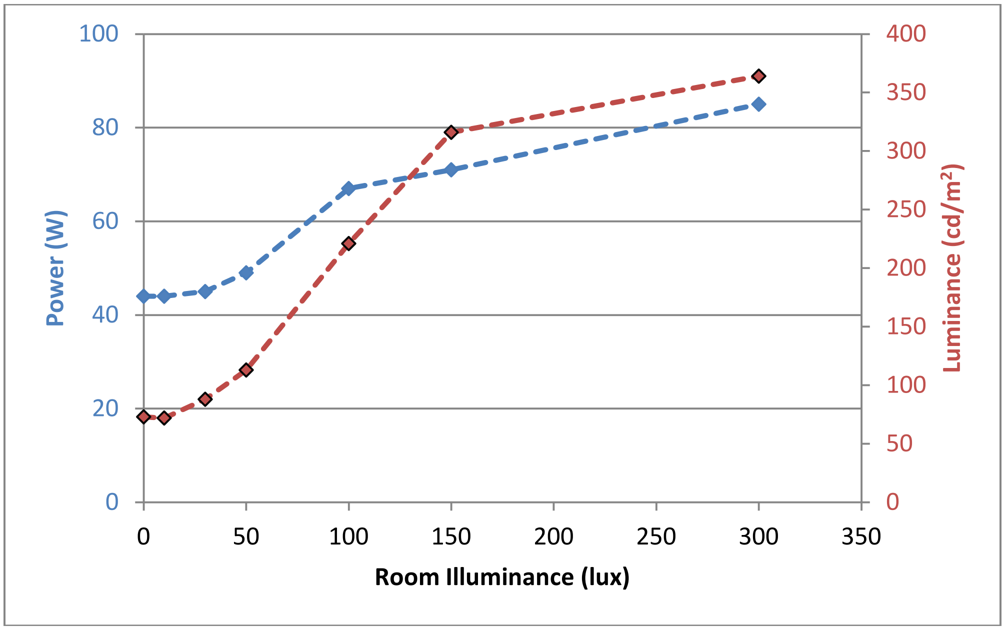

Figure 1.3.2 Screen luminance and power consumption vs. room illuminance for a TV with an incremental approach to ABC.

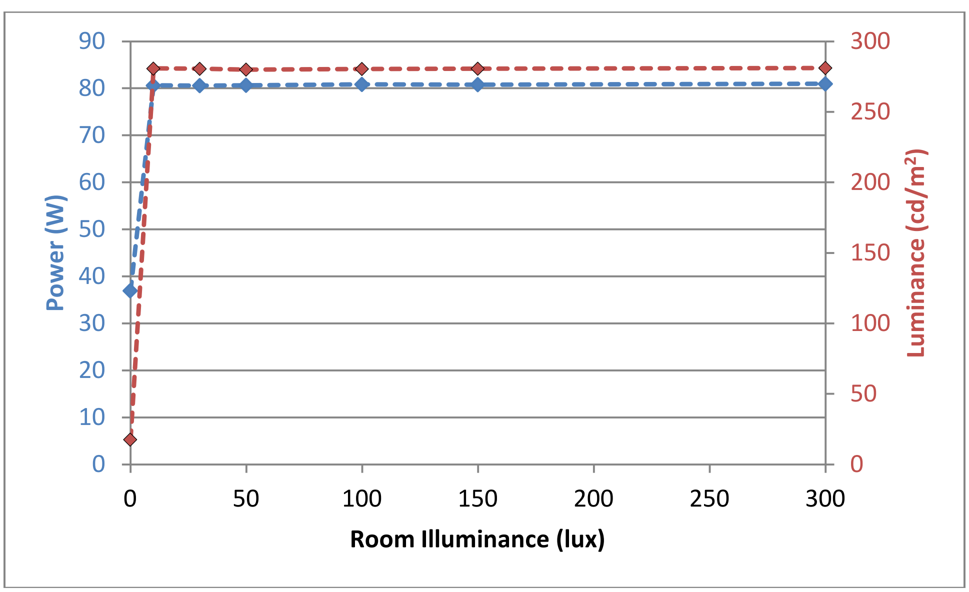

Figure 1.3.3 **Screen luminance and power consumption vs. room illuminance for a TV with a single step approach to ABC.**

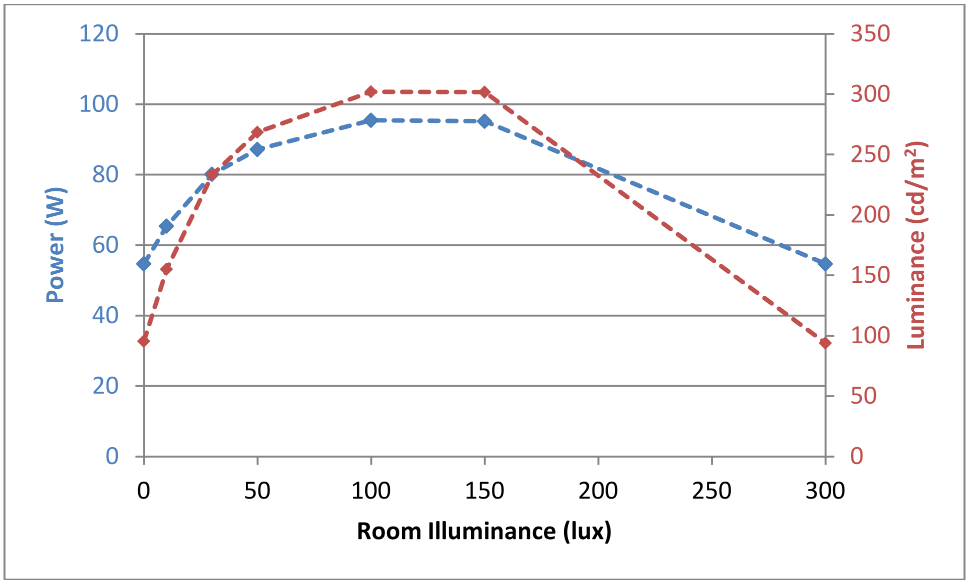

Figure 1.3.4 **Screen luminance and power consumption vs. room illuminance for a TV that reduces luminance when room illuminance increases beyond 150 lux**

Another pattern that emerges is that TV manufacturers tend to implement ABC in the same fashion across different technologies and sizes, at a given point in time (Figure 1.3.5). There were two exceptions to this pattern. One manufacturer moved from an incremental approach to a single step approach in its single 2011 model represented in this dataset. The other was a difference in a manufacturer's approach to ABC from single step to incremental in two TVs from the CLASP (non-US) TV dataset.

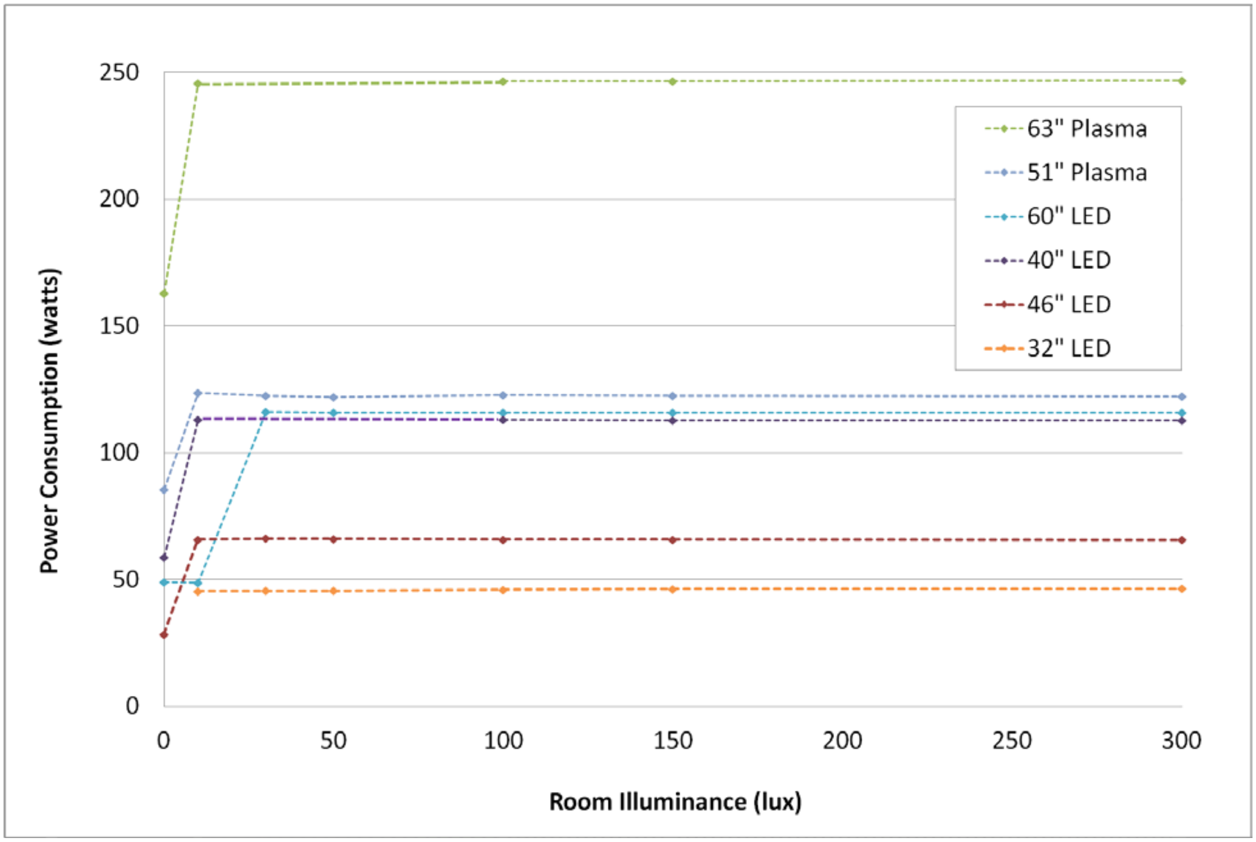

Figure 1.3.5 Power consumption vs. room illuminance for a single manufacturer that implements ABC as a single step response across six TVs of various sizes and technologies.

Figure 1.3.6 to Figure 1.3.8 show the relationship between power and room illuminance for all TVs tested. Recall that some DOE TVs were not tested at 30 and 50 lux. Televisions in the CLASP study were measured at 10, 50, 150, and 300 lux. Power levels were not assumed at 0 lux for the CLASP data.

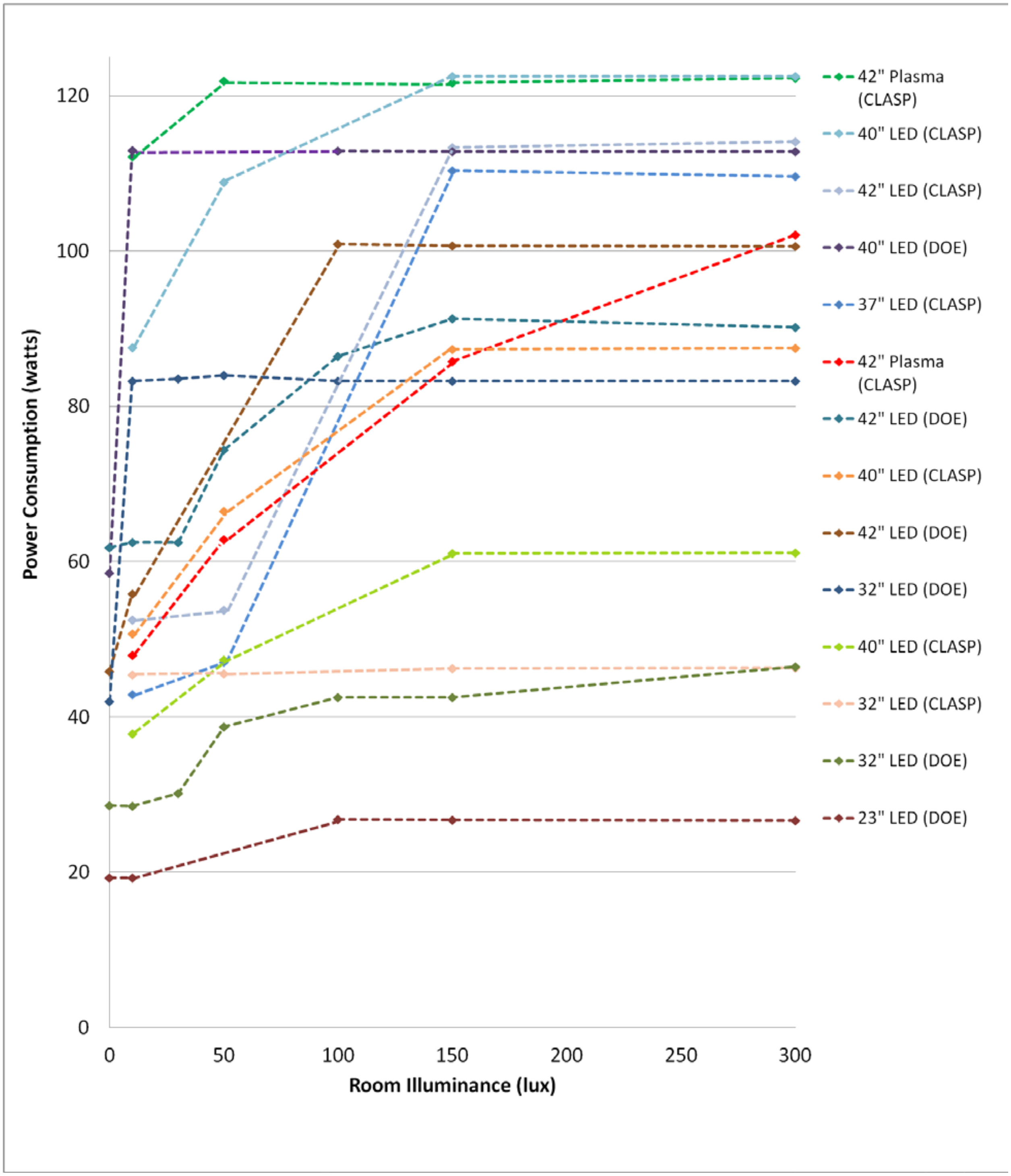

Figure 1.3.6 **Power consumption vs. room illuminance for TV sizes 23" – 42".**

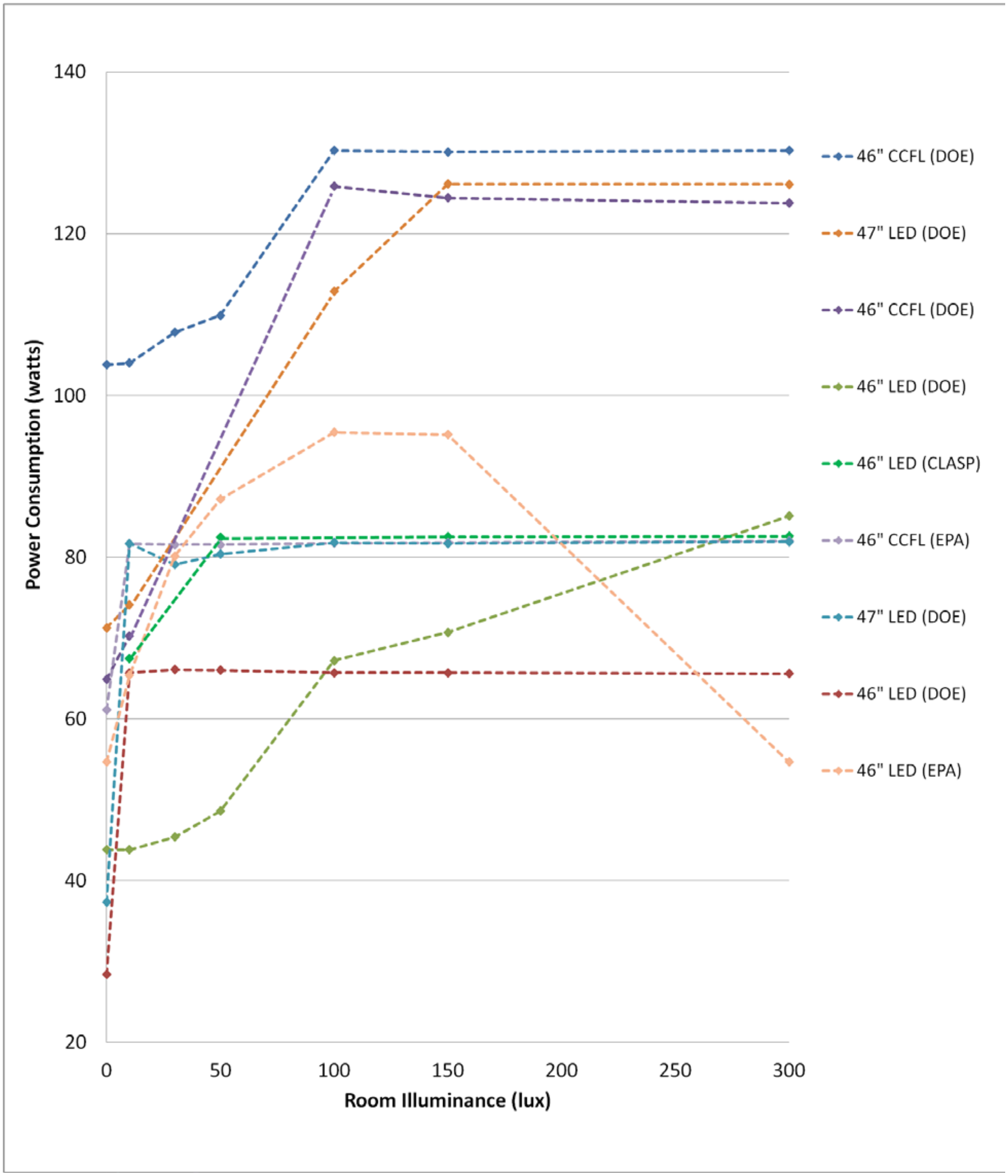

Figure 1.3.7 Power consumption vs. room illuminance for TV sizes 46" – 47".

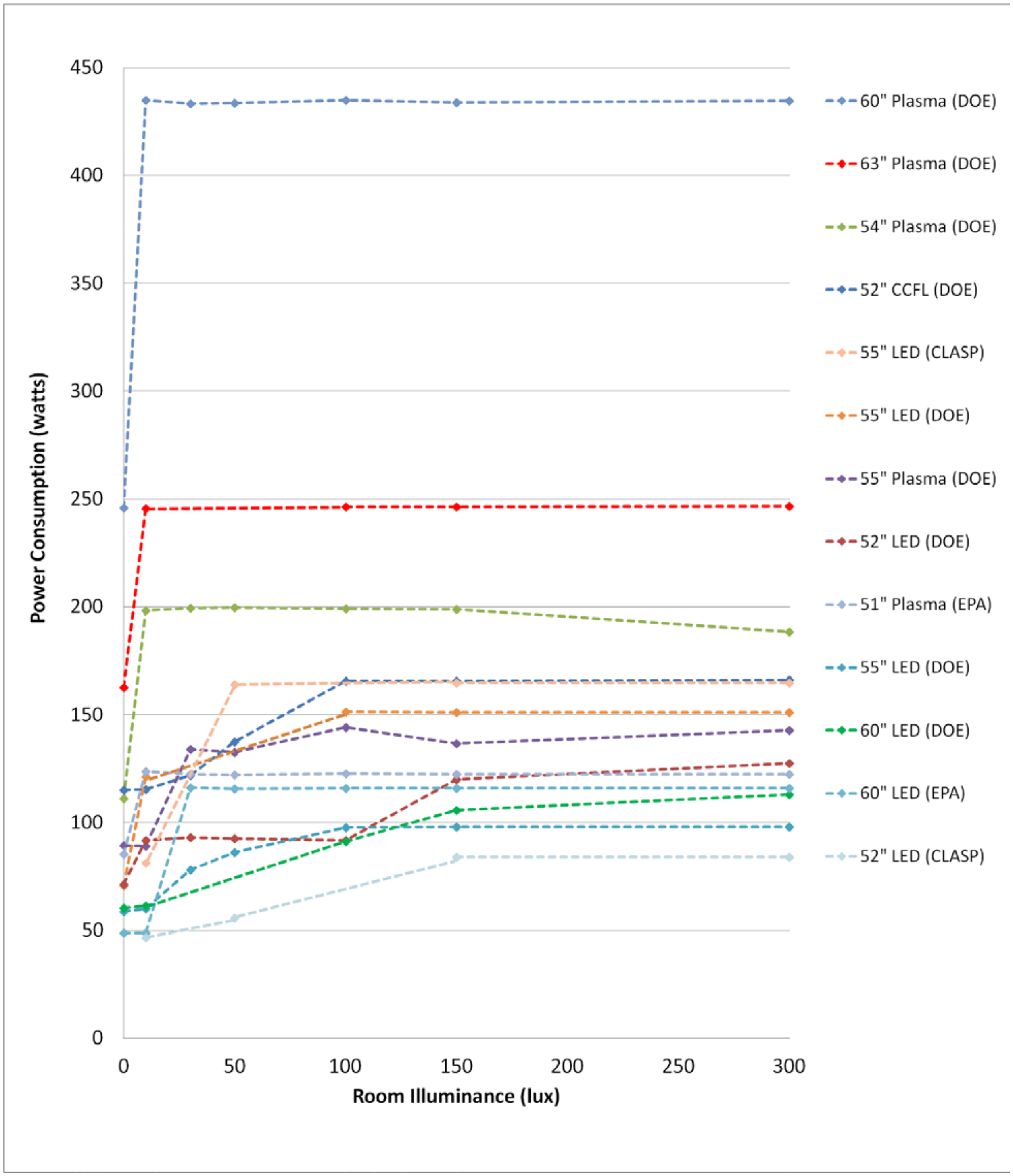

Figure 1.3.8 Power consumption vs. room illuminance for TV sizes 51 and above.

1.4 DISCUSSION

Tracking the impact of ABC on a range of different TV technologies and sizes is difficult because of their inherent efficiency differences. Nevertheless, there are a few general conclusions.

A gradual (non-single-step) ABC response curve has the potential to save a significant amount of power relative to a single-step implementation. For all TVs measured at 0 lux, there are considerable savings. However, from the earlier discussion of reported room illuminances, this was found to be an unlikely condition while TV was being viewed. Power savings are also evident at 10 and 30 lux. To a lesser extent, savings occur at 100 lux as several of the TVs measured did not achieve maximum power until the room lighting was increased further. Significantly, these TVs exhibit the more ideal “s-shaped” response function, with respect to power and room illuminance. Finally, the testing revealed that not all TVs reach maximum luminance at 100 lux.

Some stakeholders have commented publicly that, while more lux levels should be incorporated in the testing of ABC (e.g., 10 lux), the current requirements of 0 and 300 lux should be maintained.[1] There is a buildup of historical data that can be used for comparisons of future developments of the technology. Stakeholders have further argued that 0 lux provides a lower limit of the ABC and is easy to measure, minimizing testing burden, while for an upper limit, the ABC is likely to saturate at around 100 to 150 lux, so it would not matter which value is measured beyond this. Some stakeholders therefore recommend that the test should stay at 300 lux. As was shown above, however, 100 lux does not necessarily represent maximum luminance.

Some stakeholders have further suggested that 12 lux and 35 lux be added as two interim data points based on the results of the CEA study. The motivation for these illuminance values can be seen in Figure 1.4.1, which shows distributions of the data from all three studies using logarithmic bins, rather than the cumulative fraction as is done in this report. Logarithmic bins were chosen since the human eye perceives light on a logarithmic scale. The distribution shows a peak at approximately 12 lux (though 12 lux is a midpoint of a logarithmic bin), and 35 lux is simply the approximate logarithmic mean between 12 and 100 lux (the value at which the ABC sensor is assumed to saturate according to some stakeholders).The distributions are roughly consistent across all three studies.

[1] See stakeholder comments for Draft 1 Version 6.0 ENERGY STAR Televisions Specification. http://www.energystar.gov/index.cfm?c=revisions.television_spec

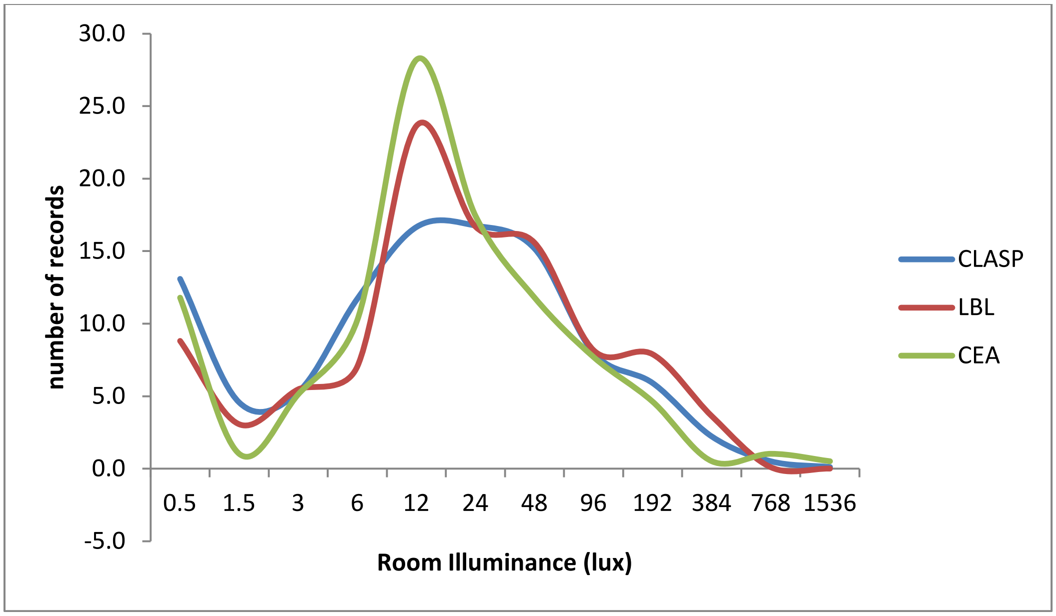

Figure 1.4.1 Distribution of measurements in CLASP, LBL, and CEA data sets. The lux values are the mid-points of logarithmic bins.

The CLASP report, on the other hand, states that only 0 and 300 lux should not be used. Their findings indicated insignificant TV viewing occurred in 0 lux conditions, and that the vast majority was below 100 lux. CLASP tested televisions for both power and luminance at 10, 50, 150, and 300 lux. They also emphasize the importance of requiring more than 2 measurement points, in order to ensure ABC operates as a gradual change in TV luminance with changing room illuminance, avoiding a step profile. They also state, however, that due to the geographical limitations of their study, further analysis would be necessary before making a final decision regarding appropriate illuminance levels. Their preliminary recommendation was to test at 3 points between 10 and 100 lux.

According to the CLASP and LBL room illuminance studies, which gathered continuous measurements during actual TV viewing, room illuminance values are approximately 1/5/10/15/30/45/100 lux at the $12^{th}/25^{th}/37^{th}/50^{th}/62^{nd}/75^{th}/87^{th}$ percentiles. One possible set of testing levels could therefore be 5/15/45/135, based on the 25^{th}, 50^{th}, and 75^{th} percentiles (plus an additional point to represent maximum luminance). Another possible set of testing levels could be 1/10/30/100/300, based on the 12^{th}, 37^{th}, 62^{nd}, and 87^{th} percentiles (plus an additional point to represent maximum luminance).

DOE performed some additional testing to determine the significance of adopting any of the above illuminance level recommendations. The additional testing was performed on the seven 2011 model year TVs in the sample, to represent the latest ABC implementations. These test results are shown in Figure 1.4.2 and summarized in Table 1.4.1 below. Table 1.4.2 shows the percent change in power calculation methods from the ENERGY STAR methodology (except for ENERGY STAR, all room illuminance points are weighted equally). For the one TV that implements a gradual and monotonically increasing ABC response curve, all of the proposed ABC calculations result in a more favorable reported energy consumption value compared to the other TVs, relative to the existing ENERGY STAR calculation. This is incentivizing the correct ABC behavior.

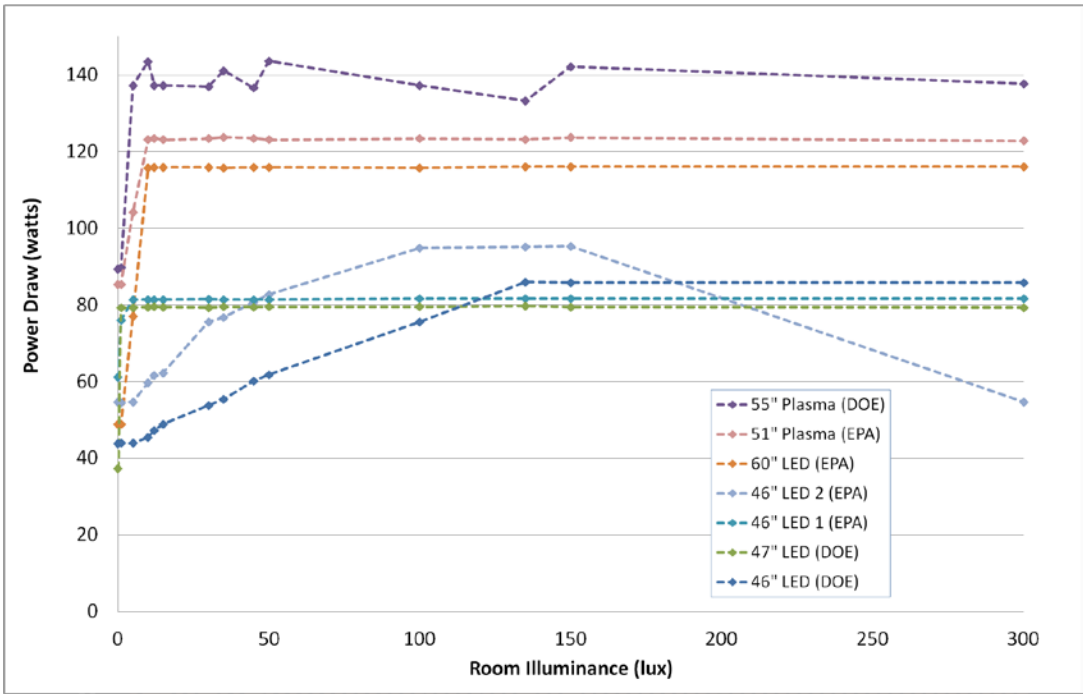

Figure 1.4.2 Power consumption vs. room illuminance at additional test points. All TVs are 2011 model year.

Table 1.4.1 Power measured at additional room illuminance levels between 0-300 lux for seven 2011 TV models.

	46" LED (DOE)	47" LED (DOE)	55" Plasma (DOE)	46" LED 1 (EPA)	60" LED (EPA)	46" LED 2 (EPA)	51" Plasma (EPA)
Power @ 1 lux (W)	43.9	79.2	89.8	76.0	48.9	54.5	85.3
Power @ 5 lux (W)	43.9	79.3	137.3	81.3	77.1	54.6	104.2
Power @ 10 lux (W)	45.5	79.4	143.5	81.3	115.7	59.7	123.2
Power @ 12 lux (W)	47.2	79.5	137.2	81.4	115.9	61.6	123.5
Power @ 15 lux (W)	48.9	79.4	137.2	81.3	115.9	62.2	123.1
Power @ 30 lux (W)	53.8	79.3	137.0	81.5	115.9	75.6	123.4
Power @ 35 lux (W)	55.4	79.5	141.1	81.3	115.8	76.8	123.8
Power @ 45 lux (W)	60.2	79.4	136.6	81.3	115.9	80.8	123.5
Power @ 50 lux (W)	61.8	79.5	143.7	81.4	115.9	82.7	123.1
Power @ 100 lux (W)	75.6	79.5	137.3	81.6	115.8	94.9	123.4
Power @ 135 lux (W)	85.9	79.7	133.2	81.6	116.1	95.2	123.2
Power @ 150 lux (W)	85.8	79.4	142.2	81.7	116.0	95.3	123.7
Power @ 300 lux (W)	85.8	79.3	137.7	81.7	116.0	54.6	122.8

Table 1.4.2 Percent change in power calculation methods from ENERGY STAR methodology.

Power Calculation Method	46" LED (DOE)	47" LED (DOE)	55" Plasma (DOE)	46" LED 1 (EPA)	60" LED (EPA)	46" LED 2 (EPA)	51" Plasma (EPA)
ENERGY STAR	-	-	-	-	-	-	-
10, 50, 100, 300	0%	31%	21%	13%	35%	34%	16%
0, 12, 35, 300	-13%	14%	9%	5%	16%	13%	7%
0,10,300	-13%	8%	6%	3%	9%	3%	4%
5, 15, 45, 135	-11%	32%	17%	12%	24%	34%	12%
1, 10, 30, 100, 300	-9%	31%	11%	11%	19%	24%	9%

Comparing with the other two room illuminance studies, the CEA data measured consistently lower lux values. This may be a result of seasonality effects, or due to the nature of the one-time measurement, as opposed to continuously monitoring during actual television viewing. Concerns raised by other studies include setting a tolerance for each illuminance level; specifying the light source during the test; and the angle at which light enters the sensor. Currently the ENERGY STAR measurement is described as "directly into the sensor."

Another important consideration raised by CLASP was that further studies were needed in countries outside the U.S. Some studies have been carried out to date in Japan and Korea, and it has been found that they tend to have much higher room illuminance levels than those found in the U.S.

1.5 SUMMARY

The main purpose of this analysis is to help illuminate discussions on appropriate room illuminance levels at which TVs with automatic brightness control should be tested. The current ENERGY STAR test procedure requires TVs to be tested at 0 and 300 lux. The data presented here indicate that these values are extreme compared to illuminance levels generally measured while watching TV. Less than 0.2% of measurements in the CLASP study are at exactly 0 lux, and in all 3 studies, only a few percent of measurements are at 300 lux or greater. Testing at 0 lux allows for potentially artificial behavior during testing (with very low luminance), behavior that was confirmed in recent testing. The current test requirements also allow manufacturers to adjust the TV brightness in a single step to receive the ENERGY STAR endorsement label. ABC measurements should occur at several room illuminance levels that are representative of actual TV viewing habits. In summary:

- The 0 lux level does not represent a typical room illuminance level. It occurs less than 0.2% of the time in the CLASP data.
- The 300 lux level (or greater) is an extreme conditioning occurring less than 5% of the time.

- The peak of the room illuminance distribution is between 10-15 lux, according to all three studies. A significant fraction of TV viewing occurs at levels below 10 lux, however, with a secondary peak at very low (but non-zero) lux values.
- According to the CLASP and LBL studies, which gathered continuous room illuminance measurements during actual TV viewing, room illuminance values are approximately 1/5/10/15/30/45/100 lux at the $12^{th}/25^{th}/37^{th}/50^{th}/62^{nd}/75^{th}/87^{th}$ percentiles. See Table 1.2.3 for more details.
- TV luminance is not necessarily maximized at 100 lux, and the ABC sensor is not necessarily saturated. Maximum luminance is reliably achieved at 300 lux, however.
- When implemented in an ideal "S" shape, ABC response has the potential to save a significant amount of TV energy. When implemented in a step or staircase fashion, the energy-saving benefits of ABC are reduced.
- For TVs that implement a gradual and monotonically increasing ABC response curve, all the various proposals for revised room illuminance levels during ABC testing result in a more favorable reported energy consumption value, as compared to TVs with a step-wise response curve.
- Further room illuminance testing is recommended to increase the current sample size. In particular, future studies need to span a representative range of dates during the year, as well as geography. As was shown here, seasonal effects do have an impact on average room illuminance levels, as does the geographic location. The current studies completed to date have been largely restricted to only a few cities.
- Future testing should ensure that weekdays and weekends are properly sampled (and the data normalized) to ensure final results are representative of a typical week. Initial results suggest an important difference in weekday and weekend viewing conditions.
- Finally, the results presented here are applicable to the U.S. only. Preliminary studies in other countries suggest that preferred room illuminance conditions vary from country to country.

APPENDIX: LATEST TESTING METHODOLOGY

The following test setup was used for the latest DOE measurements, in an effort to address some potential issues, and create a *repeatable* and *representative* methodology.

To control the amount of room illuminance entering the TV's sensor in a more reproducible manner, DOE used a dimmable halogen incandescent lamp equipped with a hood and short tube to direct light onto the ambient light sensor (ALS) (Figure 1.5.1). Before each test, the lamp output was adjusted until a room illuminance meter measured the desired level of illuminance (Figure 1.5.1, left). The lamp was then placed directly against the ALS on the TV under test, making certain the lamp hood sat flush with the TV bezel (Figure 1.5.1, upper and lower right). This ensured that the light source was the same distance and orientation in relation to the illuminance meter as it was in relation to the TV's sensor. Additionally, the light source was plugged into a regulated power source to eliminate any drifting of lamp output, which was noted in earlier testing and resulted in variations in illuminance measurements of up to 10%. A diffusing plate was also used inside the hood housing, in between the lamp and the short tube. Without the diffuser, the ALS was very sensitive to the exact alignment of the lamp, making the testing difficult to reproduce.

Figure 1.5.1 Light source directed at the room illuminance meter to confirm illuminance (left) and placement of the light source over the ALS on the TV bezel (upper and lower right).