Pilot Study: Measurement of Room Illuminance to Assess Automatic Brightness Control in Televisions

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ABSTRACT

Automatic brightness control (ABC) is an increasingly common feature found in new televisions (TVs) and computer monitors. ABC is intended to adjust TV screen brightness (luminance) according to the ambient light level (room illuminance). When implemented correctly, this can both reduce energy consumption and improve viewing quality. The current ENERGY STAR test procedure provides for a more favorable energy use rating for TVs with ABC, by measuring power consumption at two light levels (0 and 300 lux) and reporting a weighted-average energy use. However, this and other studies suggest that these levels are not representative of actual TV viewing conditions.

As there were currently only limited data available concerning room illuminance, we undertook a small pilot study in 2011 to begin to answer two key questions: 1. To what extent do room illuminance levels vary depending on the location of measurement (e.g., center of the room, on the couch, or at the TV)? 2. What room illuminance conditions are prevalent when people watch TV?

We measured room illuminance in the homes of nine volunteers in California and Colorado to begin addressing the above two questions. Although the study had the usual drawbacks of a pilot (limited sample size, time duration, etc.), it has, nonetheless, yielded useful results. The study shows definitively that there is large variability between measurements made at different locations in the room and, therefore, that location of room illuminance measurements is critical. Moreover, the majority (over 75%) of TV viewing occurred at illuminance levels of less than 50 lux (though measurements of up to several hundred lux were also recorded), a result that was consistent with subsequent larger-scale studies. This type of information can help determine how ABC-enabled TVs should be tested to best represent actual viewing conditions.

Introduction

It is increasingly common for TVs and computer monitors to include automatic brightness control. This feature is intended to adjust screen luminance in response to changes in room illuminance. Luminance (expressed in cd/m^2) is a measure of light intensity passing through or emitted from a surface area, traveling in a given direction. Illuminance (expressed in lux) is a measure of total light incident on a given surface from all directions. Both luminance and illuminance are weighted by a response function of the human eye at different wavelengths. Additionally, the human eye perceives light approximately logarithmically with increasing light intensity. The principle behind ABC is that any display will look better if its brightness is scaled to the amount of ambient light in the room. This preference was demonstrated by Matsumoto et al. (2011) for Japanese viewers. ABC, properly implemented, minimizes the need for the eye to adjust rapidly to large changes in lighting levels from one part of the field of view to another. When ambient light levels are low, the TV's brightness can be lowered as well, saving energy. The ENERGY STAR v. 5.3 standard attempts to take this into consideration, allowing TVs with ABC to achieve a lower reported energy use by testing power consumption at room illuminance levels of 0 and 300 lux, and reporting a weighted-average energy use.[1] Due to this testing requirement (which was selected as an interim solution in the full knowledge that it was not representative), the variation in screen luminance can occur in a single step (i.e., TVs viewed at 10 lux could have the same screen luminance as when viewed at 300 lux), and still receive a favorable reported energy use from ENERGY STAR. In developing its federal test procedure, the U.S. Department of Energy (DOE) wanted to ensure that measurements were taken at representative room illuminance levels. It is therefore important to understand the actual illuminance levels that TVs are commonly viewed at, to ensure that ABC is truly an energy-saving feature. This pilot study was DOE's starting point for doing that. Its information was later supplemented by two larger-scale studies, described below, undertaken by interested parties.

The ABC function responds to light entering the TV's light sensor; therefore, it is important to study typical room illuminance conditions *at the location of the sensor*. Some literature exists on typical residential illuminance levels (for example from the lighting and architectural industries), but it is unclear how average room illuminance levels, typically measured in the centers of rooms, compare to measurements at the TV sensor. In the past, in discussions concerning ABC, there had been confusion about whether the room illuminance measurement location mattered and to what extent, with some parties suggesting that the specific measurement location was not important. This study therefore attempted to explore this question by taking measurements at several room locations under various lighting conditions.

In order to determine appropriately-representative illuminance levels, it is helpful to understand the range of illuminance values observed in the places where people watch TV, when they are actually watching TV. There are currently only limited data available concerning room illuminance levels. Two key questions on this topic could benefit from further in-field data and analysis:

- Whether and to what extent illuminance levels in a room vary depending on where the illuminance measurements are taken in a given room (e.g., in the center of the room, on the couch, or at the TV)?
- Which illuminance conditions are prevalent when people watch TV?

In this paper, the results of a 9-home pilot study into room illuminance are presented. Although the study has the usual drawbacks of a small pilot (limited sample size, time duration, seasonality, geography, etc.), the results provide a useful starting point for answering the two questions posed above.

In the following section, the method used to measure room illuminance levels is described. Following this, results are presented along with a brief discussion that compares these results to those from similar studies by the Collaborative Labeling and Appliance Standards Program (CLASP, 2011) and the Consumer Electronics Association (CEA, 2012). The CEA

[1] The weighting used is 0.45 times power consumption at 0 lux and 0.55 times power consumption at 300 lux (ENERGY STAR, 2011).

study, however, used a very different methodology specifically targeting primetime TV viewing, which although valuable was more difficult to compare to our study.

Methodology

For each household participating in the study, basic demographic information was recorded, such as the number and ages of household occupants, and the room in which the TV was located. Information about the TV including screen size, technology (CRT, LCD, etc.), year of manufacture, brand and model number were also recorded. The general geographic location was noted to enable investigation of regional differences. All data were collected between mid-May and mid-June 2011.

Static Room Illuminance Levels

Participants were asked to set the room to the typical lighting conditions they use to watch the TV for the time of day that the measurements were being conducted. Light meters (Professional Measurement LX-1128SD) were placed under various lighting conditions (roughly 50% daytime and 50% nighttime) at five different positions:

- **A** was the center of the room, which was found by the point at which two tightly stretched strings secured to the corners of the room cross. The height was 45 inches above the floor – the approximate height of a typical seated TV viewer's eyes.
- **B** was the primary viewer's seated location, centered left/right relative to the TV's location and measured 45 inches above the floor.
- **C** was centered on the top of the TV cabinet
- **D** was the center of the TV screen
- **E** was the position of the TV's ABC light sensor, if available. In most cases, this was near the lower left or lower right corner of the TV's cabinet, on the front side. If a light sensor was not present the measurement was done on the bezel (edge of TV) on either lower corner of the TV. The meter was placed in a manner so as not to interfere with the operation of the ABC light sensor itself, if ABC was enabled on the TV.

These positions were adapted from work done by experts from the Lighting Research Center at Rensselaer Polytechnic Institute (Leslie & Conway, 1993), and illustrated in **Error! Reference source not found.** and **Error! Reference source not found.**. The measurements at locations A, B, and C were taken with the illuminance meter facing upward (toward the ceiling) and, where possible, on a tripod. The measurements at locations D and E were taken with the meter facing outward (in the same direction as the TV screen, towards the viewer). For each set of test conditions, the measured illuminance values in positions A through E were recorded, along with the times and dates of each measurement, outdoor lighting conditions, window shade position and lighting conditions of the room. Any other factors that may have an influence on the illuminance level were also recorded.

Figure 1. Three Dimensional Illumination of a Typical Living Room Illustrating Points D and E for Illuminance Measurement

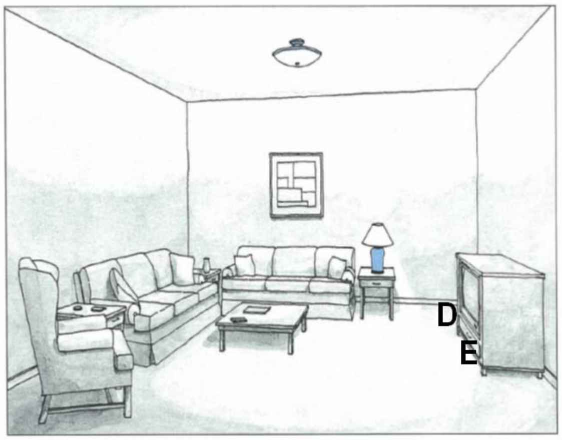
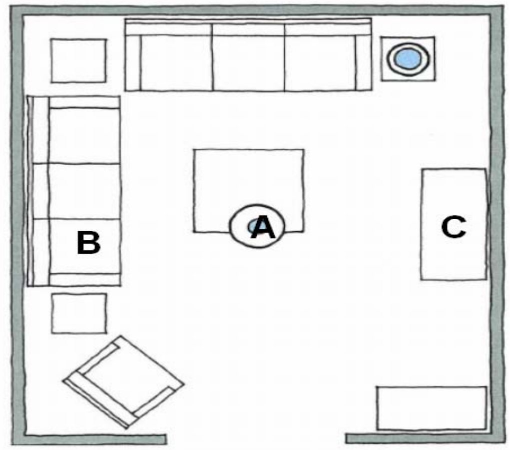


Figure 2. Floor Plan View/View from Above of a Typical Living Room Illustrating Points A, B and C for Illuminance Measurement



For rooms with windows or receiving daylight from an adjacent room, at least two sets of measurements were made: one on a sunny day and one at night. Where possible, the measurements were repeated under different outdoor lighting conditions (e.g., sunny, overcast), with blinds open and closed, with room lighting on and off, and with the TV on and off to note how the measured values changed. Illuminance and luminance values may both change considerably with the TV on, depending on the average picture level of the source material.

The measurements were taken in a way that ensured that the measurement technique had no significant influence on the measurement values. The most common unwanted influence was in darker rooms where the person doing the measurement had the potential to affect the measurement by causing shadowing over the sensor or reflecting light into the sensor. For the purposes of this study a significant effect is considered to be a 10% variation between actual illuminance and measured illuminance. The use of a tripod and/or a remote sensor, where possible, helped to achieve this condition.

Room Illuminance During TV Viewing

For the second part of the study, light meters were installed on the lower bezel of TVs with the aperture plane parallel to the TV screen, corresponding to position E. A power meter (Electronic Educational Devices WattsUp Pro) was installed on the TV to simultaneously measure the times of day when the TV was on. Participants were instructed to light their rooms normally when using their TVs. Both meters were set to record data averaged over 10-minute intervals.

Meters were retrieved after a minimum of one week (in order to capture both weekday and weekend viewing activity) for data download and analysis, and some households were metered for two closely-spaced, one-week periods. In order to identify TV viewing sessions in the light meter data accurately, the internal clocks of the illuminance meter and the power meter were synchronized to less than half the metering interval. The clocks were also synchronized to the local time, in order to facilitate time-of-day analysis of light levels and viewing habits. These illuminance and power data then formed the event history of a household.

The methodology allows us to distinguish between illuminance levels found generally in a room with a TV, as compared to the conditions in that room when the TV is on (and presumably being viewed). It provides a representative picture of room illuminance levels during TV viewing, since TV watchers can modify room illuminance levels before watching TV, by adjusting window shades or artificial light sources, or both. The resulting data assist in determining which illuminance conditions are most prevalent when people watch TV, as well as the overall range of illuminance levels during TV viewing.

Results

Nine households participated in this pilot study, with 4 households in California and 5 in Colorado. The TVs were located in either the living room (8 households) or the game room (1 household). The households included a mix of family sizes and ages, including children, teenagers, young adults, middle-aged adults, and seniors. The households are therefore viewing a representative mix of programs over the course of a typical day.

Static Room Illuminance Measurements: Variations in Illuminance Within a Room

Error! Reference source not found. summarizes the static room illuminance measurements, which were obtained for 8 of the 9 households. The mean and median room illuminance measurements, when taking static measurements, were 85 lux and 46 lux, respectively. The mean and median room illuminance measurements at position E (TV sensor) were 66 lux and 24 lux, respectively, somewhat less than the overall values.

Table 1: Basic Information for Static Room Illuminance Measurements

Number of households	8
Number of measurements	144
Average number of measurements per household	16
Diagonal screen size range	20” to 57”
Average room illuminance	46 lux (median), 85 lux (mean)

The brightest position in the room was most frequently B (couch), followed by A (room center), indicating that lighting is deliberately focused away from the TV. The darkest position in the room was most frequently at C (top of the TV) followed by D (screen center), further indicating lighting is focused away from the TV.

The variation between D (screen center) and E (sensor) was minimal in 61% of measurements, which was expected, as they are both located at the TV with the meter facing outward. However, 39% of the time there was a large difference between the two, which was unexpected. While the cause was unknown, one possibility was the presence of a lamp or window located close to one side of the TV.

The mean difference between the maximum and minimum illuminance measurements within a set of measurement points (A to E in one room on one occasion) is very high, 67 lux, with a standard deviation of 64 lux. The limited size of the dataset was probably the main reason for this high standard deviation, and a more widespread and longer-term survey would therefore be recommended in the future. Also, the number of measurements taken per home varied: for instance, while one home measured as many as 6 sets of measurements, the mean number of sets of measurement was only 3.

Room Illuminance Measurements During TV Viewing

We collected 1,079 room illuminance measurements while the TV was on (653 on a weekday, 426 on a weekend), and 10,302 measurements in total. Figure 3 shows that approximately two-thirds of viewing took place in the evening, with mean light levels much lower during evening (22 lux) than during the day (112 lux). Room illuminance during TV viewing varied from 0 to more than 500 lux. Figure 3 is compared with

Figure 4 which shows the frequency of TV viewing by time of day taken from the American Time Use Survey conducted by the Bureau of Labor Statistics (BLS, 2011). This is representative of the national average and again shows a strong preference for viewing in the evening, supporting the trend displayed in Figure 3.

Figure 3: Mean Room Illuminance by Time of Day While Watching TV

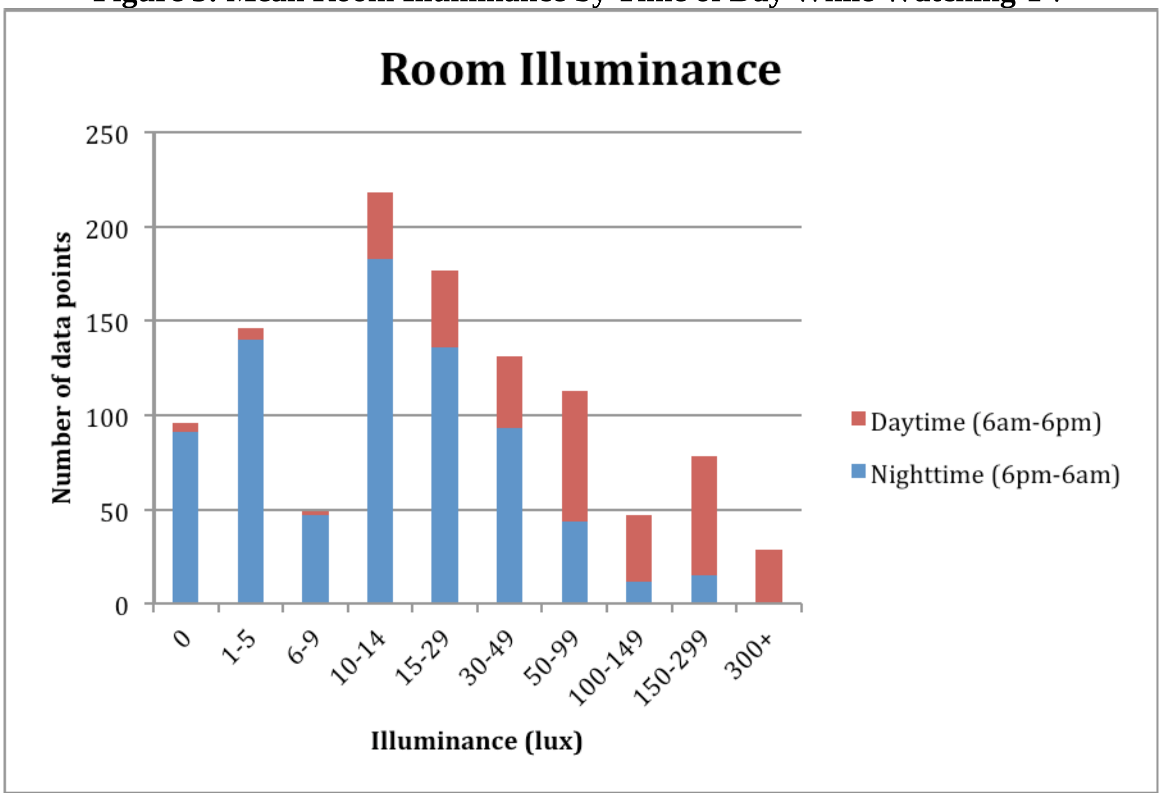


Figure 4: 2010 American Time Use Survey Time of Day Watching Television

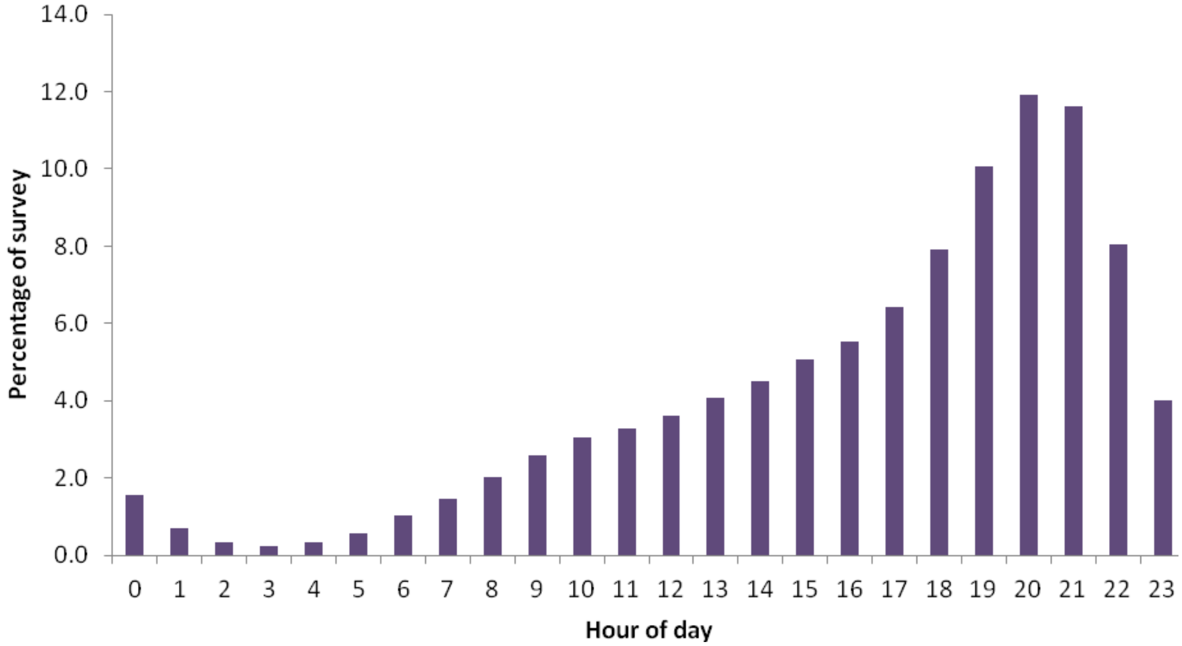


Figure 5-A and 5-B show the mean room illuminance levels during TV viewing, both as a cumulative distribution plot (Figure 5-A) and as a Q-Q plot versus a similar larger-scale study conducted by CLASP (2011)[2] (Figure 5-B). The Q-Q plot compares the same quantiles from one study versus the other. The CLASP results are also presented in Figure 5-A for comparison. The data are plotted logarithmically for 2 main reasons: (1) the high concentration of points at low lux levels; and (2) a logarithmic representation also more accurately reflects the way the eye perceives illuminance, e.g., a change from 10 to 20 lux is perceived as approximately the same increase in relative brightness as a change from 100 to 200 lux. In Figure 5-A, the upper and lower quartile and median are also plotted on the y-axis, and are shown in

Table 2 separately along with the intermediate points.

The CLASP study appears to have a greater fraction of TV viewing hours occurring at lower room illuminance levels than in the LBNL study. This is unexpected, as the CLASP study contains significantly more daytime measurements. CLASP data were taken from a similar number of homes in Sacramento, CA and Washington, DC. Deeper investigation revealed that daytime viewing was heavily concentrated in Washington, DC, and that may be attributable to the particular characteristics of that city (e.g., likely higher level of daytime news viewing). Moreover, another important consideration is the seasonal limitation of each study. As mentioned earlier, the LBNL measurements were recorded during late spring, while the CLASP measurements were recorded in late fall, when daylight hours are likely to have been shorter. This highlights the value of being able to measure data for longer periods of time in order to capture any seasonal variation.

Another study by the CEA took measurements in 234 homes between September and December 2011. The measurements were more geographically diverse than either the LBNL or

[2] The CLASP study took measurements in 60 homes evenly split between Sacramento, California and Washington, D.C., during October and November 2011.

CLASP study, although the majority (62%) were in California. The methodology was different in that it took a single measurement at the center of the bottom bezel of the TV at a fixed point in time, generally targeting prime time (7 pm to 11 pm) viewing hours by asking participants to set up the room as they normally would when watching TV (i.e., possibly drawing the blinds or turning on artificial lights). The TV was not turned on. This study provided more data on evening viewing at the expense of viewing at other times of day; therefore, it could not be directly compared to the room illuminance data from LBNL and CLASP. However, the study indicated an average prime time room illuminance level of 26 lux—roughly consistent with our average evening level—and an overall average nighttime level of 42 lux.

Figure 5-A: Mean Room Illuminance During TV Viewing (Cumulative Distribution)

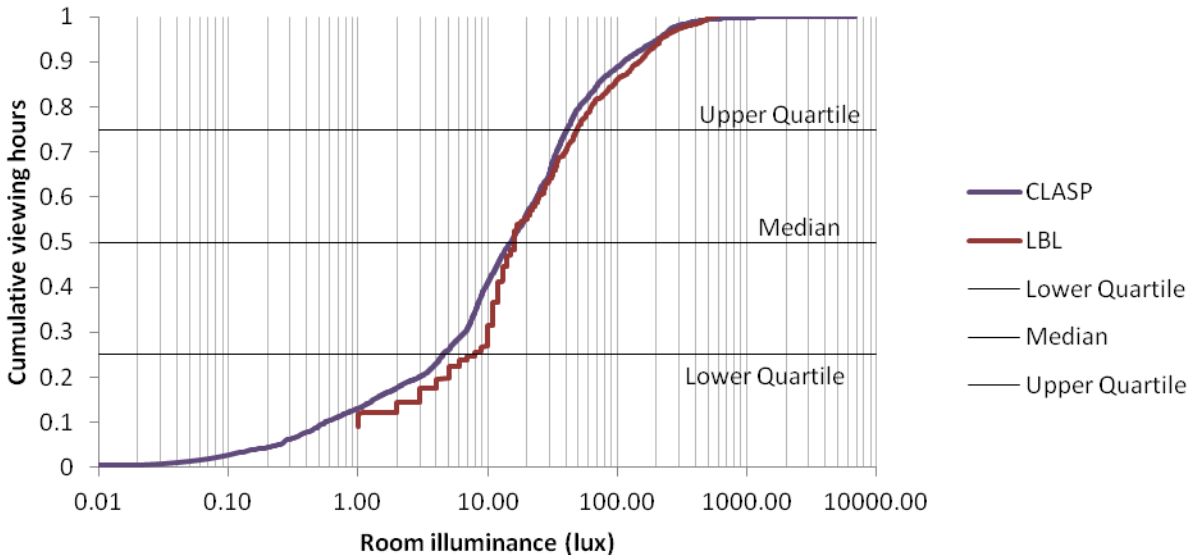


Figure 5-B: Mean Room Illuminance During TV Viewing (Q-Q Plot)

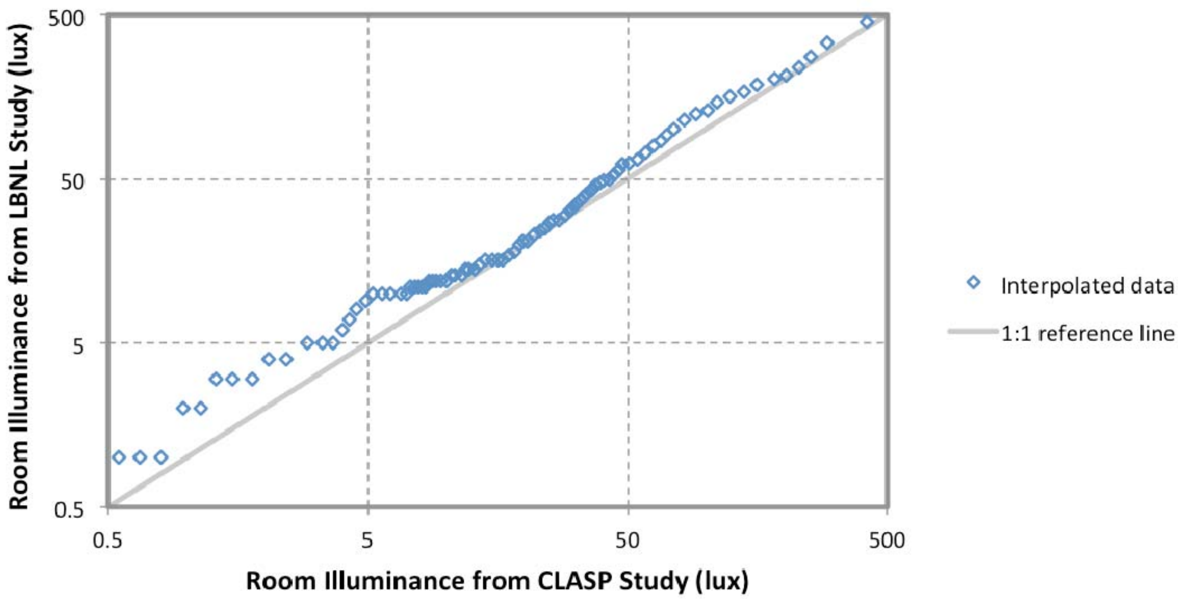
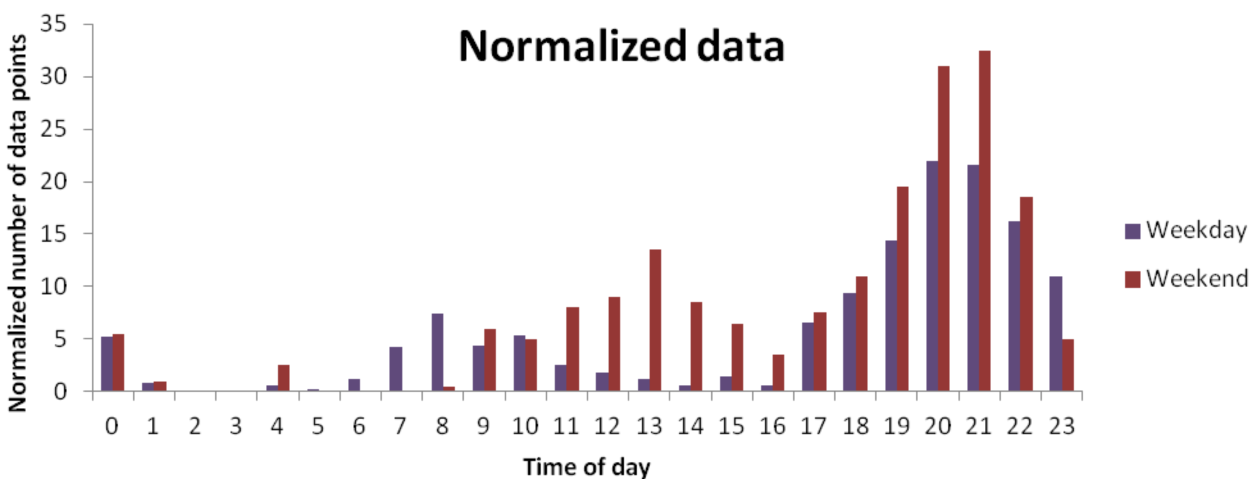


Table 2: Mean Room Illuminance vs. Cumulative Viewing Hours (Measurements at Position E)

	Cumulative viewing hours (%)						
	12.5	**25.0**	**37.5**	**50.0**	**62.5**	**75.0**	**87.5**
Study	**Room illuminance (lux)**						
CLASP	0.9	5	9	15	26	41	87
LBNL	2	8	12	16	28	49	120

We also considered 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 6 shows the number of data points separated into weekday and weekend day. The data have been normalized to a single day by dividing the weekday data by 5 and weekend data by 2. As can be seen in the Figure, more viewing was recorded on weekends than weekdays, especially during the day between 11 am and 4 pm. Overall total weekend viewing time is equivalent to 3.6 hours per household, while weekday viewing time is equivalent to 2.6 hours per household. These are much lower than the U.S. national average of 7 hours per day for a primary TV (the most watched TV in a home) (The Nielsen Company, 2011). However, it is important to remember that only 9 homes participated in the survey, and there was less significant variation in demographics.

Figure 6: Normalized Distribution of TV Viewing by Time and Type of Day



In order to determine whether the room illuminance was altered during TV viewing, the illuminance measurements were also divided into TV-on and TV-off and are presented in Figure 7. The results suggest that viewers significantly alter room conditions while watching TV. In the evening and early morning room illuminance is higher during TV viewing, suggesting that artificial lighting is likely being used, whereas during the late morning and early afternoon room illuminance is lower during TV viewing, suggesting that window shades are likely being used. The data were further separated into weekday and weekend and are shown in Figure 8 and Figure 9. The pattern is consistent over both weekdays and weekends.

Figure 7: Average Room Illuminance by Time of Day with TV On and TV Off

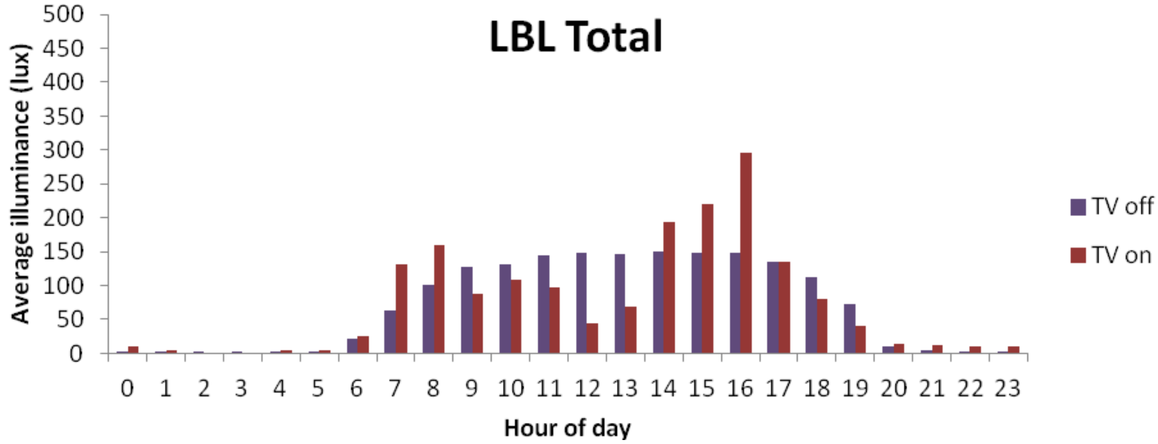


Figure 8: Average Room Illuminance by Time of Day on a Weekday with TV On or TV Off

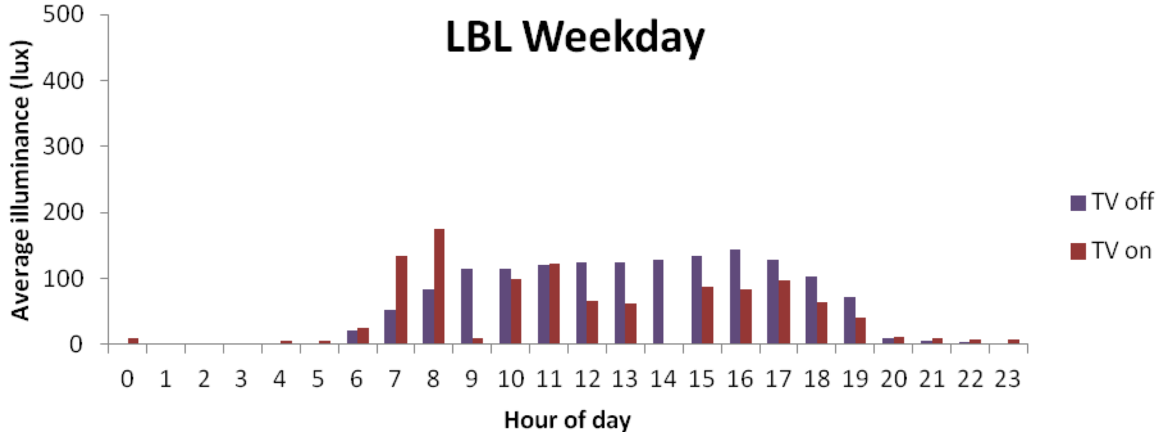
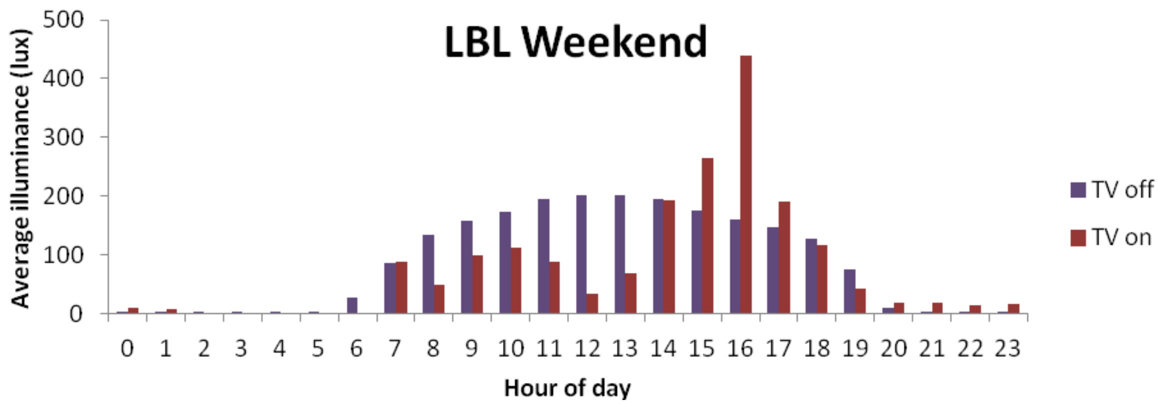


Figure 9: Average Room Illuminance by Time of Day on a Weekend Day with TV On or Off



Summary and Suggestions for Future Work

This pilot study set out to answer two important questions with respect to typical room illuminance during TV viewing:

- Whether and to what extent illuminance levels in a room vary depending on where the illuminance measurements are taken in a given room?
- Which illuminance conditions are prevalent when people watch TV?

The first question was addressed by taking illuminance measurements at 5 points in the primary TV viewing room. This study shows definitively that there is large variability between measurements at different locations in the room. The results strongly indicate that illuminance is higher away from the TV, i.e., in the center of the room, or at the main seat, and that there was significant variation across a given room and in different directions. Future studies regarding ABC should therefore ensure that room illuminance measurements are taken at the TV sensor, and not at an arbitrary location in the room. A larger sample size would be required to determine whether and to what extent measurements at one point can be used to estimate measurements at other points in the room.

The second question was addressed through continuous measurements of room illuminance and TV power use at intervals of 10 minutes for a period of one to two weeks. The results indicate that the majority (over 75%) of TV viewing occurs at illuminance levels of less than 50 lux. A preference for viewing in the evening compared to during the day was noted, in agreement with the results of the American Time Use Survey. TV viewing on weekdays predominantly occurred during the evening, whereas on weekends a significant amount of viewing also occurred during the middle of the day. Comparison of illuminance measurements with the TV on to when the TV was off strongly indicated that room illuminance levels were adjusted while watching TV. During the evening, room illuminance was consistently brighter with the TV on, indicating the use of artificial lighting in the room at this time. During the morning and early afternoon, room illuminance was dimmer with the TV on, suggesting that window shades were used while watching TV.

These results clearly indicate that the current measurement points of 0 and 300 lux are extreme conditions, and miss the overwhelming majority of room illuminance conditions typically found in homes. While this pilot study was based on a limited sample, it is consistent with both the CLASP and CEA results, suggesting that despite its limitations, valuable data were obtained. The CLASP and CEA studies have provided much of the additional follow-up needed to develop a representative set of room illuminance levels for test procedure purposes. Additional geographic and seasonal data (a span of at least half a year would be required to capture seasonal effects) would be useful to complete the picture, but are not essential. Finally, any future studies should continue to measure illuminance when people are actually watching TV, as there is evidence that room conditions are altered when actively watching TV (such as turning on lights or drawing curtains).

References

Bureau of Labor Statistics (BLS). 2011. *American Time Use Survey*. http://www.bls.gov/tus/. Last accessed 2/6/2012.

Collaborative Labeling and Appliance Standards Program (CLASP). 2011. *Analysis of Background Illuminance Levels During Television Viewing*, Available online http://www.clasponline.org/en/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2011/Background-Illuminance-Levels. Last accessed 3/7/2012.

Consumer Electronics Association (CEA). 2012. *Comment discussing conducted research results, including survey sample and collected data.* Public comment submitted to the U.S. Department of Energy, EERE-2010-BT-TP-0026-0034, 13 March. http://www.regulations.gov/#!documentDetail;D=EERE-2010-BT-TP-0026-0034.

ENERGY STAR. 2011. *TVs Key ENERGY STAR Product Criteria.* U.S. Environmental Protection Agency. http://www.energystar.gov/index.cfm?c=tv_vcr.pr_crit_tv_vcr. Last accessed 3/9/2012.

Leslie, R. P. and K. M. Conway. 2003. *The lighting pattern book for homes.* Troy, NY: Lighting Research Center.

Matsumoto, T., S. Haga, T. Nakatsue, S. Kubota, Y. Kubota, K. Imabayashi, K. Kishimoto, S. Goshi, S. Imai and Y. Igarashi. 2011. "Appropriate Luminance of LCD-TV Screens under Actual Viewing Conditions at Home." In: *Proceedings of Society for Information Display (SID) Display Week.* Los Angeles, CA: Society for Information Display.

The Nielsen Company. 2011. National People Meter Set-level TV Data: May 2007-May 2011.