3D Television Sets Research Report

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SEAD Standards and Labeling Working Group

Television Product Collaboration

Anthony Rotolo, Kevin Morrissey, and Allen Tsao
Navigant Consulting, Inc.

Navigant Consulting, Inc.
1200 19th St NW
Suite 700
Washington, DC 20036
202-973-2400
www.navigant.com

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Background

There are several existing industry test procedures for measuring TV power consumption with 2D content, but little is known of the impact 3D content has on power consumption. 3D TVs have seen a steady growth in shipments since 2009, spurred curiosity over the power consumption associated with these products.

The impact of 3D on TV power consumption has been investigated previous to this research by different agencies since 2010. Both CNET and the US Department of Energy (DOE) conducted testing on 3D TV power consumption, with the conclusion that 3D could have a large impact on TV power. Additionally, the Consumer Electronics Association (CEA) conducted an analysis of DOE's data, proposing that the change in power from 2D to 3D was due to a change in screen brightness.

The goal of this research was to evaluate the power consumption demands of 3D TVs and to expand upon previous work by determining the impact of different variables on 3D TV power consumption. Twelve 3D TVs were selected for testing based on technology characteristics in order to include different combinations of TV variables. During testing, different configuration and usage variables were explored for their impact on 3D TV power.

Methodology

This research consisted of two parts. The first part, evaluation of usage variables, investigated aspects of TV operation that could affect power consumption and should be controlled when evaluating the impact of 3D power. For the second part, the power consumption analysis, 3D stabilization time and 3D TV power consumption were measured to determine the effects of TV screen size, screen technology, and active/passive 3D on power consumption both in 2D and 3D. In addition, screen luminance and standby-passive mode power consumption were evaluated during this testing.

Results and Conclusions

After controlling for the usage variables, it was found that the percent difference in power consumption between 2D and 3D ranged from a decrease of 19% to an increase of 72%. While in some cases power consumption decreased, ten out of twelve TVs tested exhibited an increase in power consumption from 2D to 3D. The degree to which the TV increased in power was widely dependent on the screen size and screen technology of the TV. Contrary to CEA's previous conclusion, this research does not find luminance to be the major factor affecting overall 3D TV power consumption. Additionally, the research finds that the 3D technology of the TV, active or passive 3D, has little to no impact on the differences in power consumption between 2D and 3D.

Future Work

While there are currently no standard test procedures for measuring 3D power consumption, existing industry procedures for 2D TVs can serve as guidelines in 3D testing. This analysis identified areas where 3D testing may require further specification compared to a 2D test procedure.

This report also highlights trends that can be further investigated by testing a larger sample size of TVs focusing on a specific technology, such as LED. In addition, there exist new technologies not covered by this report that could have an effect on 3D TV power consumption. These technologies include glasses-free 3D and organic light-emitting diode (OLED) displays.

To investigate the impact of 3D on regional power consumption, the results from this report could be supplemented with market research analyzing 3D usage profiles as well as shipment trends of 3D TV technologies. This data could provide a valuable context for the conclusions of this research as the viewership and market of 3D TVs changes.

1. Introduction

There are many industry TV test procedures which measure power consumption of TVs for 2D content but very little is known about the power consumption of 3D TVs when displaying 3D content. As 3D TVs have become more prevalent, there is growing interest in assessing the power consumption for 3D content. Navigant Consulting Inc. was contracted by the Collaborative Labeling and Appliance Standards Program (CLASP), to conduct research and analyze the impact of displaying 3D content on the power consumption of 3D TVs. The testing on which this analysis is based was performed from December 2012 to February 2013.

1.1. 3D Television Market and Technology

Although the modern 3D movement began nearly a decade ago, shipments of 3D TVs have only seen a steady growth since 2009. In 2011, the global shipment penetration grew to 12%[1] and global sales grew by an additional 40% from 2011 to 2012[2]. 3D TV shipments are projected to continue to grow at a rate of 15-20% each year from 2013 to 2019[3]. This increase in 3D TVs shipments has spurred much curiosity surrounding the power consumption of these products and prompted studies into the effects of 3D technology on power consumption.

When evaluating 3D TVs it is important to consider that they're not all created the same, and that there are a variety of screen technologies and methods for displaying 3D content. Although there are a few different types of TV screen technologies, the focus of this report is on three specific technologies that are most commonly used by 3D TVs: light-emitting diode backlit liquid crystal display (commonly referred to as LED), cold-cathode fluorescent lamp backlit liquid crystal display (commonly referred to as LCD), and plasma display panel (commonly referred to as plasma). In addition to these common screen technologies, the predominant methods for displaying 3D content are auto-stereoscopic (glasses-free), active shuttering (active 3D) and passive polarization (passive 3D) technologies. The glasses-free technology is a newer 3D technology and is typically only seen in small handheld devices due to its restrictive viewing angles and the difficulty of implementing it with many viewers at a time. Currently, active and passive 3D technologies have roughly equivalent market presence[4] and are only distinguishable to consumers based on screen resolution and cost of 3D glasses.

Active 3D TVs use an infrared signal to synchronize the TV content with battery-powered glasses. This causes each lens to "shutter" at the same rate as the screen, allowing the left and right eye to see their respective image as it is displayed on the TV. Each eye is shown the same image at a slightly different angle which creates the 3D effect. By dedicating an entire frame to one eye, active 3D maintains the full resolution of the TV in each eye.

Passive 3D, which is commonly used in movie theatres, uses battery-free glasses to filter circularly polarized light and allow each eye to see a different image. It is inexpensive to produce polarized 3D glasses, which makes it ideal for use in movie theatres and is one of the main benefits of using passive 3D technology. Unlike active 3D, passive 3D displays both images on the screen at same time where the right eye uses clockwise polarization to see one image and the left eye uses

[1] DisplaySearch "Quarterly TV Design and Features Report," Q4'2011. Santa Clara, CA.
http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/quarterly_tv_design_features_report.asp
[2] DisplaySearch. "3D Display Technology and Market Forecast Report," 2012. Santa Clara, CA.
http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/3d_display_technology_market_forecast_report.asp
[3] Ibid.
[4] DisplaySearch. "3D LCD TV Panel Shipments Grew 27% in Q3'11," 2011. Santa Clara, CA.
http://www.displaysearch.com/cps/rde/xchg/displaysearch/hs.xsl/111122_3d_lcd_tv_panel_shipments_grew_in_q3_11.asp

counter-clockwise polarization to see the other image. The downside of this technology is that the resulting 3D image has half the vertical resolution compared to the same content on an active 3D TV.

1.2. Previous Work Evaluating 3D Television Power Consumption

CNET, a popular technology and consumer electronics website, published an article in July 2010[5] which measured the power consumption of nine 3D TVs when displaying 2D and 3D content. They used a 10-minute clip from the Blu-ray Disc™ (BD) movie *Cloudy with a Chance of Meatballs* to run their tests. These results showed that, on average, displaying 3D content consumed more power than 2D content, ranging from a -2% to 114% change between 2D and 3D. They also noted that screen luminance tended to be brighter in 3D than in 2D, though no luminance data was released.

DOE conducted similar testing in early 2011 to determine the effects of 3D content on the power consumption of five 3D TVs[6]. Like the testing performed by CNET, this testing used a 10-minute segment from the movie *Cloudy with a Chance of Meatballs*. The 3D testing was performed using a native 3D BD format whereas the 2D testing was performed with a 2D version in a Digital Versatile Disc (DVD) format. DOE found that the percent difference in power consumption from 2D to 3D ranged from -16% to 86%, which was also similar to the results found in CNET's testing. This data was published by DOE to support its release of the Television Set Test Procedure Notice of Proposed Rulemaking (NOPR)[7].

The DOE test results from 2011 were also used as part of an investigation by the Consumer Electronics Association (CEA) "Investigation of 3D TV Technology and Energy Consumption"[8]. In this study, members of the CEA's 3D TV working group discussed the test results from DOE as well as market trends of 3D televisions. The working group determined that more data was needed for both 3D TV power consumption and 3D viewing usage in order to draw more robust conclusions. They did conclude that based this preliminary data set, an increase in screen brightness in 3D can be used to overcome the dimming effects of 3D glasses and can contribute to an increase in TV power consumption. They also recommended the creation of a 3D video test signal and suggested that a 3D TV test procedure could be warranted.

The results from these investigations are informative and help to understand some of the basic differences between displaying 2D content and 3D content but these tests were conducted several years ago and it is unknown how these products have evolved since then. Additionally, neither study analyzed the effects of variables of test set-up, TV configuration, nor 3D TV features on power consumption, just the overall impact of displaying 3D. This research is designed to build upon these results, provide further analysis of 3D power consumption, and evaluate possible causes of the differences in power consumption between 2D and 3D.

1.3. Report Overview

This research was designed to evaluate the power consumption of 3D TVs when displaying 3D content in comparison to 2D content, and to expand upon previous work by determining the impact of 3D variables on TV power consumption. This was done by separating the testing into two phases, including the evaluation of TV usage variables and the impact of TV technology variables on power consumption. These results were then analyzed in order to assess the overall impact of displaying 3D on the power consumption of 3D TVs.

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[5] CNET. "Do 3D TVs use more power?" 2010. http://news.cnet.com/8301-17938_105-20009547-1.html
[6] U.S. Department of Energy. "Television 3D Mode Data," 2012. Docket #EERE-2010-BT-TP-0026 on regulations.gov. http://www.regulations.gov/#!documentDetail;D=EERE-2010-BT-TP-0026-0033
[7] U.S. Department of Energy - Energy Conservation Program. "Test Procedure for Television Sets; Notice of proposed rulemaking," 2012. Docket #EERE-2010-BT-TP-026 on reulations.gov. http://www.reguations.gov/#!documentDetail;D=EERE-2010-BT-TP-0026-0019
[8] CEA. "Investigation of 3D TV Technology and Energy Consumption," 2012. http://cea.aristotle.com/Shared%20Documents/3DTVEC%20DG%20Report_15March.pdf

2. Methodologies and Test Setup

2.1. Variables

Test variables were evaluated to determine their impact on 3D power consumption and to determine which variables needed to be controlled for comparable results. These variables were separated into two categories: usage and TV technology variables. Usage variables refer to any TV setting, configuration, or associated equipment that can impact the TV's operation. TV technology variables refer only to the specific characteristics of the TV and were used to select the TVs for this research. TV technology variables are dependent on a specific TV and are static, whereas usage variables can impact all TVs and can be changed by the consumer.

2.1.1. Usage Variables

The usage variables in Table 1 were tested to determine the impact they may have had on 3D power consumption and if they needed to be controlled in later power consumption testing. These variables included the use of active shutter glasses with active 3D TVs as well as TV settings such as picture setting and automatic brightness control (ABC). In addition, the BD player, video content, and 3D conversion by the player were investigated as variables that may potentially impact TV power consumption when displaying 3D content.

Table 1: Usage Variables

Picture Setting
Automatic Brightness Control
BD Player
3D Signal: Native, Converted
Video Content
Disc Format
Active Shutter Glasses

Picture settings refer to a preconfigured arrangement of settings such as brightness, contrast, sharpness, or color. Consumers can change the TV picture setting to quickly adjust the TV for different viewing situations, such as watching a movie or sports. Most TVs are set to a standard picture setting when shipped, but changing this picture setting can potentially impact the power consumption of the TV. ABC can also impact the power consumption of the TV as it is a feature that adjusts the brightness of the screen as a function of the ambient lighting measured by the TV's ABC sensor. In some cases, changing the picture setting can also change the configuration of the ABC sensor and further complicate the impact of these variables.

2.2. TV Technology Variables

The TV technology variables listed in Table 2 were recognized as variables that may affect 3D power consumption and used as factors for TV selection.

Table 2: TV Technology Variables

Screen Size
Screen Technology (LED, LCD, Plasma)
3D Technology (Active, Passive)

The extent of each variable's effect on power was evaluated with a controlled approach to isolating these items in the TV selection process. This was done by varying all combinations of these variables, although not all variable combinations were available on the market. For example, all explored plasma 3D TVs employed active 3D technology because passive 3D plasma TVs were not commercially available at the time of testing.

TVs were also selected based on recent release dates to ensure this research was relevant to the current TV market. However, two 2010 model 3D TVs, which had been used in previous testing, were also tested to expand upon the sample set. Table 3 shows a comprehensive list of TVs tested in this research. Note that some TV manufacturers appear multiple times in this list because 3D technology is a still considered relatively new and has yet to be adopted by many second tier TV manufacturers.

Table 3: TVs Selected for Testing

Navigant ID Number	Manufacturer	Release Year	Size (Diagonal Length, inches)	3D Technology	Screen Technology
1	A	2012	32	Passive	LED
2	B	2012	32	Active	LED
3	C	2011	32	Passive	LCD
4	D	2012	47	Passive	LED
5	B	2010	40	Active	LED
6	E	2012	46	Active	LED
7	A	2012	47	Passive	LCD
8	A	2012	42	Active	Plasma
9	C	2012	55	Passive	LED
10	F	2012	60	Active	LED
11	G	2012	55	Active	Plasma
12	B	2010	63	Active	Plasma

2.3. Test Setup

Testing was conducted with the following setup and equipment.

2.3.1. Test Equipment and Arrangement

Power consumption for stabilization, on mode, and standby-passive mode was measured using a Yokogawa WT-210 power meter. The power meter was connected to a California Instruments 1251P voltage regulator, which supplied 115 volts at 60 hertz. For luminance measurements, a Konica-Minolta LS-110 luminance meter was used.

2.3.2. Blu-ray Disc Players

On mode power consumption tests were conducted on two BD players of different manufacturers. Each BD player had the capability to play both DVDs and BDs in 2D and 3D, and could convert 2D content to 3D in real time. The BD players were connected to the TVs via a High-Definition Multimedia Interface (HDMI) cable.

2.3.3. Video Content

The DOE Test Procedure Supplemental Notice of Proposed Rulemaking for TVs (TV SNOPR)[9] measures on mode power consumption while displaying the International Electrotechnical Commission (IEC) 62087 Ed. 3.0 Blu-ray Disc Dynamic Broadcast Content (DBC) video signal for a 10 minute period. This video signal was designed to be representative of typical on mode consumer viewing, and could easily be looped up to eighteen times (3 hours).

The IEC DBC was used to stabilize the TVs, though a different video signal was displayed for the power consumption measurements because the IEC DBC was only available in a 2D format and therefore did not provide the option of testing a native 3D video signal. The IEC DBC was still used to stabilize 3D content by converting it to 3D with the BD player because it was easy to loop the content and the power consumption only needed to be compared against a previous loop, not another test. For the on mode power measurement, a 10-minute segment from the film *Cloudy with a Chance of Meatballs*[10] was used because it was available in both native 2D and 3D formats. As shown in Table 4, 2D content and converted 3D content tests were conducted using both DVD and BD formats while all native 3D tests were conducted using the BD content as native 3D content is not available in the DVD format.

Similar to the TV SNOPR, all 2D luminance testing was conducted with the IEC Three Bar Signal. For 3D luminance tests, the BD player converted the 2D version of this signal to 3D. Table 4 summarizes these content parameters for all for the three major tests.

Table 4: Video Content

Test	2D Video Content	2D to 3D Converted Video Content	3D Video Content
Stabilization	IEC DBC – BD	IEC DBC – BD (3D-converted)	IEC DBC – BD (3D-converted)
On Mode	*Cloudy with a Chance of Meatballs* – DVD, BD	*Cloudy with a Chance of Meatballs* – DVD, BD	*Cloudy with a Chance of Meatballs* – BD
Luminance	IEC Three Bar Signal – BD	N/A	IEC Three Bar Signal – BD (3D-converted)

2.4. Test Approach

Testing was broken down into three phases: evaluation of usage variables and TV settings, TV stabilization, and on mode power consumption testing.

2.4.1. Determination of TV Settings

Evaluating the TV settings was necessary to ensure that the TVs were tested in comparable modes when measuring the 3D power consumption. Not only were the TV settings and configurations evaluated during this phase, but the screen luminance in 2D and 3D was also measured[11]. This was done to establish the brightest picture setting as well as to identify relationships between picture settings, luminance, and power consumption. It was suspected that changes in power consumption between 2D and 3D could potentially be linked to changes in luminance.

[9] U.S. Department of Energy - Energy Conservation Program. "Test Procedures for Television Sets; Supplemental notice of proposed rulemaking," 2013. Docket #EERE-2010-BT-TP-0026 on regulations.gov. http://www.regulations.gov/#!documentDetail;D=EERE-2010-BT-TP-0026-

[10] *Cloudy with a Chance of Meatballs,* September 18, 2009. Sony Pictures Animation, distributed by Columbia Pictures

[11] Screen luminance was measured in accordance with Section 5.7 of the TV SNOPR for TVs.

2.4.2. TV Stabilization

The TV stabilization in 3D was conducted as a necessary step before 3D power measurements were made to ensure test accuracy. Although current 2D test procedures[12] specify a 1-hour stabilization period before on mode tests, it was unknown if this was also appropriate for 3D stabilization. To investigate this, the stabilization period for 3D content was increased from 1 hour to 1.5 hours. Power consumption was measured throughout each stabilization period to determine stability and make comparisons between 2D and 3D. This testing used the same stabilization criterion as the TV SNOPR for both 2D and 3D, which states that the TV is stable when two consecutive 10-minute power consumption intervals are within 2% of each other. Throughout TV stabilization, the TV remained in its default configuration with exception of disabling the ABC.

2.4.3. Power Consumption Testing

2.4.3.1. On mode power consumption testing

The on mode power consumption test was the primary basis for comparing 2D and 3D as well as for isolating TV variables, identified in Section 2.1.1, which may affect power consumption. This test consisted of a 10-minute power measurement while displaying content from *Cloudy with a Chance of Meatballs*. On mode power consumption testing was tested under three different conditions: testing with 2D content, converted 3D content, and native 3D content (referred to as simply 3D in this report). The on mode test with converted 3D content was performed by using the BD player to convert the 2D content rather than using a TV to perform this conversion. Using the BD player ensures that the same conversion is performed for all TVs and does not require the TV to perform additional video processing witch may change the power consumption.

Two different BD players were used throughout on mode testing to determine their impact as a usage variable. Although variability among different BD players was not expected, different manufacturers can use different algorithms to convert 2D content to 3D, which can potentially affect power consumption in that test. Similarly, both DVD and BD versions of *Cloudy with a Chance of Meatballs* were used to test 2D content and converted 3D content. Native 3D content was only tested in a BD format because it is not made in a DVD format.

Based on the TV settings evaluation, on mode power consumption was tested using two picture settings to help identify the effect of picture setting on power consumption and determine if any relationships existed between luminance and power consumption. To verify that the TV remained stable while changing between picture settings for this test, a 20 minute “re-stabilization” test was performed after the transition to the new picture setting. The re-stabilization test was then evaluated under the same conditions as the initial stabilization test discussed in Section 2.4.2.

For active 3D TVs, native 3D content was tested with and without the active glasses enabled to analyze the effect of the active shutter 3D glasses on power consumption. Passive 3D TVs do not communicate with 3D glasses so they were not evaluated for this test.

2.4.3.2. Standby-passive mode power consumption testing

The standby-passive mode was investigated because it was unknown if any residual features from displaying 3D in on mode would have an impact on the power consumption in this mode. A secondary goal of this testing was to analyze the effect of active 3D glasses while in standby-passive mode. Even though there would be no need for active glasses to synchronize with the TV like they do in on mode, this was similarly investigated to determine if displaying 3D had any additional effects on the power consumption of standby-passive mode. The test approach for standby-passive mode testing was based off of Section 5.8.2 of the TV SNOPR.

[12] DOE TV Test Procedure SNOPR, CEA 2037-A, and IEC 62087 Ed. 3.0

3. Results & Discussion

The results and discussion section is divided into two sections: evaluation of usage variables and on mode power consumption analysis. The evaluation of usage variables section discusses the necessary steps taken to control these variables in order to produce comparable results for power consumption analysis. In the power consumption analysis section, the effects of TV variables like screen and 3D technology on the change in power consumption are discussed in terms of comparison between 2D and 3D. This analysis also uses a regression model to predict the effects of displaying 3D content among other 3D TVs and investigates potential correlations between power and luminance.

3.1. Evaluation of Usage Variables

3.1.1. Picture Settings Comparison

It was discovered that TV picture setting played a significant role in power consumption when measuring the on mode power. Not all TVs used the same default picture setting making it very difficult to compare TVs, as it was unknown if differences in power consumption were associated with the picture setting or other variables. The default picture settings for each TV are shown in Table 5.

Table 5: Default Picture Settings

TV	1	2	3	4	5	6	7	8	9	10	11	12
2D	Std.	Std.	Std.	Auto	Std.	Std.	Std.	Auto	Std.	Std.	Std.	Std.
3D	Std.	Std.	Std.	Auto	Std.	Std.	Std.	Vivid	3D	Std.	Cinema	Std.

"Std.": Standard picture setting
"Auto": Picture setting tied to ABC function

By default, ten of twelve TVs used the standard picture setting in 2D and eight TVs remained in the standard picture setting when displaying 3D. In addition, three TVs had different default picture settings in 2D and 3D. However, all TVs featured a picture setting called standard, regardless of whether it was the default setting. As a note, TV 9 had only one picture setting in 3D, entitled "3D."

As a result, two possible methods were identified for making these power consumption comparisons: one which used the default picture settings for 2D and 3D and the other which used the standard picture setting for both 2D and 3D. Table 6 shows the potential impact on the percent difference in power consumption from 2D to 3D, when the two different methods were used on TV 11.

Table 6: Default versus Standard Picture Settings on TV 11

Picture Setting	Power Consumption (Watts)		Percent Difference (2D to 3D)
	2D	3D	
Standard	114.7*	195.8	70.7%
Cinema	201.8	238.5*	18.2%
Default Configuration	114.7	238.5	107.9%

** Default picture setting*

For TV 11, the default picture setting in 2D was "standard" but changed to "cinema" automatically when displaying 3D content. By measuring the power consumption in the default configurations, the resulting percent difference in power consumption was 107.9%. When only the standard picture settings were used in 2D and 3D, the percent difference in power consumption was considerably less at 70.7%. Due to the significant differences between the comparison methods, it was critical that one method be used throughout this analysis.

While using the default picture setting may be more representative of consumer usage, the default picture settings on TVs 4 and 8 required the use of ABC, which would have complicated testing. Apart from these instances, only two data points (TVs 8 and 11 in 3D) differed between the standard and default configurations. Based on the high frequency with which the standard picture setting was seen as the default setting, the standard picture setting was used as the primary picture setting for comparisons between 2D and 3D.

In addition to picture setting, the ABC function was identified as a variable with a potential impact on power consumption between 2D and 3D. Variability of ABC settings is shown in Table 7.

Table 7: ABC Default Setting

TV	1	2	3	4	5	6	7	8	9	10	11	12
2D	On	On	On	On	On	On	On	On	On	On	On	On
3D	On	Disabled	Disabled	On	Disabled	Disabled	Disabled	Disabled	On	Off	Off	Disabled

Although all twelve TVs had ABC enabled by default in 2D, only three TVs had ABC on by default in 3D. The remaining nine TVs had the sensor off by default, of which seven TVs had ABC permanently disabled in 3D. Thus, to remove any variability associated to the ABC function, all testing was performed with the ABC sensor disabled.

3.1.2. Blu-ray Disc Player Comparison

Consumers are exposed to a variety of different BD players used to play 3D content, therefore multiple BD players were tested to determine if the power consumption of a TV was dependent on the BD player. Different BD players were also used in our analysis of native and converted 3D content which is discussed in further detail in Section 3.1.3.

During the picture setting evaluation, it was discovered that when some TVs were paired with BD players of the same manufacturer, they would enter into a default picture setting in 2D that was not seen with any other BD players. It was inferred that this issue was isolated to displaying 2D content because the same TV-BD player interactions were not observed when displaying 3D content. In one instance, this interaction resulted in a difference in power of up to 22.5% between the two BD players. This effect was seen in three specific combinations of TV and BD player. It is unclear if the TV-BD player interaction altered more than just the picture setting, and therefore these data points were omitted to avoid potentially compromising the comparison data between TVs.

Other compatibility issues also occurred when four of the twelve TVs did not display any image when tested in 3D with BD player 2. Apart from the aforementioned incompatibility issues, all variations between the two players were less than 2%. For the analysis in this report, all data points used were the average of BD player 1 and BD player 2 when available. For circumstances where the BD player was not compatible with the TV or device interaction existed, only the data point from the other BD player was used.

3.1.3. 3D Signal Comparison

The goal of this comparison was to determine if a converted 3D signal from 2D to 3D created material power consumption differences in comparison to a native 3D signal. As discussed in Section 3.1.2, not all TV-BD player combinations were able to display converted 3D content, so these results were based only on cases in which a successful 3D signal was displayed. For the basis of this testing, a 3D signal was deemed to be successfully displayed if the TV automatically recognized the input content as 3D and performed any necessary processing to display the video signal. In the unsuccessful cases, the signal produced a side-by-side 3D image which required the user to manually place the TV into 3D mode, potentially changing TV processing power and invalidating the test. In these cases, the TVs were not tested in either converted or native 3D with this player because the converted 3D content for stabilization could not be displayed for either test. In another case, the converted 3D content image on TV 11, was visibly shaky when using BD player 2 to convert the content and did not produce the 3D effect, so this data point was also omitted from the analysis. Apart from these complications, the power consumption of native 3D content was compared to converted 3D content which can be seen in Figure 1.

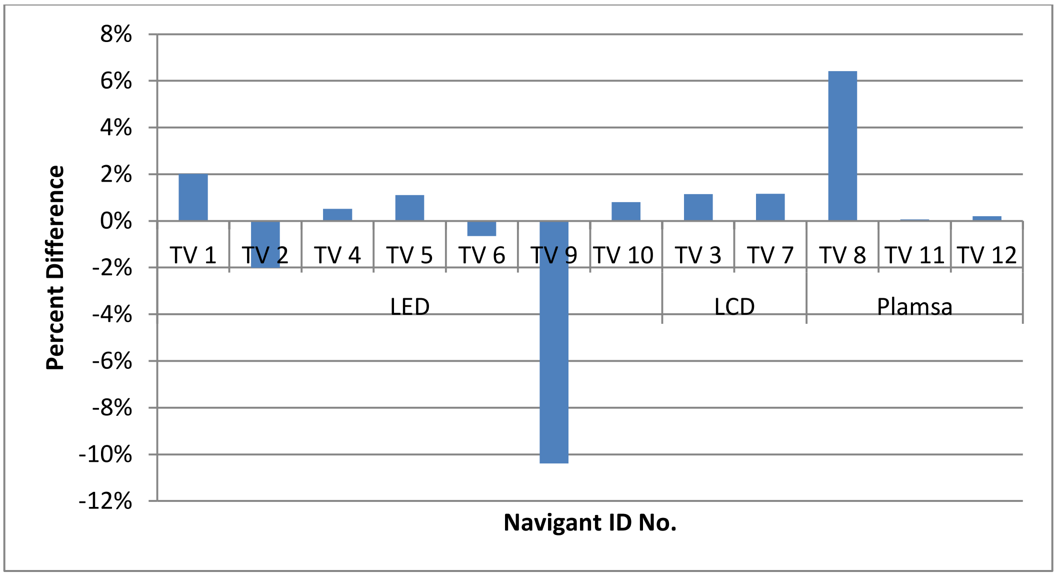

Figure 1: Percent Difference in Power Consumption, Native 3D Content to Converted 3D Content

These results show that ten of the twelve TVs exhibited less than a 2% difference in power consumption between native 3D content and converted 3D content. The two TVs that did exhibit greater variation, TVs 9 and 8, were observed to have a -10.39% and 6.41% difference respectively. Possible causes for this are further discussed in Section 3.1.4. Because of these differences, it was necessary to control for the content. As discussed in Section 3.1.4, native 3D content was chosen for power consumption analysis.

3.1.4. Disc Format Comparison

The main difference between DVD and BD formats is the screen resolution, which was a concern because a greater screen resolution could increase signal processing and in turn increase the TV power consumption. The variability due to content format was only a concern for 2D content because 3D content is only available in a BD format. This testing was especially important because 2D content was used as the basis for evaluating the change in power consumption between 2D and 3D, so any changes in the power consumption between the BD and DVD format would need to be considered in other analyses as well.

The results in Figure 2 show that in all cases, the differences in power consumption between BD and DVD formats for 2D content were less than 2%, although the differences between the two BD players were slightly greater when using BD content than when using DVD content. Based on these results, it was determined that content format had very little impact on 2D power consumption, but DVD content was used for the remainder of the 2D power measurements to ensure more consistent results.

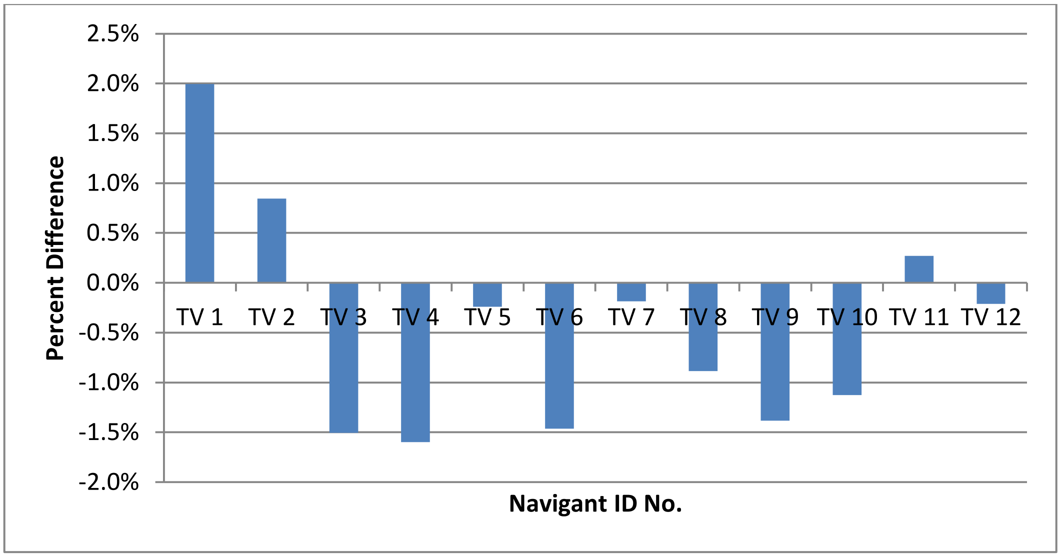

Figure 2: Percent Difference in 2D Power Consumption, BD to DVD Format

Although there were no significant differences found between BD and DVD format for 2D content, content format was also investigated for converted 3D content as a possible explanation for the differences in power consumption between native 3D and converted 3D content seen in Section 3.1.3. Video content was converted from 2D to 3D using both BD and DVD formats and compared to the power consumption of native 3D content. Like the results between 2D formats, most TVs exhibited variation of less than 2% between formats with converted 3D content. However, TVs 8 and 9 did not provide consistent results.

Figure 3 shows that TV 8 consumed 6.7% more power in a DVD format than with BD content when it was converted to 3D. This corresponds to the 6.2% difference seen between converted 3D and native 3D content in Section 3.1.3 which was also performed with DVD converted content. Contrary to TV 8, TV 9 exhibited virtually no difference in power consumption between BD and DVD formats but had a difference of -10.4% from native to converted 3D, as discussed in Section 3.1.3.

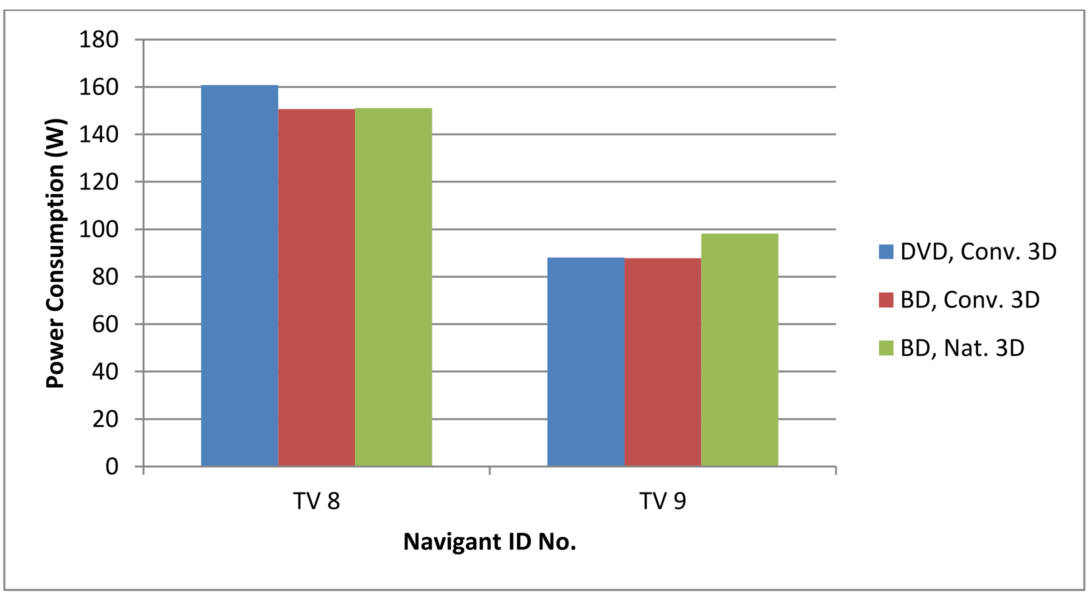

Figure 3: 3D Power Consumption versus Content on TVs 8 and 9

Based on these findings, it appears that the differences seen between native and converted 3D content in Section 3.1.3 for TV 8 were caused by using DVD format for the converted content and BD format for the native content. However, TV 9 did not appear to be affected by different content formats and therefore these results did not resolve the discrepancy between native and converted 3D content. These results continue to support the conclusion from Section 3.1.3 that it is necessary to use a single format for all testing, and also that native 3D should be used for all additional analysis to avoid inconsistent results from converted 3D.

3.1.5. Active Shutter 3D Glasses

This investigation evaluated the power consumption related to active 3D glasses by comparing the power consumption with the glasses enabled to the power consumption with the glasses disabled. All TVs tested exhibited less than a 0.3% difference between tests with the 3D glasses enabled and disabled. As a result, it was determined that 3D glasses do not have a measurable effect on total TV power consumption while in on mode. Similar testing was conducted in standby-passive mode for active 3D TVs and is further discussed in Section 3.2.3. For all other on mode power consumption testing, active shutter 3D glasses were connected to the TV as they would be under typical operation.

3.2. Power Consumption Analysis

3.2.1. Stabilization Analysis

TV stabilization was a necessary step performed to ensure that on mode power consumption results were comparable among all TVs. TV Stabilization was performed based on the configurations shown in Table 8 which were based upon the usage variable analysis.

Table 8: Controlled Usage Variables for TV Stabilization

Usage Variable	Controlled Configurations	
	2D	3D
Picture Setting	Standard Picture Setting	Standard Picture Setting
Automatic Brightness Control	Disabled	Disabled
3D Signal	Native	Converted
Video Content	*IEC Dynamic Broadcast Content*	*IEC Dynamic Broadcast Content*
Disc Format	BD	BD
Active Shutter Glasses	N/A	Connected

Table 8 shows that the IEC DBC video signal was used to stabilize the TVs when displaying 3D content, as discussed in Section 2.3.3. The data points used for stabilization are compared iterations of the same content on the same TV, meaning it would not matter that the on mode test content was not used. While this required the 3D content to be converted from 2D, we assumed based on the results from Section 3.1.3 that stabilization time using native and converted 3D content would be similar.

As discussed in Section 2.4.2, the stabilization time for 3D was set to 1.5 hours instead of the typical period of 1 hour used for 2D. Analysis of stabilization times in both 2D and 3D revealed that all TVs achieved stabilization within 1 hour; however, it did take longer for TVs to stabilize with 3D content. In Figure 4 and Figure 5, each bar represents the percent difference between two consecutive 10 minute iterations and the red line represents the 2% maximum difference stabilization criteria which all TVs must meet to be deemed stable. In Figure 4, all TVs stabilized within the first 20 minutes using 2D content, which can be seen by the first bar in each column. Figure 5, however, three TVs required at least 30 minutes to stabilize using 3D content.

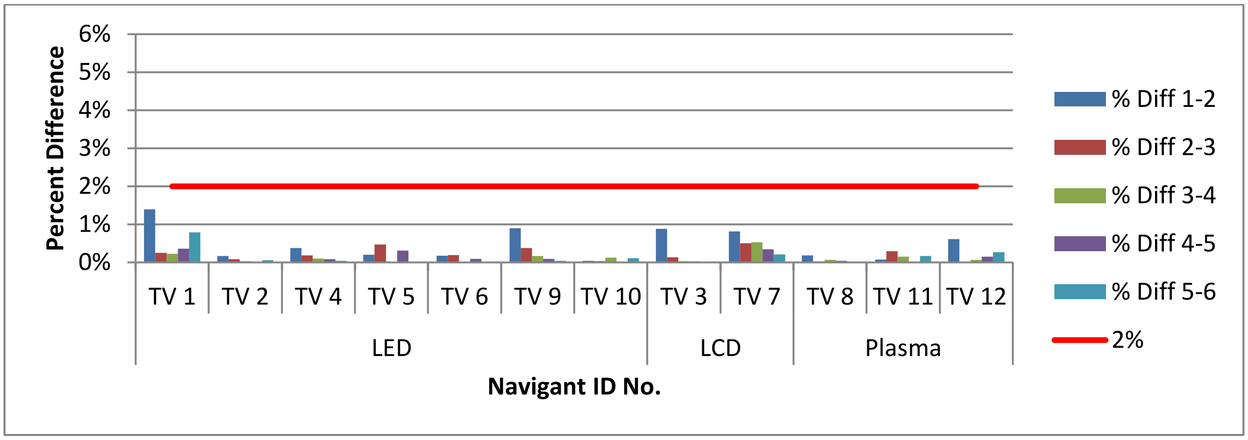

Figure 4: Stabilization Data for 2D

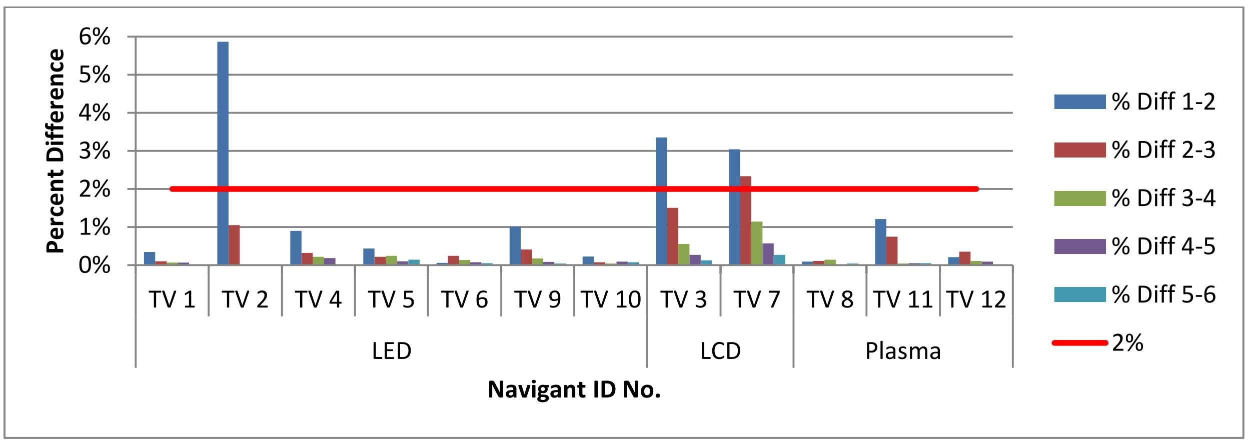

Figure 5: Stabilization Data for 3D

Two of the three TVs that required more than 20 minutes to stabilize in 3D were LCD TVs. A possible explanation for this is the increase in screen luminance in 3D for LCD TVs and is discussed further in Section 3.2.2.4. Based on these stabilization results, it was determined that 3D may take longer to stabilize compared to 2D, though 1 hour is a sufficient stabilization period for both 2D and 3D.

3.2.2. On Mode Power Consumption

Percent difference in power consumption was used as the primary comparison metric between 2D and 3D for on mode analysis. Using the percent difference allowed for the normalization of power consumption among the twelve TVs across different sizes and features. The following sections discuss the impact that TV technology variables played on power consumption between displaying 2D and 3D content. Table 9 summarizes the usage variables that were controlled for in this power consumption analysis as a result of the analysis in Section 3.1. As was previously noted, 3D on mode power consumption testing used native 3D content, which was the reason for using *Cloudy with a Chance of Meatballs* instead of the IEC DBC video signal.

Table 9: Controlled Usage Variables for On Mode

Usage Variable	Controlled Configurations	
	2D	3D
Picture Setting	Standard Picture Setting	Standard Picture Setting
Automatic Brightness Control	Disabled	Disabled
3D Signal	Native	Native
Video Content	*Cloudy with a Chance of Meatballs*	*Cloudy with a Chance of Meatballs*
Disc Format	DVD	BD
Active Shutter Glasses	N/A	Connected

3.2.2.1. Screen technology

Screen technology was one variable that was investigated as a potential cause for changes of power consumption between 2D and 3D.

Figure 6 compares results of 2D DVD content to native 3D BD content for all twelve TVs. This figure shows that ten of the twelve TVs tested increased in power consumption when displaying 3D content as compared to 2D, but the range of the percent difference in power consumption was broad, spanning from a decrease of 18.8% to an increase of 72.2%.

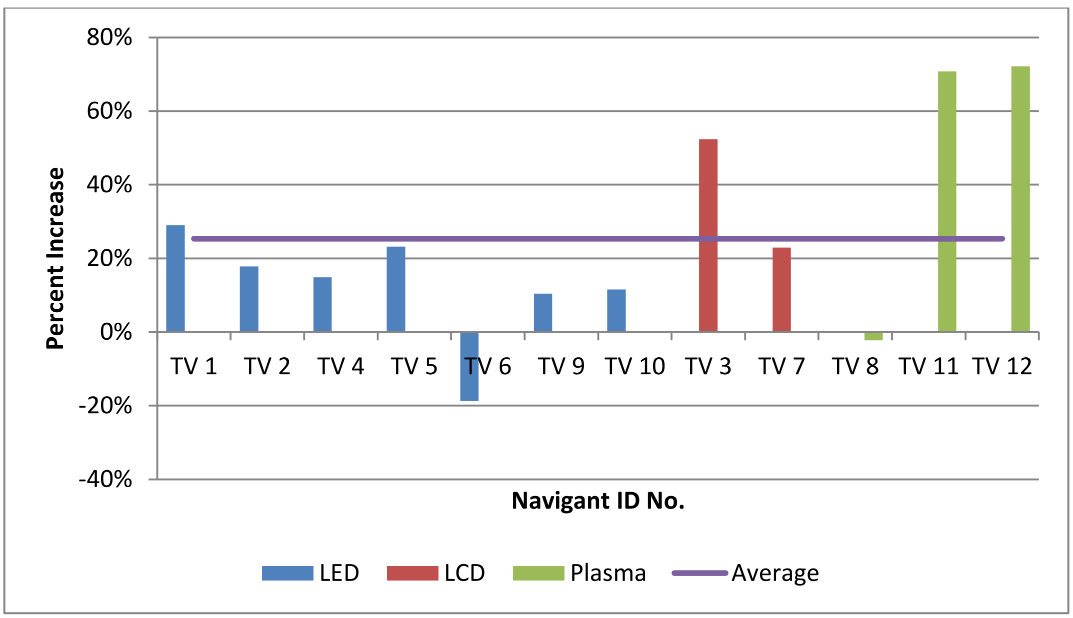

Figure 6: Percent Difference in Power Consumption from 2D to 3D, Separated by Screen Technology

Figure 6 also suggests that there may be a connection between screen technology and increase in power consumption between 2D and 3D. This was further investigated by our analysis in Figure 7 which shows the average increase in power consumption among LED, LCD, and plasma screen technologies.

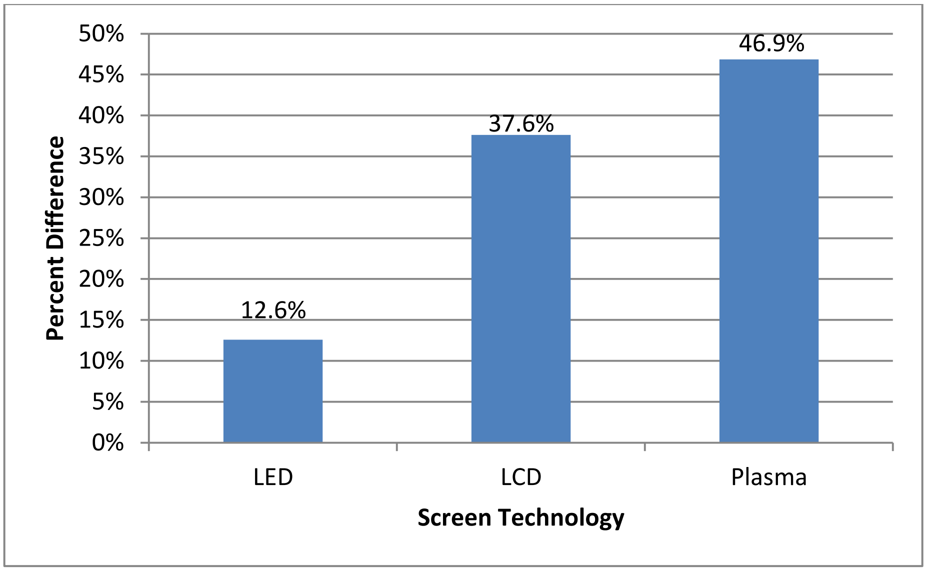

Figure 7: Percent Difference in Power Consumption from 2D to 3D versus Screen Technology

LCD and plasma TVs resulted in greater increases in power consumption in 3D than in 2D overall compared to LED TVs which exhibited a relatively small increase. The role of screen technology in affecting 3D power consumption is further supported by regression analysis in Section 3.2.2.3.

3.2.2.2. Active versus passive 3D technology

Another variable which was evaluated in relation to power consumption was 3D technology. These effects were not evaluated in the previous studies by CNET and DOE, so the effects on power consumption were unknown for active and passive 3D technologies. Figure 8 compares the average percent difference in power consumption for the seven active 3D TVs, five passive 3D TVs, and the entire sample set.

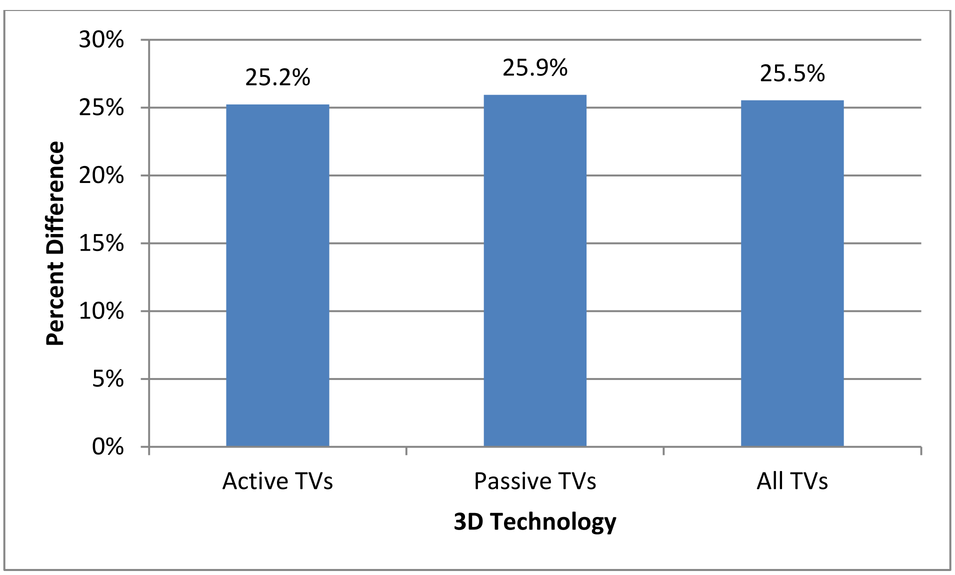

Figure 8: Percent Difference in Power Consumption from 2D and 3D versus 3D Technology

The results show a difference of about one percentage point between active and passive 3D in terms of percent difference in power consumption from 2D to 3D and both technologies have roughly the same average increase in power consumption as the total sample set average. This indicates that there is no significant difference between passive and active 3D TV power use.

3.2.2.3. Regression analysis

The regression model analyzes 3D TV power consumption trends from the collected data and extrapolates the results based on TV screen technology to TV sizes which were not tested. This analysis provided insight into these relationships and how they can relate to the overall market of 3D TVs.

Screen size, screen technology and 3D technology were the original variables identified as potentially affecting 3D TV power consumption, but when they were evaluated over the entire sample of 3D TVs, no correlations were found between screen size and the percent difference in power consumption from 2D to 3D. When the TV sample set was then separated by screen technology, correlations between screen size and screen technology began to take shape. As a result, the regression analysis was divided by screen technology to highlight these trends.

The initial results from Section 3.2.2.2 indicated that there was no correlation between 3D technology and power consumption, and this was later confirmed by the regression model for 3D technology. 3D technology was therefore removed from the final regression model to focus on the effects of screen size and screen technology.

Figure 9 shows the resulting regression model for the predicted percent difference in power consumption between 2D and 3D. The plotted data points represent measured values for each TV, and can be seen with their corresponding trend line by screen technology. The trend lines for each screen technology only cover a portion of the chart area because they are plotted with respect to the range of screen sizes of the units tested in this investigation. The trend lines are not linear because the regression model was generated using screen area, which when converted back to screen size created slight quadratic curves.
Table 10 shows the statistics for this regression model, including the overall R squared value.

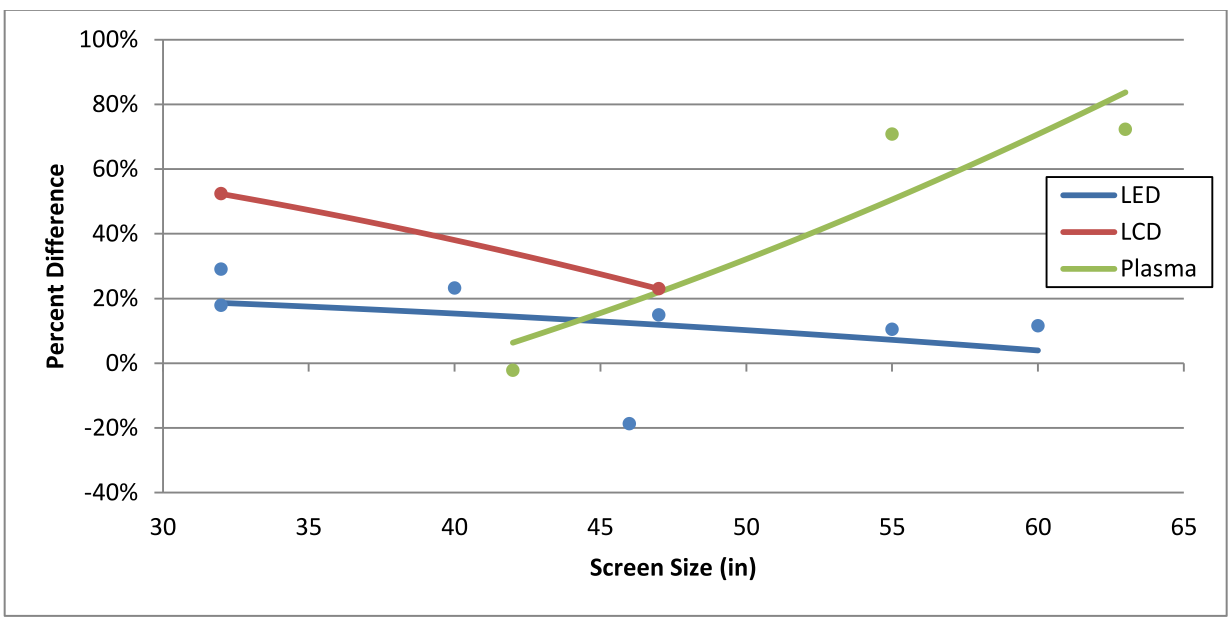

Figure 9: Regression Model - Percent Difference in Power Consumption from 2D to 3D versus Screen Size and Technology

Table 10: Overall Regression Statistics[13]

R Square	0.7793
Adjusted R	0.5954
Standard Error	0.1746
Observations	12

The results from the regression analysis show that screen size has some correlation to the power consumption by screen technology. However, it should be noted that LCD and Plasma have fewer data points than LED TVs, and thus the LED TV trend may be more representative of the market.

As shown in Figure 9, the three screen technologies exhibited distinct differences in the correlations. While LED and LCD TVs exhibited a negative correlation between size and percent difference in power consumption from 2D to 3D, plasma TVs had a steep positive correlation. These differences in trend relationships made it necessary to separate the TVs by screen technologies. It was concluded from this analysis that screen technology was the most significant variable affecting power consumption.

3.2.2.4. Luminance

Luminance measurements were performed on all twelve TVs in both 2D and 3D to assess changes in luminance against changes in power consumption. Luminance has a direct link between the increase in screen brightness and the increase in power consumption as it requires more power to increase a backlight, so it was also investigated as a potential cause for changes in total power consumption between 2D and 3D content.

Figure 10 shows the percent difference in luminance of the standard picture setting from 2D to 3D versus the percent difference in power consumption.

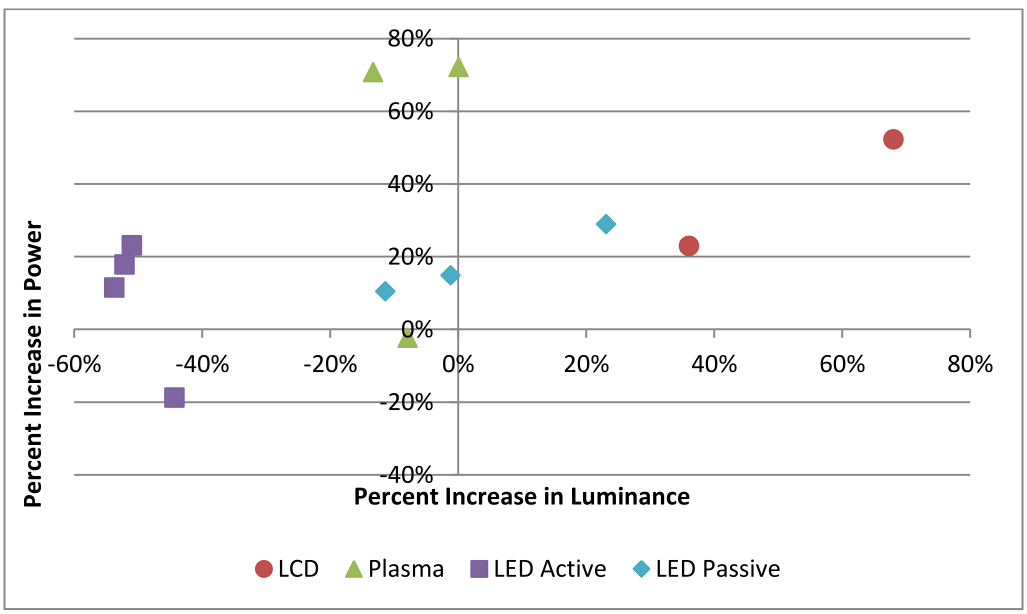

Figure 10: Percent Difference in Power Consumption versus Luminance from 2D to 3D

The results show that many TVs actually decreased in luminance between 2D and 3D while power consumption increased for most TVs. There is no clear correlation between change in luminance and change in general. A brighter or dimmer

[13] The overall regression statistics are based on the product of the of the regression models for the three screen technologies.

screen in itself may require more or less power to illuminate, but the data shows that there are other variables involved in displaying 3D that are more significant than changes in screen luminance.

However, different screen and 3D technologies seemed to have an impact on change in luminance in 3D. To investigate this, the effect of screen and 3D technologies on change in luminance between 2D and 3D was highlighted in Figure 10. This division along screen technology identified a potential trend and is further explored with Figure 11.

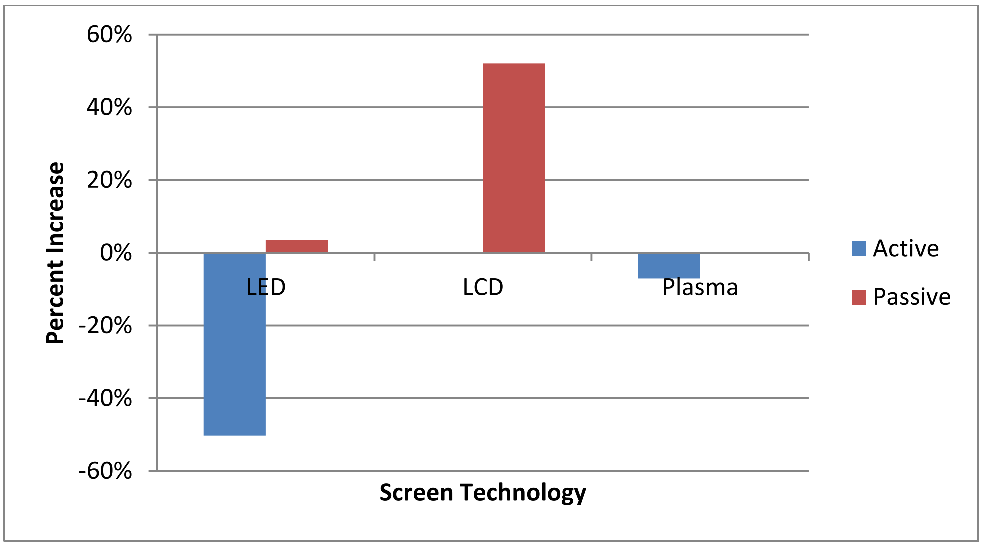

Figure 11: Percent Difference in Luminance from 2D to 3D versus Screen and 3D Technology

This analysis highlights that one of the key differences between the screen technologies is how they treat luminance between 2D and 3D. LCD screens had a consistently higher luminance in 3D than 2D, and similarly a higher power. In addition, both of these LCD TVs exhibited longer stabilization times in 3D than 2D as discussed in Section 3.2.1. This could be linked to the increase in luminance seen with these TVs.

Meanwhile, plasma screens did not exhibit much change in luminance between 2D and 3D, which could be explained by plasma screens having a higher contrast ratio. They therefore they do not need to have a high luminance to appear bright to the consumer.

Several LED screens exhibited a decrease in luminance between 2D and 3D. Figure 11 shows a split between active and passive LED TVs in luminance increase, with active TVs having a much steeper decrease in luminance from 2D to 3D than passive TVs. The low luminance in active TVs could potentially be explained by a strategy to decrease 3D crosstalk between the left and right eyes by introducing a black frame between every image frame. This would decrease the luminance of active 3D TVs as the black image would be factored into the luminance measurement.

It was concluded that luminance and TV power consumption do not have a clear correlation between 2D and 3D, though changes in luminance could be one of many factors affecting power consumption changes. In addition, screen technology is a key factor affecting luminance values and the change in luminance between 2D and 3D. This supports the results of the regression model in Section 3.2.2.3 that indicate screen technology is the most significant factor behind power consumption differences between 3D TVs.

3.2.3. Standby-passive Power Consumption

The final power consumption test was performed in standby-passive mode because it is possible that some features or functionality of 3D on mode could still be active in standby-passive mode, requiring additional power. One such feature was active shutter glasses on TVs with active 3D.

Figure 12 summarizes the results of all TVs tested in standby-passive mode as well as the six active 3D TVs tested with 3D glasses.

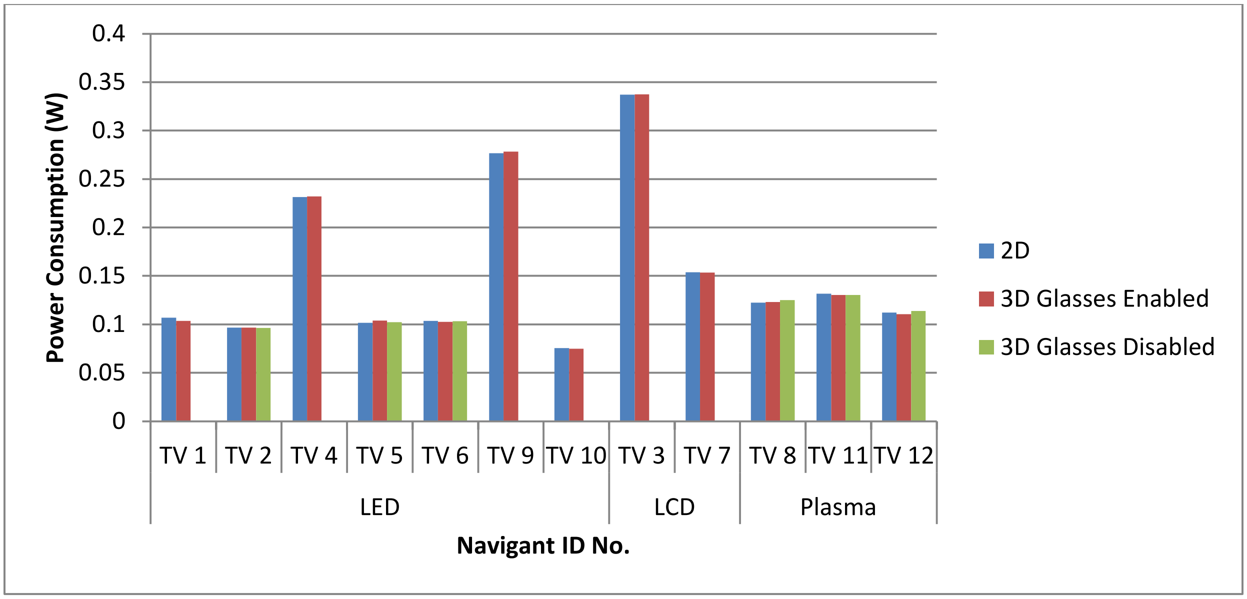

Figure 12: Standby-Passive Power Consumption in 2D, 3D, and 3D with Glasses Disabled

The results from this testing showed that the maximum difference in power between 2D and 3D was 3.4 milliwatts, with a similar difference seen between glasses enabled and disabled. It was concluded that content played previous to entering standby-passive mode does not affect the standby-passive power consumption. In addition, the presence of active 3D glasses had no effect on TV power consumption.

4. Conclusions and Future Research

For this research, it was determined that TV picture setting was the usage variable that had the greatest impact on the percent difference in power consumption between 2D and 3D. It was also determined that usage variables such as ABC, content format, and 3D signal type have an impact on power consumption and needed to be controlled to produce consistent comparisons and analysis. After controlling for these variables, it was found that the percent difference in TV power consumption in 3D compared to 2D ranged from a decrease of 19% to an increase of 72%, and ten out of twelve TVs tested exhibited an increase in power consumption. Additionally, the increase in power was widely dependent on the screen size and screen technology of the TV and the 3D technology, although active and passive 3D technologies had little impact on the difference in power consumption from 2D to 3D.

The CEA working group had speculated that a cause of increased power in 3D could be a brighter screen to compensate for the dimming effect of 3D glasses. This research found that while a brighter screen may require more power, there were other factors involved in 3D content display that outweighed this effect, such as 3D signal processing or a faster frame rate. We found that some TVs had a lower luminance in 3D than 2D but would still increase in power or stay the same.

While there are currently no standard test procedures for measuring 3D TV power consumption, existing industry procedures for 2D TVs can serve as guidelines in 3D research. The analysis into usage variables identified areas where 3D testing may require further specification compared to a 2D test procedure. These areas of specification included test clip content, format, and conversion because there is no standard 3D test clip. However, this research showed that the 1-hour stabilization time specified in 2D test procedures is sufficient.

Additionally, the effect of 3D on an AEC metric would be highly variable between TVs and technologies, as there was no universal 3D power consumption characteristic. More data regarding the market share of different TV technologies and screen sizes would therefore be required to make a generalization to this point. Even with more market data, the 3D usage profiles would need to be carefully examined to determine an appropriate hourly representation for 3D in an AEC metric.

While market data is one area to expand upon this research, individual TV technologies could also be investigated. This research highlighted many trends that can be further explored by testing a higher quantity of only active or passive 3D LED TVs or plasma TVs. In addition, the market trends of TVs should also be considered as it appears that LED TVs are becoming more prevalent while plasma and LCD TVs are slowly phasing out. Additional testing should also be performed with the advent of new 3D and screen technologies such as glasses-free 3D and organic light-emitting diode (OLED) TVs. As the viewership and market of 3D changes, so will the need for characterization of 3D TVs.

Appendix A: On Mode Power Consumption Data

Table 11: Appendix A - TV Power Consumption Data in Watts

		2D	2D to 3D Conversion	Native 3D	Native 3D Glasses Disabled
		DVD		BD	
TV 1	Standard Picture Setting	40.97	53.90	52.84	n/a
	Default Configuration	40.97	53.90	52.84	n/a
TV 2	Standard Picture Setting	50.72	58.56	59.76	59.74
	Default Configuration	50.69	58.56	59.76	59.74
TV 3	Standard Picture Setting	71.84	110.68	109.42	n/a
	Default Configuration	71.84	110.68	109.42	n/a
TV 4	Standard Picture Setting	60.56	69.92	69.56	n/a
	Default Configuration	X	X	X	n/a
TV 5	Standard Picture Setting	112.52	140.13	138.60	138.53
	Default Configuration	113.81	140.13	138.60	138.53
TV 6	Standard Picture Setting	77.77	62.77	63.18	
	Default Configuration	77.77	62.77	52.59	52.59
TV 7	Standard Picture Setting	146.67	182.44	180.35	n/a
	Default Configuration	146.67	182.44	180.35	n/a
TV 8	Standard Picture Setting	154.61	160.77	151.08	
	Default Configuration	X	175.90	165.00	165.06
TV 9	Standard Picture Setting	88.95	-	-	n/a
	Default Configuration	88.95	88.03	98.24	n/a

TV 10	Standard Picture Setting	67.48	75.86	75.25	n/a
	Default Configuration	67.48	75.86	75.25	n/a
TV 11	Standard Picture Setting	114.67	195.90	195.77	
	Default Configuration	114.67	237.64	238.55	239.25
TV 12	Standard Picture Setting	212.85	367.23	366.48	367.17
	Default Configuration	243.19	367.23	366.48	367.17

"n/a": Test not applicable
"X": ABC enabled in default picture setting
"-": Picture setting not available

Appendix B: Standby-Passive Mode Power Consumption Data

Table 12: Appendix B - Standby Passive Mode Power Consumption Data in Watts

	2D	3D	3D (Glasses Disconnected)
TV 1	0.107	0.103	-
TV 2	0.097	0.097	0.096
TV 3	0.337	0.337	-
TV 4	0.231	0.232	-
TV 5	0.102	0.104	0.102
TV 6	0.104	0.103	0.103
TV 7	0.154	0.153	-
TV 8	0.123	0.123	0.125
TV 9	0.276	0.278	-
TV 10	0.075	0.075	-
TV 11	0.132	0.130	0.130
TV 12	0.112	0.110	0.114

“-“: TV with passive 3D or not tested with glasses

Appendix C: Luminance Data

Table 13: Appendix C - TV Luminance Data in Nits

	2D On mode	3D On mode	Difference, 2D to 3D	Percent Difference, 2D to 3D
TV 1	188	231.5	43.5	23.14%
TV 2	253.1	121.1	-132	-52.15%
TV 3	144	242	98	68.06%
TV 4	186.8	184.6	-2.2	-1.18%
TV 5	259.8	127.3	-132.5	-51.00%
TV 6	258.1	143.7	-114.4	-44.32%
TV 7	281.7	383.3	101.6	36.07%
TV 8	94.42	86.97	-7.45	-7.89%
TV 9	135.2	119.8	-15.4	-11.39%
TV 10	235.3	108.8	-126.5	-53.76%
TV 11	66.03	57.25	-8.78	-13.30%
TV 12	80.53	80.58	0.05	0.06%