Tier 2 Advanced Power Strip Evaluation for Energy Saving Incentive

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Glossary

- **Active Mode**: The media device is turned on with primary functions ;

  - **User Engaged:** The user is actively engaged with the appliance (pressing buttons on the remote control);

  - **User Absent:** The user is not engaged with the appliance (Users are not actively interacting with the device, such as pressing buttons on a remote control);

- **Standby Mode:** The appliance is waiting to be switched to Active Mode with no primary functions;

- **Off Mode:** The appliance is turned off but remains plugged into the outlet;

- **P_Appliance X_Mode Y**: The power consumption of the appliance X in mode Y.

- **In-Situ Environment**: In-house data collection environment with least intrusion to user's daily activity.

CalPlug/Calit2 Introduction

The California Plug Load Research Center (CalPlug) was established to improve energy efficiency in the use and design of appliances and consumer electronic devices. The Center is primarily funded by the California Energy Commission to undertake research in energy efficiency solutions, efficiency evaluations of consumer electronics, standards development, education and public outreach, and user behavior studies.

As a core part of our research, CalPlug has focused its efforts on addressing the challenges in plug load efficiency for both residential and commercial buildings by collaborating closely with utilities, manufacturers, advocacy groups, research institutions, and energy policy makers.

A significant challenge in curtailing the plug load energy usage is in the area of evaluation and performance validation of emerging technologies designed to address plug load inefficiency. This work paper will focus on the emerging technology category of Advanced Plug Load Management Devices (APMD's) also referred to as Tier 2 Advanced Power Strips (Tier 2 APS).

Specifically the focus of this report is to develop and demonstrate our standardized Tier 2 APS device evaluation methodology in calculating deemed savings of individual Tier 2 APS devices.

This standardized performance validation methodology will help promote market adoption and further investment in this technology category by incentivizing manufacturers to develop smarter technologies, increasing energy saving performance and user friendliness.

This robust field test methodology enables validation of the energy saving potential (as a percentage of total energy used) of individual Tier 2 APS devices. By collecting in situ device functionality data and using it in conjunction with 3rd party AV/PC energy usage data (by region), we are able to determine the annual kWh saved by region for each device tested.

CalPlug conducted an analysis of all Tier 2 APS devices available in the market in an effort to formulate a robust and repeatable Tier 2 APS device assessment process. During this investigation CalPlug attained independently gathered field trial data on individual Tier 2 APS devices to test and validate our device assessment process. We hope CalPlug's efforts in formulating a field test process and deemed saving calculation methodology will facilitate widespread industry adoption of this innovative technology category.

Chapter 1: Executive Summary

1.1 Background

Also known as "vampire" power, leaking electricity or phantom load, standby power is wasted electrical energy consumed while appliances are switched off (to standby or off mode) but are still plugged in to the main power outlet. These appliances range from televisions, home entertainment systems, personal computers and their peripherals, to space heaters, room air-conditioners and coffee pots – all of which continue to draw power even when they are turned off.

Advanced power strips are energy-saving devices which control when power is supplied to the devices connected to it. Advanced power strips can automatically eliminate standby power loads of electronic peripheral devices that are not needed (DVD player, computer printer, scanner, etc.) either automatically or when an electronic control device (typically a television or personal computer) is in standby or off mode.

1.2 CalPlug Tier 2 APS Research

The scope of this research is to formulate data collection and energy saving evaluation processes for Tier 2 Advanced Power Strip (APS) to ascertain their potential market value.

Preliminary (SIM Lab) testing at CalPlug was conducted to provide a top level understanding of Tier 2 APS device functionality and their field testing challenges.

Independent field trial data on a market leading Tier 2 AV APS device was collected with minimum intrusion to user's daily activity and recorded without any status change of user's appliances. This field trial data comprised of over 120 million unbiased measurement data points enabling a detailed energy saving performance evaluation of the Tier 2 APS device tested. A detailed field trial methodology to accurately determine the energy saving performance of individual Tier 2 APS products was derived and validated from this study.

This field testing methodology enables the removal of large variations commonly associated with traditional pre/post metering and significantly lessens the limitations in a typical laboratory test environment, leading to a greater confidence in energy saving reporting and a true representation of APS device performance.

Assessment of energy savings and user functionality of Tier 2 APS performance depends on the ability in capturing the following key information:
- Connected equipment devices and their combined power (Watts) loads
- Connected equipment usage characteristics by end users in their own living environments
- Average total energy consumption in each in-situ environment
- Responsiveness of Tier 2 APS to spurious (non-consumer electronic) Infra-Red (IR) activity in the home such as sunlight and compact fluorescent light-bulbs (CFL's)
- Cumulative energy used and saved metered in each in-situ environment

CalPlug undertook a detailed analysis of the field test data to assess the effectiveness of the Tier 2 APS device in managing energy use in the home entertainment and commercial IT environments.

To further corroborate the findings from this analysis, the following two lab tests were also conducted:

- SIM Lab Living Room Tests – Tested the energy savings from the four most common home entertainment configurations room attached to a Tier 2 APS in an average American household living.
- SIM Lab Usage Tests – Tested usage patterns including the user engaged hours and absent hours.

Although there are limitations with a laboratory testing methodology when simulating real household or office environments, the SIM lab tests mimic a real life case in using the tier 2 APS. The initial laboratory assessment was a useful method to corroborate the field trial performance data on the Tier 2 APS device and assisted in validating and creating an effective field testing methodology for individual Tier 2 APS devices used to determine deemed savings of individual APS devices.

1.3 Summary

CalPlug's analysis of the independent field trial data of a Tier 2 APS device found that, on average in residential AV environments (American family room), an annual energy saving of between 48% and 53% of total family room energy consumption was consistently achieved by the field tested Tier 2 APS across each field trial (20-24 samples/households per trial – over 100 households total) conducted on this device. Applying this performance metric against a number of independent US studies on total annual AV environment energy consumption delivers an average energy saving of 346 kWh per annum, with a lower and upper range of 306 kWh - 385 kWh respectively as outlined in section 4.2 and Table 4.1 [17].

As the percentage of energy saved via a Tier 2 APS is a factor of each individual devices functionality and feature sets, the CalPlug field trial methodology was designed to capture the detailed performance and decision points of the Tier 2 APS device in question for comprehensive post trial analysis to arrive at this energy saving range.

This deemed saving value was reached through detailed field trial evaluation of the Tier 2 AV APS device by using the calculation approach outlined as follows:

Using independently acquired field trial data [17], the average percentage (%) of simulated total energy saved in the field trial environments is attained. This data in conjunction with additional third party data on total energy consumption trends in US household electronic environments facilitates a calculation methodology that can be applied to multiple regional jurisdictions.

This calculation approach enables the effectiveness of individual Tier 2 APS devices to be determined by state/region in a cost effective manner. Tier 2 APS field trials in each state/region are not required but simply data on total AV or IT annual kWh consumption. A graphical illustration of this approach is detailed in Figure 1.1.

Figure 1.1: Field Trial Data Assessment & Utilization
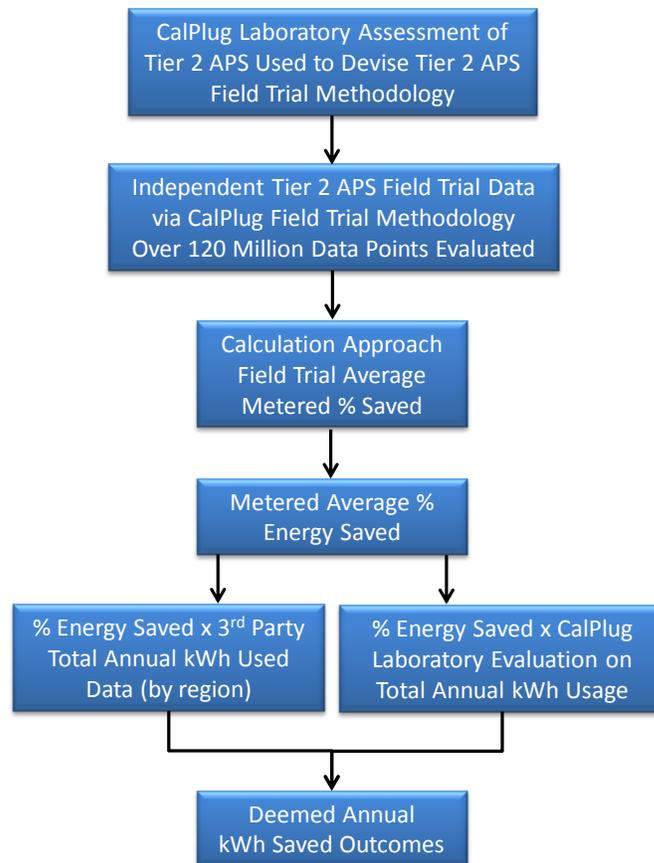
1.3.1 Average Percentage (%) of Energy Saved – Deemed Saving Calculation

The independent field trials conducted on the Tier 2 AV and PC APS device collected over 120 million data points which were made available to CalPlug for analysis. CalPlug evaluated the performance characteristics of the field tested Tier 2 APS device to verify its energy saving potential in addition to providing insight and verification as to the devices functionality and suitability for their targeted AV and PC environments [17].

The in-situ independent trials covered a variety of usage environments with variation in connected equipment and usage patterns. This was done in order to capture and determine the range of energy savings available through the use of this Tier 2 APS device. The trials targeted low, medium and high device users in both household and commercial environments in order to assess the variability in the level of energy saved as a percentage (%) of total energy used in each user category.

The Tier 2 AV APS device tested demonstrated an average annual field trial energy saved percentage which consistently tracked between 48%-53% [17] with an average of 51% across a mix of low, medium and high device penetration and user levels, capturing the entire user range.

This average energy saved percentage provided a useful basis to assess the performance of this Tier 2 APS device in any targeted region. By applying the demonstrated average percentage of energy saved against the average annual total energy (kWh) consumed for each target region, the potential annual average energy saving (in kWh) can be ascertained.

Independent research (NYSERDA [1], CEC [2], Fraunhofer [16]) has shown that average household AV environment energy usage is between 638-726 kWh per year. Applying this average annual energy consumption figure against the demonstrated average percentage (%) of energy saved across all field trials conducted on this Tier 2 device supports an average expected energy savings figure of between 325 and 370 kWh annually.

The data logged throughout these trials also enabled a thorough evaluation of the functionality of the Tier 2 AV APS device. This was useful to verify the intelligence of the device in deciphering various data inputs to determine the state of the connected equipment and when to isolate power to connected devices at the appropriate time to deliver energy savings.

1.3.2 Market Value Considerations

Using the market value formula, which is Δ **= $ Deemed Savings – ($ Upfront Cost + $ De-Installation Cost)**, the impact of savings will be easily determined. Tier 2 APS devices which are easy to setup, address the variety of changeable conditions in households (such as infra-red interference and significant power variation in each installed environment) will lead to greater retention rates, prolonged usage and therefore improved market value.

Deemed savings will also be driven by the functional attributes of individual Tier 2 APS devices. As infra-red (IR) is a particular performance driver in terms of savings it is also a challenge in terms of managing spurious IR from non AV equipment. In situ data gathering and analysis of individual Tier 2 APS devices using CalPlug's field trial methodology in addition to the technical analysis of Tier 2 APS devices is essential to enable verification as to the long term effectiveness of the Tier 2 APS device to adjust to key variables within a variety of targeted environments.

An analysis of this Tier 2 APS product, its features and CalPlug's assessment of their associated key benefits is outlined within this report (Table 7.3 and Table 7.4) and should be considered when undertaking a market value consideration of any Tier 2 APS device.

Chapter 2: Tier 2 APS Assessment Overview

2.1 Understanding Equipment Loads

Standby Power: Entertainment electronics make up 60% of all plug load consumption by home electronics while home office electronics make up 31% of all plug load consumption by home electronics [2].

The plug loads for household electronics in the United States account for almost 20% of all residential energy and that percentage is anticipated to increase as households purchase more electronics [2].

Standby loads can be eliminated if the user unplugs the device or turns the device's power source off when the device is not in use. However, users typically leave electronic devices plugged into power sources (walls or power strips) and seldom unplug their devices or turn the power off largely due to habit or poor access to wall outlets. Households that do not turn off their power strips consume more power due to standby power usage than households that do turn off their power strips. Average annual AV energy consumption in US households is between 638 and 726 kWh [1] [2] [16].

Preliminary field trial analysis on commercial energy usage in IT environments also highlights an opportunity to deliver significant energy savings for businesses who utilize Tier 2 IT APS devices.

2.2 Advanced Power Strip (APS)

There are a wide range of APS devices on the market, which has built-in intelligence to save energy, and hence the definitions are still evolving. The Northeast Energy Efficiency Partnerships (NEEP) has defined two levels of APS as Tier 1 and Tier 2 (NEEP 2011).

2.2.1 Tier 1 APS

A Tier 1 APS utilizes current sensing and a simple master / controlled configuration to sense when a TV is switched on and to then switch peripherals on, and to sense when the TV is switched off and to switch the peripherals off.

Outlets – a total of 7 outlets: 1 control / master, 2 always-on and 4 controlled.

Table 2.1: Estimated Power Consumption and Savings from using a Tier 1 APS, Typical Household

Total Annual Entertainment Energy Consumption per Household (kWh)	**602.8**
Total Annual IT Energy Consumption per Household (kWh)	**197.9**
Total Annual Consumer Electronics Energy Consumption per Household (kWh)	**800.8**
Total Annual Entertainment Change in Consumption with APS (Energy Savings in kWh)	**75.1**
Total Annual IT Change in Consumption with APS (Energy Savings in kWh)	**31.0**
Total Annual Change in Consumption with APS (Energy Savings in kWh)	**106.1**
Total Dollar Savings per Household over the Average Life of the APS	**$78.81**

The savings for this measure are typically 75.1 kWh for home entertainment systems and 31 kWh for home office systems. (NYSERDA 2011) [1].

2.2.2 Current development of the APS product category (Tier 2 APS)

The device function definitions used in past projects by EnergyConsult and EPRI, group the APS into the following technology category types:

- Single switched or remote switched power boards – where the user is required to turn off a central switch, that in turn disconnects the power to several devices
- Master/controlled – where a master device is detected to off (usually by current (a.k.a. Load) sensing) and the APS disconnects power to other controlled devices
- Infrared signal pairing – similar to the switched power boards, however the infrared signal of the master device (such as a TV) is detected and when powered off, the APS disconnects power to other devices
- Power and IR signal sensing – a combined method to dynamically and intelligently control the connected devices.

The main differentiation of Tier 2 APS, relative to Tier 1 APS, is effectively their ability to reliably capture user absent hours in addition to the energy savings which would be attained from a Tier 1 APS device.

Power (not current) and IR signal sensing APS are considered to be the more common and user friendly Tier 2 APS devices as they utilize a range of advanced sensing technologies to control an AV environment and work with all IT environments (desktop and laptop compatible).

Tier 2 APS device intelligence can range from:

- Limited current & IR sensing using a master/controlled configuration to determine when a TV is switched on or off and detect when there is an absence of user interaction to then switch peripherals on and off, to;

- More intelligent devices utilizing a master-less arrangement to further promote ease of use in addition to sensing real time power (by sensing current and voltage in real time) to determine the true power consumption (also known as true RMS power) of the connected equipment.

As the current being consumed by electronics will vary depending on the voltage from the mains power outlet; true RMS power sensing (which monitors both mains voltage and current in real time to determine and log the actual power consumption of connected equipment) is a more accurate and reliable way to determine equipment modes and usage states. Understanding these equipment modes and usage states is critical to determining when to supply or remove power to connected devices at the appropriate time.

In addition, more advanced Tier 2 APS products adjust for IR (infra-red) interference associated with sunlight and compact fluorescent light bulbs (CFL's) commonly found in households. The adjustment can be achieved through a raft of hardware and firmware filters. This feature avoids nuisance switching of connected devices used with IR sensing Tier 2 APS to ensure customer satisfaction, prolonged installation and energy savings.

As with all consumer electronic product categories, Tier 2 APS products are also evolving to deliver greater levels of user convenience, energy efficiency and information to the end user. CalPlug has recognized this and the need to understand and recognize these product features from both an energy efficiency and user convenience perspective; doing so will ensure continual market development to drive energy savings and consumer satisfaction.

Chapter 3: CalPlug SIM Lab Living Room Tests

3.1 Introduction

In order to determine the key information that would be required to be attained from field trials on Tier 2 APS devices, CalPlug conducted a simulated consumer behavior study for thirteen days involving a total of twenty undergraduate and graduate students.

This preliminary analysis was to assist in understanding the key variables in user behavior which affect the average period of inactivity during television viewing. This information assisted in determining the most appropriate way to field test Tier 2 APS devices and determine the individual energy saving potential of a Tier 2 APS device.

In order to obtain a preliminary assessment of the television viewing environment of an average American household, the test was conducted for two hours in CalPlug SIM lab's living room; set up during the American public's two most active television watching time periods: daytime from 12:00pm to 2:00pm and primetime from 8:00pm to 10:00pm. All participants were told that they would be participating in a consumer behavior study where they would watch television for two hours and were invited to bring and use phones, laptops, tablets, or anything else they usually use while watching television at their homes.

Figure 3.1: SIM Lab Living Room Setup

3.2 Methods

To acquire data indicating participants' engaged viewing time, a control board, (containing a microcontroller programmed with LabView), monitored when the participant clicked a button on the remote control; at which time the microcontroller obtained data through an Infra-red (IR) sensor.

The program recorded each participant's "number of clicks" and automatically stored the data in an Excel spreadsheet which was used for further analysis. The test was focused on recording actual user behavior without implementing the APS. Thus the functional performance of the Tier 2 APS+ device in the lab test environment was not determined via this laboratory assessment.

The Microcontroller in the circuit is the Arduino Uno Board; it collects the data from the experiment using Labview, which then records the data accordingly on a spreadsheet in real time.

Each participant's largest period of inactivity during television viewing was determined by his or her largest interval between two consecutive clicks over the period of the activity (2 hours).

Table 3.1: Pay-TV Viewing by Day-Part [11]

	6AM – 10AM	10AM – 12PM	12PM – 2PM	2PM – 4PM	4PM – 6PM	6PM – 8PM	8PM – 11PM	11PM – 1AM	1AM – 6AM
Typical TV-Watching Time	Morning	Daytime (10AM-4.30PM)			Early Fringe (4:30-7:30)		Prime Time (8-11PM)	Late Night	Overnight
358min/day	6.70%	22.60%			14.60%		27.70%	19.40%	9.00%
189min/day	6.30%	19.8%			14.5%		31.1%	19.70%	8.60%
125min/day	6.10%	18.3%			13.9%		32.1%	20.40%	9.20%
81min/day	6.00%	17.1%			13.1%		31.5%	21.80%	10.60%

According to the secondary research in Table 3.1, CalPlug determined the two most optimal TV viewing periods to be daytime, between 10:00AM - 4:30PM, and primetime, between 8:00PM - 11:00PM. With this information, it was decided that the tests would be conducted during daytime viewing hours between 12:00PM - 2:00 PM and primetime viewing hours between 8:00PM - 10:00PM.

Table 3.2: Distribution by Day Parts [12]

	2007	2008	2009	2010	2011
6AM-9AM	9%	9%	9%	9%	9%
Mon-Fri 10AM-4PM	17%	17%	17%	17%	17%
Sat-Sun 10AM-4PM	15%	15%	15%	16%	16%
4PM-7PM	12%	12%	12%	12%	12%
Prime Time 8PM-11PM	23%	24%	22%	22%	22%
11PM-1AM	10%	10%	10%	10%	10%
Over Night	8%	8%	8%	8%	8%
Other	6%	5%	7%	6%	6%

TV viewer's habit has not changed in the past few years as reported. By the secondary research in Table 3.2, it further confirms the most TV viewing among American audiences being from 10AM to 4PM and from 8PM to 11PM. The prime time has the highest TV viewership. With this knowledge, the test was conducted only as described earlier.

3.3 Results
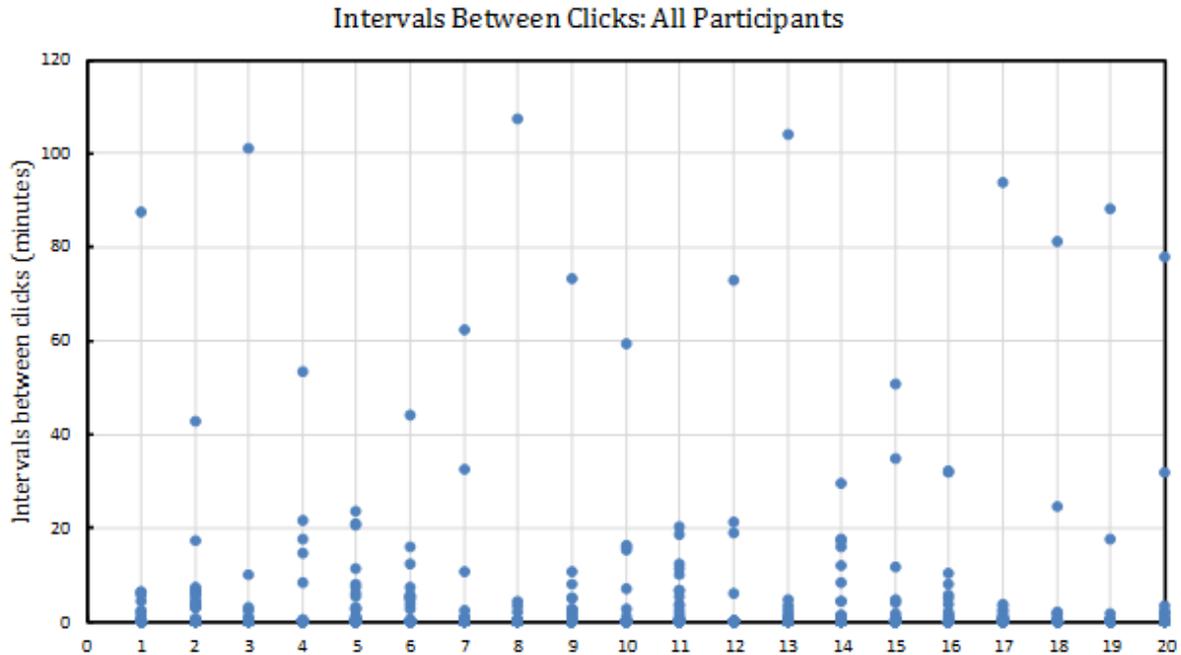
Figure 3.2: Intervals between clicks for all participants

Figure 3.2 includes all of the intervals between clicks for all participants during prime time (8 to 10 PM) and day time (12 to 2 PM) viewing hours. The results indicate that most intervals between clicks occur in the 0-10 minute range. This occurred because TV viewers frequently clicked when choosing a channel to watch or changing the volume. Since participants were asked to behave as they would do while watching TV at home, some participants had unusually large intervals. For example participant #13 fell asleep while watching television and participant #8 immediately found a channel and actively watched the program until the end of the study.

Since user's behavior can be significantly different depending on their patterns, demographics, and geographic locations, limited data points (20 points in this research) merely indicated the preliminary results of the average American TV view pattern. More detailed results will be obtained via actual field trials when more data points in actual households are captured to provide actual data on user behavior. However preliminary evaluation has shown that Tier 2 AV APS devices should be flexible for the variety of AV user types.

The average engaged hours of all the users was found through analysis of the intervals shown on the Figure 3.2.
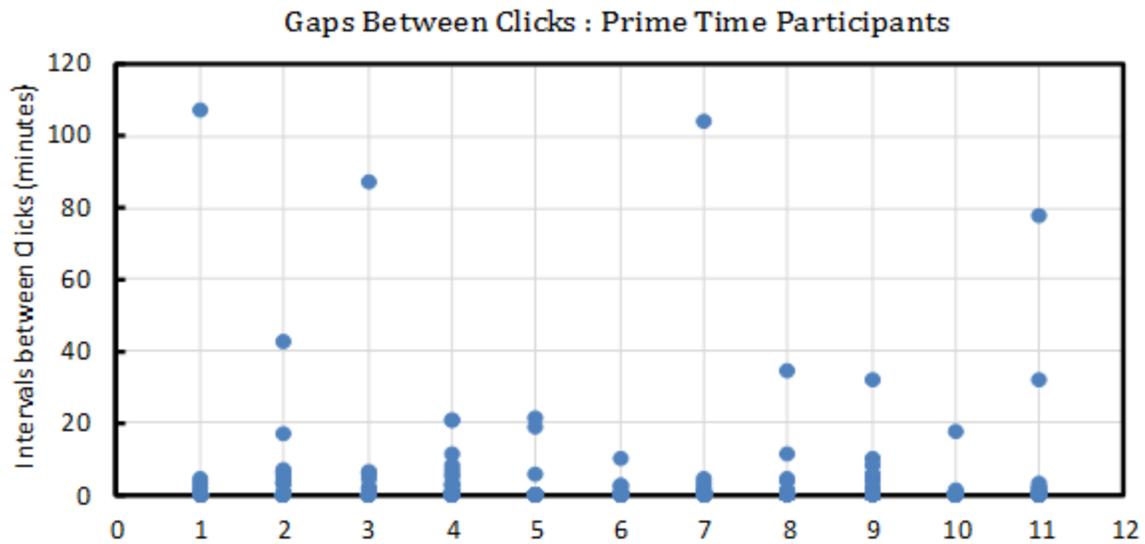
Figure 3.3: Intervals between clicks for primetime participants

Figure 3.3 shows the intervals between clicks when users watched TV during prime time viewing hours between 8:00PM to 10:00PM. Although the prime time participants were included in Figure 3.3, the participant numbers in Figure 3.3 are not equivalent to those listed in Figure 3.2 and the prime-time clicks in Figure 3.3 are only a subset of each person's other clicks in Figure 3.2.

It was found from comparing the interval between click shown in Table 3.2 and Table 3.3 that the viewers in this study group behave differently in watching TV at prime time from daytime. Thus a Tier 2 AV APS device could be designed to adapt to different user behaviors during different time periods.
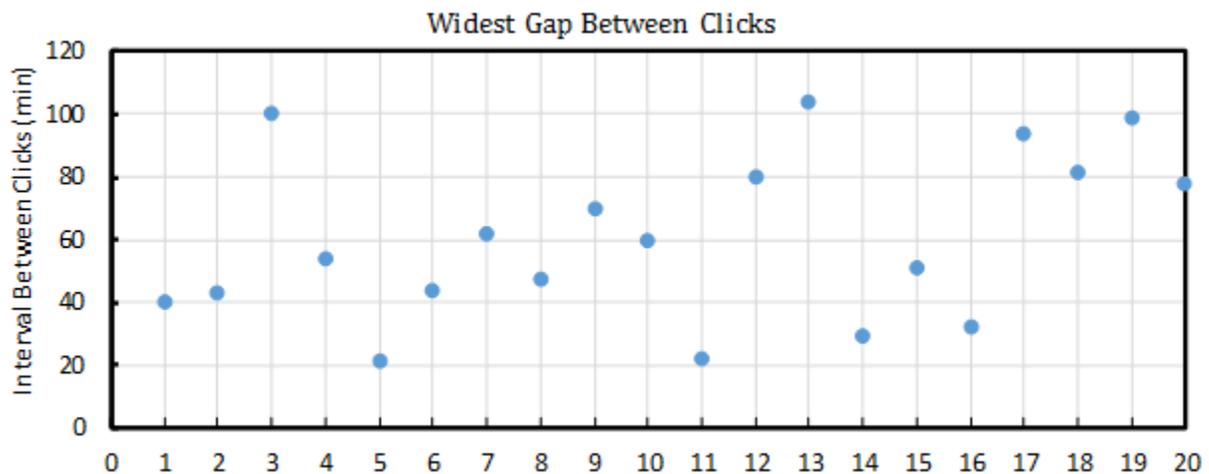
Figure 3.4: Widest gap between clicks for all participants

Figure 3.4 indicated the largest interval between clicks for all paricipants. The average largest interval can be used as a bound. If the user does not click within the average largest interval, the device can turn off the TV.
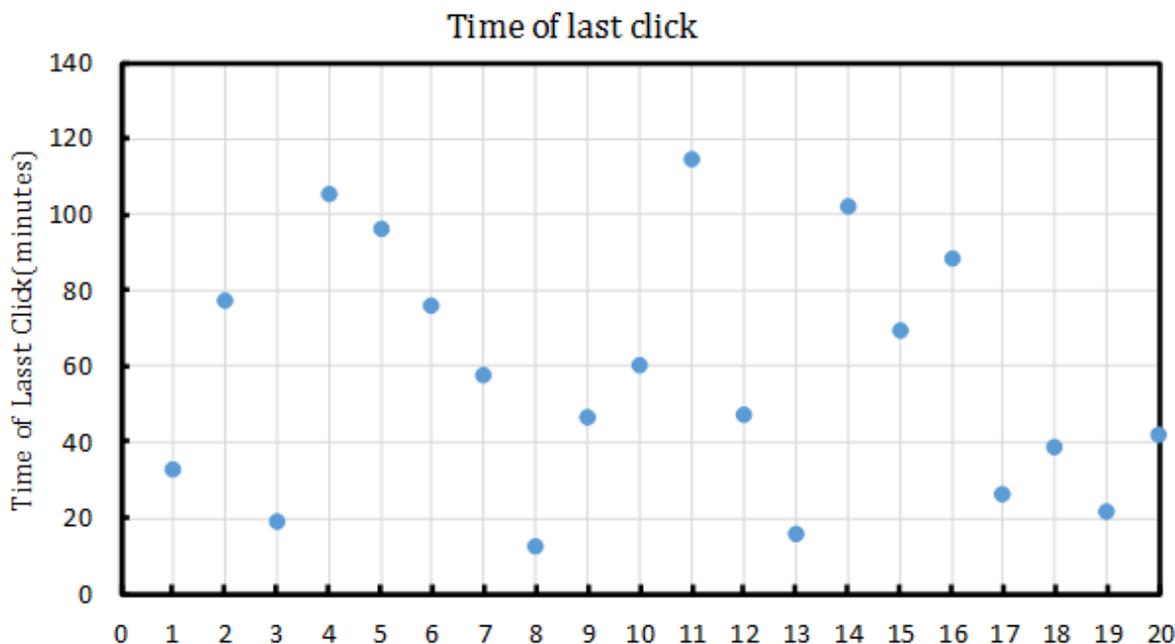
Figure 3.5: Minutes between last click and end of experiment for all participants.

The result in Figure 3.5 is a supplement for the largest interval between clicks because in certain cases the interval between our participants' last click and the end of the test (2 hour time) is larger than any interval between clicks. This graph helps us to find the accurate largest interval between clicks.

The data gathered from this consumer behavior study indicates that the average largest interval between clicks over a two hour period is 59.64 minutes and that the average time of a participant's last click is 58.27 minutes. Because of the diverse viewing habits of television viewers, it cannot be assumed that all viewers will be inactive after 59.64 minutes. In this study alone, the largest gap between clicks was 107.5 minutes.

A key learning from this laboratory simulation is that given the broad range in user interaction (via IR remote controls) with the electronic devices, having a Tier 2 AV APS device with an adjustable IR timer would likely deliver greater flexibility to the end user and remove nuisance factors for those who infrequently use their remote control. An APS device without a power down timer adjustment feature may create nuisances to some users which may lead to de-installation, reducing the market value of the product.

Simulating user interaction with AV equipment via monitoring IR activity is useful for an initial understanding of the interaction of a Tier 2 APS device in its targeted environment. In terms of determining the energy saving potential of Tier 2 APS devices, there are a number of variables in real world environments which cannot be captured in a single simulated AV environment such as that exhibited by our test laboratory; these variables include:

- Variability in the connected equipment configurations:
    - Different number and types of connected equipment will vary the power load and will influence the energy saving potential of the Tier 2 APS device
    - Laboratory environment was limited to one equipment configuration only

- Variability in the connected equipment usage patterns:
    - User interaction with their connected equipment is a key determinant for the energy savings Tier 2 APS devices can deliver
    - Laboratory environment did not simulate various device usage characteristics across a prolonged period (only 2 hour intervals) through the switching on and off of various connected devices

- Variability in number of householder occupants:
    - The number and the characteristics of occupants and users of the connected equipment at varying times of the day will alter the amount of energy that can be saved by Tier 2 APS devices
    - Laboratory test was limited to defining when one graduate/undergraduate was asked to interact with the remote control but did not actually monitor real device usage in terms of individual equipment usage trends

- Variability in interference in the target environments:
    - Tier 2 AV APS devices rely on decoding IR signals from remote controls to determine user activity. IR also stems from sunlight and CFL's which can lead to incorrect Tier 2 APS device sensing and connected equipment control
    - The laboratory test environment was only one environment which cannot replicate the significant variability in households to determine the ability for the Tier 2 APS device to deal with spurious IR
    - In addition the laboratory test environment did not monitor the Tier 2 APS device itself sensing the IR but rather the IR sensor was a third party device
    - CalPlug's field trial methodology requires the use of the IR sensor on the Tier 2 APS device itself to determine its ability to function sense and function reliably in the targeted environments

3.4 Evaluation of Tier 2 APS Devices

The most obvious benefit of Tier 2 APS (over Tier 1 APS) is through capturing User Absent Hours. A Tier 2 APS provides additional savings by automatically turning off the TV and other connected equipment during User Absent Hours via monitoring of IR activity (from the users remote control) with the IR sensor and correlating this with current or power consumption data in the environment. The User Absent Hours is defined as the time that the user is not actively engaged with the devices. On average, AV equipment is turned off "earlier" and during more energy consuming modes with Tier 2 APS devices to generate extra savings over Tier 1 APS devices.

As no Tier 2 APS device is likely to be identical to another, field trial data gathered in the approach outlined by CalPlug, provides the ability to validate the functionality and therefore the energy saving potential of various Tier 2 APS devices. Conducting field trials in actual targeted environments (households and offices) will better capture the functional attributes of the Tier 2 APS device in question and lead to a more thorough analysis of energy saving performance.

A field trial program on Tier 2 APS devices should be preceded with a thorough evaluation of the individual Tier 2 APS device features to ensure all required data points are tracked during field testing. This will ensure the appropriate data is collected to properly evaluate the functionality and performance of the Tier 2 APS device.

With actual metered field data we are able to track which devices are left "ON" and which devices are switched "OFF" by the users in real time; this was the case with the in situ field trial data collected on a Tier 2 APS device in both residential AV and commercial IT environments. This data captured actual user patterns and connected device energy consumption which was logged in real time every second to ascertain the actual energy savings that could be attributed to this device.

To further supplement in situ data on user engagement hours, CalPlug investigated secondary sources for user absence, including simultaneous consumption of media while watching TV.

After utilizing a number of data assessment and computational approaches (outlined further in this report) the average annual energy savings to be attained from the field trialed Tier 2 AV and PC APS devices are 346 and 350 kWh respectively. This represents an outstanding opportunity for large scale plug load energy savings (CalPlug 2012).

3.5 Determining Energy Savings Performance of Tier 2 APS

3.5.1 CalPlug Field Trial Methodology for Tier 2 APS

Tier 2 APS Devices are primarily designed to address both passive and active standby power in targeted AV and PC environments. Within the Tier 2 category, each device may utilize varying methods for delivering energy savings. Thus it is appropriate that these devices should be field tested in situ using a statistically appropriate methodology to determine the energy saving performance of the individual Tier 2 APS device in question.

Traditionally pre/post metering trials have been used to determine the energy saving performance of different technologies. However even slight variability in device usage patterns within the same household presents a large challenge in determining the actual energy saving performance of Tier 2 APS devices.

This variability in usage patterns from one period to the next necessitates both larger sample sizes and longer trial periods to deliver a level of confidence in the energy saving performance of the device being tested when pre/post metering is used for field trial purposes. However, a field test large enough for statistical significance would be quite expensive and creates a barrier to the feasibility of the field test.

Given these challenges, below is an outline of the key field trial execution requirements assessing Tier 2 APS devices:

- The field trial should occur in actual targeted environments (i.e. households and/or offices)
- The field trial approach should require minimal or no change in householder's interaction with their devices
- It should provide a detailed understanding of equipment usage patterns in the field trial environments
- Data shall be acquired each second for each in situ field trial environment to allow for detailed analysis of household energy and device usage and Tier 2 APS device functionality
- The Tier 2 APS device should be set to "log mode" and equipment connected to the energy saving device is monitored but not controlled by the Tier 2 APS device
- The APS device should record (every second) its decision points to track when the energy saving mode was enacted (i.e., the power to the connected equipment was switched "off"), Note - The APS device must be configured to not turn off the equipment but to monitor when it would have isolated power to the connected devices.
- All data threads should be date and time stamped (synchronised) as this will facilitate a high level of data interrogation of the power consumption data acquired.

This approach will enable real time monitoring of power consumption and energy savings while the energy saving device simulates its actual operation.

Furthermore, this logging approach allows for the monitoring of the actual power usage trends and the potential impact of the Tier 2 APS device, without distorting the equipment usage characteristics of the household by the Tier 2 APS device itself. This significantly reduces the variability in pre/post device installation metering and is the recommended approach to best determine the energy efficiency impact of Tier 2 APS devices.

The necessary data to be measured and logged by the Tier 2 APS device each second should include the following parameters:

- Date & Time (Local)

- Mains power level (voltage)

- Connected equipment current consumption

- Connected equipment Power use (W)

- IR signals determined by the IR sensor on the Tier 2 APS (if an IR sensing Tier 2 APS)

- Count down timer settings of the Tier 2 APS device

- Mechanical Relay Logged state of the Tier 2 APS

- Energy saved - cumulative watt hours

- Energy saved - instantaneous watt seconds

- Energy used - cumulative watt hours

- Energy used - instantaneous watt seconds

This field trial approach will not simply look at total power consumption over a period of time but more importantly it will monitor the power usage levels of AV and IT devices in the targeted environment in addition to numerous other operational parameters each second. The field trial method will provide highly accurate time of use information and confidence in the measurement accuracy and effectiveness of individual Tier 2 APS devices being tested.

The Tier 2 APS device being used for data collection should be calibrated before the field trial is undertaken to ensure measurement accuracy within +/- 2 %. Figure 3.6 provides a graphical illustration in the value of logging this data from a data analysis and energy saving verification perspective.

Figure 3.6: Data Plot Using CalPlug Tier 2 APS Field Trial Methodology [17]
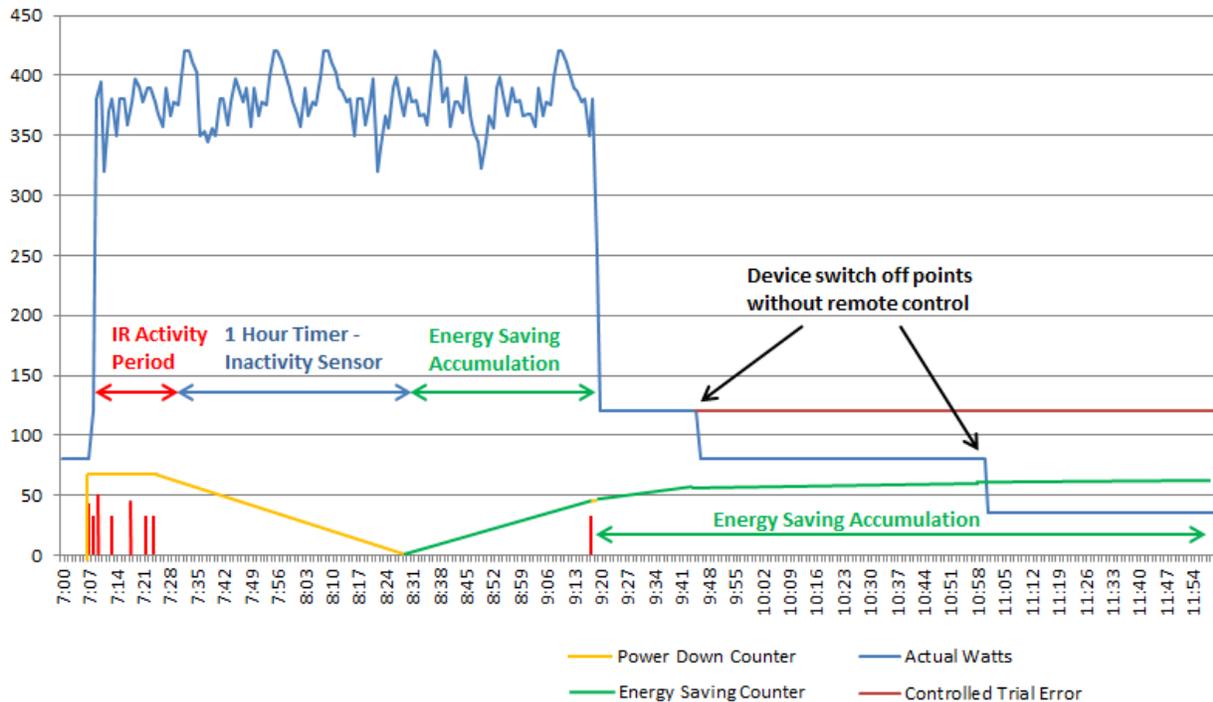
Using CalPlug's field trial methodology, the above data plot can highlight certain data to provide a clear illustration as to the events in the monitored AV environment. Some observations include:

- Real time power fluctuations of the connected equipment (shown in blue)
- IR activity (shown in red)
- Device switch off points (depicted where there is a clear prolonged power change in power level)
- Energy saving power down timer (shown in orange)
- Accumulated energy saved (shown in green) Rate of incline denotes rate of energy being saved which is a factor of the instantaneous power level (Watt seconds) being monitored

Included in Figure 3.6 is an illustration of one of the errors which can occur through an alternate metering approach. The "controlled trial error" line which depicts the Tier 2 APS device actually switching off the connected equipment would then assume that the power level monitored at the point of initial device switch off is what would continue to be saved until the environment was next used.

Should additional connected devices be switched into a lower power state or off after this point, this new power level and therefore reduced energy savings would not be calculated correctly and an overestimation of energy savings would occur. The error in this example would be the difference between the "Controlled Trial Error" line and the "Actual Watts" line from time stamp 9:45 onwards.

Through continually monitoring the power load of the connected equipment and not interfering with the power being supplied, the CalPlug field trial approach removes significant variables to ensure an accurate determination of energy savings.

3.5.2 Field Trial Test Conditions

An overview of our in situ Tier 2 AV APS field trial approach is detailed below. This approach will facilitate the intricate analysis of each electronic AV and/or IT environment for the duration of each field trial. The analysis should apply standard definitions of power modes. In addition, the active standby mode shall be defined as being present when:

- For AV Equipment, after no user (IR) activity was detected for a period of 1 hour
- For IT equipment, after the power use of the PC box was stable for a period of 30 minutes

The appliances should be connected to the Tier 2 APS device in the following format:

- STB and gaming consoles should be plugged into the non-controlled power socket/s
- TV and all other devices shall be plugged into the energy saving outlet
- IR sensor timer is set to 1 hour

Power usage in the active standby mode typically occurs when the user has moved away from the device or has inadvertently left the device on. This is evident in both the AV and PC environments.

In situ field trials providing detailed metering and data-logging of appliance energy usage, will deliver a significant insight and validation into the device usage, energy usage of connected equipment and the energy saving potential of Tier 2 APS devices.

Through logging the actual performance of Tier 2 APS devices, a detailed assessment and verification of the energy saving performance can be attained. The ability to review the detailed performance of individual Tier 2 APS devices using this field trial approach will also facilitate and promote the development of more intelligent solutions which deliver greater ease of use and energy savings. In addition, findings from these in situ field trials will aid in the development of minimum functional requirements and specifications for this device category.

As Tier 2 AV APS devices have an additional feature of a "shutting down" mechanism with the aid of the IR sensor and other intelligent algorithms within the device; the specific user behavior (the user actively presses the remote control button) must be detected to determine the user absent period. The Tier 2 AV APS isolates power to all connected devices during periods of user inactivity while devices remain on. The IR sensor of the APS device itself should be used to assess user activity and APS device decision points. This approach is much more accurate in determining the actual APS device performance and the energy savings it can achieve.

As the main differentiation of Tier 2 APS devices relative to Tier 1 APS lies in effectively capturing energy savings from user absent hours. The total savings of Tier 2 APS can be simply described as the following formula:

$$\boldsymbol{E\_Tier\ 2\_Total}(\boldsymbol{Wh}) = \boldsymbol{E\_Tier\ 2\_Extra} + \boldsymbol{E\_Tier\ 1}\ \text{(Additional Saving generated by IR Sensor of Tier 2 AV APS)}$$

Here **E_Tier 1** is what NYSERDA [1] have previously assessed and reported, and **E_Tier 2** is what CalPlug is characterizing in our labs.

Table 3.3: Investigation of different modes for energy savings of APS Tier 1 and 2

Energy Savings			Tier 2 APS+	Tier 1 APS	
Appliance Modes	Active Mode (ON)			Standby Mode	Off Mode
	User Engaged	User Absent			
NYSERDA	No	No		Yes	Yes
CalPlug	Yes	Yes		Yes	Yes

Chapter 4: Secondary Research

4.1 Introduction

In addition to CalPlug's primary research on actual independent field trial data and SIM lab tests; secondary research of usage patterns, such as total TV hours watched per week in America or total time certain peripherals are used per week, was obtained in order to further correlate and determine the average energy saving potential of Tier 2 AV APS devices.

CalPlug's main secondary research resource was Nielsen — a company dedicated to study consumers' trends and habits around the world. CalPlug primarily focused on US TV related information and reports provided by Nielsen, particularly the 'Cross-Platform' reports released quarterly and 'Social Media Reports' released yearly. Nielsen "tracks down viewing behavior down to the second, revealing detailed programming and commercial engagement" by using 'electronic metering technology' through Set-Top Boxes to obtain real-time stream of information, which is coupled with detailed analysis of consumer viewing behavior and demographic information [12].

Other secondary research sources include data from reports by the Consumer Electronics Association (CEA), New York State Energy Research and Development Authority (NYSERDA), Ericsson Consumer Lab, among others.

4.2 Annual Energy Consumption Estimate

Utilizing the independent field trial data on a Tier 2 AV APS device (EmberPlug AV APS), CalPlug ascertained that on average the percentage of total energy consumed that can be reduced in targeted AV environments was 48% - 53% across low, medium and high user categories.

It was proven via the detailed field trial data that equipment loads and usage patterns on average had very little influence on the average percentage of energy savings in the target environments but would influence total kWh saved values considerably.

CalPlug's solution was to apply the 48% - 53% figure across existing data sets on total annual kWh consumed in the target environment. Table 4.2 calculates the lower and upper average kWh saving ranges for various data sets which state average annual kWh consumption levels in US AV environments.

Table 4.1: Field Tested Tier 2 APS Deemed Saving Assessment by Total AV kWh Consumption Data Source [1] [2] [16][17].

Data Reference	Date Data Acquired	Annual AV kWh Usage	Field Trialed Tier 2 APS Energy Saving (kWh) Lower Bound	Field Trialed Tier 2 APS Energy Saving (kWh) Upper Bound
California Energy Commission (CEC)	2008	638	306	338
New York State Energy Research & Development	2011	665	319	352
Fraunhofer Report - Consumer Electronics Association (CEA)	2011	694	333	368
Energy Information Administration 2012 + CEC	2012	700	336	371
Tier 2 APS Metered Household Field Trial Data 2010 - 2014 (EPRI, Energy Consult, Energy & Resource Solutions)	2010 - 2014	726	348	385

Figure 4.1: Upper & Lower Tier 2 AV APS kWh Saved by Data Set
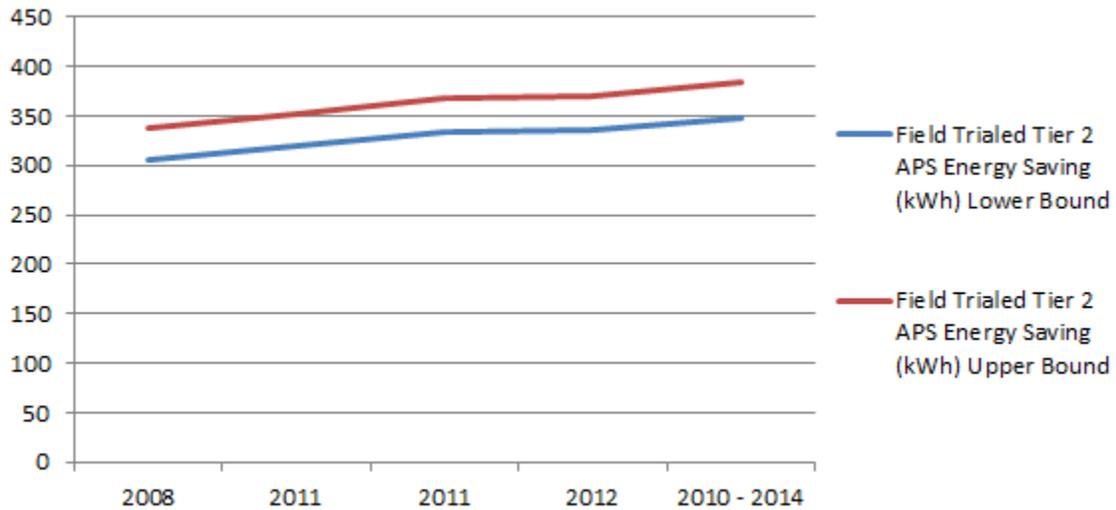
Figure 4.1 illustrates the lower and upper kWh average energy saving levels that can be attained from the field tested Tier 2 AV APS device [16]. Of interest is the upwards trend in energy saving levels year on year; this is driven by the observed increase in total kWh usage in household AV environments. This data strongly suggests that although there has been advancement in a number of energy efficiency measures in the consumer electronics (CE) industry, the increasing proliferation of CE devices is driving a net increase in annual household kWh usage to power their devices.

4.2.1 TV Engaged Hours

4.2.1.1 From Secondary Research

Until today's date, there has not been research tracking specifically user engagement hours whilst watching TV on a regular basis. In order to tackle this issue, CalPlug's approach to approximate the user engaged hours was to look at 'simultaneous usage of media while watching TV'. This would represent the user's activity other than watching TV, while the TV was still in on mode.

CalPlug's Methodology [6]:

$$Formula\ used \rightarrow Engaged\ Hrs\ = (Total\ ON\ Time) - (Non\_engaged\ Hrs)$$

$$Total\ ON\ time\ =\ \mathbf{146.62}\ hrs/month\ based\ on\ medium\ =\ \mathbf{4.887}\ hr/day\ [13]$$

4.2.1.2 From Primary Research

In this report, the definition of power states is different from the usual terms. In Table 4.2, it is seen that the new definition of power states is based on a more active role played by the consumer. The main difference from the general terms defined is that the new definition defines engagement as the "active clicking behavior on a remote control" as opposed to generally defining it as the attention of a user.

Table 4.2: Comparison of Device Operation Modes Definition

Conventional Definition of Device Operation Modes	CalPlug Definition of Device Operation Modes
• Active Mode: The television is turned on and is displaying an image. • Standby Mode: The television is turned off by the remote control and is not displaying an image but still remains plugged in. • Off Mode: The television is turned off by a power button/switch on the television and is not displaying an image but still remains plugged in.	• On/Active Mode: The appliance is turned on and the user is actively engaged with the appliance (pressing buttons on the remote control) • On/Absent Mode (also referred to as Active Standby Mode): The appliance is turned on and the user is not engaged with the appliance (They don't press any buttons and are not actively using the product, but the device is still displaying images) • Standby Mode: The television is turned off by the remote control and is not displaying an image but still remains plugged in. • Off Mode: The appliance is turned off but is still plugged into the outlet

Since this is a substantial divergence, both the User Engaged Hours and the User Absent Hours would vary from those estimated in other reports. The User Absent Hours is defined as the time that the user is not actively engaged with the devices and is calculated using primary research data.

In order to find User Absent Hours, the On Absent Time percentage must be calculated and inserted into Equation 1. This is done by the sum of all the data points above one hour divided by the product of the number of subjects and the total time duration of the test as shown in Equation 2.

Only data points above one hour are considered because these are the times that can potentially draw savings when using the 1-hour configuration for the Tier 2 APS. The User Absent Hours is the same as the T_{TV_Absent} variable used in the savings formula found in Chapter 5.

$$Absent\ Hrs = \mathbf{1.94}\ hrs/day$$

$$Using\ our\ formula \rightarrow Engaged\ Hrs = 4.887 - 1.94 = \mathbf{2.95}\ hrs/day^*$$

*During our test, we assume that user is considered to be engaged in the "watching TV" activity by actively pressing the remote control button. This assumption doesn't include all the scenarios, for example, user is watching a show while multi-tasking his/her work.

$$User\ Absent\ Hours = On\ Absent\ Time(\%) \times (Total\ On\ Time) \qquad (1)$$

$$On\ Absent\ Time\ (\%) = \frac{(Sum\ of\ time\ between\ clicks\ greater\ than\ 60\ min)}{20\ (people) \times 120\ (min)} = \mathbf{39.6\%} \qquad (\mathbf{2})$$

$$Total\ On\ Time = (User\ Engaged\ Hours) + (User\ Absent\ Hours) \qquad (3)$$

Chapter 5: Deemed Savings - CalPlug Simulation/Calculation

5.1 APS Tier 2 Energy Savings

5.1.1 Overview

The energy savings for the different configurations must be calculated separately as not all of the devices will be in use at the same time. Each common configuration in an American household can be classified under one of the following three cycles: TV cycle, Game Console cycle, DVD cycle. In addition to these cases, there could be a situation where cycles overlap. This would happen if the IR Timer has not reached the full hour and the user has switched their engagement to a different device. A laboratory simulation calculation was conducted at CalPlug utilizing the functional attributes of a recently launched Tier 2 AV APS+ device which is yet to undergo the required in situ field testing. The "desktop calculations" are outlined below.

5.1.2 Typical Configurations in US Household

Table 5.1: Typical Configurations in US Household [1] & [5]

Number of Households with Each Configuration		
Total # of Households (US Census 2011)	100%	132,312,404
DVD + TV	86%	113,788,667
Game Console + TV	56%	74,094,946
STB + TV	85%	112,465,543

Base on the US census 2011, the power consumption under four different modes of four most common appliances, TV Set (TV + Audio System with subwoofer), DVD and game console (XBOX) were measured.

5.1.3 Measurement Condition

The appliances are connected to the Tier 2 APS+ in the following format:

- STB is plugged to Always ON
- TV is plugged to Master; XBOX, DVD, and Audio System are plugged to Controlled
- IR sensor timer is set to 1 hour

5.1.4 Power Consumption for Each configuration

The power consumption data was based on SIM Lab final (3rd) test run.

Table 5.2: Power consumption for each appliance

	TV Set (W)		XBOX (W)	DVD (W)	STB (W)
	TV (W)	Audio (W)			
User Engaged	90		100	5.3	18
User Absent	90		93	5.3	18
Standby	/		/	1.0	/
Off	<0.2		<0.2	<0.2	<0.2

Note: "/" means this appliance doesn't have this mode or it's not activated during our test. It's the same for the following tables.

5.1.5 Average daily usage hours for each appliance

Table 5.3: Average usage hours under different modes [3] [4] [7] [15]

Based on preliminary primary research conducted by CalPlug from 10/03/2013 - 10/25/2013 and secondary research.

	TV (Hr/Day)	XBOX(Hr/Day)	DVD(Hr/Day)	Audio(Hr/Day)
User Engaged Hours	2.95	1.4	0.778	/
User Absent Hours	1.94*	7.46	23.2	/
Standby	/	/	/	/
Off	20.11	15.1	/	/

* The TV engaged & absent hours was obtained using CalPlug SIM Living Room primary research. The engaged and absent hours for audio system are the same as TV since they are tested as a set.

5.1.6 Average annual energy consumption

By using Table 5.2 and Table 5.3, the average annual energy consumption for US living room with 5 most common appliances (TV, Audio System, Game Console, DVD and STB) can be calculated by the following formula:

$$
\begin{aligned}
E_{Annual\ total}\ (Wh) \\
= (P_{TV\ SET_{ON}} \times T_{TV\ SET_{ON}} + P_{XBOX_{Engaged}} \times T_{XBOX_{Engaged}} + P_{XBOX_{Absent}} \times T_{XBOX_{Absent}} \\
+ P_{DVD_{ON}} \times T_{DVD_{ON}} + P_{DVD_{Standby}} \times T_{DVD_{Standby}} + P_{STB_{ON}} \times T_{STB_{ON}}) \times 365.25 \\
= (439.2 + 14 + 693.78 + 4.12 + 22.2 + 432) \times 365.25\ Wh = 586.33\ kWh
\end{aligned}
$$

*Here we assume DVD will be switch into standby mode 1 hour after the user engaged activity.

According to the field trial data, the energy saving percentage ranges from 48% to 51% (Chapter 6), thus the annual energy savings can be obtained.

$$
E_{Annual\ savings}\ (Wh) = E_{Annual\ total} \times 51\% = 299.0\ kWh
$$

5.2 Simulation with Usage Cycles for Tier 2 APS+ Energy Savings

5.2.1 TV Cycles

Below we describe the appliance usage cycle when TV is the dominant appliance that will determine the user behavior. For example, user will only watch TV or related activities during TV cycle.

$$
TV\ Set\ Savings\ (Wh) = P_{TV\_Absent}(W) \times (T_{TV\_Absent} - T_{IR\_Timer})(Hr/Day) \times (365.25)(Days)
$$

Note: TV Set = TV + Audio System (With Subwoofer)

5.2.2 Overlapping cycles

Conservative Savings:
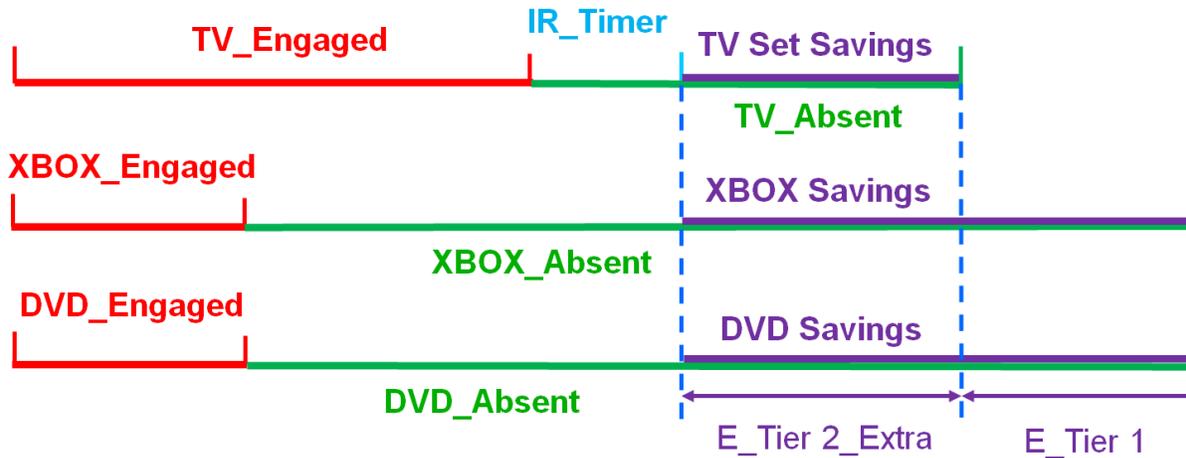
Maximum Savings:
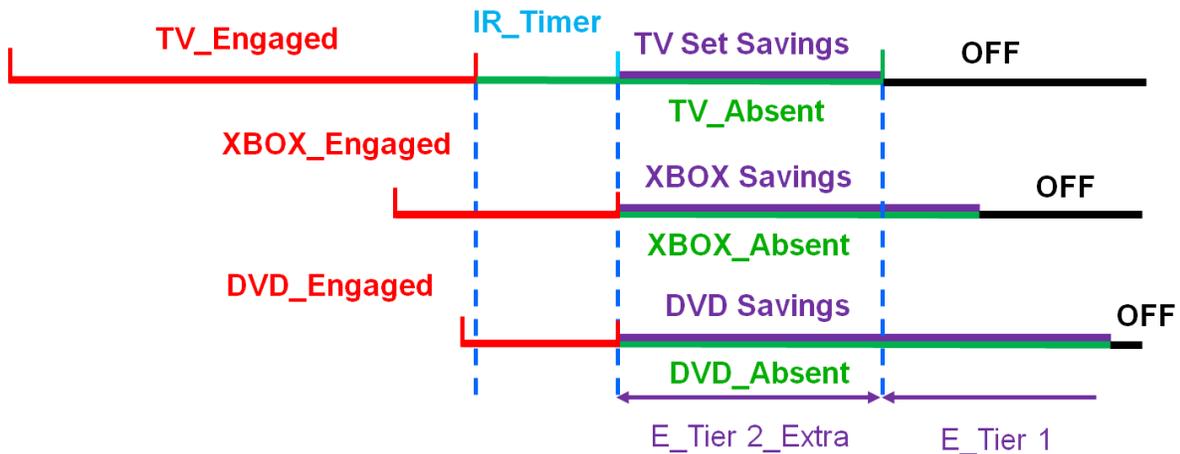
5.2.3 Deemed Savings by Calculation

The main differentiation of the energy savings of the laboratory assessed alternate Tier 2 APS+ device, relative to Tier 1 APS, lies exclusively in the user absent hours. The total savings should be simply:

$$E\_Tier\ 2\_Total(Wh) = E\_Tier\ 2\_Extra + E\_Tier\ 1$$

Here **E_Tier 1** is what NYSERDA have previously tested and reported, and **E_Tier 2** is what CalPlug is characterizing in our labs.

Based on the values in Table 5.2 and Table 5.3 and the following assumptions:

1. User has all 5 appliances in his/her living room (STB, TV, Audio, DVD, XBOX);
2. Three cycles (TV, XBOX and DVD) are all involved during user's activity;
3. The engaged hours of XBOX or DVD are less than TV engaged hours;
4. 30 % of users leave their game console idle when not in use, with the remainder putting their console into standby mode. (So absent hours will NOT be 24 hours – User Engaged Hours);
5. User will leave their DVD idle when not in use. But before the DVD turns to the standby mode, it is already shut down by APS+ (Standby timer >> IR sensor timer).

The annual minimum and maximum energy savings for APS+ **E_Tier 2_Total** can be obtained according to the following formula:

Conservative laboratory bench test case according to section 5.2.2:

$$
\begin{aligned}
E_{Tier}2_{Total}(Wh) \\
&= P_{TV_{Absent}}(W) \times \left(T_{TV_{Absent}} - T_{IR_{Timer}}\right)\left(\frac{Hr}{Day}\right) \times (365.25)(Days) \\
&+ P_{XBOX_{Absent}}(W) \times \left(T_{XBOX_{Engaged}} + T_{XBOX_{Absent}} - T_{TV_{Engaged}} - T_{IR_{Timer}}\right)\left(\frac{Hr}{Day}\right) \\
&\times (365.25) + P_{DVD_{Absent}}(W) \\
&\times \left(T_{DVD_{Engaged}} + T_{DVD_{Absent}} - T_{TV_{Engaged}} - T_{IR_{Timer}}\right)\left(\frac{Hr}{Day}\right) \times (365.25) \\
&= 30.9 + 166.8 + 38.8 \, kWh = 236.5 \, kWh/Year
\end{aligned}
$$

Maximum savings laboratory bench test case according to section 5.2.2, which assumes maximum Game Console ("XBOX_Absent") energy savings.

$$
\begin{aligned}
E_{Tier}2_{Total}(Wh) \\
&= P_{TV_{Absent}}(W) \times \left(T_{TV_{Absent}} - T_{IR_{Timer}}\right)\left(\frac{Hr}{Day}\right) \times (365.25)(Days) \\
&+ P_{XBOX_{Absent}}(W) \times \left(T_{XBOX_{Absent}}\right)\left(\frac{Hr}{Day}\right) \times (365.25) + P_{DVD_{Absent}}(W) \\
&\times \left(24 - T_{TV_{Engaged}} - T_{IR_{Timer}}\right)\left(\frac{Hr}{Day}\right) \times (365.25) = 30.9 + 253.4 + 38.8 \, kWh \\
&= 323.1 \, kWh/Year
\end{aligned}
$$

It must be considered that the assessment of this alternate Tier 2 AV APS device was limited to the laboratory evaluation environment only which illustrated a potential average annual energy saving of 280 kWh. No independent in situ field trial data on this alternate Tier 2 AV APS device was available to carry out the CalPlug deemed saving calculation methodology on this device nor could a detailed product functionality assessment be conducted on this device to validate its computational integrity.

Chapter 6 : Deemed Savings – CalPlug Field Trial Data Assessment

6.1 APS Tier 2 Energy Savings

6.1.1 Overview

As outlined in Figure 1.1, the energy saving potential of a Tier 2 APS can be best assessed using the following methodology:

- Laboratory evaluation of the functional attributes and features of the Tier 2 APS device in question to deliver the stated performance
  - This is to determine device functionality and the data collation process for the Tier 2 APS device in question when undertaking in situ field trial data collection
- Formulation and execution of CalPlug field trial methodology with Tier 2 APS device capturing:
  - The data captured and used by the APS device to determine connected equipment operational modes
  - Connected equipment loads in watt seconds and cumulative watt hours logged each second
- Evaluation of independent Tier 2 APS field trial data using CalPlug's recommended metering and data logging approach
- Determination of the average percentage (%) of total energy saved through the use of the Tier 2 APS device being tested
- Trial duration should be between 2-3 weeks per installation across between 50-100 installations for statistical significance
- Average potential energy savings of the Tier 2 AV APS device is calculated by utilizing both field data on average percentage of total energy saved and published data on total average energy consumed in a given environment [16]

6.2 Development of the CalPlug Tier 2 APS Deemed Saving Calculation Methodology

There are a number of considerations when formulating a reliable and repeatable calculation methodology for determining the performance of a Tier 2 APS device. Broadly this can be categorized as understanding what data is already largely available, where the key variables are that provide the most difficulty in determining the energy saving potential of devices and what the key elements are which will affect the performance of a Tier 2 APS device in its targeted environment. Given all these considerations a reliable and repeatable methodology for assessing the relative performance of a Tier 2 APS device can be achieved.

6.2.1 What data is already largely available?

There already exists a large volume of data on total household and office energy consumption and where this energy is used within these environments in terms of product segments. This data is largely available across many States in the US and has been compiled by recognized organizations.

Further, as plug load is not a new phenomenon, there is a large amount of data available which focuses directly on the different types and levels of plug load in both household and office environments. Given this, the focus of CalPlug's research will not be required to investigate the total energy used in these environments.

6.2.2 Why is the emphasis on percentage of energy saved useful?

There is no need to focus on the total energy used in kWh directly from field trials themselves as this data, as mentioned earlier, is already largely available. The core focus is how the Tier 2 APS device performs in terms of reducing energy consumption in the targeted environments. There are many more variables which directly vary the total energy used and saved values that can be attained from an in situ field trial, these include:

- The number of connected devices to the APS
- The power levels of the connected devices to the APS
- The usage patterns of these devices in the field trial environment

All three of these variables will have a considerable impact on the kWh used and saved from location to location. It is for this reason that field trials which typically look to reach a position on deemed kWh energy savings in absolute terms often require very large sample sizes to account for these variables.

However as Tier 2 AV APS devices largely derive additional energy savings from the television over Tier 1 devices and given this is predominantly where the largest equipment loads comes from in an AV environment, the focus of CalPlug's assessment on Tier 2 APS devices is based on their interaction with the targeted environment and management of the connected equipment. For this reason, tracking the relationship between the total energy used and the total energy saved (but not in absolute kWh terms), provides useful information with respect to the overall performance of the Tier 2 APS device being tested. This data can then be applied to a number of independent data sets on total kWh usage in the targeted environments to arrive at a lower and upper range of kWh saved values.

6.2.3 What drives the percentage of energy saved?

The ability for the device to monitor, calibrate and interpret what is happening in the installed environment as quickly as possible will be the key determinant to improving the percentage of energy that is saved by the Tier 2 APS. A detailed understanding of the Tier 2 APS device, what it monitors, and how it calculates when to control the connected equipment is required in order to track and validate the effectiveness of the device. The key data being monitored by many Tier 2 APS devices are infra-red signals, and either current or power.

CalPlug's field trial methodology is focused on capturing the key information the Tier 2 APS device uses to determine when to save energy via the APS device itself. What is imperative is not only what data the Tier 2 APS device will use but what the Tier 2 APS device itself actually monitors within the in situ environment and how it computes this to make control decisions in real time.

As each connected environment will be different to the next, trialing the Tier 2 device in a number of targeted environments to assess how it adjusts to each location (households) and loads (equipment types) is important to properly assess the performance of the Tier 2 APS device.

Obtaining this data enables us to validate that the Tier 2 APS device is functioning as intended and that it does so reliably, consistently and that it is obtaining the correct readings to make the correct connected equipment control decisions.

Through capturing and tracking the aforementioned data via the Tier 2 APS device, the performance in terms of the percentage (%) of energy saved can be accurately determined through comparing the total Watt Hours (Wh) used and saved over the trial duration. This is verified through obtaining metered data from the Tier 2 APS device itself each second during actual in situ installations so that the Wh saved cumulative counter can be cross referenced with the data and decision points made by the Tier 2 APS device as depicted in Table 6.1.

6.2.4 Other Tier 2 APS performance considerations

There are a number of features Tier 2 APS devices have over Tier 1 APS devices which are designed to provide greater levels of consumer satisfaction and energy saving performance. A detailed list of some of the observed features we have seen on existing Tier 2 APS devices and how they may reduce de-installation rates, enhance user experience and energy savings are detailed further in this report.

6.2.5 CalPlug Tier 2 APS Deemed Saving Calculation Formula

Tier 2 APS Device Deemed Savings = (Average Validated Cumulative Wh Saved / Average Validated Cumulative Wh Used) x Average Annual Energy Used (kWh) in Targeted Environment (Region Specific)

Average Validated Cumulative Wh Saved: This is effectively the cumulative Wh which have been saved during the field trial period on a household by household basis. Through analyzing the field trial data (logged each second) we are able to determine that the Wh counters commenced and ceased accumulating Wh saved at the correct intervals. IR data and the reaction of the Tier 2 APS device to this data in term of the active timer sequence reacting to this IR activity will enable validation of the device functioning correctly and accumulating energy savings at the appropriate time.

Average Validated Cumulative Wh Used: This is effectively the cumulative Wh consumed on a household by household basis during each trial. Through analyzing the data which assess the connected equipment loads in real time and the Ws counters we are able to determine the correct accumulation of Wh used.

Average Annual Energy Used: This is 3rd party data on total annual energy consumption (in kWh) in the targeted environments. There exists a number of publications that both individually and through collaborating their individual data points will deliver a defined kWh usage figure for AV and IT environments for each targeted region in the US.

6.3 Analysis of Independent Tier 2 APS Field Trial Data

The Tier 2 APS device data in question is sourced from field trials conducted on the EmberPlug Tier 2 APS devices. These devices were calibrated to gather in situ household data using the aforementioned CalPlug field trial methodology.

These devices were designed to capture the key data points in each in situ environment and the reaction of the EmberPlug Tier 2 APS device to these operational events. This data was collected and transmitted in real time to data servers via a GSM modem for storage and later analysis.

Numerous trials were conducted on the EmberPlug device by independent 3rd parties (including EPRI, ERS, Energy Consult, NEEP, Efficiency Vermont and Silicon Valley Power) gathering over 120 million lines of data, each line comprising of between 12 -17 fields being monitored each second. These data fields included all the parameters required to assess and validate the functionality of the Tier 2 APS device for device analysis and energy saving verification.

Although this data had undergone previous independent analysis, with 3rd party reports published on the field trial findings; CalPlug obtained access to over 14GB of second by second field trial data to facilitate a detailed analysis and verification on the energy saving capabilities of this Tier 2 APS device.

Upon analysis of the data it can be confirmed that the field trials were performed in line with the field trial methodology recommended by CalPlug for Tier 2 APS devices; further detail on the metering approach used in these field trials is provided below:

- The power consumption of all appliances to be attached to the Tier 2 APS is measured, using a power meter (Watts Up Pro Energy Meter3) in various modes of operation. This is a short test performed within a matter of minutes. The calculation formula is:

$$E_{Total} = \int_{Period\ Start}^{Period\ End} P_{Total}(t)dt$$

  Where E_{Total} is the total energy consumption of all appliances attached to the Tier 2 APS and $P_{Total}(t)$ is the instantaneous power consumption of all appliances.

- The power consumption of the appliances to be attached to the controlled outlets of the Tier 2 APS is also measured to estimate the energy saving percentage. The STB and game console will be attached to the Non-controlled outlets and all the other appliances (TV, DVD, Audio system and etc.) will be attached to the controlled outlets.

- Data logging of the power consumption of the controlled appliances is undertaken over 14 - 21 consecutive days.

- The controlled appliances remained connected to mains power at all times (i.e. the Tier 2 APS shall not interrupt the power supply), in order to allow for accurate calculation of energy consumption of appliances (analogous to the pre-installation period).

- The theoretical ON and OFF events of the Tier 2 APS device were logged. This allowed for the accurate calculation of the energy that would have been saved if the Tier 2 APS device had been functioning as intended. The calculation formula is:

$$E_{Saving} = \int_{Period\ Start}^{Period\ End} P_{Controlled}(t) \times u(t) dt$$

Where E_{Saving} is the energy could be saved by using the Tier 2 APS, $P_{Controlled}(t)$ is the instantaneous power consumption of the appliances to be attached to the controlled outlets and $u(t)$ (either 1 or 0) is the signal of the user switching on/off the appliances. The integration of the $P_{Controlled}(t)$ and $u(t)$ over the field trial period will give the energy saving. Furthermore, E_{Saving}/E_{Total} will give the saving percentage.

- The parameters used by the Tier 2 APS device to undertake switching events are also logged (such as infrared signals, countdown timer, etc.) in order to independently confirm that the Tier 2 APS device is functioning as intended

- STB's and Game Consoles were not connected to the energy saving controlled outlets in these field trials but were monitored in terms of total system load
    - STB devices were isolated from the controlled power outlets as they would likely not be controlled by an APS in real environments due to their long "boot up" cycles

    - Some Game Consoles (which also have a long (>25 seconds) boot cycle are used to stream media also and were removed for the same reason

    - Had Game Consoles been included in the controlled device circuit the % of energy saved would have increased overall which would lead to an increase in total annual kWh saved

The field trial data also tracked the instantaneous watt seconds (Ws) used and saved in addition to the cumulative total watt hours (Wh) used and saved throughout all trial environments; this data was accumulated each second. CalPlugs analysis of this data found that in each field trial the percentage of energy saved was consistently around 51% of total energy used across a variable range of household AV user types. Table 6.1 is an extract from the field trial data focusing on the percentage (%) of total energy saved across all trials conducted on this Tier 2 APS device in AV environments.

Table 6.1: Average Percentage (%) of Energy Saved from Total Energy Used [17]

Household AV User Type				
High	Medium	Low	Low	Low
53%	53%	48%	51%	48%

The field trials conducted on the Tier 2 APS device were designed to assess the range of energy savings that could be achieved in different household environments. Upon reviewing this data in detail it was seen that although differences in the number, power usage and usage patterns of connected equipment would vary for each household category; the percentage of energy saved was on average quite consistent.

The 2011 data on total annual AV energy consumption shows that the average annual energy consumption in a typical household AV environment typically addressed by APS devices is for example in one of studies, 694 kWh per year [16]. Combining this data with the average percentage of 51% of total energy saved across all trials conducted on the Tier 2 AV APS device delivers an average energy saving of around 354 kWh per annum; not including game console energy saving potential [17].

Utilising data from the Energy Information Administration (EIA) on total monthly household energy consumption (in kWh) and correlating this with data from the California Energy Commissions Public Interest Energy Research Program provides insight into the level of energy used for household entertainment equipment by State.

Extracting CalPlug's findings on the energy efficiency performance of the field tested Tier 2 AV APS device and applying this a number of sources which have assessed total annual kWh energy consumption in household AV environments provides an interesting overview of the Tier 2 AV APS opportunity as seen in Table 6.1.

Chapter 7: Existing Technologies and Products

7.1 Existing products

CalPlug has conducted analysis on Tier 2 APS products currently available in the market. Below is a product specification of these Tier 2 APS devices. Through secondary research, the most popular Tier 2 APS product on the market is the Embertec Tier 2 AV & IT APS device; this device has been used in a variety of energy efficiency programs since 2011. It has been extensively field tested by a number of independent parties [17] consistent with the CalPlug Tier 2 APS field trial methodology. The following sections provide a top level feature set assessment of these products.

7.1.1 Embertec Tier 2 AV APS

Figure 7.1: Embertec EmberPlug Tier2 AV APS

Table 7.1: Specifications of Embertec EmberPlug Tier2 AV APS

Embertec EmberPlug AV Features

• Energy consumption:
    ○ 0.85W - while not supplying power to connected equipment
    ○ 0.85W - while supplying power to connected equipment
• 64k Flash Memory Advanced Microprocessor measuring True RMS Power
• Automatic Savings
• Automatic Threshold Adjustment
• Saves Standby & Active Waste - Active Powerdown™

- Automatically adapts to new devices
- Proven Persistence Level Data – Over 2 million installed
- IR filtering (hardware and firmware filters)
- Adjustable Active Powerdown™ timer (1, 2 hours + Music Mode™)
- Monitors Passive and Active energy wastage
- Does not rely on the power state of any one device
- Spaced outlets
- Works with existing household's surge strip
- Surge Protection
- 15A resettable circuit breaker

Sensing Methods	CalPlug **Field Trial Evaluated** Average Annual Savings (CA)	Has device undergone CalPlug Field Trial Method to Assess Energy Savings (Y/N)	Market Share (sales)	Device Retention Probability
IR/True RMS Power Sensing with spurious IR signal shielding	346 kWh (not including game console energy savings)	Yes Demonstrated Total Energy Saved Percentage - 51%	Tier 2 AV APS Category Leader - Over 1.5 million AV APS installed	98.5% consumer retention satisfaction rate based on post program customer survey

7.1.2 Embertec Tier 2 PC+ APS

Figure 7.2: Embertec Emberplug Tier2 PC+ APS

Table 7.2: Specifications of Embertec Emberplug Tier2 PC+ APS

Embertec Features
- Energy consumption: 0.85W - while not supplying power to connected equipment   0.85W - while supplying power to connected equipment   64k Flash Memory Advanced Microprocessor measuring True RMS Power   - Works with <u>all</u> desktop and laptop PC's   - Automatic savings   - Automatic Threshold Adjustment   - Saves Standby & Active Waste - Active Powerdown™ on PC Peripherals <u>and</u> the PC itself   - Automatically adapts to new PC's   - Proven Higher Persistence Level than competing PC APS devices   64k Advanced Microprocessor measuring True RMS Power   - Monitors Passive and Active energy wastage   - Spaced outlets   - Works with existing environments surge strip   - Surge Protection   15A resettable circuit breaker

Sensing Methods	CalPlug **Field Trial Evaluated** Annual Savings	Has device undergone CalPlug Field Trial Method to Assess Energy Savings (Y/N)	Market Share	Device Retention Probability
True RMS Power and other activity sensors	350 kWh	Yes	Tier 2 PC APS Category Leader - Over 500,000 PC APS installed	98.5% consumer retention satisfaction rate based on post program customer survey

7.2 Tier 2 APS Feature Comparison

Tier 2 APS devices, in addition to delivering greater levels of energy savings have also been engineered to address the usability challenges in typical residential and commercial environments.

This is primarily to ensure a greater user experience over Tier 1 APS devices which will assist with higher retention rates for this technology category and is important when calculating the effectiveness of the Tier 2 APS device in question. Below is a top level assessment of Tier 2 AV and IT APS devices in terms of the major features which are designed to deliver greater ease of use, reliability and long term energy savings.

Main differences between Tier 2 AV APS are around:

- Master-less VS Master/Controlled
  - Master/Controlled requires a dedicated "master" device to sense activity and whether to supply power to the other connected devices
    - This will require a change in user habit with their equipment as the master device will need to be switched on first before power will be supplied to the other devices. This change in user habit may lead to nuisance and risk of de-installation in addition to this arrangement leading to an increase in energy usage in some usage cases.

  - Master-less Tier 2 APS are used like existing power strips and don't require one device to be turned on or off in order to control the other devices in the environment. Delivering greater ease of use will promote long term usage of the device and energy savings.

- Sensing methodology (Current sensing versus True RMS Power sensing)
  - Power sensing adjusts for variances in mains voltage which will alter the consumed current of connected equipment. This is important as the current consumed by the connected devices is what is used to determine their state of operation. Sensing current only to determine equipment state may lead to incorrect equipment status logic within the Tier 2 APS and hence incorrect connected equipment control

Main features of Tier 2 PC APS devices:

- Sensing methodology – Tier 2 PC APS Utilize True RMS Power Sensing which enables
  - Determination of power profiles of both desktop and laptop PC's ensuring compatibility with both to promote long term Tier 2 APS use when connected PC is changed
  - Automatic adjustment to connected PC power loads which will vary with each PC and not require the user to adjust a threshold
  - Laptop charging cycle recognition to ensure connected equipment is not left permanently powered while the connected laptop is simply being charged but not being used

- Additional Sensing features
  - Enables energy savings to both the PC peripherals <u>and the PC itself.</u>
  - <u>The PC typically consumes more energy than its peripheral devices so addressing wasteful connected PC energy consumption will lead to significant increases in energy savings over Tier 1 PC APS devices</u>

7.2.1 CalPlug Tier 2 APS Detailed Device Feature Assessment

CalPlug has researched existing Tier 2 APS devices available on the market and evaluated their functionalities to determine how they are designed to enhance consumer experience to promote device retention and long term energy savings. A list of these functions and their targeted benefits are outlined below:

- Automatic Threshold Adjustment – Requires no user setup upon installation in terms of adjustment of the Tier 2 APS to their targeted environments power load. This is designed to ensure an ease of user setup similar to an existing surge strip device.

- IR Filtering – Addresses the spurious Infra-Red (IR) present from sunlight and or Compact Fluorescent Light Bulbs (CFL's) which interfere with IR sensing Tier 2 APS devices. This filtering has been done via hardware and software solutions within Tier 2 APS products. Without adequate filtering, IR sensing APS devices can infer IR noise from sunlight or CFL's as a signal from a remote control and begin taking control actions of the connected equipment to the APS device. This will lead to incorrect actions by the APS and consumer nuisance.

- Microprocessor Flash Capacity – The higher the capacity the greater the computational power of the device. Higher computational ability is likely to ensure a more accurate determination of the operational state of the connected equipment in the environment leading to correct switching decisions and enhancing device function and retention.

- Adjustable Power Down Timer – As observed in section 3.3, this feature may prove useful to householders who regularly watch long programs (movies, etc.) so as to not continually require the householder to interact with the Tier 2 APS device every hour to delay a power down event and is unlikely to impact energy savings. Delivering greater device flexibility and consumer acceptance will likely enhance Tier 2 APS retention rates.

- Adjustable LED Brightness – As APS devices will be installed in rooms of different sizes and illumination, the LED brightness may be either too dark or too bright depending on the installation environment. As Tier 2 APS devices rely on the LED light on their IR sensor to communicate an event to the user, if this LED light is not seen it may lead to unwanted power down events. Conversely if the LED light is too bright in a dark environment (i.e. bedroom) it may lead to annoyance for the user at the culmination of the evening.

7.3 Economic Impact of savings

We propose this equation to calculate the true impact of adopting any particular energy efficient solutions based on deemed savings through reduction of electricity use, upfront installation cost and potential de-installation expenses due to lack of customer compliance.

The equation for economic impact of savings is as below:

$$\Delta(\$) = B_{Deemed\ Savings} - (C_{Upfront} + C_{De-installation})$$

Where Δ is the economic impact of energy savings, $B_{Deemed\ Savings}$ is the benefit generated by the Tier 2 APS deemed savings, $C_{Upfront}$ is the upfront cost of the APS device and $C_{De-installation}$ is the cost for the de-installation due to the users' un-satisfaction.

In Table 7.3 and Table 7.4, the sources for upfront cost are summarized, which including equipment manufacturing cost, installation cost, acquisition cost for developers and/or utility companies, consumer learning curve, and etc.
Basically, $C_{Upfront} = C_{Equipment} + C_{Shipping} + C_{Installation} + C_{Acquisition} + C_{Maintenance}$

De-installation cost: this cost is inversely proportional to the user satisfaction of the particular solution. A solution designed with minimum change of user behavior and ease of operation in a multitude of environments will yield the lowest de-installation cost, based on a **probability factor**.

Generally accepted product category features are used as the foundation to evaluate a specific solution however the most valuable approach is to assess the effectiveness of a given product in the field under existing energy efficiency programs. The probability factor for de-installation will decrease as more standard features are retained or enhances by the new solution.

In Table 7.3 and Table 7.4, it summarizes the key features of current Tier 2 APS products with different brands. It will determine the user's satisfaction by percentage. (The data will be acquired by either primary research or secondary research (CalPlug database)).

Table 7.3: Core Tier 2 AV APS features driving energy savings and user satisfaction

Factor	Tier 2 AV APS							Actual Consumer User Satisfaction (%)
	A	B	C	D	E	F	G	
Features	True RMS Power (Current and Voltage Sensing)/IR Sensing	Hardware & Firmware IR Filtering	Active Power-down Adjustability 1-2 hours	Automatic/ Smart Adjustment	Surge Protection	After Sale Service	Field Trialed - Average Energy Saving Potential Excluding Game Console	
Embertec EmberPlug	✓	✓	✓	✓	✓	✓	346 kWh Annual Average Energy Saving	98.5%

So the equation for user satisfaction is as below,

$S_{User}(\%) = F(A, B, C, D, E, F, G,)$, which is a function of multiple factors (for example, APS key features)

And then the de-installation cost will be,

$$C_{De-installation} = C_{return} \times (1 - S_{User}) = C_{return} \times (1 - F(A, B, C, D, E, F, G,))$$

where C_{return} is the cost for returning the product.

Table 7.4: Core Tier 2 PC APS features driving energy savings and user satisfaction

	Tier 2 PC APS Features									Actual Consumer User Satisfaction (%)
Factor	A	B	C	D	E	F	G	H	I	
Product	True RMS Power (Current and Voltage Sensing) + Additional Sensing	Functions with Desktop & Laptop PC's	PC Peripheral energy savings	PC energy savings	Automatic / Smart Adjustment	Surge Protection	Upfront Cost (<$50)	After Sales Customer Service	Field Trialed - Energy Saving Potential (annual kWh saved)	
Embertec EmberPlug PC+	✓	✓	✓	✓	✓	✓	✓	✓	350 kWh Annual Average Energy Saving	98.5%

Chapter 8 : Summary

Tier 2 APS devices offer a unique opportunity to deliver speedy energy savings to households across the United States. This emerging technology category has brought with it a number of unique product solutions aimed at delivering ever higher levels of energy savings and user convenience.

In order to ensure ongoing investment in this technology category to drive further innovation and improvements in energy efficiency and consumer acceptance; CalPlug has focused on evaluating and developing a field trial methodology to ensure the performance of Tier 2 APS devices can be assessed independently.

Data that will be acquired via CalPlugs Field Testing Methodology will facilitate robust evaluation of the functional and energy efficiency performance of Tier 2 APS devices.

Through CalPlug's laboratory assessment process, we were able to effectively highlight the potential of Tier 2 APS devices, whilst providing a platform to understand the limitation of laboratory testing in determining the performance levels of individual Tier 2 APS devices.

The acquisition of in situ data as outlined in this report has provided a depth of data and analysis rigor to provide industry confidence in the energy efficiency opportunity which exists through addressing plug load.

Through understanding the limitations in traditional field trial methodologies and their difficulty in application to this technology category, CalPlug has effectively devised a calculation methodology focused on determining the percentage (%) of total energy that is saved in the targeted Tier 2 APS environments.

Using this approach in conjunction with pre-existing data on total AV and IT environment energy usage provides a straight forward approach to assessing average energy saving potential on a region by region basis; thus removing the need for ongoing field trials in each target region to determine expected energy savings.

It should be noted that the percentage of energy saved in the field trials undertaken on the Tier 2 APS device will be based on a number of functional attributes of the APS device in question and the retention rates will also be driven by the intelligence of the device. Both these factors are critical drivers towards determining the long term energy efficiency potential of these emerging technologies.

The US is in an advantageous position in not being the first to deploy Tier 2 APS technologies into households and can thus learn from the international experience in the deployment of these technologies. However the field trial approach as devised by CalPlug is designed to provide a uniform assessment and benchmarking process to better evaluate Tier 2 APS technologies based on their functionality and energy efficiency potential and drive further industry investment in delivering innovative solutions in this technology field.

Based on CalPlug's analysis on the independent in situ field trial data (where energy savings were not obtained from Game Consoles) the average annual kWh saving is expected to be 346 kWh. It is also worth noting that this Tier 2 APS device has been deployed in over 800,000 homes globally since 2011 through a number of energy efficiency programs including those in the United States providing confidence in the long term consumer acceptability of this technology category. [17]

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Appendix A: Standard Test Procedures

This section introduces energy testing standards that are observed at CalPlug Engineering Lab.

Test Procedures

IEC (International Electrotechnical Commission)

- Use of a stable power supply (<2% harmonics).
- Stable ambient test room conditions.
- Digital power meter with fundamental active power accuracy of 0.5% or better – capable of measurements of 0.01W or better, capable of including components up 49th harmonic (2.5 kHz) strongly recommended.
- Calibrate the power meter using the IEC 62301 software.
- Data logging capability recommended.

Energy Star

Average power shall be measured from the AC power source to the equipment being tested.

a) General: Unless otherwise specified, measurements shall be made under test conditions and with equipment specified below.
b) Test room: The tests shall be carried out in a room that has an air speed close to the UUT of ≤ 0.5 m/s, and the ambient temperature shall be maintained at 23°C ± 5°C throughout the test. The UUT shall be tested on a thermally non-conductive surface.
c) Test voltage: An AC power source shall be used to provide input voltage and frequency of 115± 1% at 60 Hz to the UUT. (The Total Harmonic Distortion (THD) of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13th harmonic. The peak value of the test voltage shall be within 1.34 and 1.49 times its RMS value.)
d) Test leads: All leads used in the test set-up shall be of a sufficient gauge and length in order to avoid the introduction of errors in the testing process. Note: For further guidance see Table B.2, "Commonly used values for wire gages and related voltage drops" in IEEE 1515.

CEA-2043

Accuracy

Power measurements of 0.5 W or greater shall be made with an uncertainty of less than or equal to 2% at the 95% confidence level. Power measurements of less than 0.5 W shall be made with an uncertainty of less than or equal to 0.01 W at the 95% confidence level. The power measurement instrument shall have a resolution of,

a) 0.01W or better for power measurements of 10 W or less;
b) 0.1 W or better for power measurements greater than 10 W and less than 100 W;
c) 1 W or better for power measurements greater than 100 W.

For equipment connected to more than one phase, the power measurement instrument shall be equipped to measure the total power of all of the phases connected.

Test Voltage

An AC power source shall be used to provide the UUT with an input voltage of 115 V ± 1% and a frequency of 60 Hz ± 1%. The total harmonic distortion of the supply voltage when supplying the UUT in the specified mode shall not exceed 2%, up to and including the 13th harmonic. The peak value of the test voltage shall be between 1.34 and 1.49 times its root-mean-square (rms) value.

Test Equipment

The following should be considered when selecting test equipment:

a) An oscilloscope with a current probe for AC current waveform, amplitude, and frequency;
b) A true RMS voltmeter to verify voltage at the input of the UUT;
c) A frequency counter to verify frequency at the input of the UUT.

Note: Items a) and b) may be considered optional when the ac source output has sufficient accuracy.

Calibration

Test instruments shall be calibrated annually to traceable national standards to ensure that the limits of error in measurement are not greater than ± 0.5% of the measured value over the required bandwidth of the output.

True Power Wattmeter

Crest Factor

A true power wattmeter shall be used and shall have

a) Accuracy and resolution in accordance with previous section;
b) Sufficient bandwidth;
c) A crest factor rating that is appropriate for the waveforms being measured and capable of reading the available current waveform without clipping the waveform. The peak of the current waveform measured during SLEEP and ON modes for the UUT shall be used to determine the crest factor rating and the current range setting. The full-scale value of the selected current range multiplied by the crest factor for that range shall be at least 15% greater than the peak current to prevent measurement error.

Bandwidth

The current and voltage signal shall be analyzed to determine the highest frequency component (i.e., harmonic) with a magnitude greater than 1% of the fundamental frequency under the test conditions. The minimum bandwidth of the test instruments shall be determined by the highest frequency component of the signal.

Frequency response

A wattmeter with a frequency response of at least 3 kHz shall be used in order to account for harmonics up to the 50th harmonic.

Sampling Interval

The wattmeter shall be capable of sampling at intervals less than or equal to 1s.