A PLUG LOAD MONITORING AND CONTROL TECHNOLOGY FOR OFFICE BUILDINGS

Project ID ET15SDG7011

San Diego Gas & Electric
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Technology Assessment Report

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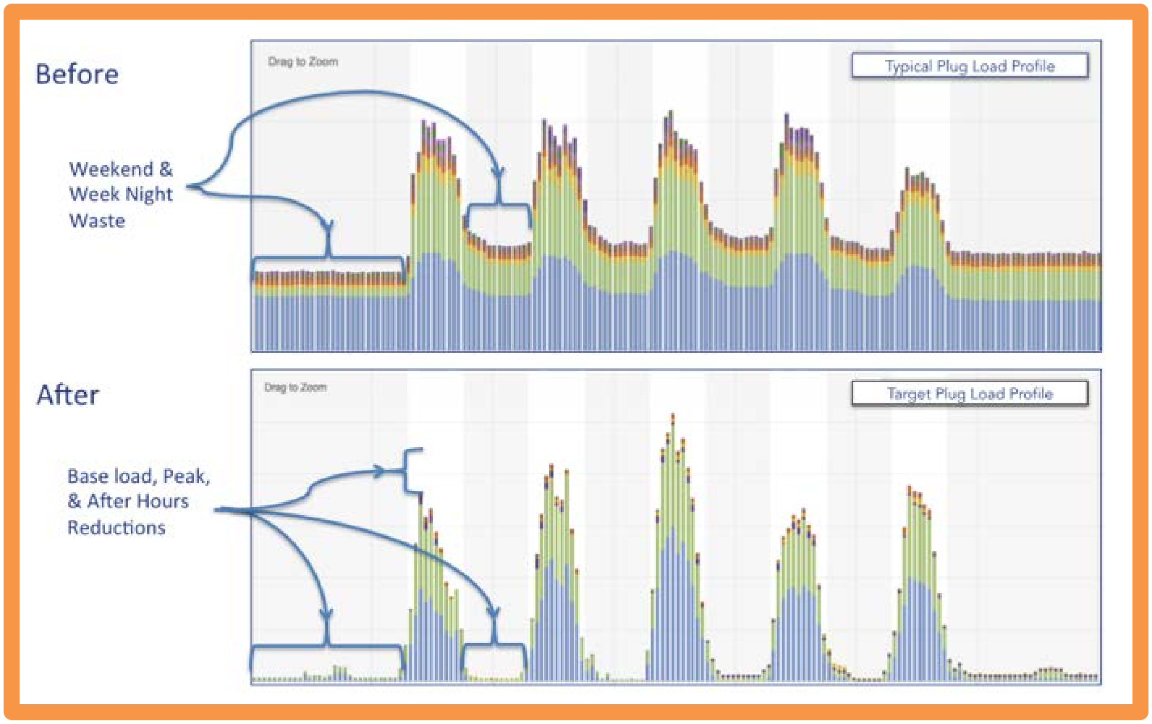

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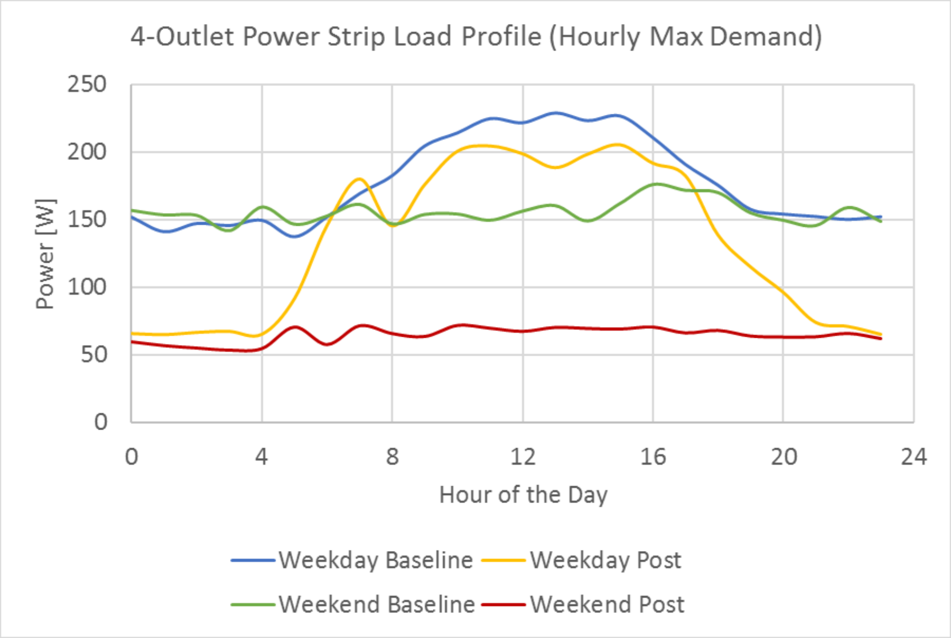
EXECUTIVE SUMMARY

In support of California's strategic plan to accelerate the penetration of energy efficiency technologies, this report presents the findings of a field evaluation of a plug load monitoring and control technology in an office building. The work was executed by Alternative Energy Systems Consulting Inc. for the San Diego Gas and Electric Emerging Technology program.

The primary goal for this project was to determine the energy savings of the plug load control technology in a typical office building setting. The technology consists of networked power strips which communicate with an external vendor cloud server. The cloud server hosts data collection, trending, and controls through the use of scheduling and logical rules. Each power strip receptacle switches on and off according to user-defined schedules or master/control rules. The estimated cost for 104 four-receptacle power strips, 3 cloud communication bridges, and annual data service fees is about $11,933 for the first year and $1,040 each subsequent year.

A field trial was conducted with 104 power strips on a single floor of a large commercial office building located in San Diego. The hourly analysis used validated data from the vendor's cloud servers to calculate savings by comparing 13 days of baseline and 29 days of post-controls energy usage. All relevant plug loads on the floor were included: printers, coffee makers, computers, monitors, speakers, as well as other typical office equipment. These savings were largely attributable to a small subset of the total plug load types: desktop computers, monitors, refrigerators, copy printers, and water dispensers. Figure 1 shows the baseline and post hourly load profile for an average 4-outlet power strip. Load profiles for various equipment types are also included in the report.

FIGURE 1 – AVERAGE POWER STRIP LOAD PROFILES



For the single office building floor, this amounted to annual energy savings of 11,419 kWh/year or 19.9% of the baseline consumption. Assuming that each 4-outlet power strip is roughly associated with one desk, the technology saves about 114 kWh per office employee or workstation. The energy savings and demand reduction were higher during off-peak hours when equipment was in less use. This distribution of savings is typical of plug load

controls whose schedules follow typical office business hours. The technology implementation reduced plug load demand and energy consumption for each time-of-use (TOU) period as listed in Table 1.

TABLE 1 - TOU SAVINGS SUMMARY AND DISTRIBUTION

TIME-OF-USE PERIOD	BASELINE ENERGY [KWH]	ENERGY SAVINGS [KWH]	BASELINE DEMAND [KW][1]	DEMAND REDUCTION [KW]
Summer on-peak	7,765	448 (5.8%)	22.34	1.69 (7.6%)
Summer semi-peak	7,401	792 (10.7%)	17.80	2.89 (16.3%)
Summer off-peak	13,578	4,469 (32.9%)	15.71	8.74 (55.7%)
Winter-on-peak	2,500	204 (8.2%)	17.91	2.57 (14.4%)
Winter semi-peak	12,667	1,037 (8.2%)	20.22	2.32 (11.5%)
Winter off-peak	13,578	4,469 (32.9%)	15.71	8.74 (55.7%)
Total Annual	**57,489**	**11,419**	**n/a**	**n/a**

Based on the technology costs and savings estimates using a TOU rate structure, the payback was shown to be about 11.7 years without any utility program incentive. This payback was calculated using the technology cost and inflation-adjusted TOU energy cost savings which amounted to about $1,783 starting on the first year.

The technology was effective at achieving energy savings through a combination of automated controls and behavioral changes. It is likely that the effectiveness of the technology could be further improved through various efforts that encourage more end-user participation and continued optimization of the control strategies. Furthermore, ROI could possibly be improved by focusing only on the plug load types which yield the greatest savings rather than performing a blanket installation across all plug loads in the building. There were many instances of receptacles having zero or near zero loads. Focusing on the plug load devices that provide the best return and including power strips with fewer receptacles may result in improved payback.

One of the risks related to this system is that energy savings could be eliminated if customers move their devices to different outlets without updating the system settings. This could result in unwanted shutdowns, ineffective shutdowns, or confusion in the energy monitoring user interface. However, this potential risk could likely be mitigated through proper workforce training and diligence by the facility or energy management staff. As a result, close collaboration and agreement between employees, facility managers, vendors, and IT staff is critical to the success of this technology. If this type of cooperation is possible, the technology has promise for behavioral and automated energy savings within a particularly unaddressed electrical end-use.

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[1] Baseline demand and demand reduction refer to hourly maximum demand (billing demand) rather than average load.

ABBREVIATIONS AND ACRONYMS

AESC	Alternative Energy Systems Consulting
DR	Demand response
EE	Energy efficiency
ET	Emerging technologies
IPMVP	International performance measurement and verification protocol
M&V	Measurement and verification
ROI	Return On Investment
SDG&E	San Diego Gas & Electric
TOU	Time-of-use rate structure

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INTRODUCTION

This study was performed by Alternative Energy Systems Consulting (AESC) on behalf of San Diego Gas and Electric's (SDG&E) Emerging Technologies (ET) program. AESC is an energy engineering practice specializing in utility programs, technology assessments, demand side audits, and measurement and verification. SDG&E's ET program strives to increase the exposure and success of emerging and underutilized energy efficiency (EE) and demand side management technologies in the California marketplace. This field test technology assessment was designed to provide information on a plug load management technology for office buildings.

Office electronics and plug loads account for a sizable portion of overall commercial energy consumption. The California Commercial End-Use Survey points out that plug load office equipment in the state and SDG&E territory accounts for up to 20.2% and 15.4% of the total building energy use, respectively (Itron, 2006). Although office electronics are increasingly implementing control logic and EE designs to reduce energy footprints, there remain few options for customers to reduce excess energy consumption of plug load equipment. Two particularly unaddressed issues are the standby, "vampire" loads and the devices remaining on when not in use.

A vampire load (sometimes called standby or phantom load) is the electric demand of a plug load device that occurs when the device is turned off by the user. Although the plug load device is turned off, manually or otherwise, it may still draw power to maintain small, often unnecessary electronics. Televisions, coffee machines, computer monitors, stereos, cell phone chargers, printers, water dispensers, and computers are only some of the common office devices that have standby loads. While each standby load is typically small, they are constant and can consume large amounts of energy over time, especially when one considers the large number of personal and general office electronics that are now required in the work place. Additionally, office equipment is often left powered on during non-business hours or when not in use. Both these modes of excess energy consumption present a good opportunity for technological and behavioral changes that can improve office building energy efficiency.

BACKGROUND

Office equipment plug loads are a growing end-use and will continue to provide widespread opportunities for energy savings. The Department of Energy's Buildings Energy Data Book shows that office buildings have the highest use of computers and other plug load office equipment (9.4% of total usage) of any building type followed by healthcare, food sales, and education. Additionally, the total fraction of energy consumption due to electronics and computers is expected to increase for all commercial sector customers from 5.7% in 2015, to 6.3% in 2025, and 6.6% in 2035 (Department of Energy, 2012).

Many studies have been performed to characterize electric plug loads and identify opportunities for EE measures within commercial applications. The data for large office buildings show a substantial need for effective EE measures for plug load controls. For the relevant customer segments, the California Commercial End-Use Survey points out that plug load office equipment in California and the SDG&E territory accounts for up to 20.2% and 15.4% of the total building energy use, respectively (Itron, 2006). A more recent study published in 2011 by the California Energy Commission showed that office plug loads accounted for more than 20% of California office buildings' energy consumption (Ecova, 2011) and 66% percent of this was due to computers and monitors while the remainder was attributable to devices such as printers, speakers, telephones, coffee makers, and water dispensers (Ecos, 2011). Figure 2 shows the total segment consumption and the portions directly relatable to plug load office equipment for four relevant customer segments in California and SDG&E territory.

FIGURE 2 - PLUG LOAD CONSUMPTION IN CALIFORNIA AND SDG&E TERRITORY (ITRON, 2006)

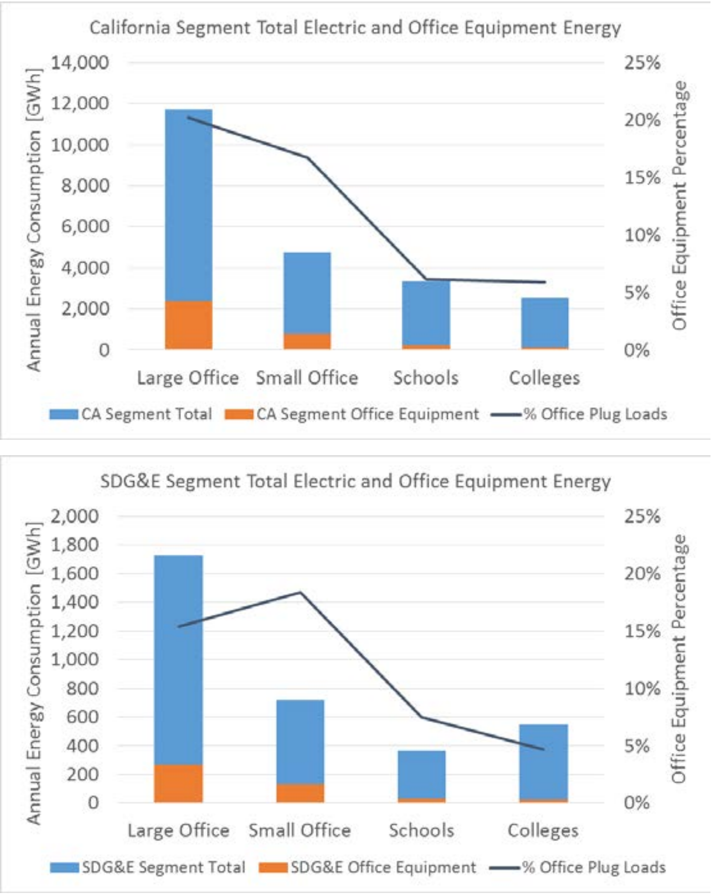
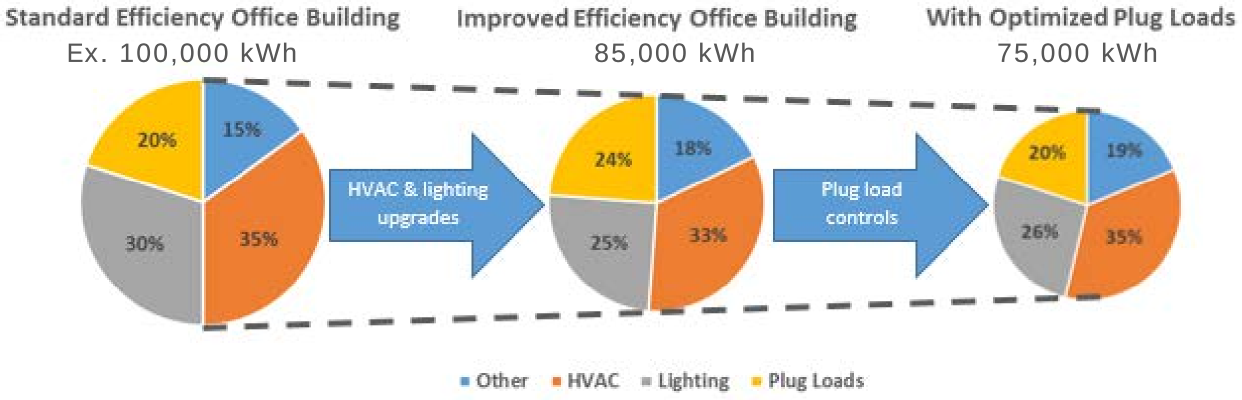


Figure 2 suggests that large and small office buildings should be the primary target for plug load control technologies. Educational buildings are good targets as well since they typically have many workstations and classrooms that could easily be scheduled or enforced with some logical control rules. However, the total plug load consumption and facility percent savings that could be achieved are greater for office buildings. Additionally, it is well known that the saturation of relevant devices such as computers, printers, and other office equipment is nearly 100% in office buildings (Itron, 2014).

Although the Department of Energy estimates about 30% of electrical energy consumed in standard commercial buildings is wasted, plug load consumption remains largely unaddressed even though it makes up 15-20% of office building consumption. As building efficiency improves due to regulatory actions, IOU programs, and utility customer initiatives, the “plug load problem” persists. Energy efficiency gains are typically made in HVAC, lighting, and process equipment while plug load energy consumption remains constant or increases. As a result, not only does plug load consumption remain constant, but the percentage of the total consumption attributable to plug loads actually increases as other end-use efficiency improves. Figure 3 illustrates this characteristic problem known as the “plug load problem,” adapting a figure from the emerging technology manufacturer’s literature. The first two pie charts reflect the typical progression from a standard efficiency to high efficiency office building, while the final chart illustrates the additional potential of plug load savings.

FIGURE 3 - THE PLUG LOAD PROBLEM (ILLUSTRATIVE ONLY – SCALES AND ENERGY USE DERIVED FOR EFFECT)



As illustrated in Figure 3 the plug load problem remains largely unaddressed and is a prime candidate for energy waste reduction. Publications have presented estimated potential savings of comprehensive office plug load system overhaul and control strategies; one report estimated plug load energy savings of 19% and 40% for two case studies (Ecova, 2011).

The market size and opportunity for such a measure is large and untapped since nearly every workstation in office buildings (and other commercial buildings) has plug load equipment that consumes excess energy. As evidence of this, one study found that office equipment was frequently left in full power state during unoccupied building hours (Marla Sanchez, 2007). During unoccupied hours, personal computers, monitors, and printers were found to be on or in a low power state 64%, 59%, and 75% of the time, respectively. Although these numbers may be slightly outdated as office equipment designs and IT best practices have improved, it demonstrates the large potential for improved energy efficiency through either technological controls or behavioral changes.

Despite this substantial, optimized end-use, there is no current energy efficiency building code that directly addresses standard commercial office electronic plug load management in

California. Although various plug load devices may have Energy Star standards or built-in energy efficiency features, no standards or code for management of these plug loads has been established.

Although no energy efficiency standards and programs related to this type of plug load management exist, there have been attempts at measures in the marketplace and encouragement from utilities, research institutions, and industry partner organizations. Despite this encouragement and obvious need for energy efficiency improvement, the standard practice for commercial office plug loads is to resort to the use of wall outlets or manual power strips which are almost never turned off. Thus, there is a need for emerging technologies that can provide energy efficiency control measures for this plug load management opportunity.

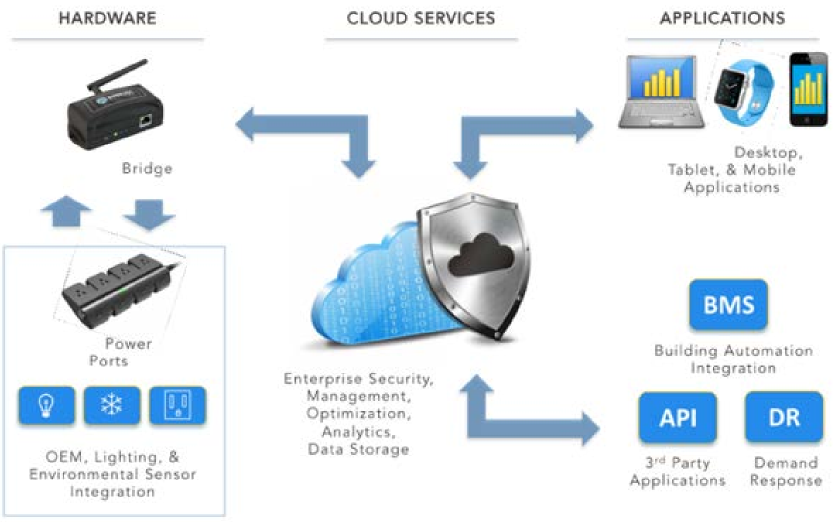
EMERGING TECHNOLOGY DESCRIPTION

As described in the preceding section, the largely unaddressed issue of standby and wasted plug load consumption necessitates an emerging technology solution. There are advanced power strip options which have control strategies using occupancy sensors, remote controls, schedules, or master/controlled schemes. Additionally, there are monitoring systems that can report plug load energy use and demand in order to inform users of their instantaneous and historical use patterns.

However, there are few options that can be used for a networked, building-wide system that integrates data collection, trending, and customizable control strategies. This type of networked, plug load energy management system is the technology under study. This type of product is offered by several vendors including Enmetric, Best Energy Reduction Technologies, and Autani.

The emerging technology studied in this report is a monitoring and control system that is a combination of hardware, software, and cloud-based services. This plug load energy management system allows users and facility personnel to optimize their plug load usage to the facility's specific needs and use patterns. The estimated cost of each set of 50 power strips with 1 bridge and annual data service fees is about $5,650 for the first year and $500 each year after that.

FIGURE 4 - PLUG LOAD ENERGY MANAGEMENT EMERGING TECHNOLOGY



The hardware comes in the form of networked power strips which have monitoring and switching capabilities. The power strips are able to energize or de-energize each receptacle independently and transmit power characteristics and control signals to and from a wireless communications hub. Each hub can register 50 different power strips (for the particular model under study) and serves as a communication bridge with exterior cloud servers. Data and control logic is transmitted between the power strips and cloud server via these bridges.

A customizable software interface allows users to view plug load consumption and demand and define automated control logic. Instantaneous and historical plug load data can be viewed at different resolutions, from the entire facility to individual receptacles with various timescales. Each receptacle or power strip can be defined with identifying nomenclature (such as “Joe’s laptop” or “printer”). Using these features, facility managers can use the technology to develop a clear, high-resolution monitoring system of a building’s plug loads. This monitoring system can provide users with insight into their usage patterns.

Although monitoring of plug loads may result in energy saving behavioral changes, automated controls can provide immediate, well-defined efficiency improvements. Thus, the technology allows users to define rules for the power strip receptacles, individually or in groups. There are three types of rules:

1. **Scheduling**. Each plug load or groups of plug loads can be placed on a schedule so that the devices are only powered during active times. For instance, a water dispenser or mini-fridge could be depowered during unoccupied building times.
2. **Master/controlled**. The master/controlled rule allows users to define a master plug load that determines whether other receptacles will be powered or not. If the master device exceeds a defined power threshold, then the controlled receptacles are powered on and vice versa. For example, if a computer is defined as the master device, then the associated monitors, speakers, and any other desired plug loads can be energized only when the computer is active. Going further, master devices can be defined for any plug loads throughout the whole building if there is a logical reason to do so.
3. **Demand response (DR)**. Demand response strategies can be defined so that if a demand response signal is received the technology can curtail load by de-energizing devices such as spare printers, lighting, conference rooms, etc. The technology can receive an OpenADR 2.0 signal even if it is not certified yet.

User permissions can be specified such that each employee can be given administrative tools and viewing capabilities to only the relevant set of plug loads and power strips. For instance, an employee may be given administrative access to only the power strip at his desk. Alternatively, facility or energy manager can have access to all building receptacles and track usage and view or override each employee’s selected control strategies.

In this way energy savings can be achieved through a variety of methods or a hybrid of such options:

- Facility energy managers can assign control logic to all connected plug loads based on facility-wide adopted best practices.
- Training can be given to staff and each employee can define their own control rules.
- Facility managers can define demand response rules in case of OpenADR events.
- Users can view their energy consumption patterns to elicit behavioral changes or adopt company best practices with respect to plug load usage.

ASSESSMENT OBJECTIVES

The goal of this technology assessment was to identify the energy savings capabilities of a plug load energy management system in an office building. Several objectives were established to order to achieve this goal:

- Measure and verify energy and demand savings of specific selected devices within the total plug load population.
- Perform an energy savings and permanent demand reduction evaluation of the controlled plug loads.
- Comment on the market potential of the technology, barriers to implementation, and recommendations.

In order to accomplish these objectives, the technology was installed on a single floor within a high rise commercial office building in San Diego. A large assortment of devices was monitored with a total of 388 individual receptacles and 97 plug strips.

TECHNICAL APPROACH AND TEST METHODOLOGY

The measurement and verification (M&V) plan for the emerging technology assessment was based on the International Measurement and Verification Protocol (IPMVP), adhering to Option B which requires all relevant performance parameters be measured. Measurements from the plug load energy management system were verified and then used to calculate energy savings and permanent demand reduction by comparing pre-controls and post-controls data. The technology was installed prior to the baseline period which consisted purely of monitoring the plug loads without any control rules established. After 13 days of baseline measurements, scheduling was established for each plug load and employees were given administrative rights to their workstation power strips. The employees were given brief training on the user interface, how to view data, and how to define control rules prior to the post-control period of 27 days.

HOST SITE

The participating host site for the field trial was a large commercial office building in the San Diego area in California climate zone 7. Business hours were standard Monday through Friday with most employees present between 7 AM and 6 PM. The plug load energy management system was installed on one floor of the building spanning all installed plug loads on that floor. The installation comprised 104 four-outlet power strips. Table 2 lists the number of plug load types that were included in the study.

TABLE 2 - PLUG LOADS OF HOST SITE[2]

Plug Load Type	Frequency	Plug Load Type	Frequency
Coffee Maker	4	Printer Copier	1
Desktop Computer	57	Printer Feeder	3
Copier	3	Projector	1
Fan	3	Mini Refrigerator	7
Laptop Computer	70	Television	1
Miscellaneous[3]	16	Vending Machine	1
Monitor	148	Water Dispenser	6

INSTRUMENTATION

The test plan utilized the measurement capabilities inherent to the technology itself after the accuracy and reliability was properly verified. The system records measurements on 1 second intervals and data is stored on external servers through the bridge communications.

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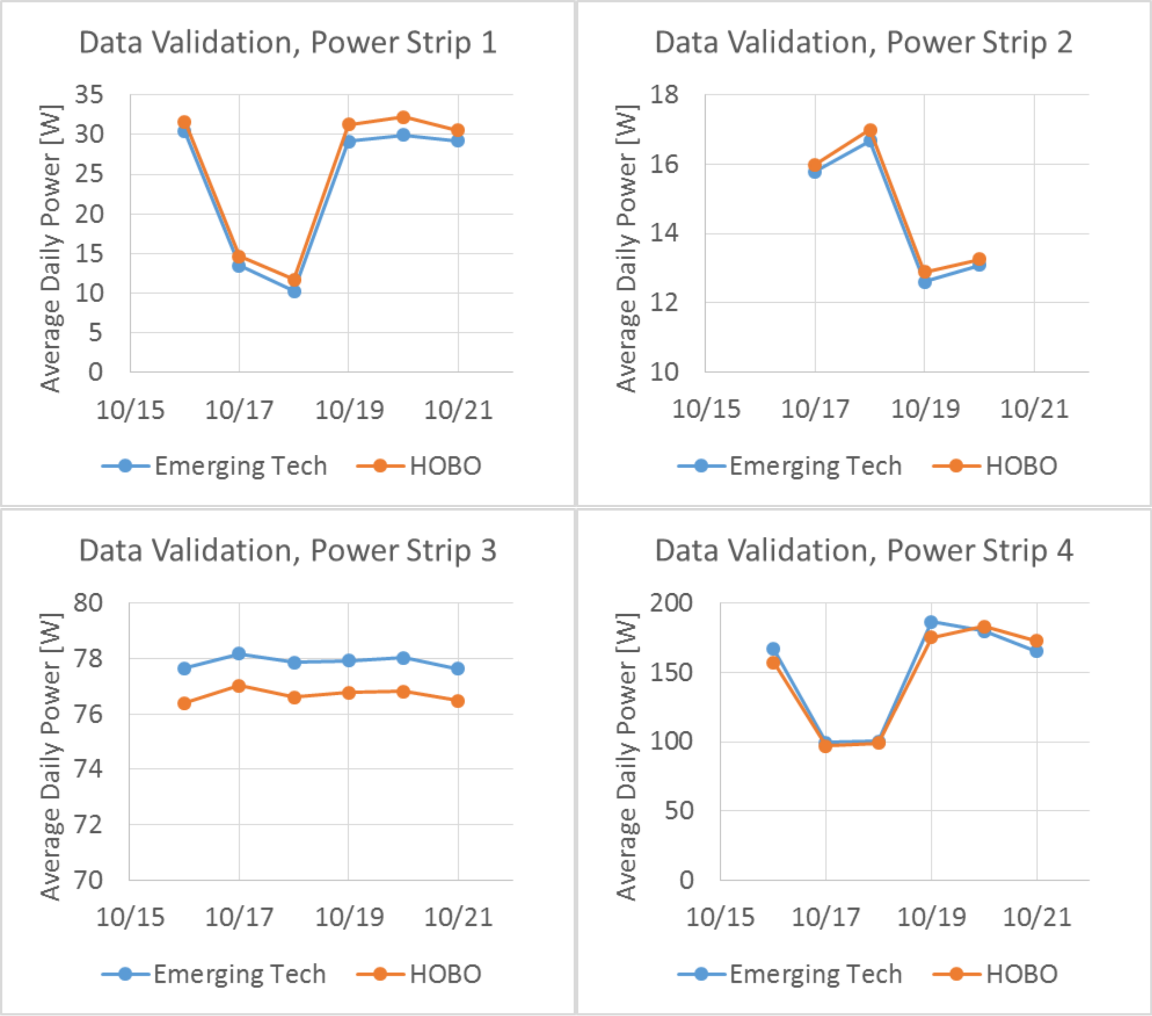
[2] There were also about 85 plugs that were unlabeled, but were either unused or had low power similar to the miscellaneous category.

[3] Miscellaneous included Ethernet switches, KVM switches, label makers, network hub, phone chargers, headsets, power supplies, routers, projector control panel, USB hub, and other low power devices.

Measurements included average power, maximum power, voltage, current, frequency, and power factor. The instrumentation accuracy was verified using independent, calibrated HOBO plug load loggers in series with the instrumentation at 4 of the power strips. The comparison of the daily average power strip demand for the two measurement methods is shown in Figure 5. Note that the y-axis scale does not begin at zero for two of the plots so that the differences can be seen.

FIGURE 5 – COMPARISON OF CALIBRATED HOBO LOGGING AND EMERGING TECH SERVER DATA



The average absolute error and absolute percent errors for the four verified strips are listed in Table 3.

TABLE 3 - VALIDATION OF TECHNOLOGY-INHERENT MEASUREMENTS

	Average absolute error [W]	Average absolute percent error
Power strip 1	1.6	7.2%
Power strip 2	0.2	1.8%
Power strip 3	1.2	1.6%
Power strip 4	6.0	3.8%

These comparisons of the technology monitored data to independent, calibrated data can serve as validation of the data received from vendor servers that was measured by the power strip hardware. Based on this validation, the data measured by the power strips and monitoring technology was used to calculate the demand, energy consumption, and savings achieved by the technology.

CALCULATION METHODOLOGY

The demand and energy savings calculations were based on vendor server data provided to AESC. Both baseline and post-installation data was given for two separate monitored periods. The monitored baseline system equipment consisted of 104 standard 120 volt power strips with four independently measured receptacles each. Each receptacle in the submitted data was given a unique identification number. Data was delivered with hourly intervals spanning the entire test period and included average hourly power and maximum hourly power per receptacle.

The analysis of the baseline and controlled plug load energy usage utilized a simple before and after energy savings calculation over the duration of the deployment. First the hourly data was consolidated into 24 hour load profiles for weekdays and weekends. The average hourly demand for each device category was determined by summing the average demand across each device instance and day of the week:

$$kW_{hr,avg} = \frac{1}{N+M}\sum_{i,j}^{N,M} kW_{avg,i,j}$$

where $kW_{hr,avg}$ is the average demand for the given hour and device category (laptop, coffee maker, etc.), *N* is the device frequency listed in Table 2, *M* is the number of weekdays or weekend days during the monitoring period, and *i* and *j* are indices spanning *N* and *M*.

Similarly, the max hourly demand per device category was calculated as

$$kW_{hr,max} = \frac{1}{N+M}\sum_{i,j}^{N,M} kW_{max,i,j}$$

Using these hourly load profiles for the baseline and post-controls period, hourly demand reduction profiles were determined using the following simple equation.

$$\Delta kW_{hr} = kW_{hr,max,baseline} - kW_{hr,max,post}$$

Similarly, annual energy savings attributable to each hour of the day were calculated using the following equation.

$$\Delta kWh_{hr} = \left(kW_{hr,avg,baseline} - kW_{hr,avg,post}\right) * (T)$$

Where T is the amount of total time spent at that hour of the day over a year. For weekend hours, *T=(52*2+10)* and for weekday hours *T=(52*5-10)* to account for 10 holidays per year.

Cost savings were calculated by combining the hourly demand reduction and energy savings profiles with the AL-TOU rate. This rate has various non-coincident, on-peak, semi-peak, and off-peak demand and energy charges which differ between summer and winter seasons.

RESULTS

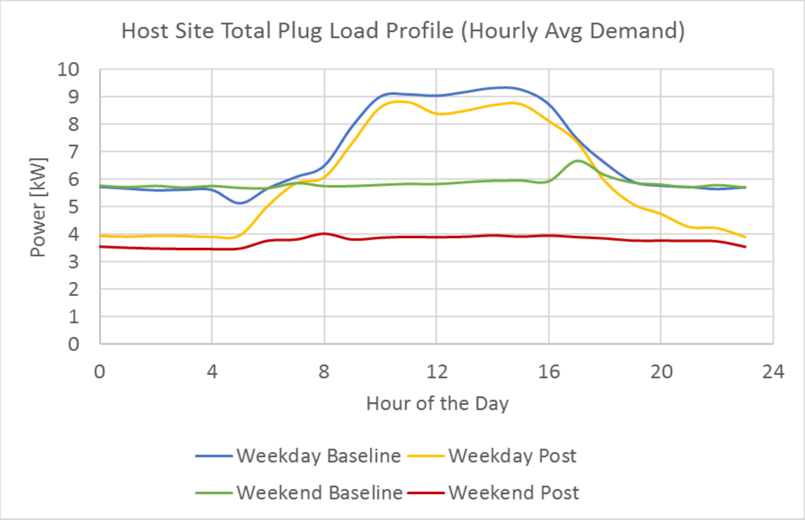
The field trial of the plug load energy management technology was conducted using the instrumentation and methods described above. Note that the study only examined a single floor of the office building rather than the whole building. Demand reduction and energy savings were calculated for each device type and for the total aggregated plug loads. These data were analyzed on an hourly basis and then extrapolated to annual estimates. The annual baseline energy usage for the 104 power strips was 57,489 kWh and the control implementation resulted in an estimated 19.9% annual energy savings of 11,419 kWh. Table 4 lists the energy and demand baseline and savings breakdown by TOU periods for the host site.

TABLE 4 – TOU USAGE AND SAVINGS SUMMARY

TIME-OF-USE PERIOD	BASELINE ENERGY [KWH]	ENERGY SAVINGS [KWH]	BASELINE DEMAND [KW][4]	DEMAND REDUCTION [KW]
Summer on-peak	7,765	448 (5.8%)	22.34	1.69 (7.6%)
Summer semi-peak	7,401	792 (10.7%)	17.80	2.89 (16.3%)
Summer off-peak	13,578	4,469 (32.9%)	15.71	8.74 (55.7%)
Winter-on-peak	2,500	204 (8.2%)	17.91	2.57 (14.4%)
Winter semi-peak	12,667	1,037 (8.2%)	20.22	2.32 (11.5%)
Winter off-peak	13,578	4,469 (32.9%)	15.71	8.74 (55.7%)

The load profiles for the aggregated host site plug loads are shown in Figure 6 and Figure 7. Note that the largest demand reduction occurs during off-business hours. Additionally, the weekday demand trends towards weekend demand during off-business hours. The demand profiles for the whole host site and individual devices are documented in the Appendix.

FIGURE 6 – TOTAL HOST SITE PLUG LOAD PROFILE (AVG HOURLY DEMAND)



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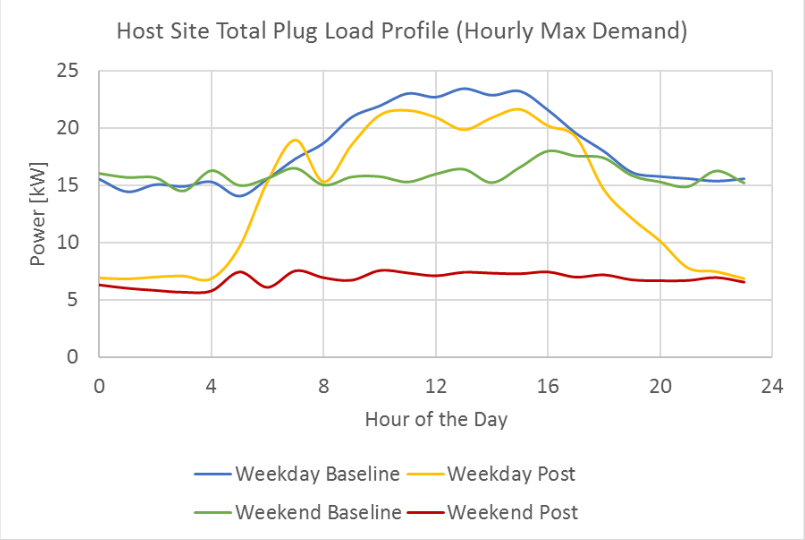
[4] Baseline demand and demand reduction refer to hourly maximum demand (billing demand) rather than average load.

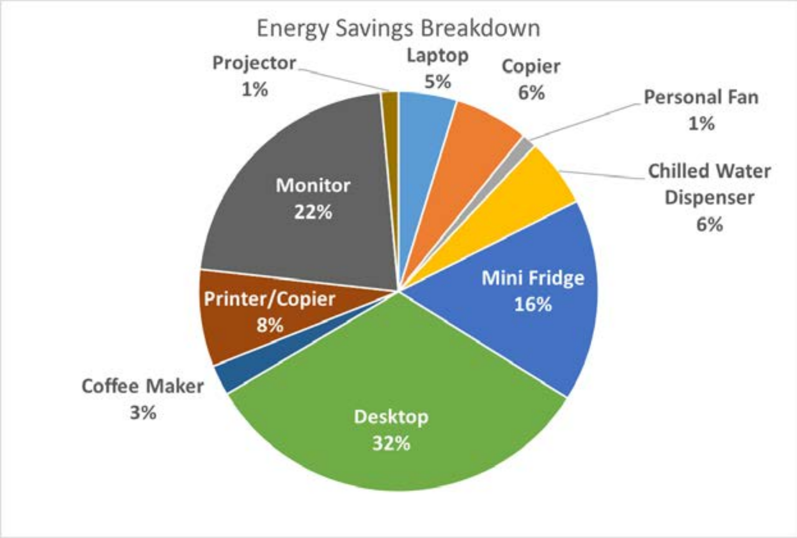
FIGURE 7 – TOTAL HOST SITE PLUG LOAD PROFILE (MAX HOURLY DEMAND)



One way to quantify the potential of the technology is to establish savings per power strip. This would likely be roughly equivalent to savings per workstation or employee. This would allow for scaling and estimation of savings for prospective customers. The load profiles and demand reduction would be about 1/104th of the profile shown in Figure 6. This load profile is also listed in the Appendix, as well as device-specific results. As is apparent in the device-specific load profiles, the greatest individual device savings are achieved for copy printers, refrigerators, coffee makers, and copiers. It is expected that vending machines would also be high on the individual device demand reduction list, but controls were unfortunately not implemented on the one vending machine in this trial.

However, Figure 8 shows that about 90% of the total annual energy savings are derived from controlling monitors, desktop computers, refrigerators, water dispensers, printers, and copiers. Although desktop computers and monitors do not have the best individual device returns, their high frequency makes them the plug loads with the highest total savings potential.

FIGURE 8 – TOTAL ENERGY SAVINGS CONTRIBUTION BY PLUG LOAD TYPE (DEVICE CATEGORIES WITH <1% CONTRIBUTION EXCLUDED FOR READABILITY)



DISCUSSION AND CONCLUSIONS

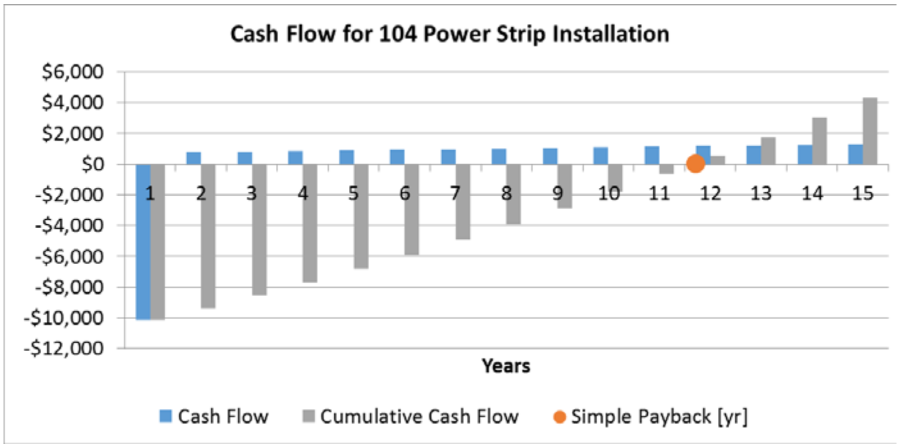
A plug load energy management system was tested on a single floor of a large commercial office building in the San Diego area. The plug load management system proved to be successful in achieving energy savings and a lower average demand profile. The energy savings of any one particular plug load is typically small, but when many loads are controlled in the office setting, the savings accumulate to large energy footprint reduction.

The test and resultant data showed that the technology, as implemented, reduced aggregated maximum demand by about 55.7% during off-peak times and 7.6% during DEER on-peak times. This in turn resulted in 19.9% annual energy savings. For the single floor of the office building with 416 controlled plug load receptacles, this amounted to about 11,419 kWh savings per year. The savings is roughly 114 kWh per workstation per year in similar office building settings. Since only one floor of the multi-floor building was included in the trial, savings per building could be many times this number. However, the TOU analysis showed that the savings were mostly achieved during off-peak hours as shown in the demand profiles in the Results and Appendix sections. Although this is expected for a technology that is largely based on scheduling of business-related equipment, it provides less value than if the savings were more concentrated during on-peak periods.

Based on the hourly and TOU analysis, the calculated ROI is about 8.5% with a payback period of about 11.7 years. This payback is based the following technology costs and cost savings:

- 104 power strips purchased at $99/unit
- 3 communication bridges purchased at $199/unit
- Annual software service fees of $10/power strip
- Hourly demand reduction as determined from the site monitoring and cost savings calculated using the AL-TOU rate. This results in about $1,783 first year savings.
- 2% energy cost inflation per year.

FIGURE 9 - CASH FLOW AND BREAK EVEN POINT FOR THE HOST SITE 104 POWER STRIP IMPLEMENTATION



The estimated payback of 11.7 years is greater than the expected useful life of the technology (about 5-10 years based on other power strip EE measures). From a pure energy perspective, it is likely that significant utility incentives would be necessary engender substantial market uptake since the estimated payback is beyond the expected useful life. However, this economic analysis does not include operational and public relation benefits not associated with direct energy cost savings. Utility incentives of about $0.60/kWh savings would be necessary to yield payback within the lower EUL limit of 5 years.

However, it could be that the energy savings per power strip could be improved by optimizing the power strip placement, connected plug loads, and control strategies. This would likely improve ROI slightly although continued commissioning and monitoring would be essential to continued maximization of savings. It appears that installing the technology only on equipment with higher average demand would reduce the payback of the system by a few years, assuming that a reduction in power strips for the base package also reduces the first year costs proportionally. This approach may also improve reliability of the savings because the equipment that showed higher average demand in this study moves infrequently within the office space, which would reduce the risk of devices not having appropriate scheduling or rules applied due to changing receptacles.

This technology not only has energy saving benefits but can also serve as empowerment and informative device for the users. By viewing historical data on a building’s plug loads, users and facility managers can gain insight into their overall usage and work patterns.

Risks of the technology include the possibility of plug loads being moved between receptacles without altering the respective control rules. This could result in inadvertent shutdowns, negation of energy savings, which could ultimately result in users removing the technology or turning off all rules. However, proper training and user information could help mitigate this risk. Although users may initially have difficulty with unexpected shutdowns or improper control rules, these difficulties would likely dissipate as users became accustomed to the technology. Additionally, since the controls work in the background without any active user input required, the technology may be more likely to be adopted than other technologies that need frequent user input.

Due the customizable nature of the technology and initial system integration, the technology is considered to be relatively complex with a steep learning curve for something as commonplace and under-the-radar as plug loads. Each system would need to be designed and commissioned for each building and particular plug load end-use. Collaboration between building owners, tenants, employees, vendors, and IT staff would be required for a seamless application of the technology.

RECOMMENDATIONS

In general, the technology is a well-designed, matured product fully ready for market adoption. However, it may not be cost-effective and there are some risks and uncertainties inherent to plug load management that could potentially be addressed. For instance, plugs are likely to be moved or added to receptacles after controls and monitoring has been established. This could then result in misleading monitoring results or perhaps unwanted or ineffective control rules if they are not updated. It is easy to imagine having to recommission the entire system after some time has passed if employees do not properly update the system as plug loads are altered.

These issues and others could potentially be addressed with recommendations such as the following:

- Develop best practices for implementers and facility managers as a foundation for integrating the system into their workforce and procedures. In this way, the guesswork and learning curve associated with the installation and commissioning can be reduced and managers can then customize their use from there.
- Provide guidance or training materials to the employees so that they become empowered participants in the technology. The end-users' appreciation of the technology is of paramount importance to the success of the measure.
- Provide a hierarchy of plug load types so that facility managers can decide which devices are the primary targets and what devices may be unnecessary to include. This will improve cost-effectiveness by decreasing the number of strips purchased, decreasing upfront investment, and improving ROI.
- Explore other building types where numerous plug loads are used on a regular schedule or infrequent basis. These could include schools, colleges, lodging, and healthcare facilities.
- Simplify user interface for employees with limited access in order to foster interest and participation.

While customers surveyed during the effort appeared very receptive and excited about the application of the technology, persistence is an uncertainty not addressed by this report. Further study or program evaluation could answer measure persistence questions regarding not only how long the technology stays in place but how users and managers use the controls and monitoring over longer periods of time.

AESC believes that the evaluated technology could be included in a utility energy efficiency program that targets operational and/or behavioral savings if cost-effectiveness is improved via price reduction, optimized installation, or significant incentives. While the overall energy efficiency savings as quantified in this report can be reasonably expected to occur and thus relied on for an incentive program, the DEER peak demand reduction is less significant.

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APPENDIX – LOAD PROFILES

This appendix presents hourly averaged load profiles for each device category.

All devices on host site office building floor

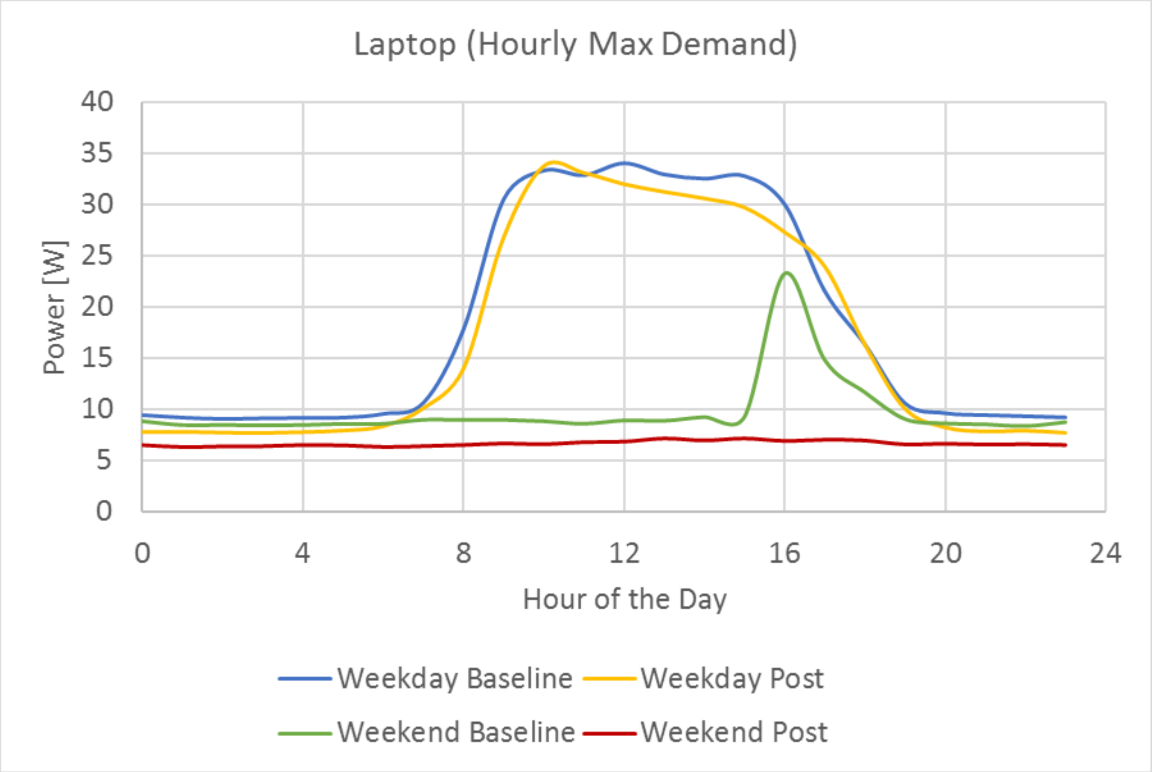
TABLE 5 - AVERAGE HOURLY DEMAND FOR TOTAL HOST SITE PLUG LOADS

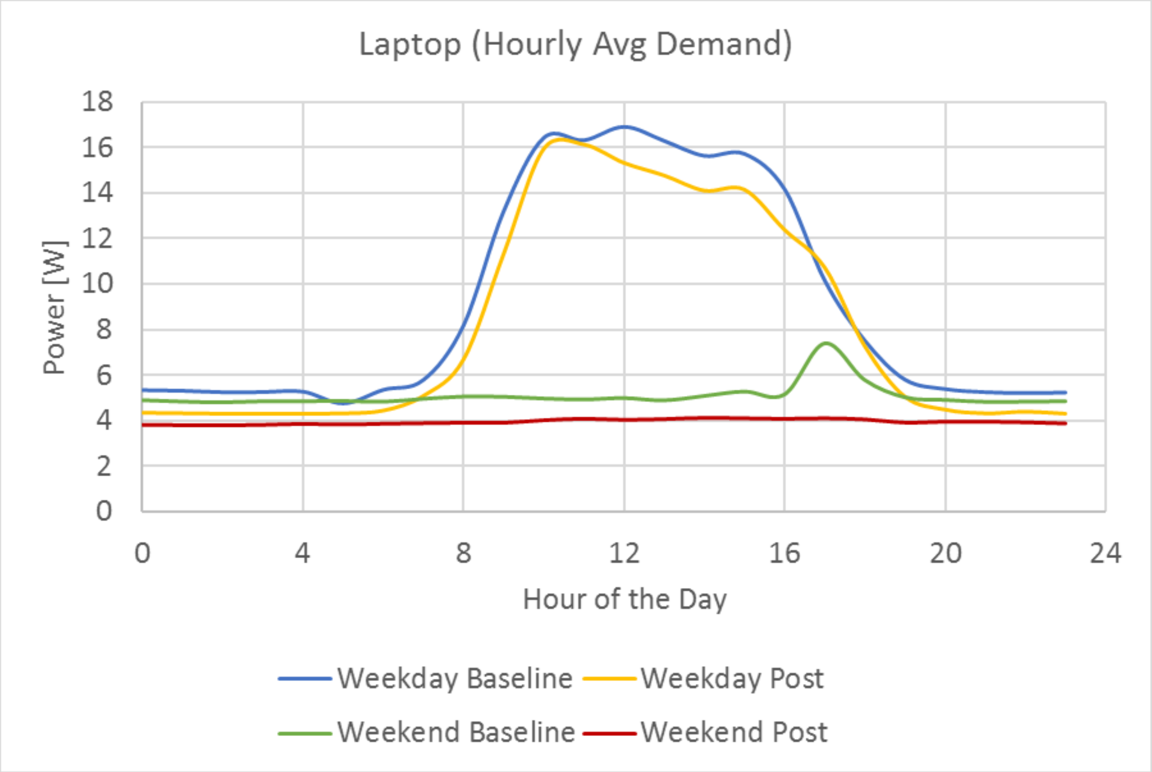
Hour	Weekday			Weekend		
	Baseline Demand [kW]	Post Demand [kW]	Demand Reduction [kW]	Baseline Demand [kW]	Post Demand [kW]	Demand Reduction [kW]
0	5.73	3.93	1.80	5.76	3.56	2.20
1	5.66	3.90	1.76	5.71	3.52	2.19
2	5.60	3.94	1.67	5.75	3.49	2.27
3	5.62	3.92	1.70	5.69	3.47	2.22
4	5.62	3.90	1.72	5.75	3.47	2.28
5	5.13	3.95	1.17	5.68	3.49	2.19
6	5.68	5.03	0.64	5.67	3.78	1.89
7	6.09	5.85	0.24	5.85	3.82	2.03
8	6.49	6.06	0.43	5.75	4.04	1.70
9	7.93	7.32	0.62	5.75	3.82	1.92
10	9.01	8.61	0.40	5.79	3.89	1.90
11	9.09	8.80	0.30	5.83	3.92	1.90
12	9.04	8.38	0.66	5.82	3.91	1.91
13	9.18	8.48	0.69	5.89	3.92	1.96
14	9.32	8.69	0.64	5.94	3.98	1.96
15	9.27	8.73	0.55	5.95	3.93	2.02
16	8.73	8.11	0.62	5.92	3.97	1.95
17	7.48	7.35	0.13	6.66	3.92	2.75
18	6.60	5.92	0.68	6.14	3.86	2.28
19	5.92	5.09	0.83	5.87	3.78	2.09
20	5.77	4.73	1.04	5.80	3.78	2.02
21	5.72	4.26	1.46	5.70	3.78	1.93
22	5.65	4.21	1.44	5.78	3.76	2.03
23	5.71	3.89	1.82	5.69	3.55	2.14

TABLE 6 – HOURLY MAX DEMAND FOR TOTAL HOST SITE PLUG LOADS

Hour	Weekday			Weekend		
	Baseline Demand [kW]	Post Demand [kW]	Demand Reduction [kW]	Baseline Demand [kW]	Post Demand [kW]	Demand Reduction [kW]
0	15.58	6.92	8.66	16.05	6.33	9.73
1	14.49	6.84	7.65	15.71	6.03	9.68
2	15.11	7.01	8.10	15.68	5.84	9.84
3	14.95	7.09	7.86	14.53	5.68	8.85
4	15.34	6.87	8.48	16.30	5.80	10.50
5	14.11	9.66	4.44	15.01	7.47	7.54
6	15.61	15.38	0.23	15.64	6.12	9.52
7	17.36	19.00	-1.63	16.51	7.58	8.93
8	18.72	15.34	3.38	15.05	6.97	8.08
9	20.96	18.57	2.39	15.75	6.74	9.01
10	21.94	21.17	0.77	15.78	7.60	8.18
11	23.02	21.58	1.43	15.32	7.38	7.93
12	22.71	20.97	1.74	16.00	7.13	8.87
13	23.44	19.89	3.55	16.42	7.45	8.97
14	22.87	20.93	1.93	15.26	7.36	7.90
15	23.22	21.67	1.54	16.59	7.31	9.27
16	21.59	20.24	1.35	18.00	7.48	10.52
17	19.57	19.25	0.31	17.57	7.02	10.55
18	17.99	14.63	3.36	17.39	7.22	10.18
19	16.17	12.13	4.04	15.87	6.78	9.09
20	15.81	10.16	5.66	15.32	6.70	8.62
21	15.63	7.80	7.83	14.91	6.72	8.19
22	15.41	7.47	7.94	16.28	6.98	9.30
23	15.62	6.87	8.75	15.23	6.58	8.66

Laptop Computer





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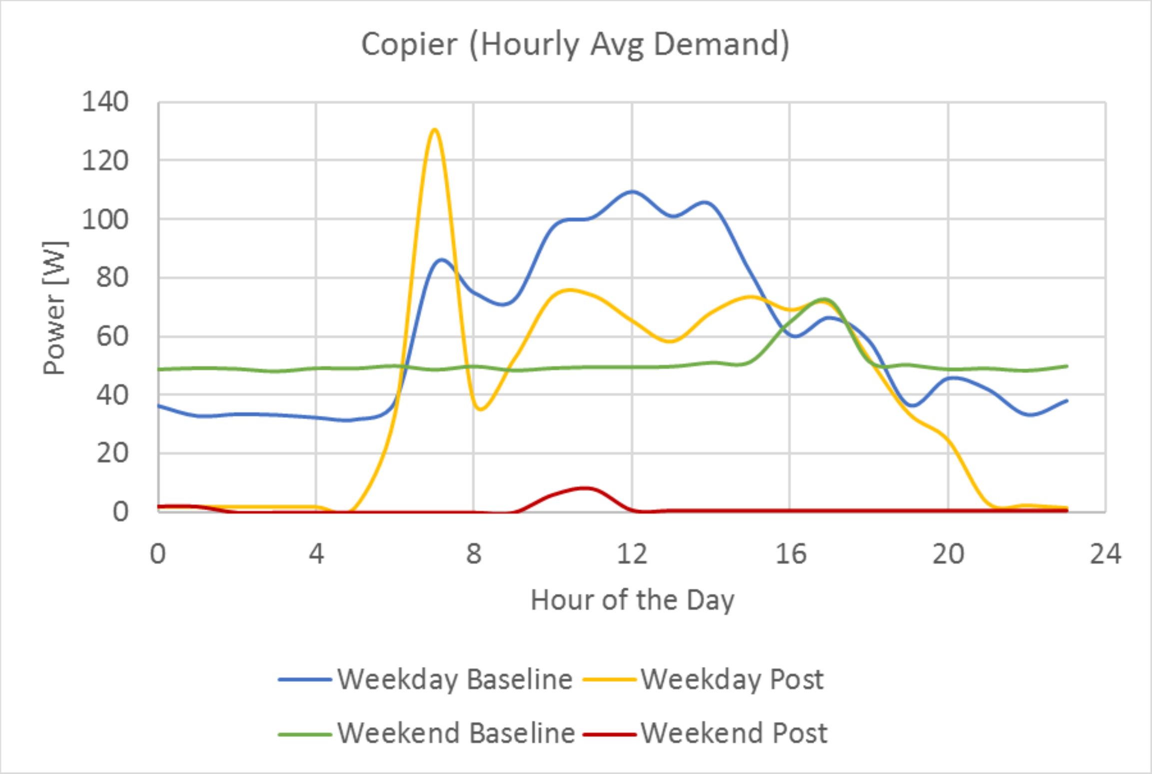
Copier (Hourly Avg Demand)
Power [W]
140
120
100
80
60
40
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0
0
4
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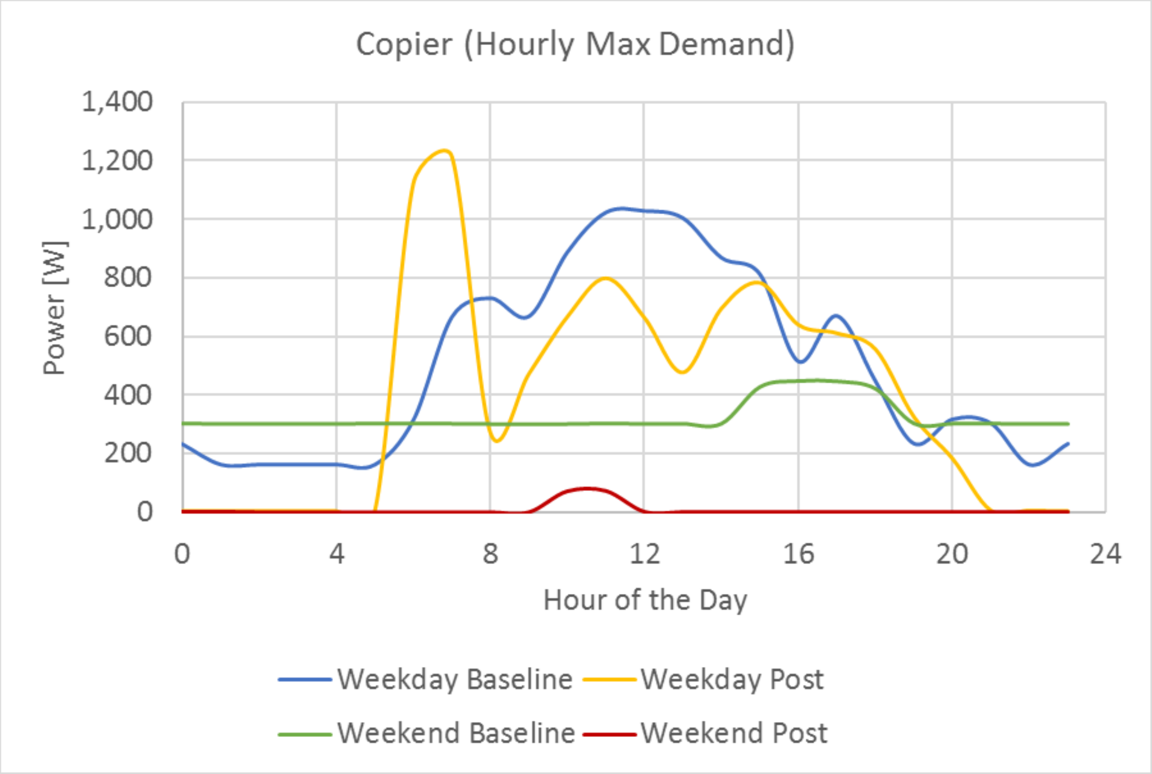
12
16
20
24
Hour of the Day
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post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1,000
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600
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20
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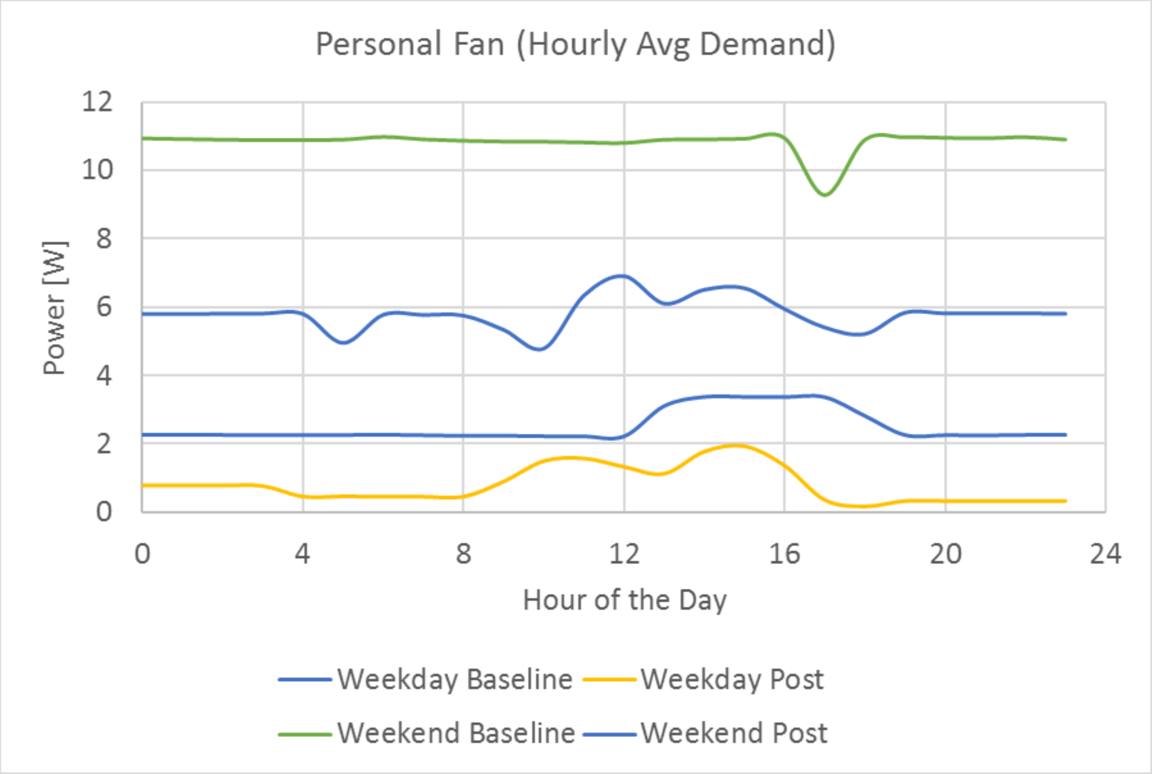
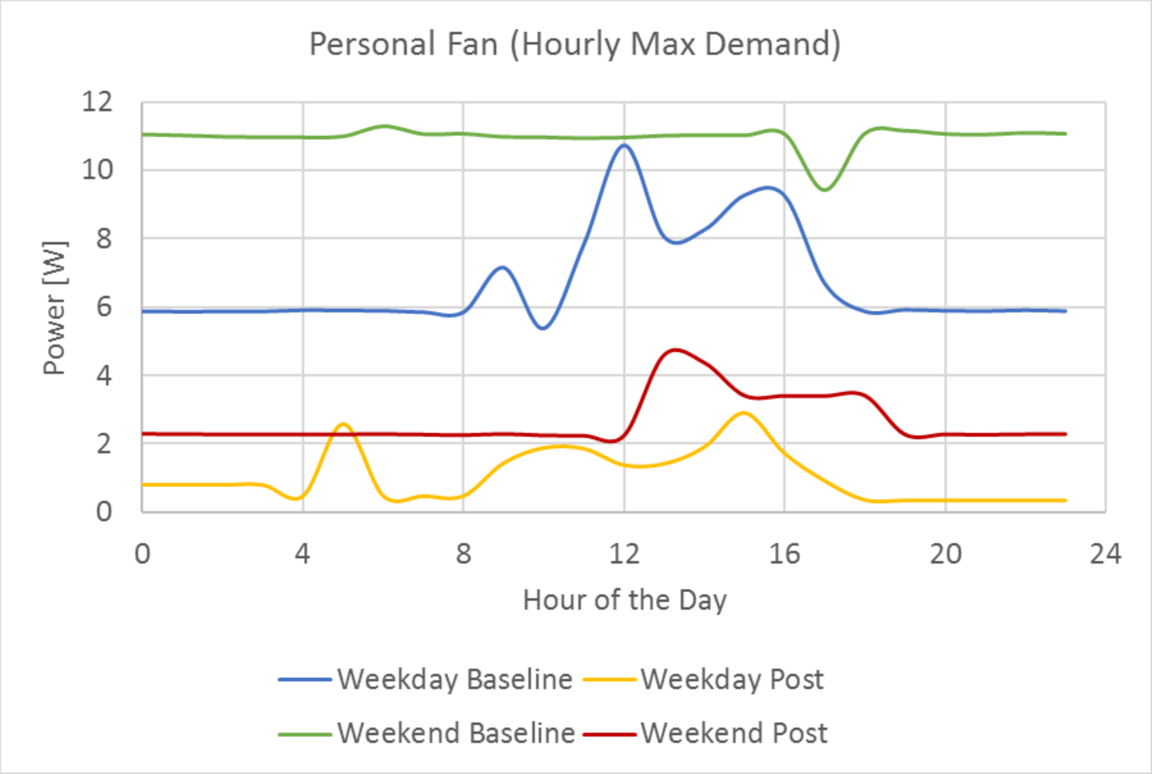
Hour of the Day
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post

Personal Fan





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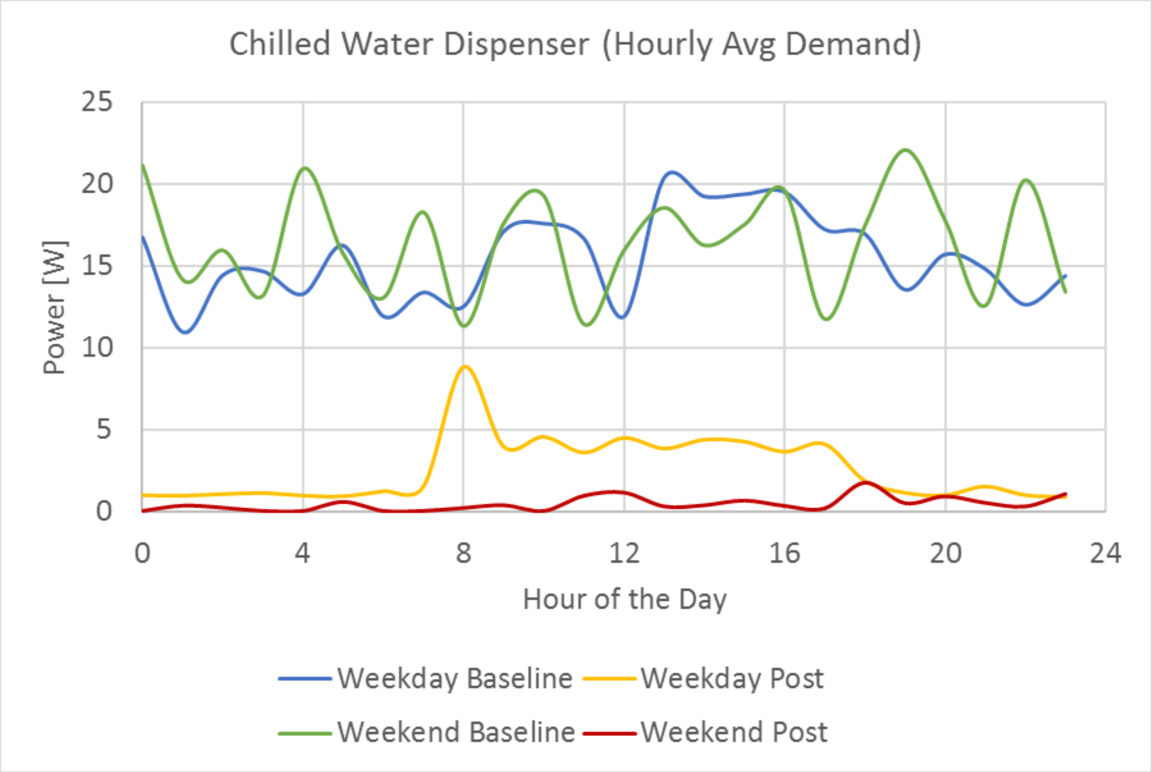

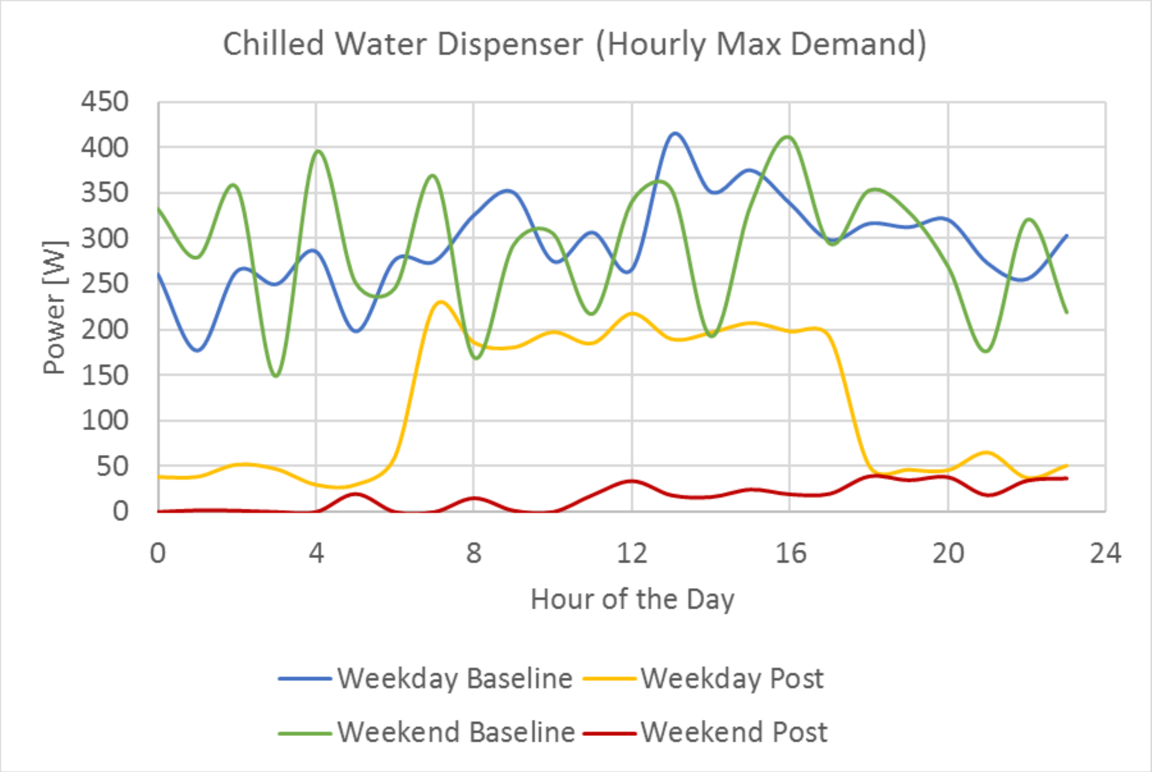

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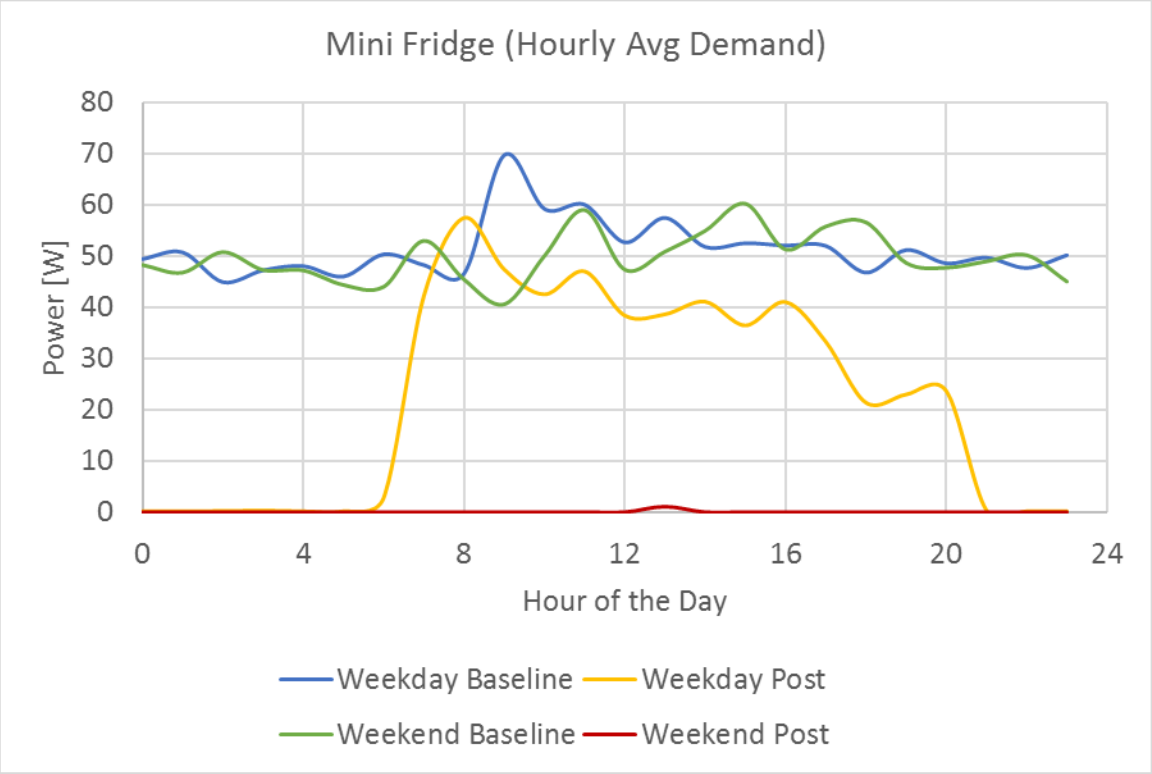

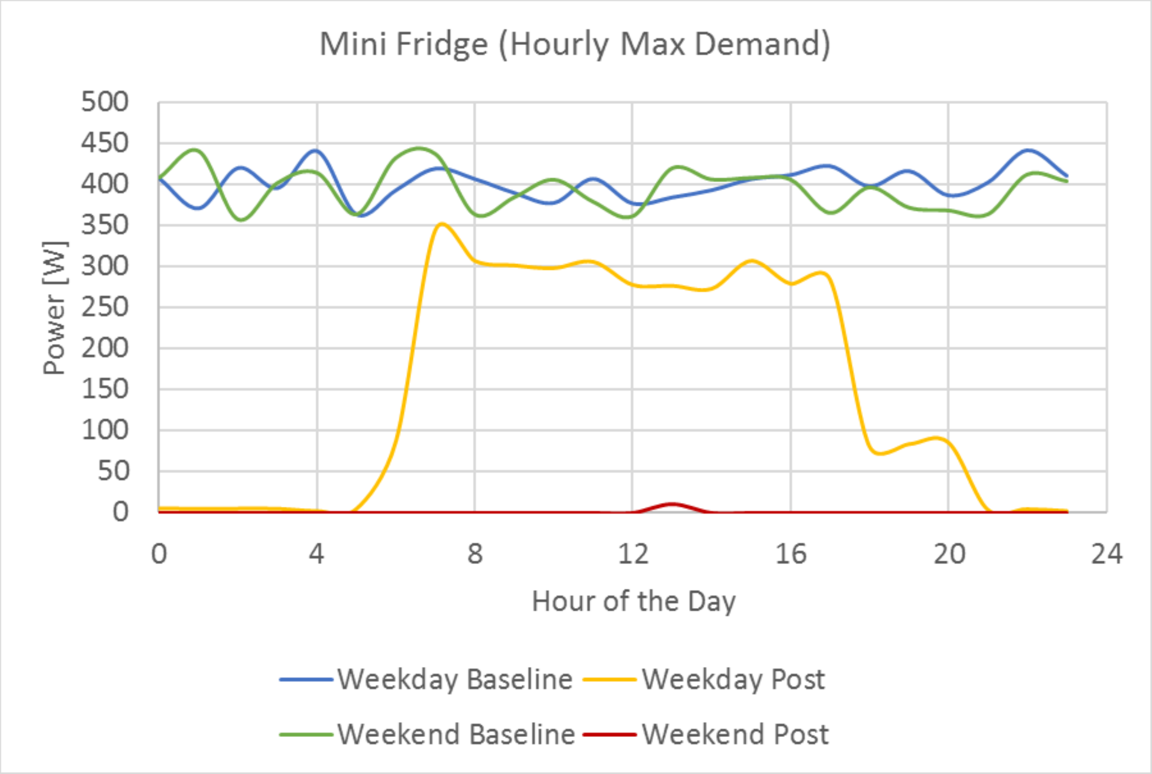

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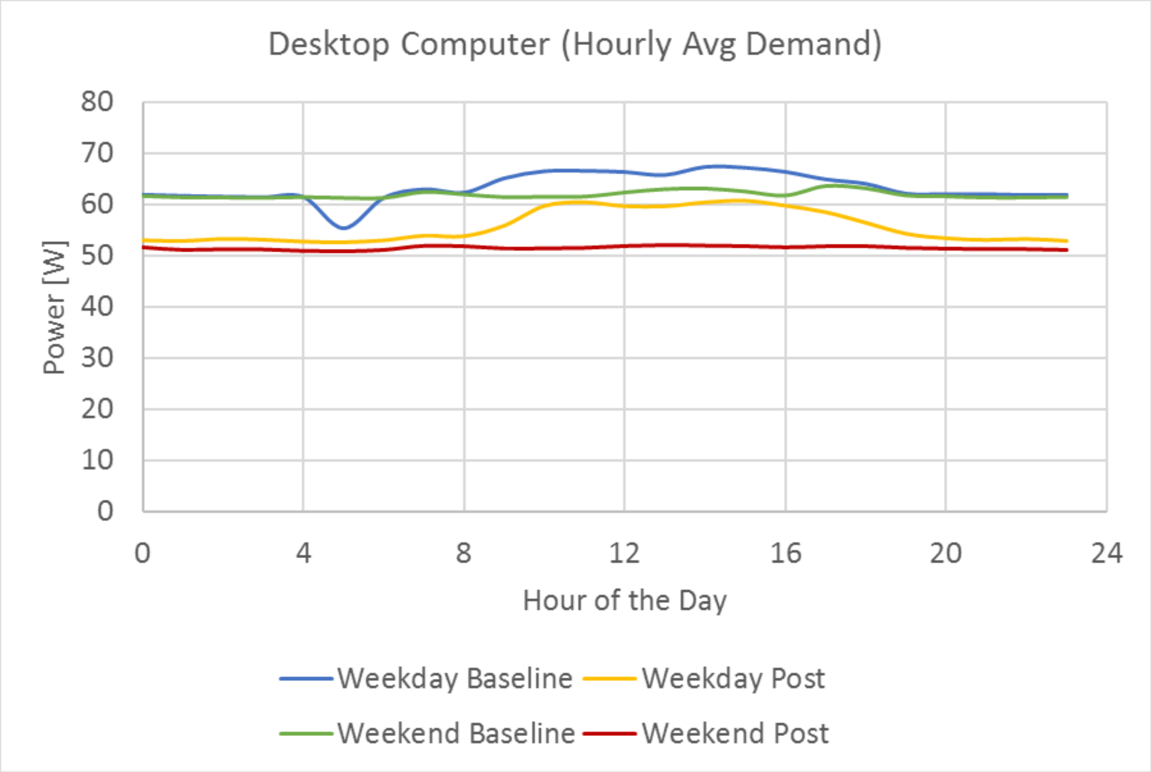
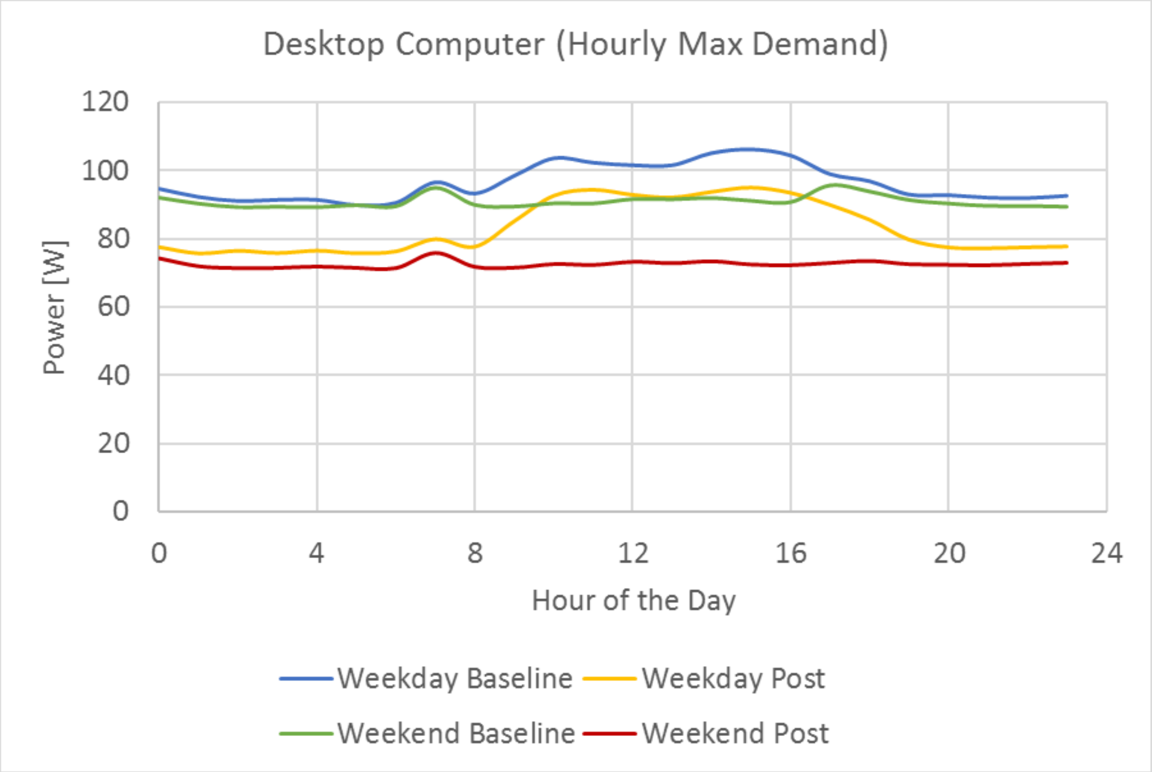
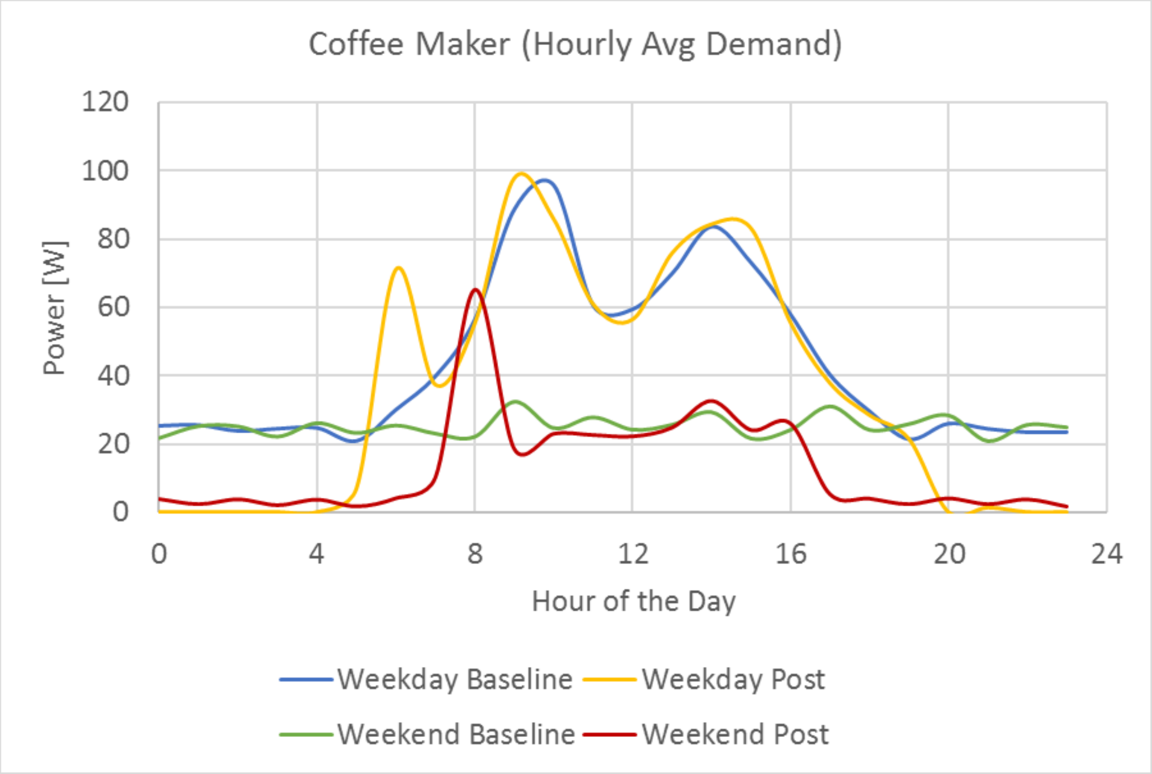
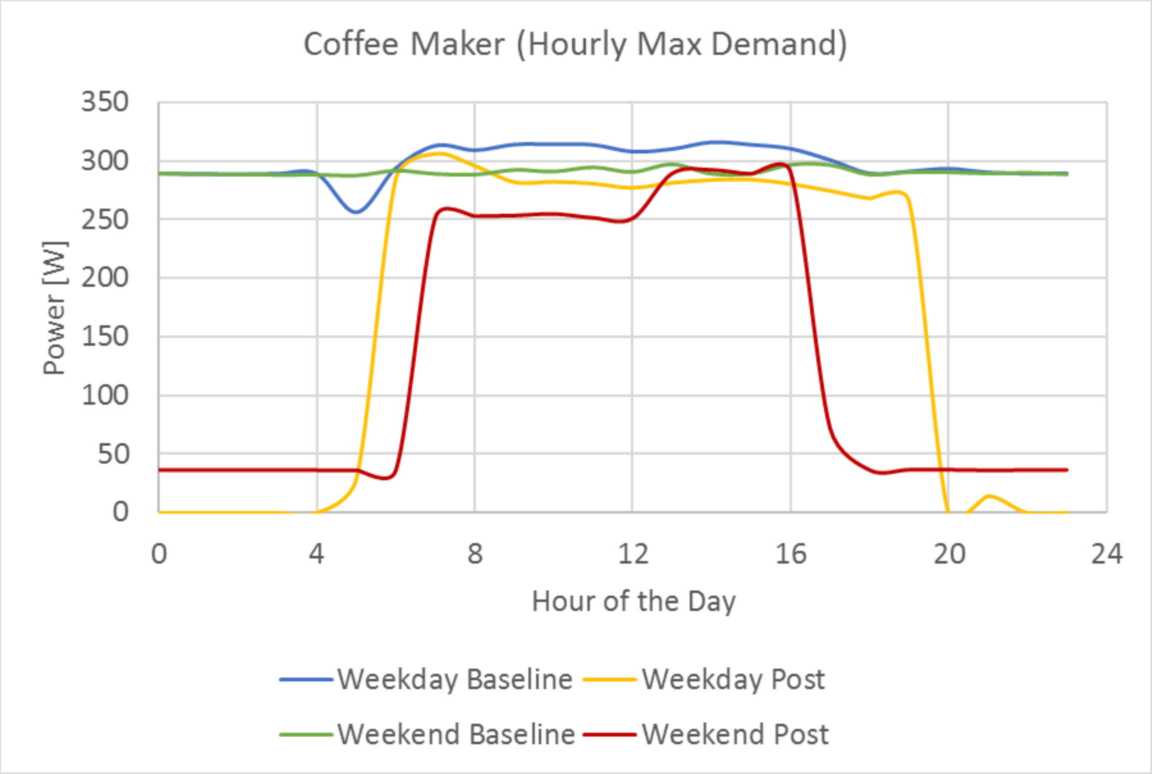


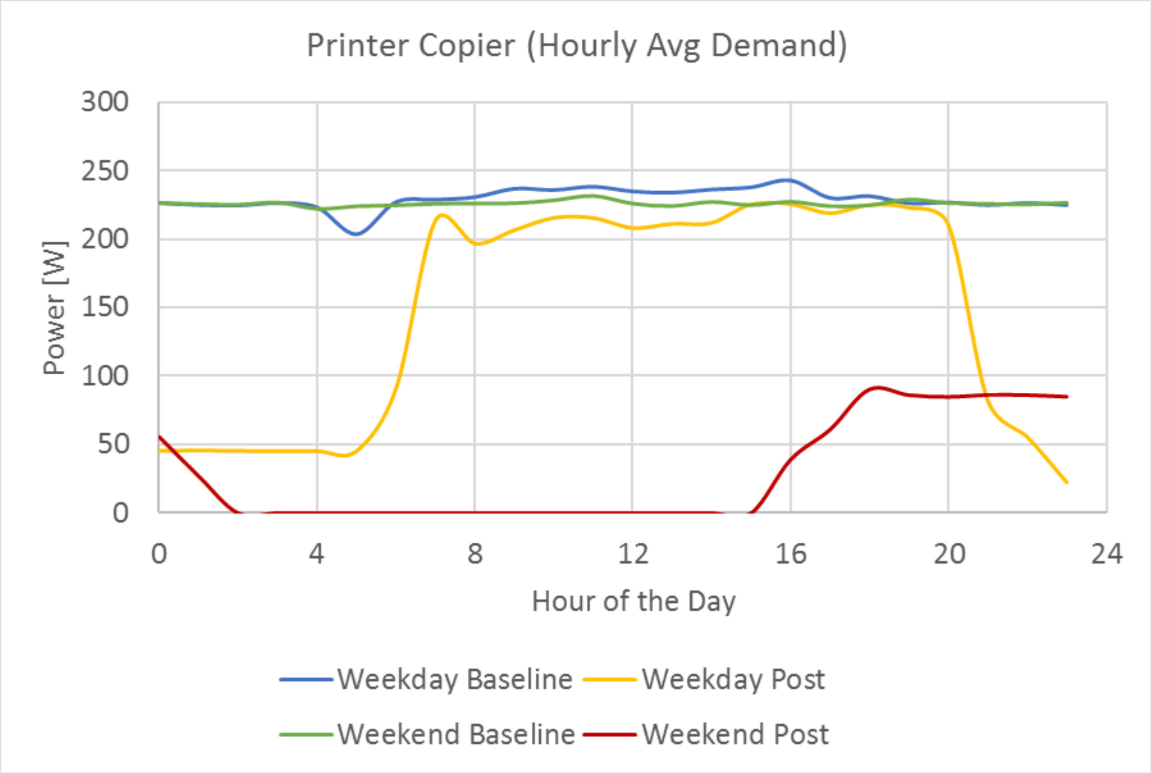


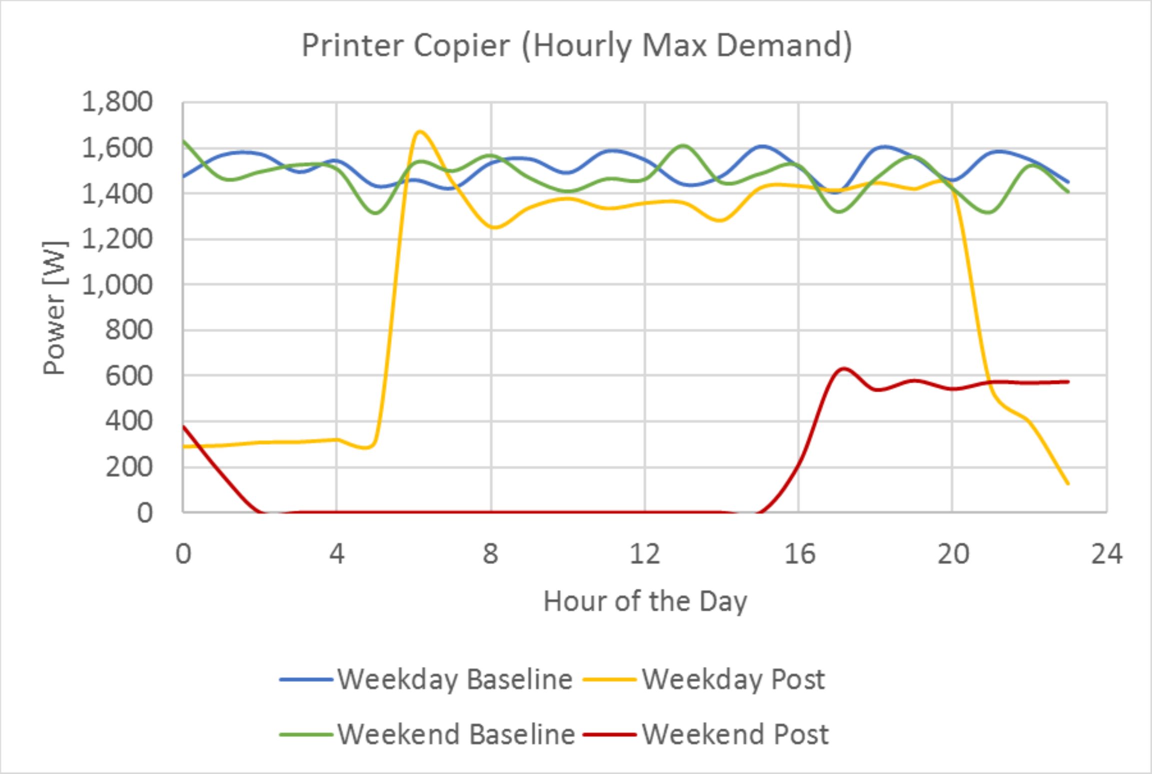
Coffee Maker



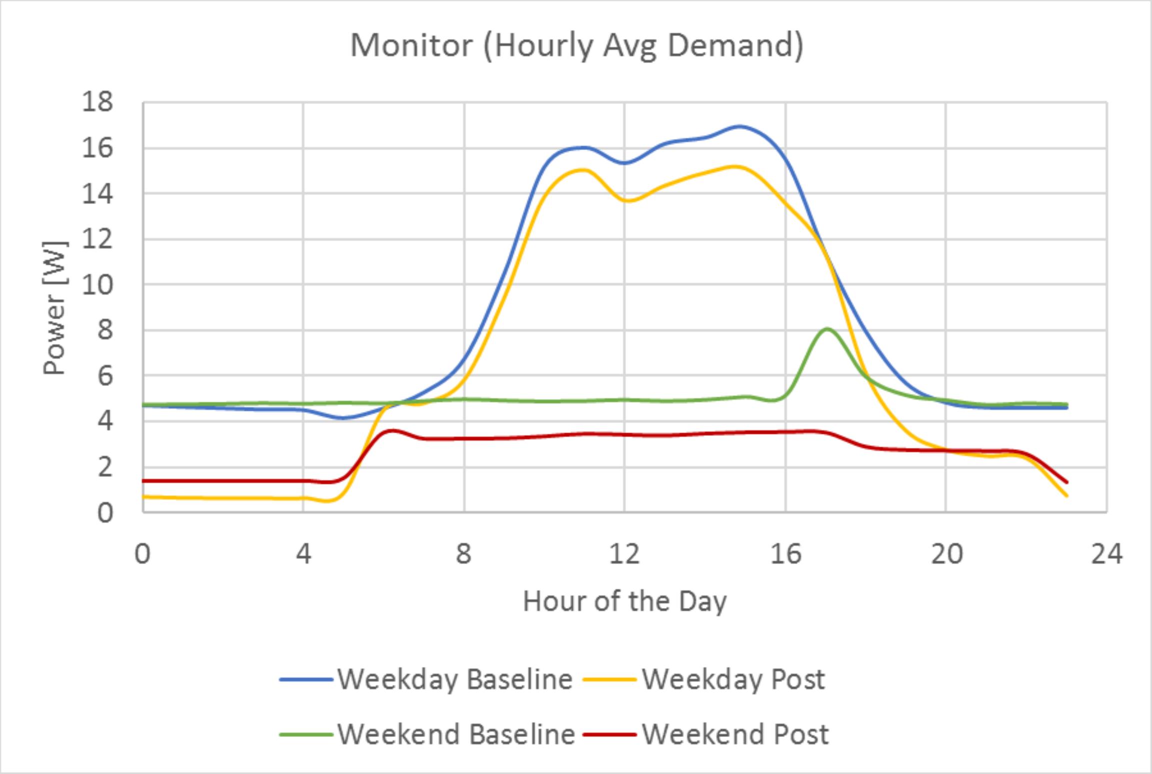


Printer Copier





Monitor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Power [W]
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2
4
6
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10
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14
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18
Hour of the Day
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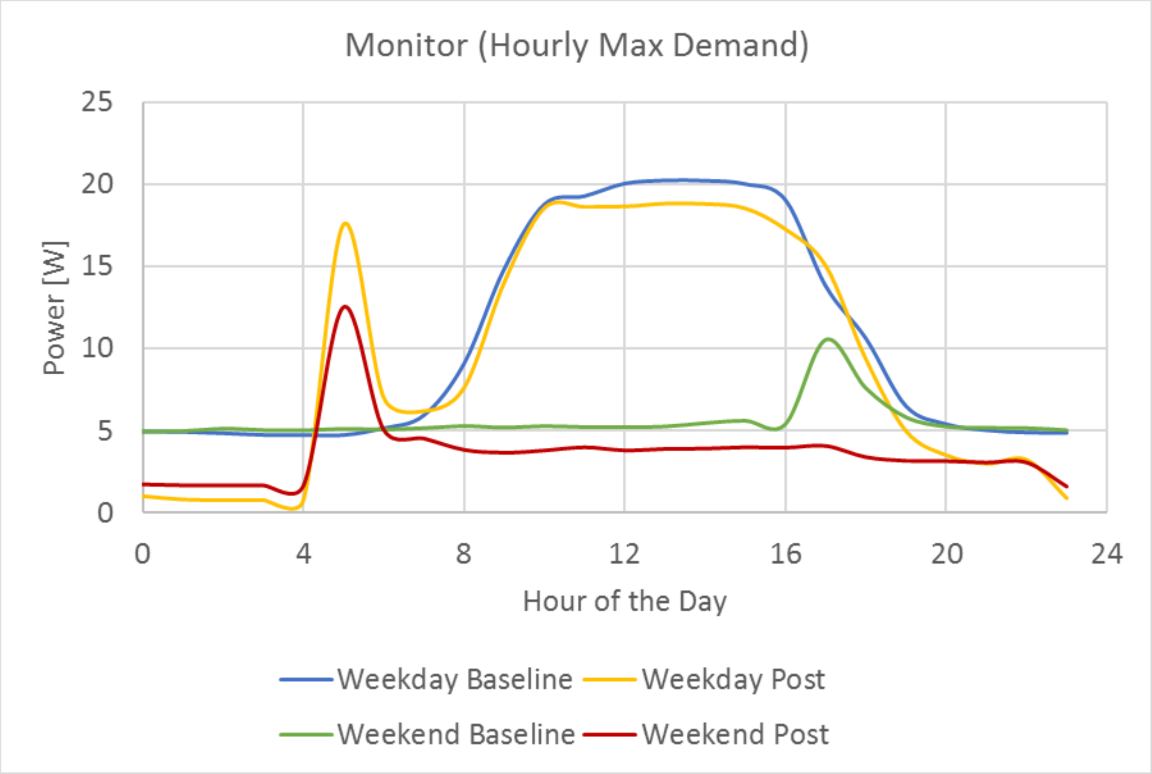
16
20
24
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post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Hour of the Day
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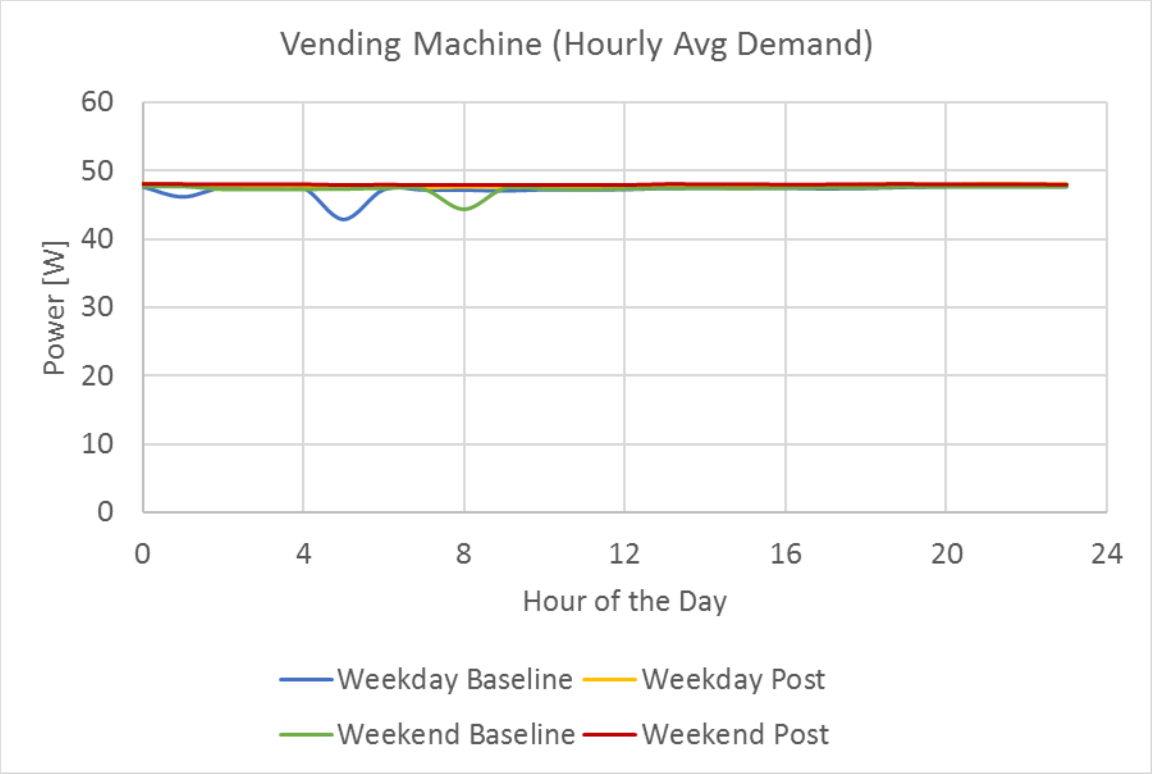
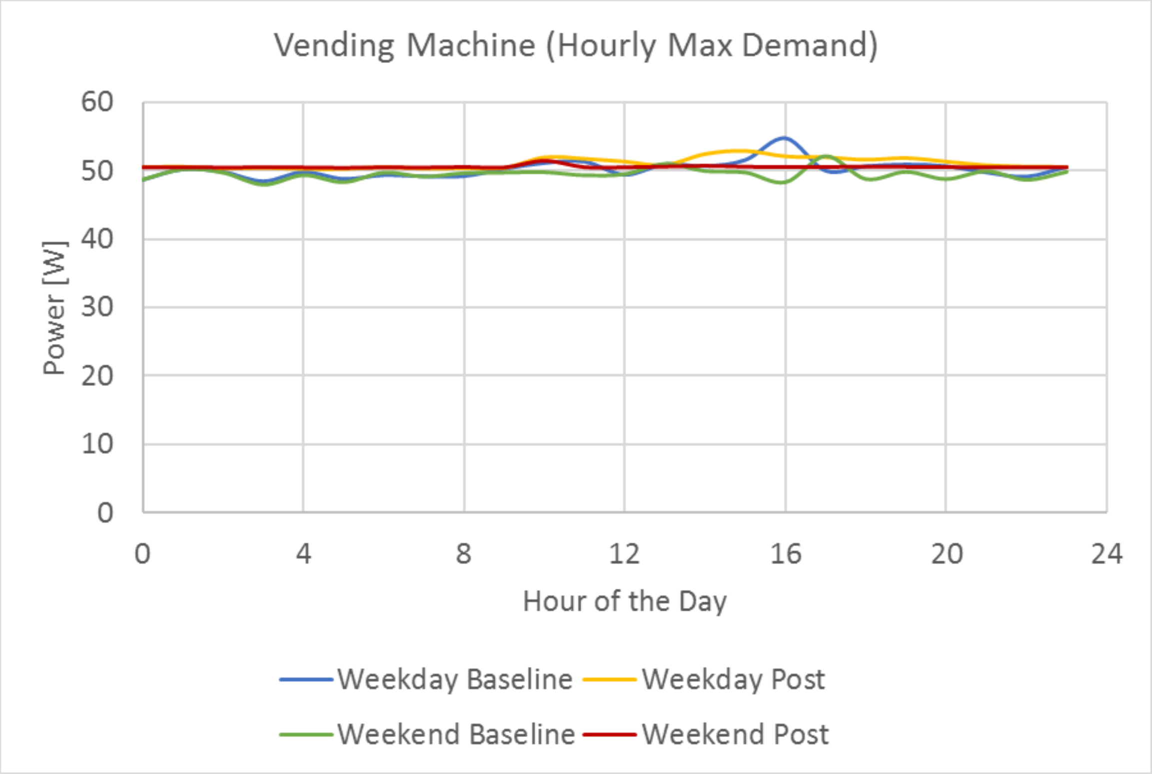
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post

Vending Machine (controls not properly implemented)





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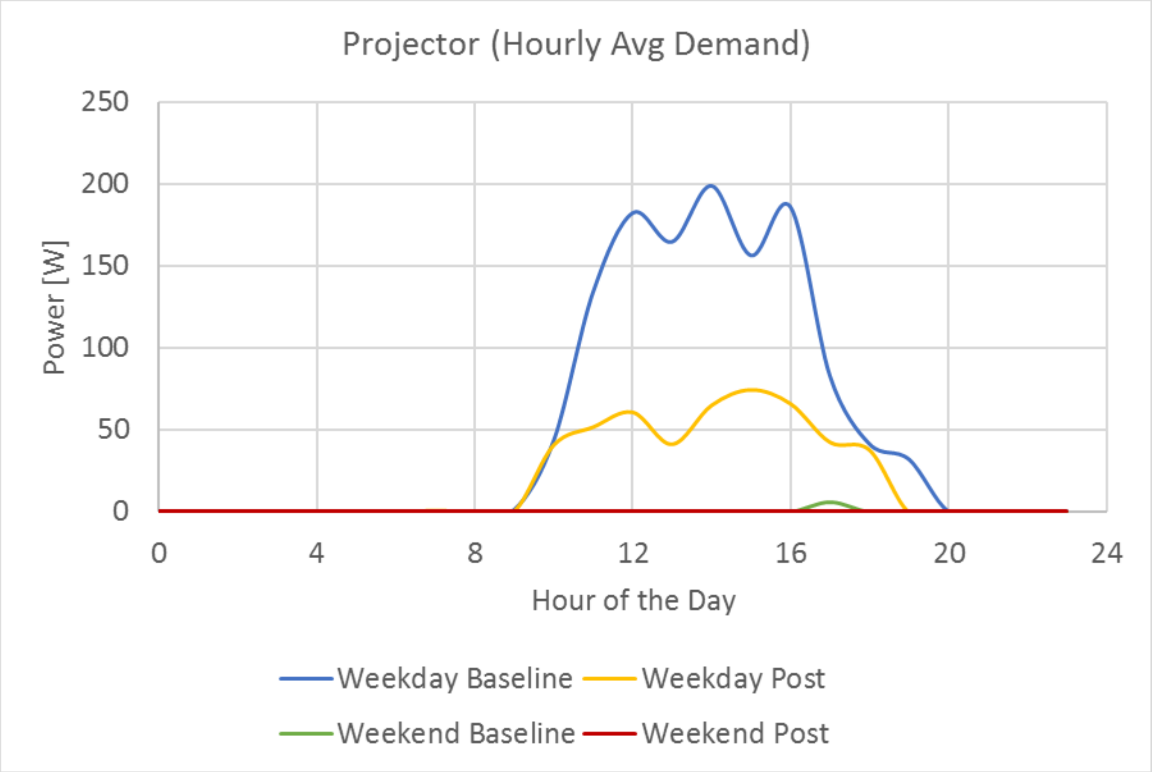
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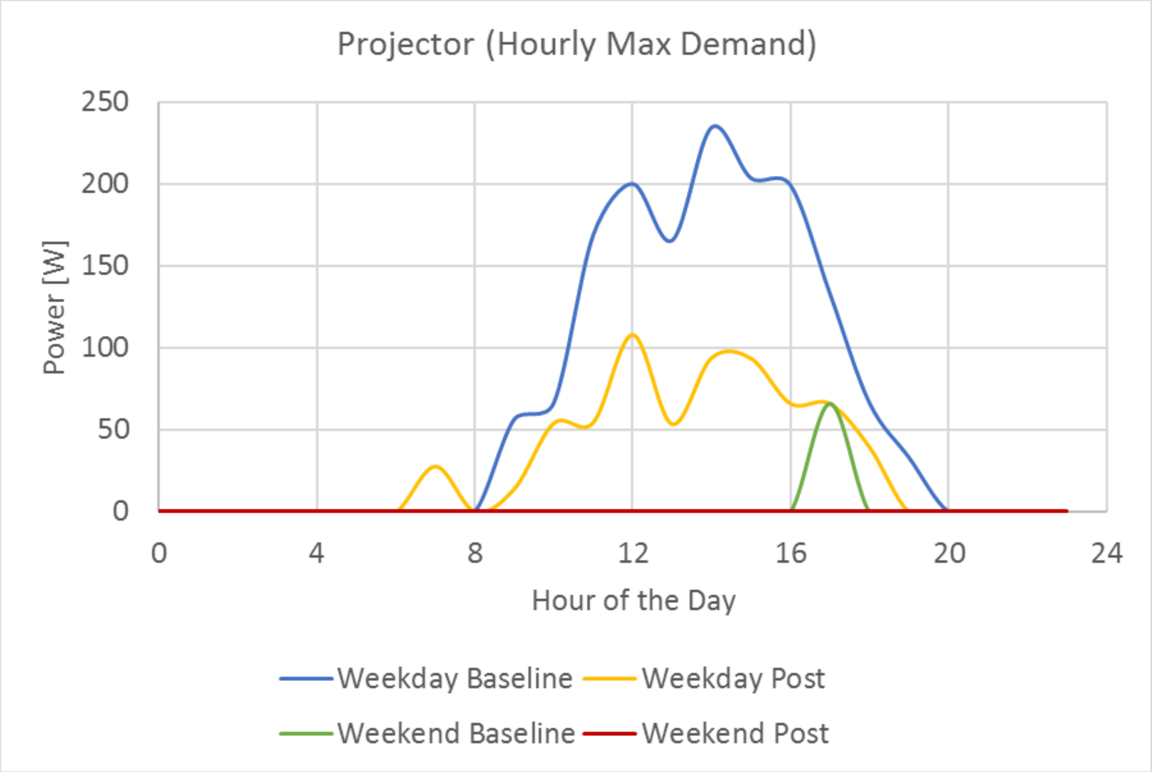
Hour of the Day
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post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20
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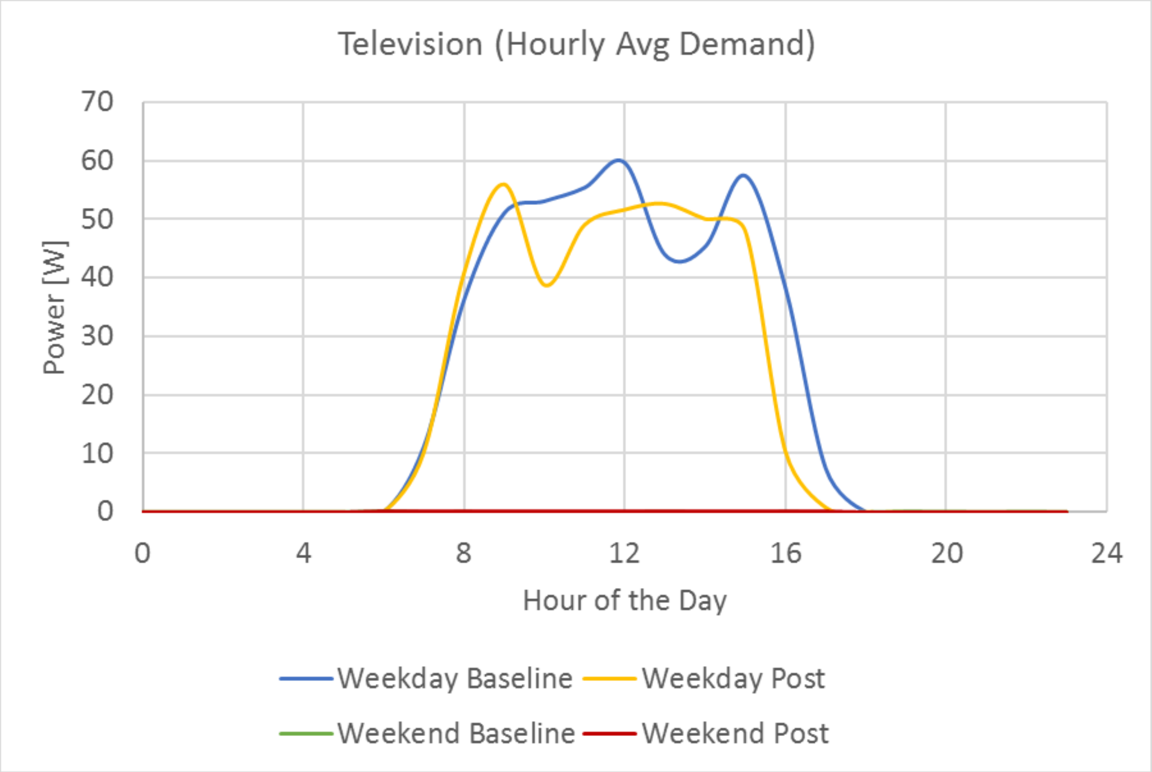
Hour of the Day
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post

Television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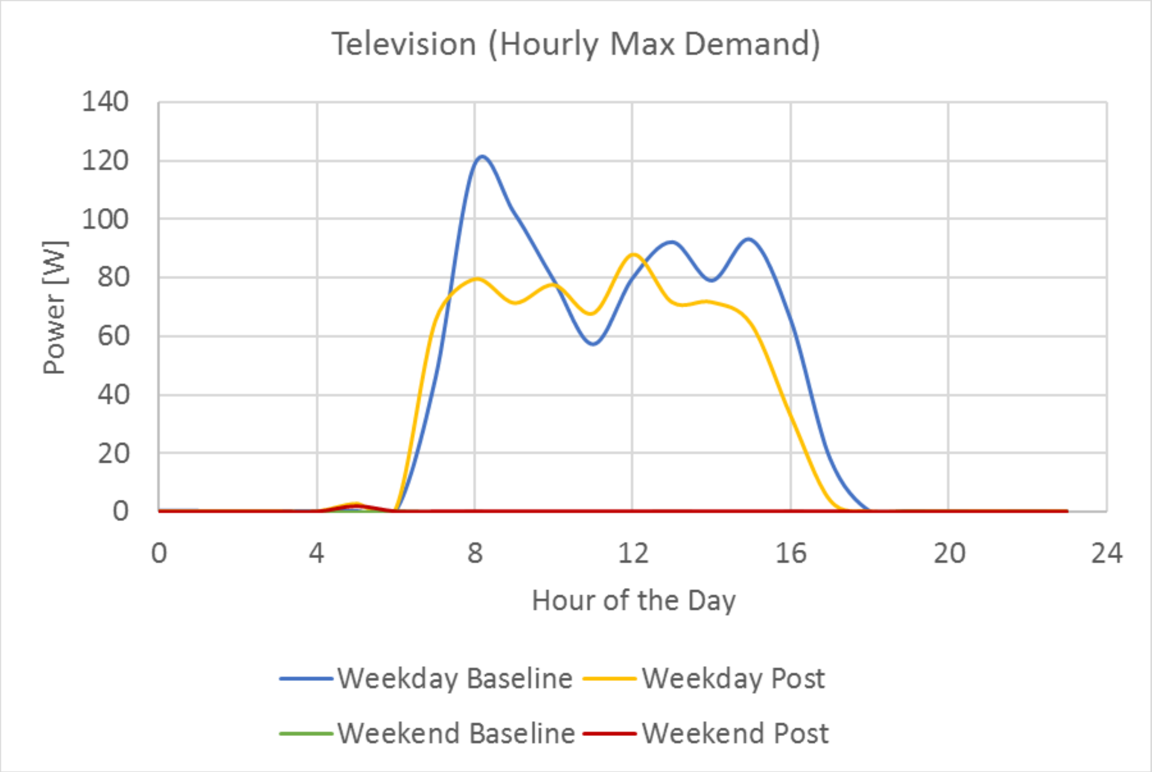
Weekend Post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140
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80
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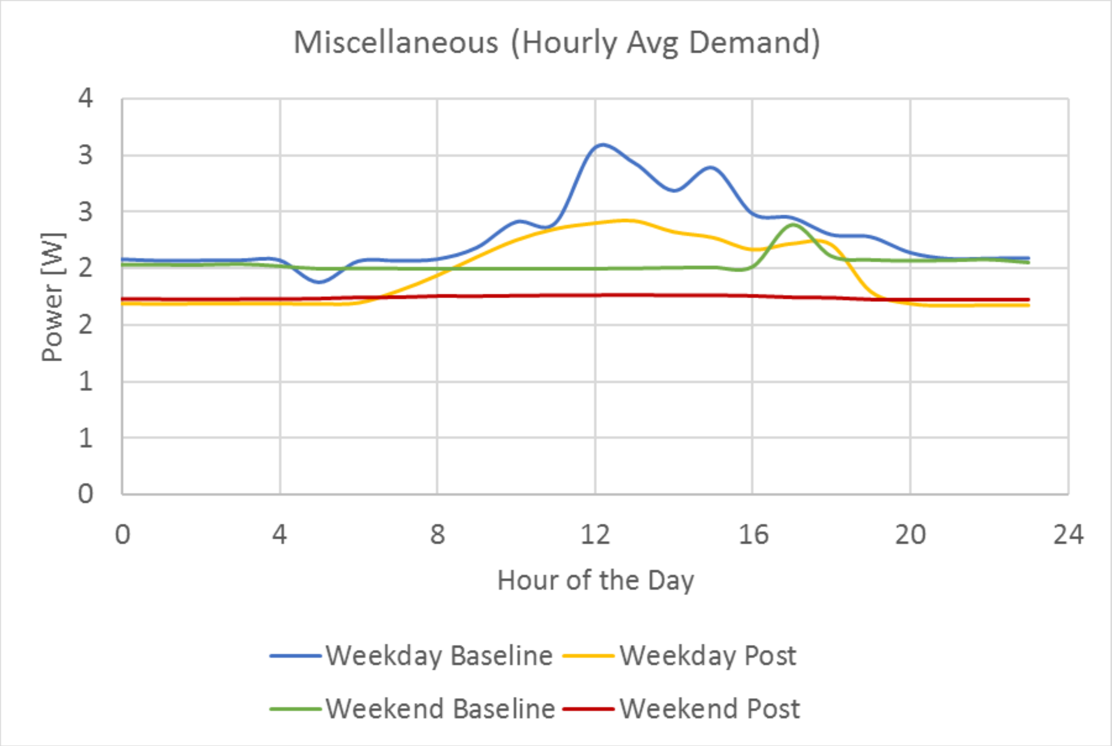
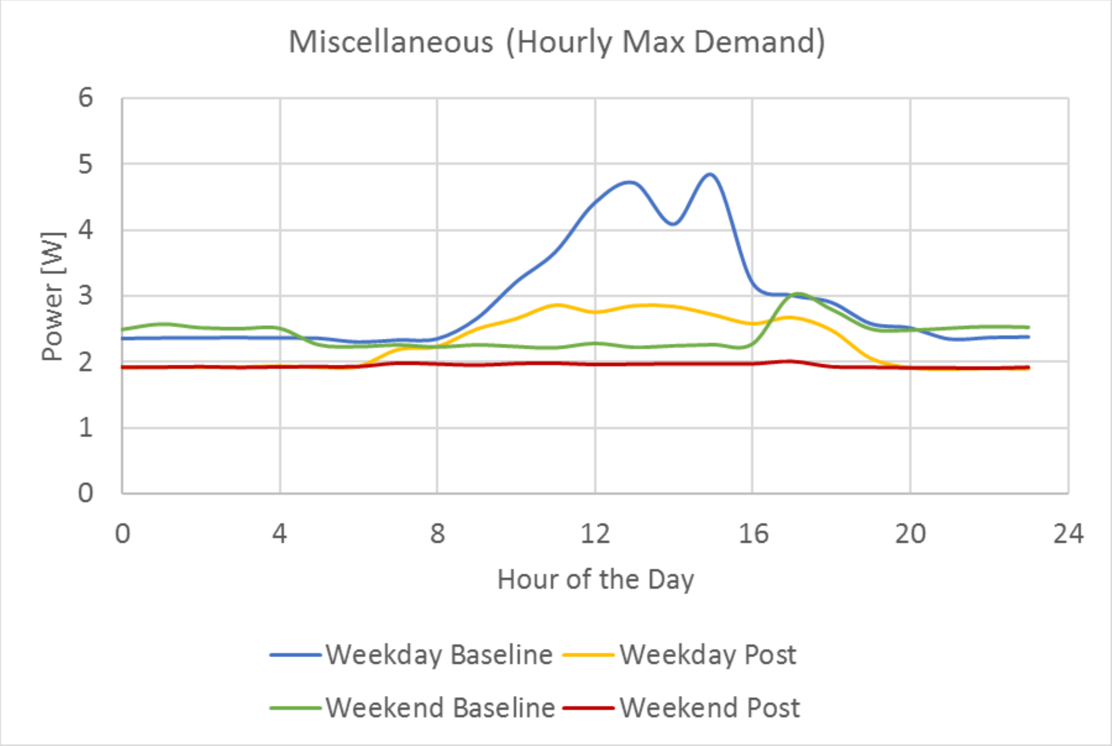
Hour of the Day
Weekday Baseline
Weekday Post
Weekend Baseline
Weekend Post

Miscellaneous[5]





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[5] Miscellaneous included Ethernet switches, KVM switches, label makers, network hub, phone chargers, headsets, power supplies, routers, projector control panel, USB hub, and other low power devices.