CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

**FINAL PROJECT REPORT**

# Flexible Control Strategies for Plug Loads to Mitigate Electricity Waste and Support Demand Response

Advancing Savings Strategies for Plug Loads

**Gavin Newsom, Governor**

**March 2023| CEC-500-2023-001**

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# ACKNOWLEDGEMENTS

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EPRI acknowledges the following individuals who served on the technical advisory committee for this project: M. Smith and S. Tyler of San Diego Gas & Electric Company; J. Huang and A. Rosillo of Pacific Gas and Electric Company; T. Abear of Southern California Edison; O. Howlett of Sacramento Municipal Utility District, and S. Miller of Eversource.

EPRI is grateful to the California Energy Commission for sponsoring the research project under the oversight of project manager Felix Villanueva.

# PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

*Flexible Control Strategies for Plug Loads to Mitigate Electricity Waste and Support Demand Response* is the final report for the Flexible Plug Load project (Contract Number: EPC 15-031) conducted by the Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at ERDD@energy.ca.gov.

# ABSTRACT

Plug loads as devices plugged into an electrical outlet, are becoming more widespread and consume an increasing share of commercial-building energy use. While other technologies like lighting have become more energy efficient, the diverse natures of plug-load devices have made it difficult to manage them for energy and demand savings. Plug-load devices range from specialized laboratory equipment to common-area appliances and individually assigned equipment like mobile devices.

Researchers designed plug load technology innovations for energy and demand savings. These were tested with commercially available plug-load energy-management systems using smart outlet automation in two pilot sites: an architectural office building and a university biology-research laboratory. These systems monitored electricity use by minute and managed the automation of smart-outlet technology with different strategies.

Energy and demand savings depended upon device type and user setting. In the office building, the team tested 54 smart strips at workstations and in common areas for energy savings; energy use was reduced by 10.7 percent. In the biology lab, 76 plug loads were monitored with 21 devices, which were put on time schedules so their energy savings could be evaluated and 18 were analyzed for energy savings; energy consumption by the 18 devices was reduced by 18 percent. The project team also developed and tested a demand-response notification system, which demonstrated the potential for laboratories to effectively contribute to 22 percent demand load reduction from one specific demand response event.

The project identified promising potential for energy efficiency and demand reductions with commercial plug loads. The high cost of plug-load energy-management systems and their long payback period range from the coffee maker which is 1 year to a charger which is 98 years. Market acceptance requires value-added benefits greater than the cost and effort required of building owners and facility managers to implement them. Some recommended pathways for wider market adoption are also included in this report.

**Keywords:** Plug Loads, Commercial Office Building, Biology Research Lab, Flexible Energy Management System, Heat Map Display, Energy Savings, Demand Savings, Smart Outlets, Automation Strategies, Demand Response.

Please use the following citation for this report:

Chuang, Angela, David Showunmi, Min Long, Chris Holmes, Colin Lee, Allison Paradise. 2021. *Flexible Control Strategies for Plug Loads to Mitigate Electricity Waste and Support Demand Response*. California Energy Commission. Publication Number: CEC-500-2023-001.

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# EXECUTIVE SUMMARY

## Introduction

Advancing energy-efficient and grid-responsive buildings is an important component of California's ambitious energy policies, programs, and mandates. Ongoing advancements in energy-efficient and smart-energy use have many environmental benefits: lower electricity use and cost, lower greenhouse-gas emissions, and less need for additional power plants. In these and other ways, smart- and energy-efficient electricity use benefit the State of California and its residents.

There are many types of plug loads, which are simply the devices plugged into electrical outlets. This project studied plug-load device types found in a commercial biology research building with laboratory equipment (including centrifuges and heating blocks), and in a typical office building with equipment including monitors, printers, and other information-technology devices. While energy usage from an individual plug load may seem minimal, plug loads in aggregate significantly increase energy consumption.

Plug loads are on the rise, so their electric energy consumption is expected to increase; the adoption of smart phones, tablets, and other common plug-load items contributes to this trend. In 2018, plug loads accounted for 27 percent of California commercial electricity consumption. The United States Energy Information Administration forecasts that this commercial end use will grow 44 percent by 2040 for office equipment, as opposed to 28 percent for other uses. This expected increase exceeds the growth rates of 23 percent for lighting, 21 percent for space heating, 18 percent for water heating, and 18 percent for ventilation.

Many obstacles hinder plug-load energy management. Plug loads today generally have manual on/off switches. Unless their users are vigilant in turning plug loads off when they are not being used, electricity is wasted. Plug loads are also unique; each piece of equipment varies by type, location, purpose, time-of-use, access rights, use patterns, and other characteristics. These differentiating factors ultimately make plug loads difficult to universally manage or automate, unlike other building loads such as space heating or cooling and lighting. For example, a plug-load device assigned to an individual with unique preferences may not adapt well to administrative management. In an effort to identify and overcome these challenges, Electric Program Investment Charge funding was invested in this taxonomy (or classification) of plug-load automation strategies for a broad spectrum of plug-load uses.

To control the unchecked operation of plug loads in commercial buildings, plug-load energy-management systems can adopt smart outlets to monitor or automate the operation of equipment plugged into electric outlets. Smart outlets can be housed in different forms ranging from smart strips and external plug-in modules to building-integrated wall outlets. Web-based software typically displays plug-load status and energy usage through graphic summaries and historic reports intended to guide energy decisions. Plug-load automation can then be enabled based on time schedules or other configurable conditions like device-power levels. Due to the novelty of plug-load energy-management systems, the impacts of this technology are difficult to study despite significant opportunities for energy reductions, demand-response applications, and integration with other building-management systems.

Although plug-load energy-management systems are commercially available, their high cost creates little financial incentive for building owners and is therefore a primary obstacle to more wide-spread adoption.

## Project Purpose

Integrating information across management systems can increase energy-efficiency and demand-response advancements in plug-load and other building-system operations. Because products and control systems in commercial buildings are built and managed by different vendors with no incentive to either communicate or collaborate outside their respective competitive markets, advancements such as application stacking and systems integration are required to develop best practices that can ultimately increase the value of plug-load energy-management systems.

Ratepayers can realize three primary benefits from this project and its technologies: energy savings from plug-load energy-management system platforms and technology extensions (for example demand-response notification systems) and societal benefits from avoided greenhouse-gas emissions.

The project's goal was to advance plug-load energy-management system control strategies that reduce energy waste in assigned spaces (offices, research labs) and common areas (break rooms, shared equipment areas) and develop and assess demand-response strategies for plug loads. The project also sought to increase understanding of these strategies so that effective changes can be incorporated into plug-load energy-management system designs. The overall objective was to assess the impacts of plug-load energy-management systems on energy-waste reductions and demand savings and demonstrate that 10-percent energy and demand reductions are achievable.

Conclusions from this research can benefit a number of stakeholders, including: technology vendors that can leverage the research to improve their products; utilities responsible for end-use energy savings and demand-response programs; the CEC, which has jurisdiction over flexible-appliance standards with passage of California Assembly Bill 49 (Skinner, Chapter 697, Statues of 2019);  and research entities like national labs and universities that conduct plug-load studies.

## Project Approach

Considering plug-load use's diverse contexts, a taxonomy or a classification system was developed to identify distinct strategies for plug-load automation in different types of commercial buildings and settings. This taxonomy examined different control strategies within the contexts of building, space, and equipment types. Preliminary findings on acceptable strategies per-pilot-site allowed refinement of the project team's developed taxonomy for plug-load controls.

The project was executed through collaboration among technical staff from the Electric Power Research Institute (S, external consultants, vendors, and pilot-site liaisons, and was guided by advice from electric-power-industry advisors who also served on the project's technical advisory committee. Project team members contributed to the research and, based on their complementary areas of expertise, identified trial automation strategies for a broad spectrum of plug-load types.

The research was conducted at two commercial-customer sites. One was a single-story architecture-office building with common areas and assigned workspaces. The plug-load equipment in those spaces was typical of offices and break rooms. The other site was a multi-story university biology research lab building with common areas containing mostly shared equipment. Scientists used a broad range of lab equipment including smart strips in the commercial office building and online plug-load energy-management system software services in the commercial building and the university biology-research-lab setting.

User feedback was gathered to determine user preferences and overcome the non-technical challenge of effectively engaging users and incorporating direct feedback into application and user-interface designs. To limit disruptions in operations, especially important in biology labs, the project team developed and tested a notification system that recommended which equipment to manually turn off in response to demand-response events. This was done in email notifications. This demand-response notification system was effectively tested in the biology lab.

The study established a baseline period without interventions. Next, plug-load control strategies were applied to selected equipment based on building-manager preferences. The impacts of energy and demand savings were then calculated and compared with the baseline. The office-building pilot employed time-scheduling and load-sensing control strategies. The research lab also implemented time-scheduling strategies and a demand-response notification system. The time-scheduling strategy enabled an administrator to set times when selected plug-load devices would automatically turn on and off.

Technology costs were calculated based on the number of years required for energy savings to break even with equipment costs. Technology performance was evaluated based on user complaints of connectivity losses. Other technology characteristics examined included the degree of accuracy of the indoor-positioning systems tested.

## Project Results

A summary of findings from the architectural office pilot follows.

- The dAlchemy plug-load energy-management system was successfully demonstrated in an office environment pilot that included:
    - 284 pieces of equipment that were monitored during the baseline period; 213 were chosen to participate in the treatment period.
    - There was a 10.8 percent overall reduction in plug-load energy consumption of the treatment group when comparing a 2-week baseline period with a 2-week treatment period. Analysis and break-even calculations were calculated for each type of equipment.
- Benefits from the pilot included:
    - 31.7 kWh energy savings over the treatment period, annual energy savings of 824.2 kWh across all devices, and average annual energy savings per plug-in strip of 15.3 kWh.
    - Average annual cost savings of $3.21 per strip.
    - 6,563.7 grams of $CO_2e$ avoided annually per smart strip.

    - Ease of universal remote control and management of plug loads by both building managers and occupants.
    - Break-even points for coffeemaker use over 5 years, compared with 27 years for workstation use (due to lower-energy-intensive equipment).
- Potential short-term market (small- and large-office building) benefits included:
    - Potential electricity savings of 684.7 GWh per year in 2020.
    - Potential customer bill savings of $143.8 million.
    - Potential greenhouse gas avoidance of 293.7 mil.kg $CO_2e$ per year in 2020.
    - The assumption that the achievement of 10.8 percent energy savings is extrapolated to other California market segments with similar equipment. These usage levels are estimated for 2012 for the state's investor-owned utility customers. These levels increased by 3 percent per year from 2012 to 2020, using an escalation factor of 26.7 percent.
- Successful development and testing of a heat-map display application can:
    - Integrate plug-load energy-management systems with indoor-positioning system data to provide graphic visualizations of user presence and plug-load energy usage combined with a building's floor plan. This allowed analyses of the relationships between presence and energy use to refine strategies for deeper savings.
    - Provide charting capabilities that target equipment and time schedules for optimum automation opportunities, which can minimize wasted energy and improve understanding of which equipment to effectively target for load shifting during demand-response events.

A summary of biology-laboratory pilot findings follows.

- The IBIS plug-load energy management system successfully achieved the following results.
    - 76 pieces of equipment were monitored during the study and 21 pieces of equipment were chosen for study.
    - An 18 percent overall reduction in energy consumption was achieved from the controlled plugs when the baseline period was compared with test results.
- Benefits of the pilot follow.
    - Devices in the treatment period saved an average of 1,279 Wh/day, with average annual energy savings of 468 kWh across all devices. Average annual energy savings per strip were 26 kWh/year.
    - Average annual cost savings per strip were $5.46.
    - 11,154 grams of $CO_2e$ were avoided annually per smart strip.
    - The ease of remote management of plug loads was effectively demonstrated.
- Potential short-term market (laboratory building) ratepayer benefits included:
    - Potential electricity savings of 35.7 GWh/year in 2020.
    - Potential utility customer bill savings of $7.5 million.

    - Potential greenhouse-gas avoidance of 15.3 million kilograms $CO_2e$ in 2020.
- The successful development and demonstration of a demand-response notification system was designed for the biology laboratory to:
    - Notify the lab manager of upcoming demand-response events and recommend equipment turn-offs.
    - Automate text messaging and email alerts sent to lab managers, who in turn initiated manual interventions through email notifications.
    - Provide recommended lists of equipment for manual interventions based on past months' energy use and equipment age, safety, and necessity.
    - Calculate estimated savings during demand-response events and recommend the top five equipment types for manual intervention.

This research and its piloted technology can potentially lower energy costs, enhance plug-load energy savings, enable centralized control, improve asset utilization, and generate demand savings for plug-in devices. It also identified strategies to efficiently manage plug-load devices in various spaces and with different types of equipment. Implementation would also lower greenhouse-gas emissions through energy-waste reductions.

The project met the objective of demonstrating that 10-percent energy savings are achievable from plug-load energy-management systems. More limited results were demonstrated for demand savings. Technology extensions successfully developed and tested included a demand response-enabling flexible plug-load mobile application and a heat-map display designed for office environments. These applications can potentially increase further plug-load energy-management system energy and demand savings and are recommended for future pilot demonstrations.

This system required significant conceptualization and design in its early stages and was tested at EPRI, where its TRL rose from 3 to 5 throughout the project. Various demand response strategies were supported by the FEMS app including power-up and power-down strategies, with plug-load equipment selected through the app. To advance to TRL 6, these strategies were demonstrated in an office environment.

## Technology and Knowledge Transfer

The Electric Power Research Institute established partnering relationships between plug-load energy-management system vendors and third-party vendors to strengthen this transition to the marketplace. The Electric Power Research Institute shared project findings with various audiences including at the CalPlug conference, Electric Power Research Institute advisory meetings, meetings with vendors and pilot-site participants, and technical-advisory committee meetings with utility advisers. The Electric Power Research Institute also connected the plug-load energy-management system vendor focused on device utilization with an indoor positioning-analytics vendor focused on space utilization; this partnership merged identified platform capabilities to develop a graphic user interface to reveal deeper insight into energy savings. Project findings were shared with utilities for inclusion in future programs, including advanced power-strip programs. The project developed a video of the flexible energy-management system implementation and posted it on YouTube (https://youtu.be/Mt0X_lVwrdE). The video shows how to automate plug loads to support user preference in demand response and advance technology transfer to eventual market adoption.

Commercial building-site managers have expressed interest in testing these applications when expected normal building occupancy returns following the global pandemic that began in 2020. The vendor Kiana Analytics is also engaging commercial sites by promoting these applications and featuring commercially available innovations (including the heat map display) on its production server. Kiana Analytics has also included the project's technology features in its user manuals.

This research and its piloted technology can potentially lower energy costs, enhance plug-load energy savings, enable centralized control, improve asset utilization, and generate demand savings for plug-in devices. It also identified strategies to efficiently manage plug-load devices in various spaces and with different types of equipment. Implementation would also lower greenhouse-gas emissions through energy-waste reductions. This report will be shared with the CEC Appliance Standard office for future consideration for codes and standards.

## Benefits to California

Ratepayer benefits from the project are multi-faceted. The first is expected energy savings from customer adoption of plug-load energy-management systems and technology extensions. The second is expected cost savings from lower energy use. The third is avoided greenhouse-gas emissions from lower energy consumption. Sharing these technical advancements with customers can also increase their familiarity (and ultimate adoption) with plug-load control strategies. A variety of plug-load management strategies were researched and demonstrated including load sensing, time scheduling, and other controls. A presence-based energy saving strategy was also developed and debugged. Among demand response-enabling strategies, the project developed power-down and power-up strategies for office environments. A demand-response notification system with manual intervention was demonstrated in the biology lab studied. Videos demonstrating innovative automation strategies like these have also been posted on YouTube at no charge to advance industry understanding and ultimate adoption.

The plug-load control strategies investigated in this project can contribute to and improve future building codes and standards for switchable wall outlets in commercial buildings. The project's analyses of plug-load data and management strategies can also advance future automation strategies, whether implemented through external plug-load automation devices, building-integrated wall outlets, or internal controls built into the plug loads themselves.

The pilot sites encompassed a broad spectrum of devices and collected individual end-use equipment load profiles, which together can influence equipment behavior and the development of load shapes for plug loads. The research's taxonomy further provides greater understanding of how building spaces and equipment influence plug-load management strategies, thus providing a framework for future studies on plug-load management beyond office buildings and biology-research laboratories. The taxonomy shows how management strategies can apply to different types of buildings. The benefits of plug-load energy-management systems can potentially penetrate other markets, as explained in Chapter 7. The taxonomy provides a roadmap for the most effective strategies for these future markets.

This project investigated user-presence sensing technologies and developed a heat-map display visualization tool to assist with linking energy use and presence in locations with various levels of plug-load energy consumption. This can be a tool to identify deeper savings when factored in with insights on user-presence in buildings.

This research has laid the groundwork for future studies in several ways. The project taxonomy provides a much-needed context on how best to apply plug-load management strategies to different types of buildings based on their spaces and equipment. The project also developed and demonstrated innovative approaches for incorporating plug-load usage in demand responses without disrupting building operations through a demand-response notification system (designed for shared lab environments), and a flexible plug-load mobile app (designed for commercial office settings). This integration of presence and plug-load energy-data streams is not yet well studied, though the foundational knowledge provided by this project can underpin future research on the intersection of these two data streams.

## Report Organization

Chapter 1 provides an overview of the challenges facing broader plug-load energy-management system adoption and its aggregate potential for energy savings. Chapter 2 addresses the project approach taken to resolve key challenges across two pilot sites: a biology-research lab and a commercial-office environment. Chapter 3 summarizes results from the office-environment pilot study, including details about strategies and energy savings. Chapter 4 provides the results from the biology-research-lab pilot study. Considering the project’s findings, Chapter 5 presents technology and knowledge transfer activities recommended for further knowledge dissemination for stakeholders and across platforms. Conclusions and recommendations are summarized in Chapter 6, and an overview of benefits to ratepayers is provided in Chapter 7.

# CHAPTER 1: Introduction

## Background

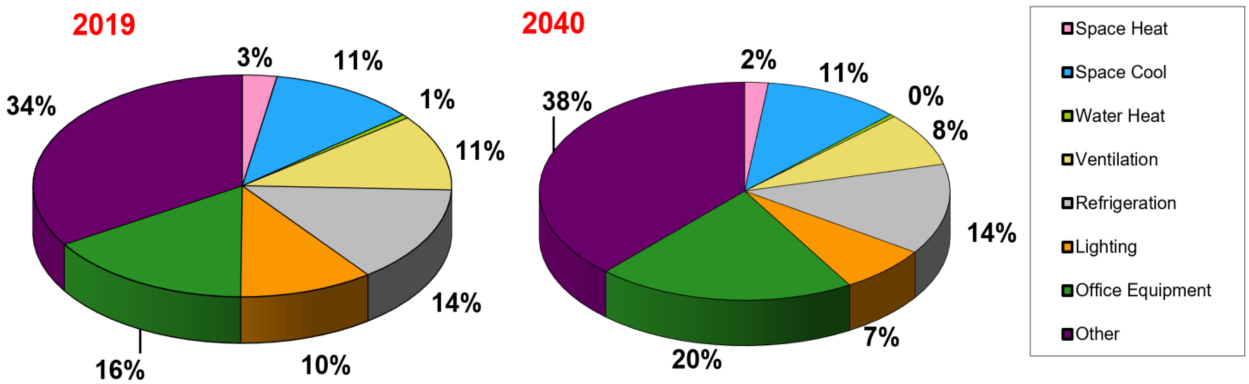
Plug-load devices in buildings range in type. Some examples include plug-in appliances (e.g., food preparation and break-room equipment), consumer electronics (computers, monitors, and chargers for personal electronic devices), miscellaneous plug loads (plug-in space heaters and mechanical-door openers), and specialty equipment (biology research and other lab equipment). While energy use from individual plug loads is generally much less than that of major building loads found in residences and commercial buildings (such as space heating and cooling, water pumping, water heating, and thermal storage), in aggregation plug loads consume significant amounts of energy. Considering total commercial building electric usage in the United States, plug-load use in aggregate exceeds energy consumption of all other major end-use categories.

Society has become increasingly dependent on plug-in connected devices with the broad adoption of smart phones, tablets, and other consumer electronics, in addition to Internet of Things (IoT) technologies. Growing proliferation of plug-in devices, along with underlying connectivity infrastructure, are driving rapid plug-load growth in buildings.

Based on the United States Energy Information Administration's (USEIA) *2020 Annual Energy Outlook*, plug-load energy usage in commercial buildings is expected to grow from 25,000 to 27,000 British thermal units (Btu) per-square-foot, per-year from 2019 to 2040 (USEIA, 2020). Figure 1 illustrates total plug-load usage (for office equipment and other uses[1]) in commercial buildings during 2019, which exceeded that of space heating and cooling, water heating, ventilation, refrigeration, and lighting. USEIA forecasts commercial end-use growth of 44 percent from 2019 to 2040 for office equipment and 28 percent for other uses, which exceed growth rates of 23 percent for lighting, 21 percent for space heating, 18 percent for water heating, and 18 percent for ventilation, as illustrated in Figure 2. Consequently, plug loads of office equipment and other uses, across U.S. commercial buildings, exceed in aggregate other major end uses in percentages of electric use and forecasted growth.

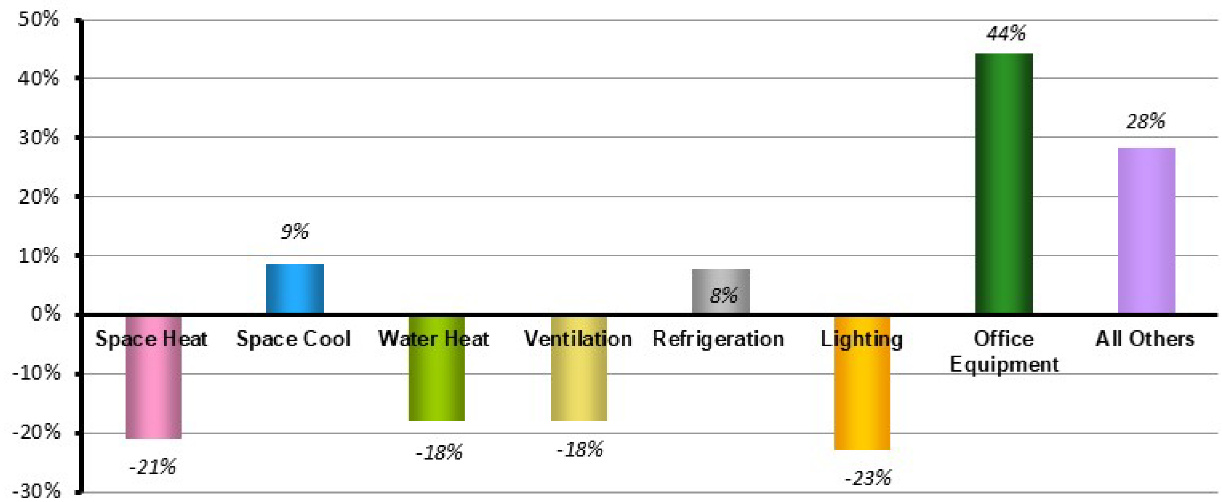
[1] Other uses include (but are not limited to) miscellaneous uses such as transformers, medical imaging and other medical equipment, elevators, escalators, off-road electric vehicles, laboratory fume hoods, laundry equipment, coffee brewers, and water services.

**Figure 1: U.S. Commercial Building Electric Usage by End-Use Category**




Source: Electric Power Research Institute, Inc.

**Figure 2: Expected Change in Electricity Consumption of Major End Uses in U.S. Commercial Buildings from 2019 to 2040**




Source: Electric Power Research Institute, Inc.

Though there have been significant energy-use reductions in other end uses (lighting and space heating each dropped 11 percent of total end-use consumption from 2003 to 2012) (EIA, 2016), development of energy-saving strategies for plug loads has been very limited. Some building codes, such as California's Title 24 (California Energy Commission, 2019) and the International Green Construction Code (International Code Council, 2018) address plug loads by adopting codes that require controllable receptacles within both new and retrofitted commercial buildings. These changes highlight the need for effective plug-load energy-management strategies.

## Challenges

Developing control strategies for plug loads is particularly challenging given the variety of plug-load types and the differing applicability of control strategies. Part of the reason is because plug loads are inherently unique; individual-user preferences complicate workable automation strategies for energy and demand savings while minimizing disruptions of equipment in use. In some cases, a plug-load device is assigned to a particular person or group with unique preferences and needs, while in other settings the same type of device is used by a broader population. Capturing the plug-load automation preferences of both individuals and groups is therefore critical for effective implementation of savings strategies. These factors make management of plug load burdensome.

Different types of plug loads are found throughout different types of building spaces. Effective energy savings strategies vary by equipment purposes, times of actual use, and other factors that together create the context for determining opportunities to mitigate use waste. Overall, plug loads are complex to manage universally, unlike building loads like space conditioning and lighting, which can be centrally controlled and managed independent of individual preferences.

## Research Needs

Given the complexity of plug-load energy management, research is needed for the development and testing of advanced-control strategies for plug loads. Vendors typically offer plug-load energy-management systems (PLEMS) as separate industries from those providing building systems with monitoring and management capabilities such as indoor positioning systems, building-energy management, electric vehicles, and other niche energy-monitoring systems. The potential integration of information across disparate systems would enable energy-efficiency and demand-response advancements in plug-load operations by creating a larger context that includes plug-load management within buildings.

PLEMS platforms generally lack support for both demand response and energy-saving automation strategies based on space, equipment type, and user presence. Considering the large investment required to advance PLEMS, Electric Program Investment Charge (EPIC) funding was required to advance plug-load control strategies with the goal of reducing electricity waste and supporting demand response. Since products and control systems in commercial buildings are built and managed by vendors that are often in industry silos, facilitation is required for cross-communication and cooperation designed to address electric power-industry concerns. Development work outside the competitive market was therefore required to create and demonstrate integrated methods and tools for plug-load management capable of deployment in different building types and contexts.

## Objectives

This research project investigated flexible plug-load control strategies for both energy savings and demand-response applications and developed promising strategies for office-building and biology-lab environments based on participant preferences. The research was designed to provide a perspective of plug-load controls based on context, and also considered user presence and preferences to develop workable control strategies.

Given the diverse contexts in which plug-load devices are used in commercial buildings, the project began by developing a taxonomy for different plug-load control strategies by type of commercial building, space, equipment, and equipment assignment. These strategies investigated the automation of plug loads based on time schedules, real-time load sensing, controller/agent control, and user-presence sensing. This taxonomy illustrated how different contexts of plug-load usage (for example building, space, and equipment type) shape strategies that may be most applicable. These strategies can be fine-tuned based upon user-selected preferences to address individual plug-load control preferences.

Commercially available PLEMS platforms were used, and in some cases augmented, to demonstrate flexible plug-load control strategies in two commercial pilot settings: a university research lab and an architectural-office building. The overall objective of the pilot demonstrations was to evaluate energy savings and demonstrate the effectiveness of the strategies. The target was to demonstrate an overall 10-percent energy-use reduction that also supported demand-response applications.

A research goal was to further advance market adoption of plug-load controls. This encompassed the design and demonstration of a:

1) Flexible energy-management system for plug-load control based on user presences in assigned spaces of an office building.
2) Flexible energy-management notification system for demand response in biology labs.
3) Heat-map display that integrated plug-load usage data with a graphic building floor plan to visually demonstrate energy- and demand-savings strategies.

## Audience

The outcomes of the research inform a number of stakeholders, including:

- Technology vendors that may add value for their customers (such as labs and office-building energy managers) through energy savings.
- Utilities responsible for end-use energy savings and demand-response programs.
- The California Energy Commission (CEC), which, with passage of Assembly Bill 49 (Skinner, Chapter 697, Statues of 2019) has jurisdiction over flexible appliance standards.
- Research entities such as national labs and universities that conduct plug-load research and demonstration projects.

Project technology vendors can apply research results to product enhancements, spurring market adoption among their customers. Utilities can use research results to develop future energy-efficiency and demand-response programs. Many of these stakeholders were also a part of the technical advisory committee for the project. The CEC can use the findings to identify effective plug-load control and automation strategies to advance standardization of control strategies for flexible appliances. Project results can also be leveraged by other research entities conducting plug-load research and demonstrations including national labs and universities. To the extent that plug loads contribute to energy and demand savings, these strategies can keep overall utility costs and customer rates low.

# CHAPTER 2: Project Approach

## Project Team

The Electric Power Research Institute (EPRI), headquartered in Palo Alto, California, served as prime contractor on the research, supported by the three technology vendors Enmetric Systems, IBIS Networks, and Kiana Analytics, and four utility partners: Southern California Edison Company (SCE), San Diego Gas & Electric Company (SDG&E), Pacific Gas and Electric Company (PG&E), and the Sacramento Municipal Utility District (SMUD). The pilot-site technical advisers were MyGreenLabs, Stanford University, and AP+I Designs. EPRI coordinated project activities among team members and led the overall execution of each project task, and also served as the primary contact with the CEC, external parties on the technical advisory committee, and project vendors.

## Structured Approach

### Primary Steps

The project adopted a structured, step-by-step approach for developing flexible plug-load control strategies for commercial buildings. Key steps of this structured approach follow.

1. Develop a Taxonomy of Plug-Load Contexts: Develop a taxonomy that provides context for plug-load control in different building types and spaces. Spaces vary by degree of user assignment so a continuum of building spaces is included in the taxonomy. For example, the taxonomy differentiates common areas from shared areas as well as from user-assigned workspaces like offices and cubicles. The taxonomy also categorizes different types of plug loads based on characteristics that could impact common-control strategies.
2. Develop Flexible Plug-Load Control Strategies for Commercial Contexts: Research and develop plug-load control strategies for each plug-load context. Refine control strategies based on consumer behavior and acceptance of plug-load controls. Group control strategies by common contexts and plug-load features (e.g., electronic plug loads with rechargeable batteries) and by the extent to which the strategies apply to plug loads with similar usage and waste characteristics. Extend control strategies for greater savings by integrating a building’s energy and lighting systems.
3. Test Developed Control Strategies: Test in a controlled environment, followed by real-world customer pilot sites to evaluate energy-savings potential. Implement flexible-management systems (FEMs) and work with multiple-vendor platforms to directly control vendor smart-power outlet products (e.g., 4-outlet smart-power strips, single-outlet modules, and outlet receptacles). Use FEMs interfaced with vendor plug-load management platforms to test control strategies and estimate savings. Test a series of control strategies and allow adjustment of user preference settings between tests.

4. Evaluate Benefits of Plug-Load Control Strategies: Evaluate savings from the most promising plug-load control strategies developed for commercial markets. Evaluate savings and other benefits at pilot sites (commercial offices and research labs).

### Context-Based Approach

EPRI's approach was to develop integrated plug-load control strategies based on plug-load uses. The EPRI team recognized that plug-load technologies and platforms will necessarily evolve over time and eventually support different plug interfaces, sleep protocols, and outlet styles that power plug-in devices. The project was, therefore, designed to produce integrated plug-load control strategies that apply to different styles of smart-power outlets (e.g., receptacle outlets, single-outlet modules, and multi-outlet strips) as well as different power-reduction modes (e.g., on/off, sleep, standby) as these will inevitably become available over time. This approach ensured the broad and ongoing relevance of project findings, physical interfaces, hardware styles, and device communication protocols as they evolve over time.

### Deeply Leverage Existing Vendor Data, Platforms and Tools

The project's technique to rapidly advance industry knowledge concerning plug loads, especially in commercial buildings, was to deeply leverage existing vendor data collected over time. Project vendors provided plug-load data from commercial office buildings and research labs, which have among the highest concentrations of electronic and miscellaneous plug loads. The vendors agreed to share data on their spaces and plug loads and fill in information gaps when required. Deeply leveraging existing plug-load data collected in real-world settings ensures rapid and cost-effective knowledge advancement.

EPRI's approach to developing the proposed heat-map display was to use existing commercial data-visualization tools for the graphic visual presentation of user presence and plug-load usage. This approach also leveraged existing PLEMS from multiple vendors by coordinating their servers and sending control commands. Vendor-team members were carefully selected to extend the reach to a variety of plug-loads, including smart-power strips (Enmetrics), and single- and dual-outlet plug-in modules (IBIS Networks). By teaming with multiple vendors with complementary hardware and reaching out to different customer segments, EPRI's technique was to develop integrated plug-load control strategies that are broadly applicable across multiple customer segments.

The project technique was to develop integration software and displays where critical gaps existed in plug-load control technology. This ensured sharing these developments broadly across the vendor community. These developments include critical aspects of user interface designs and displays as well as plug-load control know-how.

### Approach to Behavioral Research

Plug-load usage behavior research was examined in three steps. The initial step considered the behavioral aspects that create opportunities for plug-load control strategies. User interface design options were developed and messaging and information conceptualized. The second step identified preferences for control strategies. The third step measured satisfaction of the control strategies after the demonstration. User and building-management interviews were conducted and documented both during the baseline period and each successive treatment period. The purpose of the interviews was to establish a baseline satisfaction level with the work environment and determine how treatment applications may have changed it.

## Barriers and Challenges Overcome

### Taxonomy for Plug-Load Control

Given the diverse contexts for plug-load device use, the project's first challenge was to develop a taxonomy for plug-load controls. At the time of the study there was little industry clarity research investigation, the industry lacked clarity on effective plug-load control strategies in different usage scenarios. The industry had not yet developed technologies to manage flexible plug-load automation for energy savings and demand response.

A taxonomy helped identify and develop plug-load automation strategies and address plug-load control strategies for different types of space and equipment. A structured taxonomy allowed readers to determine which plug-load control strategies could apply to different contexts within commercial settings.

### Plug-Load Strategy Development and Demonstration

The project team faced challenges in developing, implementing, demonstrating, and analyzing select control strategies in piloted environments. The project ultimately chose to test a load-sensing automated-control strategy in the office environment and an automated time-scheduling strategy in the biology lab environment.

Demand-response control strategies were developed for both environments. During the development of demand-response applications for plug loads, the objective was to effectively control specific devices based on user preference. The project team, therefore, designed an application that accounted for user preference and integrated it with PLEMS to develop individualized plug-load operations in office environments. To limit disruption to operations, a sensitivity in biology labs, the project created a notification system to prompt lab users to check which equipment to turn off manually during a demand-response event.

Preliminary findings for trial per pilot site allowed refinement of the project team's taxonomy for plug-load controls aimed at connecting different control strategies with different types of buildings, spaces, and equipment. This taxonomy is described in detail in Appendix A.

The research integrated disparate PLEMS with other building systems (e.g., indoor positioning) and monitoring platforms (e.g., Eaton smart circuit breaker platform) to produce a heat map designed to reveal further energy savings and demand-response strategies.

# Technology Characteristics

## Novel Developments

Technology development was required to test selected control strategies to automate both user notification of demand-response (DR) events and plug-load operation based on user preference. The project developed several demonstration systems and applications to support various piloted control strategies and gain further insights into both energy and demand-response savings. Descriptions of these systems and applications follow.

1. A novel flexible plug-load mobile application took user-equipment preference into account when automating plug loads and interfacing with existing PLEMS platforms.
2. A DR notification system was designed and developed to alert lab managers of upcoming DR events and recommend equipment to be turned off. This notification system coordinated lab-user manual actions.
3. A novel heat-map display integrated indoor-positioning and plug-load energy-consumption data to develop energy-savings and demand-response automation strategies for commercial settings.

A final step was to analyze results from the different strategies and recommend their application.

## Technology Readiness Level Advancement

The FEMS encompassed a variety of strategies, each reaching different degrees of Technology Readiness Level (TRL). For the lab environment a FEMS notification system was created to allow lab workers to manually opt in to DR events. This system required significant conceptualization and design in its early-development stage and was fully tested in the biology-lab environment. Its TRL was, therefore, raised from 3 (prototype developed) to 5 (pilot demonstrated) over the course of the project.

For the office environment a FEMS application was designed to automate plug loads for DR applications. This system required significant conceptualization and design in its early stages and was tested at EPRI, where its TRL rose from 3 to 5 throughout the project. Various DR strategies were supported by the FEMS app including power-up and power-down strategies, with plug-load equipment selected through the app. To advance to TRL 6, these strategies were demonstrated in an office environment. Their full-scale demonstration in real-world commercial office environments will, however, require multiple test sites, which is the next step for advancement to TRL 7. Demonstration of power-up and power-down applications as strategies become increasingly available in integrated plug-load energy-management systems could both reduce implementation costs and help boost TRL to 8-9.

For presence-based automation, the project originally used Meridian beacons for location data. Since the beacons were insufficiently accurate for the office environment, the project selected a new vendor that uses Wi-Fi pings for indoor-positioning system data. However, the pilot site was unable to test the new technology before its activities were interrupted by restrictions mandated by the global pandemic that began in 2020, which meant that the system was only tested in a research environment, where the TRL was advanced from 3 to 5.

The heat-map display components required the integration of energy data with indoor positioning data to develop a visual floor plan. Though not pilot tested due to a lack of time remaining after its development, it was vendor-tested in a controlled environment and advanced from TRL 3 to 5. Upon consideration of feedback received from utility technical advisers at a technical advisory committee meeting (conducted during the first quarter of 2020), the project team incorporated additional smart devices capable of monitoring heating, ventilation, air conditioning (HVAC) and lighting into the heat-map display platform. This capability is available for future testing.

# CHAPTER 3:
# Plug Load Trial in Office Building

## Office-Pilot Setup

### Site

Figure 3 shows the one-story floor plan of the office-pilot site, an architectural-office building located in Mountain View, California, that houses the architectural firm AP+I Designs. At this site a total of 284 plug-load devices were plugged into smart strips to monitor power use. Each participating plug-load device was plugged into one of the four smart outlets, or channels, that made up a single smart strip. A total of 71 smart strips and three gateways were installed as part of the office site's plug-load energy-management system (PLEMS).

**Figure 3: AP+I Floor Plan**

Source: Electric Power Research Institute, Inc.

### Smart Strip Technology

The PLEMS vendor dAlchemy provided smart strip hardware branded as Enmetrics Powerports, shown in Figure 4. The PLEMS platform uses four-outlet smart strips for real-time monitoring and automating switching operation of individual outlets on each strip. Users acting to administrators can use time schedules and load-sensing automation strategies to automatically turn devices on and off. The time-scheduling option allows administrators to set times when plug-load devices will be turned on and off. The load-sensing option also allows an administrator to set a threshold-consumption value on the master port to determine when selected equipment will be turned on and off. The strip collects detailed energy-consumption data for each device plugged into it. Historical and real-time data can be viewed with the same web-based application where automation strategies are also configured.

**Figure 4: Enmetric Smart Strip**


Source: Electric Power Research Institute, Inc.

## Baseline and Treatment Periods

The 2-week baseline study began Monday, July 16, 2018 through Sunday, July 29, 2018. During this period, plug-load office and break-room equipment electricity usage was monitored and data collected, but without automation strategies. Occupants were asked to operate equipment as they would on any normal workday. Load-sensing and time-scheduling automation strategies were then implemented during a 2-week treatment extending from Monday, July 30, 2018, to Sunday, August 12, 2018. These two periods are summarized in Table 1.

**Table 1: Baseline and Strategy Periods**

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| ■ = baseline ■ = strategy | July 16 | 17 | 18 | 19 | 20 | 21 |
| 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 29 | 30 | 31 | Aug 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 12 | 13 | 14 | 15 | 16 | 17 | 18 |

Source: Electric Power Research Institute, Inc.

During the automation period, time-scheduled devices were set to turn off at 10 p.m. and back on at 5 a.m. on weekdays. During this period there were neither holidays nor significant office events. Weather during business hours was consistent, ranging between 70 and 76 degrees Fahrenheit (21 and 24 degrees Celsius).

## Office Equipment and Selected Automation Strategies

Of the 284 pieces of equipment monitored during the baseline period, 213 were automated during the treatment period. Most of the selected equipment was located in office occupants' workstations, though some was located in break rooms, conference rooms, and common-area equipment spaces. Table 2 lists the equipment.

**Table 2: Equipment Types and Inventory Count**

| Equipment on Smart Outlets (284) | Equipment Chosen for Strategies (213) |
|---|---|
| Chargers (15) | Chargers (15) |
| Computers or Laptop (55) | Computers or Laptop (54) |
| Monitors (59) | Monitors (54) |
| Water Dispenser (2) | Water Dispenser (2)* |
| Task Light (47) | Task Light (47) |
| Coffee Maker (2) | Coffee Maker (2)* |
| Ice Maker (1) | Ice Maker (0) |
| Media devices (4) | Media devices (0) |
| Microwave (1) | Microwave (0) |
| Power Strip (3) | Power Strip (3) |
| Network Switch (1) | Network Switch (1)* |
| Available Port (47) | Available (31) |
| Unknown (44) | Unknown (0) |
| Printer (1) | Printer (1)* |
| Shredder (1) | Shredder (1)* |
| Refrigerator (1) | Refrigerator (0) |

**Note: * denotes equipment set to automate within a time schedule.**

Source: Electric Power Research Institute, Inc.

The first column of Table 2 shows each equipment type plugged into smart strips, along with an inventory count of each device type (shown in parentheses). In the table, "Available Port" shows a smart outlet at a workstation smart strip designated for any equipment that needs to be either plugged in or switched on the smart strip. Most of the "available" equipment was likely phone chargers.

The second column identifies only equipment types involved in an automation strategy during the treatment period, along with their inventory count. An asterisk (*) denotes equipment automated under a time schedule. All other equipment was set to automate under a load-sensing strategy.

The office building's PLEMS administrator was most comfortable testing load-sensing strategies on occupant workstations so that operations from time-schedule automation would not be disturbed. The remaining non-workstation equipment used the time scheduling strategy. Most of this equipment, however, did not have robust enough usage to yield significant results.

In summary, only non-workstation equipment used the time-scheduling strategy (e.g., printer, network switch, shredder, water dispenser, and coffee maker). All other device types were automated under a load-sensing strategy.

## Energy Savings Results

Energy savings were calculated by observing two-week baseline and treatment periods where selected devices were put under both time-scheduling and load-sensing automation strategies. Energy consumption over the treatment period was then subtracted from energy consumption during the baseline period. Table 3 summarizes the overall savings at the conclusion of the treatment period. The overall reduction in energy consumption from the baseline period to the treatment period was 10.8 percent. Extending to a year-long timeframe, the corresponding average annual energy savings per smart strip is 15.3 kWh (Source: Electric Power Research Institute, Inc Table 4).

**Table 3: Overall Savings**

| Baseline Consumption over 2 weeks (kWh) | Strategy Consumption over 2 weeks (kWh) | Overall Savings (kWh) | Overall % Savings |
|---|---|---|---|
| 294.1 | 262.4 | 31.7 | 10.8 |

Source: Electric Power Research Institute, Inc.

**Table 4: Annual Savings**

| Number of Smart Strips Used | Annual Savings Across All Devices (kWh) | Annual Savings Per Smart Strip (kWh) | Annual $CO_2e$ avoided Per Smart Strip (g) |
|---|---|---|---|
| 54 | 824.2 | 15.3 | 6563.7 |

Source: Electric Power Research Institute, Inc.

Energy savings by device type are summarized in Table 5 for each device type included in the treatment period. The second and fourth columns of the table show total energy consumption during the baseline and treatment periods, expressed in kilowatt-hours. The third column shows average consumption per device during the baseline period. The fifth column provides the overall usage savings by subtracting energy consumption during the treatment period from that consumption during the baseline period. The sixth column extrapolates two-week energy savings to provide an annual savings estimate. The seventh column shows percentage savings for each device type when savings across all equipment types were considered. The last column provides a range of percentage savings for particular equipment types.

**Table 5: Savings by Device Type**

| Strategy Devices Type | Total Usage during Base-line Period (kWh) | Average Usage per Device during Baseline period (kWh) | Total Usage during Treat-ment Period (kWh) | Overall Savings over 2-week period (kWh) | Annual Savings across all devices (kWh/ year) | % Savings | % Savings Range |
|---|---|---|---|---|---|---|---|
| CPU / Laptop (54) | 137.2 | 2.5 | 135.3 | 1.8 | 47.6 | 1% | 1-7% |
| Charger (15) | 5 | .3 | 4.1 | 0.9 | 23.9 | 18% | 0-24% |
| Monitors (54) | 103.0 | 1.9 | 85.0 | 17.9 | 467.4 | 17% | 6%-28% |
| Task Light (47) | 11.9 | .25 | 10.1 | 1.8 | 46.4 | 15% | 0-22% |
| Power Strip (3) | 0.2 | .07 | 0.2 | 0.0 | 0.0 | 0% | 0 |
| Coffee Maker* (2) | 25.1 | 12.5 | 18.1 | 7.0 | 182.9 | 28% | 29%-41% |
| Shredder* (1) | 1.7 | 1.7 | 1.7 | 0.0 | 0.1 | 0% | 0 |
| Available Outlet (31) | 10.2 | .31 | 8.0 | 2.2 | 56.9 | 21% | 0-18% |

Source: Electric Power Research Institute, Inc.

Note: The printer, network switch, and water dispenser were not used during either the baseline or treatment periods. Therefore, their energy savings were 0. Total usage of dumb power strips was also minimal, resulting in zero savings after rounding.

The savings attributed to central-processing unit (CPU)/laptop automation averaged one percent because this equipment served as controller in the selected load-sensing strategy; other workstation equipment was turned on and off based on the CPU/laptop outlet state.

The greatest energy savings were attributed to the coffee maker, a heavy energy-consuming device. By automating the coffee maker to a time schedule, energy waste was eliminated during after-work hours. At workstations, monitors were the greatest potential energy savers, followed by chargers and task lights.

Select smart outlets at workstations were labeled “Available” in the PLEMS data collection, representing available ports where users were free to plug and unplug their equipment into available smart outlets. Differences between device types and the fluctuation of equipment plugged into available outlets led to a wide range (0-18 percent) of savings, which were not documented by device type.

## Economic and Carbon Savings

Economic savings were computed at the A-1 time-of-use (TOU) commercial electricity rate offered by PG&E. Considering the office building's normal 8 a.m. to 5 p.m. business hours, the building operates for one hour during the partial-peak electricity rate for three months of the year and operates during the off-peak electricity rate during the remainder of the year. A weighted calculation of these electricity rates reflects this. The weighted price of electricity consumed was $.21/kWh[2], and the average annual electricity cost savings were $3.21 per smart strip.

The annual energy savings of 15.3 kWh per smart strip translates into 6,563.7 grams of $CO_2$e avoided annually per smart strip, using an emissions factor of 429g/kWh of $CO_2$e (2019, U.S. Environmental Protection Agency [EPA]).

## Break-Even Calculation

Table 6 shows the simple payback for each device type, assuming that all four outlets on the smart strip are plugged into a given device. Since a smart strip is assumed to cost $100, the cost of one smart outlet on the smart strip is assumed to be $25 in this break-even calculation. The second column shows the annual savings per device. The third column shows the annual savings across all devices within that device type during the treatment period. The fourth column shows the average annual cost savings for each device within the given device type. The last column shows the years to breakeven assuming all four outlets on the smart strip are plugged into the given device.

Other than the coffee maker, very long periods are required for a return on investment (ROI). Additional steps are needed to reduce these payback periods. These include targeting more energy-intensive equipment to improve ROI beyond savings that look at plug loads inclusively. Moreover, stacking applications of value to the user can more effectively justify ongoing service fees, which contribute to overall costs.

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[2] PG&E Electricity Rates. Commercial/general service A-1 TOU from March 1, 2018 to August 31, 2018 rate used for computing an average electricity price. The summer part-peak price is $0.24 and off-peak price is $0.21, while winter part-peak price is $0.23 and off-peak price is $0.20. The building operates during partial peak for one hour a day during 3 months of the summer period and during partial peak during the remaining time. Therefore, the average rate is computed from: ($0.24435(partial peak rate) * 0.04) +($0.217(off peak rate) *0.96) = $0.21809 weighted rate. Next a weighted calculation is performed between weighted 3 summer months and 3 months of summer which the building operates off-peak: (0.217*0.5) +(0.21809*0.5) = $0.217545. Finally, the weighted summer rate and the off-peak winter rate give the annual weighted price for electricity: (0.217545*0.5) +(0.20530*0.5) = $0.2114225 or $0.21.

**Table 6: Break-Even Calculation**

| Device | Annual Savings per device (kWh/year) | Average Annual Savings Across all Devices ($/year) | Average Annual Savings per device ($/year) | Years to Breakeven, per smart outlet (years) |
|---|---|---|---|---|
| CPU / Laptop | 2.2 | $25.15 | $0.47 | 54 |
| Charger | 1.2 | $3.81 | $0.25 | 98 |
| Monitors | 10 | $114.32 | $2.12 | 12 |
| Task Light | 1.3 | $12.93 | $0.28 | 91 |
| Power Strip | 2.6 | $1.65 | $0.55 | 45 |
| Coffee Maker* | 123.3 | $52.20 | $26.10 | 1 |
| Network Switch | 0 | 0 | $0.00 | 0 |
| Printer* | 0 | 0 | $0.00 | 0 |
| Shredder* | 0 | 0 | $0.00 | 0 |
| Available | 4.1 | $26.91 | $0.87 | 29 |
| Water Dispenser* | 0 | 0 | 0 | 0 |

Source: Electric Power Research Institute, Inc.

PG&E's commercial/general service A-1 TOU from March 1, 2018 to August 31, 2018[3] was used to determine the price of electricity. The office operated one hour during partial-peak time 3 months of the year and operated during off-peak time the remainder of the year; a weighted calculation of the rates was done to reflect this. The weighted price of electricity used for the break-even calculation was $.21/kWh.

There is a secondary effect of devices; the electricity consumed emits heat into the building while they are in use. The heat emitted can lower the use of heating during the winter and increase air conditioning during the summer. Although the exact contribution of this heating to HVAC operation in the office is out of the scope of this study, a kWh-to-BTU calculation can estimate the heating impact from the equipment. Given that 1Btu = 0.00029 kWh, an annual savings of 825.2 kWh across all devices would be the equivalent of a 2815699.3 BTU decrease in annual heating.

The ROI calculations for two use cases follow.

## Break-Even Workstation Use

The first use case of smart-outlet automation is for an office workstation. A workstation smart strip typically contained a computer, task light, monitor, and charger or available outlet. There were 54 workstations and 2 gateways at the office building site, for a total cost of $6,000 (i.e., $5,400+$600) for PLEMS equipment. One workstation with the specified equipment saved $4.01 annually, given savings from CPU ($0.47) + task light ($0.28) + monitor ($2.12) + cost

[3] PGandE Electricity Rates

savings split between charger and available port (0.28+ 0.87) / 2. Annually all 54 workstations saved \$216.54. Assuming the price of electricity is \$0.21/kWh, the workstation smart-strip with this equipment has a 27-year break-even point.

The smart strips and gateway also consume electricity when they are plugged in. Adjusting for the operating costs of 8.0 watt-hours (Wh) per strip and 9.6 Wh per gateway, all workstations saved \$107.14 and had a 56-year break-even point. It should be noted that traditional power strips also have associated operational consumption, typically between 0.1 - 0.8 watts. Thus, the gateway is the only added operational cost when comparing traditional power strips with PLEMS operational requirements.

### Coffee Maker Break-Even Use Case

The second use case involves automating a coffee maker to a time schedule. The ROI computation assumes a shared cost of a gateway in a 10-strip-per-gateway setup (i.e., \$1,000+\$300). That is, hardware costs per smart strip (i.e., \$1,300 for 10 smart strips) is \$130 per smart strip. The coffee maker only used one outlet on the 4-outlet smart strip, so the break-even calculation assumes that no other equipment contributed to savings. This use case yields a savings of \$26.10 annually. Assuming an electricity price of \$0.21/kWh, the coffee maker-use case has a break-even point of 5 years.

It should be noted that the PLEMS data collection for the coffee-maker power consumption contained 47 minutes of missing data (from 7/16/2018 to 8/12/2018) over the entirety of the baseline and treatment periods. Data loss occurs when gateway connectivity to the internet is lost since no local data storage was incorporated into the hardware of the particular PLEMS used in the office pilot.

## Advances Developed for Future Pilot Testing

### Demand-Response Application Design and Development

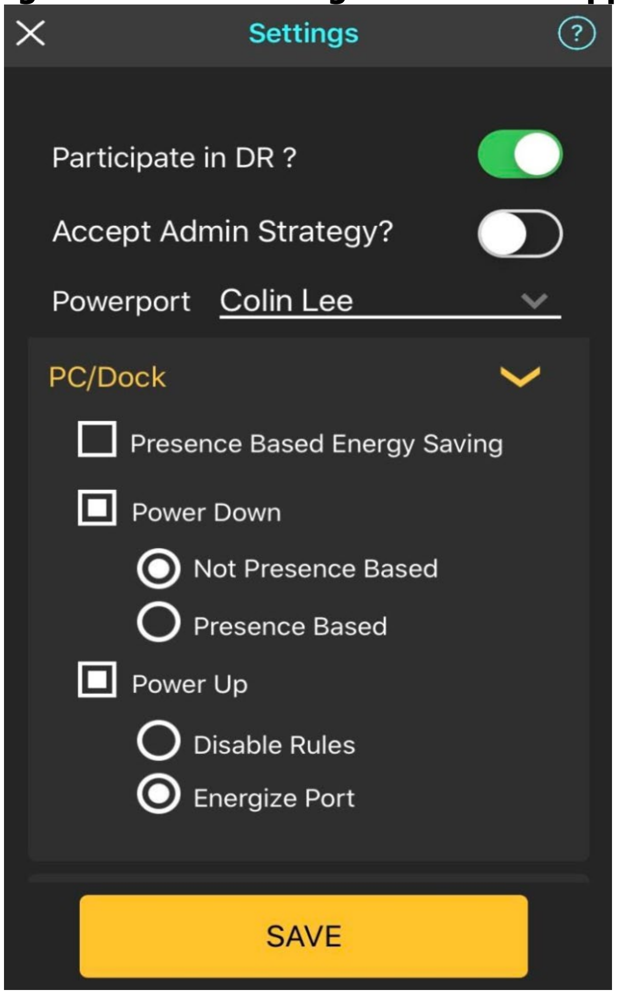
The project developed a demand-response-enabling application for the automation of plug-load equipment as an extension of the PLEMS platform. Software development included the design and creation of a mobile application that allowed occupants to choose which outlets to opt into during demand-response events. The goal of the mobile application was to consider user preference when automating devices so that individual preferences could be easily configured to avoid disruptions during demand-response events.

Users were given the ability to set, from their mobile apps, the following demand-response strategies for equipment plugged into their smart strips:

1. Power Down: Turn users' selected outlets off during DR events.
2. Power Up/Energize Port: Turn users' selected outlets on during DR events.
3. Disable Rules: Disable all rules on outlets during DR events.

Figure 5 shows a screenshot of the graphic user interface for the flexible plug-load mobile application, where users may select outlets for their savings strategies. During a DR event, users may select a piece of equipment plugged into a smart outlet and check which strategies apply to that smart outlet.

**Figure 5: Flexible Plug-Load Mobile App**




Source: Electric Power Research Institute, Inc.

A mobile web application was developed concurrently for an administrator to set administrative global preferences for automation strategies and assign users to smart strips. The flexible plug-load application was first tested at EPRI offices where EPRI employees used an OpenADR server to issue demand-response events to assess whether designated ports performed according to their demand-response strategies. Given project delays and timing constraints from outside events (such as the global pandemic), the office pilot site incorporated a telecommuting plan early on, before the DR application and strategies could be tested. A future pilot test of this developed application is recommended to assess its potential.

## Power and Presence Heat-Map Display

One of the original project aspirations was to integrate disparate PLEMS platforms with other building monitoring systems to maximize energy and demand savings. Specifically, technical advisors recommended including HVAC and other large plug loads for common visualization. The project team subsequently integrated multiple PLEMS and smart-device platforms with an indoor positioning monitoring system that established spatial and quantitative views of user presence alongside power consumption within physical spaces.

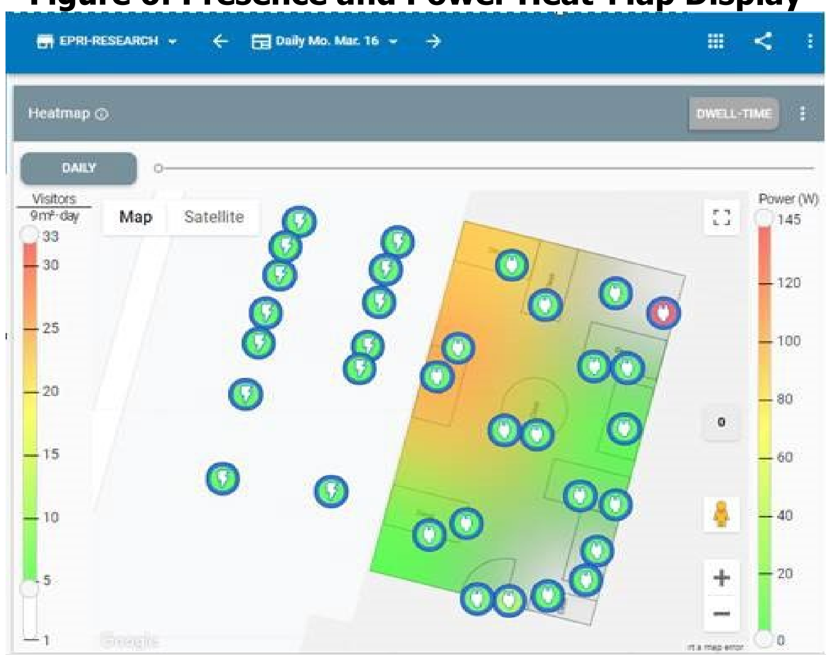
The chosen vendor with an indoor positioning monitoring system was Kiana Analytics, which through EPRI integrated an existing online visualization platform with multiple PLEMS and smart-device vendor platforms. The indoor position monitoring system uses a mobile phone or other smart devices' Wi-Fi ping as a proxy for presence. The integration of these systems created a descriptive understanding of plug-load energy consumption data in relation to presence data within specific spaces.

The project team developed a visual representation of the relationship between presence and energy by feeding both data streams into a displayed with a building floor plan. A screenshot of the heat map is shown in Figure 6.

The plug icons shown within the blue circles represent locations of smart-outlet devices (for example smart strips or smart-plug modules) within the building, while the lighting symbol represents Eaton electric-vehicle charging stations in the office's parking lot. Upon hovering, the user can see the names of the devices on each of the four outlets that comprise the smart strip, as well as their power consumption.

The color scale within the circle shows how much power is being used on the strip; green represents relatively low averaged power usage while red represents relatively high averaged power usage. The infrared color scale overlaid over the floor plan represents user presence within different spaces in the building, using the same color-scale scheme.

**Figure 6: Presence and Power Heat-Map Display**




Source: Electric Power Research Institute, Inc.

With this heat-map display for visualization, an administrator can study usage and presence patterns by time of day, day of the week, and other filters to effectively identify potential equipment candidates for automation when no one is present. The heat-map display provides both real-time and historic visualization within selected time frames.

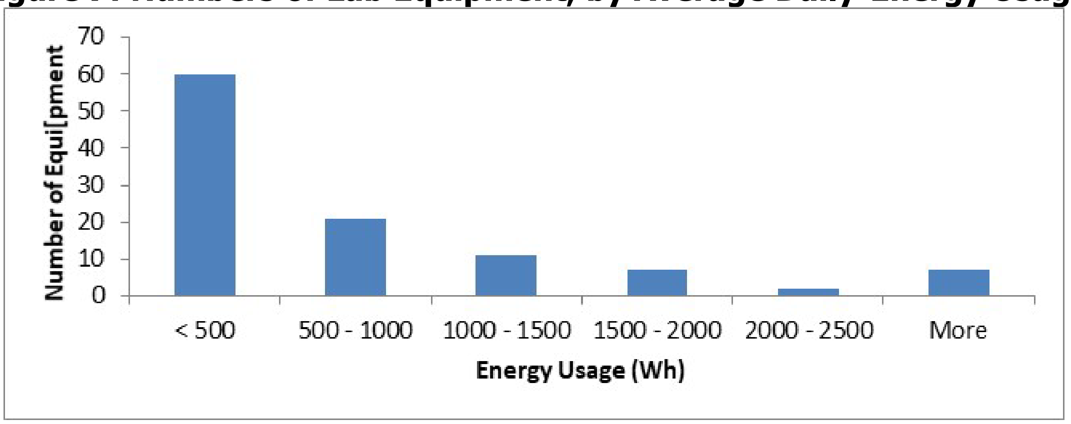
The heat-map display was integrated with two plug-load vendor PLEMS platforms (dAlchemy and IBIS), as well as with a smart circuit-breaker platform developed by Eaton. User presence can be detected using any of the user's smart-device Wi-Fi pings as a proxy for presence, including a smart tablet, laptop, phone, or other mobile device. The heat-map display was developed for an office setting and its functionality confirmed at a development site. The display was interfaced with electric-vehicle charging-station data originating with EPRI's office and plug-load data from AP+I Designs, as well as with Stanford Labs. Pilot testing in an office environment is recommended for future study.

# CHAPTER 4: Biology Lab Results

At the biology lab pilot site more than 100 types of laboratory equipment were monitored using the IBIS plug load energy management system (PLEMS). At the start of the research investigation from November 2016–March 2017, 27 of those devices used an average of more than 1 kWh of energy per day. Moreover, 25 unique devices had a monthly average peak load of more than 400 watts, as illustrated in Figure 7. Figure 8 illustrates the number of lab equipment by monthly average peak load.

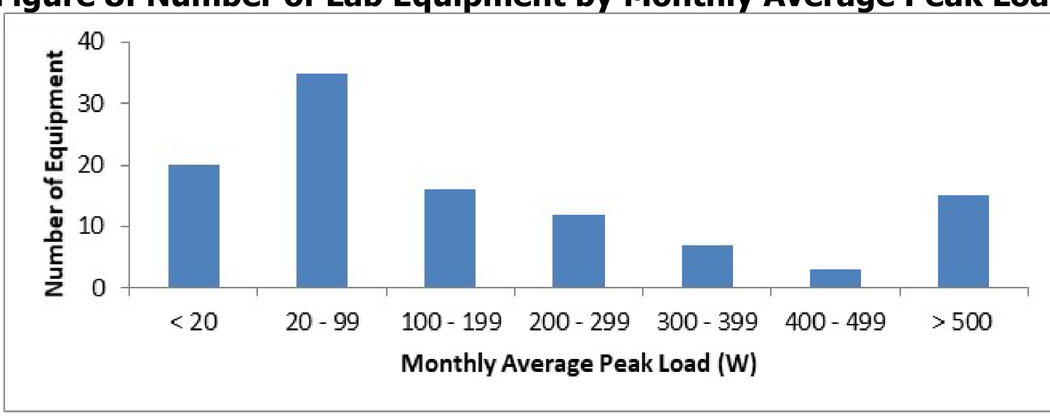
The PLEMS monitored energy usage and enabled the automated switching of laboratory equipment plugged into smart-plug devices. The biology lab participated in lab-equipment time scheduling and tested a demand-response notification system designed specifically for a lab environment. The energy saving results from time scheduling and the average power reductions from the demand-response notification system are summarized in this chapter.

**Figure 7: Numbers of Lab Equipment, by Average Daily-Energy Usage**




Source: Electric Power Research Institute, Inc.

**Figure 8: Number of Lab Equipment by Monthly Average Peak Load**




Source: Electric Power Research Institute, Inc.

## Biology Lab Energy Savings

### Time Schedules Per Participating Lab

Of the 76 plug loads tracked in this study, 21 were put on time schedules so their energy savings could be evaluated. These time schedules essentially involved turning the devices off at night and during holidays. These "off" times varied between 5 p.m. and 12 a.m., and the "on" times varied between 6 a.m. and 8 a.m. The shortest time frame for devices to be turned off was six hours, from 12 a.m. to 6 a.m.; the longest time frame for devices to be turned off was 15 hours, from 5 p.m. to 8 a.m. The number of tracked devices and time-scheduled devices, per lab, is shown in Table 7.

**Table 7: Inventory and Device Schedules, Per Lab**

| Lab | Number of Monitored Devices | Number of Devices on Time Schedules | Date Time Schedules Set | Time Schedule (OFF period) |
|---|---|---|---|---|
| Weissman | 21 | 11 | 6/6/2017 | 12am – 6am |
| Feldman | 5 | 2 | 4/18/2017 | 8pm – 7am |
| Roncarolo-Baccetta | 26 | 3 | 4/27/2017 | 11pm – 6am |
| Majeti | 10 | 2 | 4/18/2017 | 7pm – 7am |
| Mackall | 10 | 1 | 9/6/2017 | 12am – 6am |
| Sebastiano | 9 | 2 | 4/10/2017 | 5pm – 8am |

Source: Electric Power Research Institute, Inc.

Smart power strips were used for time-scheduling some plug loads in the labs. Not all the equipment in the labs was put on time schedules because of both safety and convenience concerns. For example, some equipment, such as water baths, have a long start-up time, which could be inconvenient for researchers. Other equipment, such as the plate reader or centrifuges, may need to be operated during off hours. Some lab managers were, therefore, more comfortable posting signs reminding users to turn off the equipment when not in use, rather than relying upon time-scheduled equipment control. Two methods of calculating energy savings were performed. A description of overall energy savings appears in the next section. The amount of energy savings when the devices were employed is outlined in APPENDIX C:*Energy Savings When Lab Devices Are in Use* .

### Baseline Determination

A separate calculation was done to understand overall energy savings from implementation of PLEMS for automating equipment in time-scheduled operations. The baseline was determined from the total energy usage of time-scheduled devices in each participating lab for two weeks before the time schedules were implemented. If there was a device with more than 10 percent of data loss during the baseline or trial periods, the device was dropped from the analysis.

### Energy Savings Calculations

In order to calculate overall energy savings, the difference was measured between the energy usage during the baseline period and the energy use two weeks after the time schedules began.

Using this method to calculate overall energy savings, the energy savings per lab are summarized in Table 8. Negative savings indicate that energy use increased after time schedules were set, possibly from behavioral changes in equipment use.

**Table 8: Lab Energy Savings**

| Lab | Average Energy Before Schedule (Wh/day) | Average Energy After Schedule (Wh/day) | Average Energy Saved (Wh/day) | % Lab Savings | Average Energy Savings* for Device Type (Wh/day) |
|---|---|---|---|---|---|
| Weissman | 4981 | 4177 | 804 | 16% | (8**) Centrifuges: 673<br>(3) Heating Blocks: 132 |
| Feldman | 406 | 201 | 204 | 56% | (2) Centrifuges: 204 |
| Roncarolo-Baccetta | 803 | 618 | 185 | 23% | (2) Water Baths: 159<br>(1) Electronic Balance: 26 |
| Majeti | 565 | 494 | 71 | 13% | (1) Centrifuge: 147<br>(1) Printer: -76 |
| Mackall | 198 | 231 | -33 | -17% | (1) Plate Washer: -33 |
| Sebastiano | 182 | 136 | 47 | 26% | (2) Heating Blocks: 47 |

**** Average Energy Savings represents the average savings per day between the baseline and trial periods.**

****Only 8 of the centrifuges were included - 3 of the centrifuges in the Weissman Lab did not have enough data to be computed and were dropped from the calculation.**

Source: Electric Power Research Institute, Inc.

There is a wide variation in savings among device types. The savings varied by actual equipment use and by model. Table 9 shows overall energy savings, by device type. Again, negative savings indicate that energy use increased after time schedules were set, possibly from behavioral changes in equipment use.

**Table 9: Device Energy Savings**

| Device Type | Number of Devices | Average % Saving | % Savings Range | Average Annual Energy Savings across all devices (kWh/year) |
|---|---|---|---|---|
| Centrifuge | 8 | 19% | -55% - 91% | 376 |
| Electronic Balance | 1 | 29% | N/A | 9 |
| Heating Block | 5 | 39% | 4% - 61% | 65 |
| Plate Washer | 1 | -17% | N/A | -12 |
| Printer | 1 | -30% | N/A | -28 |
| Water Bath | 2 | 22% | 21% - 23% | 58 |

Source: Electric Power Research Institute, Inc.

### Break-Even Calculations

ROI was calculated by taking the total annual energy saved across 18 time-scheduled devices with adequate usage data: 468 kWh/year. The total energy saved annually was then divided by the 18 time-scheduled outlets to compute the energy saved per outlet: 26 kWh/year.

**Table 10: Break-Even Per Device, Organized by Equipment Type**

| Return on Investment by Device Type | Baseline Period Average Energy Usage per device (Wh/day) | Average Energy Savings per device (Wh/day) | Average Energy Savings per device (kWh/yr) | Annual Savings Assuming @ $.21 / kWh | Years to break Even |
|---|---|---|---|---|---|
| Centrifuge (8) | 678 | 128 | 47 | $9.82 | 12 |
| Electronic Balance (1) | 88 | 26 | 9 | $1.97 | 61 |
| Heating Block (5) | 131 | 46 | 13 | $2.73 | 44 |
| Plate Washer (1) | 198 | -33 | -12 | -$2.54 | N/A |
| Printer (1) | 254 | -76 | -28 | -$5.83 | N/A |
| Water Bath (2) | 357 | 80 | 29 | $6.11 | 20 |

Source: Electric Power Research Institute, Inc.

The total savings across all labs was calculated to be 1,279 Wh/day. With the baseline energy consumption of 7,136 Wh/day, this is equivalent to 18 percent.

The cost per smart outlet was $100, and the cost per gateway was $295. The cost unit used in ROI was the cost of the smart outlet plus each outlet's share of the gateway cost: ($295/15) + $100 = $120 per smart outlet.

The break-even point for each device was then computed by dividing the monetary annual energy savings of each device assuming $.21 per kWh, by the $120 cost per smart outlet for the number of years it will take to break even.

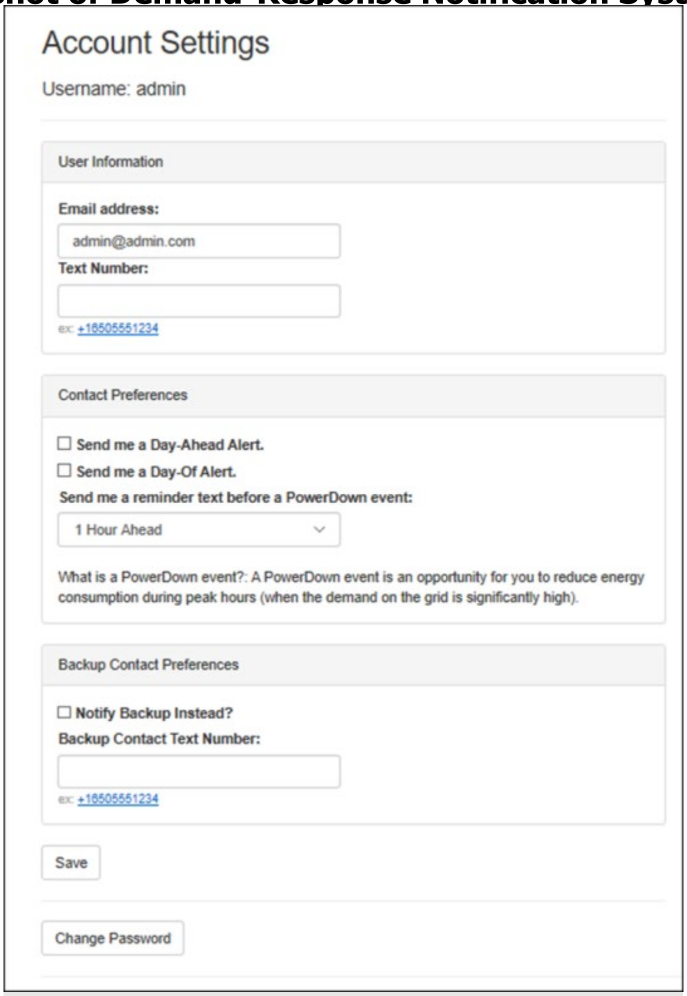
## Demand-Response Pilot

The demand-response pilot for the biology lab was designed by interviewing lab managers to design a process that engaged labs to respond to demand-response event notifications. Originally, six lab managers and liaisons with the labs contributed to the pilot's design, though only one lab ultimately agreed to participate. The Weissman lab had a total of 21 devices monitored by a PLEMS. Of that total, five of the equipment were recommended to lab managers to turn off during demand-response events. The selection was done through a recommendation algorithm that considered the past month of power use and equipment safety to determine demand-response potential. The recommended equipment included 2 centrifuges, one thermomixer, one water bath, and one heating block. Ten out of the 21 pieces of equipment had no data during the pilot, possibly due to being unplugged from the PLEMS.

### Notification System

The notification system was designed to text the lab manager's mobile phone to communicate demand-response events. The process of implementation then starts with a one-time setup (lab managers only) where lab managers log into their DR notification system account via a Web browser and specify the email and text numbers to receive that event notification. A screenshot follows in Figure 9.

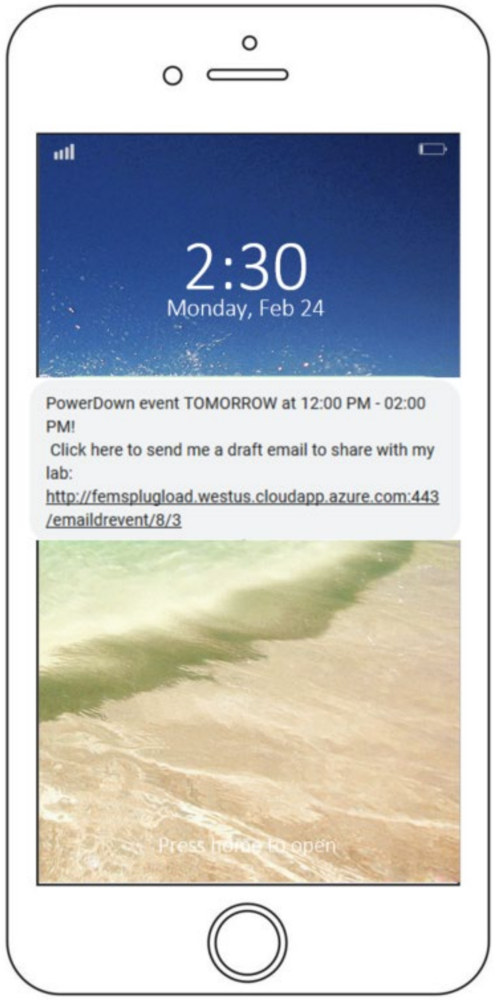
**Figure 9: Screenshot of Demand-Response Notification System Account Setti**




Source: Electric Power Research Institute, Inc.

One day ahead of the event, lab managers receive text notifications the morning before the DR event. The text message provides a hyperlink to send a draft email that can be forwarded by the lab manager to lab users. See a sample text message in Figure 10 and draft email in Figure 11.

**Figure 10: Example of Notification Text Message**




Source: Electric Power Research Institute, Inc.

## Figure 11: Example of Draft Email

[EXTERNAL] Power down event for Tuesday, February 04, 12:00 PM to 02:00 PM

P plugloadforlabs@gmail.com
To
Cc Plugloadforlabs

Reply | Reply All | Forward | ...

Mon 2/3/2020 1:00 PM

Suggested Meetings

+ Get more add-ins

*** Exercise caution. This is an EXTERNAL email. DO NOT open attachments or click links from unknown senders or unexpected email. ***.

*** Email is from plugloadforlabs@gmail.com ***.

Dear Lab members,

Our lab has a saving opportunity at **Tuesday, February 04, 12:00 PM to 02:00 PM.** Turning off the following equipment would be the equivalent of offsetting the emissions from driving 3.2 miles.

| Location | Equipment | Average Power (W) | Socket ID |
|---|---|---|---|
| G3155 | Eppendorf R 1.5 ml Thermomixer - 66 deg. C | 572 | 00ED4556 |
| G3155 | Eppendorf R 1.5 ml Thermomixer - 66 deg. C | 572 | 00ED4556 |
| G3155 | Eppendorf R 1.5 ml Thermomixer - 66 deg. C | 572 | 00ED4556 |
| G3155 | Grant JB Nova Water Bath - 37 deg. C., 20L | 999 | 00ED4556 |
| G3165 | Eppendorf 5430R Centrifuge | 16 | 00E7802D |

Please participate!

Regards,
Alex B
Lab Manager

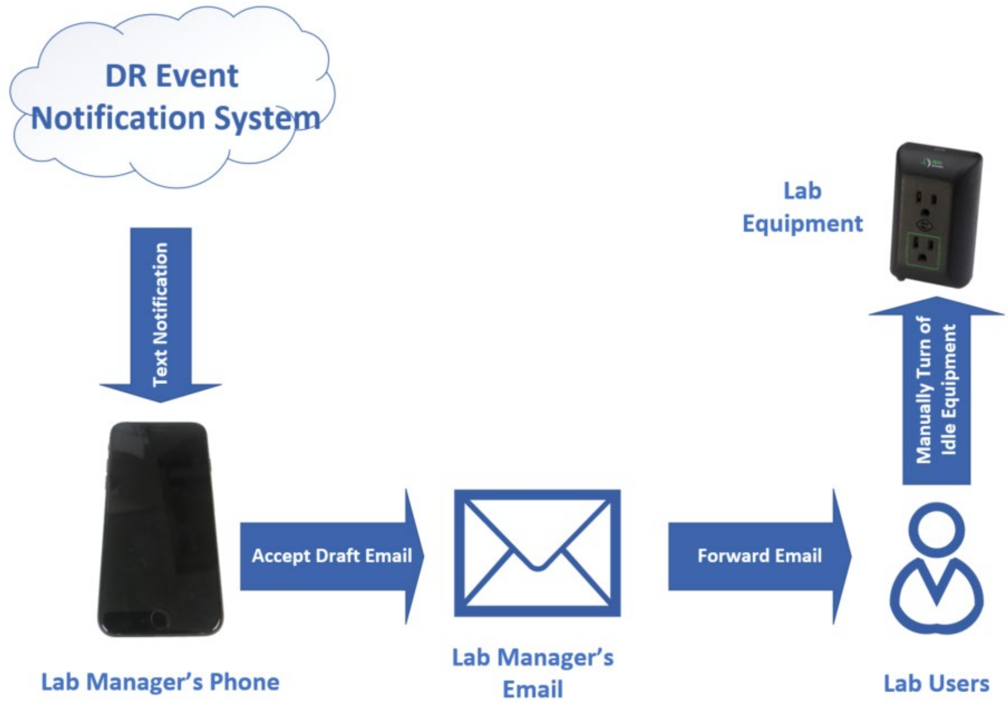
P.S. Details below:
What is a PowerDown event: a PowerDown event is an opportunity for you to reduce energy consumption during peak hours (when the demand on the grid is significantly high).
How you can help: Power down or turn off power-hungry equipment that is not in use or is not needed during the event hours.
Why you should help: Contribute to the grid reliability in your community. Save energy by reducing consumption during peak hours.

Source: Electric Power Research Institute, Inc.

The lab manager receives a draft email that can be edited before he or she forwards the email notification to lab users about the following day's event. The email includes a list of suggested equipment to manually check and possibly turn off during the DR event. The lab manager's email is sent to lab users and copies are retained for administrative-tracking purposes (plugloadforlabs@epri.com).

On the day of the DR event, the lab manager receives a reminder of the time of the event by text message. The lab manager may then click on the link in the text message to send a draft email that can be forwarded to lab users to remind them of the time of the DR event. This reminder is designed to prompt lab users to manually turn off idle lab equipment during the demand-response event. The entire process flow to engage lab managers and lab users is shown in Figure 12.

**Figure 12: Demand-Response Event Notification Process Flow**




Source: Electric Power Research Institute, Inc.

For the implementation of DR notifications, the Stanford DR pilot used a customized interface for scheduling and processing DR events. While EPRI did possess a functional virtual top node (VTN) system that could automatically process DR events, a customized notification system provided more control of the pilot's testing parameters. The pilot required customized messages to send to users. These customized messages required knowledge of the users' lab and devices for manual intervention during DR events. The VTN did not carry the requisite information on the recommended devices, so the project team recommended manual entries into a customized Web app, which was a graphical user interface of the FEMS notification system. Both the suggested devices per DR event and the DR events were entered via the Web app for the Stanford DR trial.

## Biology Lab Demand Savings

### Baseline Method

To compare demand savings during event periods, a baseline was calculated. Initially, hourly load profiles were developed by taking the hourly power-consumption data for each device over two weeks and one month before the pilot trial (without including data for Sunday). Sunday data was excluded because lab members worked infrequently on Sundays. Due to the sporadic work natures of biology lab environments, there was less variability in a 2-week period so a 2-week baseline was created for each piece of equipment. The 2020 dates shown in Figure 13 were used for the baseline and trial periods.

**Figure 13: Schedule for Demand-Response Trial**

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| Feb 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 16 | 17 | 18 | 19 | 20 Initial Trial | 21 | 22 |
| 23 | 24 | 25 DR Event 3-5pm | 26 | 27 DR Event 3-5pm | 28 | 29 DR Event 3-5pm |
| March 1 | 2 | 3 | 4 DR Event 4-6pm | 5 DR Event 4-6pm | 6 DR Event 4-6pm | 7 DR Event 4-6pm |

= Initial Trial
= DR Event
= Baseline Period

Source: Electric Power Research Institute, Inc.

## Demand Savings Calculation

Demand savings were calculated by taking the average power usage during the demand-response hours during the trial day and comparing it with the average power usage during demand-response hours. The following equation was used to calculate the savings percentages for the study:

$$\% \, Savings = \frac{Baseline \, Power_{DR \, Event} - Pilot \, Study \, Power_{DR \, Event}}{Baseline \, Power_{\, DR \, Event}} * 100\%$$

The demand savings are shown in Table 11.

**Table 11: Biology Lab Average Power Reductions**

| Power Down Event Period | Forwarded Email (Day-ahead of Event)? | Aggregate Savings** (W/%) | Average Power Reduction | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Beckman CS-6KR Centrifuge | Eppendorf R 1.5 ml Thermomixer | Grant JB Nova Water Bath | Eppendorf 5424R Centrifuge | VWR Standard Heating Block | Eppendorf 5430R Centrifuge* |
| Feb 25 3-5PM (Tues) | Yes | -119W -13% | -125W -147% | -30W -5% | 0W 1% | 55W 53% | -19W -19% | 2W 8% |
| Feb 27 3-5 PM (Thurs) | Yes | 14W 2% | -33W -39% | -3W -1% | 0W 1% | 54W 53% | -4W -4% | 0W 2% |
| Feb 29 3-5 PM (Sat) | Yes | 192W 22% | 85W 100% | 0W 0% | 1W 4% | 9W 9% | 97W 100% | 1W 3% |
| March 4 4-6 PM (Wed) | Yes | -55W -6% | 61W -62% | 13W 2% | 2W -8% | 3W 3% | -8W 9% | 0W 2% |
| March 5 4-6 PM (Thu) | No | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| March 6 4-6 PM (Fri) | Yes | 12W 1% | 10W 10% | 12W 2% | -2W -8% | 2W 2% | -10W -11% | 0W 2% |
| March 7 4-6 PM (Sat) | Yes | 15W 2% | 5W 5% | 13W 2% | 1W 5% | 2W 2% | -7W -7% | 0W 0% |

Source: Electric Power Research Institute, Inc

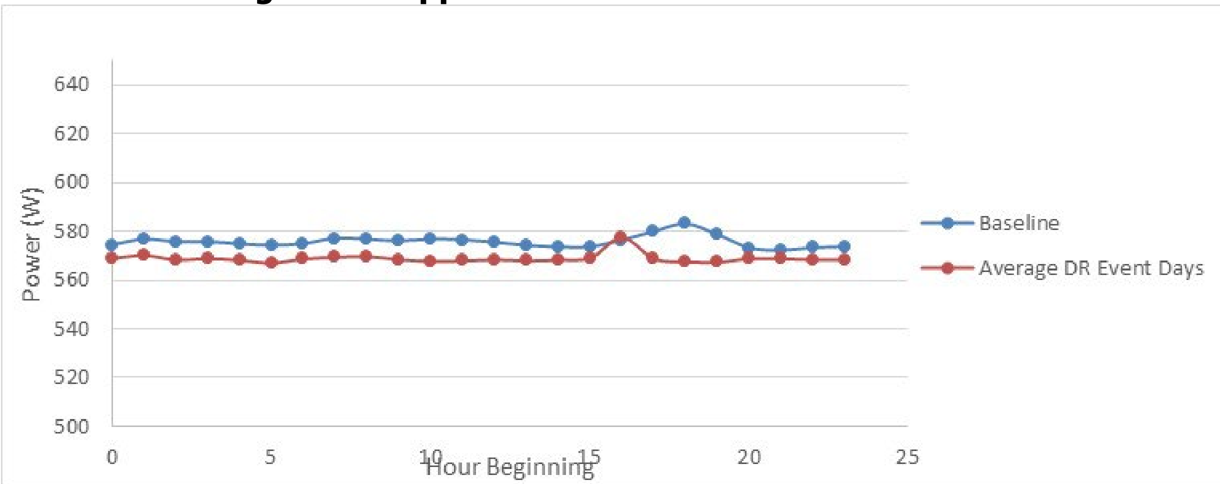
Negative values represent lack of savings
*Equipment was not recommended for demand response. Included for comparison
**Aggregate Savings is of the 5 recommended devices

Boxes without savings values had increased power consumption, likely due to behavioral variances. The Eppendorf 5430R Centrifuge (denoted with *) was a device that was not recommended to lab managers for demand response. However, its inclusion shows the data variability that may account for usage behavior.

The demand-response event on March 5 w,as communicated to the lab manager via text message. However, the lab manager did not forward the email to lab members so there were no expected impacts from that specific demand-response event. Data from March 5 was, therefore, not included in the analysis.

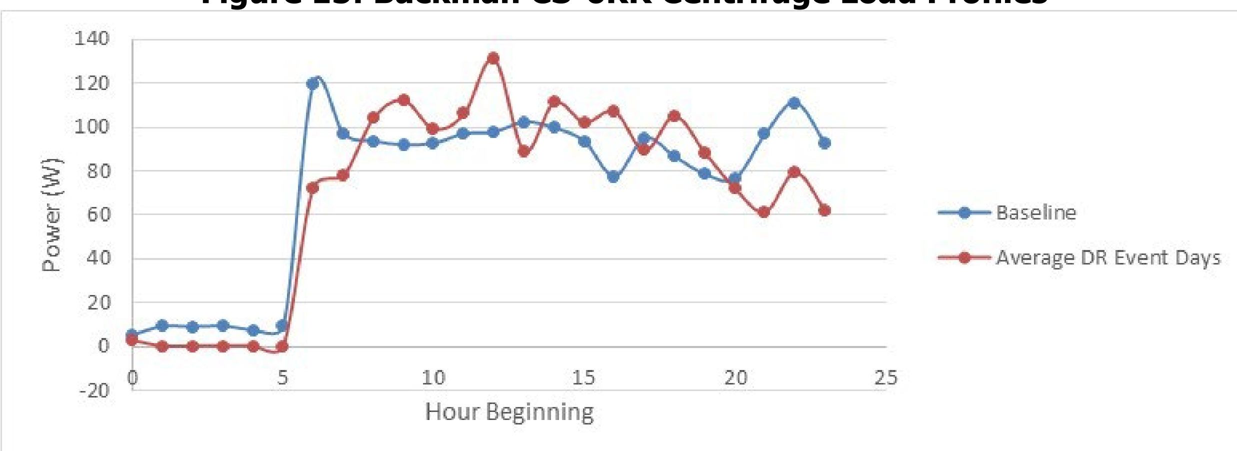
The load shapes during the average DR-event days and the 2-week baseline are shown in Figures 14 through 18. The average DR-event day is the average load profile of all the demand-response event days.

**Figure 14: Eppendorf Thermomixer Load Profiles**



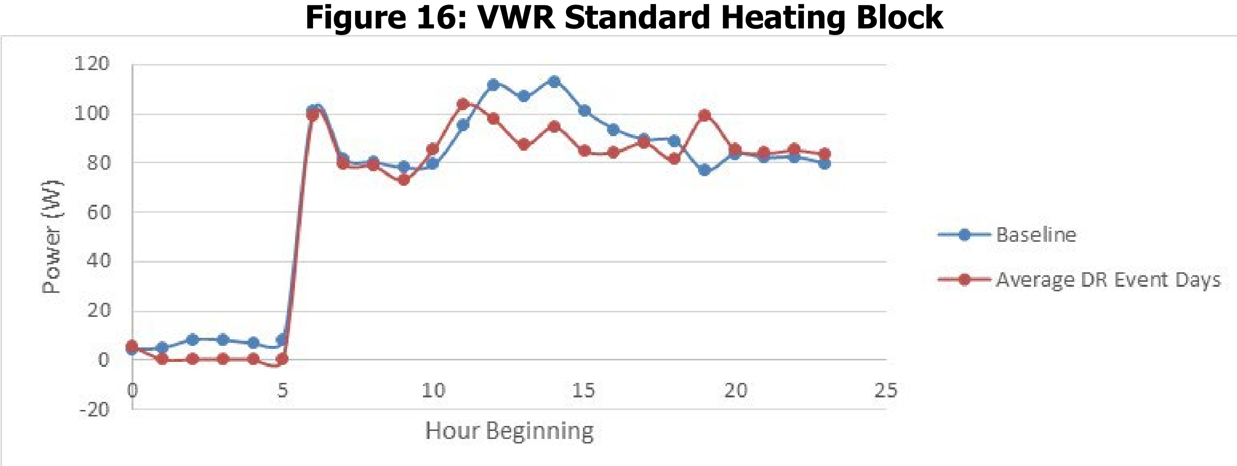

Source: Electric Power Research Institute, Inc.

**Figure 15: Backman CS-6KR Centrifuge Load Profiles**



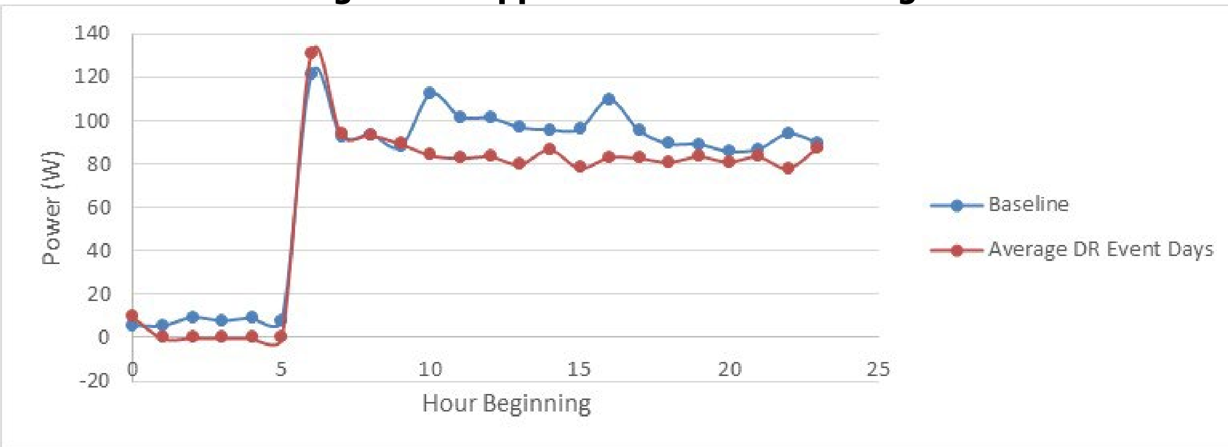

Source: Electric Power Research Institute, Inc.

**Figure 16: VWR Standard Heating Block**



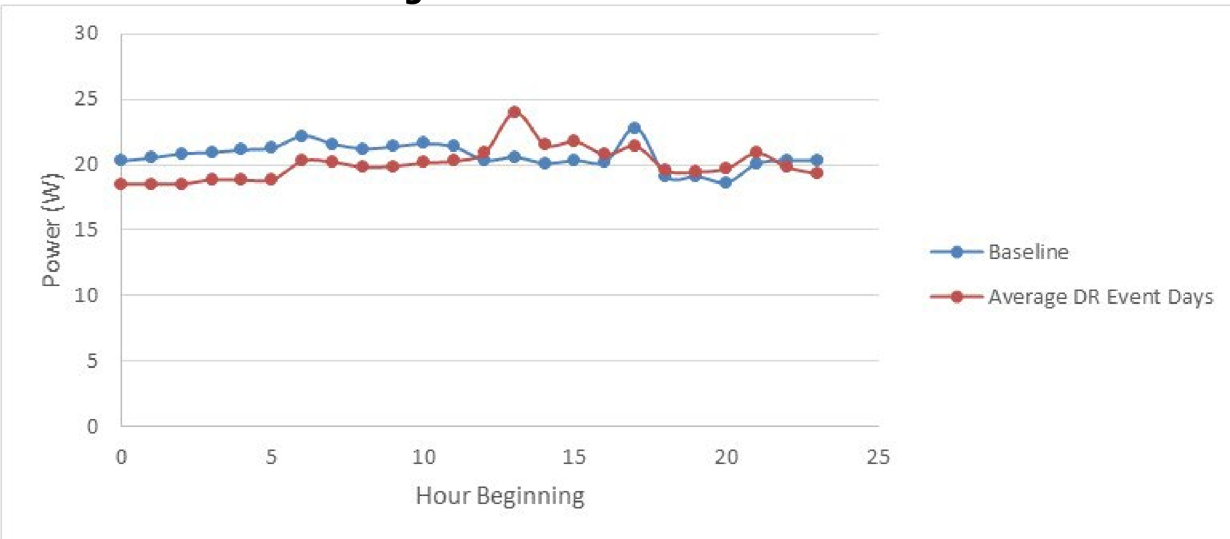

Source: Electric Power Research Institute, Inc.

**Figure 17: Eppendorf 5424R Centrifuge**




Source: Electric Power Research Institute, Inc.

**Figure 18: Grant JB Nova Water Bath**




Source: Electric Power Research Institute, Inc.

### Implications

On average, the load profiles were minimally impacted by the demand-response events, showing little deviation from the 2-week baseline period. However, there were a few individual events that showed significant load reductions of more than 50 percent in individual equipment. The Eppendorf 5424R Centrifuge had a 53-percent drop in power usage during demand-response hours on Tuesday, February 25, and Thursday, February 27, between the 3-5 p.m.

The VWR Standard Heating Block and Beckman CS-6KR Centrifuge achieved a 100 percent load reduction on Saturday, February 29, between 3-5 p.m., compared with the baseline. This reduction was not repeated during the second Saturday, March 7. Due to a lack of data, it is possible that these impacts may be coincidental due to variability in usage behavior.

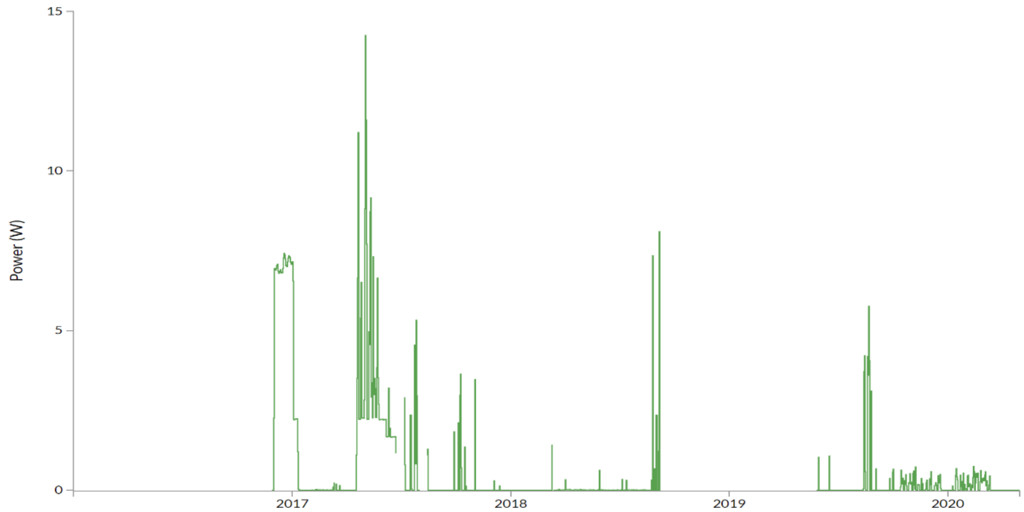
In summary, the lab was able to save up to 22 percent, or a 192-watt power reduction on Saturday, February 29, between 3-5 p.m. This met the goal of 10 percent demand savings and shows the potential for load flexibility in laboratories. However, the average aggregate demand savings were 10 W (or 1.1 percent) for the five recommended devices across the entire trial period. Further long-term studies may verify the statistical significance in biology lab environments.

## Missing Data Analysis

An analysis examined missing data on select equipment for the times they were logged into the IBIS system. There were two cases behind missing data in the system. Case 1 was when a device was unplugged from the smart outlet so no longer submitted data to the management system's database. This resulted in a NAN which is the value for missing data for the equipment's active power reading. Case 2 was when internet connection was down, so either the actual management system failed to pull data from the database or the smart-outlet hardware malfunctioned. This caused a skip in the equipment's data collection for a given time-stamp reading.

An example of the cases of missing data appears in Figure 19. The Labnet AccuBlock Digital Dry Bath (with beads) Heating Block had continuous missing data from September 3, 2019, to May 29, 2019. It had 390,242 Minutes of Case 2 missing data and 283 Minutes of Case 1 missing data. APPENDIX E provides a detailed account of each case of missing data for Stanford Lab's participating equipment. It was found that missing data is a reality and needs to be considered in plug-load data analyses.

**Figure 19: Digital Dry Bath Visual Missing Data**




Source: Electric Power Research Institute, Inc.

Table 12 summarizes missing data for participating equipment in the Stanford DR Pilot. There was no significant missing data in this equipment during the DR testing or time-scheduling trial.

**Table 12: Missing Data Summary for Equipment Participating in DR Pilot**

| Device Name | Location | Equipment Timeline | Case 1 overall Minutes offline | Case 2 Approx. Months offline | Case 2 overall Minutes offline |
|---|---|---|---|---|---|
| Grant JB Nova Water Bath | SIM1 G3161 | 2020-02-09 to 2020-03-25 | 199 | 0 | 1,772 |
| VWR Standard Heating Block | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 317 | 0 | 3,354 |
| Eppendorf 5424R Centrifuge | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 276 | 0 | 3,049 |
| Beckman CS-6KR Centrifuge | SIM1 G3155 | 2016-11-29 to 2020-02-08 | 140 | 5 | 225,592 |
| Eppendorf R 1.5 ml Thermomixer | SIM1 G3155 | 2016-11-28 to 2020-02-08 | 487 | 25 | 1,082,174 |
| Eppendorf 5430R Centrifuge | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 287 | 0 | 3,106 |

Source: Electric Power Research Institute, Inc.

## User Feedback

The lab manager and lab members provided feedback on the notification system.

### Lab Manager

The lab manager who participated in the testing provided feedback in our survey. The lab manager stated that she forwarded the email generated by the notification system to lab members every time they were received. The lab manager said that she felt the process was about the same as regular email notification. Besides forwarding the emails, she also sent additional day-of reminders. The lab manager also checked on the devices that were pointed out as ON all the time (such as the thermomixer) and let the lab members know to turn them off in the evenings and over the weekends.

The lab manager indicated that she would probably use the system. There were some days and times when the lab manager and lab members would most likely respond to event notifications. The start of the day between 9-11 a.m. was when the lab manager would most likely forward the email. The lab members would most likely take actions at the end of the day after wrapping up their experiments and turning off their equipment, around 6 p.m.

### Lab Members

Three lab members gave user feedback. All stated that they remembered receiving email notifications from their lab manager. Two of them were able to turn off equipment in some, but not all, of events. One member did not plan to use the equipment.

The top three motivations behind their actions were: contributing to energy savings and grid sustainability, responding to the lab manager's reminder, and considering it generally good practice to turn off equipment when it's not being used.

One lab member cited unwillingness to reschedule equipment use as the major reason for not turning off recommended equipment. Other reasons included forgetting about the notifications, not planning to be in the lab during DR-event hours, and assuming that others will take action.

### Learnings From User Experiences

User-experience feedback indicates that the effort of forwarding the notification email is reasonable for lab managers, and that timing is important for users to take actions. Timing needs to coordinate with users' routines to be effective. For example, the lab manager was more likely to forward email between 9-11 a.m., while lab members are more likely to turn off equipment around 6 p.m. Forgetting the notification could, therefore, be a reason for not seeing resulting actions. During the testing additional reminders from the lab manager played an important role in overcoming this timing challenge.

The testing also showed that it would be difficult for lab members to change their equipment-use schedules. The best current opportunity is turning off equipment when it is not being used. It was crucial that lab members receive notifications from the lab manager rather than from an automated system since responding to the lab manager was a key reason given for taking action.

## IBIS Dashboard-User Feedback

Two versions of the IBIS platform were online at different stages of the project. Compared with the original version, the updated version displayed processed results that summarize the operation status of lab assets. The survey collected responses from two lab managers, one of whom had experience with the original version and the other access to the updated version.

When asked how often the users visited the IBIS dashboard, the user of the original version stated that she almost never visited, while the user of the new version visited once a month. The users of both versions liked that the dashboard can help monitor the operation status of lab equipment in general. The user of the updated version also stated that the interface is pleasant to view, though the user of the original version did not share this impression.

Users of both versions felt that the system was difficult to use. One user stated that the requirement to log in reduced the likelihood of using the system, and also found data in the original version hard to digest.

The users provided several ideas for making the dashboard more useful and convenient for them, including:

- Showing the top 10 devices using most energy for the day and week.
- Showing average energy consumption and the usual "on" hours next to types of equipment.
- Flagging equipment that is never turned "off" for further review.

## Improvement Suggestions for the IBIS Platform

Improvements for consideration include flagging devices that require user actions and communicating useful information in an easy-to-understand way. Users should not have to process the data to have access to information that is useful to them.

# CHAPTER 5: Technology and Knowledge Transfer

This chapter highlights the project team's efforts to share research findings and advance demonstrated technologies into the marketplace. It identifies target markets, both primary and secondary, steps taken for technology transfer, and other future plans.

## Market Adoption and Intended Use

The information from this research is tailored for electric-power companies to better understand plug-load energy consumption and asset utilization in commercial-building and biology-lab settings and ultimately implement its findings for energy and demand savings. The outcomes of the research can also be used by vendors for product improvements and features that support energy savings, and by pilot-site personnel for insights on upgrades required for energy improvements. The pilot sites also have the option to continue use of the PLEMS deployed within their spaces.

More broadly, other types of commercial entities with similar plug loads (e.g., hospitality suites and food service restaurants, as described in the taxonomy deliverable of this project) can benefit from PLEMS and the plug load control strategies investigated. The plug-load data can also be leveraged by data scientists and researchers interested in plug-load energy data within office and laboratory environments. Utilities have additionally been kept abreast of the findings developed in the project and are using the information to improve their future programs, including advanced power-strip programs. For the demonstrated heat-map display capabilities, which provide visualization of user presence and power usage on a common floor plan, the project team vendor intends to explore offering the capabilities to other potential customers, including in the hospitality industry.

## Target Markets

In the near term (2-3 years), target markets for this technology include existing office buildings (mostly assigned spaces), similar laboratories (mostly shared assigned spaces), and schools (hybrid mixes of both types of spaces). In the midterm (4-6 years), target markets include commercial buildings with similar characteristics like lodging, hospitality, and food services. In the long-term (7-10 years), target markets include public-assembly facilities like libraries and stadiums. Various market segments may benefit from adoption of a FEMS. These segments share common characteristics of buildings with both assigned spaces and common areas, and present opportunities for plug-load control awareness and demand savings. In addition to small and large commercial offices and post-high-school education institutions, other sectors well-suited for FEMS adoption include hospitals, hotels, and retail spaces like electronic cafes and other retail establishments with high plug-load use. When assessing target markets for this technology the project team looked at the CEC's 2006 California Commercial End-Use Survey for data on California's building stock. This is the most up-to-date data on California's building stock as a new survey is being conducted in 2020; we can assume the number of buildings for these target markets has grown significantly over the years. According to the survey, in 2006 there were at least 600,000 commercial buildings in

California. Commercial buildings include offices, lodging, food service, stadium, labs, and some public-assembly building types. There are at least 18,000 K-12 and community college buildings. There are at least 35,000 local-government structures, including some public-assembly building types.[4] Considering the future requirements of switchable outlets in existing commercial building energy codes in California, the anticipated size of the target markets for the developed control strategies could reach 100 percent of new commercial buildings and major remodel construction projects as future building codes are developed. It should be noted that the benefits for each of these target markets vary and are space-type and equipment-specific.

## Technology Transfer

To spur market adoption, the project recognized the importance of working with vendors with the ability to transition from project development into full production. The PLEMS vendors that supported EPRI on this project have demonstrated such capabilities and are capable of offering its services to consumers at the conclusion of the study, given the proper financial and legal circumstances.

EPRI provided introductions and established potential partnering relationships between PLEMS vendors and third-party vendors that will strengthen the product's transition from research to the marketplace. EPRI also shared the project's findings in various relevant settings such as the Cal Plug conference, EPRI advisory meetings, vendors, pilot-site participants, and project TAC meetings with utility advisers. In the concluding phase of the project, feedback from EPRI and pilot-site participants was shared with vendors on how to improve their products to increase usability and potential market adoption. At the conclusion of the project, products were still being developed by their respective vendors.

Feedback from pilot-site users was communicated so further improvements can be made. EPRI conducted presentations and shared project findings at relevant public venues. EPRI also connected the project's PLEMS vendor focused on device asset utilization with an indoor positioning analytics vendor focused on space utilization to merge select platform capabilities identified in the project and develop a graphical user interface to reveal deeper insights into energy savings.

Additionally, project findings were shared with utilities to inform future programs, including advanced power-strip programs. The project developed a video recording of the FEMS implementation and posted the video on YouTube at: https://youtu.be/Mt0X_lVwrdE. The video shows how to engage plug loads in automation in support of demand response based on individual-user preferences and is designed to assist in technology transfer towards market adoption by additional vendors.

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[4] Market Size Assessment

## Future Work for Technology Transfer

Although there are no further plans to continue with commercialization by EPRI, there have been discussions to continue tech transfer by project-team vendors. Utility advisers have also discussed possible application of the demonstrated heat-map display to interface with lighting systems (such as dimming areas with less presence) but posed the question on the possibility of interfacing with commercial-building lighting systems. For such an application, utility advisers identified the need for more granular control at the lighting-fixture level (for example, zoned lighting control), which could be a challenge. Although there are no current identified utility incentives for this technology beyond the home office, utility advisers also discussed potential application in supermarkets (such as bakery equipment, mixers). EPRI plans to continue sharing project findings and PLEMS information at future conferences and in other venues.

Project results are expected to raise awareness of various applications for PLEMS and are designed to provide further understanding of the difficulties and nuances for automating plug loads in different contexts of buildings and spaces. Market growth is stimulated by broadly sharing findings on control strategies and their applicability in different plug-load contexts and by showing how leveraging plug-load data from PLEMS can result in additional benefits to attract consumers (for example asset use, space use, energy savings, central management, and demand-response applications).

The plug-load management strategies trialed in the project can help improve future building codes that will require switchable outlets in commercial buildings. The project's analysis of plug-load data and management strategies can help fill the gap for automation algorithms in the future. Furthermore, organizations can use the information from this project to better understand the diverse number of plug-load devices and technologies that may or may not take advantage of emerging plug-load management technologies.

# CHAPTER 6:
# Conclusions and Recommendations

## Conclusions From Office Pilot

### Energy Savings From Automation

Managing plug-load energy use in commercial-building environments is a growing challenge as plug-load devices become more common. In a commercial-office pilot, PLEMS was found to be an effective tool for achieving energy savings through automation of individual outlets on smart strips via time scheduling and load-sensing strategies. The office site saved 31.7 kWh during a 2-week treatment period when compared with a 2-week baseline period, resulting in a 10.8 percent reduction in total plug-load energy usage. With the exception of CPU/laptop devices, all other workstation device types involved in the pilot achieved energy savings greater than 14 percent using a load-sensing strategy. Since CPU/laptop devices served as controllers on the smart strips utilizing the load-sensing strategy and peripheral agent ports automated based on a pre-determined controller-port power threshold being reached, the controllers did not contribute to savings under the load-sensing strategy. Time-scheduled control was effective for a coffee maker that achieved 28 percent savings after being automated, based on normal office operating hours. However, most equipment that used a time-scheduling strategy did not yield significant usage during the baseline and treatment periods, and consequently did not contribute significant savings despite being included in overall energy-savings calculations.

While there was a reduction in overall energy usage among the workstation equipment on agent ports, energy savings were minimal when translated into cost savings in relation to the cost of the PLEMS. The results show that in terms of ROI, plug-load devices that do not use significant energy, such as phone chargers and task lights, are low priority when targeting devices for PLEMS automation. With respect to ROI, the results of the pilot determined that among tested equipment coffee makers and monitors were the best candidates for automation.

### Remarks

In summary, while the PLEMS functioned as intended and was able to reduce energy usage by 10 percent in the study, it could not be justified in this particular office environment given its relatively high cost in relation to its cost savings. The technology must mature to better economics before it can penetrate the market and be widely adopted in office buildings. Consequently, PLEMS is not likely to gain customer acceptance purely to achieve more aggressive energy savings.

PLEMS may add value to customers through additional benefits and applications such as presence awareness to assist understanding of asset and space utilization in office buildings and to help building managers better optimize investments. For example, the demonstrated heat-map display visually depicting office-user presence and power usage combined with a building floor plan can aid identification of deeper savings strategies utilizing PLEMS-enabled automation of plug loads. Moreover, the flexible plug-load application developed in the research project may add value by engaging office users to participate in DR.

## Lessons Learned

There were several important lessons learned that would be valuable for replicating in other office settings:

- The good candidates for plug-load automation strategies in offices spaces are those that use significant energy and present an opportunity for savings through automation at times that can be associated with wasted electricity consumption.
- PLEMS automation strategies effectively reduced workstation-equipment electricity usage by utilizing load sensing and controller/agent strategies on workstation equipment to turn off peripheral equipment when a controlling device is turned off. However, when considering ROI low-energy equipment such as phone chargers can be prioritized below equipment like monitors and individual plug-in space-conditioning equipment such as personal heaters.
- It is possible to reduce plug-load energy usage in offices by using time-scheduling automation strategies on equipment that is left on after business hours. This includes break-room equipment such as coffee makers and water dispensers.
- There are opportunities for further savings in the office environment by utilizing DR strategies and taking occupant DR participation preferences into account such as via a mobile app like the developed Flexible plug-load app.
- There are opportunities for further savings in an office environment by leveraging a visual representation of the relationship between presence and power and streaming both data streams to a heat map displayed with a building floor plan.
- Smart outlets need to be routinely checked to confirm that the equipment plug into the outlets matches the ID specified in the PLEMS, which may change over time as equipment is switched out with other equipment.
- PLEMS platforms help raise energy-usage awareness at the individual plug-load level. The platforms evaluated relied on continuous connectivity to the Cloud. When connectivity is interrupted user experience is impacted.

## Future Work

Important areas to further energy and demand savings for plug loads in office environments include:

- The flexible plug-load app was developed and tested in EPRI offices to enable office users to configure energy- and demand-savings automation preferences for individual workstation equipment. A next step is to test the app in a pilot-site office environment to evaluate energy and demand savings that support power-up and power-down events. Details on the app design for presence-based and demand response automation are found in Chapter 2.
- The heat-map display was developed and tested in an office within the Plug and Play Center building in Sunnyvale, California, where development testing was successfully completed. A next step is to test the application at a pilot site to demonstrate real-world

insights into which equipment can be targeted for automation for energy and demand savings. Details on the heat-map display design and its deeper savings insights are found in Chapter 2.

# Recommendations for Commercial Offices

## Augmenting Strategies for Energy Savings

The pilot site chose only load-sensing automation for workstation equipment. However, data revealed that some of the equipment stayed on outside of normal office hours. This may be due to sleep modes not being enabled on specific laptops or computers. It is recommended that unneeded workstation equipment be placed on time schedules, too, to turn off outside of business hours even if they are already using the load-sensing automation strategy. Building managers may prioritize the most energy-intensive equipment when targeting equipment for time-schedule automation.

## Heatmap Display for Deeper Savings

Recommendations include evaluating the heat-map display in sizable commercial-office settings to gain insight on opportunities for deeper savings. When power-usage data is augmented with user-presence information, visual representation of these two data streams can inform specific equipment to target for automation strategies and can further help refine settings to use for time scheduling, demand response, and other strategies.

With the heat-map display's powerful visualization capabilities through a graphical user's interface, building administrators can readily examine electricity usage and user presence patterns throughout a specified period of time, including by time of day, day of the week, and other available filters in order to identify equipment for automation such as equipment using significant energy when no one is present. When the administrator detects a particular smart outlet satisfying conditions such as high usage with low-user presence, they can drill down on usage patterns of specific equipment to discern suitable automation strategies.

## Integrated Energy Systems for Greater Insights

Further savings insights may be gained by collectively analyzing energy information across additional monitoring systems in a commercial building (such as HVAC, lighting, local solar generation, and electric vehicle [EV] charging). Though these data streams were present in the commercial-building pilot site (AP+I Designs), they existed in disparate systems not yet integrated with plug loads. Through information integration with a common platform for data analyses, the building manager can gain a collective view of the entire building's systems and readily analyze savings opportunities in a cohesive and optimal manner. Furthermore, the heat-map display is recommended for visualization of user-presence information along with integrated energy-system information (for example HVAC, lighting, plug loads) to inform optimal strategies for automating disparate systems. By doing so, greater insights may be revealed for achieving energy savings and effective demand response.

# Conclusions From the Laboratory Pilot

## Laboratory Application of PLEMS for Energy Savings

Laboratory plug loads present untapped potential for energy savings. Among the over 100 pieces of equipment that were part of the laboratory study, 27 consumed more than 1 kWh/day on average, while 25 unique devices had an average monthly peak load of more than 400 W. With over 260,000 laboratories[5] in the United States (My Green Lab, 2015), finding ways to reduce laboratory plug-load energy consumption is a growth area.

The IBIS PLEMS platform was successfully used to monitor plug loads in Stanford's laboratories. The platform was used to identify opportunities for energy efficiency through time-based controls, and a subset of equipment was successfully time-scheduled through the IBIS platform. In addition, data gathered from the IBIS prototype was used to educate scientists on opportunities for plug-load energy reductions through behavior interventions such as turning off equipment when it's not in use.

A total of 76 pieces of equipment were monitored during the study, and 21 pieces of equipment were chosen for the treatment period. Time-scheduling automation strategies were tested on the 21 pieces of equipment across 6 participating labs where scheduled off-times varied between 5 p.m. and 12 a.m., and scheduled on-times varied between 6 a.m. and 8 a.m. The study calculated an 18-percent overall reduction in energy consumption (comparing a defined baseline period with the treatment period).

## User Interface

The operation of the PLEMS did not generate any reported issues from laboratory users. However, the original design of the software platform may have appeared cumbersome and difficult for lab managers since none of them chose to use it. An improved interface, especially an improved mobile interface, could lead to greater acceptance. At the time of publication, the vendor had newly introduced data-analytics summary reports to Stanford, which will be evaluated outside the scope of this concluded project.

It has been noted in other studies that the real-time visualization of energy data influences how scientists interact with their equipment. The perceived difficulty in accessing the vendor's energy data made it difficult to leverage the platform as a powerful behavioral-change tool. The more recent version of the vendor's platform may improve initial perceptions and increase lab-manager interest in logging on to view real-time data.

The vendor platform functioned as designed yet did not prove to be very effective. Laboratories are unique environments with irregular schedules and multiple pieces of shared equipment. While there were opportunities to reduce energy consumption through turning off equipment overnight, the same savings could easily be achieved with a standard outlet timer.

An argument could be made that the IBIS platform provides valuable insight into changes in behavior patterns over time. For example, it was found that a thermomixer was being left on continuously in February 2020, even though in May 2017 it was being turned off regularly. However, rather than rely on the vendor technology, a comprehensive education program for

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[5] Market Size Assessment

the labs on when to turn off equipment could restore long-lasting habits of turning off equipment when not in use. The project partner, My Green Lab, has employed this technique to great success in hundreds of laboratories worldwide. The combination of education and outlet timers appears more cost-effective for empowering scientists to assume responsibility for their energy consumption. Without this sense of personal responsibility, opportunities for energy reductions are easily ignored.

### Demand-Response Notification System

Although the IBIS platform was not designed to support demand response, the project team worked with Stanford lab mangers to design a process of email notifications alerting the lab manager of DR events. The team developed a notification system designed to engage lab mangers and lab users in responding to DR events. The notification system was successful in bringing awareness to lab users on suggested equipment to turn off during a DR event. Nevertheless, the lab that participated had limited results. Moreover, although the lab manager had reportedly identified idle usage of a thermomixer and called it out to her lab users, there was no action to turn off the thermomixer either during the week or over the weekend of DR events. A single DR event produced noticeable demand savings during a Saturday when select equipment was manually shut off the Friday evening before the event.

### Remarks

In summary, while the vendor platform functioned as intended, the tested PLEMS technology is not necessarily the best choice for this particular market given its associated technology costs. That is, PLEMS is not likely to gain customer adoption purely to achieve more aggressive energy standards. However, data gathered with PLEMS could be used to inform design standards for laboratory buildings so that they are not over-designed in their plug-load capacity, especially considering other studies that show similar results.[6]

### Lessons Learned

Despite the limitations of PLEMS for this market segment, there were several important lessons learned that could be valuable in other lab settings:

- The best equipment candidates for plug-load monitoring and intervention strategies in labs are: rarely in use overnight, can be brought to temperature in the morning with no interference in laboratory operations, can be easily cycled on or off with no consequence to equipment functionality, and are used by a known set of users in the lab (specifically not shared among multiple labs).
- It is possible to reduce plug-load energy usage in laboratories through time-scheduling strategies in laboratories. This can be accomplished after overcoming some initial natural resistance to time-scheduling equipment.
- Signage may not prove as effective over the long term as time-scheduling strategies. As noted in the case of the cited thermomixer, behavior may change over time so that initial energy-saving vigilance may be lost. Consequently, automation strategies,

[6] Labs are typically designed for 5-10 watts per square feet, although most lab spaces use less than 1 watt per square feet. It was outside of the scope of the study to apply results to identify, verify, or minimize over-design of labs.

including with timers, could be shared with laboratories to encourage them to use time-scheduling whenever possible.

- There are opportunities for DR in laboratories, specifically with pieces of equipment that are not in use continuously (such as, such as centrifuges, heating blocks, and water baths). Further insight on specific times of idle usage of equipment not in experimental use would inform more opportunities to recommend equipment to be turned off during DR events.
- Contact with laboratories throughout a study period is needed to review and ensure the continuous implementation of savings strategies. After implementing the time schedule, many labs were not engaged for several months. Since they were not checking the vendor PLEMS platform, lab managers were unaware of instances when power consumption was increasing (such as a thermomixer that had previously been turned off but later always turned on). Increased communication and engagement may have prevented excess power consumption from idle equipment.
- Automating plug loads in laboratory environments is exceptionally challenging due to the risk of disrupting equipment while in use. An accidental disruption to operations in a lab can have negative consequences. Therefore, discerning when equipment is actually being used versus idle is a necessity in furthering adoption of plug-load automation strategies in lab environments.

### Discerning Experimental Usage

A primary barrier to lab managers using equipment in automation strategies was uncertainty about periods of experimental usage to avoid disruption of lab activities. Labs often allow users access to equipment and spaces after normal business hours. And some lab equipment requires an extended startup time before it's ready for use. If PLEMS could properly distinguish actual experimental equipment usage from idle operation disruptions could be minimized while automating lab equipment.

The EPRI team explored applying data analytics to determine when equipment is running by utilizing IoT push buttons. In an EPRI test environment, when a water dispenser was actually dispensing water, users clicked on an IoT button corresponding to the temperature of the water dispensed. The IoT button showed when equipment is actually operated. A button press indicated a change in mode of operation so that the corresponding snapshot of energy-usage data collected could be evaluated. The IoT button clicks were correlated with the power-data reads. This data can be used to develop algorithms that use machine learning to identify when equipment is in actual use. Further details on research conducted under the IoT button experiment can be found in Appendix D.

# Recommendations for Laboratory Environments

## Engaging Laboratories for Energy Savings

Recommendations for energy conservation were made to labs based on the baseline data analysis. Equipment found to be left on or unused overnight or on weekends was recommended for an automated schedule. The recommendations were discussed with lab managers and they were shown representative load shapes from their equipment to support the recommendations.

If the usage pattern could be determined from the load profile, lab managers were asked to automate, turning off equipment when it was not in use. If the usage pattern could not be determined from the load profile, lab managers were asked if they could come up with a workable schedule for that particular piece of equipment. If lab managers indicated that they were uncomfortable putting a piece of equipment on a schedule, then they were asked to explain why that was the case. This approach proved highly effective as it empowered lab managers with the data they needed to make decisions that could reduce energy usage with minimal impact on laboratory operations.

## Challenges in Engaging Laboratories for Energy and Demand Savings

There are several challenges in getting labs to engage with energy savings and DR, the biggest being that labs do not directly pay the energy bill and are, therefore, not motivated to reduce energy for cost savings. In addition, laboratory practices have for decades favored an environment where equipment is left on all the time "just in case" it is needed for an experiment. Scientists are not accustomed to waiting for equipment to heat up or cool down. They are instead used to having the equipment they need ready at all times. The combination of these two factors causes the greatest barrier to energy savings and DR. In addition, laboratories do not operate at traditional hours, and the type of equipment that is found in labs is incredibly diverse. This makes it difficult for labs to follow a prescriptive schedule at all times.

## Overcoming Challenges

Educating scientists about opportunities for energy efficiency and the impact of leaving equipment on can help overcome these barriers. Equating energy savings with a unit of measure that is more tangible, such as the number of trees saved or miles driven, has been found to be more effective than simply stating kWh saved. Giving scientists a choice about which pieces of equipment to turn off, and then making it easy for them to turn it off or on with automated controls is also an effective strategy for overcoming the habit of leaving equipment on all the time. Continuous engagement over the course of several months has also been shown to be an effective strategy in establishing long-lasting behavioral change.

## Future Work

Important areas to further advance energy and demand savings for plug loads in lab environments follow.

- Understanding the operational modes and power usage of different types of equipment can increase opportunities for energy savings. A wide range of energy-consumption values was observed for different pieces of equipment in the Stanford labs. For example, biosafety-cabinet energy consumption ranged from 25 W to 140 W when they were on; incubator-shaker energy consumption ranged from 8 W to 270 W; and water-bath energy consumption ranged from 10 W to 100 W. Characterizing the power consumption of lab equipment under separate operational modes can reveal opportunities for energy and demand savings.
- Given the difficulty in determining the experimental usage of lab equipment by just remotely monitoring power data, there is an opportunity to apply data analytics and machine learning to determine when equipment is running to process lab experiments. When actual experimental use of equipment can be discerned there is greater insight into when recommended strategies can apply without disrupting operations.
- Experimental usage data needs to be collected concurrently with power data in future studies. This could further insight into energy savings opportunities through time-scheduling equipment when not in use and identifying pieces of equipment running idle during DR events. Such data collection was explored under an IoT button experiment described in APPENDIX D: IoT Button Experiment.
- Future investigation is needed into whether there are other, more cost-effective and accessible means of both monitoring and controlling plug loads in labs. Based on this study, a technology that costs approximately $10 per socket would be a worthwhile investment.
- Future work may also examine leveraging user-presence data with power data to identify periods of actual experimental equipment usage from idle periods. Using historical presence and power data, along with knowledge of user settings, can inform recommendations such as priority ranking equipment for time-schedule automation or DR participation.

# CHAPTER 7: Benefits to Ratepayers

## Overview

For each of the two pilot studies, ratepayer benefits were estimated by applying pilot results to primary target markets. Target markets were further segmented into short-term, midterm, and long-term markets depending upon the expected speed of market penetration and acceptance.

Three main ratepayer benefits were estimated. The first was the estimated energy savings anticipated by customer adoption of tested strategies enabled by PLEMS platforms and technology extensions (for example DR notification system). The second was the expected energy bill savings participating customers may see. These were determined as the product of energy savings and expected electricity usage levels. The third benefit was greenhouse-gas (GHG) savings from lower energy generation. The GHG savings were based on EPA estimates for California power markets and reflect GHG savings for a marginal reduction in energy production from both in-state and energy imports[7]. The EPA estimates are based on 2018 values of 429g/kWh $CO_2e$[8].

## Benefits in Office Buildings

### Assumptions

Benefits to ratepayers were calculated by applying the results found at the office-pilot site to other similar market segments in California. Energy savings of 10.8 percent were derived from office equipment and miscellaneous usage in the office building studied. These savings were applied to the estimated energy consumption for office equipment and miscellaneous usage across several other commercial building segments[9]. These usage levels were estimated in 2012 for investor-owned utility (IOU) customers in California. Those levels were increased by 3 percent per year from 2012 to 2020 using an escalation factor of 26.7 percent.

The short-term market segments targeted for adoption in two-to-three years are small and large office buildings.

The midterm market segment, assumed for adoption in four-to-six years, includes hospitals and schools.

The long-term market segments, assumed for adoption in seven-to-ten years, include 10 percent of the usage for miscellaneous building segments. Miscellaneous building segments

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[7] EPA GHG Emission Factors

[8] Note: $CO_2e$ is a weighting of GHG components to reflect the different impact on the protective ozone layer in the atmosphere. There are three components included in this estimate, $CO_2$, $CH_4$ and $N_2O$ commonly produced when generating electricity.

[9] California Energy Commission, Attachment 13 - References for Calculating Energy End-Use and GHG Emissions, Commercial Electricity Use in California IOU Service Areas (GWh) – 2012.

include public-assembly and other types of buildings with office and miscellaneous equipment. The equipment included in the office and miscellaneous equipment is summarized in Table 13.

**Table 13: Office and Miscellaneous Equipment**

| Office Equipment | Miscellaneous |
|---|---|
| Laptops | Cell Phone Chargers |
| Desktops | Microwaves |
| Desk Lamps | Dishwashers |
| Task Lighting | Refrigerators |
| Computer Docks | Beverage Coolers |
| Monitors | Ice Makers |
| Telephone | Toaster Ovens |
| Printers | Personal Heaters |
| Plotters | Tablets |

Source: Electric Power Research Institute, Inc.

## Short-Term Ratepayer Benefits

The office pilot results show electricity savings of 10.8 percent. Applying that 10.8 percent savings to estimated California office and miscellaneous equipment in small and large office segments resulted in potential electricity savings of 684.7GWh/year in 2020.

The corresponding customer bill savings of $143.8 mil. per year are based on a retail rate of $0.21/kWh.

Expected GHG savings are 293.7 mil.kg $CO_2e$ per year in 2020 based on a marginal emission rate of 429g $CO_2e$/kWh.

## Midterm Ratepayer Benefits

Applying the 10.8 percent savings to estimated California office and miscellaneous equipment (to hospitality and school segments) usage resulted in potential future electricity savings of 181.6GWh/year in 2026.

The corresponding customer-bill savings are $38.1 mil. per year in 2026 based on a retail rate of $0.21/kWh.

The expected GHG savings are 77.9 mil. kg $CO_2e$ per year in 2026 based on a marginal emission rate of 429g $CO_2e$/kWh.

The cumulative short-term and midterm savings are:

- 999.3 GWh/year in 2026.
- $209.9 mil. /year in 2026.
- 428.7 mil. kg CO2e/year in 2026.

### Long-Term Ratepayer Benefits

Applying the 10.8 percent savings to California office and miscellaneous equipment in miscellaneous buildings (10 percent) resulted in potential future electricity savings of 57.3GWh/year in 2030.

Corresponding estimated customer-bill savings are $12.0 mil. per year in 2030 based on a retail rate of $0.21/kWh.

The expected GHG savings are 24.6 mil. kg $CO_2e$ in 2030 based on a marginal emissions rate of 429g $CO_2e$/kWh.

Cumulative short-term, midterm, and long-term savings are:

- 1,181.4 GWh/year in 2030.
- $248.1 mil. /year in 2030.
- 506.8 mil. kg CO2e/year in 2030.

## Benefits for the Laboratory Pilot

System benefits are two-fold. The first benefit stems from energy savings produced by using time-schedule control of laboratory equipment. The second is from peak-demand reductions when lab users either curtail or shift equipment use to lower-demand time periods. As described in Chapter 4, demand reductions were achieved from behavioral responses to called DR events, though in some cases did not produce any reductions at all. Such results emphasize the need for further work to quantify the ability of participants to respond to called demand-response events.

The energy savings in this pilot were more substantial. Based upon energy-savings results measured during the pilot and a market-assessment study of energy-efficiency potential in laboratory settings (Paradise, 2015)[10], energy-efficiency benefits can be quantified.

A prior study (Paradise, 2015) estimates the number of laboratories in California, shown in Table 14.

[10] Allison Paradise. (2015). Market Assessment of Energy Efficiency Opportunities in Laboratories, Emerging Technology Program, Table 74. https://www.etcc-ca.com/sites/default/files/reports/ceel_market_assessment_et14pge7591.pdf

**Table 14: Number of Laboratories in California (2015)**

| Market Segment of Labs | Number |
|---|---|
| Academic | 6,200 |
| Life Science Research (LSR) | 11,700 |
| Hospitals | 1,700 |
| Other | 540 |
| Total | 20,140 |

Source: Electric Power Research Institute, Inc.

This study provided an average number of laboratory devices across these laboratory types. Applying the results from this pilot to that equipment produced an estimate of energy savings potential from time-schedule strategies. Assumptions included 3.78 centrifuges per laboratory, 2.99 heating blocks per lab, 2.59 water baths per lab, and 1.00 electronic balance per lab. The remaining lab equipment either produced insignificant savings or showed increased usage and was therefore not included in a benefits assessment. The sum of energy-savings impacts for identified types of equipment produced energy savings of 1,774.85 kWh/year in 2020.

Applying these average laboratory savings to the number of laboratories produced electricity savings of 35.7 GWh/year in 2020.

Corresponding customer bill savings were $7.5 mil. per year based on a rate of $0.21/kWh.

The average laboratory savings applied to the stock of laboratories produced GHG reductions of 15.3 mil.kg CO2e based on a marginal emission rate of 429g CO2e/kWh.

## Short-Term Ratepayer Benefits (Laboratory Pilot)

Short-term market segments targeted for adoption in two-to-three years included the laboratories identified in Table 14 (for example academic, life-science research, hospitals, and others). These facilities have plug loads in offices as well as in miscellaneous categories that can be considered for time-schedule automation. According to Paradise, 2015, 10 percent of the office and miscellaneous loads could be put on time-schedule controls.

The laboratory pilot results generated electricity savings of 35.7GWh/year in 2020.

Corresponding customer bill savings are $7.5 mil. per year based on a retail rate of $0.21/kWh.

Expected GHG savings are 15.3 mil. kg $CO_2$e based on a marginal emissions rate of 429g CO2e/kWh.

## Midterm Ratepayer Benefits (Laboratory Pilot)

It is assumed that the midterm market segment, targeting customer adoption in four-to-six years, includes food service, health care (but not hospital labs) and 25 percent of miscellaneous buildings usage. The midterm segments include food service (such as groceries, restaurants, and refrigerated warehouses), hospitals and health care, and 25 percent of large and small offices that could be reached in four-to-six years.

Total office and miscellaneous consumption in 2026 is estimated at 16,151.8GWh/year. Of that total, 10 percent could be placed on time-schedule controls for a total of 1,615.2GWh/year in 2026.

Corresponding customer bill savings are $339.2 mil. per year in 2026 based on a retail rate of $0.21/kWh.

The expected GHG savings are 692.9 mil. kg $CO_2$e in 2026 based on a marginal emissions rate of 429g CO2e/kWh.

Cumulative short-term and midterm savings are:

- 1,619.4 GWh/year in 2026.
- $340.1 mil. /year in 2026.
- 694.7 mil. kg CO2e/year in 2026.

### Long-Term Ratepayers Benefits (Laboratory Pilot)

No long-term market segments have been identified.

## Qualitative Benefits to Ratepayers

Flexible plug-load operation can contribute to system reliability, sustainability, and energy savings as well as to the costs of maintaining the system and keeping rates low. Flexible DR from plug loads can contribute to renewable-energy integration by absorbing excess generation during over-generation periods.

The research conducted in the project can help ratepayers develop strategies to efficiently manage plug-load devices. The research and technology involved in the project can increase energy savings. In the office environment an 11-percent reduction in energy usage was demonstrated over the trial period. The lab environment had a-percent reduction in energy use over its trial period.

Ratepayers may be interested in this technology and research because it can be applied to a diverse range of devices and consumer demographics. Due to the diversity of plug loads, this technology can be adapted to both business and residential consumers. The costs are expected to be around $100 for each smart strip and $300 for the bridge needed for operation.

Ratepayer adoption of the technology provides centralized, automated remote control of plug-load devices, eliminating the manual manpower required to continually turn off unneeded plug-in devices. Ratepayers concerned with asset utilization and maintenance can calculate when and how much the asset is being used, as well as abnormalities that can point to problems with the asset. Development of FEMS during the project will enable DR applications for ratepayers. Using power up-and-down strategies, ratepayers can access demand savings from shifting plug loads during demand-response events. When leveraged in the aggregate, this technology can also aid in grid stabilization through demand controls and ultimately lower GHG emissions through energy-use reductions.

Due to the difficulty of fully understanding plug-load devices and behaviors, this research provides essential groundwork for understanding plug loads. It is a valuable tool for monitoring plug loads and identifying future opportunities for energy and demand savings.

# LIST OF ACRONYMS

| Term | Definition |
| --- | --- |
| BSC | Biosafety Cabinet |
| BEMS | Building Energy Management System |
| Btu | British Thermal Unit |
| C | Celsius |
| CBC | Carbon Block |
| CBECS | Commercial Building Energy Consumption Survey |
| CEC | California Energy Commission |
| CO2 | Carbon Dioxide |
| CO2e | Carbon Dioxide Equivalent |
| CPU | Central Processing Unit |
| DNA | Deoxyribonucleic Acid |
| DR | Demand Response |
| USEIA | Energy Information Administration |
| EPA | Environmental Protection Agency |
| EPIC | Electric Program Investment Charge |
| EPRI | Electric Power Research Institute |
| F | Fahrenheit |
| FACS | Fluorescence-Activated Cell Sorting |
| FEMS | Flexible Energy Management System |
| GHG | Greenhouse Gas Saving |
| GWh | Gigawatt hours |
| HEPA | High-efficiency Particulate Air |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IoT | Internet of Things |
| IOU | Investor-Owned Utility |
| IT | Information Technology |
| kg | Kilograms |
| kWh | Kilowatt Hour |

| Term | Definition |
|---|---|
| LED | Light Emitting Diode |
| LSR | Life Science Research |
| mil. | Million |
| mL | Milliliter |
| PC | Personal Computer |
| PCR | Polymerase Chain Reaction |
| PLEMS | Plug Load Energy Management System |
| qPCR | Quantitative PCR |
| ROI | Return on Investment |
| SDS-PAGE | Sodium Dodecyl Sulfate Polyacrylamide |
| TAC | Technical Advisory Committee |
| TOU | Time-of-Use |
| TRL | Technology Readiness Level |
| UV | Ultraviolet |
| VTN | Virtual Top Node |
| W | Watt |
| Wh | Watt hour |

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# APPENDIX A: Taxonomy for Plug Load Control

## Background

As the information age progresses, buildings are becoming more and more dependent on plug in devices and technologies (US General Services Administration, 2019). While there have been significant improvements in other end uses (lighting and space heating have each dropped 11 percent of total end use consumption since 2003 (EIA, 2016)), there has been little progress in developing energy saving and management strategies for plug load equipment. Additionally, various building codes such as California's Title 24 and the International Green Construction Code are starting to take a closer look at plug load control and reduction strategies, the adoption of controllable receptacles among other codes within new buildings is being implement and  likely requirements of the nature become more stringent and wide spread in the upcoming years. Part of the reason plug loads are so troublesome is they present inherently unique management challenges. For example, plug loads are abundant throughout all spaces in a building, and are often assigned to a particular person or group rather than to the entire building. This makes plug loads a burden to universally manage; unlike HVAC and lighting, which can easily be centrally controlled without overly engaging occupants or disturbing their equipment. A plug load energy management system (PLEMS) can address some of these challenges. These systems use smart plug sensors, management software, and varying automated saving strategies in order to manage and reduce plug load energy consumption. With a PLEMS, admins and occupants can set rules to determine when their plug load equipment will automatically turn off and on. Viable plug load automation strategies are ultimately informed by a baseline period of plug load energy consumption data collection and the building's space and equipment characteristics. Since the context of plug load usage varies widely between each building, a generalized automation strategy applicable to all space and equipment types typically is not feasible. This chapter defines a taxonomy based on the spaces and equipment within a building. The taxonomy is ultimately used to describe the context of plug load usage in a building, so viable saving strategies can more easily be chosen and applied.

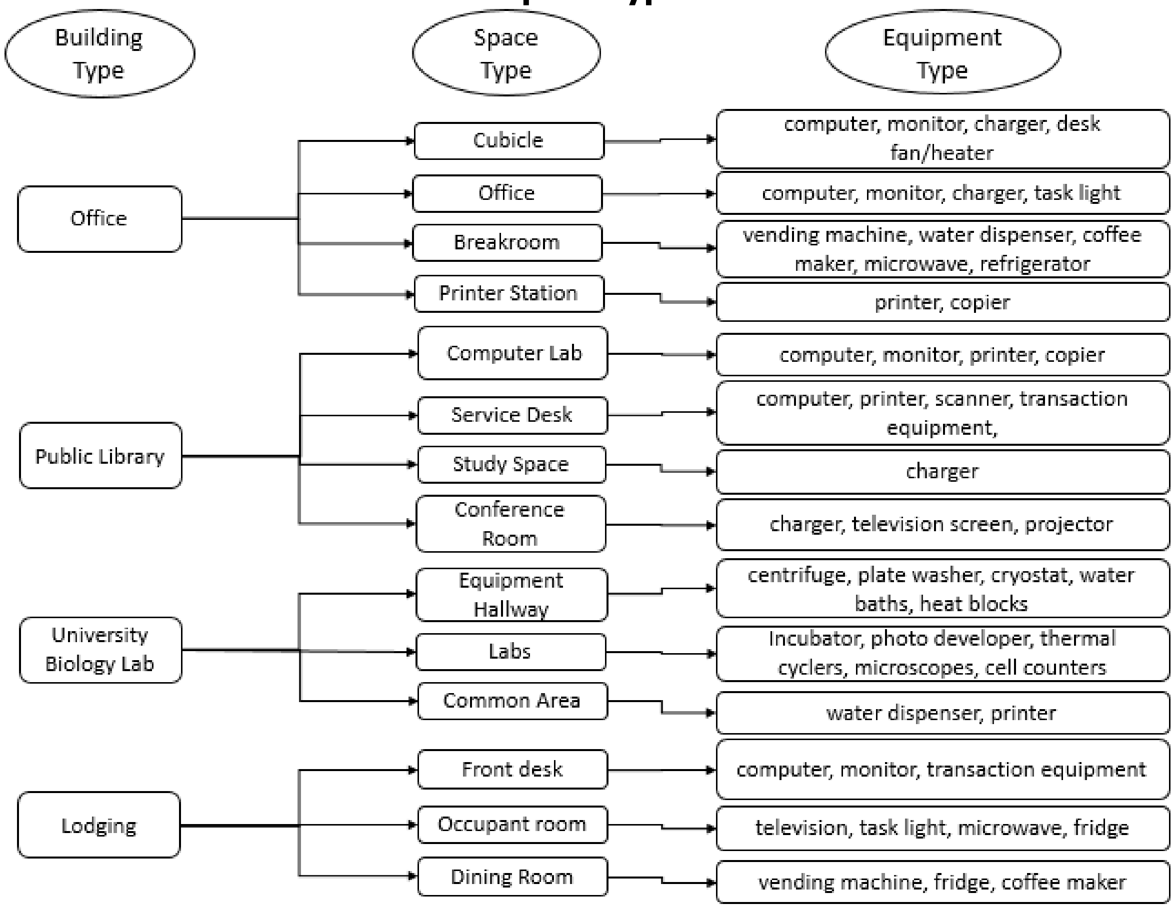
### Taxonomy Diagram

The taxonomy was developed to highlight important relationships between varying building characteristics and viable saving strategies. Given these varying building characteristics, the taxonomy provides the contextual language needed to readily discern applicable strategies in differing situations. The taxonomy is applied by first defining the spaces and equipment within a building, the spaces and equipment are then grouped by specific characteristics. A diagram for how the taxonomy defines spaces and equipment is shown below in Figure A-1. A diagram is shown in Figure A-2 for how spaces are grouped by assignment and equipment are grouped by load type and equipment characteristics.

## Classification of Building Equipment

- Building type
- Space type
- Equipment type

**Figure A-1: Taxonomy Diagram for Classifying Building Equipment by Building Type and Space Type**

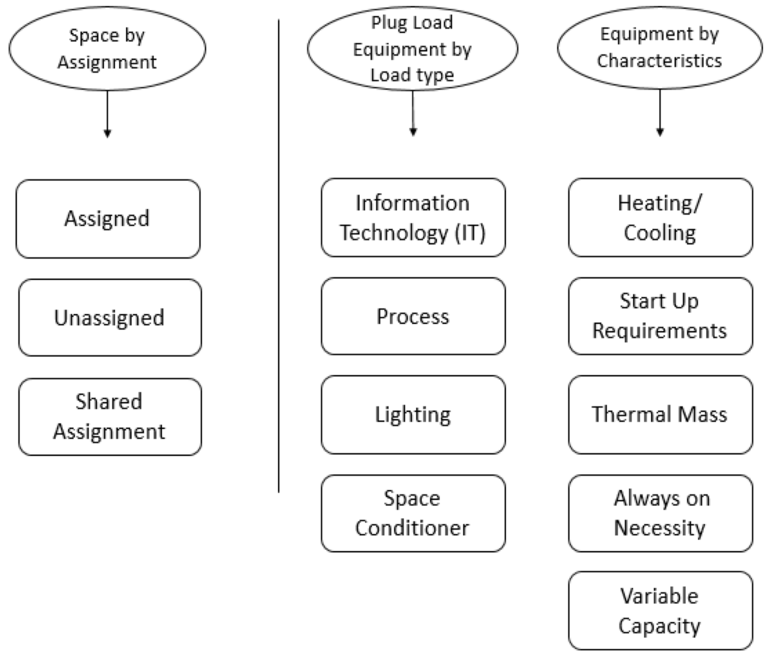



Source: Electric Power Research Institute, Inc

### Groupings:

- Spaces by Level of Assignment
- Equipment Type by Load type
- Equipment Type by Equipment Characteristics

**Figure A-2: Taxonomy for Grouping Spaces and Equipment**




Source: Electric Power Research Institute, Inc

# Components of Taxonomy

Building Classification: this component of the taxonomy classifies and defines the building in terms of the spaces and equipment that make it up. The different categories of the building classification are explained below.

- "Building Type" refers to the classification of a building according to its principal activity. The building types included in the taxonomy are derivations of the buildings types used in the Energy Information Administration's (USEIA) Commercial Building Energy Consumption Survey (CBECS). Office and Food Service are explicit building types used in CBECS, while Public Library and University Biology Lab are subcategories of CBECS's Public Assembly and Education building types respectively. The reader may refer to CBECS for additional examples of building types.11
- "Space type" refers to the spaces and/or rooms found within a building. Buildings often contain spaces which have varying operational purposes and types of equipment. Because of this variability, specific saving strategies may only apply to certain locations within a building. Examples of types of spaces included in the taxonomy are breakroom, computer lab, data center, etc.
- "Equipment type" refers to the types of plug load equipment found within a space. Plug load equipment varies throughout different space types and it is important to know where and what type of equipment is being used in each space. Various plug load strategies will apply to differing equipment types depending on the equipment's

[11] Commercial Building Energy Consumption Survey

location, assignment, load type, pattern of usage, and characteristics. Examples of equipment types include printers, vending machines, water baths, etc.

Grouping by Characteristics: this component of the taxonomy focuses on grouping the building's spaces and equipment by common characteristics. Different ways to form groupings are explained below.

- "Assignment" is a characteristic of the spaces within a building. A space can be assigned, unassigned, or have a shared assignment among multiple users. In office buildings occupants are often assigned to a cubicle with their own plug load equipment; whereas public libraries, which are considered public assembly type buildings, are dominated by shared equipment spaces that are not dedicated assignment-wise to one particular user (such as, public computer labs with shared computing equipment).
- Assignment is an important attribute for informing saving strategies. It is essential to know the preferences of the assigned occupant's automated equipment, so they aren't disturbed by their equipment turning off during their work hours. Typically, in assigned spaces the user is best involved in customizing preferred automation strategies. In unassigned spaces the administrator and general community is best involved in setting up automation strategies deemed workable for multiple users using the space.
- "Load type" is a characteristic of the equipment within a building and refers to whether plug load equipment is a process load, information technology (IT) load, lighting load, or space conditioner load. A process load includes equipment that performs a physical process and usually has an associated output. IT loads are equipment associated with storing, retrieving, and sending information using information processing technology. Lighting loads are associated with plug in equipment used for lighting. Space Conditioning loads refers to plug in equipment that either heats or cools a space. Knowing equipment's load type can inform its usage patterns and necessity, which is useful for setting up automation. Usually, process loads have higher consumption values while actively being used and lack sleep modes. Since process load are more likely to be unassigned, they are often left on when they are not being used; their usage is also more irregular when compared to IT and lighting loads. IT loads include mass market equipment subject to efficiency standards like ENERGYSTAR and tend to use less electricity than process loads. In many cases within office environments, IT loads can be shut off after business hours when the building is not being used.
- "Equipment characteristics" refers to the characteristics possessed by equipment types found within the building. Characteristics can be described in terms of possession of: Heat/Cooling capability, Start-up requirements (such as, ramp-up time, power outage recovery feature), Thermal mass, and Level of needing to be Always-on, as further described below.
    - Heating/Cooling refers to equipment that performs heating or cooling functions. Equipment that possess this characteristic are continuously heating or cooling to maintain a threshold temperature, some examples being heating blocks and water baths. When applying automated controls to these devices one must consider if it's possible to turn off the equipment without negative consequences (such as, disruption of lab experiments, food spoilage, or user inconvenience) and the appropriate turn on time that factors in ramp-up time for heating/cooling

before the equipment can be used. The time scheduling and remote turn-on strategies may be useful for some of these equipment (such as, equipment that otherwise could be turned off, if its ramp-up time would not pose an inconvenience to users).

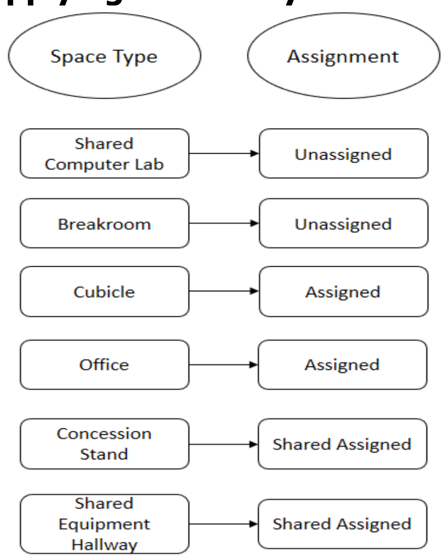
- Start-up Requirements are associated with equipment that have required steps after being turned on. Some lab equipment may need an extended amount of time before it's ready to be used after being turned on. Moreover, when certain devices are cycled after a power outage, they lose memory of last states of operation and/or various other important settings that are needed to return to normal functionality. Some equipment may consume more power upon startup, which could impact the energy economics of cycling them off and on. Start-up requirements of this nature must be considered when determining viable automation strategies. Unless occupants are willing to deal with the required startup steps, such equipment may not be effectively automated. However, the capability for users to remotely turn on such equipment may be useful as a savings strategy to encourage turning off unused devices that have large ramp-up times.
- Thermal mass refers to equipment that can store thermal energy. Soda machines and water dispensers are examples of equipment with this characteristic. When equipment of this nature is automated off, their contents can maintain an acceptable temperature for a period of time depending on their thermal mass. Automation times can be optimized on these devices by timing their scheduled turn off at an earlier time which will allow the equipment's contents to lose their acceptable temperature threshold as the building's business hours are ending. Additionally, during DR events equipment with thermal mass may be automated off and still maintain their temperature range for some time before needing to be cycled back on (for heating or cooling).
- Always-on Need refers to the extent a piece of equipment needs to be on during normal building operations. Time and presence-based control strategies can be useful in turning off devices that are not needed but are often left on. Equipment that always needs to be on should not be automated. This characteristic also has applications during demand response events. For example, in a space with three printers, where one printer is only used 10 percent of the time, the rarely used printer may be automated off during an event without greatly obstructing building operations.
- Variable Capacity refers to equipment that can adjust its power settings depending on what is needed at the given time. This characteristic applies to equipment like space conditioners, and can extend to other load types too. This characteristic is useful for saving energy because it allows equipment to stay out of its peak energy using state when it's not needed. This characteristic can complement plug load automation strategies when the admin/occupant doesn't necessarily want to completely shut off a piece of equipment, but doesn't need the equipment's full power setting at the given time.

## Taxonomy Application Examples

### Example to Describe Equipment and Spaces found in Buildings

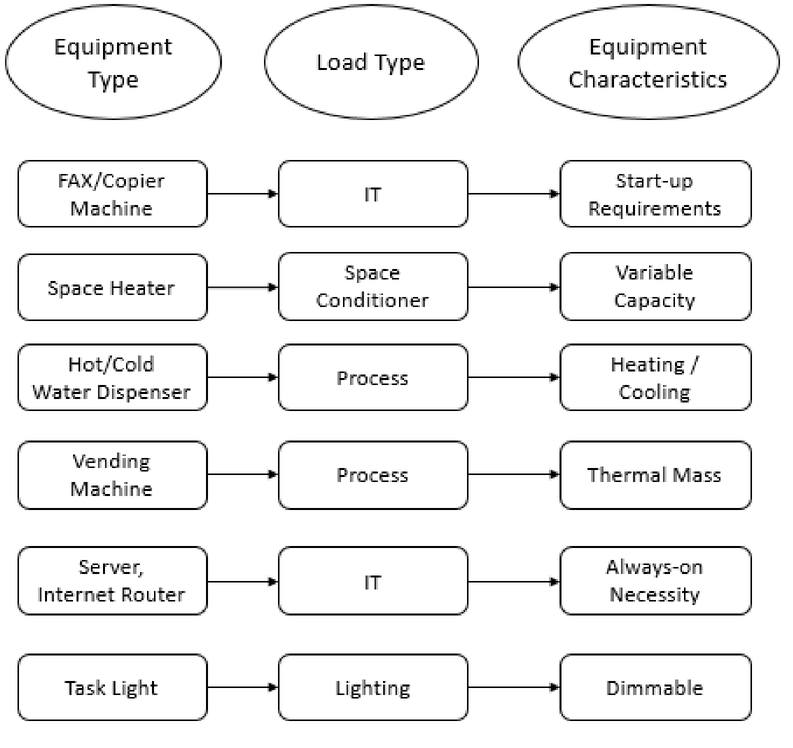
The taxonomy can be applied to describe equipment and spaces found in buildings. This is done by first classifying the different spaces and equipment within a building. The grouping characteristics discussed above are used to describe the given space and equipment types within the building. Examples of this process are shown below in Figure A-3; the space type column signifies what spaces are used in the building, while the assignment column uses the assignment characteristic to group and describe the given space. In the space type column in Figure A-3 "shared computer lab" is a space type within the building. Since shared computer labs are usually used by multiple people and not assigned to a single person, its assignment is characterized as "unassigned" in the assignment column. This same process is used when characterizing equipment type below in Figure A-4.

**Figure A-3: Applying Taxonomy to Characterize Spaces**



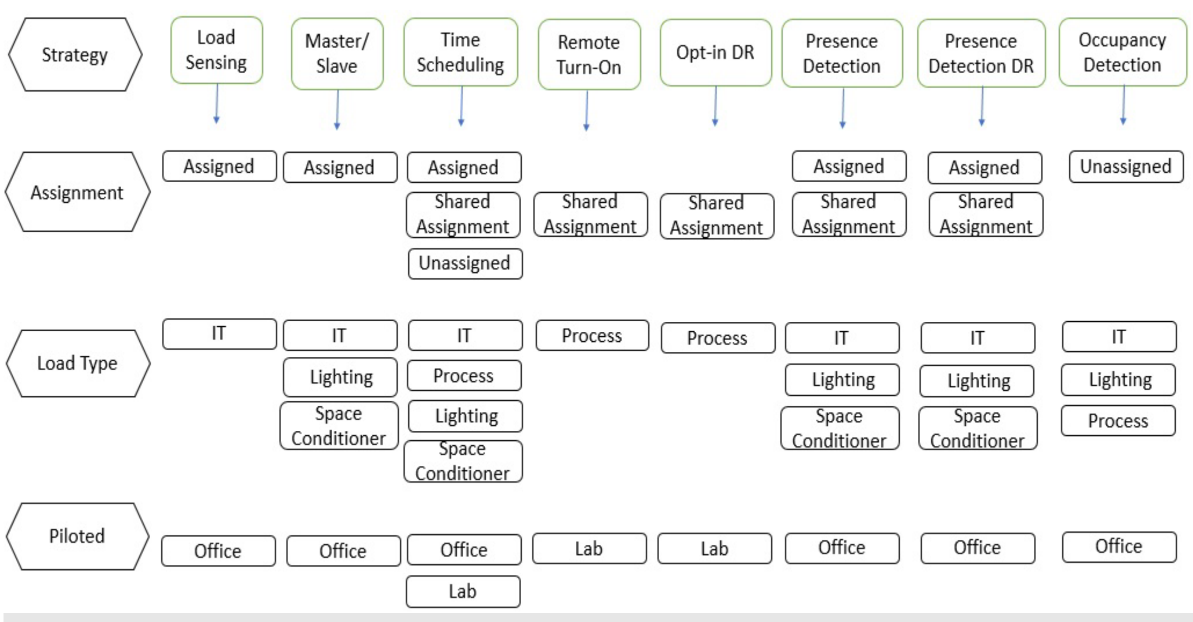

Source: Electric Power Research Institute, Inc

**Figure A-4: Applying Taxonomy to Characterize Equipment**




Source: Electric Power Research Institute, Inc

**Figure A-5: Applying Strategies Based on Context**




Source: Electric Power Research Institute, Inc

## Applying Taxonomy to Identify Applicable Strategies by Context (Building, Space, and Equipment Type)

Figure A-5 above gives an overview of what strategies generally could apply based on the context of space assignment, load type, and building type. The next section (Overview of Plug

Load Automation Strategies and Applications) describes in more detail each of the saving strategies to be considered based on these given characteristics.

### Generalizing Strategies for Similar Building Types

Certain building types share similarities in terms of space and equipment characteristics. When deciding which plug load saving strategies will be viable for varying building types, one can generalize across building types which strategies will be most effective based on shared characteristics between building types. For example, although they have very different operations, the food service and university lab building types both primarily contain spaces with shared equipment. In the food service setting employees often share equipment within kitchen workstations, while in the lab setting researchers often share lab equipment to conduct their experiments. Additionally, both of these building types contain spaces that often have equipment with start-up requirements; for example, an oven in the food service setting or an incubator in the laboratory setting. These subtleties in shared characteristics between the buildings can ultimately inform what plug load strategies may be applicable in both building types.

Table A-1 identifies similarities between types of spaces and equipment typically found across different building types. Each table entry denotes similarities shared between the building type in the row with the building type in the column. For example, office buildings mostly possess information technology (IT) type equipment, and contain mostly assigned spaces for occupants. Office buildings and lodging share similarities in that they possess mostly assigned spaces (such as, offices and cubes; hotel or motel rooms), some IT loads (such as, display monitors in offices or hotel rooms), and some task lighting loads in offices and hotel rooms.

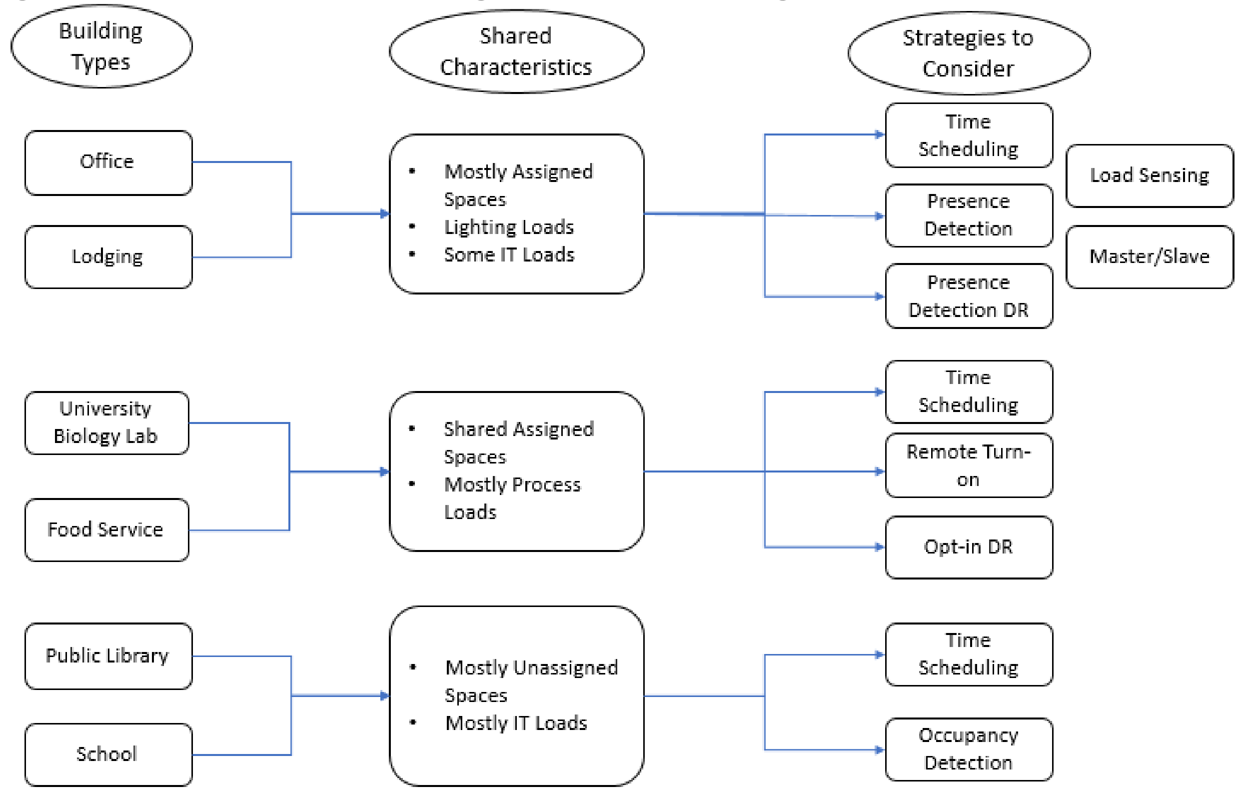
**Table A-1: Shared Characteristics Matrix**

| | Office Building | Lodging | University Lab | Food Service | School | Public Library |
|---|---|---|---|---|---|---|
| **Office Building** | Mostly IT loads and Assigned Spaces | Mostly Assigned Spaces, Some IT and task lighting loads | Some IT loads and Assigned Spaces | Not Similar | Mostly IT loads, Some Assigned Spaces | Mostly IT Loads |
| **Lodging** | Mostly Assigned Spaces, Some IT and Task Lighting Loads | Temporarily Assigned Spaces, Mixed Load Type | Mostly Process Loads | Mostly Process Loads | Temp. Usage, Some IT loads | Temp. Usage, Some IT loads |
| **University Lab** | Some Assigned Spaces and IT loads | Mostly Process Loads | Mostly Shared Assigned Spaces and Process Loads | Mostly Shared Assigned Spaces and Process loads | Some IT loads, Some Shared Assigned Spaces | Some IT loads |
| **Food Service** | Not Similar | Mostly Process Loads | Mostly Shared Assigned Spaces, Mostly Process loads | Mostly Shared Assigned Spaces, Mostly Process Loads | Some Shared Assigned Spaces | Not Similar |
| **School** | Mostly IT Loads, Some Assigned Spaces | Temporary Users, Some IT Loads | Some IT loads, Some Shared Assigned Spaces | Some Shared Assigned Spaces | Mostly Shared Assigned Spaces, Mostly Unassigned IT Loads | Mostly Shared Unassigned Spaces, Mostly IT Loads |
| **Public Library** | Mostly IT Loads | Temporary Users, Some IT Loads | Some IT loads | Unassigned | Mostly IT Loads | Mostly Unassigned Spaces, Mostly IT Loads |

Source: Electric Power Research Institute, Inc

Figure A-6 below shows examples of similarities between space and equipment characteristics for varying building types and how these similarities ultimately inform what saving strategies can be generalized across building types. Furthermore, building energy managers looking to reduce plug load consumption within any specific building type can apply these associations by noting what space and equipment characteristics make up the building. Once the characteristics are understood one can refer to Figure A-5 and Figure A-6 to identify plug load saving strategies that maybe applicable for the given building and equipment characteristics.

**Figure A-6: Generalized Strategies Across Buildings with Similar Characteristics**




Source: Electric Power Research Institute, Inc

The process for developing the associations illustrated in Figure A-6 starts at grouping a building's spaces by assignment and its equipment by load type and characteristics as seen in Figure A-2 through Figure A-4. After these characteristics are identified for the building, one can apply the taxonomy to understand what saving strategies are generally more applicable depending on the context given by the building's spaces and equipment as seen in Figure A-5.

The recommendations given in Figure A-5 are informed by results from EPRI studies which piloted PLEMS in the office and lab environments. Nevertheless, each building is unique in some ways, and the strategies that apply can vary beyond building contexts. Therefore, Figure A-5 represents a generalization and attempt at best capturing the results of the study.

The characteristics and results that were used to define optimal saving strategies in the office and lab environment were extended to other buildings types to create a relationship between a building type's characteristics and the saving strategies that may be most helpful to consider given those characteristics. The thought process to create associations between automation strategies and building equipment contexts is illustrated in Figure A-6. In this figure the characteristics that defined applicable saving strategies are taken from Figure A-5 and are used to group and create a relationship between building types with shared characteristics. Further details on each automation strategy identified to the right of Figure A-6 and its potential applications are discussed below, given a building's space and equipment characteristics.

### Overview of Plug Load Automation Strategies and Applications

1. Automated time scheduling: plug load equipment is put on a time schedule for when equipment will automatically be switched off or on at its power source.
    - Functionality of this strategy: equipment is plugged into a smart strip; then the admin or occupant inputs a schedule for the equipment to automatically turn off and on based on building operation times and usage data. Equipment that is automatically turned off can be overridden by pressing a button on the smart strip, the port is then turned on until the next scheduled off time.
    - Automated time scheduling has useful applications across buildings types. However, in buildings where operation times are flexible and occupant dependent, time scheduling would be more applicable to equipment that follows the building's normal business hours. For example, university lab occupants often use certain lab equipment during non-business hours, so that equipment used irregularly during non-business hours would not be put on a time schedule.
    - Degree of space assignment would be considered when implementing automated time schedules. When a space is assigned, an individual occupant is the main operator of the equipment within that space. So the occupant best determines the usage of the equipment in his or her assigned space, and when the equipment can be automated off or on. In some context, if occupants have irregular schedules it may be more efficient to have them set a time schedule for their own equipment. In spaces that are unassigned, equipment time schedules would be based on the equipment's baseline data and the building manager's recommendation. Spaces with shared assignment most likely should not be time scheduled unless equipment usage follows normal business hours. Equipment in spaces assigned to multiple people, such as labs, may have large variation in time of experimental usage, rendering them difficult to automate.
    - Generally, IT loads may be good candidates for time scheduled automation; but the equipment's characteristics ultimately inform if it's viable for time scheduling. If a piece of equipment has start-up requirements, then occupants must be willing to deal with the required set up steps upon turning on the equipment. For example, equipment with heating / cooling functionality would be placed on a time schedule considering the time needed to appropriately warm or cool to the target temperature before occupants would use them.
2. Remote turn-on: plug load equipment can be remotely switched on by a user manually through a mobile app.
    - Functionality of this strategy: The admin or occupant can switch equipment on remotely from an app or controller. Even if the user is not near the equipment, the equipment can be turned on remotely while the user is away to avoid

inconvenient wait times. This feature better encourages users to manually switch off equipment at the close of normal business hours, by providing a way to remotely switch on equipment with ramp-up requirements before returning to work with the equipment.

- Remote turn-on could primarily be useful in Laboratory or Food Service building types. This strategy is manually executed. Spaces where this strategy could be useful include assigned spaces or spaces with shared assignment. This strategy is more applicable to process loads and equipment that aren't well-suited to time schedule automation due to irregular occupant usage times. For example, some Lab and Food service equipment have start-up requirements that entail long ramp-up or heating and cooling times. Equipment of this nature can use remote turn-on to avoid these start-up requirements. Additionally, equipment that is used to run lab experiments may be left running after the lab's normal business hours; in this case, remote turn-on capability when offered to occupants may encourage them to manually turn off equipment with significant start-up times before departure from work (such as, on a Friday before returning to work on a Monday).

3. Load sensing: plug load equipment is turned off when a monitored consumption value falls below a certain threshold, and/or turns on when consumption exceeds a pre-determined threshold.
    - Functionality of this strategy: An admin or occupant pre-designates thresholds of consumption to be monitored. When the designated equipment's consumption goes below the inputted value indicative of "sleep" mode, the smart strip senses the change in load and automatically turns off equipment. Conversely, when the designated equipment's consumption exceeds the inputted value indicative of "normal" mode, the smart strip senses the change in load an automatically turns on equipment.
    - This strategy typically can be applied to all building types but is most useful in specific applications. In assigned office and cubicle spaces this strategy can be used for computer workstations with IT loads. When certain work station equipment (such as, the controller equipment) goes into sleep or standby mode from inactivity, the smart strip will sense the load change and can turn off the "slave" devices at the same work station or based on devices that are not being used. For this strategy, the owner of the workstation should input the threshold value indicative of inactivity. For example, if the computer is in sleep or standby mode or a laptop is not consuming energy to be considered active, the load sensing strategy could turn off computer peripheral devices for lack of workstation activity.
    - This strategy could also be applied with shared equipment and spaces lacking assignment. In this application, the workstation's equipment must be used together and the usage of each piece of equipment should be based on other equipment also plugged into the smart strip. For example, there is lab which contains a shared workstation that is designated for testing circuits. Since all the equipment at this workstation is only used when someone is testing circuits load

sensing can be used by turning off all the equipment when the essential piece of circuit measuring equipment is turned off or put into standby. In this application users should be informed of the workstation's load sensing smart strip.

4. Scheduled DR: The day before a DR event, the admin chooses which equipment will be scheduled to automatically turn off during the event.
   - Functionality of this strategy: The day before a DR event the admin receives a list of unassigned and assigned equipment shown in order by "always on necessity" level. The admin then chooses which equipment should automatically turn off for the DR event. Occupants of the buildings are then sent the list of devices which will automatically turn off during the DR event and can choose to opt certain selected devices out of the DR event, for those devices with planned use during the event.
   - Though this strategy could be used on equipment with any assignment level, it is potentially less disruptive to automate rarely used, unassigned equipment during DR events to avoid disrupting users. Typically process loads which have "back-up equipment" are a good choice to automate during DR events. For example, if there are three centrifuges or three copiers in the vicinity and data shows that that the third device is only ever used in the morning, then automating the third device during an afternoon DR event is potentially less disruptive.
   - Other considerations in applying this strategy include: i) equipment with thermal mass to be turned off during a DR event must maintain an acceptable temperature until the DR event is over; and ii) start-up requirements need to be considered for equipment that is turned off to avoid wait times for user access upon conclusion of the DR event.
5. Master/Slave: Occupant designates certain plug load equipment as "master" or "slave", when the designated "master" is turned off, the "slave" equipment automatically turns off as well. Functionality of this strategy: Occupant plugs controlling equipment into "master" port, the controlled equipment is plugged into "slave" port. Equipment that should remain on regardless is plugged into "always on" port.
   - This strategy may be used in office and cubicle spaces containing IT loads. When the master piece of equipment at the workstation is turned off (usually a computer), all other equipment plugged into the smart strip will also turn off. This is a basic strategy which is effective in eliminating "vampire" loads associated with leaving peripheral equipment such as monitors plugged in.

**Presence-Based Strategies:**

1. Presence-based energy savings automation for conservation: plug load equipment is turned off when user is away.
   - Functionality of this strategy: An admin or occupant inputs the amount of time that is needed after leaving a space before being considered "away" from his or her assigned space. After the user leaves his/her workstation, the smart strip automatically turns off equipment after the user-selected "away" time has lapsed. Equipment turns back on when the user's presence is redetected after the user returns to his/her assigned space.

- Since this strategy is based on a specific occupant's presence it is applicable mainly in assigned spaces. The occupant would consider their equipment's start-up requirements before automating them based on presence. Equipment that possess thermal mass or heating / cooling characteristics would not normally be automated based on presence. Typically, this strategy is suitable in assigned office or cubicle spaces containing IT loads.

2. Presence-based automation during DR event: During a DR event, this strategy turns off plug load equipment when a user's presence is not detected. Functionality of this strategy: Before the DR event begins, participants receive a notification about a DR event, including type of event (PowerDown or PowerUp), start time, and duration of the event. The occupant is asked if they would like to opt-out of the event. If no response is received nor user override, the user's pre-selected equipment is automated off during the DR event if the user was not presence before the event began. The equipment will restore to normal state (turn back on) at the conclusion of the DR event. During the DR event, the equipment remains off even if user presence is redetected in the space during the event.
    - This strategy is well-suited in assigned spaces. Other considerations in applying this strategy include: i) equipment with thermal mass to be turned off during a DR event must maintain an acceptable temperature until the DR event is over; and ii) start-up requirements need to be considered for equipment that is turned off to avoid wait times for user access upon conclusion of the DR event.
3. Occupancy-based automation in shared/unassigned space: plug load equipment is only turned on if occupancy is detected in space. Occupancy detection is triggered by any occupant and differs from presence detection which is specific to an individual user's presence being detected.
    - Functionality: Under this strategy, equipment is automated off for lack of occupancy. Optionally, equipment may be turned on when occupancy is detected. This application is well-suited for unassigned spaces wherein equipment can automatically be turned off after a pre-configured amount of time elapses without occupancy detected. In such cases wherein equipment is automated off due to lack of occupancy, users are generally not notified before automation occurs.

# APPENDIX B: Lab Equipment Descriptions

The definitions below provide context for the equipment that was metered, by both describing how the equipment is used as well as how its use might impact energy consumption. In addition to the equipment listed below, other electronic equipment metered for this study included computers, monitors, printers, scanners, microwaves, water coolers, projectors, and ice machines.

**Balance, Electronic (Benchtop):** A balance is used to measure the mass of samples.

**Biosafety Cabinet (Floor):** Biosafety cabinets (BSCs) are enclosed, ventilated spaces used for working with biological materials requiring a specific biological safety level. Unlike fume hoods, air is filtered through a HEPA-filter to remove viruses and bacteria and thus ensure the safety of laboratory personnel and the sterility of samples.

- **Class I:** Only the exhaust air is HEPA-filtered in BSC Class I devices. This type of BSC is used to protect laboratory personnel and the environment.
- **Class II:** Both the intake and exhaust air are HEPA-filtered in BSC Class II devices. These cabinets are the most common, and can be further subcategorized into Type A1, A2, B1, and B2. Type A1 cabinets have a minimum inflow velocity of 75 ft/min, whereas Type A2 cabinets have a minimum airflow velocity of 100 ft/min. Both types recirculate 70 percent of the air through the supply HEPA filter and exhaust the other 30 percent through the exhaust HEPA filter. In contrast, while Type B1 and B2 both have a minimum inflow velocity of 100 ft/min. Type B1 exhaust 60 percent of the air and recirculate 40 percent and type B2 exhaust 100 percent of the air. Because of the large amount of exhausted air, these types of cabinets must be ducted to an exhaust system. Type A2 cabinets are the most widely used Biosafety cabinet. Many Class II BSCs are equipped with a UV light for sterilization. This light is often left on when the cabinet is not in use.
- **Class III:** These devices are used in laboratories working with pathogens that are easily transmissible and cause deadly diseases, such as the Ebola virus. Special precautions are taken to ensure that contaminated materials do not enter or leave the highly specialized cabinet.

**Cell Counter, Automated (Benchtop):** Automated cell counters are used to count and sort live and dead cells. Cells are typically stained in some way, although cells may be counted in the absence of a dye. Cell counters operate using white light illumination (brightfield) or fluorescence illumination. The type of illuminator may impact the energy consumption of the device.

**Centrifuge:** Centrifuges are used to separate liquids of differing densities, and to separate liquids from solids. Centrifuges may have temperature control, samples to be separated at temperatures other than room temperature. Centrifuges operated exclusively below room temperature are known as refrigerated centrifuges. While most centrifuges with temperature control are classified as refrigerated centrifuges, there are centrifuges that can be operated up to 40 °C.

- **Microcentrifuge (Benchtop):** Microcentrifuges are used to spin samples in small tubes (usually 0.2mL to 2.0mL tubes). These devices have a relatively small footprint and are located on benchtops. Microcentrifuges can either operate at room temperature or they may be refrigerated, typically to 4 °C. Both the set point temperature and the speed settings affect the energy consumption of these units.
- **Benchtop (Benchtop):** Benchtop centrifuges are larger than microcentrifuges and can hold larger samples. The total volume of samples that can be used with a benchtop centrifuge ranges from 1mL to several liters. These centrifuges are so named because they fit on a benchtop. Benchtop centrifuges can either operate at room temperature or they may have temperature control. Both the set point temperature and the speed settings affect the energy consumption of these units.
- **Floor (Floor):** Floor centrifuges are very large devices, used to separate large samples. These centrifuges are so named because they are too large for a benchtop and must be placed on the floor. Floor centrifuges can either operate at room temperature or they may have temperature control. Both the set point temperature and the speed settings affect the energy consumption of these units.

**Cryostat (Floor):** In biological research applications, cryostats are refrigerated devices used to section (cut) frozen tissue onto glass slides.

**Flow Cytometer (Benchtop):** Flow cytometers are laser-based or impedance-based devices used to detect and sort specific cell populations. Fluorescence-activated cell sorting (FACS) is a type of flow cytometry, in which fluorescent-labeled cells are sorted. FACS machines employ lasers and electromagnets to sort diverse populations of cells. This equipment is often managed by someone with expert knowledge in the field.

**Heating Block (Benchtop):** Also known as a dry block heater, heating blocks are used to heat samples to a desired temperature, typically between 37°C and 100°C. These devices can accommodate a range of samples, from microcentrifuge tubes to test tubes. They derive their name from the metallic blocks that are used to hold samples of varying sizes. Dry block heaters come in a variety of sizes, though the most common sizes hold 1-4 blocks and range from 12 x 8 x 3” to 18 x 8 x 5” in size.

**Ice Machine (Floor):** Ice machines are dedicated to the production of ice. Ice is stored in frozen state until dispensed upon demand.

**Imager (Benchtop):** An imager is a generic term used to refer to a device that allows researchers to image their samples. In the context of this study, the imager is a device that has UV illumination capabilities for the purposes of viewing and taking pictures of DNA gels. The imager is connected to a camera and a computer, and, using software, researchers are able to adjust camera settings and capture images.

**Incubator (Benchtop/Floor):** In its simplest form, an incubator is a device used to maintain a set temperature. Incubators are commonly used in biology to keep samples alive. Many biological samples have both temperature, $CO_2$, and humidity requirements for survival. $CO_2$ incubators allow for the control of humidity and $CO_2$ levels.

- **Water Jacket:** Some incubators are insulated with water. Water-insulated incubators are thought to hold temperature better than air jacketed incubators in the event of a power failure.
- **Air Jacket:** Incubators may also be insulated with air. These incubators are considered to be less reliable in the event of a power outage, and as such many are purchased with a backup power option.

**Incubator Shaker (Benchtop/Floor):** Incubator shakers are commonly used in laboratories to grow bacteria, though they also have other applications. As the name implies, incubator shakers both maintain a set temperature (to incubate the sample) and shake the sample at a particular speed. Both the set point temperature and the shaking speed influence energy consumption.

**Optical Microscope (Benchtop):** An optical microscope is also known as a light microscope. This instrument uses visible light and a system of optics to magnify small objects. There are several different types of light microscopes, and they can be classified in a variety of different ways. For the purposes of energy consumption, the illumination source is the most important factor.

- **Brightfield Microscope:** Microscopes that use only a halogen bulb or white light LED are commonly known as 'brightfield' or 'transmitted light' microscopes.
- **Fluorescence Microscope:** Microscopes that employ a mercury, metal halide, or LED illuminator for the purposes of viewing fluorescent-labeled samples are collectively known as 'fluorescence' microscopes.

**Microscope Camera (Benchtop):** Imaging samples on a microscope often requires a specialized camera. These cameras are typically connected to screens (either computer monitors or specialized screens), where the sample can be viewed. In this study, the proprietary monitor attached to the camera was metered.

**Photo Developer (Benchtop):** A photo developer is a machine used to process film. Photo developers are used in laboratories primarily for viewing proteins that have been separated using a sodium dodecyl sulfate polyacrylamide (SDS-PAGE) gel.

**Plate Reader (Benchtop):** A plate reader is a piece of equipment designed to quantify samples. Samples are placed in multiwell plates, and they are 'read' by comparing absorbance, fluorescence, and/or luminescence measurements against positive and negative controls. Plate readers therefore contain illumination sources. They can also be programmed to run different types of quantification programs. The duration of the program (typically tens of minutes) and the type of illumination source will affect the energy consumption of the unit.

**Plate Washer (Benchtop):** Plate washers are used to wash microplates in between experiments. They can be programmed to use different liquids, volumes, wash times, and cycles for maximum efficacy. Different wash programs may impact energy consumption.

**Power Supply (Benchtop):** Many pieces of equipment in laboratories use power supplies. The type of power supply evaluated in this study provides either constant-voltage or constant-current output. Attached to the power supply are two cables, one positive and one negative, that are then attached to a box containing a gel with DNA samples for DNA gel electrophoresis (a technique used to separate DNA by size).

**Projector:** A piece of equipment used to project images onto a wall-mounted screen from a computer. This device is often found in conference room spaces.

**Shaker (Benchtop):** A shaker is a device used to keep samples in constant motion. Shakers come in a wide range of sizes to accommodate different types of samples. Their size, and their speed, affect energy consumption.

**Thermal Cycler (Benchtop):** Thermal cyclers are also known as thermocyclers or PCR machines. They are used to amplify pieces of DNA (i.e. increase the number of copies of DNA) using a technique known as the polymerase chain reaction (PCR). Like a heating block, thermal cyclers have thermal blocks that have holes into which small tubes containing reaction mixtures are inserted. Thermal cyclers are so named because they heat and cool samples according to specific programmed settings.

**qPCR Machine (Benchtop):** A quantitative PCR machine (qPCR, also known as real-time PCR) is a specialized version of a thermal cycler, used to quantitatively assess the amount of DNA amplified throughout the cycles. Dyes are used to label the DNA or the probes, and the qPCR machine uses light to illuminate the sample and quantify the amount of fluorescence being emitted. As a result of this additional capability, qPCR machines tend to consume more energy than traditional thermal cyclers.

**Thermomixer (Benchtop):** A thermomixer is a brand name that describes a device that heats, mixes, and cools samples. The unit has a footprint similar to a heating block or a thermal cycler. A thermomixer is principally used when samples need to be mixed in combination with temperature control. It can be used with any type of sample that will fit inside the device.

**Vortex Mixer (Benchtop):** A vortex mixer is a device used to vortex samples. Most vortex mixers have the option for continuous mixing or pulse operation. Vortex mixers do not heat or cool samples, and they are usually used when samples need to be rapidly mixed.

**Water Bath (Benchtop):** A water bath is a container filled with water heated to a certain temperature. Water baths are used to heat samples or reagents, and they are found in various sizes, usually ranging from 10-20 liters. The temperature set point of a water bath affects its energy consumption, as will the water bath's size. Water bath units that have two small containers for water are called 'dual water baths' in which the temperature of each container can be independently controlled. An innovation for water baths uses small porcelain beads instead of water as the medium. These beads can be used in traditional water bath containers, or they may be used in specialized containers, known as bead baths. Bead baths eliminate the need to monitor the water level of a water bath, and, because of the composition of the beads, bead baths will reach a set point temperature more quickly than a water bath. They are marketed as consuming less energy due to better heat retention.

**Water Cooler:** A piece of equipment used to cool and dispense potable water for drinking. It may include a water filter, though not necessarily always the case.

**Western Blot Machine (Benchtop):** This machine enables researchers to conduct western blots, a method of detecting proteins, quickly and easily. Unlike the traditional method of running western blots, which involves several hands-on steps over the course of at least two days, the new western blot machines accomplish this task in a few hours using fewer reagents, by controlling internal robotics through software programs. The robotics perform the function of a scientist, such as adding the sample and the necessary reagents at different stages of the protocol.

# APPENDIX C: Energy Savings When Lab Devices In-Use

## Energy Savings of Lab Equipment in Use

In order to analyze the effectiveness of time scheduling, a method was initially chosen for baseline determination. The initial method is detailed in this appendix along with savings results, although the final methodology chosen is distinct and detailed in Chapter 4.

An initial baseline was determined considering the equipment usage variability of a research lab. Because of equipment usage variability, two different procedures were used for calculating the baseline and energy savings. Energy savings of devices in-use was calculated first, separately from overall energy savings.

### Initial Baseline Determination

For the steps below, selecting the top five days of energy consumption is to understand the device power consumption when in use.

Due to the variability of lab user behavior in a university setting across academic quarters and individual experiments, the amount of energy savings was first determined for time scheduled devices that were actually in use during the study period. Time schedules were then implemented for each participating lab equipment. Impact of time schedule control on energy consumption was determined as follows:

1. Examine previous 10 days before day of initiation of time-schedule control. If appropriate for the building type (such as, office), consider the exclusion of weekends or holidays. However, for Stanford labs, weekends and holidays are included given a week-long lab operating schedule.

2. If there are any significant weather changes or special event occurrences during the 10-day period before time-schedule initiation, then adjust the baseline as follows. For special event days impacting lab equipment usage, shift the baseline window past the previous 10 days to exclude the special event days. For weather changes impacting equipment electricity usage, take note to weather normalize the 10-day baseline period. (Note: Since lab equipment in general are not weather sensitive loads, weather normalization was not employed.)

3. Of the 10 previous days, identify the 5 highest energy consumption days. If there are less than 5 days of energy data during this period, only use those days with energy data. If there is no energy data available at all, then go back another 10 days (such as, Day 20 to Day 11 before time schedule initiation). Repeat Step 3 to examine this new collection of 10 days of data for sufficiency of energy data to perform the next step.

4. Average the 5 (or less) highest energy consumption days during the chosen 10-day period. The resulting average provides a ***baseline average daily profile*** for the period prior to time-schedule initiation.

5. To establish a ***post average daily profile***, examine the 10 days after start of time-schedule control. Employ an averaging method similar to the 10/5 baseline construction described above in Steps 1-4, except looking forward in time following the day of time schedule initiation instead of backward time.

6. Compare the resulting average daily profiles before and after time schedule initiation. Resulting energy savings is computed as the difference in baseline and post average daily profiles.

## Energy Savings per Lab

Table C-1 below shows each lab's energy savings achieved using time-schedule controls after the start of automation. In this table, energy consumption was only recorded for the devices that were placed on time schedule, and the percentage savings are averaged across all time-scheduled devices in that lab. For each lab equipment, the baseline period used to compute savings was comprised of 10 days before time schedule control was initiated, except for one piece of lab equipment in Feldman lab, two in Weissman lab, and one in Sebastiano Lab. The table below lists the labs in order of amount of energy saved (in Wh/day) by using time-schedule controls.

**Table C-1: Energy Savings per Lab from Time-Schedule Controls**

| Lab | Average Energy Before Schedule (Wh/day) | Average Energy After Schedule (Wh/day) | Average Energy Saved (Wh/day) | % Lab Savings | Average Energy Savings** for Device Type (Wh/day) |
|---|---|---|---|---|---|
| Weissman | 9755 | 7298 | 2456 | 25% | (8) Centrifuges: 2081<br>(3) Heating Blocks: 375.4 |
| Feldman | 591 | 263 | 328 | 56% | (2) Centrifuges: 328.2 |
| Roncarolo-Baccetta | 1141 | 879 | 263 | 23% | (2) Water Baths: 207<br>(1) Electronic Balance: 27.5 |
| Majeti | 838 | 666 | 173 | 21% | (1) Centrifuge: 169<br>(1) Printer: 26.6 |
| Mackall | 480 | 400 | 80 | 17% | (1) Plate Washer: 80.2 |
| Sebastiano | 3 | 115 | -112 | 3733% | (2*) Heating Blocks |

**** Average Energy Savings is the average savings per day saved between the baseline and trail periods.**

*** The plug load energy usage for the Sebastiano Lab actually increased during the time-schedule period. This was due to the fact that the device that had been time-scheduled, a heating block, had barely been in use during the baseline period comprised of 20 days before the time-scheduling began. When the time-scheduling began, the heating block began to be used every day.**

Source: Electric Power Research Institute, Inc

Most of the labs achieved energy savings during the study period. However, the plug load energy usage for the Sebastiano Lab actually increased during the time-schedule period. This was due to the fact that the device that had been time-scheduled, a heating block, had barely been in use during the baseline period comprised of 20 days before the time-scheduling began. When the time-scheduling began, the heating block began to be used every day.

Several other devices experienced "negative savings" as well. This included four centrifuges in the Weissman lab. For the four centrifuges, the reason for "negative savings" was similar, in that the lab equipment usage was not sufficient during either the baseline or strategy period for a practical comparison. In total, 6 devices were dropped from calculations of Return on Investment (ROI), due to lack of usage data, resulting in a total of 15 time scheduled devices that contributed to energy savings.

## Energy Savings by Type of Lab Equipment

Table C-2 below shows the average percentage savings, as well as the range of percentage savings, per lab device type under time schedule controls. The table does not include devices that experienced "negative savings," as explained above.

There was a wide range of energy savings across different devices, from savings as low as 1 percent to as high as 92 percent achieved by an individual device. Some of these savings may not have been due exclusively to time schedule control. Similar to how the "negative savings" resulted from equipment being turned off during the baseline period and turned on during the time-schedule period, some equipment may have been used less during the time-schedule period, resulting in a higher percentage savings than might be explained by the time-schedule alone.

**Table C-2: Energy Savings by Device Type, per Device from Time-Schedule Controls**

| Device Type | Number of Devices | Average % Savings | % Savings Range | Average Annual Energy Savings across all devices (kWh/year) |
|---|---|---|---|---|
| Centrifuge | 7 | 33% | 1% - 72% | 940.2 |
| Electronic Balance | 1 | 29% | N/A | 10.2 |
| Heating Block | 3 | 56% | 8% - 92% | 136.9 |
| Plate Washer | 1 | 17% | N/A | 29.2 |
| Printer | 1 | 5% | N/A | 9.9 |
| Water Bath | 2 | 19% | 8% - 31% | 75.9 |

Source: Electric Power Research Institute, Inc

## Breakeven Calculations

Return on Investment (ROI) calculations were derived for the 15 time-scheduled devices with adequate usage data. Their total annual energy saved was 1204.68 kWh/year. The total energy saved annually was then divided by the 15 time-scheduled outlets to find the energy saved per outlet of 80.31 kWh/year.

The cost per smart outlet was $100 and the cost per gateway was $295. The cost unit used for ROI calculation is the cost of the smart outlet plus each outlet's share of the gateway cost or ($295/15) + $100 = $120 per smart outlet.

The breakeven point for each device was then computed by dividing the monetary annual energy savings of each device assuming $.21 per kWh by the $120 cost per smart outlet to determine the number of years to breakeven.

**Table C-3: Breakeven per Device Organized by Equipment Type**

| Equipment Type | Baseline Period Average Energy Usage per device (Wh/day) | Average Energy Savings per device (Wh/day) | Average Energy Savings per device (kWh/yr) | Annual Savings Assuming @ $.21 / kWh | Years to Break Even (per device*) |
|---|---|---|---|---|---|
| Centrifuge | 1115 | 368 | 134.3 | $28.22 | 4 |
| Electronic Balance | 97 | 28 | 10.2 | $2.10 | 54 |
| Heating Block | 223 | 125 | 45.6 | $8.22 | 15 |
| Plate Washer | 471 | 80 | 29.2 | $6.14 | 20 |
| Printer | 540 | 27 | 9.8 | $2.04 | 59 |
| Water Bath | 547 | 104 | 38.0 | $7.93 | 15 |

***4 centrifuges and 2 heating blocks were not included in ROI calculations due to insufficient usage data either during the baseline period or strategy period. There was a total of 15 devices used in ROI calculations as opposed to the 21 devices put on time-schedules.**

Source: Electric Power Research Institute, Inc

# APPENDIX D:
# IoT Button Experiment

To understand if power data can be used to determine usage, a water dispenser at a breakroom in EPRI offices was studied. Two buttons were placed on top of the dispenser with Hot and Cold labels on them. All members in the office were asked to press one of the buttons before dispensing water of the respective type. The water dispenser was also monitored using an Enmetric smart strip which would provide minutely power data. The specifications of the water cooler are in Table D-1.

**Table D-1: Water Dispenser Specifications**

| Specification | Description |
|---|---|
| Type available: | Tower |
| Dimensions: | 15.5" (W) x 46" (H) x 14.25" (D) |
| Dispense area height: | 9.0" |
| Weight: | 60 LBS |
| Recommended filtration: | Reverse Osmosis or 1 x Carbon Block (CBC) |
| Additional features: | Three stage water level control Leak detection |
| Capacity: | Header tank:11 liters, Cold tank:4 liters, Hot tank:1.5 liters |
| Compressor: | 110v / 60Hz compressor |
| Water temperatures: | Cold: 41°F / Hot: 178°F |

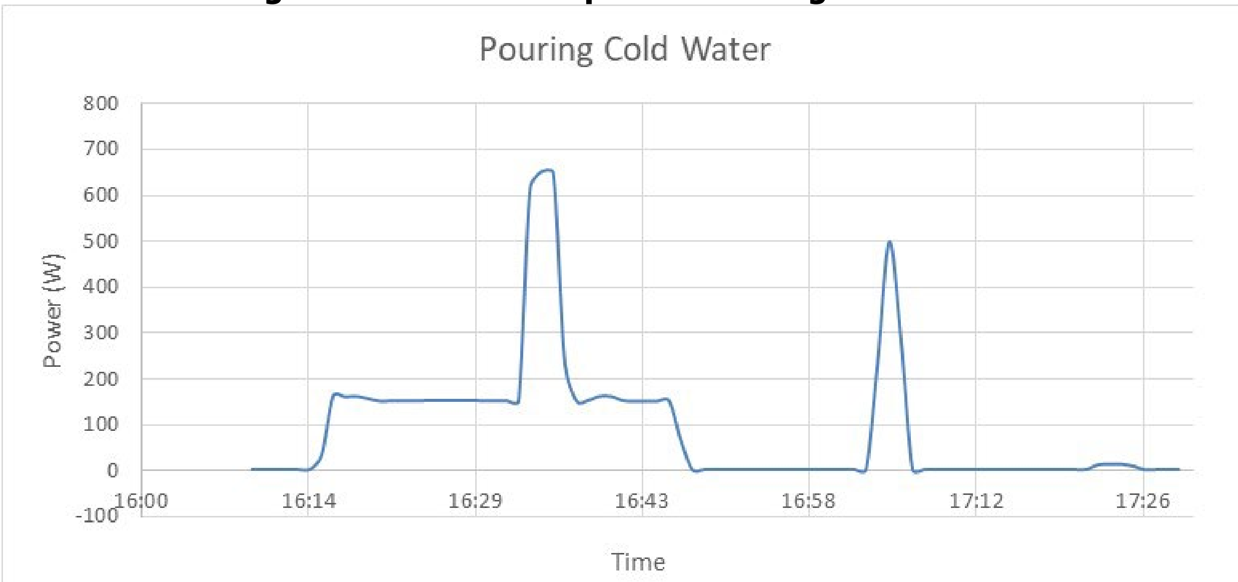
Source: Electric Power Research Institute, Inc

**Figure D-1: Water Dispenser**

Source: Electric Power Research Institute, Inc

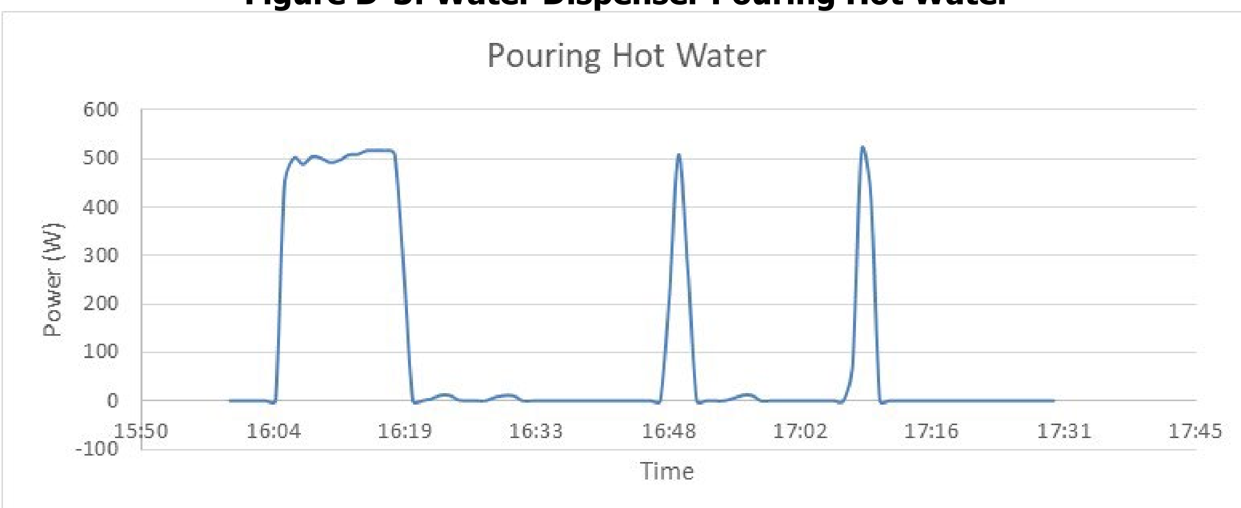
The water dispenser was tested for hot and cold dispenses separately seen below. After pouring a large amount cold water, the dispenser's power consumption sharply increased to around 150W for a long period of time. From this, the cooling function of the water dispenser can be characterized as power behavior at 150W. Similarly, for pouring hot water, the power consumption sharply increased to about 500W. This is indicative of the heating element working in the water dispenser. With this information, if the power of the water dispenser is at 500W or 150W, the dispenser is heating or cooling, respectively. If the power is at around 650W, the dispenser is heating and cooling simultaneously.

**Figure D-2: Water Dispenser Pouring Cold Water**




Source: Electric Power Research Institute, Inc

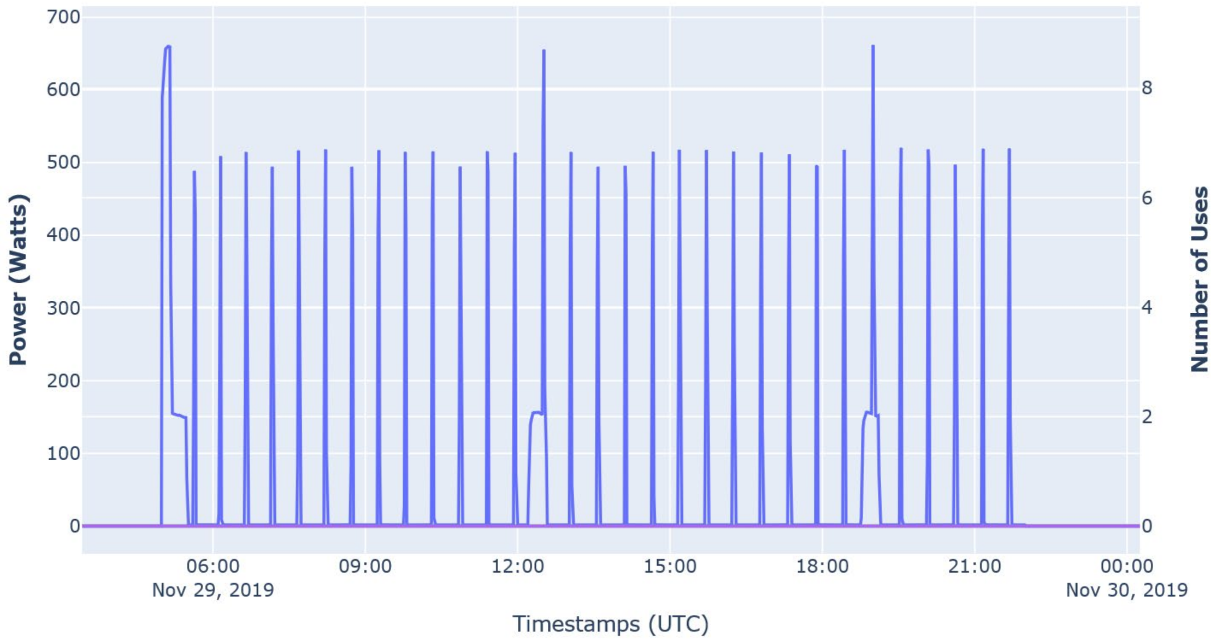
**Figure D-3: Water Dispenser Pouring Hot Water**




Source: Electric Power Research Institute, Inc

Below is the power profile of the water dispenser on a holiday. There is no usage by anybody, but there are still spikes seen in power consumption. The spike at 5am is longer than others because the dispenser is put on a time schedule and both heating and cooling need to be done to return the water tanks to their respective setpoints. Throughout the day, there are 4-minute spikes that occur approximately every half hour corresponding to heating. This may be to prevent the water from dropping too much in temperature to maintain the setpoint for hot water. There are two additional spikes caused by cooling shown around 12PM and 6:30PM. These may be triggered when the cold water is heating up due to the ambient environment

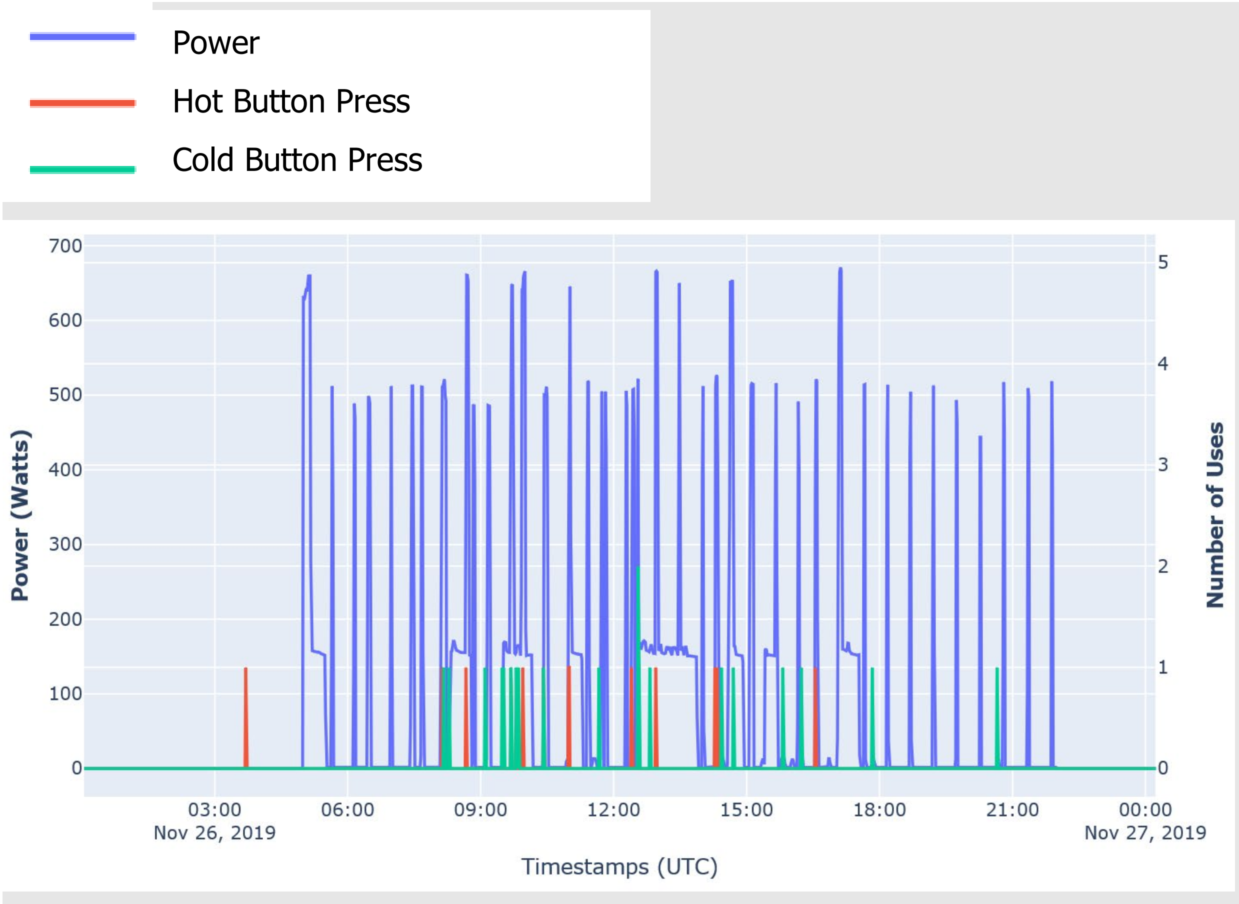
**Figure D-4: Water Dispenser Power Usage and Number of Uses on Holiday**




Source: Electric Power Research Institute, Inc

On a normal workday (example shown below), there is a larger spike at 5 a.m. when the water dispenser is time scheduled to turn on every day. This is to return ambient temperature water in the tank to the set point. Another thing to note is that most of the uses occur during work hours between 8 a.m. to 5 p.m. This shows that people are pressing the correct buttons when using the water dispenser. From the heating and cooling power usage determined above, the data can also be disaggregated to understand when the dispenser is in cooling or heating mode. This may correspond to the type of button press as well, where additional cooling is needed after multiple cold button presses and additional heating is needed after hot button presses.

**Figure D-5: Water Dispenser Power Usage and Number of Uses on Workday**




Source: Electric Power Research Institute, Inc

This study shows that it is possible to identify device usage based on power data alone. Disaggregation of the power curve by understanding both heating and cooling usage modes can show when the dispenser is heating and/or cooling. This may be useful in identifying equipment that can be more aggressively time scheduled or automated by smart strip technology in the future.

# APPENDIX E:
# Missing Data Analysis for Laboratory Pilot Site

An analysis was done to check for missing data on select equipment for the duration they were logged into the IBIS system. An algorithm was created in python to check through the data for missing values. There were two types of cases for missing data in the system. Case 1 was when a device was unplugged from the smart outlet and no longer sent data to the management system's database. This resulted in a "NAN" value for the equipment's active power reading, an example of this case can be seen in Figure E-1E-.

**Figure E-1: Case 1 Missing Data**

Out[10]:

| | time_slot | active_power |
|---|---|---|
| **7171** | 2020-02-13 23:44:00 | NaN |

Source: Electric Power Research Institute, Inc

Case 2 for missing data was when internet connection was down, the management system would fail to pull data from the database, or the smart outlet hardware malfunctioned. This resulted in a skip in the equipment's data collection for a given timestamp reading, an example of this case is how the 2016-11-28 23:29:00 timeslot reading jumps to 11-28 23:33:00 in Figure E-2 below.

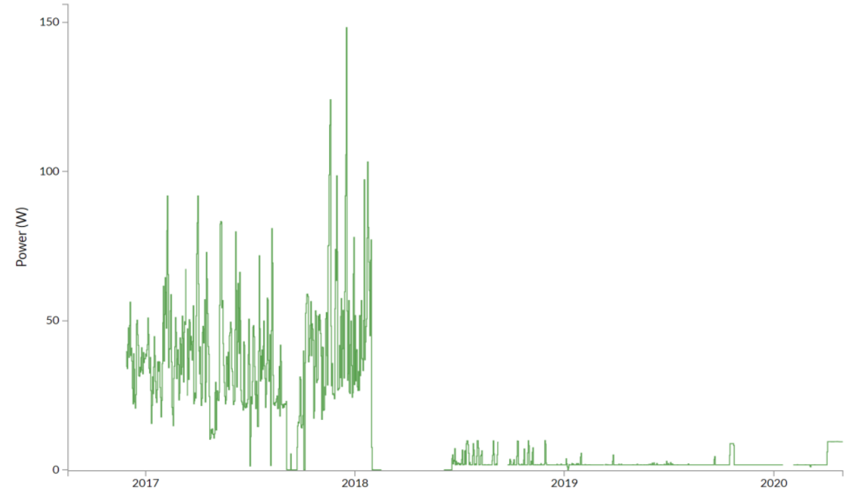
**Figure E-2: Case 2 Missing Data**

| | time_slot | active_power |
|---|---|---|
| 0 | 2016-11-28 23:29:00 | 663.000000 |
| 1 | 2016-11-28 23:33:00 | 664.013333 |
| 2 | 2016-11-28 23:34:00 | 663.400000 |
| 3 | 2016-11-28 23:35:00 | 660.983333 |

Source: Electric Power Research Institute, Inc

Table E-1 describes missing data stats for the Weissman Lab equipment. The asterisks denote equipment chosen to participate in the demand response notification system testing. There was no significant missing data from this equipment during the DR testing or time scheduling trial. The analysis also found based on the consumption data for certain equipment becoming significantly different after a long period of missing data it is likely that some of the equipment may have been unplugged and replaced with other equipment during the study. An example of this can be observed in Figure E-3, where the water bath has an average active power rating of about 75W up until 2018 before dropping to about 5W in 2019 after a long period of missing data. Additional equipment that may have been switched during the trial are as follows: Eppendorf 5424R Centrifuge, Peltier PTC-200 Thermal Cycler, BioRad C1000 Touch Thermal Cycler, and BioRad C1000 Touch Thermal Cycler.

**Figure E-3: VWR Model 1229 Water Bath**




Source: Electric Power Research Institute, Inc

**Table E-1: Missing Data Summary**

| Device Name | Location | Equipment Timeline | Case 1 overall Minutes offline | Case 2 Approx. Months offline | Case 2 overall Minutes offline |
|---|---|---|---|---|---|
| Grant JB Nova Water Bath*** | SIM1 G3161 | 2020-02-09 to 2020-03-25 | 199 | 0 | 1,772 |
| VWR Standard Heating Block*** | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 317 | 0 | 3,354 |
| Eppendorf 5424R Centrifuge*** | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 276 | 0 | 3,049 |
| Beckman CS-6KR Centrifuge*** | SIM1 G3155 | 2016-11-29 to 2020-02-08 | 140 | 5 | 225,592 |
| Eppendorf R 1.5 ml Thermomixer *** | SIM1 G3155 | 2016-11-28 to 2020-02-08 | 487 | 25 | 1,082,174 |
| Eppendorf 5430R Centrifuge*** | SIM1 G3165 | 2020-02-09 to 2020-03-30 | 287 | 0 | 3,106 |
| VWR Model 1229 Water Bath | SIM1 G3159 (Tissue Culture Room) | 2016-11-29 to 2020-02-08 | 110 | 8 | 356,796 |

| Device Name | Location | Equipment Timeline | Case 1 overall Minutes offline | Case 2 Approx. Months offline | Case 2 overall Minutes offline |
|---|---|---|---|---|---|
| Labnet AccuBlock Digital Dry Bath (w/ beads) Heating Block | SIM1 G3155 | 2020-02-09 to 2020-03-30 | 283 | 0 | 3,242 |
| Peltier PTC-200 Thermal Cycler | SIM1 G3155 | 2016-11-28 to 2020-02-08 | 124 | 5 | 194,955 |
| VWR Model 1228 Water Bath | SIM1 G3157 (Tissue Culture Room) | 2016-11-29 to 2020-02-08 | 130 | 8 | 326,233 |
| VWR Digital Heating Block | SIM1 G3165 | 2016-11-17 to 2020-02-08 | 1180 | 1 | 62,466 |
| Canon CanoScanF Scanner | SIM1 G3165 | 2016-11-28 to 2018-11-10 | 0 | 3 | 142,735 |
| BioRad C1000 Touch Thermal Cycler | SIM1 G3165 | 2016-11-28 to 2020-01-02 | 121 | 5 | 197,565 |
| BioRad C1000 Touch Thermal Cycler2 | SIM1 G3165 | 2016-11-28 to 2019-01-17 | 0 | 4 | 177,107 |
| Beckman Coulter Allegra 6R Centrifuge | SIM1 G3155 | 2016-11-29 to 2017-09-20 | 0 | 1 | 38,015 |
| Eppendorf 5418 R Centrifuge | SIM1 G3155 | 2016-11-29 to 2017-07-10 | 0 | 0 | 6,575 |
| Labnet AccuBlock Digital Dry Bath Heating Block | SIM1 G3155 | 2016-11-29 to 2017-11-10 | 0 | 1 | 43,383 |
| Beckman Coulter Allegra 6R Centrifuge2 | SIM1 G3161 | 2016-11-29 to 2017-06-12 | 0 | 0 | 2812 |

| Device Name | Location | Equipment Timeline | Case 1 overall Minutes offline | Case 2 Approx. Months offline | Case 2 overall Minutes offline |
|---|---|---|---|---|---|
| Thermo Scientific HERAcell 150i incubator | SIM1 G3161 | 2016-11-30 to 2018-02-01 | 0 | 1 | 61,447 |
| Beckman Coulter Allegra X-15R Centrifuge | SIM1 G3159 (Tissue Culture Room) | 2016-11-30 to 2019-01-17 | 0 | 5 | 196,178 |
| Beckman Coulter Allegra X-15R Centrifuge2 | SIM1 G3165 | 2016-11-30 to 2017-04-29 | 0 | 0 | 646 |
| Peltier PTC-200 Thermal Cycler | SIM1 G3155 | 2016-11-28 to 2020-02-08 | 124 | 5 | 194,955 |
| VWR Model 1228 Water Bath | SIM1 G3157 (Tissue Culture Room) | 2016-11-29 to 2020-02-08 | 130 | 8 | 326,233 |
| VWR Digital Heating Block | SIM1 G3165 | 2016-11-17 to 2020-02-08 | 1180 | 1 | 62,466 |
| Canon CanoScanF Scanner | SIM1 G3165 | 2016-11-28 to 2018-11-10 | 0 | 3 | 142,735 |
| BioRad C1000 Touch Thermal Cycler | SIM1 G3165 | 2016-11-28 to 2020-01-02 | 121 | 5 | 197,565 |
| BioRad C1000 Touch Thermal Cycler2 | SIM1 G3165 | 2016-11-28 to 2019-01-17 | 0 | 4 | 177,107 |
| Beckman Coulter Allegra 6R Centrifuge | SIM1 G3155 | 2016-11-29 to 2017-09-20 | 0 | 1 | 38,015 |
| Eppendorf 5418 R Centrifuge | SIM1 G3155 | 2016-11-29 to 2017-07-10 | 0 | 0 | 6,575 |

| Device Name | Location | Equipment Timeline | Case 1 overall Minutes offline | Case 2 Approx. Months offline | Case 2 overall Minutes offline |
|---|---|---|---|---|---|
| Labnet AccuBlock Digital Dry Bath Heating Block | SIM1 G3155 | 2016-11-29 to 2017-11-10 | 0 | 1 | 43,383 |

***Denotes Equipment that participated in DR notification trial.**

Source: Electric Power Research Institute, Inc