Advanced Plug Load Operating Strategies in BEMS

I. INTRODUCTION

This report captures the methodologies, results, and conclusions from integrating plug load control with a building energy management system (BEMS). This project provided an opportunity to explore different strategies for both the management and control of over 800 plug load controllers across 14 campus office buildings and 59 different departments which provides diverse real-world challenges for the deployment. The main outcomes of this project are data sets of real-world plug load use, new technologies, and best practices for plug load controllers.

II. OPERATING STRATEGIES

A. PLC Operation with Existing BEMS

The project first explored the capabilities of the existing campus BEMS to manage plug load controllers and to identify what features are needed for PLC management. After identifying the limitations of the BEMS, a parallel system was developed to prototype and demonstrate an alternative architecture and features that can better support the integration of plug-load controllers with a BEMS.

The existing campus BEMS is used by UCSD Facilities Management (FM) to manage the Heating, Ventilation, and Air Conditioning (HVAC) of campus buildings. Each building has a network engine that HVAC components communicate to. To add the PLCs, a server was set up to act as an additional network engine for all PLCs to communicate with via the BACnet protocol. A network engine is only capable of supporting a limited number of data points, so the large number of PLCs necessitated a dedicated engine for them. The capabilities and limitations of this architecture are noted in Table 1.

The parallel system utilizes the BRICK Schema which provides a standardized ontology and taxonomy for building systems. This schema, along with the system's architecture of using a graph database in conjunction with a time-series database, enables greater levels of interoperability between heterogeneous devices.

Table 1: Comparison of BEMS' and BRICK Server's Capabilities

Functions	Existing Campus BEMS	BRICK Server & PLC Ops Application
Adding & Removing PLCs from the System	Adding and removing PLCs is a lengthy, manual process. Discovery of new devices on the network can take hours due to all of the other HVAC components on the network. Adding a new PLC manually requires individual data points to be mapped and added.	BRICK Server receives messages directly from the PLCs through the User Datagram Protocol (UDP). New PLCs can be automatically added to the database based on whether the PLC's MAC address already exists in the database.
Meta-data Management	Meta-data such as the device's location and what appliance is attached to the PLC are only stored in the name given to the PLC. PLCs were named following the standard format that FM uses for HVAC such as SERF-136-PRINTER (building-room-appliance). The limitation of this approach is that PLCs cannot be easily sorted by this meta-data which is crucial for managing PLCs in batches. Also, the BEMS lacks additional spatial information such as how rooms are connected or which rooms belong to certain departments. While this information may not be needed for HVAC, it is more important for PLC.	The BRICK Server's graph database enables PLCs to be connected with all necessary meta-data and to use it for sorting and management purposes. A graph database works by creating a node for each entity such as the building, rooms, plug load controller, and appliance. Relationships can then be created between nodes such as giving the PLC a 'haslocation' relationship to the room it is installed in. The meta-data in the BRICK Server is also more complete than the BEMS as additional information was found to be needed such as which rooms a variable air volume box (VAV) feeds and how rooms are physically connected. For the system operator, a PLC Operations Application was made to give them a graphical user interface to easily manage this information.

PLC Management	In the BEMS, equipment is primarily organized by just its location and what parts of the building it serves. When PLCs were added to the BEMS graphical interface you could see where PLCs were located on the floor plan which was helpful. However, other contextual information is not as readily available.	For the PLC Operations App, we took a different approach that focused on the stakeholders. PLC impacts occupants more directly so their preferences and input are more important. The app allows the operator to create accounts and then associate people and relevant PLCs to the account. Each PLC can then be set to the desired control strategy per the input from occupants.
PLC Use of HVAC Data	Attempts were made to actuate PLCs using occupancy data from the BEMS. Two main issues were faced. First, the campus does not use occupancy data for HVAC controls as it operates on a static schedule. This limited the availability of occupancy data. Secondly, there is a system limitation for using data between network engines. We attempted to use the BEMS interlock feature to actuate a PLC based on data from one occupancy sensor that was available, but this test was unsuccessful.	In addition to storing HVAC, PLC, and metadata, the BRICK Server also has an application programming interface (API) that enables software applications, such as our PLC operations application, to access all of this data, allowing for interoperability between heterogeneous devices. While the BEMS also has its own API, it lacks the additional historical and metadata needed.
Scheduling	Integrating PLC with a BEMS offers the convenience of reusing schedules for multiple systems. At UCSD the HVAC system operates off of static weekly schedules. This same schedule was used to turn PLCs ON and OFF at the same times as HVAC. Since our PLCs are wireless, connectivity was an issue though. There were several instances where PLCs failed to receive the signal to turn ON due to loss of wifi connectivity, due to changes from the IT department that unintentionally disrupted communications, or because the PLC server rebooted and failed to restart the gateway software. These experiences highlighted the advantage of PLCs that can store and operate using a schedule uploaded to it rather than relying on signals from a central source. This approach was attempted with the BEMS, however, this was not practical as the schedule object for each individual PLC had to be updated manually and could not be connected to or copied from the existing HVAC schedule. Therefore, algorithms that generate updated schedules on a daily basis would require manual updates each time. This BEMS limitation made scheduling time-consuming to create and update.	The BRICK Server is designed to store a schedule for the building, for departments, and a custom one for each device. This allows the operator to select a batch of PLCs and to apply that stored schedule to them easily. In this way, the information can be reused for all building systems that rely on schedules. Based on the lessons learned about operating PLCs with stored schedules instead of receiving commands from a server, the majority of our control strategies use stored schedules. For example, an algorithm that processes historical occupancy data daily will output a one-week schedule that can be stored on the PLC. Anytime the algorithm receives new information it will generate a new one-week schedule and upload it to the PLC. In that way, if communication is functional, only the first (most accurate) day will actually be used for scheduling; but if communication fails, six additional days are available for the PLC to use as a failsafe.
Alerts	BEMS has standard alerts that can be applied such as if a PLC is OFF or offline. The OFF alert was only useful in confirming that the PLCs did turn OFF at the correct times. Other alerts such as those listed in the right column could not be developed.	The BRICK system supports any program logic. Therefore, the following alerts that are critical for operating a large fleet of PLC were created: - PLCs that were offline for more than 24 hours, which could indicate that the PLC was removed from the wall. - PLCs that were reporting 0 watts for more than 48 hours, which could indicate that the attached appliance was removed. - PLCs that had a different appliance attached to it. A Gaussian mixture model

		was used to characterize power signatures for device types. If the signature changed, then an alert would be generated.

B. Operation Strategy Takeaways

The key aspects of PLC operation are as follows:

1. Set up your system to capture and use meta-data including
    a. Building
    b. Floor
    c. Room & Type (e.g. kitchenette, conference room, private office, etc.)
    d. Plug Load Controller ID (typically MAC address)
    e. Plug Load Type, Make, and Model
    f. Plug Load Use
2. Have a simple process for adding, removing, and editing PLCs as it is common for equipment in offices to change.
3. Have the ability to sort PLCs by location, plug load types, and stakeholders.
4. Set up the BEMS to store trends so that historical data, such as occupancy, can be used by PLCs.
5. Implement distributed control to reduce reliance on a central server. In particular, storing schedules in the PLC is recommended.

III. PLUG LOAD CONTROLS

The following describes approaches for designing and implementing plug load controls. This information can be used by BEMS operators to design controls that meet their specific needs, risk tolerances, and plug loads.

A. Control Levels

Controls were classified into different levels that represent the risk of disrupting occupants. Higher levels offer great energy savings but at higher risk. Defining these levels helps align your controls with the risk tolerance of your building occupants. Additionally, if the plug load management system is tracking manual overrides, then a fail-safe program can be made to default plug loads to lower risk level controls if too many overrides are detected. A manual override is required when the PLC is OFF but an occupant needs to use the appliance.

Level 0: No control. PLC is always ON.

Level 1: Repeating static weekly schedule - generally given by stakeholders. The schedule should have extra time added before and after occupants are typically in the building.

Level 2: Schedule tightening - these types of controls use additional sensors and/or data to determine better start and end times for the PLCs to be ON and may result in a schedule that changes each week. There will only be one ON and OFF event per day. For example, PLCs can be set to turn ON when occupancy is first detected in a space and then turn OFF at a specified time.

Level 3: Usage-optimized scheduling - these types of controls may turn the PLC ON and OFF multiple times a day so that ON periods align more closely with usage. The controls may use direct inputs or occupancy and power data to determine when PLCs are likely to be used.

Level 4: Special control events - While Levels 0 through 3 are designed to be non-disruptive, level 4 controls are generally disruptive and are used in special cases such as demand response events, building peak load reduction, or in islanded operation.

B. Control Types

We classified plug load controls into four main types based on the information and data that is available. Control strategies may also be a combination of these types.

1. Static Schedules: the system follows a static schedule that repeats weekly. The schedule often reflects the business hours of the facility with some extra time before and after to allow devices to turn ON before occupants arrive and to turn OFF after most people are likely to leave. This strategy is the simplest to implement as well as the safest as there is a low risk for systems to be OFF when people need them. It is also the most convenient for BEMS operators as they can 'set it and forget it'. Generally, this strategy will produce savings by eliminating wasted energy in the evenings and weekends.

2. User Input: this strategy takes advantage of any direct inputs from users that can also be used to trigger the PLC. This results in the appliance only being ON when it is actually needed which results in the greatest energy efficiency. An example of this type of automation is our printer PLC strategy which automatically turns ON a printer when a print job is received. The printer then turns OFF after 30 minutes of inactivity.

3. Plug Load Use: if the usage of a plug load can be tracked, then that data can be used to generate an optimized PLC schedule that only turns the plug load ON when it is likely to be used. While most plug load use is stochastic, some patterns can become clear such as little to no use during lunch periods, as an example. One approach for tracking usage is to use PLCs that can record power measurements of the appliance they are attached to and then analyze those power measurements to detect usage. For example, TVs have distinct power consumption levels for when they are in standby versus active modes and a power threshold can be set to differentiate between the two. While this strategy can yield high energy savings similar to the User Input strategy, caution must be taken. Some appliances will periodically have a spike in energy consumption that results in a false positive that can result in inaccurate schedules. Also, user behavior patterns may evolve, resulting in errors as the system learns these new patterns. Therefore this strategy of levering plug load use is best used in a Level 2 control and possibly with other sensor and data inputs to make the forecasts of use more accurate.

4. BEMS Data-Driven Control: for some appliances, it is not possible to detect when they are being used without adding additional sensors. In these cases we can only infer usage from occupancy, assuming that there is a higher chance for the appliance to be used when people are nearby. Thus integration of PLC with a BEMS is especially effective so that PLCs can take advantage of additional data. Occupancy data from a specific room or neighboring rooms within the same department can be used to generate occupancy-driven schedules. Alternatively, specific occupancy sensors can be used to trigger the PLCs ON the moment motion is detected and then to set to turn OFF after a set period of inactivity. How occupancy data can be used with PLC depends on the quality of these additional data streams which is dependent on what systems a building has. Newer buildings may have smart LED systems with occupancy sensors in every room. In older buildings, occupancy data may be incomplete as is the case with many older UCSD buildings. In these buildings, occupancy data can only be attained from the HVAC thermostats which are only installed in certain rooms and may not be located in the best place to reliably detect occupancy.

C. Control Levels and Types by Plug Load

Table 2 shows how the control levels from Section III.A and the control types of Section III.B can be applied to different types of plug loads. The data extracted from the control types is leveraged to implement different control levels that are associated with different savings and risks.

Table 2: Example progression of control strategies for different plug loads.

Plug Load	Lower Savings/Risk ——----------------------------> Higher Savings/Risk	
Individual Printers & Scanners	(L1) Static Schedule	(L3) Usage Optimized - User Input: connect printer to a central print server which can trigger PLCs to turn ON when a print job is received. Turn the printer OFF after 30 minutes if no additional print jobs are received. We found that printers in private offices generally get very little use so turning them OFF during the day is effective.
Shared Copiers	(L1) Static Schedule	(L2) Schedule Tightening - User Input: connect the copier to a central print server that triggers the PLC to turn ON when the first print job of the day is received. The PLC can be scheduled to turn OFF at the end of the business

		day. Alternatively, usage data can be used to determine a better OFF time. Should avoid turning Copiers ON and OFF frequently due to their long start-up time and more frequent use throughout the day.	
Shared Printers & Scanners	(L1) Static Schedule	(L2) Schedule Tightening - User Input: same strategy as copiers	(L3) Usage Optimized - User Input: same strategy as individual printers if usage is not very high
TVs (digital signage)	(L1) Static Schedule	(L2) Schedule Tightening - BEMS Data-Driven Schedule: Use occupancy data from BEMS to generate a tightened schedule for the TV to be ON based on when people are nearby	(L3) Usage Optimized - BEMS Data-Driven Schedule: Similar to L2 but with additional mid-day actuations.
TVs (conference rooms)	(L1) Static Schedule	(L3) Usage Optimized - BEMS Data-Driven: BEMS turns ON the PLC whenever the conference room is occupied and turns it OFF after a set period of time when no motion is detected. This approach is best because for TVs, the PLC is often installed behind it and it is difficult to reach the manual override button if a forecasted schedule is wrong. This usage is also difficult to forecast due to its stochastic nature.	
Individual Water Dispensers or Coffee Makers	(L1) Static Schedule	(L3) Usage Optimized - Plug Load Use + BEMS data: algorithm identifies hot and cold water usage from power measurements. Combined with HVAC data, the water dispenser schedule is aligned with actual usage which is more dependent on the single occupant's usage patterns and presence.	
Shared Water Dispensers or Coffee Makers	(L1) Static Schedule	(L2) Schedule Tightening - Plug Load Use + BEMS data: algorithm identifies hot and cold water usage from power measurements. Combined with HVAC data, a tightened schedule is generated.	(L3) Usage Optimized - Plug Load Use + BEMS data: algorithm identifies hot and cold water usage from power measurements. Combined with HVAC data, the water dispenser schedule is aligned with actual usage but with a larger buffer since more occupants share usage.

IV. CASE STUDIES

A. Static Schedules:

Two building-wide interventions were run that used static schedules. A list of plug loads was sent to the facility managers who then returned a subset of approved plug loads to control as well as the desired schedule for them.

1. Global Policy School (Robinson Hall): 33 plug loads were approved. All of them were to follow the same schedule of being ON from 7 am to 6 pm on weekdays and staying OFF on weekends. After collecting baseline power measurements, 8 plug loads were found to have been removed which reduced the number of PLCs to 25. This count consists primarily of printers along with smaller counts of water dispensers, copiers, a coffee maker, and a TV. Compared to a baseline week, a week of controls used 67.4 kWh (66%) less energy (Figure 1). Assuming an average electricity cost of 34¢ per kWh in San Diego, this equates to an annual savings of $1,192. Utility rates can be found at the U.S. utility rate database (www.apps.openei.org/USURDB/).

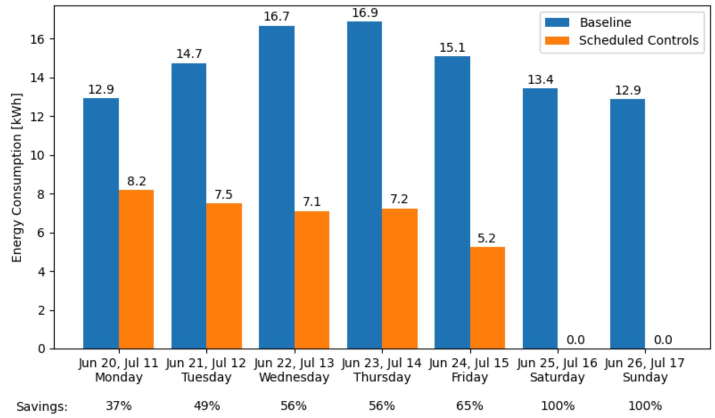

Figure 1: One week of controls consumed 66% less energy than the baseline week.

2. <u>McGill Hall:</u> 14 plug loads were approved. 6 TVs were to be ON Mondays to Sundays from 6 am to 11 pm. 8 water dispensers were to be ON Mondays to Fridays, from 7 am to 10 pm. Compared to a baseline week, one week of level 1 controls used 7.1 kWh (38%) less energy, equating to an estimated cost savings of $126 per year (Figure 2). In this case, students and faculty are more likely to use the facilities during the evenings so most of the savings were achieved from turning the plug loads off on the weekends.

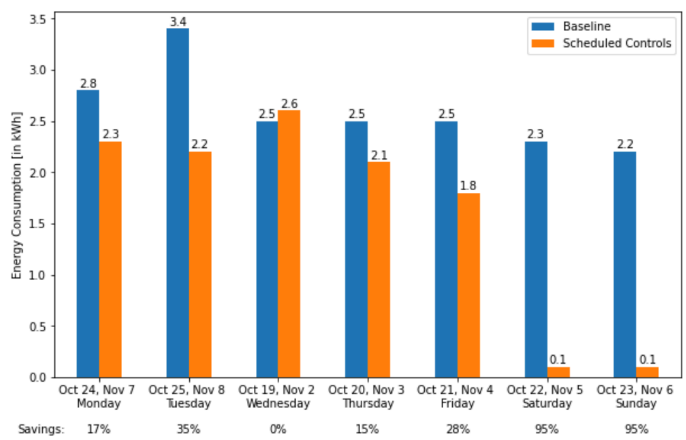

Figure 2: One week of controls consumed 38% less energy than the baseline week.

B. User Input:

Printers offer a unique opportunity when they are paired with a print server. When print jobs are routed through the print server it is possible to monitor that traffic and to use that information for plug load control.

<u>Engineering Building Unit 2:</u> A printer in the business office of the Mechanical and Aerospace Engineering Department was chosen to test the integration of a print server with plug load control. Software was written that checks the print server logs for accepted print jobs and which printer it is for. When a print job is received the software then sends a command to turn ON the appropriate PLC which also turns the printer ON. The print server holds onto the print job until the printer is ready to process the job. This system provides a seamless experience for occupants and enables the printer to be ON only when it is actually needed. This also eliminates the need for occupants to perform any manual overrides. It is a frustrating experience for occupants to walk to a printer only to find out that their job was never printed since the printer was OFF. Since a BEMS needs to run on a server, it is possible to also run standard print server software on the same system.

Two levels of controls were tested. For the first week, a level 2 control was applied. The printer started OFF and would turn on each day when it received its first print job. It then turned OFF at a set time given by our department contact. For the second week, level 3 control had multiple ON and OFF events by turning ON the printer each print job received and then turning it OFF after 30 minutes of inactivity. The baseline data resulted in an average energy consumption of 3,870 Wh per week (Table 4). Level 2 controls resulted in an energy consumption of 1,215 Wh for one week, which is 69% less than the baseline and equates to an estimated annual savings of $47 per printer. Applying Level 3 controls resulted in a consumption of 496 Wh for one week, which is 86% less than the baseline and equates to an estimated annual savings of $60 per printer.

Table 3: Summary of energy savings from the application of level 2 and 3 PLC on a printer

Week	Energy Consumed	% Saved vs Baseline	Annual $ Saved Per Printer	Energy Per Print Job
Baseline	3,870 Wh	----	----	184 Wh
Level 2 Control	1,215 Wh	69%	$47	110 Wh
Level 3 Control	496 Wh	86%	$60	33 Wh

C. ***Plug Load Use & Occupancy Data:***

Water dispensers were chosen as a focus as they are the second highest (per plug load) energy consumer of our plug load types as they maintain hot and cold water 24/7.

Student Services: A water dispenser in the Student Financial Services department was used to test control strategies for water dispensers. First, an algorithm was developed to identify when hot and cold water was being used by analyzing power measurements from the dispenser. Water dispensers consume a notable amount of energy because they are consistently heating and cooling water throughout the day. Power measurements show distinct signatures for heating and cooling and that they occur in fairly regular cycles (Figure 3). By identifying time variations between these heating and cooling events as well as analyzing the aggregated energy consumption of all water dispensers monitored in the building, usage from occupants can be identified to produce a level 2 schedule based on that usage pattern. Level 2 controls resulted in 4.88 kWh consumed for the week, a 49% reduction in energy compared to a baseline week of no controls. This equates to an estimated $53 saved annually per water dispenser.

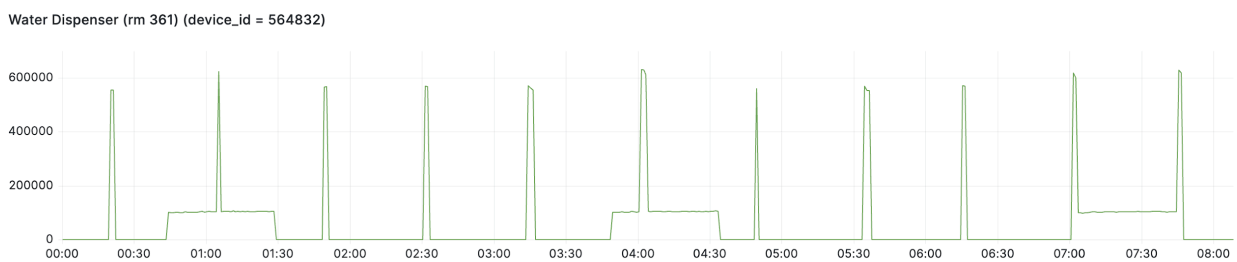

Figure 3: Example of Baseline Power measurements [mW] from the water dispenser in the Student Financial Solutions department. The x-axis shows time in HH:MM.

To gain further savings and robustness, another strategy was simulated that employed the use of occupancy data from HVAC thermostats. This level 3 control strategy uses both historical and real-time occupancy data from the BEMS to forecast when spaces may be occupied, and thus when water dispensers may be used, as well as real-time data to account for changes in occupant behaviors such as after-hours or remote work. The control works by turning ON plug loads prior to when occupants are forecasted to arrive. If no motion is detected for 2 hours after the forecasted arrival time, then the plug loads are turned OFF, such as in the case where occupants are working remotely. A forecasted OFF time is also determined based on past occupancy data. If motion is detected at any time though, then plug loads will be turned back ON. This level 3 control resulted in a simulated savings of 53% in addition to better-managing changes in occupant behavior patterns.

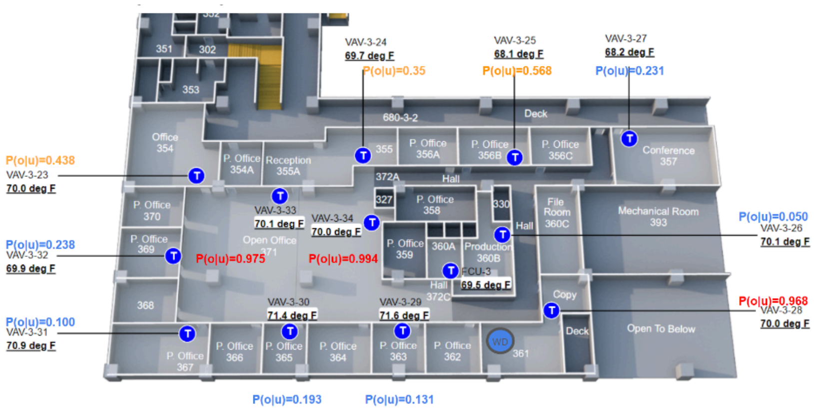

Figure 4: Floor plan showing thermostat locations in Student Financial Solutions and their probabilistic relationship to water dispenser usage.

D. BEMS Data-Driven Schedule:

For some plug load types, it is not possible to know if they are actually being used without adding additional sensors. For example, with TVs, we do not know if someone is actually looking at the TV or if they just forgot to turn it OFF. In this case, we must assume that if someone is detected to be near the TV, then the TV is in use.

Engineering Building Unit 2: Two hallway TVs outside of the Design Studio were chosen. The TVs are being used as digital signage and they play a repeating slideshow of student projects. Initially, a static schedule was given to keep the TVs on from 8 am to 8 pm every day including weekends. This resulted in 50% energy savings. The next step was to use motion detector data from the hallway to generate an occupancy-driven schedule. Motion data was aggregated and grouped by weekday and time to produce a heatmap that shows when the hallway is actually occupied. Data points were grouped into 15-minute intervals and thresholds were set to identify clusters of motion. This then produced a level 2 schedule that would turn the TVs ON when larger groups of people were expected. This approach was simulated and resulted in 68% energy savings and an estimated $180 saved annually per TV.

V. COST AND BENEFIT EVALUATION

A. Cost Benefit Evaluation

For the 1,000 PLCs commercial plug load controllers used in this project, the costs came out to $109 per controller including the hardware, vendor support of the installation, the license for the BERT Software required for integration with the campus BEMS, two virtual machines ($122 per month for 3 years), 131 hours of installation support by the UCSD project, and support costs from BERT.

It cost $299,434 for Johnson Controls to perform the necessary work to integrate the PLCs into the campus BEMS including configuration of the virtual network engine, importing of the PLCs, and adding them to the BEMS user interface graphics. This brings the final cost of the PLCs to $408 per controller.

The average commercial electricity rate in San Diego is $0.34 per kWh. For a 3-year payback period, this would require 400 kWh of savings per year or 7,692 Wh of savings per week. Assuming typical UCSD business hours, PLCs could be turned OFF for 103 hours per week (7 pm to 6 am on weekdays and all day on weekends). For the electricity cost savings to equal the installation costs in 3 years, each PLC would need to turn OFF an appliance that would normally consume at least 75 Watts during those time periods. Large TVs that are used as digital signage and older copiers that are left ON 24/7 would meet this requirement, while most smaller appliances and devices that are on standby would not.

If more affordable consumer PLCs are used, ranging in cost from $10-$25, and the project team's BRICK app was used instead of a commercial BEMS, then appliances that use between 10-15 watts could meet the 3-year payback period.

B. Benefits Evaluation

1. BEMS Operator Pros & Cons:
    a. Having a single interface for PLC and HVAC provides convenience. It also promises time savings by consolidating information into a single system such as schedules for buildings. Limitations within our particular BEMS and our approach of storing schedules in the PLC limited this benefit.
    b. Integration of PLC into the BEMS allows the operator to create more effective controls by using BEMS data, such as occupancy from thermostats, for PLC.
    c. A primary concern for the BEMS operator is the additional workload that PLC introduces. IT departments also share this concern since many plug loads fall under their responsibility.
        i. The addition of plug loads adds many more devices that the operator is responsible for. It also makes troubleshooting more complex as the fault could be with the plug load controller or have something to do with how occupants are using the plug load.
        ii. Whereas HVAC equipment does not change often, plug loads are more susceptible to changes (appliances being moved, removed, or added). While automated alerts can be set up, operator time is still required to keep the system updated.
        iii. The priority for BEMS operators is to meet occupant needs. HVAC changes or even failures are less disruptive to occupant work, especially in San Diego where there are small differences between indoor and outdoor temperatures. Plug loads on the other hand are directly used by occupants for work and thus require a higher level of reliability.
        iv. PLC requires adoption by the occupants that use them. Thus the BEMS operator must invest time to coordinate with more individual users and communicate frequently.
    d. To mitigate the time burden concerns, BEMS operators can first focus on plug loads that are not as relied on for work such as water dispensers and digital signage. From there, shared equipment such as copiers and shared printers can be targeted as they are less likely to be moved. Level 1 strategies can be implemented first to also reduce the risk of disruption. As occupants become more aware and comfortable with implementing smart plugs, then more energy-effective strategies can be used.

2. Occupant Pros & Cons
    a. Most occupants are supportive of energy-saving measures. Some are skeptical of the savings, citing that their plug loads are already energy efficient.
    b. Plug loads can be used to automate existing routines for occupants to save them time.
    c. Generally, occupants do not see a direct value added from plug load controllers (other than the potential for automation) and it is more likely for PLCs to disrupt their work. Thus the value of energy savings and environmental impact must be communicated to occupants regularly to keep them engaged in the efforts.

VI. LIMITATIONS & CHALLENGES

Several limitations and challenges were faced during the project.

A. The project started during COVID. The return to campus learning, adoption of hybrid schedules, and other changes due to this period of transition produced many logistical challenges. Many plug loads were moved or removed. Plug load usage patterns also changed rapidly.

B. UCSD Facilities Management only operates the HVAC system using static schedules and does not use additional data such as occupancy from thermostats. This also reduced the usefulness of some HVAC data for forecasting occupancy and plug load use since readings like temperature are driven by those static HVAC schedules and are not responding to changes in occupancy. Additionally, for this reason, the thermostats are not often placed in the ideal locations to properly detect occupancy.

C. A BEMS product flaw was discovered when trying to extract occupancy data from the BEMS that prevented the data from being published properly. These historical occupancy trends were not available until late into the project.

D. User adoption varied greatly across departments. Some were very supportive of energy savings efforts. Others were skeptical that the effort was worthwhile as they believed that their plug loads were already energy efficient.

E. Department IT support groups were generally not in favor of plug load control due to concerns about damaging electronic equipment by cutting off power and not allowing the device to properly shut down.

F. Despite extensive communications through fliers and emails, it was common for occupants to just remove the plug load controllers.
G. Testing PLCs in a live production environment was valuable but also slowed progress as many more logistical steps had to be taken to integrate them into campus operations.
H. Computers, servers, and network infrastructure are also identified as primary plug load energy consumers. However, controls of these devices were not permitted due to concerns about loss of productivity and user inconvenience.
I. Use of the BEMS to control PLCs via the BACnet gateway was not always reliable. For example, sending an ON command from the BEMS sometimes produces multiple ON actuations. This was likely due to how the BACnet gateway works where it will retry commands if it does not receive a confirmation message from the PLC.

VII. PROJECT GOALS

This section discusses how our project goals were met through this project.

A. Reduce PLC setup costs

1. The time installing and configuring each PLC is the primary installation cost. A Best Practices Brief was created to help save operators time providing a more efficient process to select and configure plug loads to control. The ability to apply control schedules in batches is also a key time savings.

B. Reduce PLC operation costs

1. BRICK Server and PLC Operations Application, our own custom software application for plug load control, demonstrates that applying configuration settings in batches is a key time-saving.
2. Automated alerts are needed and were developed to catch issues before they impact occupants which can lead to more time investment.

C. Reduce plug load energy consumption of each building using the integration of the PLCs and BEMS by 20 percent

1. If looking at plug loads that are controllable then yes it was demonstrated that savings between 50-60% can be easily achieved with static schedules. However, when looking at the total plug load energy consumption of a building, then this target is not achieved. Much of a building's plug load energy consumption is not allowed to be controlled. For example, servers and networking infrastructure were not allowed to be controlled. Additionally, desktop computers make up a significant portion of an office building's plug load. The need for an occupant to remotely log into their computer limited the ability to control those loads.

D. Demonstrate enhanced PLCs energy savings

1. Our advanced PLC strategies demonstrated that additional savings can be achieved beyond the use of static schedules.

E. Demonstrate demand response potential

1. This activity is in progress.