PG&E ADVANCED LIGHTING CONTROLS SYSTEM TOOL TRIAL EVALUATION

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EXECUTIVE SUMMARY

INTRODUCTION

The Pacific Gas and Electric Company (PG&E) Advanced Lighting Controls System (ALCS) Tool is an interactive workbook commissioned by PG&E designed for use by lighting contractors when assessing the energy and demand savings potential of possible commercial lighting retrofits specific to ALCS. Intended to streamline the savings estimation process, the ALCS Tool (the Tool) would support increased utilization of ALCS in California commercial-sector retrofit programs. The Tool was built to integrate single and layered control strategies and was also designed to calculate above code savings. The Tool's design offers the user four levels of rigor in the accuracy of savings estimates. The levels of rigor are based on the amount of detail on the existing and future lighting design input into the Tool:

- **Level 1 – Screening.** The user inputs the year the building was built (vintage), building type, and square footage. Default values and specifications for existing lighting systems and schedule are automatically populated by the Tool. Only minimal inputs are required at this level.
- **Level 2 – Custom.** After consulting with a facilities manager, many of the default values automatically populated in the Screening phase can be overridden to provide a more thorough assessment of the building type, existing lighting installations, and usage patterns.
- **Level 3 – Site Audit.** An onsite visit from the contractor or auditor can provide additional specifics with which to populate the Tool inputs. This may also include a tour from the facilities manager and/or interviews with occupants to determine usage patterns and preferences that could also aid in choosing controls strategies.
- **Level 4 – On-Site Monitoring.** This method encompasses the most exhaustive determination of building specifics, usage patterns and occupant behavior. Savings estimates at this level would rely on monitored baseline lighting schedules and measured lighting system power output that could be fed into the Tool.

The Tool has been through conceptual and user testing in the PG&E Emerging Technologies program and was used in a field trial of ALCS installations, starting in the fall of 2016 through December 2018. The goal of the PG&E ALCS Tool Trial (the Trial) was to test the Tool in the field while advancing the understanding and awareness of ALCS opportunities among contractors and customers in the PG&E service territory.

The Trial sought to enroll 15 project sites, seven monitored sites (Level 4 rigor) and eight non-monitored sites, through a network of Control Agents who would promote the trial and utility incentive to their potential ALCS customers. The Trial implementation contractor provided training to the Control Agents on energy efficiency sales strategies and the benefits of participating in the Trial, marketing and sales collateral, and training on how to properly use the Tool. Despite utilizing various engagement strategies and significantly extending the recruitment timeline, only four monitored sites, of the desired seven, and no non-monitored sites, of the desired eight, were enrolled into the Trial. Additionally, two of the four enrolled sites were from the same company. One additional site was enrolled (Site 0), but experienced significant commissioning issues and dropped out of the Trial.

The implementation contractor identified three common recruitment barriers:

- **Cost.** ALCS projects routinely do not meet simple payback requirements for customers. Although the Trial offered an incentive, the financial assistance was designed to compensate customers for metering, participation, and evaluation interviews rather than to influence up-front cost.
- **Long Sales Cycle.** At least two metering site candidates that decided not to enroll in the Trial are still considering installing an ALCS. The Control Agents for the respective sites have noted long sales cycles that often span multiple years or budgeting cycles are not uncommon for ALCS projects. These long sales cycles made it challenging to enroll participants within the Trial timeline.
- **Building Use Types.** This Trial targeted classroom spaces at schools, medium office buildings, and floors of large office complexes. The evaluation prioritized spaces within the Trial sites for monitoring based on space types that were likely to benefit from ALCS (i.e. common areas or conference rooms) and de-prioritized those that would likely not see substantive impacts from ALCS (i.e. restrooms or storage areas). However, it is sites with longer occupancy/operating hours that benefit more from ALCS energy savings and controls than sites operating during normal business hours.

EMI Consulting and its partner, kW Engineering, (collectively the Evaluation Contractor) evaluated the Tool during a recent field trial of ALCS installations (the Trial). The evaluation had four research objectives:

- **Research Objective 1:** Assess the accuracy of savings calculations generated by the Tool based on existing conditions baselines and identify and quantify the reasons behind savings discrepancies.
- **Research Objective 2:** Assess the accuracy of savings calculations generated by the Tool based on Title 24 requirement baselines and identify and quantify the reasons behind savings discrepancies.
- **Research Objective 3:** Analyze the overall satisfaction of contractors and others using the Tool, the issues they discovered, and their experiences marketing the ALCS savings estimates to end-users in the promotion of more extensive retrofits.
- **Research Objective 4:** Analyze the satisfaction of facility managers with the retrofit marketing and implementation process, including the influence of the Tool over their decision-making regarding more extensive retrofits.

To accomplish these objectives, the original evaluation activities included an initial assessment of the Tool, on-site monitoring, calculator tool testing and error analysis, and contractor and facility manager interviews. However, the Trial experienced challenges, which heavily impacted this evaluation of the Tool. The main challenges the Trial experienced were:

- **Recruitment:** PG&E sought to enroll seven monitored sites and eight non-monitored sites in the Trial. However, the implementation contractor was only able to enroll four monitored sites and no non-monitored sites.
- **Data collection:** The evaluation plan initially included the collection of a suite of data obtained from the implementation contractor during the Trial including contractors' scopes of work, field data from the implementation contractor, detailed site audit reports, remote access to the ALCS systems, existing and new lighting plans and specifications, and Level 3 Tools for each site from the ALCS Contractors. However, the implementation contractor did not obtain Tools from the contractors. The implementation contractor provided Level 2 Tools they filled out and some limited site information.

The evaluation team worked with PG&E and the implementation contractor to identify alternative data sources and evaluation activities in order to support the research objectives. As recruitment slowed, the evaluation team conducted near-participant interviews[1] with contractors and facility managers to better understand the barriers to participation in the Trial and to identify actionable recommendations to help improve recruitment. The implementer for PG&E's LED Accelerator Program,[2] Energy Solutions, also provided detailed pre- and post-retrofit data for four Accelerator sites to estimate savings using the Tool. The LED Accelerator sites, however, did not include monitored data. Therefore, the accuracy of the savings calculated by the tool (Research Objective 1 and Research Objective 2) could not be assessed in the same way as the Trial participant sites. Instead, the LED Accelerator sites were used to inform the Tool testing and error analysis task by better understanding how the Tool works with field data as collected by other programs, the level of effort needed to collect Tool inputs, inform issues with the Tool, and understand usability.

KEY FINDINGS

The challenges experienced by the Trial were driven by the fact that, despite high market interest, ALCS is still a very expensive and complex technology. The theory behind the Trial was that contractors would utilize the Tool to help them sell ALCS projects to customers. In actuality, contractors associated with the Trial did not appear to be using the Tool in their marketing or sales processes and, in general,

[1] Near-participant interviews occurred with PG&E customers and control agents who interacted with the implementation contractor, but who did not enroll into the trial.
[2] The LED Accelerator (LEDA) Program run by PG&E is a commercial lighting retrofit incentive program whose mission is to make it cost effective to install the highest quality, most energy efficient LEDs and networked controls in retail locations for maximum energy savings. (from www.pge.com)

reported they are not actively promoting ALCS to their customers.[3] For example, all three of the near-participant contractors indicated they rarely bring up the idea of ALCS with customers. One near-participant contractor said they are "currently looking for stability [and are] not trying new things with their pipeline." This was confirmed by the fact that Trial participants were early adopters who installed ALCS for reasons other than energy and cost savings and who sought out contractors to complete their ALCS projects. Near participants also discussed that customers most likely to pursue ALCS projects are those who are interested in staying on the front end of the latest technological developments, even if there is some uncertainty regarding performance or cost. Additionally, near-participant contractors and facility managers cited cost and return-on-investment (ROI) as the main barrier to participating in the Trial.

As Trial participants sought out contractors for their projects, the contractors did not need to use the Tool for sales and marketing. Instead, the Trial implementation contractor filled out the Tools for participating sites. As a result, some of the values entered in the Tool might be different than if they had been entered by a contractor during the design and installation process. For example, the proposed lighting power density (LPD) values had not been modified in the Tool, despite three of the four sites receiving luminaire upgrades. Since changing the LPD was the most critical source of variance found for each site, and the sensitivity analysis showed LPD was a highly sensitive input, we believe **not having correct pre- and post-retrofit LPD values accounts for the majority of the differences between the Tool estimates and the monitored estimates**. In addition to LPD, correctly specifying existing lighting controls and proposed lighting controls affects the accuracy of savings estimates. Therefore, going forward with Tool implementation, it should be clearly indicated in the Tool that inputting correct pre-retrofit and post-retrofit specification and LPD values is critical to getting accurate savings estimates.

Other key findings from the evaluation included, organized by evaluation activity:

- Calculator tool initial assessment:
    - The formulae and theory in the tool appear to be developed in keeping with the literature and best practices[4], as applicable.
    - The intended approach of the Tool is sound and is consistent with industry best practices. The implementation of the formulae and concepts employed for the savings calculations in the Tool are reasonable and straightforward, although the documentation could be improved.
    - The underlying assumptions for the control factors are based on very limited data that does not cover all building types in the model and, in some cases, does not cover the control type at all. The most critical

[3] Only two contractor interviews were secured for this evaluation. This key finding was inferred from these interviews as well as informal dialogue between the evaluation team, the implementation contractor, and the contractors throughout the Trial.
[4] Citations of literature reviewed are included in relevant footnotes of Appendix B.

function of the Tool for calculating savings is building control factors for ALCS. This is also where the Tool exhibits the greatest uncertainty. As such, one of the important parts of the on-site monitoring activity discussed below was to examine whether the control factor calculations correctly emulate the field data.

    - There are several instances where the Tool does not capture modifications or exemptions from Title 24 code[5], mainly because of the space-type roll-up methodology employed. As such, the Tool is unable to identify and quantify incentive-eligible control applications that the code specifically exempts, such as adding controls to an existing system. These should be captured in the Tool for maximized utility-claimed savings.
    - There were multiple instances where we could not trace a variable's impact because of the complex lookup method which relies on matching numbers in rows and columns to identify another value. This presents a risk to ensuring modifications to the Tool are complete.
- On-site monitoring:
    - ALCS system design, setup, and programming drives control savings. Any deficiencies in these steps, such as improper application of daylighting controls or real-time task tuning settings that are not properly saved, prevent projects from achieving their maximum savings.
    - Lighting efficacy improvements (i.e. improvement in lumens per watt due to replacing bulbs) had a much larger impact on energy savings than changes in controls. When this finding is combined with field observations, one possible explanation of efficacy improvements being so much larger than controls savings is that the control programming is often done improperly and that users may not receive adequate training to make use of the advanced control features.
    - Using ALCS system data directly instead of stand-alone data meters could result in better quality data (fewer losses of battery power or removal of data meters, as experienced during our study) and significantly reduce M&V costs.
- Calculator Tool testing and error analysis:
    - The approaches taken to implement the control factors (occupancy, primary sidelit or skylit daylighting, secondary sidelit daylighting, task tuning, demand response, time switching, and manual dimming) in the Tool are reasonable and are supported by data from the on-site monitoring. Overall, the calculated control factors appropriately disaggregated energy savings for each site, indicating control factors are calculated correctly despite the lack of supporting documentation.

[5] This evaluation used the Title 24-2013 code implemented July 1, 2014. The Tool was developed to incorporate Title 24-2013 code.

  - Savings values as estimated by the Tool (Levels of Rigor 1 and 2) using an existing baseline are internally consistent with each other (typically within 2%-5%), but do not generally align with savings estimates from the metering data (Level of 4), where variances range from roughly 37% to 130% of the Level 1 estimate.
  - Since changing the LPD was the only source of variance for the differences between the savings estimates from the Tool to estimates from the metering data found for each site, as detailed below, we believe not having correct pre- and post-retrofit LPD values accounts for the majority of the differences between the Tool estimates and the monitored estimates. Going forward with Tool implementation it should be clearly indicated in the Tool that inputting correct pre-retrofit and post-retrofit LPD values is critical to getting accurate savings estimates.
  - For a given site using a code baseline, there is a high level of consistency between Levels 1 and 2. No comparison is possible with metered data, because the only way to compare metered data with a code baseline would be to construct a whole building simulation which was outside the scope of this project.
  - There was little to no difference between savings estimated by the Tool between Level 1 and Level 2, for either of the participating sites or the four LED Accelerator Sites from PG&E’s LED Accelerator Program. Based on the extremely limited sample in this evaluation, it appears that collecting Level 2 data does not improve accuracy so using Level 1 estimates may suffice for utility programs. However, even though it doesn’t produce more accurate results, interviewed contractors said they would use the Level 2 detailed inputs tab in the Tool as they walk/audit a site, so they may practically never use the Level 1 tab.
  - Four variables were qualitatively determined to have a high likelihood of affecting savings estimates: (1) the specification of existing lighting controls, (2) the existing lighting power density (LPD), (3) the specification of proposed lighting controls, and (4) the proposed (post-retrofit) LPD
- Facility manager interviews:
  - The facility managers participating in the Trial did not use the tool in their decision-making process as they installed ALCS for reasons other than energy and cost savings. Therefore, the Tool was not influential in their decision-making and, therefore, the accuracy of energy savings estimates was not important.
  - However, all of the facility managers said energy savings were presented by the contractors as a part of their quote for the project the customer and the implementation contractor brought them. Three of the facility managers (Site 0, Site 1, Site 3/Site 4) said the Tool was presented to them by the implementation contractor. Of the three, two

said it was easy to understand the savings estimates. These two facility managers were unable to comment on how accurate they thought the savings estimates were.

- When asked about what factors had the most impact on their project related decision-making, they referenced the ability to control the lights from outside the office for security purposes and how automated the system was.
- Facility managers were highly satisfied with their ALCS contractors, Trial contractors, the installation process, and their new lighting systems. They were less satisfied with the commissioning process[6].
- All of the facility managers said the commissioning process took longer than expected; two of the facility managers described the commissioning process as "tedious" and "time consuming." They both discussed difficulty with having to pair each fixture individually.
- None of the facility managers reported any difficulty with assessing project eligibility as it related to the ALCS Trial. While indirectly related to the Trial, one facility manager was frustrated with assessing the eligibility of their office space to receive rebates (the facility manager was referring to the fact that office lighting did not qualify for deemed rebates).

- Contractor interviews:
    - While only one contractor interview was secured, facility managers told us it was the implementation contractor who filled out the Tool, not the ALCS contractor. Therefore, even if an interview had been conducted, those contractors would likely not have been able to provide feedback on using the Tool or how they incorporate the Tool into their marketing practices.
    - The contractor interviewed did not use the Tool in the field. Instead, they used a tool called "Snap Count" to collect and enter data in the field and then entered the data into the Tool in the office.
    - The contractor gave specific feedback on the Tool as they were entering the sample project data into the Tool during the interview[7]:
        - The Tool asks for room areas in percentages, but using square feet is generally how they get data in real life. So, the Tool should be in square feet not percentages.
        - The contractor would prefer to start with the Detailed Inputs tab as the layout of fields in this tab better represent how they would acquire the data as they move through a building.

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[6] Note there was no separate commissioning agent or commissioning process for the Trial sites. Instead, the installation contractor commissioned the systems.
[7] These suggestions were made by one contractor and, thus, may not be representative of all contractors.

    - The dashboard should also include a cost savings per year**.** The contractor reported this is a very important metric for their clients and could be easily obtained by having an input field for a client's $/kWh rate.
  - The contractor also said it would be nice if the Tool was online and could be submitted online and if it automatically populated rebate opportunities, and if it could integrate with their existing software so that they could export data from their existing software into the Tool (assuming using the Tool was a requirement to get a rebate).
- Near-participant interviews:
  - ALCS' long sales cycles may pose a barrier for utility program participation. According to the implementation contractor's experience on this project, deciding whether a property will go forward with an ALCS project takes a long time. The time between when interest is expressed and initiating an order with an electrical distributor usually takes months, if not more than a year. During this time, there are many events that can derail the ALCS project (e.g. tenant decides to lease elsewhere; budget is constrained and ALCS is value-engineered out of the project; building sale occurs; staff turn-over; etc.) While the Tool could serve a valuable means of quantifying savings, it has limited use for a utility program if the prospective participants are lost due to attrition separate from the program itself.
  - Overall, near-participants cited cost as the primary barrier for ALCS adoption. Most near-participants did not move forward with the proposed project because the project did not meet ROI requirements.
  - Contractors reported that a two to three-year payback, at most, is what customers are willing to accept. While all the contractors believed bigger rebates could help ALCS adoption, they believe the true challenge is the lack of available up-front capital. As rebates can take a while to materialize, contractors reported adoption would not increase substantially until the cost of materials comes down.
  - Feedback suggests that ALCS technology is not being widely marketed and the majority of the feedback on future improvements to the Trial focused on lowering up-front costs. This supports the findings, discussed in other sections throughout the report, that current ALCS customers are early adopters who are installing the technology despite low cost-benefit.
  - Some interviewees also reported complexity, timeline, and negative perceptions of lighting controls (for example, one facility manager had a previous bad experience with less advanced occupancy sensors, where inaccurate triggering resulted in complaints) as additional factors.

- All of the facility managers also discussed the functionality benefits, such as improved maintenance and remote control, offered by ALCS as the main benefits that attracted them to ALCS.
- Two near-participants reported having a method to quantify savings would have improved the Trial offering in the future. As such, it seems these near-participants did not experience the Tool as a part of the Trial.

RESEARCH OBJECTIVE FINDINGS

The findings by research objective are summarized below.

ACCURACY OF SAVINGS CALCULATIONS GENERATED BY THE TOOL BASED ON EXISTING CONDITIONS BASELINE

Overall, we did not observe substantial alignment between the estimates from the Tool and the estimates from the metered data *at the site level*. There is a high level of agreement between Level 1 savings estimates and Level 2 savings estimates, using existing conditions baseline,[8] but very limited agreement between Level 1 savings estimates and Level 4 (monitored data) or Level 2 savings estimates and Level 4 savings estimates. The range of variance for Level 1 savings estimates generated by the Tool was between -116.3% to +57.4% for energy savings, and between -129.1% to +54.8% for demand savings. This means that at the site level, the Tool would sometimes underestimate and sometimes overestimate savings, when compared to the metered data savings estimates.

It is important to note that the Tool generates savings for the whole site whereas the monitored savings is based on field data collection for spaces within the site and, therefore, may not be representative of the site as a whole. At the more granular space level, we did observe some degree of alignment between energy saving estimates produced by the Tool and estimates produced from the metered data. However, we were unable to detect a clear pattern to predict when such estimates might be similar and when they would not.

ACCURACY OF SAVINGS CALCULATIONS GENERATED BY THE TOOL BASED ON TITLE 24 REQUIREMENT BASELINE

The savings estimates based on a Title 24 requirement baseline produced by the Level 1 and Level 2 Tools were highly consistent, differing by less than 10% in all cases. These results are shown in Table 8-2. The evaluation team was unable to make a direct comparison between the savings estimates from the Tool using code

[8] These findings are consistent with findings from the analysis of metered sites and aligns with findings from the LED Accelerator test, which showed little or no difference between the Level 1 and Level 2 estimates. Without supporting data, such as the contractor's scope of work, hardware and controls submittals, space by space inventories, as-built hardware and quantities, and notes from interviews with occupants about usage patterns, the evaluation team was unable to construct Level 3 calculators for the sites and Level 3 calculators were not received from the implementation contractor.

baseline to the savings estimates from the Tool using the metered data (Level 4) since there was no way to ascertain Level 4 code baseline values without using the Tool itself[9]. However, we do observe that for all four metered sites, there is general agreement between Existing Baseline savings and Code Baseline savings estimates (within a given site and the level of rigor). Site 1, which exhibits savings in the Existing Baseline scenario but "anti-savings" in the Code Baseline scenario, is a clear exception.

CONTRACTOR SATISFACTION USING THE TOOL

Overall, the evaluation was not able to rate contractor satisfaction using the Tool. One of two contractors interviewed did not use the Tool in the field and this contractor could not answer any questions about using the Tool, because they said that they did not recall.

The second contractor interviewed reported "some issues with the calculator tool not working properly for [the implementation contractor]." This contractor ultimately said the output of the Tool was not important to him and that it did not influence their customers' decision-making process.

FACILITY MANAGER SATISFACTION WITH THE RETROFIT MARKETING AND IMPLEMENTATION PROCESS

All three of the facility managers interviewed reported project scoping went well, and none of the facility managers reported any difficulty with assessing project eligibility as it related to the Trial. Overall, facility managers were very satisfied with their interactions with their ALCS contractor, implementation contractor, and the field metering staff; no facility manager ranked any of their interactions below an eight (out of 10). Facility managers had lower satisfaction with the retrofit installation and commissioning processes. Overall, facility managers were more satisfied with the installation process than with the commissioning process. All of the facility managers said the commissioning process took longer than expected. One facility manager reported that installation went smoothly, but that the controls were never functional, so they decided to un-install the system entirely. All three facility managers reported the quality of the new light was very good and that their satisfaction was also high. None of the facility managers believe occupants will alter their work environment (such as moving their work location for better lighting) because of the new lighting system.

CONCLUSIONS AND RECOMMENDATIONS

This section presents the evaluation team's key findings and associated recommendations regarding the Tool and its future implementation. Overall, the

[9] A code baseline uses the equipment, equipment efficiency, control settings etc. that meet the legal requirements in place in the site locations instead of the actual equipment in the building. Thus, there is no way to monitor (Level 4) the sites using a code baseline. Instead, savings can only be calculated using modeling software.

evaluation found the Tool was designed and implemented with current industry best practices and that the formulas and theory were appropriate. However, in practice there are a few improvements that could be made to support its widespread adoption.

Specific key findings and recommendations follow.

- **Key Finding 1: The high cost for ALCS is the primary barrier for increased adoption.** Both participants and near-participants cited the high cost of ALCS as the main barrier for doing more spaces within their facility or for participating in the Trial, respectively. Both facility managers and contractors interviewed reported that customers require a ROI of three years or less to implement a project.
    - **Recommendation 1: Consider offering a rebate specifically for the installation of ALCS that is large enough to help meet customers' ROI requirements.** Based on the feedback from facility managers, it appears that the current incentive structure for lighting projects may not be meeting the market's needs. For example, one facility manager reported the deemed incentive allowed the manufacturing portion of their project to proceed quickly, whereas the complicated nature of the office lighting incentive prevented that part of the project from proceeding, because the facility manager was unsure of the final incentive amount. Another respondent said receiving a rebate for their infrastructure upgrades would have brought the ROI for the total ALCS project closer to their ROI requirements. In return for a larger incentive, PG&E should consider making access to system data a participation requirement. Having access to such data has the potential to reduce M&V costs (see Recommendation 3B) and increase savings (see Recommendation 3E). Customers' security concerns related to allowing 3rd parties access to their systems could be overcome by downloading data and conducting analysis separately as opposed to viewing real-time data in the ALCS interface. Of course, *this recommendation would have to be taken in context with ongoing changes to the lighting market and California regulatory policy and proceedings*.

- **Key Finding 2: Market actors may be wary of installing ALCS because of previous poor experiences with lighting controls and the fact that ALCS' are still a new and unknown technology.** We heard from multiple interviewees that there is institutional anxiety around installing ALCS. This is due to previous poor experiences with occupancy sensors not working properly, hearing stories of early ALCS installations not working (as experienced with Site 0 in this Trial), and also due to maintenance teams' reservations about switching to systems that are unfamiliar and more complicated than their current system. IT departments also have privacy concerns about ALCS connecting to their internal internet. While many types of ALCS provide similar features and functionality (e.g., daylight dimming, task tuning, remote access), the methods by which they are implemented (e.g., how fixtures are paired to hubs, whether the fixture is integrated or not) can vary significantly. These variations can cause differences in cost, ease of installation, and user experience. As ALCS is still an emerging technology, market actors may have a hard time distinguishing between the products.

- **Recommendation 2A: Publish successful ALCS case studies targeted to various audiences.** Trial participants' concerns about lighting control technology were resolved after ALCS installation. They reported high satisfaction with the quality of light, the control strategies, and had not received any complaints from occupants. As ALCS adoption grows, publishing case studies or success stories from customer implementation may help overcome some of the negative perception of lighting control technologies in the market. Providing specific messaging for the different market actors would also be helpful; the information a financial decision-maker needs in a case study is different than the information maintenance staff needs.
- **Recommendation 2B: Investigate hosting ALCS trainings for facility managers at IOU energy centers.** The trainings could include presentations on the differences between the products, occupant and facility manager experiences and satisfaction, examples of control operation, and information on programs and available incentives.
- **Recommendation 2C: Consider conducting bench testing or demonstration projects of different ALCS manufacturers' products.** All of the participating facility managers discussed how having results from bench testing various ALCS products, or having a demonstration project, would help increase ALCS adoption. ALCS technologies are complicated, and facility managers found it hard to understand exactly what their lighting would be like after the retrofit, and they reported their ability to see it would have helped their decision-making process. In fact, having a demonstration project is the precise reason why one facility manager, the lighting contractor, installed it in their offices.
- **Recommendation 2D: Future pilots or programs could explore the maturity and market-readiness of ALCS technologies.** All of the participating facility managers discussed having installation difficulties. For example, one, Site 0, experienced severe enough wide-scale system glitches they chose to uninstall the system. While these experiences may indicate ALCS technology may not be fully matured, this is an extremely small sample size and assessing maturity was not a part of this evaluations' scope. Alongside bench testing or demonstration projects (Recommendation 3B), future research could investigate the technology's maturity and how utilities could partner

with manufacturers to further address customers' concerns and barriers.

- **Key Finding 3: If future ALCS pilots are conducted by PG&E, changes to the Trial and evaluation design could improve results.** As with any research, the Trial and this evaluation faced some challenges. If another pilot is undertaken, below are suggestions for improving the design.
    - **Recommendation 3A: Conduct interviews as project phases are completed.** The interviews were originally designed to have the least impact on participants, meaning one interview was conducted to collect all the needed data. However, the sales cycle and implementation timelines are so long for ALCS that it resulted in interviewees not recalling their experience or staff turnover. As such, data collection should occur immediately after each task is finished. For example, interviews about the sales cycle and completing the Tool should be conducted during the pre-retrofit metering period instead of at project completion. This would also mean staggering the incentives at each interview stage.
    - **Recommendation 3B: Implement a different monitoring approach.** The monitoring approach to verify the output of the Tool, monitoring each control factor in 30 second to five minute intervals in up to ten spaces for Trial sites, used in this evaluation was more complicated and time intensive than the project justified. Due to the combined costs of this approach, limitations on the ability to collect data, and a limited timeframe, only a subsection of spaces in these facilities could be studied. Future efforts would benefit from taking advantage of the monitoring features already built into the lighting control systems (including those listed by the DesignLights Consortium, DLC) which have the ability to monitor the on-going operation of the lighting system, reporting what the system is doing at any given time for any given zone (e.g. dimming signal, daylighting signal, occupancy status, etc.). Using the ALCS-generated reports to determine the system behavior would provide higher quality data (no battery failures or occupant interference), reduce assumptions (aligning data with expectations and observations) and lower cost (fewer site visits; potentially no site visits if VPN access is available) compared to the approach taken for this evaluation. One potential barrier to this recommended approach is a lack of trust in the ALCS-generated data. However, it would be feasible to perform a small demonstration project (e.g. a bench-top wiring and programming exercise with short term power monitoring) or a functional test of the system in the field to verify the successful installation and configuration in the field. A small randomly selected field test to verify the system self-reporting is accurate could help utilities and public utilities commissions trust the data, which in turn would build trust in the eventual results when a much larger program relies on ALCS

reported data. Fundamentally, the real-time data collected by ALCS could be utilized in Normalized Metered Energy Consumption (NMEC) calculations. Note, this calibration/trust exercise could be avoided if there were an industry-standard test procedure and certification (like the DLC Networked Lighting Controls Program).

- If the in-depth field monitoring is desired, we recommend utilizing different meters than those that were utilized in this evaluation that would overcome some of the data collection errors experienced by this Trial. These include using meters where remote-download is possible and/or more data can be stored on-board and where there is a warning about failed batteries.
- **Recommendation 3C: Create a financial connection for PG&E contractors between site recruitment and site measurement and verification.** For future pilots, the two scopes of work should be closely tied so that the measurement and verification contractor can have access to the hardware on site, a design review, and a single site visit to gather the needed data themselves. Doing so would have avoided the needed remote access, which may continue to create security concerns (participants reported they were concerned about the security of allowing external parties access to their control systems) for participants in future projects.
- **Recommendation 3D: Incorporate training for customers on ALCS controls programming into the pilot.** The on-site monitoring found efficacy improvements had a much larger impact on energy savings than changes in controls. One possible explanation, based on field observations, was that control programming is often done improperly and that users may not receive adequate training to make use of the advanced control features. While the Trial included training for contractors, the next iteration of an ALCS pilot should also include training for participating customers after installation and commissioning is complete.
- **Recommendation 3E: Consider using ALCS data for opportunity identification.** As ALCS adoption increases, there may be an opportunity to analyze the data from across many installations to identify potential lighting controls measures. For example, buildings or areas with high daylight levels and high daytime lighting consumption could be flagged as a potential candidate for daylight harvesting recommissioning. While doing so has the potential to increase projects' savings over what they might achieve without this type of opportunity identification, this type of analysis has been difficult in the past because there is so much variation in each building and area within a building. For example, one of the conference rooms for a participant site in this study is used as a connecting corridor between segments of office areas. When considered as a part of a larger data set, this conference room would show a higher occupancy rate and longer run hours than a typical conference room but result in a non-actionable

finding. Repeated unactionable flags may result in lower engagement or burnout of operators, so opportunity identification must take into consideration building nuances and whether operators can take action on the recommendations.

The concept of using ALCS data for opportunity identification could also be included in well-established programs such as retrocommissioning and strategic energy management. However, the success of this concept is dependent on gaining access to the ALCS data, which was a barrier experienced in the Trial and discussed in the evaluation report. Recommendation 1 (providing a large incentive for ALCS installation) offers a potential method for overcoming this barrier but would need to be tested with customers to determine its potential effectiveness.

1. GLOSSARY

Advanced Lighting Controls System (ALCS) – Provides networked control and monitoring capabilities of connected luminaires that include software configurable zoning and lighting settings, data exchange with building management or heating and cooling systems, and historical and real-time reporting capabilities.

Above Code Savings – Energy used with a "to code baseline" equipment minus energy used with an "above code baseline" equipment.

ALCS Contractors/Control Agents - Qualified ALCS manufacturers, manufacturers' representatives, lighting designers, architects, or value-added resellers. In particular, regional installation contractors and lighting specifiers.

Code Baseline – The equipment, equipment efficiency, control settings etc. that meet the legal requirements in place in the location where an efficiency project is implemented.

Evaluation Contractor – The contractor responsible for the PG&E ALCS Tool Trial Evaluation.

Existing Baseline Conditions – The type of equipment, equipment efficiency, equipment count, and control settings as found in the Trial participant facilities before retrofits were made.

Single Control Strategy – A lighting control strategy that employs one type of lighting control such as dimming, task tuning, or daylighting.

Layered Control Strategies – A lighting control strategy that employs multiple types of lighting controls at once.

Implementation Contractor – The contractor responsible for implementing the PG&E ALCS Tool Trial.

Installation Contractors – Contractors that were hired by PG&E ALCS Tool Trial participants to install ALCS in their facilities.

PG&E ALCS Tool (the Tool) – The PG&E ALCS Tool is an interactive workbook commissioned by PG&E and developed by TRC in 2012. The Tool was designed for use by lighting contractors when assessing the energy and demand savings potential of possible commercial lighting retrofits specific to ALCS.

PG&E ALCS Tool Trial – A field trial of the PG&E ALCS Tool in the PG&E service territory. The goal of the PG&E ALCS Tool Trial (the Trial) was to test the Tool in the field while advancing the understanding and awareness of ALCS opportunities among contractors and customers in PG&E service territory.

PG&E ALCS Tool Trial Evaluation – An evaluation of the PG&E ALCS Tool during the PG&E ALCS Tool Trial that provides recommendations to inform future ALCS program design and use of such tools by program staff and implementation contractors.

2. PG&E ADVANCED LIGHTING CONTROLS SYSTEM TOOL

The PG&E Advanced Lighting Controls System (ALCS) Tool is an interactive workbook commissioned by PG&E and developed by TRC. The ALCS Tool (the Tool) was designed for use by lighting contractors when assessing the energy and demand savings potential of possible commercial lighting retrofits specific to ALCS. The underlying hypothesis was that the Tool would improve retrofit project screening and streamline the savings estimation and verification process, thereby leading to increased utilization of advanced lighting controls technologies in the California commercial-sector retrofit programs. The Tool concept anticipated that other market actors, including manufacturers, engineers, and architects would also incorporate the Tool into their lighting planning activities. Though the current version of the Tool was developed for use in the California policy framework, there is broader interest for these computational capabilities and promoting ALCS nationwide. To promote deep retrofits, the Tool should accurately determine savings from pre-existing baseline conditions to a potentially complex set of new lighting technologies. Therefore, the Tool was built to integrate single and layered control strategies and was also designed to calculate above code savings with the goal of streamlining IOU savings claims and verification.

The ALCS Tool allows a contractor to input both existing and planned lighting technologies, their associated power densities and hours of use and control systems. The Tool uses control factors for each control system, including occupancy sensors, daylighting, dimming and personal tuning. These controls systems can be layered to calculate lighting energy usage and savings. Incremental savings are calculated by adding or removing control systems to optimize the strategy to match the customer's preferences. Though varying degrees of specificity can be used to establish energy usage, the Tool generally facilitates four levels of rigor (below). At any point a savings estimate can be generated.

- **Level 1 – Screening.** The user inputs the year the building was built (vintage), building type, and square footage. Default values and specifications for existing lighting systems and schedule are automatically populated by the Tool. Only minimal inputs are required at this level.
- **Level 2 – Custom.** After consulting with a facilities manager, many of the default values automatically populated in the Screening phase can be overridden to provide a more thorough assessment of the building type, existing lighting installations, and usage patterns.
- **Level 3 – Site Audit.** An onsite visit from the contractor or auditor can provide additional specifics with which to populate the Tool inputs. This may also include a tour from the facilities manager and/or interviews with occupants to determine usage patterns and preferences that could also aid in choosing controls strategies.
- **Level 4 – On-Site Monitoring.** This method encompasses the most exhaustive determination of building specifics, usage patterns and occupant

behavior. Savings estimates at this level would rely on monitored baseline lighting schedules and measured lighting system power output that could be fed into the Tool.

The specifics of how the four levels of rigor were applied in this evaluation are discussed in Section 6: Approach.

3. PG&E ADVANCED LIGHTING CONTROLS SYSTEM TOOL TRIAL DESIGN

The Tool went through conceptual and user testing in the PG&E Emerging Technologies program and was used in a field trial of ALCS installations, starting in the fall of 2016. The goal of the PG&E ALCS Tool Trial (the Trial) was to test the Tool in the field while advancing the understanding and awareness of ALCS opportunities among contractors and customers in PG&E service territory.

The Trial sought to enroll 15 project sites, seven monitored sites (Level 4 rigor) and eight non-monitored sites, through a network of Control Agents who would promote the Trial and utility incentive to their potential ALCS customers. The Trial implementation contractor provided training to the Control Agents on energy efficiency sales strategies and the benefits of participating in the Trial, marketing and sales collateral, and training on how to properly use the Tool.

PG&E, EMI Consulting, kW, and the implementation contractor jointly developed site selection and eligibility requirements. PG&E was primarily interested in three space types:

- Classroom space at a school
- Typical medium office buildings (10,000 – 15,000 sf each)
- A typical floor of a large office complex (~10,000 sf)[10]

In order to ensure a high-quality evaluation of ALCS savings, the Trial set ideal eligibility requirements. These requirements were as follows:

- All Sites
    - Minimum of 2,500 sf of space or 10 fixtures in at least two different space types (e.g. private office and conference room)
    - No maximum project size limit – total lighting systems of large projects may be sampled
    - Maximum of 10 spaces monitored for each site
    - Site was expecting same occupancy before and after installation[11]
    - Site was not exceptional in location, size, or use case (e.g., no glass buildings on a hill)
    - Spaces with existing controls were considered
    - Willing and able to provide a knowledgeable contact who is involved in decision making for evaluation interviews

[10] These primary facility and space combinations are not exclusive or requirements. It is possible that the Trial will not include any schools, for instance.
[11] One of the participating sites did split a private office into two during the post-period.

- Metered Sites
  - Willing and able to provide access to site for metering, walkthroughs, and interviews
  - Willing and able to accommodate an additional nine weeks of pre-installation work (planning, metering, data collection, etc.)
  - All spaces included in metering will be occupied (i.e., no meters in empty spaces)
  - No other renovations scheduled during the time from planning to four months after installation (no painting, no relocating walls[12] or luminaires, no new windows, no new window films, no new window treatments or shades, no major furniture changes)[13]
  - No hard-cap (drywall) ceilings unless the conduit is exposed or the room has a dedicated lighting circuit

3.1 TRIAL SITE RECRUITMENT AND ENROLLMENT

The implementation contractor conducted site recruitment and enrollment starting in October 2016. The original recruitment approach utilized a top down method, leveraging the implementation contractor's relationships with ALCS manufacturers and their project pipelines in PG&E service territory to identify leads and Control Agents.

As the Trial progressed, through the implementation contractors' interactions with installation contractors, it became apparent that installation contractors had the most information about project pipelines in the PG&E service territory. So, the implementation contractor started using a bottom up method for recruitment whereby they approached other installation contractors and electrical distributors to recruit them into the Trial.

As Trial recruitment slowed, EMI Consulting conducted near-participant interviews (discussed in Section 7.1 below) in order to gain additional insights on possible recruitment barriers the Trial could work to overcome. Most of the near-participants and participants reported hearing about the Trial from PG&E representatives. During this time, the implementation contractor engaged PG&E Trade Pro managers and Business Energy Solutions (BES) representatives to conduct outreach assistance in a "middle out" method. In this method property managers, facility managers, and other programs such as San Francisco Energy Watch were also targeted.

Despite utilizing various engagement strategies and extending the recruitment timeline, only four monitored sites, of the desired seven, and no non-monitored sites,

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[12] As described in the Approach section, one site split a private office into two during the post-retrofit period.
[13] The 16-week post-period begins after installation and acceptance testing is completed and occupants have returned to the space.

of the desired eight, were enrolled into the Trial (Table 3-1). Additionally, two of the four enrolled sites were from the same company. One additional site was enrolled (Site 0), but experienced significant commissioning issues and dropped out of the Trial. Where possible, we have included the experiences obtained from this Site to help inform the goals of this evaluation.

Table 3-1. Sites Participating in the Trial

Site Number	Disposition	Site Type	Site Type
Site 0	Enrolled, Dropped Out	Monitored	Processing Facility
Site 1	Enrolled	Monitored	Electrical Distributor Offices
Site 2	Enrolled	Monitored	Office Building Shared Spaces
Site 3 (Same company as Site 4)	Enrolled	Monitored	Manufacturing Building Conference Spaces
Site 4 (Same company as Site 3)	Enrolled	Monitored	Manufacturing Open Office

3.2 RECRUITMENT BARRIERS

The implementation contractor identified three common recruitment barriers:

- **Cost.** ALCS projects routinely do not meet simple payback requirements for customers. Although the Trial offered an incentive, the financial assistance was designed to compensate customers for metering, participation, and evaluation interviews rather than to influence up-front cost. The significant financial investment required for ALCS projects is a major market barrier to adoption. The near-participant interviews with facility managers and contractors, discussed below, support this observation; all interviewees cited cost as a reason they did not participate in the Trial.
- **Long Sales Cycle.** At least two metering site candidates that decided not to enroll in the Trial are still considering installing an ALCS. The control agents for the respective sites have noted long sales cycles that often span multiple years or budgeting cycles are not uncommon for ALCS projects. This observation is also confirmed by the feedback from near-participant, facility manager, and contractor interviews discussed below. These long sales cycles made it challenging to recruit and enroll participants within the Trial timeline.
- **Building Use Types.** This trial targeted classroom spaces at schools, medium office buildings, and floors of large office complexes. However, it is sites with longer occupancy/operating hours that benefit more from ALCS

energy savings and controls than sites operating during normal business hours. While larger office buildings that may have longer operating hours (e.g., high rise building, office complexes) are beginning to install ALCS projects, industrial buildings with longer hours of operation tend to be the current early adopters of ALCS. This matches the feedback received from near-participants, who discussed warehouses, private businesses, owner-occupied spaces, and office buildings as good candidates and also discussed how schools are not good candidates because they often would not have the up-front capital available to install the systems.

3.3 TRIAL DATA COLLECTION

The Trial design included pre- and post-installation facility assessments, conducted by the Control Agents with support from the implementation contractor, that included the collection of the data shown in Table 3-2 below. However, the implementation contractor was only able to obtain Level 2 pre- and post-installation Tools and some limited site information, also shown in Table 3-2. The impact of the Trial data limitation on this evaluation is discussed in detail in the Approach sections.

Table 3-2. Data Disposition

	Data Point	Received?
Metered Sites	Field data (i.e. existing equipment, controls schedules, etc.) verified by the implementation contractor	No
	Contractor's scope of work	No
	Hardware and control submittals	No
	Detailed site audit report including space by space inventories	No
	New and existing lighting plans and specifications	No
	Notes from interviews with occupants to determine usage patterns	No
	Completed out Level 3 calculator tools	Yes
	Remote access to the ALCS, or ALCS usage reports to document system performance	No
	From site selection	
	Facility type	Yes
	Space types and sizes	Yes
	Existing lighting system documentation	Partial
	Reflected ceiling plans and sensor locations	Yes
	New ALCS design plans/specifications	No
	Estimate of facility operation, glazing, etc.	Yes
Non-Metered Sites	Level 3 Calculator tools	No
	Site data (i.e. lighting audit, equipment counts, pre- and post-retrofit information, etc.) from the ALCS contractor	No

4. PG&E ALCS TOOL TRIAL EVALUATION OVERVIEW

PG&E contracted with EMI Consulting and its partner, kW Engineering, to evaluate the Tool during the Trial and provide recommendations to inform future ALCS tool design. The underlying hypothesis was that the Tool would improve the retrofit project screening and streamline the savings estimation and verification process, thereby leading to increased utilization of ALCS in commercial sector retrofit programs. This evaluation had four overarching research objectives:

- **Research Objective 1:** Assess the accuracy of savings calculations generated by the Tool based on existing conditions baselines and identify and quantify the reasons behind discrepancies.
- **Research Objective 2:** Assess the accuracy of savings calculations generated by the Tool based on Title 24 requirement baselines and identify and quantify the reasons behind discrepancies.
- **Research Objective 3:** Analyze the overall satisfaction of contractors and others using the Tool, the issues they discovered, and their experiences marketing the ALCS savings estimates to end-users in the promotion of more extensive retrofits.
- **Research Objective 4:** Analyze the satisfaction of facilities managers with the retrofit marketing and implementation process, including the influence of the Tool over their decision-making regarding more extensive retrofits.

Given the Trial faced challenges in recruiting participants and obtaining data, the evaluation team worked with PG&E and the implementation contractor throughout the Trial to identify alternative data sources and evaluation activities in order to support the research objectives. As recruitment slowed, the evaluation team conducted near-participant interviews with contractors and facility managers to better understand the barriers preventing customers from participating in the Trial, and to identify actionable recommendations to help improve recruitment for a future program design and offering. Additionally, the implementer for PG&E's LED Accelerator Program,[14] Energy Solutions, provided detailed pre- and post-retrofit data for four accelerator sites to estimate savings using the Tool. The LED Accelerator sites, however, did not include monitored data. Therefore, the accuracy of the savings calculated by the tool (Research Objective 1 and Research Objective 2) could not be assessed in the same way as the Trial participant sites. Instead, the LED Accelerator sites were used to inform the tool testing and error analysis task by better understanding how the tool works with field data as collected by other programs, the level of effort needed to collect tool inputs, inform issues with the tool, and understand usability.

[14] The LED Accelerator (LEDA) Program is a commercial lighting retrofit incentive program whose mission is to make it cost effective to install the highest quality, most energy efficient LEDs and networked controls in retail locations for maximum energy savings. (from www.pge.com)

To accomplish the research objectives, the evaluation team completed a suite of intersecting and complementary evaluation activities. These activities included an initial assessment of the Tool, on-site monitoring, calculator tool testing and error analysis, contractor and facility manager interviews, near-participant interviews, and using the Tool with LED Accelerator data. Table 4-1 presents an overview of the research objectives and all the evaluation activities used in this evaluation.

Table 4-1. Tool Evaluation Framework

Evaluation Objective	Initial Assessment	On-Site Monitoring (n= 4 Trial sites)	Tool Testing and Error Analysis (n = 8 sites; 4 Trial and 4 LED Accelerator)	Participant Interviews (n=4)	Near-Participant Interviews (n=6)	Using the Tool with LED Accelerator Data (n = 4 LED Accelerator sites)
Tool Accuracy with Existing Conditions Baseline	X	X	X			
Tool Accuracy with Code Baseline	X	X	X			
Contractor Satisfaction				X	X	X
Facility Manager Satisfaction				X	X	X

5. KEY FINDINGS

The challenges experienced by the Trial were driven by the fact that, despite high market interest, ALCS is still a very expensive emerging technology.

The original concept of the Trial was that contractors would utilize the Tool to help them sell ALCS projects to customers. In actuality, contractors associated with the Trial did not appear to be using the Tool in their marketing or sales processes and, in general, reported they are not actively promoting ALCS to their customers.[15] This was confirmed by the fact that Trial participants were early adopters who installed ALCS for reasons other than energy and cost savings and who sought out contractors to complete their ALCS projects. Additionally, near-participant contractors and facility managers cited cost and return-on-investment (ROI) as the main barrier to participating in the Trial. The emerging nature of the technology, combined with the fact that Trial participants reported ALCS has long sales cycles—often spanning multiple years, posed significant Trial recruitment barriers and resulted in limited data for this evaluation.

As Trial participants sought out contractors for their projects, there was little impetus for the contractors to use the Tool as a sales or marketing strategy. Instead, the Trial implementation contractor filled out the Tool for participating sites. As a result, some of the values entered in the Tool might be different than if they had been entered by a contractor during the design and installation process. For example, the proposed lighting power density (LPD) values had not been modified in the Tool, despite three of the four sites receiving luminaire upgrades. Since changing the LPD was the most critical source of variance found for each site, and the sensitivity analysis showed LPD was a highly sensitive input, **we believe not having correct pre- and post-retrofit LPD values accounts for the majority of the differences between the Tool estimates and the monitored estimates**. In addition to LPD, the specification of existing lighting controls and the specification of proposed lighting controls also affected savings estimates. Therefore, in a future Tool implementation, it should be clearly indicated in the Tool that inputting correct pre-retrofit and post-retrofit specification and LPD values is critical to getting accurate savings estimates.

Other key findings, organized by evaluation activity, from the evaluation included:

- Calculator tool initial assessment
    - The formulae and theory in the tool appear to be developed in keeping with the literature and best practices[16], as applicable.
    - The intended approach of the Tool is sound and is consistent with industry best practices. The implementation of the formulae and

[15] Only two contractor interviews were secured for this evaluation. This key finding was inferred from these interviews as well as from informal dialogue between the evaluation team, the implementation contractor, and the contractors throughout the Trial.
[16] Citations of literature reviewed are included in relevant footnotes of Appendix B.

concepts employed for the savings calculations in the Tool are reasonable and straightforward, although the documentation could be improved.

- The underlying assumptions for the control factors are based on very limited data that does not cover all building types in the model and, in some cases, does not cover the control type at all. The most critical function of the Tool for calculating savings is building control factors for ALCS. This is also where the Tool exhibits the greatest uncertainty. As such, one of the important parts of the on-site monitoring activity discussed below was to examine whether the control factor calculations correctly emulate the field data.
- There are several instances where the Tool does not capture modifications or exemptions from Title 24 code,[17] mainly because of the space-type roll-up methodology employed. As such, the Tool is unable to identify and quantify incentive-eligible control applications that the code specifically exempts, such as adding controls to an existing system. These should be captured in the Tool for maximized utility-claimed savings.
- There were multiple instances where we could not trace a variable's impact because of the complex lookup method which relies on matching numbers in rows and columns to identify another value. This presents a risk to ensuring modifications to the Tool are complete.

- On-site monitoring
  - ALCS system design, setup, and programming drives control savings. Any deficiencies in these steps, such as improper application of daylighting controls or real-time task tuning settings that are not properly saved, prevent projects from achieving their maximum savings.
  - Lighting efficacy improvements (i.e., improvement in lumens per watt due to replacing bulbs) had a much larger impact on energy savings than changes in controls. When this finding is combined with field observations, one possible explanation of efficacy improvements being so much larger than controls savings is that the control programming is often done improperly and that users may not receive adequate training to make use of the advanced control features.
  - Using ALCS system data directly instead of stand-alone data meters could result in better quality data (fewer losses of battery power or removal of data meters, as experienced during our study) and significantly reduce M&V costs.

[17] This evaluation used the Title 24-2013 code implemented July 1, 2014. The Tool was developed to incorporate Title 24-2013 code.

- Calculator Tool testing and error analysis
    - The approaches taken to implement the control factors (occupancy, primary sidelit or skylit daylighting, secondary sidelit daylighting, task tuning, demand response, time switching, and manual dimming) in the Tool are reasonable and are supported by data from the on-site monitoring. Overall, the calculated control factors appropriately disaggregated energy savings for each site, indicating control factors are calculated correctly despite the lack of supporting documentation.
    - Savings values as estimated by the Tool (Levels of Rigor 1 and 2) using an existing baseline are internally consistent with each other (typically within 2%-5%), but do not generally align with savings estimates from the metering data (Level of 4), where variances range from roughly 37% to 130% of the Level 1 estimate.
    - Since changing the LPD was the only source of variance for the differences between the savings estimates from the Tool to estimates from the metering data found for each site, as detailed below, we believe not having correct pre- and post-retrofit LPD values accounts for the majority of the differences between the Tool estimates and the monitored estimates. Going forward with Tool implementation it should be clearly indicated in the Tool that inputting correct pre-retrofit and post-retrofit LPD values is critical to getting accurate savings estimates.
    - For a given site using a code baseline, there is a high level of consistency between Levels 1 and 2. No comparison is possible with metered data, because the only way to compare metered data with a code baseline would be to construct a whole building simulation which was outside the scope of this project.
    - There was little to no difference between savings estimated by the Tool between Level 1 and Level 2, for either of the participating sites or the four LED Accelerator Sites from PG&E's LED Accelerator Program. Based on the extremely limited sample in this evaluation, it appears that collecting Level 2 data does not improve accuracy so using Level 1 estimates may suffice for utility programs. However, even though it doesn't produce more accurate results, interviewed contractors said they would use the Level 2 detailed inputs tab in the Tool as they walk/audit a site, so they may practically never use the Level 1 tab.
    - Four variables were qualitatively determined to have a high likelihood of affecting savings estimates: (1) the specification of existing lighting controls, (2) the existing lighting power density (LPD), (3) the specification of proposed lighting controls, and (4) the proposed (post-retrofit) LPD

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- Facility manager interviews
    - The facility managers participating in the Trial did not use the tool in their decision-making process as they installed ALCS for reasons other than energy and cost savings. Therefore, the Tool was not influential in their decision-making and, therefore, the accuracy of energy savings estimates was not important.
    - However, all of the facility managers said energy savings were presented by the contractors as a part of their quote for the project the customer and the implementation contractor brought them. Three of the facility managers (Site 0, Site 1, Site 3/Site 4) said the Tool was presented to them by the implementation contractor. Of the three, two said it was easy to understand the savings estimates. These two facility managers were unable to comment on how accurate they thought the savings estimates were.
    - When asked about what factors had the most impact on their project related decision-making, they referenced the ability to control the lights from outside the office for security purposes and how automated the system was.
    - Facility managers were highly satisfied with their ALCS contractors, Trial contractors, the installation process, and their new lighting systems. They were less satisfied with the commissioning process[18].
    - All of the facility managers said the commissioning process took longer than expected; two of the facility managers described the commissioning process as "tedious" and "time consuming." They both discussed difficulty with having to pair each fixture individually.
    - None of the facility managers reported any difficulty with assessing project eligibility as it related to the ALCS Trial. While indirectly related to the Trial, one facility manager was frustrated with assessing the eligibility of their office space to receive rebates (the facility manager was referring to the fact that office lighting did not qualify for deemed rebates).
- Contractor interviews
    - While only one contractor interview was secured, facility managers told us it was the implementation contractor who filled out the Tool, not the ALCS contractor. Therefore, even if an interview had been conducted, those contractors would likely not have been able to provide feedback on using the Tool or how they incorporate the Tool into their marketing practices.

[18] Note there was no separate commissioning agent or commissioning process for the Trial sites. Instead, the installation contractor commissioned the systems.

- The contractor interviewed did not use the Tool in the field. Instead, they used a tool called "Snap Count" to collect and enter data in the field and then entered the data into the Tool in the office.
- The contractor gave specific feedback on the Tool as they were entering the sample project data into the Tool during the interview[19]:
  - The Tool asks for room areas in percentages, but using square feet is generally how they get data in real life. So, the Tool should be in square feet not percentages.
  - The contractor would prefer to start with the Detailed Inputs tab as the layout of fields in this tab better represent how they would acquire the data as they move through a building.
  - The dashboard should also include a cost savings per year**.** The contractor reported this is a very important metric for their clients and could be easily obtained by having an input field for a client's $/kWh rate.
- The contractor also said it would be nice if the Tool was online and could be submitted online and if it automatically populated rebate opportunities, and if it could integrate with their existing software so that they could export data from their existing software into the Tool (assuming using the Tool was a requirement to get a rebate).

- Near-participant interviews
  - ALCS' long sales cycles may pose a barrier for utility program participation. According to the implementation contractor's experience on this project, deciding whether a property will go forward with an ALCS project takes a long time. The time between when interest is expressed and initiating an order with an electrical distributor usually takes months, if not more than a year. During this time, there are many events that can derail the ALCS project (e.g. tenant decides to lease elsewhere; budget is constrained and ALCS is value-engineered out of the project; building sale occurs; staff turn-over; etc.) While the Tool could serve a valuable means of quantifying savings, it has limited use for a utility program if the prospective participants are lost due to attrition separate from the program itself.
  - Overall, near-participants cited cost as the primary barrier for ALCS adoption. Most near-participants did not move forward with the proposed project because the project did not meet ROI requirements.
  - Contractors reported that a two to three-year payback, at most, is what customers are willing to accept. While all the contractors believed bigger rebates could help ALCS adoption, they believe the true challenge is the lack of available up-front capital. As rebates can take

[19] These suggestions were made by one contractor and, thus, may not be representative of all contractors.

a while to materialize, contractors reported adoption would not increase substantially until the cost of materials comes down.

- Feedback suggests that ALCS technology is not being widely marketed and the majority of the feedback on future improvements to the Trial focused on lowering up-front costs. This supports the findings, discussed in other sections throughout the report, that current ALCS customers are early adopters who are installing the technology despite low cost-benefit.
- Some interviewees also reported complexity, timeline, and negative perceptions of lighting controls (for example, one facility manager had a previous bad experience with less advanced occupancy sensors, where inaccurate triggering resulted in complaints) as additional factors.
- All of the facility managers also discussed the functionality benefits, such as improved maintenance and remote control, offered by ALCS as the main benefits that attracted them to ALCS.
- Two near-participants reported having a method to quantify savings would have improved the Trial offering in the future. As such, it seems these near-participants did not experience the Tool as a part of the Trial.

More detailed findings on the evaluation topics are presented in Section 7.

6. APPROACH

As described in the introduction, EMI Consulting completed a suite of research activities to achieve the evaluation objectives. Described in the following sections are the data collection activities and the analysis approach. Included in each section is a discussion of any changes made to the original approach, data limitations, and impact of the limitations on the evaluation outcomes.

6.1 DATA COLLECTION

The evaluation team collected data from all of the evaluation activities except for the tool testing and error analysis task, which used data collected from the on-site monitoring of the four Trial participant sites and the four LED Accelerator sites. Data from each of the research activities was aggregated to inform the research objectives per Table 4-1. The following sections present the data collected and analysis performed from each research activity.

CALCULATOR TOOL INITIAL ASSESSMENT

The evaluation team received an unlocked version of the Tool 'Beta Version 1.0b6-CA' and the associated developer's manual from PG&E. While the unlocked version of the Tool is not available to the market, it was used for this evaluation as it allowed the evaluation team to trace its theory and formulas in the tool initial assessment, as described below in Section 6.2, in a manner the locked version of the Tool would not allow.

ON-SITE MONITORING

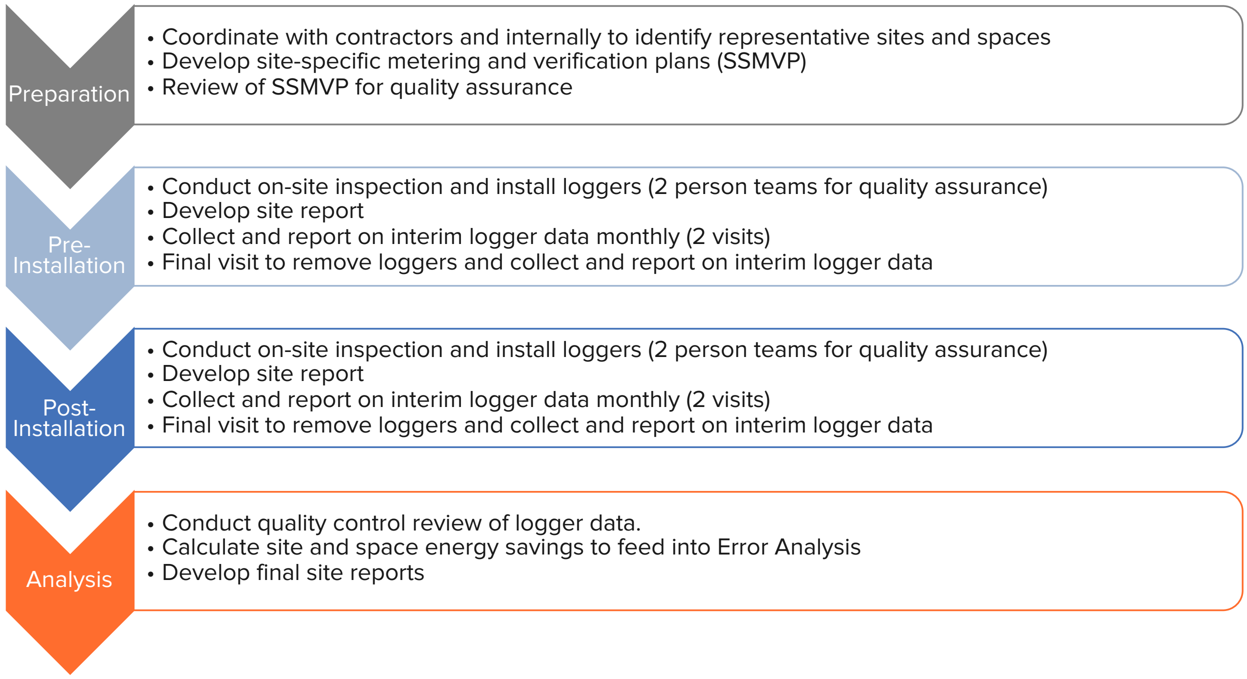
Two of this evaluation's objectives (Objective 1 and Objective 2) were to assess the accuracy of the savings calculations generated by the Tool. The accuracy of the tool was assessed by comparing the metered savings and observed conditions to the estimated savings provided by the Tool and is discussed in detail in the Analysis Approach section (Section 6.2) below. The overarching goal of the on-site monitoring was to obtain the data needed for the comparison. The evaluation team conducted pre- and post-retrofit on-site monitoring of the four sites enrolled in the Trial.

Figure 6-1 outlines the overarching approach taken for the on-site monitoring data collection, which includes some overlap between the site selection discussed in Section 3 above and the analysis approach. While site documentation was not readily available during the M&V study (discussed in detail below), we were able to execute an M&V plan that was consistent with the approach in Figure 6-1. For a site-by-site discussion outlining specific deviations from this general M&V approach, please refer to Appendix B.

EMI CONSULTING

Approach

Figure 6-1.On-Site Monitoring and Data Collection Approach



kW Engineering sought to develop site-specific measurement and verification plans (SSMVP) for each site, ahead of the site visits, using the data from the implementation contractor shown in Table 3-2. However, most of this data was not obtained during the Trial and, thus, unavailable for the development of the SSMVPs, both prior to the retrofit and after the retrofit. Only Site 2 had detailed documentation for the existing system. Due to the limited site information available prior to meter installation, the SSMVP was developed in the field by the evaluator for each site. Therefore, the evaluation team spent time on-site generating site-specific reflected ceiling plans, documenting luminaires, and control locations. These details were aggregated into information included in the site-specific metering plans, as described in Section 6.2.

Overall, the monitoring design was intended to assess the accuracy of the Tool and the control factors for each lighting control technology. The analysis approach disaggregated energy consumption, and thus savings, from each installed technology (e.g., occupancy sensing, daylighting, manual dimming, top trimming, schedules). Thus, kW Engineering deployed monitoring devices for each control factor as shown in Table 6-1. The team coordinated with the PG&E Tool Lending Library to borrow the necessary monitoring equipment, and PG&E purchased the illuminance meters for this evaluation.

Table 6-1. Control Factors and Meters Used

Control Factor	Measurement	Proposed Meter	Data Logging Interval	Quantity
Occupancy/ Vacancy	PIR Occupancy	Onset Computers UX90-006M	30 seconds	1 per zone
Occupancy/ Vacancy	Luminaire Illuminance	Onset Computers U12-012	1 minute	1 per zone
Primary Sidelit or Skylit Daylighting	Task Plane Illuminance	T&D Corporation TR-74Ui	5 minutes	1 per zone
Secondary Sidelit daylighting	Task Plane Illuminance	T&D Corporation TR-74Ui	5 minutes	1 per zone (if present)
Task tuning/ demand response/ time switching/ manual dimming	Power Consumption	DENT Corporation Elite Pro	5 minutes	1 per space

A brief discussion of the specific strategies and specifications to meter each control factor is below:

- The **occupancy** period of each zone was evaluated using occupancy sensors and luminaire illuminance. The change in occupancy status versus the change in light output was evaluated to assess when the control system turned off the overhead lighting.
- The **primary sidelit or skylit zones** used a single illuminance meter for each daylight control group. The T&D TR-74Ui is the data meter that limited the maximum time between data collection site visits, since it only supports 8,000 data sets. At 5-minute intervals, this meter can only collect 27 days and 18 hours of data without overwriting the existing data and the manufacturer offers no means of increasing data storage with this model data meter. In practice, the daylighting data was not analyzed. As discussed in the SSMVPs, only Site 1 installed daylighting controls and site-specific factors prevented the daylighting system from ever responding in a meaningful manner.
- The **secondary sidelit daylighting zones** were logged only if secondary daylighting zone strategies were used. No sites implemented secondary sidelit daylighting controls.
- **Task tuning, manual dimming, and manual switching** were evaluated using the power metering hardware and the following specific assessments:

- **Task Tuning.** To evaluate task tuning, we planned on comparing the maximum power observed during the trend period to the nominal luminaire wattage and the number of luminaires in each zone. The ratio of the total installed watts to maximum measured watts provides a metric for evaluating the task-tuning setpoint as a percentage. In practice, we were able to verify the nominal wattage for Site 1, 3, and 4. Site 2 had no nominal wattage data visible on the luminaire and we did not receive luminaire submittals that indicated the nominal wattage.
- **Manual Dimming.** As the only truly random control factor included in this study, after accounting for all other variables, a process of elimination should identify manual dimming. Our original plan included reviewing the ALCS interface to spot-check the extent of manual dimming. During the post-installation period, we were not given credentials or access to the ALCS interface and could not verify the manual dimming fractions using the ALCS. Since there were no other systems that modulated the light output, we used our relative light output meters installed in the field and used the changing output to assess when the lighting system was manually dimmed.
- **Manual On/Off.** The original monitoring plan excluded manual on/off or bi-level control. We found that many of the pre-retrofit spaces relied on manual control far more than the automatic shut-off controls. We therefore accounted for manual manipulation of the light switches based on when the light status changed before the occupancy sensor timeout occurred or while the space was still occupied. Due to the amount of bi-level lighting, the on/off status was not recorded as a binary value, but a changing decimal value equivalent to the manually shut-off lighting load at the last-observed power state.

Note, none of the Trial sites elected to implement time-switching (e.g. scheduling loads on and off based on time of day and day of the week) or demand response strategies; therefore, they were not analyzed.

Spaces at each site were selected based on the occupant's willingness to accommodate the meter installation and the ability to isolate the retrofit lighting loads on electrical circuits separate from unaffected retrofit areas. kW Engineering worked with the Trial implementation contractor to set a project boundary around the portions of the project that would have lighting controls installed. Based on information provided by the Implementation contractor and verified by kW Engineering, zones were then eliminated on electrical circuits where more than 50% of the electrical load was out of the project scope. Generally, as many spaces were metered as was practical by site type, as summarized below:

Table 6-2. On-Site Monitoring Space Type Summary

Space Type	Site 1	Site 2	Site 3	Site 4
Private Office	3 (4 post)	N/A	N/A	N/A
Open Office	3	N/A	N/A	1
Conference Room	2	1	1	N/A
Huddle Room	N/A	4	N/A	N/A
Training Room	N/A	N/A	1	N/A
Storage Room	N/A	1	N/A	N/A

During interim site visits to collect data, reset meters, or remove meters, information about the space and data meters was collected and the team noted anything that might result in unusual or faulty data. During the study, there were frequent instances of meters failing to capture data due to battery loss, meter removal by occupants, and insufficient memory. The original intent was to correct disruptions by relying on the ALCS interface (remote login) to fill in data gaps and correct any faulty conclusions. kW Engineering specifically planned on using this data to verify: task tuning percentages, occupancy sensor delay-to-off time, and manual dimming manipulation. The intent of the verification would be to better understand any transient events in the data we collected independently. However, remote login to the ALCS interface was not available during the study period. Therefore, reasonable assumptions were made and the lengthy data collection periods avoided any significant problems. This is discussed in detail from the SSMVPs below.

The site-specific measurement and verification plans for each site enrolled in the Trial are presented in Appendix B.

CALCULATOR TOOL TESTING AND ERROR ANALYSIS

The evaluation team also collected two Tool spreadsheet files, a proposed case and an installed case, that were filled out by the Trial implementation contractor for each of the four sites enrolled in the Trial. The purpose of collecting the Tools from the implementation contractor was to give the evaluation team the detailed inputs needed (i.e., Level 3 rigor) to calculate savings estimates from existing baseline and code baseline for the four levels of rigor for each site. The Tools received, however, were Level 2 and lacking the site audit details needed to construct a Level 3 analysis. Without supporting data, such as the contractor's scope of work, hardware and controls submittals, space by space inventories, as-built hardware and quantities, and notes from interviews with occupants about usage patterns, the evaluation team was unable to construct Level 3 calculators for the sites. This is discussed further in Section 3.3.

LED ACCELERATOR DATA

The overarching goal of this study was to evaluate the ALCS Tool and provide recommendations that would support wide-scale use of the Tool by program staff and implementation contractors. When recruitment proved more challenging than expected, the project team sought out other ways to obtain data to inform the research objectives. PG&E's LED Accelerator Program's[20] implementer, Energy Solutions, is one market actor looking to the Tool as a possible way to streamline the savings estimation and verification process of ALCS projects. As such, Energy Solutions provided detailed data for four accelerator sites to use in the Tool.

The LED Accelerator data included details on the building information by space type, existing lighting and controls information by space type, proposed lighting and controls information by space type, and often provided excerpts of the lighting table used to calculate energy savings. The data is summarized in Table 6-3 below, and the full table of calculator fields requested and received from Energy Solutions is in Appendix B. The data provided by Energy Solutions was of sufficient quality that Level 1 and Level 2 inputs in the tool could be completed. The LED Accelerator sites, however, did not include monitored data. Therefore, the accuracy of the savings calculated by the tool (Research Objective 1 and Research Objective 2) could not be assessed in the same way as the Trial participant sites. Instead, the LED Accelerator sites were used to inform the research by better understanding how the tool works with field data as collected by other programs, the level of effort needed to collect tool inputs, inform issues with the tool, and understand usability.

Table 6-3. Summary of LED Accelerator Data

Site	Building Description	Data Received		Tool Building Type
		Tool Inputs	Lighting Table	
5	Unconditioned Warehouse	Yes	Yes	Unconditioned Warehouse
6	Big Box Retail	Yes	Yes	Retail, Single-Story Large
7	Repair Facility	Yes	Yes	Manufacturing, Light Industrial
8*	Switch Center	Yes	Yes	Office, Small

**Site 8 was 50% office and 50% low-power-density racks of telecom (phone) equipment with light battery back-up load. This site did not map well to the room types in the Tool, so the line items for the spaces were entered and the evaluation team ensured the lighting power density and installed controls aligned properly in order to assign the site as an "Office, Small".*

[20] The LED Accelerator (LEDA) Program is a commercial lighting retrofit incentive program whose mission is to make it cost-effective to install the highest quality, most energy-efficient LEDs and networked controls in retail locations for maximum energy savings (from www.pge.com).

NEAR-PARTICIPANT INTERVIEWS

The purpose of the near-participant interviews was to better understand barriers preventing customers from participating in the Trial, and to identify actionable recommendations to help improve recruitment for a future program design and offering. The near-participant interviews covered the following topics:

- **Awareness:** The evaluation team identified how control agents and customers become aware of advanced lighting controls and the PG&E ALCS Tool Trial.
- **ALCS marketing:** The evaluation team assessed how ALCS systems are explained and presented to customers and how control agents sell ALCS to potential customers. This included learning about any information or materials that control agents or customers found particularly helpful.
- **Perceived benefits:** Customers and control agents were asked what benefits they thought ALCS provided to businesses.
- **Barriers:** The evaluation team explored the reasons customers and control agents decided not to participate in the Trial.

The evaluation team conducted interviews with three control agents and four business customers[21] who decided not to install an Advanced Lighting Control System (ALCS). This was a census of the near-participant control agents, and near census (3/4) of the near-participant business customers.

The near-participant interview guide is presented in Appendix C.

FACILITY MANAGER INTERVIEWS

One of the evaluation's research objectives was to assess the satisfaction of facilities managers with the retrofit marketing and implementation process, including the influence of the Tool over their decision-making. To achieve these objectives, the evaluation team explored the following research questions:

- Do facility managers understand and trust the output of the Tool?
- How influential was the Tool in their retrofit decisions?
- How satisfied are the facility managers in their interactions with the contractor and the program staff?
- How satisfied are facility managers with the retrofit implementation process?

[21] The four near-participant interviews included three interviews with near-participant business customers and one interview with the facility manager whose site originally enrolled in the Trial but later dropped out due to installation issues (site 0). This facility manager was also interviewed after installation but before dropping out of the Trial, for the facility manager interviews associated with Research Objective 4.

The evaluation team interviewed all four participating facility managers. However, Site 3 and Site 4 had the same facility manager so that person was only interviewed once for both sites. Also included are two interviews from Site 0's facility manager who enrolled into the Trial, went through installation, but removed the equipment after significant commissioning issues were experienced; the first interview was conducted after installation during commissioning, and the second was conducted after the site dropped out of the Trial. The final interview disposition is shown in Table 6-4 below, and the facility manager interview guide is presented in Appendix D.

Table 6-4. Facility Manager Interview Disposition

Site	Facility Manager Interview
Site 0 (enrolled, dropped out)	X
Site 1 (self-install)	X
Site 2	X
Site 3 (same facility manager as Site 4)	X
Site 4 (same facility manager as Site 3)	

CONTRACTOR INTERVIEWS

One of the evaluation's research objectives was to analyze the overall satisfaction of contractors and others using the Tool, the issues they discovered, and their experiences marketing the ALCS savings estimates to end users in the promotion of more extensive retrofits. The specific research questions that were explored in the interviews were:

- How satisfied are contractors and other users with the Tool?
- Have the contractors received adequate training?
- Do contractors face any barriers using the Tool?
- How do contractors and other Tool users incorporate the Tool output in marketing?

The contractor interviews also included an exploration of the usability of the Tool. The contractors were given a sample project that contained detailed information on the building, existing conditions, and the proposed project. They were asked to use the Tool on the sample project. The interviews were conducted remotely using the web-based interface software *GoToMeeting,* which allowed the interviewer to observe the contractors entering data into the Tool while also asking probing questions about their experience. The goal of observing contractors using the Tool was to identify which project details they entered and which fields they skipped, how they entered them, and any points of frustration or confusion they had.

Over the course of the project, the evaluation team attempted to interview all participating contractors. EMI Consulting tried to reach contractors via phone and email, on different days of the week and at different times of day. This resulted in one contractor interview. When recruitment with this approach slowed, the implementation contractor also attempted to schedule interviews while on site with contractors and through follow-up emails and phone conversations with contractors. This resulted in a second contractor interview.

In total, interviews were conducted with contractors for two of the four enrolled sites. The final interview disposition is shown in Table 6-5. Site 1 was a self-install, so the facility manager interview also served as the contractor interview. Site 3 and site 4 were done by the same contractor, but this contractor experienced staff turnover between the time the calculator was filled out and the completion of installation. The new staff person was willing to be interviewed but could not answer any of the interview questions and was not included in the analysis.

The contractor interview guide is presented in Appendix E.

Table 6-5. Contractor Interview Disposition

<table>
<tr><th>Site</th><th>Facility Manager Interview</th><th>Contractor Interview</th></tr>
<tr><td>Site 0 (enrolled, dropped out)</td><td>X</td><td>n/a</td></tr>
<tr><td>Site 1 (self-install)*</td><td>X</td><td>X</td></tr>
<tr><td>Site 2</td><td>X</td><td>X</td></tr>
<tr><td>Site 3 (same facility manager as Site 4)</td><td rowspan="2">X</td><td rowspan="2"></td></tr>
<tr><td>Site 4 (same facility manager as Site 3)</td></tr>
</table>

One interviewee completed both the facility manager and contractor interview

6.2 ANALYSIS APPROACH

This section describes the analysis approach for each research activity, using the data collection methods described in the previous section, as shown in Table 6-6. The following sections describe the analysis approach for the calculator tool initial assessment, the on-site monitoring, the calculator tool testing and error analysis, the facility manager and contractor interviews, and using the Tool with the LED Accelerator data.

Table 6-6. Data Used in Each Research Activity

Analysis Task	Tool Initial Assessmen t	On-Site Monitoring	Remote Access*	Near-Participant Interviews	Participant Interviews	LED Accelerator Data
Calculator tool initial assessment						
On-site monitoring		X	X			
Calculator tool testing and error analysis	X	X	X			X
Contractor and Facility Manager satisfaction				X	X	
Using the calculator for LED Accelerator projects						X

**The original evaluation plan called for using remote access to the ALCS system to collect data on system performance (Table 3-2). However, as no remote access was granted this data was not used in the evaluation.*

CALCULATOR TOOL INITIAL ASSESSMENT

The evaluation team conducted an initial assessment of the Tool to verify the formulas, assumptions, and key variables in three sequential steps:

- Review of the formulas and theory
- Sensitivity analysis
- Variable review

In reviewing the formulas and theory of the Tool, the evaluation team assessed the soundness of the formulas and audited the Tool to determine if the intended approach was reflected in the Tool's programming. The formulas were compared with industry standard protocols including the U.S. Department of Energy Uniform Methods Project and California Investor-Owned Utility work papers, relevant ACEEE papers, and other technical references. The results include an analysis of how representative the calculation methods are of industry best practices, any issues or potential sources of undue error from the use of these methods, and recommendations for improvements.[22]

[22] The Tool uses matrix multiplication of hourly control factor profiles for each control strategy to determine the interaction between control strategies. These control factors represent the portion of the control strategy available at that time. The control factors for daylight sensors are climate dependent based on radiance, and the other control factors are based on engineering models.

The goal of the sensitivity analysis was to identify the variables that have the most impact on estimated savings. Each user-adjustable input variable in the Tool, 37 in total, was systematically tested over a range of likely values for 23 building types. The range of tested values for each input was determined through a review of the Tool manual and documentation, Commercial Buildings Energy Consumption Survey (CBECS), Title 24 Code, and other publicly available census data. To allow for comparison, a “standard” case was set for all building types, against which the varied cases were compared. The standard case and varied cases could result in values that may or may not be reasonable for each building type, but the goal is to understand the responsiveness of the outputs to variation, not the absolute value of the outputs.[23]

The results classified each user adjustable input variable into “high,” “medium,” and “low” responsiveness, as determined by each variable’s impact on energy and demand outputs of the Tool across the building types. This information was also used to help identify the most important variables when conducting the error tracing in the Calculator Tool and Error Analysis task.

The goals of the variable review were to verify:

- Sources of reference for variables identified in the sensitivity analysis that had high responsiveness, were responsive in unexpected ways, or were not responsive at all, and to ensure that there were no syntax or programming errors
- Proper interpretations and application of Title 24 code requirements

The variable review used a California Advanced Lighting Controls Training Program (CALCTP)-Certified Acceptance Technician Provider to conduct the analysis. The technician drew upon their experience with actual projects in California as well as the Title 24 requirements, the California Commercial End Use Survey (CEUS), California Alternative Calculation Method (ACM) Approval Manual, California climate zones, and DEER values to identify how important (substantive) the sources of discrepancies were in California applications.

ON-SITE MONITORING

Energy savings were calculated using the on-site monitoring data with one of two approaches – electrical circuit power or calculated control factor power.

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[23] This note of caution is important; there is no reason to use the energy or demand savings reported in this sensitivity analysis for any purpose. The standard case sets values like square footage and lighting power density that are uniform. A 10,000 sf Office – Large is not likely, just as a 10,000 sf Relocatable Classroom is not likely. While the inputs are varied over a reasonable range for that input, it is not always reasonable for a particular space, building type, or vintage.

Electrical Circuit Power

Using the power data collected on-site, the energy consumed over each interval was calculated and the results totalized. Then the PG&E peak period definitions were used to calculate the average power consumption for each interval peak and part-peak interval.

During the analysis, a few data irregularities were noted:

- Site 2: During data meter installation, a 72W baseload was observed on the circuit. The electrical plans and our own circuit analysis on site could not identify the load. The baseload was consistently present during Monday through Friday and appeared to cycle off on the weekend (Figure 6-2), suggesting that the load is perhaps scheduled off on those dates. After October 18th, the baseload dropped to 38W and remained that way through the post-installation period. A similar baseload anomaly appeared in the post-installation monitoring period. However, the baseload was mostly consistent, regardless of the day of the week (Figure 6-3). Since the baseloads were roughly the same, we elected to leave them in the power analysis.

Figure 6-2. Site 2 Pre-Retrofit Unidentified Baseload

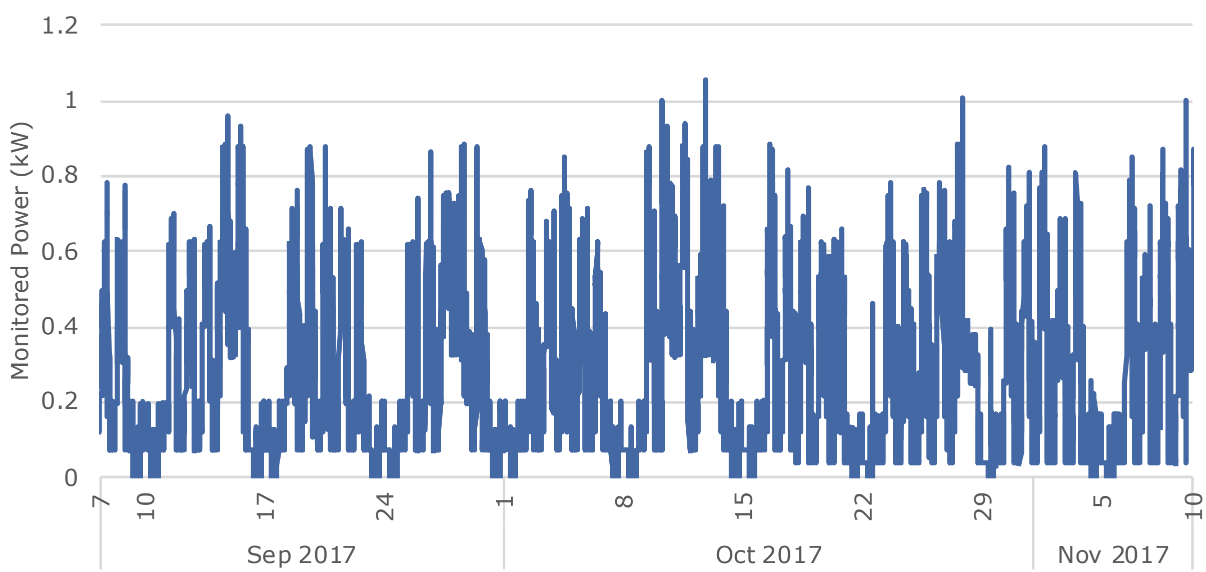
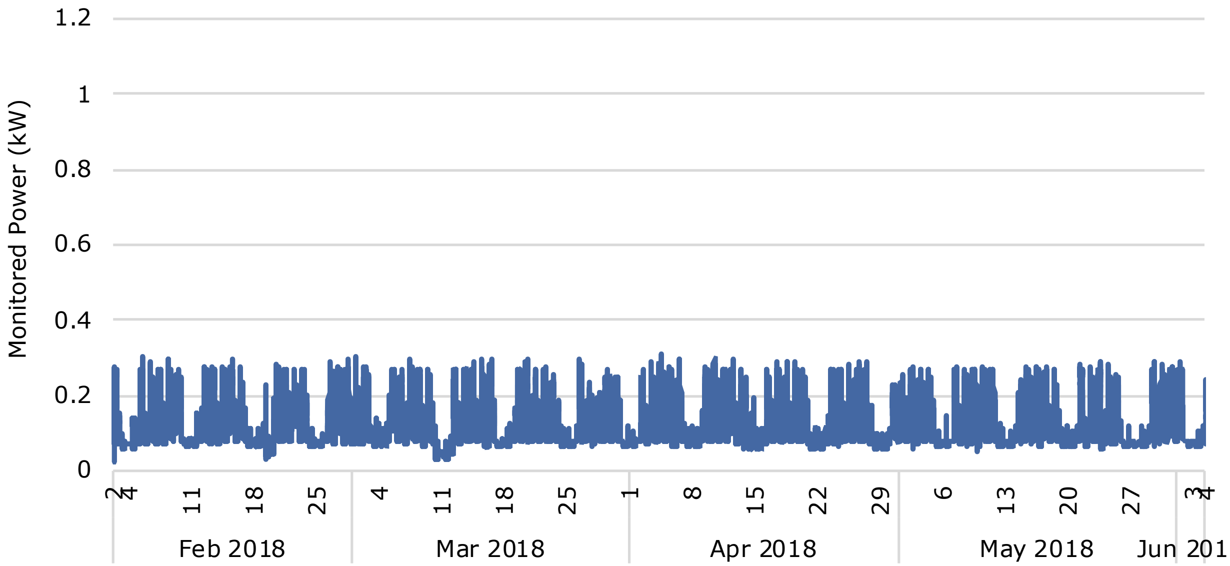
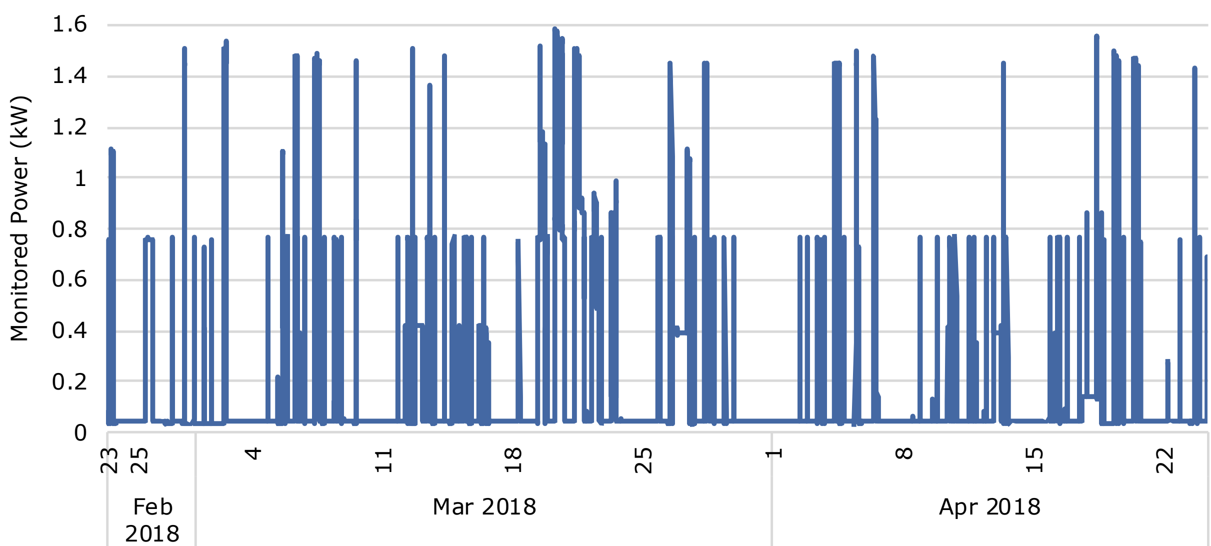


Figure 6-3. Site 2 Post-Retrofit Unidentified Baseload



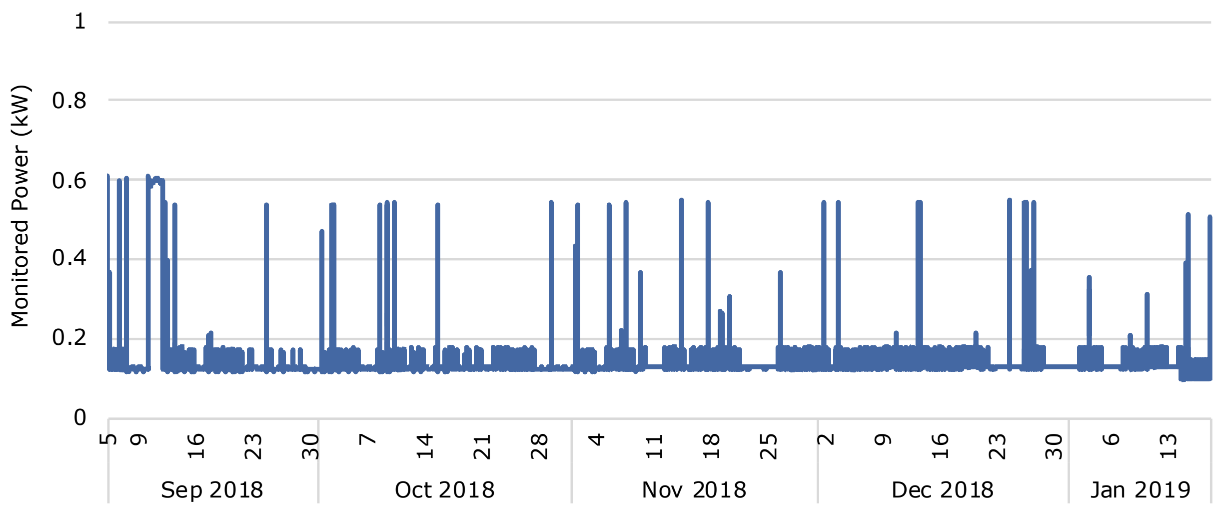
- Site 3: During meter installation in the Training Room, a 40W constant load was found on circuit 37. The baseload persisted during the pre-installation period but was absent in the post-retrofit data. Since this load was eliminated after installation of the new system, we elected to leave the baseload in the pre-installation data.

Figure 6-4. Site 3 Pre-Retrofit Unidentified Baseload



- Site 3: In the post-installation monitoring period, the lighting in the Small Conference Room was found to have a baseload of 122W that persisted through the entire post-installation monitoring period (Figure 6-5). Due to a scheduling issue, we had collected one month's worth of data prior to programming the lighting control system. It was only after the system was programmed that the baseload appeared, suggesting the occurrence was due to an increased electrical load on the circuit. Based on the customer's existing electrical systems the customer may have increased the load on this circuit to address some other need. The baseload added to the monitored on-off lighting load exceeds the nominal system wattage significantly, making the baseload unlikely to be associated with the lighting loads.

Figure 6-5. Site 3 Post-Retrofit Unidentified Baseload



Calculated Control Factor Power

After data collection was completed for each site, the data was analyzed to calculate energy savings by monitored space, site, and technology. The data was aligned and compiled by electrical circuit using Universal Translator 3.[24] Using one-minute interval data was excessively slow to process, so the data was aggregated to five-minute intervals in order to accelerate the analysis.

The analysis was grouped by the metered electrical circuit. Each zone on the given lighting circuit was then analyzed. kW Engineering processed the data collected in each zone and, through a series of logic statements based on the on-site zone characterization, calculated energy savings for them. Energy savings were further attributed to individual control factors, discussed further below. The difference between power shed due to controls and the nominal system power is the assumed to be the lighting system power draw (e.g., when a 100 watts system is dimmed saving 20 watts, the lighting system draws 80 watts).

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[24] Universal Translator 3 is a data processing tool produced by the PG&E Pacific Energy Center. This tool is free to the public to use and available online at http://utonline.org/cms/

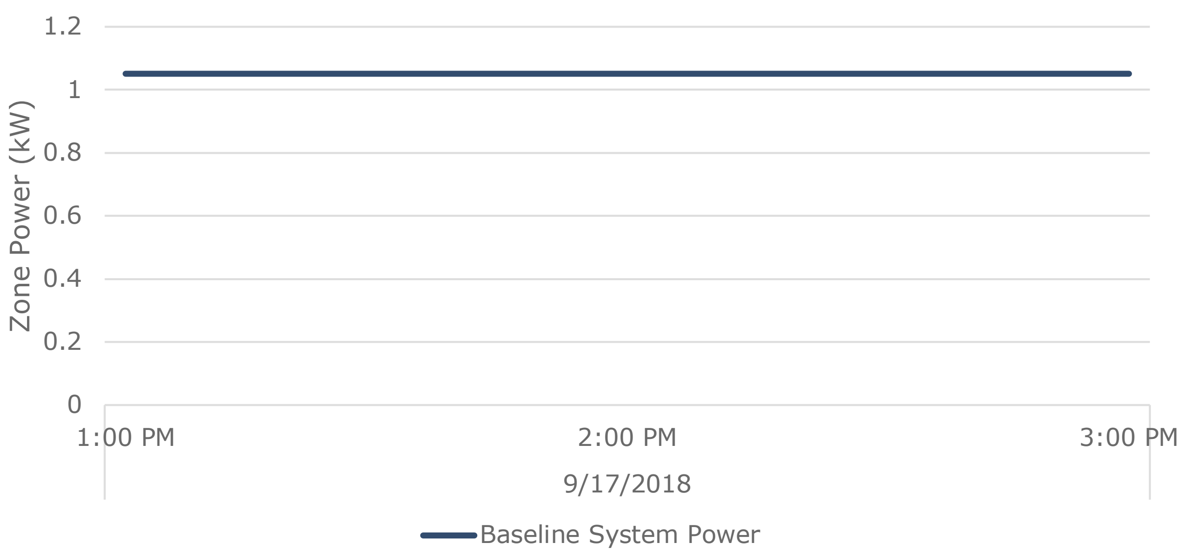
The control factors were calculated by summing energy savings for each technology and calculating it as a fraction of the theoretical uncontrolled energy the system would have consumed had no controls been present. A detailed overview of disaggregating energy savings follows below.

Control Factors, Load Order, and Power Metering

The M&V effort for this project involved attributing energy savings from the improved efficacy of new luminaires and the reduction in operating hours or light output due to lighting controls installed as part of the retrofit. For both the pre-installation system and the post-installation systems, we used the zone maximum power and evaluated how the controls pre- and post-retrofit reduced the zone power (e.g., dimming or bi-level switch) and how the controls shut-off the lighting. This provides us with the power consumption over time and thus energy use.

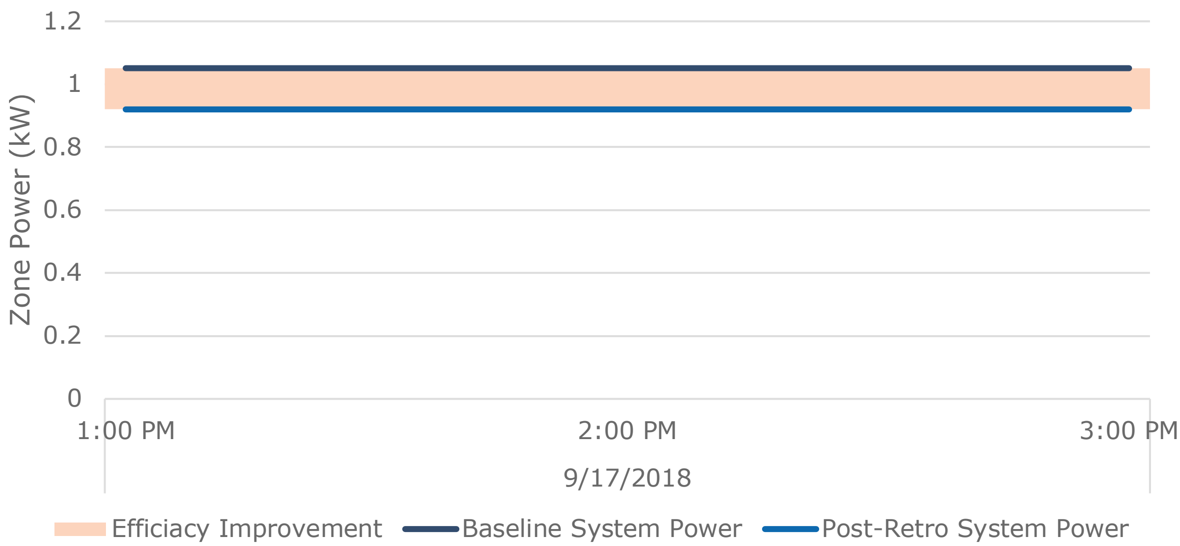
We attributed energy efficiency savings to the difference between the pre- and post-installation system power evaluated using the pre-installation system load profile, which combines operating hours and any existing controls that reduced the system power (e.g., bi-level switching). This approach assumes that were the luminaires replaced without controls, the system would operate in a similar manner and that the post-installation controls are solely responsible for changes in use patterns.

Figure 6-6. Site 4 – Training Room – Baseline Power Example



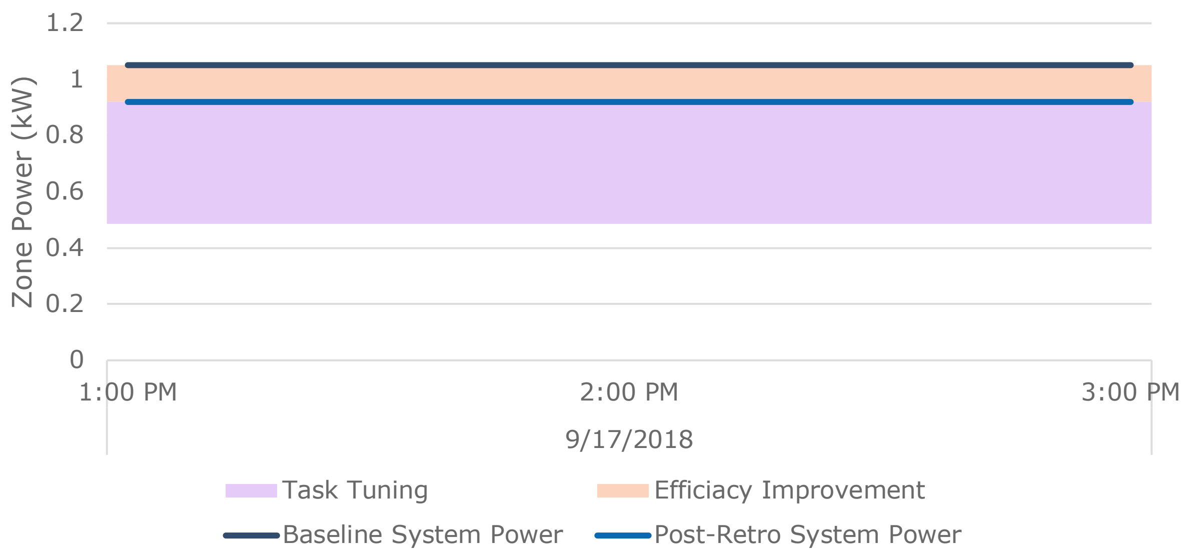
In the post-installation case, we compared the baseline zone power to the proposed zone power, the difference being the power reduction due to efficiency improvement. The energy savings were calculated using per the baseline control system operating hours. This avoids evaluating the efficacy change and control changes in parallel.

Figure 6-7. Site 4 – Training Room – Baseline versus Post-Installation Power



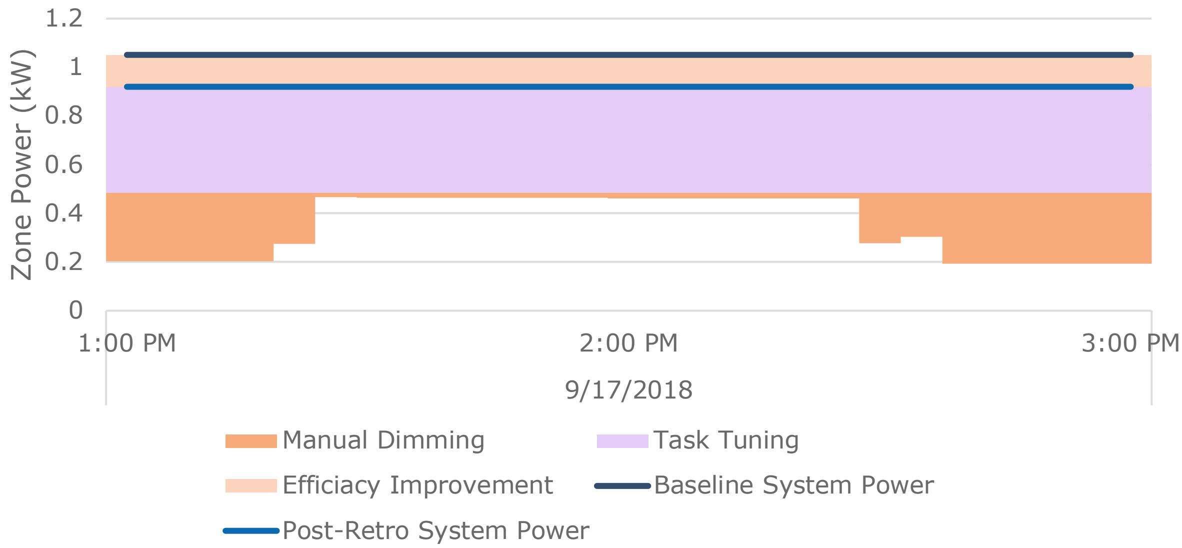
Next, we layered the control savings by control strategy. The first control strategy we considered was task tuning. Like the efficacy improvement, task tuning was uniformly applied for the entire data collection period. When we had details on the installed luminaire model number, we could measure the task tuned power in the field and compare it against the nominal luminaire wattage. When we did not have the luminaire nominal wattage details, we assumed our field-measured luminaire power was the rated luminaire input power and, thus, did not have a task-tuning power measurement to compare against.

Figure 6-8. Site 4 – Training Room – Task Tuning Component



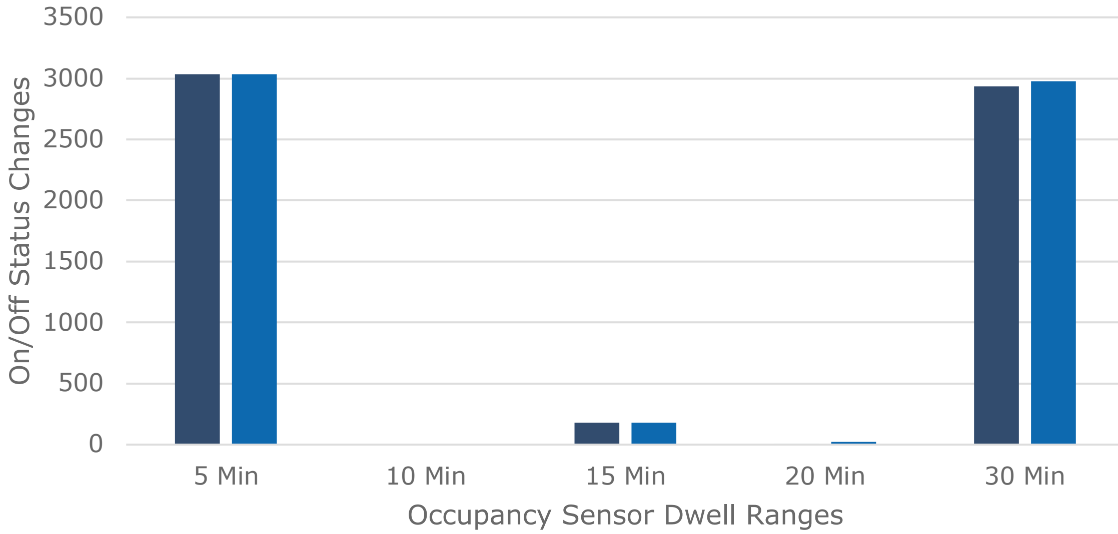
We used the U12 illuminance data meters to compare the changes in luminaire output over the course of the day. These data meters were installed in the luminaire pointed at the light source, to minimize the contribution from neighboring lighting systems. We used field measurements to correlate the changing light output between maximum luminaire output measured by the U12 data meter and the instantaneous U12 data meter reading at each interval. Changes in the luminaire output were thus attributed to manual (user-controlled) dimming. When the system is turned off (whether from an occupancy sensor, manual switch, or scheduling device), the shut-off event is credited with the reduction in power at the time of shut off. Therefore, if a 100-watt system was dimmed to 20 watts before the occupancy sensor timed out and shut off the system, the occupancy sensor would receive credit for the 20W power reduction.

Figure 6-9. Site 4 – Training Room – Manual Dimming Component



Using the U12 data meters, we could determine when each lighting circuit was shut off due to either a user turning off the light or a vacancy sensor. To determine the difference between vacancy sensing and user interaction, we counted the intervals between when our occupancy meter detected vacancy and when the lighting turned off. We then looked at the distribution of occupancy sensor shut-off periods, as shown in the chart below.

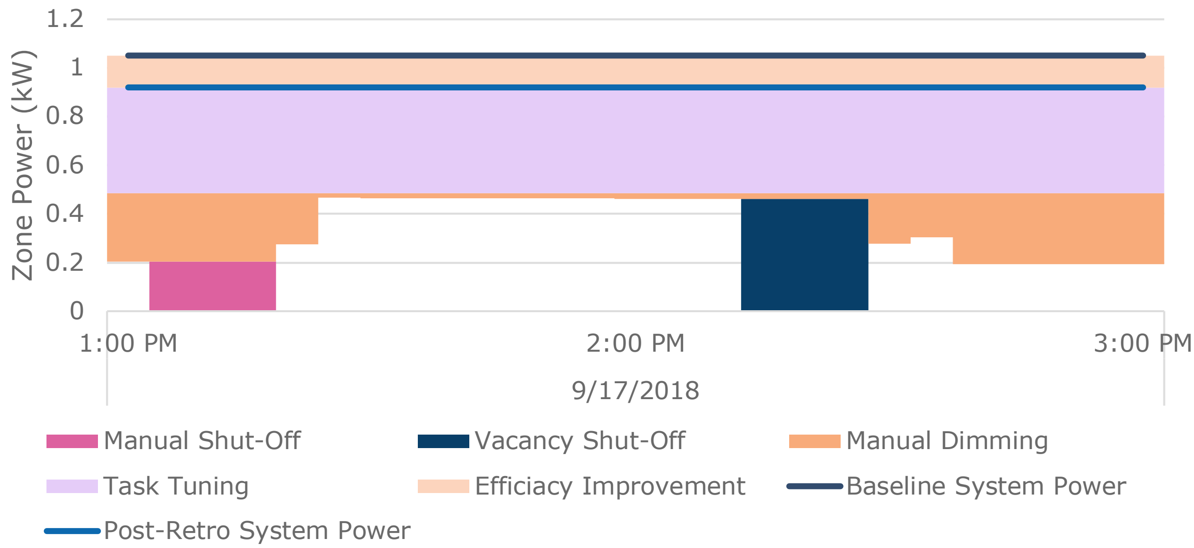
Figure 6-10. Zone Occupancy Status Changes Coincident with an Off-Cycle



We attributed the shut-off of lighting to the occupancy sensor whenever the shut-off event happened after the most frequent occupancy sensor dwell (i.e., delay-to-off) post-vacancy for each zone. Occupancy sensors do not instantaneously shut off the lighting immediately after it detects no occupancy, as this would create many false-positive events and be annoying for occupants. Occupancy sensor manufacturers include a configurable delay between that requires a persistent vacant state for a period of time called the "dwell" before the sensor will shut off the lighting.

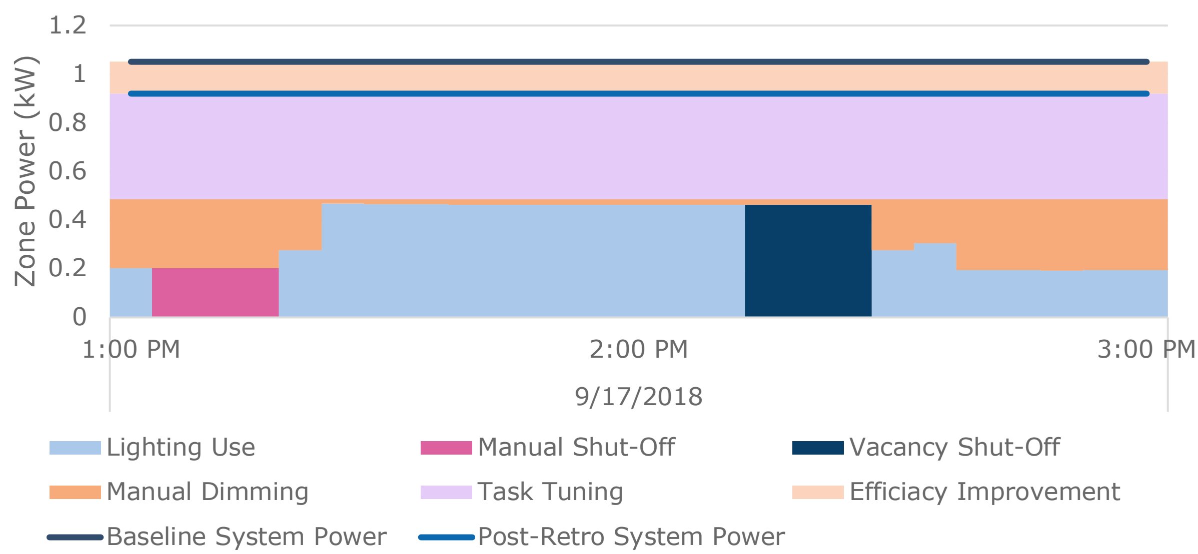
Many zones with significant manual shut-off events saw a 5-minute occupancy sensor dwell in the data. We attributed those shut-off events to occupants manually shutting off the controls because of a subsequent shut-off events well after the occupancy ended.

Figure 6-11. Site 4 – Training Room – with Manual & Vacancy Shut-Offs



By deduction, the remaining difference between the installed system power less calculated power reductions from the control factors is attributed to the use of the electric lighting.

Figure 6-12. Site 4 – Training Room – with Manual & Vacancy Shut-Offs

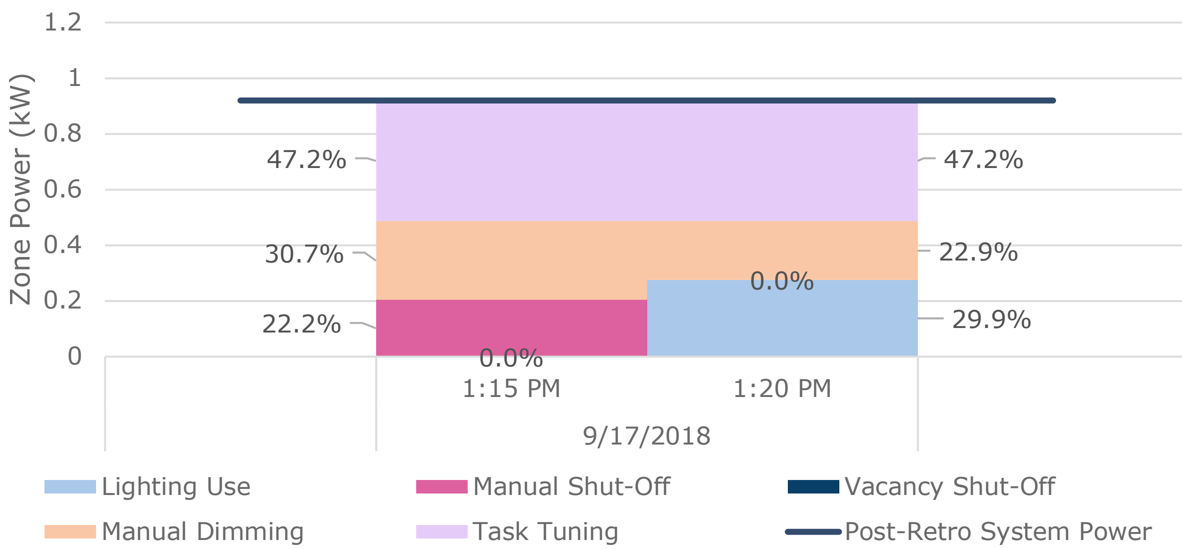


Control Factors as a Percentage of Total Installed Power

We calculated the percent avoided power use for each 5-minute interval for each zone based on the system capacity. For example, if a 500-watt lighting system was dimmed 40% before being shut off, the manual dimming control factor would be 40% and the manual shut off control factor would be 60%. Due to the differences in control behavior between the baseline lighting system and the post-installation lighting system, we did not calculate the "control factor" for the efficacy improvement. The graph below provides a diagrammatic break down of the control factors, for two five-minute intervals. The first interval (1:15 pm) shows the control factors for a zone that is powered off. The second interval (1:20 pm) shows the control factors after the zone is occupied and the lights are turned on.

The control factors plus the lighting use factor will always add up to 100% (fewer rounding errors) based on how they are defined as a fraction of the installed system power. When the lighting system is completely powered off, the control factors will total to 100% all on their own.

Figure 6-13. Site 4 – Training Room – Control Factors as Percentages



We calculated the average control factors for each monitoring period (pre- and post-retrofit) by averaging the control factors for every 5-minute interval during the monitoring period.

Pre-Installation and Post-Installation Annual Extrapolation

The evaluation team originally planned on using the electrical power data to directly calculate energy use and using the lighting measurements to disaggregate energy use by technology. However, the two approaches did not align perfectly. Thus, energy savings were presented in two approaches:

- **Energy use according to power meter by electrical circuit.** This approach leveraged the electrical meters on their own and is a straight calculation between the pre- and post-installation power consumption annualized from the monitoring periods.
- **Energy use calculated by using indirect metrics by zone.** This approach leveraged the data collected in the zone to calculate what the system power should be based on the typical operations of a lighting control system. To convert what are essentially a set of duty factors by technology, nominal luminaire power was used to calculate energy saved by each change

in the operation of the lighting system. A full explanation follows in the next section.

The results and a comparison between the two approaches, by site, can be found in Section 7.3.

As mentioned above, daylighting controls were either not present (Sites 2, 3, and 4) or nonfunctional (Site 1). Thus, seasonal variability of the lighting system was not included in the analysis approach. Instead, we calculated the energy use during weekdays (Monday through Friday) and weekends (Saturday and Sunday), and then scaled each value up to a full year. This approach was not impacted by the site-specific schedules and mimics the approach taken in the calculators.

Post-retrofit data was collected over a 16-week period and was annualized to a typical 12-month period. The annualization process was similar to the pre-retrofit data. With the power data disaggregated by space, energy use of the post-installation lighting system during the post-installation period was calculated. The marginal savings benefit of the new lighting controls was also calculated with the following, hierarchal approach:

- **Efficiency Savings.** The savings due to the replacement of the existing luminaires was calculated using the extrapolated annual operating hours from the post-installation lighting system and the manufacturer-listed power consumption of the new luminaire at full light output.
- **Task-Tuning (Top-Trim, Maximum Output Limiting).** The power data collected during functional testing on-site was compared to the nominal luminaire power. This spot check metric was applied against the lighting system, provided that the relative light output meter and the power metering agreed that the system appeared to be task-tuned.
- **Daylighting Savings.** The evaluation team planned on calculating savings based on any changes in lighting power that occur while maintaining the task plane illuminance and changes in luminaire status. In practice, daylighting controls were not effectively deployed at these sites, thus savings were not accrued, and the calculation approach could not be verified.
- **Manual On/Off (User Control).** Savings for manual, user-enabled on/off control were calculated based on changes in power that occur accompanied by variable relative light output from the luminaire and the occupancy sensor status. When it appeared that the lights turned off before the approximate dwell elapsed on the occupancy sensor, the savings were attributed to the user control. When the lights turn off after the dwell elapsed, the savings were attributed to the occupancy sensor (below).
- **Manual Dimming (User Control).** Savings for manual, user-enabled dimming were calculated based on changes in power that occur with changes in the relative output of the luminaire.

- **Timeclock Schedule.** Originally, the evaluation team planned to calculate any schedule-based energy reductions in power by reviewing the ALCS interface schedules and correlating the schedules with observed changes in lighting power. The timeclock schedule would have received partial credit after all part-load zone-level controls (e.g., when the timeclock schedule turns of a lighting load operating at 20% of nominal, the occupancy sensor receives credit for 20% of load; while the remaining 80% is attributed to the control factors responsible for allowing the system to operate at that reduced load). However, the implementation contractor was not able to secure remote access to the ALCS interfaces for any of the sites. However, it is suspected this had little impact on the calculation approach, as there were no scheduling controls pre-installation and all spaces had occupant sensing controls post-installation. The only thing that may not be captured is differential scheduling of the occupancy sensor functionality (that is, programming an occupancy sensor to behave differently at different times of day on different days of the week). Since there is no reason to believe scheduling was deployed as part of the project, scheduling savings were not attributed to the project.
- **Occupancy Sensor.** We calculated occupancy sensor savings based on changes in the luminaire and occupancy status in each space during the occupied period. The occupancy sensor received partial credit after all part-load zone-level controls were calculated (e.g., when the occupancy sensor turns of a lighting load operating at 20% of nominal, the occupancy sensor receives credit for 20% of load; while the remaining 80% is attributed to the control factors responsible for allowing the system to operate at that reduced load).

CALCULATOR TOOL TESTING AND ERROR ANALYSIS

In the evaluation plan, the team developed specific research questions to identify the most critical inputs for the calculations and the primary sources of variance between the tool estimates and metered energy savings. The Calculator Tool Testing and Error Analysis was designed to answer these specific research questions:

- Does the tool work in the field?
- What needs to be changed to make it more user friendly and accurate?
- What is the range of variance from the calculated savings values for the 4 levels of rigor in the Tool compared to metered values?
- What is the nature of the discrepancy leading to the variance, (e.g. inaccuracies or non-representativeness of the assumed variable values, incorrect formulas, order of operations issues, coding/programing syntax errors, or other)?
- How common are the sources of the variance (are they isolated to this/these cases or likely to be found in many sites)?

To conduct the **Tool Testing** task, EMI Consulting collected versions of the completed Tool from the implementation contractor for the four metered sites. The evaluation team then took these versions of the Tool and modified the inputs to obtain multiple versions of each Tool, one for each level of rigor (for each site). The original idea was that the Tools would be Level 3 and contain detailed site information from site audits. However, in accordance with the definitions of each level of rigor, the EMI Consulting team treated the completed Tools initially received from the implementer to be level of rigor 2. To get to level of rigor 1, the team removed inputs from the "Detailed Inputs" tab. Since detailed site information was not provided in the Tools or supporting documentation, the evaluation team could not calculate level of rigor 3 for any participating sites. The team recorded the savings estimates from each version of the tool and used these values, along with the calculated energy savings from the on-site data collection (4 sites), as inputs to the Error Analysis (discussed next).

There were several limitations associated with the Tool Testing analysis:

- The energy savings calculated from on-site monitoring will not exactly match the estimated savings from the Tool for Level 1, as the Tool's estimated savings includes spaces outside the monitoring scope.
- For each site, EMI Consulting attempted to match spaces from the metered data with spaces in the Tool as entered by the implementation contractor. However, the implementation contractor was not available to verify the mapping between spaces in the Tool with monitored spaces. This combined with the lack of data from the Trial, resulted in potential errors in cases where the spaces had not been accurately mapped to one another.
- The evaluation team collected two Tool spreadsheet files, a proposed case and an installed case, that were filled out by the implementation contractor for each site. The purpose of collecting the Tools from the implementation contractor was to give the evaluation team the detailed inputs needed (i.e., Level 3 site audit) to calculate savings estimates from two baselines for the four levels of rigor for each site. The Tools received, however, were Level 2 and lacking the site audit details needed to construct a Level 3 analysis. Without supporting data, such as the contractor's scope of work, hardware and controls submittals, space by space inventories, as-built hardware and quantities, and notes from interviews with occupants about usage patterns, the evaluation team was unable to construct Level 3 calculators for the sites.

The **Error Analysis** involved comparing savings estimates from the Tool to savings estimates from the metering data (Level of Rigor 4), and tracing sources of variance to account for any observed differences between the two. When doing this comparison, we focused on the most sensitive variables identified in the sensitivity analysis. We also examined key assumptions to identify any key differences.

For the final reporting of the Error Analysis results, the EMI Consulting team used the field data and the Tool outputs to report savings per site, as well as a space-by-space comparison where possible. These steps are outlined in more detail below:

1. Using the Tools obtained from the implementation contractor, we determined the variance between what the tool predicted and the savings calculated using the monitored data.
2. We attempted to identify the sources of variance by changing initial assumptions to actual conditions.
    a. We focused on the variables identified in the sensitivity analysis, including the control factors.
    b. We quantified how much each source contributed to the variance.
    c. Where possible, we documented whether there were substantial differences in the site values from the assumptions for occupancy, baseline conditions, LPD, or control factors.
3. We determined the range in variance for the different levels of rigor.

Collectively, this analysis was aimed at helping answer the question: "**What level of rigor with the Tool achieves the most accuracy with the least effort?** [25]

FACILITY MANAGER AND CONTRACTOR SATISFACTION

Due to the small number of facility manager and contractor interviews, no specific quantitative analysis methodology was used. Instead each question in the guide was mapped to the research questions and analyzed in aggregate.

USING THE CALCULATOR WITH THE LED ACCELERATOR DATA

The data received from Energy Solutions was entered into the Tool in two stages. The first stage included entering all the appropriate inputs for the Existing Inputs sheet and the Proposed Inputs sheet; essentially describing the existing and installed hardware in broad terms (i.e., "basic inputs" or "Level 1"). For the second stage a copy of the calculator was made, and data was entered into the Detail Inputs sheet (Level 2). The following sections describe accommodations we had to make for each project site and the impact on the calculated energy savings.

SITE 5

This project was limited to the storage portions of the facility. Ancillary support areas were excluded from the Tool. The existing luminaires were a combination of 400W HID (likely metal halide) and linear fluorescent lamps.

For the basic inputs (Level 1), the entire warehouse area was treated as one space. No other accommodations were necessary.

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[25] We define the metered results as the "best" estimate of savings. Therefore, we judged accuracy of savings predicted at the various levels against the metered savings.

As the detailed inputs were entered, the warehouse was split into two duplicate space types, one with daylighting and the other without. This allowed for the most accurate modeling of daylight availability. The lighting was then divided between the two space types, based on the lighting table provided by Energy Solutions. Energy Solutions did not have details on the skylights at Site 5 on hand. So, Google Earth imagery was used by kW Engineering to calculate the floor area and the skylight area to determine an internally consistent ratio of Skylight Area to Floor Area.

Site 6

This facility consisted of two key areas – a retail show room and a storage area. The existing luminaires were high-bay T8 and T5HO luminaires.

For the basic inputs (Level 1), the weekend schedule was approximated as there were unique Saturday and Sunday schedules.

For the detailed inputs (Level 2), Energy Solutions did not have details on the skylights at Site 6 on hand. So, Google Earth imagery was used by the kW Engineering to calculate the floor area and the skylight area to determine an internally consistent ratio of Skylight Area to Floor Area.

Site 7

This facility consists of eight areas classified for both warehousing and working products as well as ancillary support spaces, including office areas and restrooms.

For the basic inputs (Level 1), the weekend schedule was approximated, as there were unique Saturday and Sunday schedules.

For the detailed inputs (Level 2), the emergency lighting fraction was adjusted. The data available from Energy Solutions was used to adjust the daylighting model, but a significant impact was not seen.

Site 8

This facility appeared to be a telecom switching building, with about half of the project area dedicated to electrical and mechanical rooms. The existing lighting was largely fluorescent.

For the basic inputs (Level 1), the project site type was adjusted. Energy Solutions originally classified this building type as Small Retail. However, after examining the lighting table, the building was more accurately characterized as an office building, and we specified additional lighting zones to more accurately model the building.

The small office building type was chosen due to the number of space types in scope that better aligned with default space types for an office building. However, unlike most office buildings, this site has on-site staffing 24/7. Telecom switch centers are an edge-case use for the tool, making the identification of a perfect building type somewhat difficult.

The detailed inputs (Level 2), did not require any specific modifications from the data provided by Energy Solutions.

7. DETAILED RESULTS

The detailed results for each research activity are presented below. Included is a discussion of results, data limitations and their impact on results, and comments that integrate supportive or similar results from different research activities. Findings by research objective are presented in Section 5: Key Findings

7.1 NEAR-PARTICIPANT INTERVIEWS

Overall, near-participants cited cost as the primary barrier for ALCS adoption in general. Most near-participants did not move forward with the proposed project because the project did not meet ROI requirements. Some interviewees, however, reported complexity, timeline, and negative perceptions of lighting controls as additional factors. Interestingly, while energy and cost savings are the focus of most ALCS marketing materials, near-participant interviewees emphasized functionality, convenience, and "having the cool new technology" as the ALCS benefits customers are most interested in. Feedback suggests that ALCS technology is not being widely marketed and the majority of the feedback on future improvements to the program focused on lowering up-front costs. This supports the findings, discussed in other sections throughout the report, that current ALCS customers are early adopters who are installing the technology despite low cost-benefit.

The near-participant interviews were guided by the following objectives:

- Identify factors that contribute most to business customer interest in ALCS.
- Better understand challenges business customers face when deciding to pursue ALCS.
- Provide actionable suggestions for ongoing recruitment efforts.
- Provide actionable suggestions for improving the program offering.

The results for each of these objectives are discussed in detail below.

FACTORS THAT CONTRIBUTE MOST TO BUSINESS CUSTOMER INTEREST IN ALCS

ALCS marketing materials often stress energy and cost savings, describing how ALCS can automatically coordinate multiple control strategies to save end-users even more energy. While one of three contractors and two of four facility managers mentioned energy savings as a benefit of ALCS, none of them reported energy savings as the primary benefit that most interested them about ALCS.

Instead, contractors emphasized the functionality ALCS provides as the most interesting benefit to their customers. Two discussed how ALCS, in particular the dimming functionality, improves the light quality. One contractor said, "Too little light and customers complain; too much light and they say it's too harsh. ALCS is good because they get to customize their lighting to their needs." The fact that ALCS gives customers the opportunity to customize their lighting to their specific needs was also discussed by two contractors as a benefit of ALCS, who said, "People in spaces can customize the lighting to the task at hand."

When asked why their customers choose ALCS in general, none of the contractors discussed energy or cost savings. One said the customers who are most interested in ALCS are those who tend to leave lights on accidentally and do not want to. Another said convenience (e.g., if light switches are in inconvenient places). The third discussed the status or novelty of customers wanting the "cool new thing." They have observed that customers who have "spent money on standup desks and a high-tech security system, [are] willing to invest in their building." This observation implies that current ALCS customers are early adopters, which is supported by the results of this evaluation and discussed throughout this report.

All of the facility managers also discussed the functionality benefits offered by ALCS as the main benefits that attracted them to ALCS. One facility manager described how it was the equipment capability and design that attracted them to ALCS. They had a previous bad experience with less advanced occupancy sensors, where inaccurate triggering (lights going on/off inappropriately) resulted in complaints. A second facility manager discussed how ALCS was a "maintenance solution" for them, because their current system was old and it was difficult to obtain replacement parts. This facility manager did discuss how their awareness of the energy and cost savings potential of ALCS was also attractive. The last facility manager described how being green is an "important marketing distinction" for their company. They also reported that their building had "lots of glass and sunlight so [it] seemed like a good candidate." This facility manager also mentioned the building was seeking LEED certification.

Challenges Business Customers Face When Deciding to Pursue ALCS

The primary barrier to ALCS adoption in general is the high up-front cost. All of the near-participant contractors and facility managers interviewed cited cost as the primary challenge for customers. Further, all three contractors and two of the facility managers said cost was the main reason their respective sites did not participate in the Trial. Complexity, negative perceptions of lighting controls, and program timeline were other barriers mentioned by interviewees.

When asked about the barriers customers face when investigating ALCS, two of the participating contractors discussed how customers may not think the added cost of ALCS, relative to more simple controls, is worthwhile. In particular, one contractor said many customers "just don't see the cost-benefit of the incremental energy savings [relative] to the costs, [as] the same energy savings could be achieved with dumb controls, or with just occupancy sensors. So, unless they need daylight harvesting and demand response because of *code requirements*, it's hard to sell the package."

All of the near-participant contractors cited the cost-benefit of ALCS as the reason the sites did not proceed with the ALCS project. One contractor said the "incremental energy savings for the controls was not worth the added cost," while another said, "Quicker payback was the biggest challenge," and the last contractor said, the additional cost relative to the simple control system they chose was not worth the rebate." This last contractor also said that the "savings from the advanced versus the simple controls would not pay for itself in a useful period of time." Contractors reported that a two to three-year payback, at most, is what customers are willing to accept. While all the contractors stated bigger rebates could help ALCS adoption, they said the true challenge is the lack of available up-front capital. As rebates can take a while to materialize, contractors believed adoption would not increase substantially until the cost of materials comes down. Alternatively, one contractor mentioned on-bill financing as a potential option for increasing the adoption of ALCS, because such an option could help to alleviate up-front costs for customers.

Similar to the near-participant contractor's feedback, two of three near-participant facility managers also cited cost-benefit as the main reason they did not participate in the Trial. One facility manager was looking at upgrading their sites' controls (i.e., not replacing their fixtures), but the ALCS project scoping determined their ballasts were not dimmable.[26] The cost to upgrade the T5 lighting to include dimmable ballasts in addition to the controls would have vastly increased the scope of the project and resulted in payback period that was too long. This facility manager, similar to the contractors, reported they only consider projects with a ROI under three years. When asked what would have helped them to participate, this facility manager said that receiving a rebate for their ballast and other infrastructure upgrades would have helped to bring the ROI for the total ALCS project closer to their requirements.

In addition to cost, three other potential barriers to customer adoption were mentioned by interviewees. One of the contractors discussed how previous bad experiences with lighting controls can be a challenge for some customers when considering ALCS. Some customers have a negative perception of lighting controls because they did not like having to wave their arms to turn the lights back on after the occupancy sensors turned lights off. One facility manager reported a similar challenge when they installed a lighting control product in an executive office: the lights timed out due to the occupancy sensor, and the occupant had to walk over to the switch to turn them back on. As a result, some end-users may think that ALCS is not always appropriate for every space. Another contractor cited complexity as a potential barrier, discussing how customers expect their lighting upgrade to be much simpler, like installing a sensor and switching to LEDs, than a full upgrade to ALCS. One facility manager discussed how ALCS' were too complicated for their maintenance team to manage. The third contractor cited the program timeline as a barrier, discussing a building where they did install ALCS but didn't participate in

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[26] The Facility Manager stated that the dimming capability got "value engineered" out of a previous lighting project.

the PG&E Trial because it "would have taken too much time to put through the program, and the client needed it in a hurry."

One facility manager discussed uncertainty regarding how much additional energy savings ALCS could provide on top of switching to LED lighting and how, as a result, they were uncertain to invest in the ALCS technology as the "costs were really high" compared to the "marginal savings" they would achieve. In addition to the cost-benefit, this facility manager cited several other reasons they did not participate in the Trial:

- Learning about ALCS and how it worked took a long time. They ended up needing to proceed with their LED upgrade before their education process was complete.
- Institutional anxiety about changing to an unfamiliar and complex system, especially as they had heard stories about ALCS not working.
- Most of their clients are high energy use laboratories. So even though lighting might be a high dollar amount, within the lens of total bills, lighting is a small portion of their energy use.

One facility manager, when asked what would have helped them participate in the Trial, said rebates would have helped address some of the costs. However, they also said that "being able to quantify the savings would have been the most helpful"[27] and having a demonstration project to help customers understand what ALCS is and how it works would have also helped.

Another facility manager was working with a manufacturer on a proposal for an ALCS system. However, this facility manager said the contractor was not willing to share the worksheet they were using to do their calculations. Without seeing the calculations and financial justifications behind the energy and cost savings claims, the proposal did not pass muster for this customer. They did not offer any suggestions on what would have helped them to participate in the Trial.

Of the six near-participant sites discussed in these contractor and facility manager interviews, four of the projects moved forward with simple controls (off the shelf-occupancy/motion sensors) and LED upgrades. Two sites had not completed any projects at the time of the interviews.

Suggestions for Ongoing Recruitment Efforts

The primary source of Trial awareness for contractors and facility managers was through PG&E representatives. Two of three contractors and two of three facility managers learned of the Trial through discussions with their PG&E representatives. In all four cases, the PG&E representative, as part of a discussion with the near-

[27] The evaluation team does not know if this facility manager saw the Tool but based on their feedback they likely did not.

participant about possible projects, brought up the Trial as a good opportunity to achieve additional savings. The third contractor learned of the Trial from the Trade Pro Alliance web page, while the third facility manager learned of it “on their own”. This facility manager said they are “always out there looking for these types of things.” As the near-participant interviews were conducted part-way through the recruiting effort, the remaining recruitment efforts focused on the “middle-out” methodology described above, wherein the Trial implementation contractor engaged PG&E Trade Pro managers and BES representatives to conduct outreach assistance in order to leverage existing relationships.

Near-participant contractors and facility managers thought the following types of sites best fit the program:

- Private businesses (one interviewee)– As the cost for ALCS is still high, private businesses are more likely to have the available up-front capital to do projects. Buildings such as schools, are less likely to have the needed up-front capital.
- Office buildings (two interviewees) – Office buildings have many occupants all who have different preferences for their lighting needs. One of the main advantages of ALCS is the ability to customize lighting levels to occupants’ needs.
- Warehouses (two interviewees) – Warehouses have irregular occupancy with staff routinely going in and out. ALCS controls are a good fit for this type of occupancy pattern.
- Property management firms and owner-occupied buildings (one interviewee) – These types of owners are more likely to accept paybacks that are longer than the typical two to three-year payback, which would be more accommodating to ALCS payback periods.

In general, ALCS is not being widely promoted, and companies that are deciding to pursue ALCS upgrades tend to be “early adopters.” All three of the near-participant contractors indicated they rarely bring up the idea of ALCS with customers. One near-participant contractor said they are “currently looking for stability [and are] not trying new things with their pipeline.” One of the near-participant contractors does bring up ALCS as an additional opportunity if their clients are already considering a lighting and controls upgrade. The other two, however, said they have never had a customer ask for ALCS. Similarly, two of the near-participant facility managers had never heard of ALCS before the PG&E representative discussed it with them. The one near-participant facility manager who had heard of ALCS is part of a company with a 100% renewable goal, and said this company follows new technologies closely because they are always looking for additional energy savings opportunities. Collectively, these findings corroborate findings from the interviews with participating facility managers and contractors and suggest that customers most likely to pursue ALCS projects are those who are interested in staying on the front end of the latest technological developments, even if there is some uncertainty regarding performance or cost.

Findings from these interviews indicated that the main barrier to participation for near-participants was cost, suggesting that future recruitment efforts should focus on how the Trial *reduces* the up-front cost. Also, interviewees said focusing messaging on customization and improved light quality might help. Continuing conversation and outreach would help to keep the program top of mind, as one contractor said, they "do not recommend the PG&E ALCS program for no reason, it is just not on the top of [their] mind."

Suggestions for Improving the Program Offering

The near-participants interviewed offered several ideas for improving a future program offering:

- Reconsider rebates that are being reduced or eliminated by PG&E, as the incentives really are needed to help offset the high cost of ALCS.
- Offer a deemed incentive, per sensor.
- Have an integrated incentive that covers the whole system upgrade (bulbs and ballasts)
- Eliminate the monitoring requirement, as it delays installation (two interviewees cited this). There are other methods for collecting similar data to evaluate the Tool's accuracy, as described in the on-site monitoring section.
- Conduct a side-by-side comparison of different systems to test and report on their functionality as not all installations work as intended. This would offer transparency into the market into the features and functions of the various products.
- Have a demonstration project where customers can come and see how ALCS works.
- Offer a method for quantifying savings. As such, it seems these near-participants did not experience the Tool as a part of the Trial.[28]
- Have a PDF or handout about ALCS for different types of people including financial people and facilities people that explains the technology with the different information they need in an overview.

7.2 CALCULATOR TOOL INITIAL ASESSMENT

The Calculator Tool Initial Assessment reviewed the ALCS Calculator 'Beta Version 1.0b6-CA.'

Our key findings from the initial assessment were:

[28] No information was available from the Trial regarding whether the near-participants interviewed were shown the Tool during the sales process.

- The formulae and theory in the tool appear to be developed in keeping with the literature and best practices, as applicable.
- Where we could verify the implementation, the Tool appears to be implemented in keeping with the documentation with two exceptions: the savings do not appear to take into account the type of lighting or ballasts as described in the documentation and the documentation description for daylight zones is not in the model.
- The underlying assumptions for the control factors are based on very limited data that does not cover all building types in the model and, in some cases, does not cover the control type at all. The most critical function of the tool for calculating savings is building control factors for ALCS. This is also where the Tool exhibits the greatest uncertainty.
- There were multiple instances where we could not trace a variable's impact because of the complex lookup method which relies on matching numbers in rows and columns to identify another value. This is not only a risk to our sensitivity analysis and key variable assessment but also presents a risk to ensuring modifications to the tool are complete.
- There are a number of exceptions to the Title 24 requirements that the tool does not capture; ultimately, this means that the savings from code baseline can be conservative when these exceptions apply.

A summary of the results, including a review of the formulas and theory, sensitivity analysis, and variable review, is presented below. The full memo for the calculator tool initial assessment is in Appendix F.

REVIEW OF FORMULAS AND THEORY

The documentation of the Tool is technical, covering the calculation methodology, building prototype development, and control factor development. Instead of repeating the descriptions given in the Tool documentation, this analysis answered two overarching questions about the Tool design and theory:

- Is the intended approach sound and consistent with industry best practices?
- Is the intended approach from the documentation reflected in the Tool programming?

Each of these questions is discussed in the following sections.

Is the Intended Approach Sound and Consistent with Industry Best Practices?

The intended approach in the Tool is to simplify energy savings calculations by setting up a framework for default spaces and buildings, where prototypical values are pulled in to develop savings estimates. Users can modify the defaults based on their knowledge of the project. **This evaluation found that the intended approach of the Tool is sound and is consistent with industry best**

practices. The defaults and prototypical values for building and lighting data are derived from multiple studies and described in the Tool documentation. Therefore, we assessed the documentation for the prototypes, the control factors, and the savings calculations.

The Tool prototypes are based off of the Database for Energy Efficiency Resources (DEER) and ASHRAE spaces. The underlying prototype assumptions were vetted through the California Public Utilities Commission (CPUC) and ASHRAE and are a valid and referenced starting point.

The control factors are derived from the lighting energy use profiles, which are 24-hour curves based on the expected performance of the lighting control. However, there is a lack of extensive literature on this topic; a meta-study from 2012 was the primary reference for the implementation of the control factors and the control factor multiplication method. As such, we reviewed the references and approach for each control type and assessed whether the approach was reasonable, identified possible issues with the approach, and provided additional comments where relevant.

- For Occupancy Sensors, the Tool relies on three studies: a meta-analysis of lighting controls savings covering 7 building types, a study of occupancy patterns, and a study of the probability that people turn lights on.[29] Essentially, data on expected occupancy settings and savings by building type (for 7 building types) is mapped to the 23 ALCS Tool prototype building types. Partial occupancy reductions are implemented by simple multiplication. The Tool attempts to adjust occupancy sensor savings for the percent of the space that may be impacted by daylight sensors.
- For Daylight Sensors, the Tool relies on a study of daylighting in offices and a study on predicting daylighting irradiance.[30] The general idea is to simulate the amount of available radiance without requiring extensive calculations. The Tool develops an hourly curve for each of three zones (primary, secondary, and not daylit). The curve depends on illuminance (from radiance templates), required illuminance (entered on '3 Detailed Inputs'), and type of lighting. The documentation is not clear, and the Tool is not clear, but it appears that the developers ran 9,270 simulation runs to develop 4 radiance templates. Essentially, based on the amount of daylight illuminance and the required illuminance, the lighting percent required (on the portion of lighting in the daylight space) is adjusted to develop a curve. The documentation refers to separate lighting energy use profiles or impacts by lighting type, but the lighting energy use profile is a blended profile. There likely is an

[29] Williams A, Atkinson B, Garbesi K, Page E, and Rubinstein F. 2012. Lighting Controls in Commercial Buildings. Leukos. IESNA: 8.6. Chang WK, Hong T. 2013. Statistical analysis and modeling of occupancy patterns in open-plan offices using measured lighting-switch data. Building Simulation: 6.1. D.R.G. Hunt. 1979. Building and Environment. Pergamon Press. 14:22-23.

[30] Saxena, M. (Heschong Mahone Group). 2011. Office Daylighting Potential. California Energy Commission. Publication Number: CEC- 500- 2013- 002 and Saxena M., Ward G., Perry T., Heschong L., Higa R. 2010. Dynamic Radiance – Predicting Annual Daylighting with Variable Fenestration Optics Using BSDFs. Proceedings of 2010 IBPSA SimBuild Conference. New York.

interaction with the "enhanced daylighting options." It is not clear how the daylight sensor control factor is developed.

- A note on implementation: The documentation refers to separate calculations for primary, secondary, and not daylit portions of lighting, but the Tool does not have a place to define these regions. The portion of lighting in the daylight zone defaults to 20% for each kind of lighting, and this value is in the '3 Detailed Inputs' tab. Users may not realize where to find this value in the spreadsheet. The other "80%" is not defined as secondary or not daylight. In addition, users may not realize that the lighting type does not have an impact on savings (per our sensitivity analysis discussed below), so may expend extra effort trying to identify the type of lighting within each portion of daylighting.[31] Similarly, users may not realize that the required illuminance by space type (in lux) is on the '3 Detailed Inputs' tab, with a default by space type – these defaults appear reasonable compared to ASHRAE 90.1 guidance.
- For Demand Response, there are no cited studies, but the development of the control factor is sound, assuming the user enters appropriate values. The Tool allows modeling of between 3-20 events per year. The number of events called per year depends on the utility, but the user can input the number of events expected, the percent of the wattage impacted (0% to 100%), and the percent that the lighting can be dimmed during an event (0% to 100%). The control factor is based on the utility peak period (which can be modified by the user), assuming an equal distribution of the events across the peak season. During an event, the control factor is based on the multiplicative value between the wattage impacted and degree of dimming. Assuming that 100% of the wattage is covered and the dimming is 25%, and there are 5 events, each event would show a 25% reduction in the lighting energy use profile. The biggest risk here is for users who: incorrectly define the peak period, enter an optimistic number of events (like entering 20 when the typical number is 5), or do not update the portion of wattage and degree of dimming.
- For Task Tuning, the Tool documentation indicates that users must input this value because there is not enough existing literature to determine reasonable values. The Task Tuning control factor is developed as an even reduction in power across operation hours with a default of 20% and a possible range of 10% to 50%. The meta-analysis is cited here again.
- For Manual Dimming, the Tool documentation indicates the same method as Task Tuning and suggests that users must input this value because the literature does not cover enough instances. The Manual Dimming control factor is developed as an even reduction in power across operation hours with a default of 10% and a possible range of 5% to 40%. The meta-analysis is cited here again.

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[31] EMI Consulting expected lighting type to matter because there are different assumptions identified in the documentation regarding ballasts and response. However, we did not see an impact of changing the lighting type.

- For the Time Switch, the Tool does not indicate any references. The time switch is implemented in the same way as changing the facility operating hours (discussed above). The default of one hour before and after is reasonable but may not be conservative.

The Tool presents savings as the difference between the calculated energy consumption of the proposed condition to that of the baseline and Title 24 code. The calculations are based on annualization of the underlying prototype data for the energy savings and identifying average savings during the peak period for demand savings. The implementation of the formulae and concepts employed for the savings calculations in the Tool are reasonable and straightforward. However, the documentation lacks a description of how the calculations are done or what is included. For example, the documentation could be clearer that HVAC interactive savings are not included, as these may be significant in some installations.

Is the Intended Approach from the Documentation Reflected in the Tool Programming?

Overall, the descriptions provided in the manual were reflected in the Tool. However, in many cases, the manual suggests that the user input data because the default is questionable, but the user is not urged to do so in the Tool. The Tool is a Microsoft Excel Workbook that is driven by a complex set of lookup references which fill in key cells with the prototype value based on a match to the user entry. For example, when the user first selects the type of building on the 'Existing Inputs' tab, the Tool automatically populates the building size, ceiling height, floors, operating schedule, type and extent of spaces, and the type of lighting, lighting power density, lighting controls, and usage by space. From the sensitivity analysis and error analysis tasks, we know the building square footage is a key driver for the accuracy of the savings and something the user should override to further refine the savings analysis. However, this is not highlighted nor encouraged in the Tool.

The approach in the documentation is also implemented in the Tool, except the savings does not appear to include the type of lighting or ballasts as described in the manual.

While the intended approach from the documentation is mostly reflected in the Tool programming, the implementation with complex lookups is difficult to follow and might prove difficult logistically to update, especially if the person (or persons) who developed the Tool are not available. The lookups are not coded to be human readable, as the complex lookup method relies on matching numbers in rows and columns to identify another value. We strongly urge updates of the Tool to shift to a human readable (and commented) lookup method.

Sensitivity Analysis

The overall responsiveness was evaluated based on the changes across the four energy and demand outputs for 23 buildings. Of the 37 inputs tested, 30 were responsive – 8 demonstrated a high responsiveness, 10 medium, and 12 low (as shown in Table 7-1 below). The remaining seven inputs had no responsiveness to variation over their range. In each case, we considered how the variable was coded and how it is expected to contribute to savings calculations. Some variables were more responsive in particular buildings; this relates directly to the prototype selections and codes underlying the Tool. Some variables are more responsive when comparing energy or demand or to code rather than baseline. These results were used to guide the sources of variance in the on-site monitoring analysis discussed below.

Those that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all, were included in our variable review (discussed in the next section).

Detailed Results

Table 7-1. Overall ALCS Calculator Tool Input Variable Responsiveness

Input Variable	Relative Responsiveness	Included in Variable Review?
Building size (sq. ft.)	High	Yes
Existing lighting controls	High	Yes
Existing LPD	High	Yes
Occupied start time	High	Yes
Percent on by hour	High	No
Project type	High	Yes
Proposed lighting controls	High	Yes
Proposed LPD	High	Yes
Code trigger reason	Medium	Yes
Code trigger Y/N	Medium	No
Demand response control	Medium	No
Manual dim percent	Medium	Yes
Occupied end time	Medium	Yes
Portion of lighting daylight	Medium	No
Skylight visible transmittance	Medium	No
Task tuning dim	Medium	Yes
Window visible transmittance	Medium	No
Building ceiling	Low	No
Daylight sensor control	Low	Yes
Demand response events	Low	No
Exterior wall window wall ratio (WWR)	Low	No
Majority windows facing	Low	No
Manual dim type	Low	No
Occupancy sensor delay	Low	No
Occupancy sensor type	Low	No
Occupied days	Low	Yes
Permit cycle	Low	Yes
Time switch	Low	No
Zip code	Low	No
Ballast type	None	Yes
Building floors	None	Yes
Daylight sensor zone	None	Yes
Enhanced daylighting	None	Yes
Installed lighting portion	None	Yes
Minimum lighting level	None	Yes
Unoccupied percent on	None	Yes

VARIABLE REVIEW

Based on the results of the sensitivity analysis above, the variables that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all, were analyzed to verify their sources of reference and proper application. The Tool was also reviewed to evaluate the extent to which Title 24 exceptions are captured. Each of these analyses are summarized below, with key takeaways from each variable highlighted.

Summary of Variable Review

A brief discussion of each variable that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all, is included below. The full detailed analysis of each variable is presented in Appendix F.

- **Building size (sf).** The building size is used in calculations for control factors, lighting power density (LPD), and space square footages and is a large driver of overall savings. Because this parameter has substantial influence on the final savings estimates, **users should be strongly urged to modify this value even at their very first screening phase**.
- **Code trigger reason.** While the "Yes" and "No" override has a medium sensitivity, the code trigger default is reliant on room size, LPD, window area for certain control types, building types, and space types. Therefore, it is important to emphasize to the user the importance of inputting those particular values rather than relying on defaults. If the user understands the variables influencing the code trigger, this reason and the code trigger should be able to remain at the default. In addition, **a note should be added that changing the reason for the code trigger will change code savings and is not just a documentation reference for the selection of "Yes" or "No"**.
- **Proposed lighting controls.** The user may modify the proposed lighting controls to select "Yes" or "No" for the full list of control options available. The tool then develops controls factors for each selected control strategy that applies to the DEER based lighting energy use profile for each space. For the sensitivity analysis, we tested a combination of Daylight Controls, Demand Response, Task Tuning and Manual Dimming controls by turning them "On" and "Off." We observed large changes in savings suggesting that these variables are together highly sensitive; individually, Task Tuning and Manual Dimming variables appear the most sensitive. Unfortunately, these are some of the control factors for which the documentation and literature suggest limited information on which to base assumptions. Thus, it is important for the assumptions underlying the control factors and other relevant parameters for these variables to be as accurate as possible. Our review indicates that for the most part, the basis for the Daylight Controls assumptions are adequate. The hourly illuminance is not directly based on studies, but instead are based on four pre-ran radiance models that are matched based on the user defined inputs and appear to be a reasonably thorough method for implementation. Also, the lux set point and lighting

technology mix assumptions appear to be based on best available data. However, for the Demand Response controls, the control factor is based on limited information using the utility peak period, events and wattage provided by the user. The Tool currently provides default values for control wattage, events per year, and event power reduced, but does not show supporting data for these. Manual Dimming and Task Tuning are sensitive variables, and the default assumptions are based on insufficient data. Therefore, we recommend that the tool should alert the user more clearly that the details about the proposed lighting controls are required input values. As stated for other variables related to the lighting controls, given the uncertainty in the literature, the **implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available**.

- **Task tuning dim.** See proposed lighting controls input review above.
- **Existing lighting controls.** A combination of time switching and occupancy sensors in the existing case were tested. Large changes in energy savings were observed, suggesting that these inputs were highly sensitive, although testing them individually showed lower sensitivity. According to the manual, and also due to a lack of sufficient study data, the user is expected to enter the type of occupancy sensor and the delay off time setting. The default for delay time is reasonable, if not conservative. However, according to the manual there were no reasonable studies that provided default savings for time switches. Thus, the default assumptions may or may not be reasonable. As this is a sensitive variable, **we recommend that the user be encouraged and enabled to modify those assumptions**.
- **Existing LPD.** The implementation is consistent with the developer's manual and best practices.
- **Manual dim percent.** The manual indicates that there is not enough data to derive models of the manual dimming percent. Similar to other control factors (see proposed lighting controls above), given the uncertainty in the literature, the **implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available**.
- **Occupied days.** The lighting energy use profile curves for weekends are still in place when weekends are occupied, and weekends have usually very low energy use profile curves per the DEER values. If the default values have very low weekend energy use and the facility under analysis has weekend use similar to weekday use, the user should modify the usage profile. **A flag or guidance to the user could be added to ensure this is communicated**.
- **Occupied start and end times.** The default values have valid sources and the approach to modifying these inputs are reasonable. However, both the start and end times are moderately to highly sensitive inputs, so **attention should be paid to setting these variables as accurately as possible**.

- **Permit cycle.** The low responsiveness is valid as changing the permit cycle does update the existing LPD and controls, which impacts the consumption and savings.
- **Project type. This is a critical input to set correctly**. As such we recommend adding more clarifying guidance for users to better understand how the project type and permit cycle inputs are used. For example, in the current Tool implementation, it is not clear to users that the permit cycle is meant to populate the existing building defaults, and that changing the project type clears out the existing building savings output.
- **Proposed LPD.** Proposed LPDs are required user inputs, so there are no LPD assumptions to verify. The proposed LPD entries all appear to be properly referenced in the underlying virtual models and the savings calculations.

The implementation for the seven variables that exhibited no responsiveness was also assessed. A summary review is below, and the detailed review can be found in Appendix F.

- **Ballast type, enhanced daylighting, unoccupied percent on, and minimum lighting level.** These inputs were traced through the virtual models, and the resulting values have no formulas that refer to them. This suggests either a coding error or that it was impossible to trace due to the complex referencing method employed by the Tool.
- **Building floors.** This input was traced through the virtual models, and the resulting values have no formulas that refer to them. Based on our understanding of the virtual models, there is no reason to include building floors except for a reference to the user, as it is a necessary piece of information for project installation.
- **Installed lighting portion.** This input was traced through the virtual models, and the resulting values have no formulas that refer to them. This suggests either a coding error or that it was impossible to trace due to the complex referencing method employed by the tool. However, a review of the documentation and the underlying lighting energy use profiles do not mention the type of lighting or ballasts. The LPD is the only lighting value used in these calculations.
- **Daylight sensor zone.** The manual does not document how secondary and primary zones are determined for a site; nor does it state what assumptions make the basis for the percentage of space allocated to each zone for each space type or building type. The manual also does not describe the effect of selecting a daylighting zone. Therefore, it is difficult to understand whether the savings should change based on a change in selecting the zone. We suggested developing additional documentation and clarity on this variable.

Application of Title 24 Code Requirements

We reviewed the Tool to evaluate to what extent Title 24 exceptions are captured. **We found that the Tool is unable to identify—and thus quantify—incentive-eligible control applications that code specifically exempts**, as detailed below.

The Tool's primary method for applying Title 24 code requirements is through the underlying reference models for required lighting and lighting controls. Therefore, this review is more global than the single inputs review above. The version of the Tool that we reviewed is designed to reflect the most recent (2016) Title 24 code.

A card on the Proposed Inputs tab lists the code triggering options. By default, the Tool assumes code is triggered by the following events:

- Adding any control device to space where one does not already exist.
- Populating the proposed LPD (regardless of whether it is different from the existing system)

Generally speaking, the Tool does not handle the following blanket modifications/exceptions to Title 24 lighting control requirements:

- Entire Luminaire Alterations occurring in a space with one or two luminaires[32]
- Luminaire Component Modifications occurring in a space with one or two luminaires[33]
- Lighting Wiring Alterations in space affecting one or two luminaires[34]
- Lighting Wiring Alterations specifically to accommodate lighting controls with no luminaire modifications[35]

The Tool cannot capture the first three modifications because the spaces are aggregated by space-type line item. Thus, the specific nuance of these modification is lost. The last modification, however, adding controls to an existing system, is specifically exempt from Title 24 and should be captured in the Tool for maximized utility-claimed savings.

Similarly, the Tool does not handle partial exceptions in the following cases:

- Entire Luminaire Alterations occurring in office, retail, and hotel occupancies achieving 50% LPD reductions[36]

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[32] Title 24-2016 §141.0 (b) I ii Exception 2, grandfathered in to Title 24-2013
[33] Title 24-2016 §141.0 (b) J ii Exception 2, grandfathered in to Title 24-2013
[34] Title 24-2016 §141.0 (b) 2 K Exception 2, grandfathered in to Title 24-2013
[35] Title 24-2016 §141.0(b) 2 K Exception 1 and Title 24-2013 §141.0(b) 2 I iv Exception
[36] Title 24-2016 §141.0 (b) 2 I ii, grandfathered in to Title 24-2013

- Entire Luminaire Alterations occurring in other occupancies achieving 35% LPD reductions[37]
- Luminaire Component Modifications occurring in office, retail, and hotel occupancies achieving 50% LPD reductions[38]
- Luminaire Component Modifications occurring in other occupancies achieving 35% LPD reductions[39]

The Tool does not claim savings or incentives for hardware that is not required by code, given the exceptions for significant reductions in energy through high-efficiency retrofits (evaluated via a reduced LPD). The calculator correctly identifies when code compliance is required for a section (e.g. §130.5 (d) is triggered for Daylighting), but the calculator does not have the flexibility or specificity to allow users to identify that code would provide an exception from that section (e.g. rooms with windows <24ft² or ≤120W of lighting in the daylit zone do not have to have daylighting). Thus, projects that exceed code by installing daylighting controls where an exception exists do not capture this increased performance. The following control strategies captured in the tool where exceptions existing include the daylighting, demand response, task- tuning, and manual dimming.

Further, using the space-type roll-up methodology discussed above, the Tool is unable to identify—and thus quantify—incentive-eligible control applications that code specifically exempts. We have summarized the exceptions the Tool does not capture below and noted the relevant section of code (note, the citations pertain to Title 24-2016; however, most of these exemptions exist in Title 24-2013).

- Individual Areas < 100 sf do not require multi-level controls[40]
- Individual Areas with an LPD ≤ 0.5 W/sf do not require multi-level controls[41]
- Classrooms with an LPD ≤ 0.7 W/sf require only bi-level lighting controls[42]
- Public restrooms only require bi-level lighting controls[43]
- Spaces with a single luminaire do not require multi-level controls[44]
- Areas requiring partial-OFF or full-OFF controls do not require multi-level controls[45]
    - Warehouse aisle ways and open areas
    - Library book stack aisles
    - Corridors & Stairwells in Commercial buildings

[37] Title 24-2016 §141.0 (b) 2 I ii, grandfathered in to Title 24-2013
[38] Title 24-2016 §141.0 (b) 2 J ii, grandfathered in to Title 24-2013
[39] Title 24-2016 §141.0 (b) 2 J ii, grandfathered into Title 24-2013
[40] Title 24-2016 §130.1 (b)
[41] Title 24-2016 §130.1 (b)
[42] Title 24-2016 §130.1 (b) Exception 1
[43] Title 24-2016 §130.1 (b) Exception 1
[44] Title 24-2016 §130.1 (b) Exception 2
[45] Title 24-2016 §130.1 (b) Exception 3

  - Corridors & Stairwells in high-rise residential or hotel areas
  - Parking Garages
- Secondary daylighting zones are not required in existing buildings[46]
- Spaces with less than 0.3 W/sf that do not require continuous dimming daylighting controls[47]
- Spaces with fewer than 120 W/sf in the daylit zone that do not require daylighting controls[48]
- Rooms that have < 24 sf of glazing do not require daylighting[49]
- Buildings smaller than 10,000 sf do not require demand response controls[50]
- Spaces that use UL924 emergency shunts to turn off emergency lighting at night[51]
  - Areas with an LPD ≤ 0.5 W/sf are not counted in the DR load shed calculation and are thus exempt[52]

Users are allowed to override the code triggering statement (in the Tool) and claim incentives; however, the Tool does not capture specifics, including section of code that describes a useful exception. As such, verifying the accuracy of these inputs will be difficult without reaching-out to the party responsible for populating the Tool.

7.3 ON-SITE MONITORING

On-site monitoring was performed for the four participating sites. Of those sites, lighting efficacy improvements often outweighed the lighting control improvements (in terms of estimated energy savings). Task tuning was by far the biggest source of energy savings after efficacy improvements, followed by manual dimming controls. However, the separation between manual dimming and task tuning was somewhat blurry without the ability to check the ALCS interface remotely. Both task tuning and manual dimming savings are non-existent when the facility was either not task tuned during the programming phase (Site 1) or when the space was not provisioned with dimmers (Site 2).

Energy savings due to efficacy improvements were separated from energy savings due to control improvements using the metered power data and calculating an intermediate step for efficacy – using the post-installation luminaire wattages and the full-load operating hours from the pre-installation system. The results are summarized in Table 7-2. As expected, Site 1 had no efficacy improvement and

[46] Title 24-2016 §140.6 (d) is only triggered during additions or new construction
[47] Title 24-2016 §130.1 (d) 2 D ii
[48] Title 24-2016 §130.1 (d) 2 Exception 1
[49] Title 24-2016 §130.1 (d) 2 Exception 2
[50] Title 24-2016 §130.1 (e) 1
[51] Title 24-2016 §130.1 (a) 1 Exception 1
[52] Title 24-2016 §130.1 (e) 1

negative controls savings, due to the greater peak loads post-retrofit and the added private office. Site 2 likely over-estimated the metered energy savings attributed to efficacy improvement, since luminaire details were not provided. Site 3 showed negative efficacy savings due to the high number of burned out luminaires in the baseline. Site 4 showed the most dramatic improvement, both in terms of efficacy and controls, due to the reduction in installed power (2.4 kW to 1.2 kW) and a reduction in full load hours (from 7,070 hours per year to 3,000 hours per year).

Table 7-2. Energy Savings from Efficacy versus Greater Control Using Control Factors

Site	Efficacy Energy Savings	Control Energy Savings	Total Savings
Site 1	22	-672	-650
Site 2	902	38	940
Site 3	-212	332	120
Site 4	8,130	5,479	13,609

Overall the peak demand reductions and energy use reductions calculated using the control factors were generally consistent with the monitored results, as shown in Table 7-3. The modest differences are explained below:

- Site 1 shows differing demand reduction and energy savings, with the indirectly-calculated (control factor) demand positive, while the metered electrical demand reduction is negative. The difference is explained by the small increase in individual luminaire power consumption after the installation of the control modules on each luminaire. The spot check measurements used to calibrate the control factor model did not align with the long-term power trends observed over the course of the post-installation period.
- The Site 3 demand reduction difference is largely due to the misconfigured lighting controls. We installed one light output meter to verify the circuit status; however, post retrofit, the baseload was elevated for the duration of the study. We attribute this elevated baseload to added electrical load on the circuit not with lighting loads.
- Site 2 and Site 4 are relatively similar.

This means the calculated control factors appropriately disaggregate energy savings for each site. Site 3 had a significant disagreement due to the addition of the baseload in the post-installation monitoring period that is attributed to faulty programming of one of the zones (as discussed in the analysis approach section), which resulted in a large energy penalty in the monitored results.

Table 7-3. Summary of Energy Savings by Site

Site	Calculated Control Factors, Including Efficacy Improvement		Electric Power Metering at the Circuit-Level	
	Savings		Savings	
	Peak Demand (kW)	Energy Use (kWh)	Peak Demand (kW)	Energy Use (kWh)
Site 1	1.75	-650	-0.22	-1,241
Site 2	0.17	940	0.34	1,260
Site 3	1.25	120	-0.04	-711
Site 4	0.80	13,609	1.78	13,185

There are four general conclusions regarding measured energy savings:

- The energy savings calculated from on-site monitoring will not exactly match the estimated savings from the Tool, as the Tool's estimated savings includes spaces outside the monitoring scope.
- The energy savings do not provide feedback on daylighting controls, because these controls were not successfully implemented at any of the monitored sites.
- Spaces with existing occupancy sensors controlling the lighting do not see an appreciable reduction in metered energy use when the sensors are replaced with new ALCS occupancy sensors.
- The use of manual dimming controls varies significantly in a manner hard to predict. The blanket 10% manual dimming value used in the calculator likely underestimates how occupants use manual dimming controls. To attribute savings accurately either requires greater vetting of the system post-installation (using reported ALCS data) or more industry research to better characterize when, where, and how occupants use manual dimmers to develop and empirical model.
- Changes in light source efficiency had a much larger impact than changes in controls, suggesting that control programming is often lacking and that users may not receive adequate training to make use of the controls.

There were also a few recurring themes observed with data meter installation and data review:

- **System design, setup, and programming drives achieved control savings.** The monitored lighting control systems had a few deficiencies that prevented the projects from achieving their maximum savings. These deficiencies included improper application of daylighting controls, missing manual controls, excluding lighting systems, and task tuning settings that are not saved in the control system. While these lighting controls and strategies may be required by code for these areas, they're either not specified during design, forgotten during installation, or applied in spaces with dubious effectiveness. This has a negative impact on technology adoption due to the reduced cost-effectiveness of these projects.

- **Phantom loads[53] on lighting circuits decreased savings.** New luminaires with controls showed small phantom loads that persisted the entire time the system was connected to power, not just when the system is energized and emitting light. In some zones, these loads accounted for up to 500 kWh/yr. It is unclear whether these loads were associated with new equipment on the same electrical circuit or due to power draw associated with the newly installed lighting controls.
- **LED luminaire upgrades were difficult to differentiate from task tuning.** The implementation contractor did not provide information about the retrofit hardware to the evaluation team. We were able to verify some information after the monitoring hardware installation, leveraging information from the electrical distributor for Site 3 and Site 4. We could not accurately differentiate between an efficacy improvement and task tuning for Site 2.
- **The monitoring approach ended up being far more complicated and time-intensive than the project justified.** Only a subsection of spaces in these facilities was studied due to data collection and timeline limitations. Subsequent studies should consider using the ALCS interface itself, conducting a trained functional testing effort, and using an electric meter for the affected systems. If the concern is whether to trust the results of the ALCS system, it will be more cost-effective to perform a control bench-top verification that the system is trustworthy than to do a field installation of temporary metering equipment.

7.4 CALCULATOR TOOL TESTING AND ERROR ANALYSIS

The **Tool Testing and Error Analysis** involved comparing savings estimates from the Tool to savings estimates from the metering data, and tracing sources of variance to account for any observed differences between the two. When doing this comparison, we focused on the most sensitive variables identified in the sensitivity analysis. We also examined key assumptions to identify any key differences. As part of this analysis, we also compared two versions of the Tool to each other: (1) a "proposed Tool" which was expected to contain proposed controls and lighting upgrade information presented to the facility manager before the project commenced, and (2) an "installed Tool" which was expected to contain information on the controls and lighting upgrades as they were actually installed.[54]

Savings estimates from the Tool and the metered data are summarized by site and level of rigor below in Table 7-4. Overall, we observed the following:

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[53] A phantom load is any device that still consumers electricity when turned off.

[54] In practice, these two versions of the Tool were so similar that the evaluation team did not spend significant time exploring any minor differences between the two.

- **Existing Baseline.** Savings values as estimated by the Tool (Levels of Rigor 1 and 2) are internally consistent with each other (typically within 2%-5%), but do not generally align with savings estimates from the metering data (Level of 4), where variances range from roughly 37% to 130% of the Level 1 estimate.
- **Code Baseline.** For a given site, there is a high level of consistency between Levels 1 and 2. No comparison is possible with metered data.
- **Comparison Between Existing and Code Baselines:** There is general agreement for three sites between Existing Baseline savings and Code Baseline savings estimates within a given site and the level of rigor. Site 1, however, exhibits savings in the Existing Baseline scenario but higher energy use in the Code Baseline scenario.

These results lead to several broader conclusions:

- Given the finding that Level 1 and Level 2 estimates were almost identical in most cases, this suggests that the extra effort required to fill out a Level 2 tool is not required. In some cases, however, filling out the Level 2 inputs (i.e., the "Detailed Inputs" tab") may provide a contractor with the ability to more precisely estimate savings at the individual space level.
- The findings from the analysis of metered sites aligns with findings from the LED Accelerator test, which showed little or no difference between the Level 1 and Level 2 estimates.

It is important to note significant limitations associated with this site-level analysis.

- As noted earlier in this report, the energy savings calculated from on-site monitoring will not exactly match the estimated savings from the Tool, as the Tool's estimated savings includes spaces outside the monitoring scope.
- For each site, the evaluation team attempted to match spaces from the metered data with spaces in the Tool. However, this mapping was not able to be verified with the implementer, resulting in potential errors in cases where the spaces had not been accurately mapped to one another.
- The evaluation team collected two Tool spreadsheet files, a proposed case and an installed case, that were filled out by the implementation contractor for each site. The purpose of collecting the Tools from the implementation contractor was to give the evaluation team the detailed inputs needed (i.e., Level 3 site audit) to calculate savings estimates from two baselines for the four levels of rigor for each site. The Tools received, however, were Level 2 and lacked the site audit details needed to construct a Level 3 analysis. Without supporting data, such as the contractor's scope of work, hardware and controls submittals, space by space inventories, as-built hardware and quantities, and notes from interviews with occupants about usage patterns, the evaluation team was unable to construct Level 3 calculators for the sites.

Table 7-4. Energy and Demand Savings Values by Site and Level of Rigor

Site	Level of Rigor	Existing Baseline				Code Baseline			
		Energy Savings (kWh)[a]	% Variance (relative to Level 1)	Demand Savings (kW)[a]	% Variance (relative to Level 1)	Energy Savings (kWh)[a]	% Variance (relative to Level 1)	Demand Savings (kW)[a]	% Variance (relative to Level 1)
Site 1	1	19,488.70	-	6.8	-	-16,767.80	-	-5.2	-
	2	20,485.80	5.1%	6.9	1.5%	-16,544.10	-1.3%	-5.2	0.0%
	4	-3,181.02	-116.3%	-1.23	-118.1%	b	b	b	b
Site 2	1	83,987.40	-	34.1	-	53,207.50	-	15.4	-
	2	86,109.40	2.5%	34.7	1.8%	54,010.20	1.5%	15.4	0.0%
	4	115,009.13	36.9%	51.6	51.4%	b	b	b	b
Site 3	1	54,922.90	-	10	-	30,665.10	-	4.2	-
	2	54,922.90	0.0%	10	0.0%	30,597.40	-0.2%	4.3	2.4%
	4	13,980.37	-74.6%	-2.91	-129.1%	b	b	b	b
Site 4	1	22,849.40	-	4.2	-	9,021.90	-	1.1	-
	2	22,849.40	0.0%	4.2	0.0%	9,262.70	2.7%	1.2	9.1%
	4	35,962.59	57.4%	6.5	54.8%	b	b	b	b

[a] *Energy savings values for Level 4 were back-calculated from the % savings values.*

[b] *Code Baseline values for Level 4 could not be calculated using metering data.*

The Error analysis focused on identifying possible reasons behind the discrepancies between the savings estimates from the Tools and the savings estimates from the metered data. In this analysis, the research team focused on those variables that the sensitivity analysis had identified as highly sensitive. By analyzing how the tools had been filled out, we were able to qualitatively assess the likelihood that each of these variables would have on savings estimates *in practice*:

- Four of these variables were qualitatively determined to have a high likelihood of affecting savings estimates: (1) the specification of existing lighting controls, (2) the existing lighting power density (LPD), (3) the specification of proposed lighting controls, and (4) the proposed (post-retrofit) LPD.
  - In particular, we found that in several instances, the proposed LPD had not been modified, and therefore would not account for changes to equipment in a given space. Based on the data we collected during the on-site monitoring, three of the four sites in fact included a luminaire retrofit in addition to controls installation and would have experienced a significant change in pre- and post-retrofit LPD. However, as discussed in the on-site monitoring section, **LED luminaire upgrades were difficult to differentiate from task tuning in the data.** No information about the retrofit hardware was provided to the evaluation team. We were able to verify some information by contacting the contractors directly to obtain model numbers. Site 2 replaced 100W two-by-four troffers with LED luminaires and experienced a reduction in peak power of about 700W. There was no information about the differences in equipment installed for Site 3, but the site did experience a reduction in peak power of about 600W based on our on-site monitoring. We know Site 4 had a luminaire retrofit but no further data was available to the evaluation team. Through the facility manager interviews we found that the implementation contractor, not the ALCS contractor, filled out the Tools for participating sites. As they are not a lighting specifier nor a lighting contractor, obtaining correct LPD values would be difficult. **Since changing the LPD was the only source of variance found for each site, as detailed below, we believe not having correct pre- and post-retrofit LPD values accounts for the majority of the differences between the Tool estimates and the monitored estimates. Going forward with Tool implementation it should be clearly indicated in the Tool that inputting correct pre-retrofit and post-retrofit LPD values is critical to getting accurate savings estimates.** Within the Tool, it was not obvious that such an error had been made. Thus, this variable was determined to have a high practical likelihood of impacting savings values.
- Another three variables—including building size, occupied start time, and project type (i.e., alteration vs. new construction)—were determined to have a lesser practical impact, as these variables are easier to specify within the Tool (and result in more obvious errors when miss-specified).

- In the case of project type, a critical difference is based on the applicable building code. Since the Tool limits which codes can be selected, it is less likely that a user will select the wrong one.

These results are shown below in Table 7-5.

Table 7-5. Summary of Practical Impacts of Key Variables in Tool

Input Variable	Practical Likelihood of Impacting Savings Estimates
Existing lighting controls	High
Existing LPD	High
Proposed lighting controls	High
Proposed LPD	High
Building size (sf)	Low
Occupied start time	Low
Project type	Low

In the following sections we provide more details on the results of the Tool Testing and Error Tracing analysis for each metered site.

SITE 1

For Site 1, we were able to directly compare the savings estimates from the metered data with savings estimates from the Tool for three spaces.[55] As shown in Table 7-6, there was not agreement between these two sets of savings estimates except for one space (the conference room), which showed a moderate level of agreement. From the metered data analysis, we observe that Site 1 had no efficacy improvement and negative controls savings, due to the greater peak loads post-retrofit and the added private office.[56] So whereas the metered data showed savings only for the conference room, the Tool showed savings for all three zones. The conference room showed some degree of agreement (16% from the metered data; 27% from the Tool).

[55] As discussed in the "Error Tracing" section for Site 1, the tool received from the implementer classified the building as a "Large Office," though this led to an estimate of "anti-savings." The evaluation team re-classified the site as a "Small Office" before running the analyses shown here.
[56] This retrofit involved no change in luminaires. The new control system was layered on top of the existing LED lighting

Table 7-6. Site 1 Comparison of Savings Estimates by Zone

Metered Data (Level 4)				Tool (Level 2)	
Zone	Overall % savings	Efficacy % savings	Controls % savings	Zone	Overall % savings
Private Office	-26%	-	-26%	OfficeSmall	28.0%
Open Office	-6%	-	-6%	OfficeOpen	33.1%
Conference Room	16%	-	16%	Conference	27.0%

Similarly, the demand savings estimates from the metered data did not closely align with the demand savings estimates from the Tool (Table 7-7).

Table 7-7. Site 1 Comparison of Demand Savings Estimates by Zone

Metered Data (Level 4)		Tool (Level 2)	
Zone	Overall % demand savings	Zone	Overall % demand savings
Private Office	-22%	OfficeSmall	28%
Open Office	-5%	OfficeOpen	35%
Conference Room	-4%	Conference	27%

Error Tracing

The Site 1 Tool provided for Site 1 initially classified the site as a "Large Office" building. While technically correct, this led to the Tool producing substantial "anti-savings" values and did not appear to produce reasonable savings estimates. After speaking with the Tool developer to understand what could be causing this error, the evaluation team determined that the most appropriate solution for the purposes of this analysis was to re-classify the site as a "Small Office" building. This re-classification resulted in the Tool producing more reasonable savings estimates, though the precise mechanism behind why this was the case remains unclear.[57]

More generally, the results of the error tracing analysis (Table 7-8) showed that besides the building size/classification, the existing and proposed LPD values were the only variables that could be changed to modify the resulting savings estimates sufficiently to match the estimates from the metered data. (Other parameters such as weekly schedules could be modified, though the effect of these other

[57] The rationale for making this change is that it is very unlikely that a version of the Tool showing projected "anti-savings" would have been presented to an actual client during the scoping phase of a lighting controls project. In discussions with the Tool developer, we were unable to pinpoint the precise cause of this discrepancy. It is important to note that this version of the Tool was a beta version, and subsequent updates may have fixed this issue.

modifications typically did not change the resulting savings estimates sufficiently to align with the Level 4 estimates). The evaluation team lacked the data necessary to assess the accuracy of the proposed LPD values as entered in the Tool; therefore, we cannot determine if the reason for the discrepancy between the two sets of savings values was based on inaccurate LPD values being entered, or underlying differences in the assumptions.

Table 7-8. Site 1 Summary of Error Tracing Analysis

Input Variable	Relative Contribution	Description of Adjustment
Building size (sf)	High	"Large Office" vs. "Small Office" classification had a large impact on resulting savings estimates.
Existing LPD	High	Adjusting some combination of the existing LPD and proposed LPD was the only way to align the estimates from the Tool with the estimates from the metered data.
Proposed LPD	High	
Existing lighting controls	Low	Minor impact
Occupied start time	Low	Minor impact
Proposed lighting controls	Low	Minor impact

Proposed vs. Installed Tool Estimates

The difference in the savings estimates between the proposed version of the Tool and the installed version of the Tool were substantial. As discussed above, because the initial version of the tool classified the site as a "Large Office" but subsequent analyses classified the site as a "Small Office," the evaluation team did not spend additional time to analyze differences between the proposed and installed versions of the tool.

Site 2

The savings estimates from the metered data and from the Tool showed some alignment for Site 2. The evaluation team was able to directly compare two spaces from each source, a set of small offices and a small conditioned storage area. The small office zone exhibited an estimated 82% savings (overall) based on metered data, and 80% overall savings in the Tool. The storage zone exhibited less alignment (89% from metered data, but only 50% from the Tool). In the metered data analysis (Level 4), Site 2 likely over-estimated the efficacy savings, since luminaire details were not provided.

Table 7-9. Site 2 Comparison of Savings Estimates by Zone

Metered Data (Level 4)				Tool (Level 2)	
Zone	Overall % savings	Efficacy % savings	Controls % savings	Zone	Overall % savings
Huddle Rooms	82%	78%	4%	OfficeSmall	80%
Storage 250A	89%	81%	8%	StorageSmlCond	50%

As shown in Table 7-10, demand savings estimates for Site 2 were also fairly close between the metered data and the Tool for both zones (90% vs. 80% overall for the small offices, and 73% vs. 50% overall for the storage area).

Table 7-10. Site 2 Comparison of Demand Savings Estimates by Zone

Metered Data (Level 4)		Tool (Level 2)	
Zone	Overall % demand savings	Zone	Overall % demand savings
Huddle Rooms	90%	OfficeSmall	80%
Storage 250A	73%	StorageSmlCond	50%

Error Tracing

Consistent with other sites, the results of the error tracing analysis for Site 2 (Table 7-11) showed that adjusting the existing and proposed LPD values were the most direct method of aligning the savings estimates from the Tool with the estimates from the metered data.

Table 7-11. Site 2 Summary of Error Tracing Analysis

Input Variable	Relative Contribution	Description of Adjustment
Existing LPD	High	Adjusting some combination of the existing LPD and proposed LPD was the only way to align the estimates from the Tool with the estimates from the metered data.
Proposed LPD	High	
Building size (sf)	Low	Minor impact
Existing lighting controls	Low	Minor impact
Occupied start time	Low	Minor impact
Proposed lighting controls	Low	Minor impact

Proposed vs. Installed Tool Estimates

The proposed and installed versions of the Site 2 calculators produced identical savings estimates; thus, the evaluation team did not spend additional time comparing the two.

Site 3

Site 3 showed alignment between savings estimates for the one zone that could clearly be mapped from the metered data to the Tool (a conference room with 50% savings from the metered data and 74% savings from the Tool). In the metered data analysis, Site 3 showed negative efficacy savings due to the high number of burned out luminaires in the baseline.

Table 7-12. Site 3 Comparison of Savings Estimates by Zone

Metered Data (Level 4)				Tool (Level 2)	
Zone	Overall % savings	Efficacy % savings	Controls % savings	Zone	Overall % savings
Conference room	50%	-41%	91%	Conference Room	74%

As shown in Table 7-13, demand savings for Site 3 showed much less alignment between the metered data and the Tool (15% vs. 74% for the conference room).

Table 7-13. Site 3 Comparison of Demand Savings Estimates by Zone

Metered Data (Level 4)		Tool (Level 2)	
Zone	Overall % demand savings	Zone	Overall % demand savings
Conference room	15%	Conference Room	74%

Error Tracing

Consistent with other sites, the results of the error tracing analysis for Site 3 (Table 7-14) showed that adjusting the existing and proposed LPD values were the most direct method of aligning the savings estimates from the Tool with the estimates from the metered data.

Table 7-14. Site 3 Summary of Error Tracing Analysis

Input Variable	Relative Contribution	Description of Adjustment
Existing LPD	High	Adjusting some combination of the existing LPD and proposed LPD was the only way to align the estimates from the Tool with the estimates from the metered data.
Proposed LPD	High	
Building size (sf)	Low	Minor impact
Existing lighting controls	Low	Minor impact
Occupied start time	Low	Minor impact
Proposed lighting controls	Low	Minor impact

Proposed vs. Installed Tool Estimates

The proposed and installed versions of the Site 3 calculators produced identical savings estimates; thus, the evaluation team did not spend additional time comparing the two.

Site 4

For Site 4, the research team was able to directly compare savings estimates from the metered data and from the Tool for one zone (an open office). This comparison showed that the Tool projected a 57% relative savings, while savings calculated with the metered data were 82%. In the metered data, Site 4 showed the most dramatic improvement, both in terms of efficacy and controls, due to the reduction in installed power (2.4 kW to 1.2 kW) and a reduction in full load hours (from 7,070 hours per year to 3,000 hours per year).

Table 7-15. Site 4 Comparison of Savings Estimates by Zone

Metered Data (Level 4)				Tool (Level 2)	
Zone	Overall % savings	Efficacy % savings	Controls % savings	Zone	Overall % savings
Open Office	82%	49%	33%	Office (Open Plan)>250sf	57%

As shown in Table 7-16, demand savings for Site 4 showed values that were similar to the energy savings (81% for the metered data vs. 57% for the Tool).

Table 7-16. Site 4 Comparison of Demand Savings Estimates by Zone

Metered Data (Level 4)		Tool (Level 2)	
Zone	Overall % demand savings	Zone	Overall % demand savings
Open Office	81%	Office (Open Plan) >250sf	57%

Error Tracing

Consistent with other sites, the results of the error tracing analysis for Site 4 (Table 7-17) showed that adjusting the existing and proposed LPD values were the most direct method of aligning the savings estimates from the Tool with the estimates from the metered data.

Table 7-17. Site 4 Summary of Error Tracing Analysis

Input Variable	Relative Contribution	Description of Adjustment
Existing LPD	High	Adjusting some combination of the existing LPD and proposed LPD was the only way to align the estimates from the Tool with the estimates from the metered data.
Proposed LPD	High	
Building size (sq. ft.)	Low	Minor impact
Existing lighting controls	Low	Minor impact
Occupied start time	Low	Minor impact
Proposed lighting controls	Low	Minor impact

Proposed vs. Installed Tool Estimates

Differences between the proposed version of the Site 4 Tool and the installed version of the Site 4 Tool were minimal, as shown below in Table 7-18. This comparison shows that the installed version of the Tool estimates slightly lower savings (between 1.3% and 8.3% less, depending on the baseline) compared to the proposed version of the tool.

Table 7-18. Summary of Proposed vs. Installed Tool Estimates

Calculator Version	Energy Savings Estimates (kWh)		Demand Savings Estimates (kW)	
	Existing Baseline	Code Baseline	Existing Baseline	Code Baseline
Proposed	23,148.6	9,561.8	4.2	1.2
Installed	22,849.4	9,021.9	4.2	1.1
% Difference [a]	-1.3%	-5.6%	-	-8.3%

[a] *Relative to the Proposed Tool estimates.*

7.5 FACILITY MANAGER SATISFACTION

One of the evaluation's research objectives was to assess the satisfaction of facilities managers with the Trial retrofit marketing and implementation process, including the influence of the Tool over their decision-making. To understand facility manager's satisfaction and decision-making, the interviews explored the following research questions:

- How satisfied are the facility managers in their interactions with the contractor and the program staff?
- How satisfied are facility managers with the retrofit implementation process?
- Do facility managers understand and trust the output of the Tool?
- How influential was the Tool in their retrofit decisions?

Facility managers were highly satisfied with their ALCS contractors, Trial contractors, the installation process, and their new lighting systems. They were less satisfied with the commissioning process. Most interviews were conducted after the completion of the post-retrofit monitoring period (4 months), so the interviewees had spent a good amount of time using their new systems before the interviews.

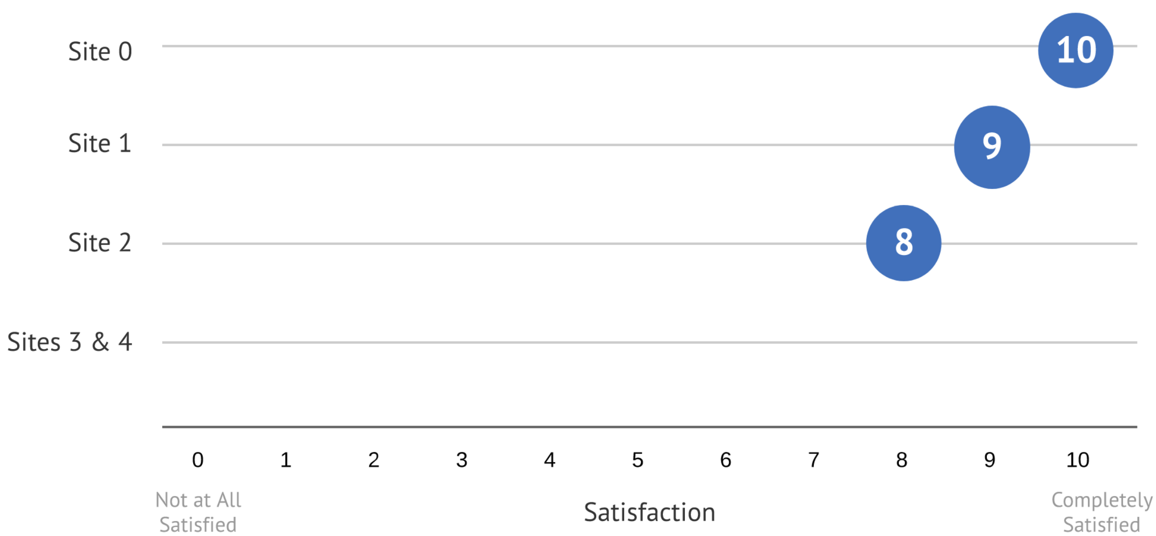
The following section discussed each of these questions in detail. We included the responses from Site 0 where possible, but not all questions were applicable since they dropped out during the commissioning process. Therefore, the total number of interviews included in each analysis varies.

FACILITY MANAGER SATISFACTION IN INTERACTIONS WITH THE CONTRACTOR AND PROGRAM STAFF

Overall, facility managers were very satisfied with their interactions with their ALCS contractor (Figure 7-1), CLEAResult (Figure 7-2), and the field metering staff

(Figure 7-3). All the facility managers spoke very highly of their interactions with the contractor and Trial staff. While one facility manager reported their contractor had to go through a learning curve on how to install ALCS, the facility manager discussed how the contractor did a good job going through that process. Another facility manager appreciated the flexibility of the contractor coming back to complete commissioning after IT approval was obtained. The third facility manager said their contractor "understood our real needs—this was good." Their satisfaction is apparent in that no facility manager ranked any of their interactions below an eight out of 10, including Site 0, which experienced significant difficulties during their installation and commissioning process.

Figure 7-1. Facility Manager Satisfaction with Their ALCS Contractor*



**Site 3 and 4 self-installed, so they did not have any experience with an ALCS contractor.*

Figure 7-2. Facility Manager Satisfaction with Trial Implementer (CLEAResult)

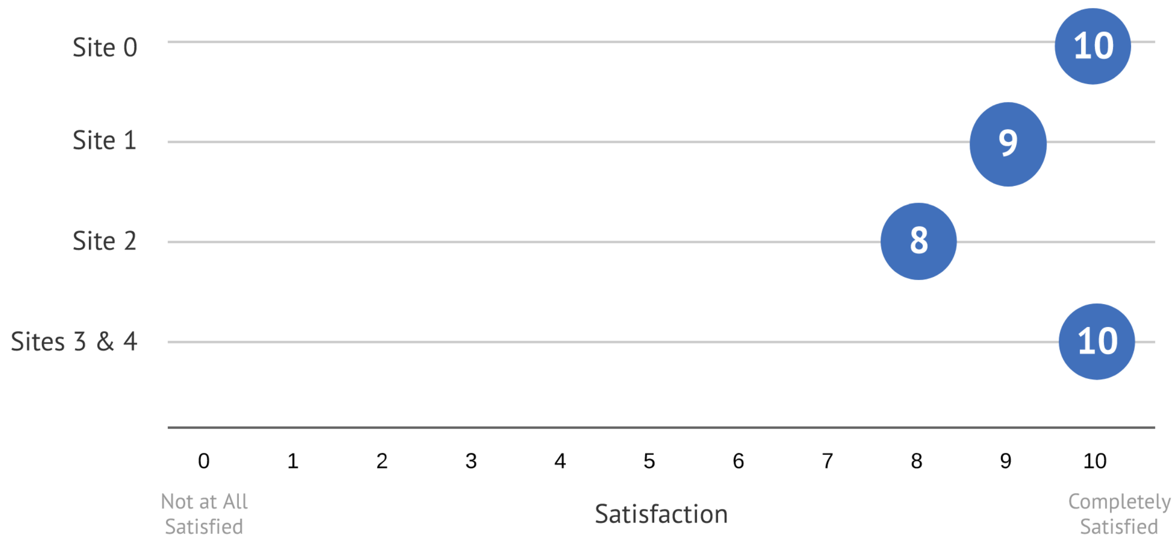
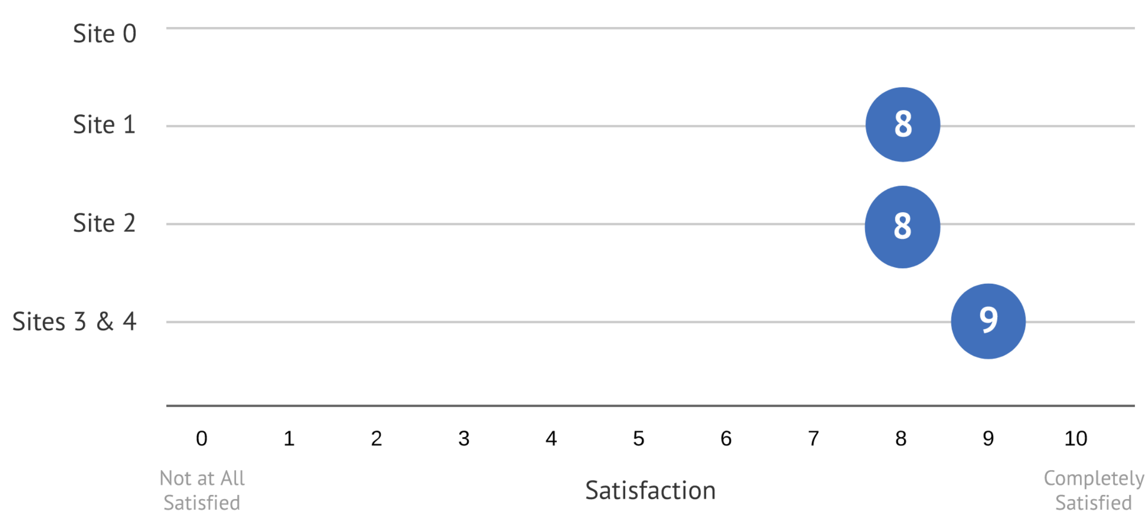


Figure 7-3. Facility Manager Satisfaction with the Field Metering Staff*



**Site 0 dropped out of the study, thus had no experience with the field metering staff.*

All facility managers reported project scoping went well. One facility manager said the project was explained well and the savings the project would achieve was clearly demonstrated through the calculations. A second facility manager reported their contractor gave them samples of the fixtures to test for one month during the scoping process. During testing, the office personnel found the lights too bright, so they decided to replace four fixtures with just two fixtures.

None of the facility managers reported any difficulty with assessing project eligibility as it related to the ALCS Trial. While indirectly related to the Trial, one facility manager was frustrated with assessing the eligibility of their office space to receive rebates (the facility manager was referring to the fact that office lighting did not qualify for deemed rebates). This facility manager said they were unable to get a consistent contact and was passed to multiple PG&E representatives due to staff turnover. The facility manager also expressed frustration with the approval process as there were multiple requests from PG&E for project information as well as many layers of approval before they could purchase the ALCS. This facility manager also reported representatives were unresponsive.

When asked if any aspects of the project scoping did not go well, three of the facility managers each reported something different. For one system, the fixtures did not have the controls already installed and installing the controls into the fixtures was not included in the overall budget. The facility manager said the contractor worked with them to find a solution, including weekend work, but there was an added cost.

A second facility manager thought the requirement for four months of post-monitoring was too onerous. In particular, they mentioned providing an escort for the monthly on-site field metering staff for data pulls was challenging. They recommended using meters that would store more than one month of data. The third facility manager said, "I know there were some issues with the calculator tool not working properly." (This was discussed in detail in Section 7.4.)

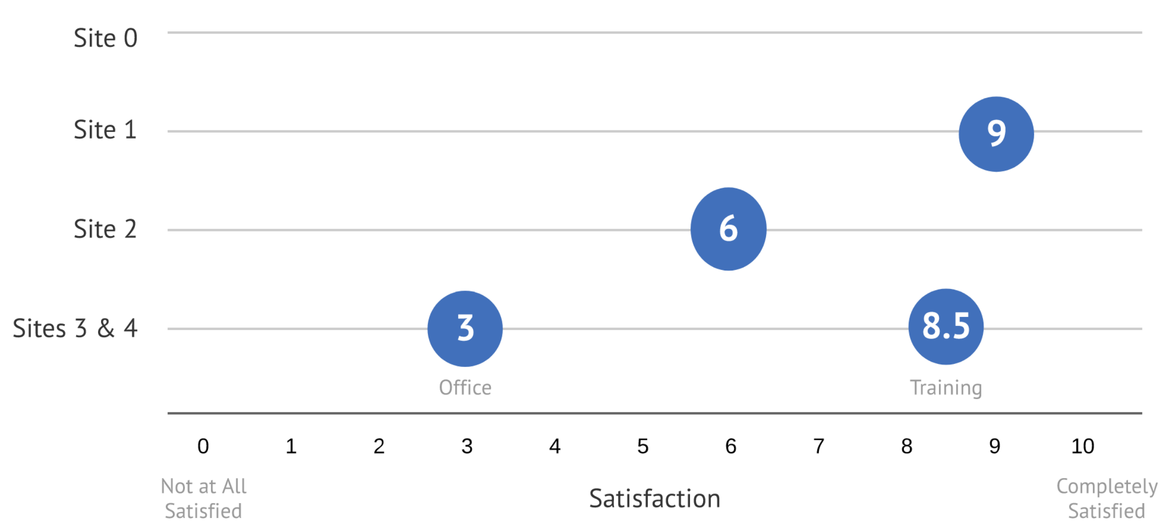
FACILITY MANAGER SATISFACTION WITH THE RETROFIT IMPLEMENTATION PROCESS

Compared to their satisfaction with their interactions with contractors and program staff, facility managers had lower satisfaction with the retrofit installation (Figure 7-4) and commissioning (Figure 7-5) processes. Overall, facility managers were more satisfied with the installation process than with the commissioning process. Three facility managers described the installation process as simple, but one described the installation in the offices as "challenging." This facility manager also discussed how they have to fit installation into their regular work schedule and are not allowed overtime. So, it seems this lower satisfaction is due to internal challenges at their company as opposed to issues with the ALCS itself.

All of the facility managers said the commissioning process took longer than expected; two of the facility managers described the commissioning process as "tedious" and "time consuming." They both discussed difficulty with having to pair each fixture individually. At one site, the building occupants were not comfortable relying on the control system to turn off lights in a conference room. In this case, the contractor went back and installed a manual switch. The facility manager described this as a possible barrier to ALCS, as occupants who are unfamiliar with the technology might be unwilling to rely solely on the automatic controls.

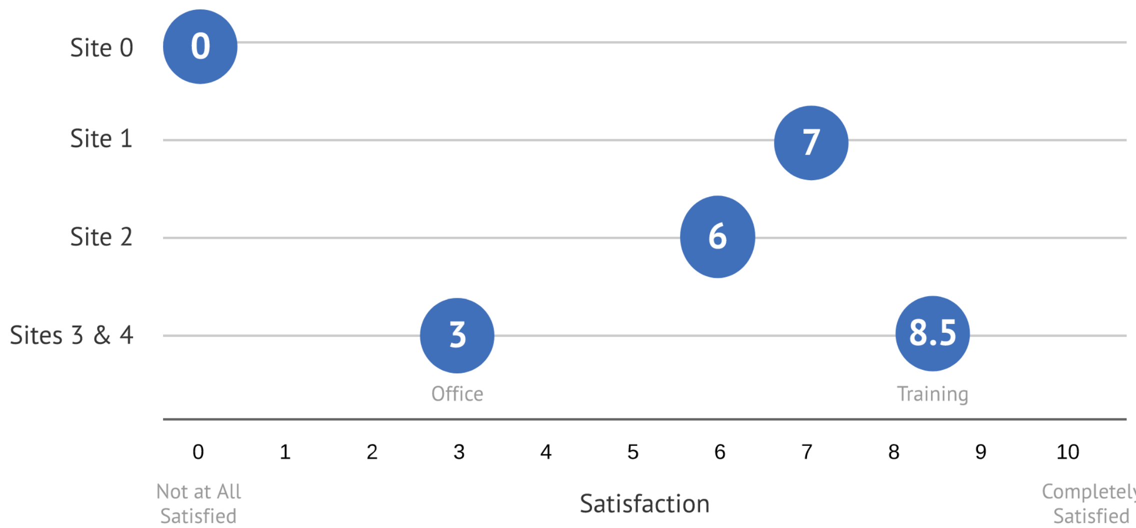
Site 0 reported that installation went smoothly, but that the controls were never functional. This facility manager described the system as having a control center, a control hub (a hub is for an individual space, like a private office), and each light fixture as a node. The problem with the system was that each node did not communicate properly with the hub. They described how one day they got each node properly paired with a hub within an office, but then overnight the system "went haywire" and the next day the nodes would be shifted to someone else's office. So, if the occupant attempted to adjust the lighting in their office, they would actually be adjusting the lighting in someone else's office. They also described a situation where they came into their office and turned on the switch, but it took the control system 30-60 seconds to actually turn the lights on. These issues were never resolved, so Site 0's facility manager decided to un-install the system entirely.

Figure 7-4. Facility Manager Satisfaction with the Installation Process*



**Site 0 not included. Site 3 and Site 4 were rated separately by the facility manager*

Figure 7-5. Facility Manager Satisfaction with the Commissioning Process*



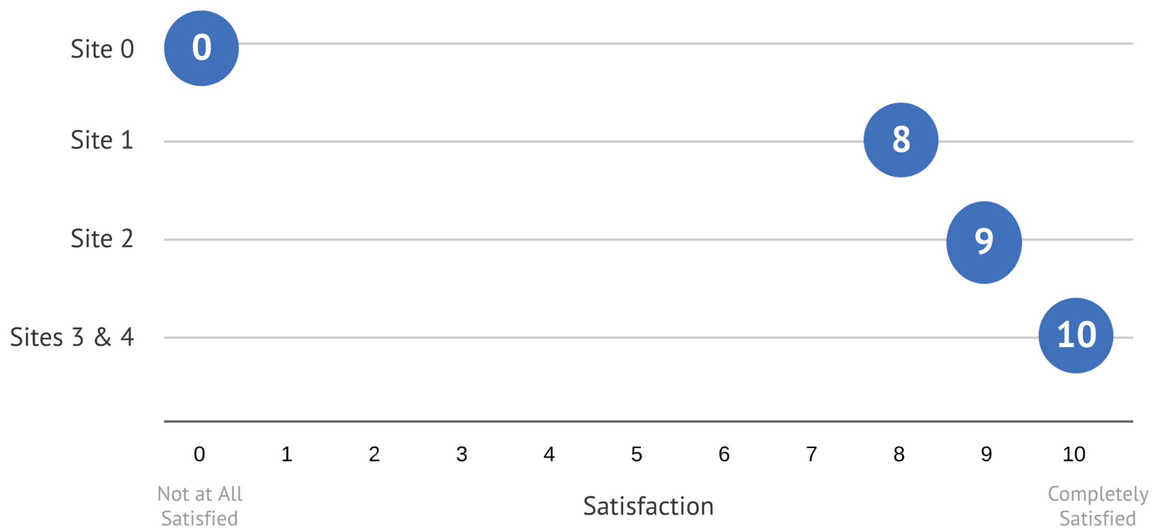
**Site 0 included. Site 3 and 4 were rated separately by the facility manager*

The evaluation team also discussed the facility manager's perspectives of the new lighting system after the commissioning of the system. All three facility managers[58] reported the quality of the new light as very good. One facility manager (the self-install site) described how they went from 100% on to 45% on over incremental periods and how the occupants never noticed it. Another facility manager said, "The beauty of this lighting is that [they] can adjust even just a single fixture if need be."

The facility manager's satisfaction with their ALCS is reflected in Figure 7-6. Two of three facility managers received complaints of the lights being too bright before commissioning, but that commissioning the dimming settings resolved those concerns. When asked about any issues with the new system since commissioning was completed, one reported not having any issues. Another said the only issue was that there wasn't enough budget to retrofit the entire building. The third had had one complaint – when an employee came in to work on the weekend, they did not like how the other half of the building went dark. This facility manager reported that weekend work does cause them to override the lighting controls, while a second reported that occupants do override the ALCS controls with the manual switch discussed above. None of the facility managers believe occupants will alter their work environment (such as moving their work location for better lighting) because of the new lighting system.

[58] Site 0 was not asked these questions as the system never moved past commissioning.

Figure 7-6. Facility Manager Satisfaction with the New ALCS



**Site 3 and 4 were rated together by the facility manager*

HOW INFLUENTIAL WAS THE TOOL IN THEIR RETROFIT DECISIONS?

At the outset of the Trial, the expectation was that contractors would be selling ALCS to customers. In actuality, three of the four participating facility managers (Site 0, Site 1, Site 2, Site 3/Site 4) brought the projects to the contractors. In these three projects the contractors and the tool did not influence the facility manager's decision-making. Only one facility manager reported that the Tool estimate had "quite a bit of influence on the decision to go ahead with the project."

One of the participating facility managers is a lighting contractor and follows the market and new technologies closely. They sell the product they installed and wanted to have it in their offices for a "showcase" to show to potential customers. Thus, when discussing what factors had the most impact on project-related decisions, this facility manager reported the Tool had no influence in their retrofit decision-making process. Specifically, they said the Tool was "not that important to me because I know we were going to save energy. I don't need to see [the energy savings] on paper or know exactly how much." A second facility manager reported they were actively interested in lighting controls, and it was the additional rebate offered by this Trial that was most influential in selling the project. The third facility manager cited energy savings and the ALCS ease of use were most influential in their decision-making.

The one facility manager that cited the Tool as impacting their decision-making said, "Theoretically [it] was all explained and…the calculations done [in the Tool] to demonstrate there was going to be savings. So, the concept was great on paper."

When asked about what factors had the most impact on their decision-making, they referenced the ability to control the lights from outside the office for security purposes and how automated the system was.

DO FACILITY MANAGERS TRUST THE OUTPUT OF THE TOOL?

Most of the facility managers participating in this Trial did not use the Tool in their decision-making process because they decided to install ALCS for reasons other than energy savings. However, all of the facility managers (Site 0, Site 1, Site 2, Site 3/Site 4) said energy savings were presented by the contractors as a part of their quote. Three of the facility managers (Site 0, Site 1, Site 3/Site 4) said the Tool was presented to them, one could not remember if the Tool was used or if the results were used by the contractor in their quotation.

Of the three who had the Tool presented to them, two said it was easy to understand the savings estimates. These two facility managers were unable to comment on how accurate they thought the savings estimates were.

One facility manager, however, said the Tool "ask[ed] some off questions about behavior" and further explained the assumptions about the behavior of tenants regarding occupancy, specifically percent occupied, did not seem correct. They reported some people were in their offices all day, whereas others were in and out of the office all day, and that the schedule for each person changed each day. This facility manager also reported there were issues with the tool and that it was not working properly (this was confirmed by the evaluation team and is discussed more in Section 7.4).

All four of the facility managers reported there were no additional savings information they had available, but all of them also said they could not remember specifically, because the Tool had been presented to them too long ago.

7.6 CONTRACTOR SATISFACTION

Only one contractor interview was secured (plus some feedback from the facility manager who self-installed). The facility manager interviews discussed in the previous section revealed it was the facility managers who approached the contractors about the projects. Additionally, two of those facility managers told us it was the implementation contractor who filled out the Tool, not the ALCS contractor. Therefore, even if an interview had been conducted, those contractors would likely not have been able to provide feedback on using the Tool or how they incorporate the Tool into their marketing practices.

In the following sections we present the information from the contractor interview and add observations made by the self-install facility manager where applicable.

HOW SATISFIED ARE CONTRACTORS WITH THE TOOL?

The evaluation was not able to rate contractor's satisfaction with the Tool. The contractor did not use the Tool in the field. Instead, they used a tool called "Snap Count" to collect and enter data in the field. Their team walks through a space under consideration for a project room by room, logging all data for each room into a Snap Count. The contractor is very familiar with this tool and is highly satisfied with its results. For the project included in this Trial, they collected data in the field using their established techniques and Snap Count, then entered the data into the Tool in the office. Unfortunately, the contractor could not answer any questions about how easy it was to enter data into the Tool, how time consuming it was to enter the data, how using the Tool compares to using other methods for estimating project savings, or if they were able to complete data entry in the Tool without assistance from PG&E. For these questions the contractor cited the Tool estimates were done 10 months prior to the completion of installation, so they could not recall the specifics of their experience.

As discussed in Section 7.5, the self-install facility manager did not have a good experience with the Tool. Even though this facility manager is a lighting contractor, the implementation contractor filled out the Tool on their behalf. The facility manager reported "some issues with the calculator tool not working properly for [the implementation contractor]" and also gave feedback that the Tool's assumptions about behavior "seemed off." This facility manager ultimately said the output of the Tool was not important to them and that it did not influence their decision-making process.

HAVE THE CONTRACTORS RECEIVED ADEQUATE TRAINING?

Two people from the contractor's firm attended the Tool training, the interviewee and one other person. The contractor reported no one else from the company was using the Tool. The contractor did not recall anything positive or negative about the training, instead stating their "memory of the specifics of the training were not detailed as it was over 10 months ago" but said that doing the training close to the time of the project would be helpful to keep learnings fresh. They did say that webinars work really well, because these types of trainings fit their schedule better than having to go to a site for training, but they did not have any recommendations for how to improve the webinar or training.

DO CONTRACTORS FACE ANY BARRIERS USING THE TOOL?

The contractor did not report any challenges with using the Tool, but again cited that the project scoping was done so long ago their memory was not specific. As already discussed above, the self-install facility manager did report that the tool was not working properly but could not offer any more specifics.

HOW DO CONTRACTORS INCORPORATE THE TOOL OUTPUT IN MARKETING?

The contractor reported that their customers are "looking to reduce their carbon footprint and save energy." Adding controls to a lighting project adds up-front costs and extends the ROI, but the contractor reported their customers know it is the right thing to do. Therefore, the contractor's company always promotes lighting controls and energy savings in their proposals. Their proposals are also typically conservative with energy savings as the controls typically end up saving more than anticipated.

The contractor interviewed uses other software to provide project estimates and reported being very satisfied with that tool. They said the estimates this tool provides are "very useful; in some cases, it is the only thing [customers] want to know about." Due to their satisfaction with their existing software, the contractor reported they do not use the Tool in their marketing, proposals or project estimates. In fact, the contractor reported they believed their customers might not trust the Tool results and that PG&E branding might help establish trust.

When asked how likely they were to use the Tool if it was available beyond the Trial the contractor said they "would only use it if required to do so for receiving a rebate" because they already have software that they are satisfied with and wouldn't want to add additional work unless it was necessary. The contractor did, however, express an interest in using the Tool to check calculations of their existing software to see if the estimates aligned.

CONTRACTOR FEEDBACK ON USEABILITY TESTING

The evaluation team observed the contractor entering the sample project data into the Tool. The interviewer did not report any instances of confusion or frustration from the contractor. It seemed the contractor could easily navigate and populate the Tool. The contractor did, however, give specific feedback on the Tool as they were entering the sample project data into the Tool:

- The Tool asks for room areas in percentages, but using square feet is generally how they get data in real life. **So, the Tool should be in square feet not percentages**.
- The contractor would prefer to start with the Detailed Inputs tab as the layout of fields in this tab better represent how they would acquire the required data as they move through a building.
- **The dashboard should also include a cost savings per year.** The contractor reported this is a very important metric for their clients and could be easily obtained by having an input field for a client's $/kWh rate.

When the interviewer asked the contractor about general improvements that could be made to the Tool, the contractor said it would be nice if the Tool was online and could be submitted online, if it automatically populated rebate opportunities, and if it could integrate with their existing software so that they could export data from their existing software into the Tool (assuming using the Tool was a requirement to get a rebate).

7.7 USING THE CALCULATOR WITH THE LED ACCELERATOR DATA

Two of the four sites analyzed using LED Accelerator data had no difference in the estimated savings between the Level 1 and Level 2 inputs (Site 6 and Site 8). One of the sites had a small difference in estimated savings between Level 1 and Level 2 inputs (Site 5), while the last site had significant differences (Site 7). The results are shown in Table 7-19.

Site 5 saw modest changes (5-6%) in estimated savings between Level 1 and Level 2. The primary source of the difference was due to splitting the storage space into two spaces in Level 2; one storage space with no daylighting and one storage space with daylighting.

Site 7 had a large change in the estimated savings between Level 1 and Level 2. However, clearly tracking the sources of variance was difficult. The sources of variance were classified into five broad categories:

- Changes to the area types that increased the existing baseline savings but dramatically reduced the code savings
- Changes to the lighting technology definitions that resulted in a net decrease in the existing baseline and code baseline energy use but had little effect on the existing baseline demand reduction
- Changes to the side lighting details that increased the claimed energy savings
- Changes to the skylighting details that decreased the existing baseline savings and increased the code baseline savings

In theory, it would be possible for a user to elect to define only the variables that increase the savings. However, to do so would require a trial and error approach.

In one of the sites the Tool takes credit for “above code” energy savings when the existing system was already above code. For example, if an existing space has 0.3 W/sf where code allows 0.60 W/sf and a new lighting system is installed that consumes 0.2 W/sf; the calculator will claim 0.1 W/sf as baseline savings but 0.4 W/sf as “to-code” savings. In practice, this could overstate the savings the project delivered.

Site 8 was 50% office and 50% low power-density racks of telecom (phone) equipment with light battery back-up load. This Site did not map well to the room types in the Tool nor to DOE-2[59] models. So, the line items for the spaces were entered in the Tool and the evaluation team ensured the lighting power density and installed controls aligned properly in order to assign the Site as an “Office, Small.” However, the Tool may not be applicable to this type of building in the field. Since estimated savings are highly sensitive to building type and space type, the incorrect selection of building type or space type could result in large error of estimated savings.

[59] DOE-2 is a building energy simulation tool developed by Lawrence Berkeley National Labs and the US Department of Energy.

Table 7-19. Summary of LED Accelerator Calculator Output Values

Site	Input Level	Existing Baseline				Code Baseline			
		Energy Savings (kWh/yr)	% Difference	Demand Savings (kW)	% Difference	Energy Savings (kWh/yr)	% Difference	Demand Savings (kW)	% Difference
5	1	135,279.5	n/a	33.4	n/a	60,804.1	n/a	9.8	n/a
5	2	127,807.9	-5.8%	31.4	-6.4%	60,711.2	-0.2%	12.8	23.4%
6	1	109,604.3	n/a	18.0	n/a	192,957.5	n/a	28.3	n/a
6	2	109,604.3	0.0%	18.0	0.0%	192,918.7	0.0%	28.3	0.0%
7	1	56,685.7	n/a	17.6	n/a	30,224.3	n/a	10.1	n/a
7	2	39,369.4	-44.0%	12.1	-45.5%	61,329.3	50.7%	20.5	50.7%
8	1	66,755.5	n/a	10.5	n/a	15,382.4	n/a	1.7	n/a
8	2	66,755.5	0.0%	10.5	0.0%	15,348.8	-0.2%	1.7	0.0%

8. RESEARCH OBJECTIVE FINDINGS

This section summarizes the results and findings from each of the evaluation activities by research objective.

8.1 ACCURACY OF SAVINGS CALCULATIONS GENERATED BY THE TOOL BASED ON EXISTING CONDITIONS BASELINES

Overall, we did not observe substantial alignment between the estimates from the Tool and the estimates from the metered data *at the site level*. There is a high level of agreement between Level 1 savings estimates and Level 2 savings estimates, using existing conditions baseline,[60] but very limited agreement between Level 1 savings estimates and Level 4 (monitored data) or Level 2 savings estimates and Level 4 savings estimates. These results of the site level comparison are shown below in Table 8-1. The range of variance for Level 1 savings estimates generated by the Tool was between -116.3% to +57.4% for energy savings, and between -129.1% to +54.8% for demand savings. This means that at the site level, the Tool would sometimes underestimate and sometimes overestimate savings, when compared to the metered data savings estimates.

As noted in previous sections, it is important to note that the Tool generates savings for the whole site whereas the monitored savings is based on field data collection for spaces within the site and, therefore, may not be representative of the site as a whole. At the more granular space level, we did observe some degree of alignment between energy saving estimates produced by the Tool and estimates produced from the metered data. However, we were unable to detect a clear pattern to predict when such estimates might be similar and when they would not.

The evaluation also found that adjusting the existing and proposed LPD values was the most direct method for aligning the savings estimates from the Tool with the estimates from the metered data. As the Tools were filled out by the Trial implementation contractor as opposed to the ALCS contractor and the evaluation team did not have any field data to verify the LPDs, we were unable to assess the accuracy of the Tools' LPD values. It is possible that if the LPD values had been entered differently, the savings estimates from the Tool may have been substantially closer to the savings estimates from the metered data.

[60] These findings are consistent with findings from the analysis of metered sites aligns with findings from the LED Accelerator test, which showed little or no difference between the Level 1 and Level 2 estimates.

Table 8-1. Energy and Demand Savings Values by Site and Level of Rigor

Site	Level of Rigor	Existing Baseline			
		Energy Savings (kWh) [a]	% Variance (relative to Level 1)	Demand Savings (kW) [a]	% Variance (relative to Level 1)
Site 1	1	19,488.70	-	6.8	-
	2	20,485.80	5.1%	6.9	1.5%
	4	-3,181.02	-116.3%	-1.23	-118.1%
Site 2	1	83,987.40	-	34.1	-
	2	86,109.40	2.5%	34.7	1.8%
	4	115,009.13	36.9%	51.6	51.4%
Site 3	1	54,922.90	-	10	-
	2	54,922.90	0.0%	10	0.0%
	4	13,980.37	-74.6%	-2.91	-129.1%
Site 4	1	22,849.40	-	4.2	-
	2	22,849.40	0.0%	4.2	0.0%
	4	35,962.59	57.4%	6.5	54.8%

[a] *Energy savings values for Level 4 were back-calculated from the % savings values.*

8.2 ACCURACY OF SAVINGS CALCULATIONS GENERATED BY THE TOOL BASED ON TITLE 24 REQUIREMENT BASELINE

The savings estimates based on a Title 24 requirement baseline produced by the Level 1 and Level 2 Tools were highly consistent, differing by less than 10% in all cases. These results are shown below in Table 8-2. The evaluation team was unable to make a direct comparison between the Title 24 savings estimates from the Level 1 and 2 Tools and savings estimates from the metered data (Level 4) since there was no way to ascertain Level 4 code baseline values without using the Tool itself. However, we do observe that for all four metered sites, there is general agreement between Existing Baseline savings and Code Baseline savings estimates (within a given site and the level of rigor). Site 1, which exhibits savings in the Existing Baseline scenario but “anti-savings” in the Code Baseline scenario, is a clear exception.

Table 8-2. Energy and Demand Savings Values by Site and Level of Rigor

Site	Level of Rigor	Code Baseline			
		Energy Savings (kWh) [a]	% Variance (relative to Level 1)	Demand Savings (kW) [a]	% Variance (relative to Level 1)
Site 1	1	-16,767.80	-	-5.2	-
	2	-16,544.10	-1.3%	-5.2	0.0%
	4	b	b	b	b
Site 2	1	53,207.50	-	15.4	-
	2	54,010.20	1.5%	15.4	0.0%
	4	b	b	b	b
Site 3	1	30,665.10	-	4.2	-
	2	30,597.40	-0.2%	4.3	2.4%
	4	b	b	b	b
Site 4	1	9,021.90	-	1.1	-
	2	9,262.70	2.7%	1.2	9.1%
	4	b	b	b	b

[a] *Energy savings values for Level 4 were back-calculated from the % savings values.*
[b] Code Baseline values for Level 4 could not be calculated using metering data.

8.3 CONTRACTOR SATISFACTION USING THE TOOL

Overall, the evaluation was not able to rate contractors' satisfaction using the Tool. One contractor interviewed did not use the Tool in the field. Instead they used a software program called Snap Count to collect the data and then input the information into the Tool back in the office. Unfortunately, the contractor could not answer any questions about using the Tool because they said the estimates were done so far in the past they did not remember their experience.

The second contractor interviewed was the self-install facility manager. Even though this facility manager was a lighting contractor, the implementation contractor filled out the Tool on their behalf. The facility manager reported "some issues with the calculator tool not working properly for [the implementation contractor]" and also gave feedback that the Tool's assumptions about behavior "seemed off." This facility manager ultimately said the output of the Tool was not important to them and that it did not influence their decision-making process.

8.4 FACILITY MANAGER SATISFACTION WITH THE RETROFIT MARKETING AND IMPLEMENTATION PROCESS

All the facility managers reported project scoping went well and none of the facility managers reported any difficulty with assessing project eligibility as it related to the ALCS Trial. When asked if any aspects of the project scoping did not go well, three of the facility managers each reported something different. For one system, the fixtures did not have the controls already installed and installing the controls into the fixtures was not included in the overall budget and resulted in an added cost. A second facility manager thought the requirement for four months of post-monitoring was too onerous. The third facility manager cited some issues with the Tool not working properly.

Overall, facility managers were very satisfied with their interactions with their ALCS contractor, implementation contractor, and the field metering staff. All the facility managers spoke very highly of their interactions with the contractor and Trial staff.

Compared to their satisfaction with their interactions with contractors and program staff, facility managers had lower satisfaction with the retrofit installation and commissioning processes. Overall, facility managers were more satisfied with the installation process than with the commissioning process. Three sites described the installation process as simple. One site described the installation in the offices as "challenging," but the challenges appeared to be due to internal challenges with the facility manager's company as opposed to issues with the ALCS itself.

All of the facility managers said the commissioning process took longer than expected; two of the facility managers described the commissioning process as "tedious" and "time consuming." The Site 0 manager reported that installation went smoothly, but that the controls were never functional. These issues were never resolved, so Site 0's facility manager decided to un-install the system entirely.

All three facility managers[61] reported the quality of the new light was very good and that their satisfaction was also high. When asked about any issues with the new system since commissioning was completed, one reported not having any issues. Another said the only issue was that there wasn't enough budget to retrofit the entire building. The third had had one complaint – when an employee came in to work on the weekend, they did not like how the other half of the building went dark. None of the facility managers believe occupants will alter their work environment (such as moving their work location for better lighting) because of the new lighting system.

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[61] Site 0 was not asked these questions as the system never moved past commissioning.

9. CONCLUSIONS AND RECOMMENDATIONS

This section presents the evaluation team's key findings and associated recommendations regarding the Tool and its future implementation. Overall, the evaluation found the Tool was designed and implemented with current industry best practices and that the formulas and theory were appropriate. However, in practice there are a few improvements that could be made to support its widespread adoption.

Specific key findings and recommendations follow.

- **Key Finding 1: The high cost for ALCS is the primary barrier for increased adoption.** Both participants and near-participants cited the high cost of ALCS as the main barrier for doing more spaces within their facility or for participating in the Trial, respectively. Both facility managers and contractors interviewed reported that customers require a ROI of three years or less to implement a project.
    - **Recommendation 1: Consider offering a rebate specifically for the installation of ALCS that is large enough to help meet customers' ROI requirements.** Based on the feedback from facility managers, it appears that the current incentive structure for lighting projects may not be meeting the market's needs. For example, one facility manager reported the deemed incentive allowed the manufacturing portion of their project to proceed quickly, whereas the complicated nature of the office lighting incentive prevented that part of the project from proceeding, because the facility manager was unsure of the final incentive amount. Another respondent said receiving a rebate for their infrastructure upgrades would have brought the ROI for the total ALCS project closer to their ROI requirements. In return for a larger incentive, PG&E should consider making access to system data a participation requirement. Having access to such data has the potential to reduce M&V costs (see Recommendation 3B) and increase savings (see Recommendation 3E). Customers' security concerns related to allowing 3rd parties access to their systems could be overcome by downloading data and conducting analysis separately as opposed to viewing real-time data in the ALCS interface. Of course, *this recommendation would have to be taken in context with ongoing changes to the lighting market and California regulatory policy and proceedings*.

- **Key Finding 2: Market actors may be wary of installing ALCS because of previous poor experiences with lighting controls and the fact that ALCS' are still a new and unknown technology.** We heard from multiple interviewees that there is institutional anxiety around installing ALCS. This is due to previous poor experiences with occupancy sensors not working properly, hearing stories of early ALCS installations not working (as

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experienced with Site 0 in this Trial), and also due to maintenance teams' reservations about switching to systems that are unfamiliar and more complicated than their current system. IT departments also have privacy concerns about ALCS connecting to their internal internet. While many types of ALCS provide similar features and functionality (e.g., daylight dimming, task tuning, remote access), the methods by which they are implemented (e.g., how fixtures are paired to hubs, whether the fixture is integrated or not) can vary significantly. These variations can cause differences in cost, ease of installation, and user experience. As ALCS is still an emerging technology, market actors may have a hard time distinguishing between the products.

- **Recommendation 2A: Publish successful ALCS case studies targeted to various audiences.** Trial participants' concerns about lighting control technology were resolved after ALCS installation. They reported high satisfaction with the quality of light, the control strategies, and had not received any complaints from occupants. As ALCS adoption grows, publishing case studies or success stories from customer implementation may help overcome some of the negative perception of lighting control technologies in the market. Providing specific messaging for the different market actors would also be helpful; the information a financial decision-maker needs in a case study is different than the information maintenance staff needs.
- **Recommendation 2B: Investigate hosting ALCS trainings for facility managers at IOU energy centers.** The trainings could include presentations on the differences between the products, occupant and facility manager experiences and satisfaction, examples of control operation, and information on programs and available incentives.
- **Recommendation 2C: Consider conducting bench testing or demonstration projects of different ALCS manufacturers' products.** All of the participating facility managers discussed how having results from bench testing various ALCS products, or having a demonstration project, would help increase ALCS adoption. ALCS technologies are complicated, and facility managers found it hard to understand exactly what their lighting would be like after the retrofit, and they reported their ability to see it would have helped their decision-making process. In fact, having a demonstration project is the precise reason why one facility manager, the lighting contractor, installed it in their offices.
- **Recommendation 2D: Future pilots or programs could explore the maturity and market-readiness of ALCS technologies.** All of the participating facility managers discussed having installation difficulties. For example, one, Site 0, experienced severe enough wide-scale system glitches they chose to uninstall the system. While these experiences may indicate ALCS technology may not be fully matured, this is an extremely small sample size and assessing maturity was not

a part of this evaluations' scope. Alongside bench testing or demonstration projects (Recommendation 3B), future research could investigate the technology's maturity and how utilities could partner with manufacturers to further address customers' concerns and barriers.

- **Key Finding 3: If future ALCS pilots are conducted by PG&E, changes to the Trial and evaluation design could improve results.** As with any research, the Trial and this evaluation faced some challenges. If another pilot is undertaken, below are suggestions for improving the design.
    - **Recommendation 3A: Conduct interviews as project phases are completed.** The interviews were originally designed to have the least impact on participants, meaning one interview was conducted to collect all the needed data. However, the sales cycle and implementation timelines are so long for ALCS that it resulted in interviewees not recalling their experience or staff turnover. As such, data collection should occur immediately after each task is finished. For example, interviews about the sales cycle and completing the Tool should be conducted during the pre-retrofit metering period instead of at project completion. This would also mean staggering the incentives at each interview stage.
    - **Recommendation 3B: Implement a different monitoring approach.** The monitoring approach to verify the output of the Tool, monitoring each control factor in 30 second to five minute intervals in up to ten spaces for Trial sites, used in this evaluation was more complicated and time intensive than the project justified. Due to the combined costs of this approach, limitations on the ability to collect data, and a limited timeframe, only a subsection of spaces in these facilities could be studied. Future efforts would benefit from taking advantage of the monitoring features already built into the lighting control systems (including those listed by the DesignLights Consortium, DLC) which have the ability to monitor the on-going operation of the lighting system, reporting what the system is doing at any given time for any given zone (e.g. dimming signal, daylighting signal, occupancy status, etc.). Using the ALCS-generated reports to determine the system behavior would provide higher quality data (no battery failures or occupant interference), reduce assumptions (aligning data with expectations and observations) and lower cost (fewer site visits; potentially no site visits if VPN access is available) compared to the approach taken for this evaluation. One potential barrier to this recommended approach is a lack of trust in the ALCS-generated data. However, it would be feasible to perform a small demonstration project (e.g. a bench-top wiring and programming exercise with short term power monitoring) or a functional test of the system in the field to verify the successful installation and configuration in the field. A small randomly selected field test to verify

the system self-reporting is accurate could help utilities and public utilities commissions trust the data, which in turn would build trust in the eventual results when a much larger program relies on ALCS reported data. Fundamentally, the real-time data collected by ALCS could be utilized in Normalized Metered Energy Consumption (NMEC) calculations. Note, this calibration/trust exercise could be avoided if there were an industry-standard test procedure and certification (like the DLC Networked Lighting Controls Program).

- If the in-depth field monitoring is desired, we recommend utilizing different meters than those that were utilized in this evaluation that would overcome some of the data collection errors experienced by this Trial. These include using meters where remote-download is possible and/or more data can be stored on-board and where there is a warning about failed batteries.
- **Recommendation 3C: Create a financial connection for PG&E contractors between site recruitment and site measurement and verification.** For future pilots, the two scopes of work should be closely tied so that the measurement and verification contractor can have access to the hardware on site, a design review, and a single site visit to gather the needed data themselves. Doing so would have avoided the needed remote access, which may continue to create security concerns (participants reported they were concerned about the security of allowing external parties access to their control systems) for participants in future projects.
- **Recommendation 3D: Incorporate training for customers on ALCS controls programming into the pilot.** The on-site monitoring found efficacy improvements had a much larger impact on energy savings than changes in controls. One possible explanation, based on field observations, was that control programming is often done improperly and that users may not receive adequate training to make use of the advanced control features. While the Trial included training for contractors, the next iteration of an ALCS pilot should also include training for participating customers after installation and commissioning is complete.
- **Recommendation 3E: Consider using ALCS data for opportunity identification.** As ALCS adoption increases, there may be an opportunity to analyze the data from across many installations to identify potential lighting controls measures. For example, buildings or areas with high daylight levels and high daytime lighting consumption could be flagged as a potential candidate for daylight harvesting recommissioning. While doing so has the potential to increase projects' savings over what they might achieve without this type of opportunity identification, this type of analysis has been difficult in the past because there is so much variation in each building and area within a building. For example, one of the conference rooms for a participant site in this study is used as a connecting corridor between segments of

office areas. When considered as a part of a larger data set, this conference room would show a higher occupancy rate and longer run hours than a typical conference room but result in a non-actionable finding. Repeated unactionable flags may result in lower engagement or burnout of operators, so opportunity identification must take into consideration building nuances and whether operators can take action on the recommendations.

The concept of using ALCS data for opportunity identification could also be included in well-established programs such as retrocommissioning and strategic energy management. However, the success of this concept is dependent on gaining access to the ALCS data, which was a barrier experienced in the Trial and discussed in the evaluation report. Recommendation 1 (providing a large incentive for ALCS installation) offers a potential method for overcoming this barrier but would need to be tested with customers to determine its potential effectiveness.

PG&E ADVANCED LIGHTING CONTROLS SYSTEM TOOL TRIAL EVALUATION

APPENDICES

July 11, 2019

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APPENDIX A: SITE-SPECIFIC MEASUREMENT & VERIFICATION PLANS

The following subsections provide background details for each of the measurement and verification (M&V) sites. Each section includes a description of the building and its occupants, the lighting and lighting control systems pre- and post-retrofit, and the M&V plan as applied to each individual site.

SITE 1 – ELECTRICAL DISTRIBUTOR OFFICE SPACE

Site 1 was an electrical supply distributor office building located in the East Bay Area. The Site 1 office area is on the first-floor suite of a multitenant office building. According to the office manager, the office typically follows a 9-5, Monday through Friday schedule. Approximately 40% of the occupants play roles in the lighting industry (as specifiers and purchasers) and are very knowledgeable and proactive about lighting technologies.

The M&V study focused on a fraction of the office suite, including three (and subsequently four) private offices, a large open office broken into three areas, and two conference rooms. Two private offices and one open office area have daylight availability, pointing due east; however, there is an approximately six-foot deep overhang that shades the windows. In practice, there is not much daylight availability.

For Site 1, the area included in the M&V analysis was limited to the south end of the suite.

Pre-Retrofit Lighting Description

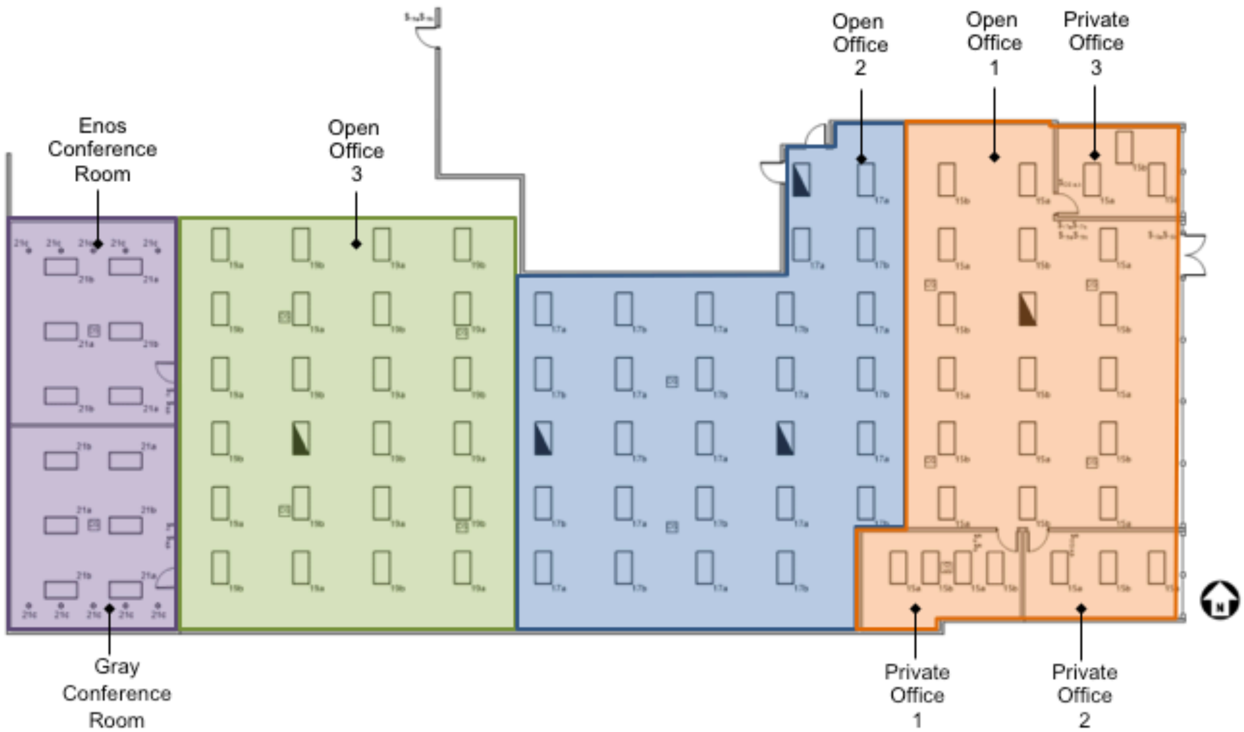
The office uses two-by-four troffers in a dropped T-bar ceiling in most areas of the building. The troffers were previously retrofitted with a 4,000K LED troffer kit (Philips EvoKit, 3rd Generation). Each troffer has two LED light bars rated for 21.1W apiece, for a total luminaire wattage of 42.2W. In addition to the troffers, each of the studied conference rooms have five recessed, medium-base downlights with 40W incandescent A-line lamps.

The entire suite uses occupancy sensors for complying with the Title 24 automatic shut-off control requirement. Pre-retrofit, the open offices, Office 1, and the conference rooms had ultrasonic, ceiling-mounted occupancy sensors. Offices 2 and 3 had switch-box passive infrared occupancy sensors.

Each zone had checker-board bi-level switching. In addition to the bi-level switching in the conference rooms, the LED troffers had a wireless dimming system that used a hand-held remote control to adjust the overhead lighting. When turned on, the conference room troffers briefly came up to full brightness and then, less than 5 seconds later, the luminaires dimmed down approximately 28% (72% of full output). Users had the option of using the remote control to raise the light output to 100% and reduce the light level down to approximately 5% of full output. Each

LED troffer in the conference room also had an embedded control module with an IR receiver and an integral passive infrared occupancy sensor. Per site staff, this occupancy sensor was disabled in each fixture in favor of the area ultrasonic sensor. The downlights in the conference rooms also had a phase-cut dimmer with a discrete shut-off switch.

Figure 1. Pre-Retrofit Site 1 Layout and Circuiting for Monitored Areas



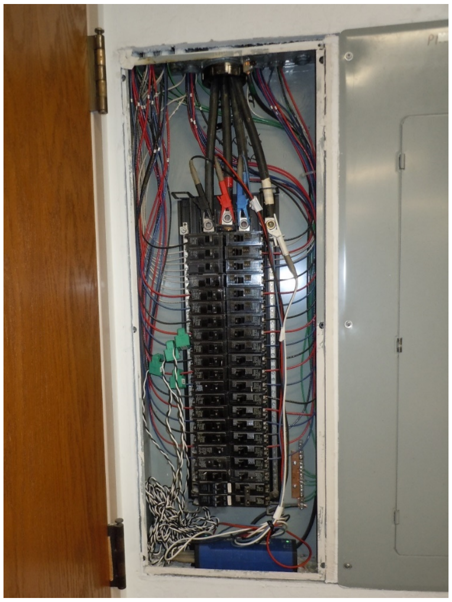
Pre-Retrofit Monitoring

We identified areas that were powered separately based on information collected from on-site staff. Per the site staff, separate circuits powered the lights in the following areas:

- Circuit 15: Office 1, Office 2, Office 3, Open Office (first three rows)
- Circuit 17: Open Office (mid five rows)
- Circuit 19: Open Office (last four rows)
- Circuit 21: Enos & Gray Conference Rooms

We verified the circuits were dedicated to their indicated lighting loads by turning off the luminaires and confirming that their individual power consumption matched the total circuit consumption. Similarly, we verified that adjacent areas did not impact the power readings. The electrical panel circuit metering installation is shown below in Figure 2.

Figure 2. Site 1 Electrical Panel Meter Installation



Each open office at Site 1 included a limited number of emergency luminaires (5 total, shown in Figure 1 above as a half-shaded rectangle). These luminaires were separately powered from a different lighting circuit and were not monitored as part of this study.

A horizontal irradiance meter was installed on the roof of the building after one month of baseline data logging, when the evaluation team was granted roof access. The horizontal irradiance meter ended up being unnecessary, as there were no daylighting controls in the existing system.

Occupancy data loggers were installed in Private Offices 1,2, and 3 adjacent to the existing occupancy sensors. For Private Office 1, the occupancy logger was installed on the ceiling. For Private Office 2 and Private Office 3, the occupancy logger was installed on the wall, adjacent to the existing occupancy sensor. The occupancy data loggers are shown in Figure 3.

Figure 3. Occupancy Data Loggers, Private Office 1 (Left), Private Office 2 (Middle), Private Office 3 (Right)

To capture any daylighting response, illuminance meters were installed near the edges of the primary daylit zones. The data loggers were installed at the workplane level, approximately 30 inches above the floor, as shown in Figure 4.

Figure 4. Workplane Illuminance Meters Private Office 2 (Left) and Private Office 3 (Right)

Figure 5. Luminaire Illuminance Loggers, Private Office 1 (Left), Private Office 3 (Right).

Figure 6. Luminaire Illuminance Loggers, Private Office 2 Switch Gang A (Left), Switch Gang B (Right)

In the front open office, ceiling-mounted occupancy data loggers were installed adjacent to the existing ceiling occupancy sensors, as shown in Figure 7. To capture daylighting response, illuminance meters were installed near the edges of the primary daylit zone and the secondary daylit zone.[1] The light meters were installed at approximately 30 inches above the floor, as shown in Figure 8.

To monitor the specific changes in the use of each switch gang, we installed illuminance meters pointed directly at a representative luminaire (for each switch gang).

Figure 7. Luminaire Illuminance Meters and Occupancy Sensors

Figure 8. Workplane Illuminance Meters, Primary Sidelit Zone (Left), Secondary Sidelit Zone (Right)

For the middle and rear open offices, ceiling-mounted occupancy data loggers were installed near the existing occupancy sensors. There were not sufficient illuminance loggers to monitor the output of the luminaires in these zones; therefore, one illuminance logger was installed on a representative fixture (for each switch gang in each zone). We used this single illuminance logger and the electric power logger to determine when the other switch gang was active. These are shown in Figure 9 and Figure 10.

[1] Note, there were no luminaires in the primary daylit zone.

Figure 9. Open Office Middle Data Loggers

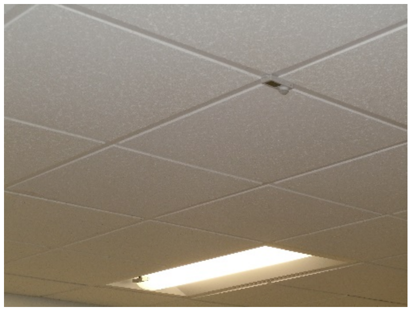
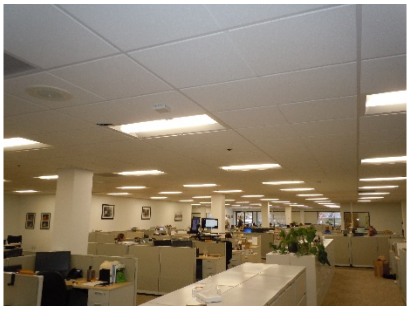



Figure 10. Open Office Rear Data Loggers




In the Enos and Gray Conference Rooms, ceiling-mounted occupancy data loggers were installed adjacent to the existing ceiling-mounted occupancy sensors. Luminaire illuminance meters for each of the three circuits were also installed. These are shown in Figure 11 and Figure 12.

Figure 11. Enos Conference Room Data Loggers.


Figure 12. Grey Conference Room Data Loggers.

Post-Retrofit Lighting Description

The luminaires were not changed as part of the retrofit activity. The controls, however, were substantially upgraded as part of the retrofit. Each private office received a new dimming light switch and ceiling-mounted passive-infrared occupancy sensor. The bi-level switching was eliminated, and no daylighting controls were installed. In addition to the control changes, Private Office 1 was subdivided into two smaller offices with the same aggregate luminaire total (Private Office 1 and Private Office 4).

The open office received similar upgrades as the private offices. The bi-level lighting controls were replaced with a single dimming circuit to control all the lighting. The ultrasonic ceiling sensors were replaced with passive infrared sensors. Open Office 1 received a daylighting sensor in the primary daylit zone; however, after functional testing and discussing the sensor location with occupants, we determined that the daylit zone (and thus, the sensor) did not receive enough daylighting to curtail the lighting load.

Bi-level controls were also eliminated in the conference rooms and the ultrasonic sensors were replaced with passive infrared sensors. The downlights in the conference room were left as-is, on a standard dimming light switch that is not controlled by the ALCS.

Post-Retrofit Monitoring

The electrical power metering did not change for the post-installation.

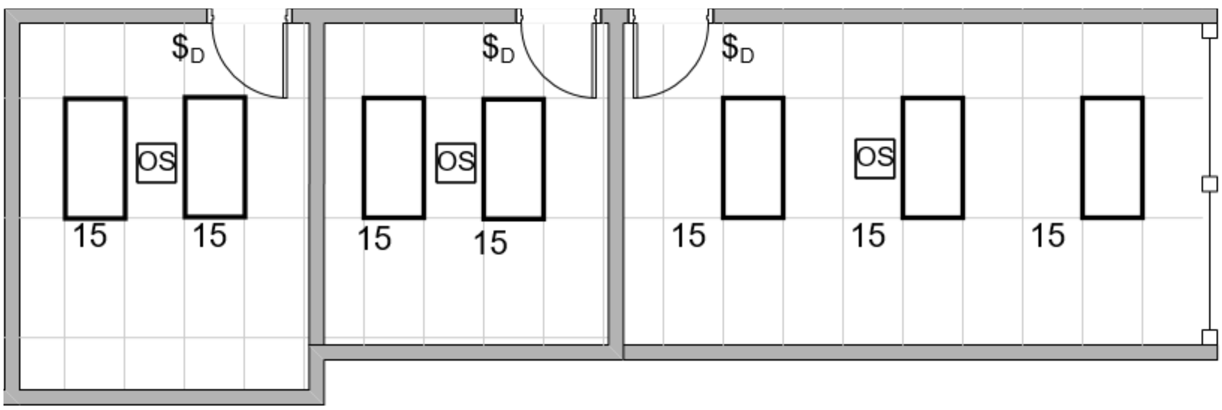
During the first month of post-retrofit data collection, the voltage leads were mis-matched with the current leads and resulted in flawed power data collection. This error was corrected at the start of the second month of post-period monitoring.

While the solar irradiance M&V approach did not change for the post- case, the data was not used given that the primary sidelit daylighting zone did not respond to daylight availability.

During the retrofit phase, site staff decided to subdivide Private Office 1 into two offices, as shown in Figure 13. This retrofit was complete by the third month of data collection and was metered once we had access to the space.

Data was gathered in a similar manner to the pre-period for this new office. As in the pre-period, occupancy and relative light output were measured. Since the private offices did not receive daylighting controls, daylighting was not monitored. Similarly, since bi-level switching was removed, only one circuit was measured for relative light output.

Figure 13. Revised Private Office Layout with the Interstitial Wall on the Left



The only difference between the pre-retrofit and post-retrofit monitoring for the open office area was the use of a single relative light output logger, given the loss of checkerboard bi-level lighting.

The only difference between the pre-retrofit and post-retrofit conference monitoring for the Enos and Gray Conference Rooms was the use of a single relative light output logger for the troffer luminaires, given the loss of checkerboard bi-level lighting. The separate relative light output data logger on the incandescent downlights was retained.

Site 1 Data Collection Anomalies

Site 1 experienced a few data collection errors, summarized below:

- During the first month of pre-installation metering, the power meter lost power, reducing the overall baseline power-metering duration to one month.
- During the second month of pre-installation metering, the relative illuminance meter in the rear open office had a battery failure, resulting in approximately seven days of data loss.
- During the first two months of post-installation metering, Office 1 and Office 4 were not available for metering, as construction was ongoing, splitting Office 1 into two offices. This change in space configuration makes leveraging these two spaces difficult for the purposes of this study. Even

after construction was completed, the new occupant in Office 4 required significantly more light than the previous occupant, making a direct comparison, even after the fact, less clear.

SITE 2 – OFFICE BUILDING SHARED SPACES

Site 2 was a two-story, single-tenant office building located in the East Bay Area. The Site 2 office area is located on the second floor of the building. According to site staff, the facility has typical 9-5 occupancy Monday through Friday; although there are some folks who arrive very early and/or stay very late.

The monitoring focused on the one lighting circuit that could be easily monitored with in-scope luminaire retrofits. The other circuits planned for retrofit had significant portions of open office area lighting that would not be included in the retrofit.

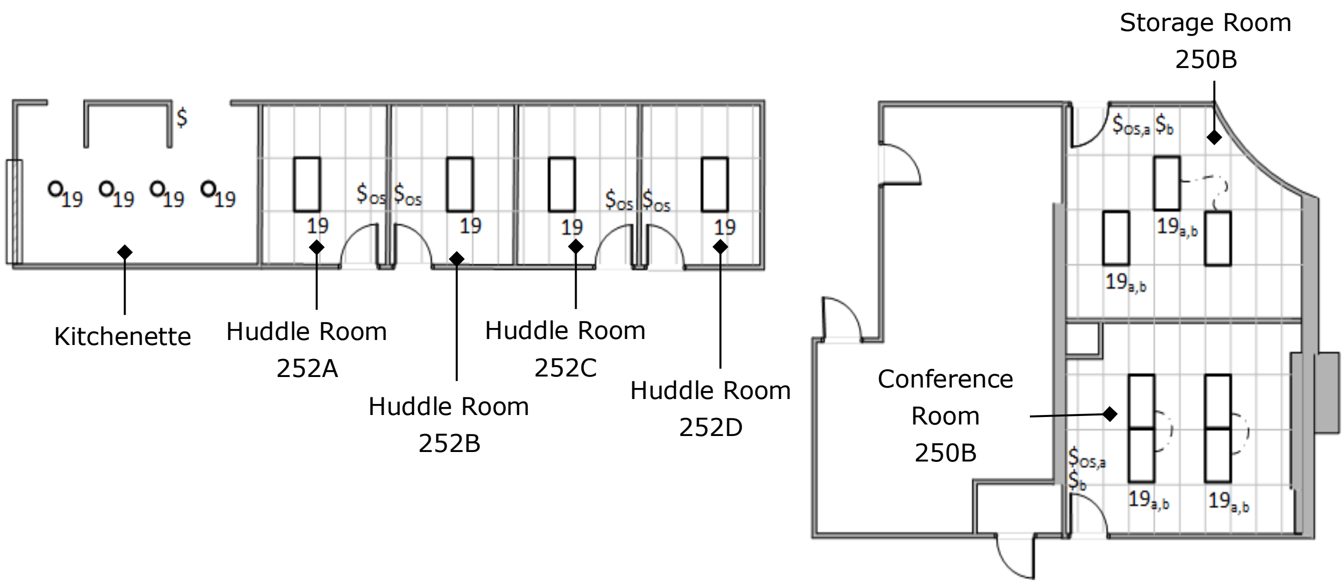
Pre-Retrofit Lighting Description

The spaces monitored for Site 2 are shown in Figure 14. Pre-retrofit, the lighting in the huddle rooms, conference room, and storage closet used two-by-four volumetric troffers with a perforated metal basket and thin acrylic diffuser. Each luminaire was wired for in-board/out-board switching with three four-foot T8 lamps. However, only the conference room and storage rooms made use of the bi-level luminaire wiring. Luminaires near one another in the conference and storage rooms were tandem wired. The huddle rooms had switch box PIR occupancy sensors. In the conference room and storage room, one of the switch legs was controlled by a switch box occupancy sensor, while the other switch leg was on a manual toggle switch.

Due to the electrical wiring, an out-of-scope kitchenette was also monitored. The kitchenette had a manual toggle switch and four pendant compact fluorescent lamp luminaires with a frosted glass diffuser.

None of the spaces retrofitted had daylight exposures and thus no daylighting controls were installed. Therefore, no horizontal irradiance meters were installed.

Figure 14: Pre-Retrofit Site Layout and Circuiting for Monitored Areas, All on One Circuit



PRE-RETROFIT MONITORING

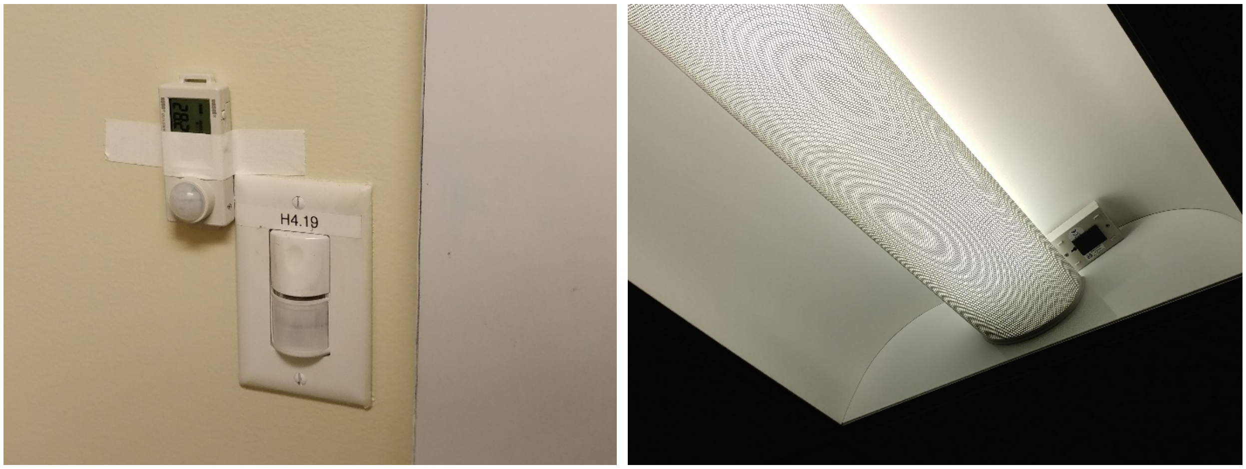
Areas that were powered separately were identified based on information gathered from site staff. Per the site staff, a single circuit powered the lights in the following areas:

- Circuit 19: Kitchenette, Storage 250A, Huddle 252 A-D, Conference 250B

The evaluation team verified the circuit was dedicated to their indicated lighting loads by turning off the luminaires and confirming that their individual power consumption matched the total circuit consumption. Similarly, the evaluation team verified that adjacent areas did not impact the power readings. This circuit has a phantom load of approximately 70W that could not be isolated during logger installation.

The huddle rooms were intended for staff working in the open office areas to take conference calls, thereby minimizing noise. In practice, the huddle rooms were reserved on a first-come/first-served basis and employees use these spaces as private offices. Each room was identically provisioned, thus our monitoring approach for each room was identical. Occupancy data loggers were placed on the wall, adjacent to the switch box occupancy sensor, and the relative light output data logger was located inside the luminaire, above the perforated metal basket, as shown in Figure 15.

Figure 15. Huddle Room Metering Approach, Occupancy Sensor (Right) Relative Light Output (Left)



The conference room was used periodically for large group meetings. An occupancy meter was installed adjacent to the existing switch-box occupancy sensor. The space has bi-level lighting, but the in-board/out-board control only required a single relative light output meter capable of measuring both lighting steps simultaneously.

The storage room was a limited access area used for storing janitorial supplies. Since the existing switch-box occupancy sensor was largely blocked by boxes and other materials, the evaluation team elected to install the occupancy sensor on the ceiling. Like the conference room, a single relative light output meter was used to measure the bi-level lighting use in the space.

The kitchenette was located centrally on the floor and was a heavily trafficked area as it contains the refrigerator, vending machines, and coffee station. The existing space had no occupancy sensor. Therefore, the occupancy sensor was installed in a reasonable location on the ceiling, as shown in Figure 16. The existing luminaires were aluminum, so the logger could not be attached magnetically and taping the logger to the reflective surface inside the luminaire would have likely damaged the finish. Therefore, the relative light output data logger was installed on top of one of the vending machines as shown in Figure 16.

Figure 16. Kitchenette Data Logging: Occupancy Upper Right, Relative Output Lower Left.

Post-Retrofit Lighting Description

As part of the retrofit, each troffer was retrofitted with an LED troffer kit that included an integral passive infrared occupancy sensor manufactured by Enlighted. Each 2x4 troffer is approximately 80W.

The huddle rooms retained their old switch-box occupancy sensors. However, these were disabled in favor of the overhead occupancy sensor, making the switch effectively an on/off sensor. There was no manual dimming control installed in the huddle rooms.

The conference room manual switch was entirely removed. The removal of the manual switch in the conference room violates Title 24's requirement for manual switches (§130.1 (a) 2 A & B). The evaluation team does not have any information about why this switch was removed.

The storage room had the tandem wired luminaire removed during the retrofit, presumably to eliminate the need to pull power to the tandem wired luminaire. Like the huddle rooms, the manual switches were retained in favor of providing user manual control and the switch-box occupancy sensor was disabled.

Post-Retrofit Monitoring

There was no change to the site electrical power measurements. As in the pre-retrofit, the solar irradiance meter was not installed. Each huddle room was identically provisioned, thus the metering approach for each room was identical. For the huddle rooms, conference room, and storage room for the post-retrofit monitoring, a relative light output meter was installed in a similar location as in the pre-retrofit monitoring and the occupancy meter was relocated to the ceiling next to the luminaire-integrated sensor, an example is shown in Figure 17.

Figure 17. Post-Retrofit Huddle Room Metering Approach

During the first month of data logging, the loggers in the storage room were removed by someone on-site and had to be reinstalled at the start of month 2.

The kitchenette remained unchanged and thus the monitoring approach was unchanged from the pre-retrofit monitoring.

Site 2 Data Collection Anomalies

Site 2 experienced a few data collection errors, summarized below:

- During the first month of post-installation metering, the relative illuminance meter battery died 21 days into the month.
- During the second month of post-installation metering, the huddle room D occupancy logger replacement battery failed.
- During the third month of post-installation metering, the relative illuminance meter in the kitchenette was launched incorrectly and only collected two weeks of data.

SITE 3 – MANUFACTURING BUILDING CONFERENCE ROOMS

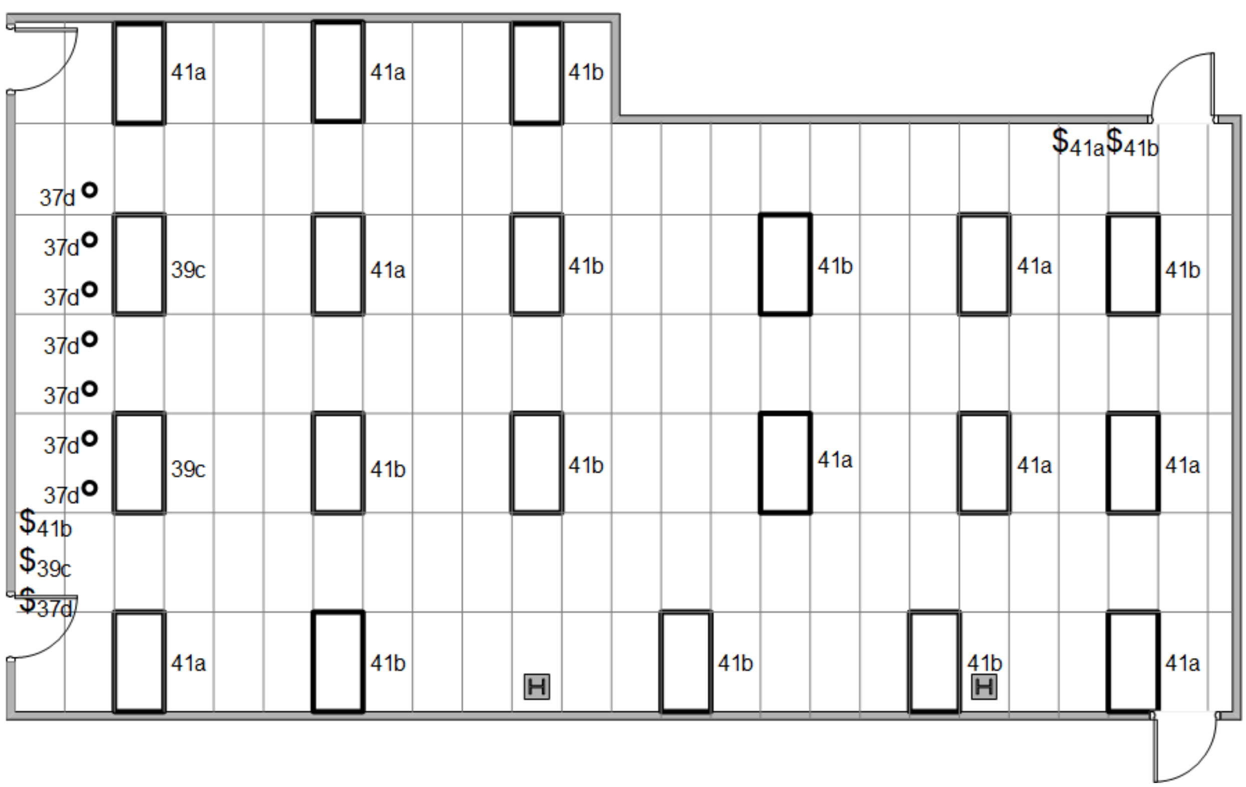
Site 3 was a two-story, mixed-use facility on the San Francisco Peninsula. The Site 3 retrofit area was limited to one large training room and one smaller conference room. These spaces are used for manufacturing plant staff meetings.

PRE-RETROFIT LIGHTING DESCRIPTION

The existing light design relied on two-by-four prismatic troffers with two 32W T8 lamps and six-inch incandescent downlighting for accenting purposes. There were no lighting controls installed prior to retrofit and neither zone had access to daylighting. Each of the two conference rooms retrofitted had a slightly different layout.

The training room had 20 two-by-four troffers and seven 50-watt incandescent downlights, as shown in Figure 18. The space had uneven bi-level lighting with no clear zoning intent. Four luminaires were burned out on the b-switch leg during the pre-retrofit study. Two of the two-by-four troffers were on a dedicated switch leg, located in front of the presentation screen. The seven downlights were independently controlled using a dimming switch.

Figure 18. Pre-Retrofit Site Layout and Circuiting for the Training Room

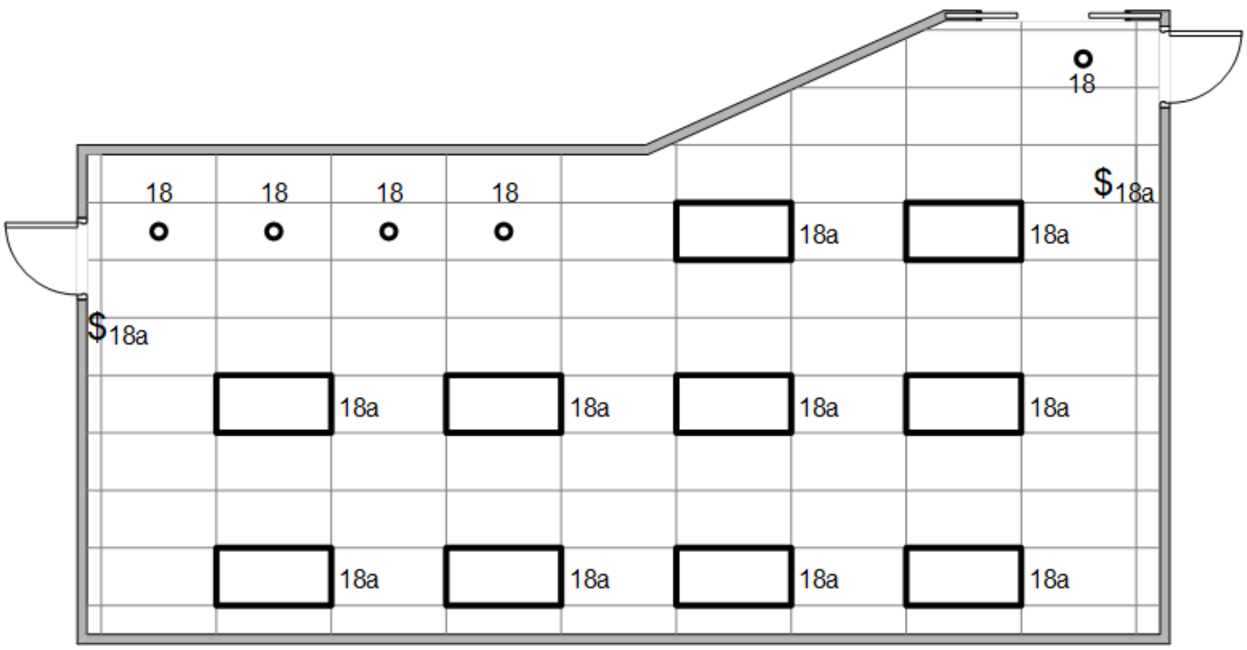


EMI CONSULTING

Pre-Retrofit Monitoring

The small conference room had ten two-by-four troffers and five 50-watt incandescent downlights, as shown in Figure 19. During the pre-retrofit M&V period, two of the incandescent downlights were burned out. The space had two manual switches for the troffer lighting; however, the downlights in this space were uncontrolled and operate continuously. We were told the downlights are on circuit 18.

Figure 19. Pre-Retrofit Site Layout and Circuiting for the Small Conference Room.



Between the two spaces, the lighting was wired to three circuits in two different electrical panels:

- Circuit 41: Training Room, 18 Troffers
- Circuit 39: Training Room, 2 Troffers and projector screen
- Circuit 18: Small Conference Room, 5 Downlights, 10 Troffers

The evaluation team verified the circuit was dedicated to their indicated lighting loads by turning off the luminaires and confirming that their individual power consumption matched the total circuit consumption. Similarly, the evaluation team verified that adjacent areas did not impact the power readings. As the projector screen was often left in the down position, the projector screen power draw was ignored.

None of the spaces retrofitted had daylight exposures and thus no daylighting control were installed. Therefore, no horizontal irradiance meters were installed.

To meter the relative light output in the training room, one relative light output meter was put on each fluorescent lighting zone (41a, 41b, 39c in Figure 18). A relative light meter was not installed on the incandescent lighting, as those luminaires were not in the scope of work and on-site staff said they were not used frequently. Two occupancy loggers were installed on the ceiling to provide adequate coverage.

To meter the relative light output in the small conference room, one relative light output meter was put on one troffer in the zone. A relative light meter was not installed on the incandescent lighting, as those luminaires are not switchable and operate continuously. Two occupancy loggers were installed on the ceiling to provide adequate coverage.

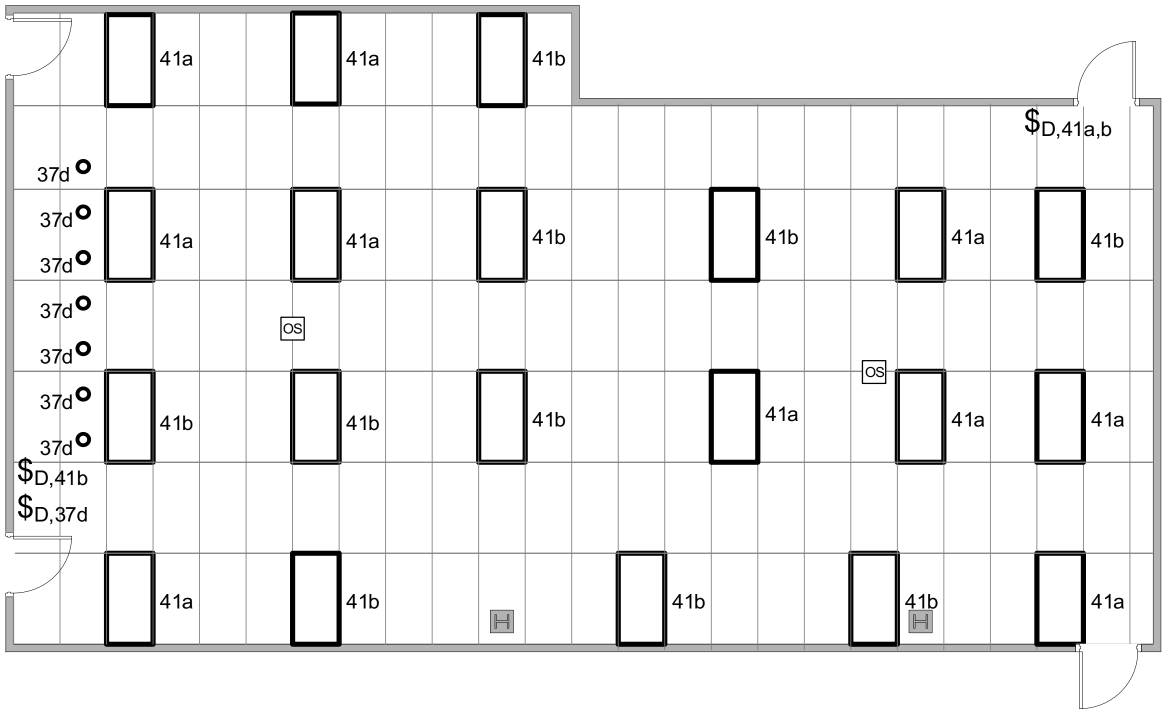
Post-Retrofit Lighting Description

As part of the retrofit, new Audacy lighting controls were installed. Each space received new manual dimming switches and occupancy sensors. According to site staff, they could also control the lighting using a mobile application.

The evaluation team contacted the electrical distributor for this project and were told that the EiKO VOL24-5CP-40K-U luminaire was used on this project (46W, 5800 lumen LED). The luminaire in the cutsheet appears to match the luminaire we saw in the field. However, no nameplate on the luminaire was visible.

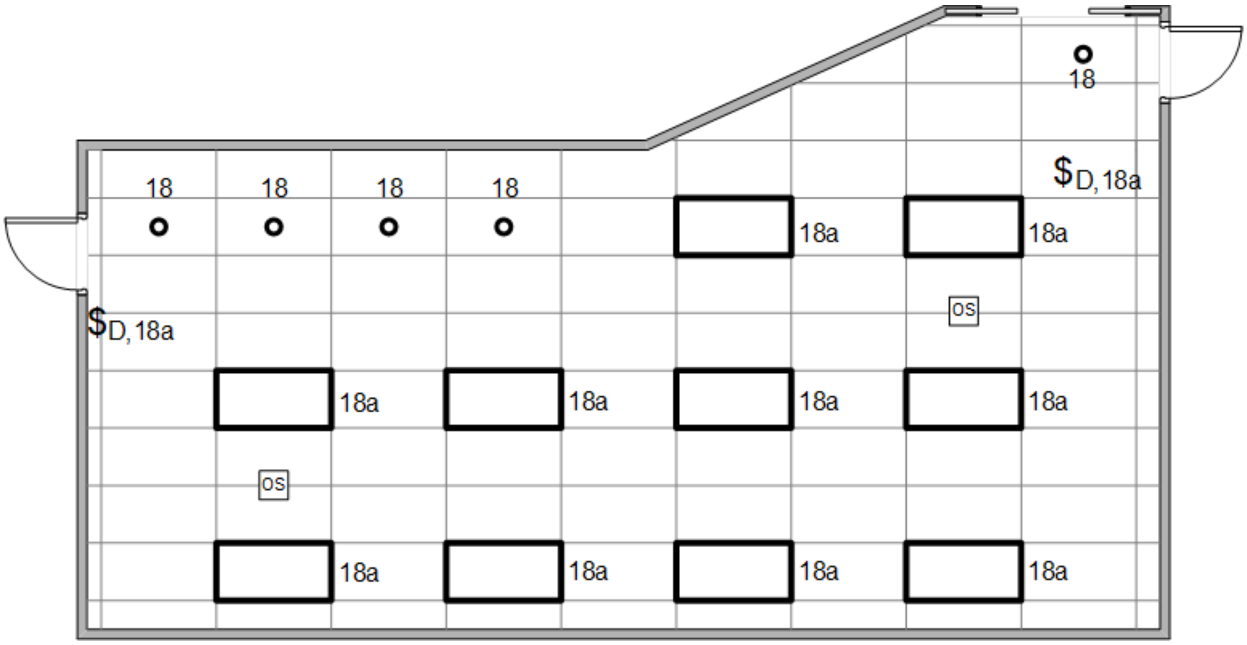
The luminaire count in the training room remained unchanged. However, the circuiting was modified. The two luminaires on switch gang 39c, near the projector screen, were transferred to switch gang 41a. Therefore, 39c no longer had any lighting on the circuit. Both switch gangs were still separately controlled with individual dimming switches. All of the two-by-four troffers were replaced with an LED troffer, drawing approximately 24W. The seven downlights were independently controlled using a dimming switch, but this switch was not incorporated into the control system. The new layout and circuiting for the training room is shown in Figure 20.

Figure 20. Post-Retrofit Site Layout and Circuiting for the Training Room.



All of the two-by-four troffers in the Small Conference Room were replaced with an LED troffer, drawing approximately 40W. Two passive infrared occupancy sensors were installed on the ceiling near the entrances to the room. The light switches controlling the troffers were replaced with wireless dimming switches. The five downlights remain uncontrolled, and the two burned out lamps were still in place. The new layout and circuiting for the Small Conference Room is shown in Figure 20.

Figure 21. Post-Retrofit Space Layout and Circuiting for the Small Conference Room



Post-Retrofit Monitoring

The electrical power measurement plan was very similar to the pre-retrofit monitoring plan. During the retrofit, two of the training room troffers were relocated to circuit 41; therefore, we stopped monitoring circuit 39.

- Circuit 41: Training Room, 20 Troffers
- Circuit 18: Small Conference Room, 5 Downlights, 10 Troffers

As in the pre-retrofit, the solar irradiance meter was not installed.

To meter the relative light output in the training room, one relative light output meter was put on each fluorescent lighting zone (41a and 41b in Figure 20). A relative light meter was not installed on the incandescent lighting, as those luminaires were not in the scope of work and on-site staff said they were not used frequently. Two occupancy loggers were installed on the ceiling to provide adequate coverage.

To meter the relative light output in the Small Conference Room, one relative light output meter was put on one troffer in the zone. A relative light meter was not installed on the incandescent lighting, as those luminaires are not switchable and operate continuously. Two occupancy loggers were installed on the ceiling to provide adequate coverage.

Site 3 Data Collection Anomalies

The Small Conference Room occupancy sensor was removed by an occupant during the first month of pre-installation M&V and yielded no useful data.

SITE 4 – MANUFACTURING OPEN OFFICE

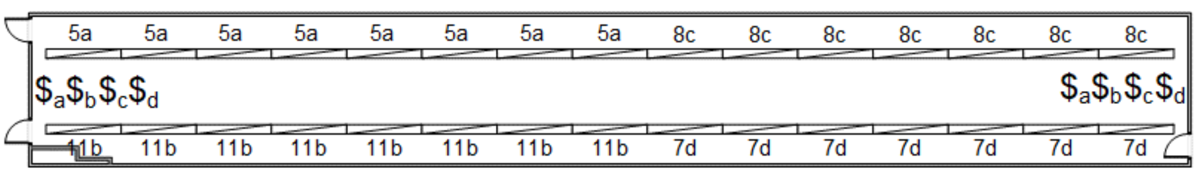
As was discussed in the recruiting section, Site 4 is occupied by the same company as Site 3 but is a separate building from Site 3. Site 4 is a two-story, mixed-use facility on the San Francisco Peninsula. For Site 4, the retrofitted area was limited to one large open office area, as shown in the layout below.

Pre-Retrofit Lighting Description

The existing light design used a continuous run of luminaires in two rows that spanned the entire length of the office, as shown in Figure 22. Each luminaire was four feet long and included four 32W T8 lamps and two, four-foot prismatic wrap lenses. The office area was zoned in four quadrants, with two switch banks located on opposite ends of the room. During the pre-retrofit monitoring period, there as a high number of burn-outs (12 out of 30). These luminaires were not replaced during the evaluation study.

There were no lighting controls installed prior to retrofit and the zone had no access to daylighting.

Figure 22. Pre-Retrofit Space Layout and Circuiting for Monitored Areas.



Pre-Retrofit Monitoring

The lighting in the open office area was wired to four discrete circuit breakers:

- Circuit 5: Upper Left Quadrant
- Circuit 8: Upper Right Quadrant
- Circuit 7: Lower Right Quadrant
- Circuit 11: Lower Left Quadrant

The evaluation team verified each circuit was dedicated to their indicated lighting loads by turning off the luminaires and confirming that their individual power consumption matched the total circuit consumption. Similarly, the evaluation team verified that adjacent areas did not impact the power readings. As the projector screen was often left in the down position, the projector screen power draw was ignored.

The retrofitted space did not have daylight exposure and thus no daylighting controls were installed. Therefore, no horizontal irradiance meters were installed.

To meter the relative light output in the open office, one relative light output meter was put on each lighting circuit in the zone. Similarly, one occupancy sensor was installed in each quadrant. The occupancy sensors were put on the ceiling to best capture the occupancy behind cubical walls.

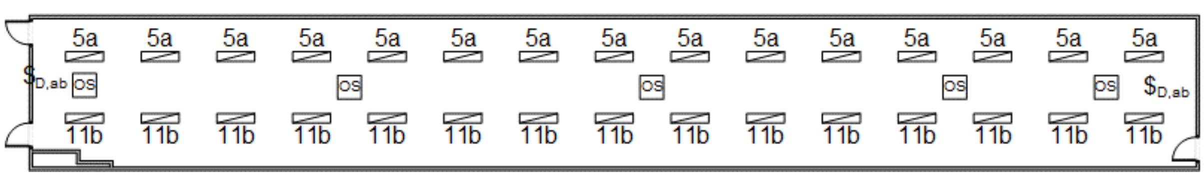
Post-Retrofit Lighting Description

The Open Office Area retrofit replaced the 30 eight-foot luminaires with 26 four-foot, surface-mount LED wrap luminaires for the first month of M&V. Sometime during the first month of post-retrofit monitoring, the luminaire count was increased to 30 four-foot luminaires. The post-retrofit space layout and circuiting is shown in Figure 23.

The luminaires in the open office were consolidated on two switch gangs, each gang served by a separate circuit breaker. Five wireless Audacy, passive infrared occupancy sensors were installed on the ceiling and the manual switches were replaced with Audacy dimming switches.

The evaluation team contacted the electrical distributor for this project and were told EiKO LLW-5CP-40K-U luminaire was used on this project (40W, 5200 lumen LED). The luminaire in the cutsheet appears to match the luminaire we saw in the field; however, no nameplate on the luminaire was visible.

Figure 23. Post-Retrofit Space Layout and Circuiting for Monitored Areas.



Post-Retrofit Monitoring

The electrical power metering plan was adjusted to reflect the new electrical circuiting in this space, using the two consolidated luminaire circuits.

- Circuit 5: Upper Half
- Circuit 11: Lower Half

To meter the relative light output in the open office, one relative light output meter was put on each lighting circuit in the zone. Due to the reconfigured behavior in the zone (essentially auto-on), occupancy sensors were installed near the entrances to the zone to best capture short term occupancy that might keep the lights on longer than expected.

Site 4 Data Collection Anomalies

The site experienced a single anomaly during the end of the third month. Due to schedule conflicts arising from the winter holidays, there was a 20-day delay in retrieving the data loggers. During this window, no relative illuminance or occupancy sensor data was collected in the zone, as the data loggers had reached their on-board storage capacity limit.

APPENDIX B: CALCULATOR TOOL INITIAL ASSESSMENT MEMO

MEMO

Initial Assessment
January 3, 2017

To: Doreen Caruth, Pacific Gas and Electric Company (PG&E)

From: Jess Chandler, EMI Consulting

cc: Bruce Chamberlain, kW Engineering
James Donson, kW Engineering

RE: Advanced Lighting Control System (ALCS) Calculator Tool Initial Assessment

The fundamental question that drives the ALCS Calculator Tool (Tool) Evaluation is: "Does the Tool work in the field?" Our team conducted an initial assessment as a first step in the evaluation of the Tool.

The initial assessment is designed to verify the formulas, assumptions, and key variables, providing findings to respond to two of the key research questions from our Research Plan[2]:

- Are the underlying savings estimation formulas of the Tool sound?
- Which variables in the Tool have the greatest impact on savings Impacts?

Findings from the initial assessment will inform training for the Tool Trial Contractors (separate project), inform future iterations of the Tool, provide context for understanding differences between the Tool output and metered findings in later steps of this Tool evaluation, and contribute to the Tool evaluation final report.

Next steps from this memo are:

1. Discuss the findings from the initial assessment with PG&E and Tool Trial team. EMI Consulting will do this in a regularly scheduled joint meeting.
2. Work with PG&E to share key findings with parties outside the evaluation that can benefit from these learnings. EMI Consulting will share a separate document of key findings.

[2] EMI Consulting. 2016. PG&E ALCS Tool Evaluation Proposed Research Plan. Available from CPUC: http://www.energydataweb.com/cpuc/search.aspx?did=1678

INTRODUCTION AND SUMMARY

For the initial assessment of the ALCS Calculator Tool, our team assessed the Tool in three sequential steps:

1. Review of the Formulas and Theory,
2. Sensitivity Analysis, and
3. Variable Review.

Our key findings in the initial assessment are:

1. The formulae and theory in the tool appear to be developed in keeping with the literature and best practices, as applicable. We found some risk in the control factors development (see finding 3).
2. Where we could verify the implementation, the Tool appears to be implemented in keeping with the documentation with two exceptions: the savings do not appear to take into account the type of lighting or ballasts as described in the documentation and the documentation description for daylight zones is not in the model.
3. The underlying assumptions for the control factors are based on very limited data that does not cover all building types in the model and, in some cases, does not cover the control type at all. The most critical function of the Tool for calculating savings is building control factors for Advanced Lighting Controls. This is also where the Tool exhibits the greatest uncertainty.
4. There were multiple instances where we could not trace a variable's impact because of the complex lookup method which relies on matching numbers in rows and columns to identify another value. This is not only a risk to our sensitivity analysis and key variable assessment but also presents a risk to ensuring modifications to the Tool are complete.
5. There are a number of exceptions to the Title 24 requirements that the Tool does not capture; ultimately, this means that the savings from Code can be conservative when these exceptions apply.

While we did not anticipate recommendations to come out of this assessment, we have a few recommendations for use or future updates of the Tool:

- (Related to Finding 3) We urge greater clarity and guidance in the Tool to ensure that users focus on those variables for which the Tool authors are most uncertain in the default values in addition to those we highlight as highly responsive. In particular, users should be given greater urgency or guidance to override default assumptions for control parameters where applicable.
- (Related to Finding 3) Given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.
- (Related to Finding 4) We strongly urge updates of the Tool to shift to a human readable (and commented) lookup method.

FINDINGS AND RECOMMENDATIONS

For the initial assessment of the ALCS Calculator Tool, our team assessed the Tool in three sequential steps:

1. Review of the Formulas and Theory: We reviewed the documentation and how the Tool implemented the savings calculations represented in the documentation.
2. Sensitivity Analysis: We tested 37 variables across their reasonable range in the sensitivity analysis, 30 were responsive – 8 highly, 10 medium, and 12 low; the remaining seven had no responsiveness to variation over their range. In each case, we considered how the variable was coded and how it is expected to contribute to savings calculations. Those that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all were included in our variable review.
3. Variable Review: We verified the sources of reference, default values, and coding for 21 variables identified in the Sensitivity Analysis (14 high/unusual and 7 not responsive). We also checked for proper interpretation and application of Title 24 code requirements.

Here, we provide our key findings and recommendations (which are summarized in the Introduction).

KEY FINDINGS

Our key findings in the initial assessment are:

1. The formulae and theory in the tool appear to be developed in keeping with the literature and best practices, as applicable. We found some risk in the control factors development (see finding 3).

2. Where we could verify the implementation, the Tool appears to be implemented in keeping with the documentation. Exceptions are summarized here; however, there are many places where the documentation or approach is not clear, and those are identified in separate findings.
    a. The documentation suggests that ballasts matter in the introduction as section 5, "Saving Calculation from LPD change" is referred to in the introduction (erroneously as Section 4) as describing the "calculation method to calculate savings from change in LPD along with change in lighting technology and ballast type." However, review of section 5 and the underlying lighting energy use profiles make no mention of the type of lighting or ballasts. The LPD is the only lighting value that is used in these calculations.
    b. There are three kinds of daylight zones documented in the documentation (daylight, secondary, and none); however, the Tool inputs only show a percentage of each type of installed lighting is in the daylight zone. As we note below, the portion of lighting in a daylight zone is on the detailed inputs tab, and it is not clear to the user that they should update this value when known when dealing

with daylight sensors.

3. The underlying assumptions for the control factors are based on very limited data that does not cover all building types in the model and, in some cases, does not cover the control type at all. The most critical function of the Tool for calculating savings is building control factors for Advanced Lighting Controls. This is also where the Tool exhibits the greatest uncertainty.
    a. Occupancy Sensor: According to the documentation, due to a lack of sufficient study data, the user is expected to enter the type of occupancy sensor (vacancy sensor or occupancy sensor), and the delay off time setting (1 - 30 mins), however currently this expectation isn't made clear enough to the user. The default sensor type does appear to change with space type; however, the default for delay time remains 30 minutes regardless of the space and building type. This appears to be a conservative estimate (good) when compared with the few studies mentioned in the documentation that indicate most buildings have 5 to 15-minutes delay time, and only a few are at 30 minutes.
    b. Daylight Sensor: The documentation is not clear, and the Tool is not clear, but it appears that the developers ran 9,270 simulation runs to develop 4 radiance templates. Essentially, based on the amount of daylight illuminance and the required illuminance, the lighting percent required (on the portion of lighting in the daylight space) is adjusted to develop a curve. The documentation refers to separate lighting energy use profiles or impacts by lighting type, but the lighting energy use profile discussed previously is a blended profile. Within the Tool, the daylight sensor control is supposedly included by selecting the appropriate radiance template. There likely is an interaction with the "enhanced daylighting options". It is not completely clear how the daylight sensor control factor is developed.
    c. Demand Response: There are no cited studies, but the development of the control factor is sound, assuming the user enters appropriate values. The biggest risk here is for users who: incorrectly define the peak period, enter an optimistic number of events (like entering 20 when the typical number is 5), or do not update the portion of wattage and degree of dimming.
    d. Task Tuning: The Tool documentation indicates that users must input this value because the literature does not cover enough instances. The Task Tuning control factor is developed as an even reduction in power across operation hours with a default of 20% and a possible range of 10% to 50%.
    e. Manual Dimming: The Tool documentation indicates the same method as Task Tuning and suggests that users must input this value because the literature does not cover enough instances. The Manual Dimming control factor is developed as an even reduction in power across operation hours with a default of 10% and a possible range of 5% to 40%.

f. Time Switches: According to the documentation, there were no reasonable studies that provided generalized savings for time switches. The default assumptions used may or may not be conservative and thus is a source of risk. Because this is a sensitive variable, we recommend that the user be informed of the backend assumptions, and encouraged and enabled to modify those assumptions. Currently, the tool assumes the lighting system turns on 1 hour before scheduled operation and the override switch is engaged once a weekday in the last hour of operation.

4. There were multiple instances where we could not trace a variable's impact because of the complex lookup method which relies on matching numbers in rows and columns to identify another value. This is not only a risk to our sensitivity analysis and key variable assessment but also presents a risk to ensuring modifications to the Tool are complete. We followed five of our variables of interest through the virtual models and the resulting values have no formulas that refer to them.[3] This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool.
    a. Ballast Type
    b. Enhanced Daylighting
    c. Installed Lighting Portion
    d. Minimum Lighting Level
    e. Unoccupied Percent On

5. There are a number of exceptions to the Title 24 requirements that the Tool does not capture; ultimately, this means that the savings from Code can be conservative when these exceptions apply.

Recommendations

While we did not anticipate recommendations to come out of this assessment, we have three recommendations for use or future updates of the Tool.

We urge greater clarity and guidance in the Tool to ensure that users focus on those variables for which the Tool authors are most uncertain in the default values in addition to those we highlight as highly responsive.[4] In particular, users should be given greater urgency or guidance to override default assumptions for control parameters where applicable. Here, we break up this recommendation into three specific areas: Greater clarity, guidance for users, urgency to override defaults[5]:

- We suggest greater clarity when documentation or the Tool do not clearly set the user up to make choices about when and how to override the default

[3] Because we only traced variables with high, unexpected, or no sensitivity, we cannot say if these five are the only instances.
[4] Related to Finding 3.
[5] Because these can be related, some variables are repeated in these lists. For example, if there is a need to override defaults and no clear guidance, we list the variable in both places.

assumptions for a variable. This could be implemented by the Tool developer through concurrent updates to the documentation and updates to the front page (first sheet) of the Tool in MS Excel. There are two variables that would benefit from greater clarity.

  - Daylight zones: The documentation does not document how secondary and primary daylight zones are determined for a site. It does describe that savings are calculated separately per daylight zone, but again, it is not stated what assumptions make the basis for how much % space is allocated to each for each space type or building type. There are three kinds of zones documented in the documentation (daylight, secondary, and none); however, the Tool inputs only show a percentage of each type of installed lighting is in the daylight zone. The default is 20%; it is not clear whether the additional 80% is secondary or not in a daylight zone. The documentation does not describe the effect of selecting a Daylighting Zone. Therefore, it is difficult to understand whether the savings should change based on a change in selecting the zone.
  - Code Trigger Reason: The reason is not defined as driving a selection in the documentation. The code trigger option activates when changes are entered into the Proposed Inputs tab. The Tool automatically selects lighting controls and a "Yes" or No" in terms of whether the code is triggered for each space type. According to the documentation, similar to LPD, minimum required lighting controls per code are assigned to each space type, which can then be overridden by the user. The documentation also states that the Title 24 lighting requirements are based on code triggers including room size, LPD, window areas, etc. For ASHRAE 90.1, the description is similar but provided as more simplified look-up table against ASHRAE space types. There are sets of 'Control Trigger Logics' discussed in detail in the documentation and also found in the tool within the underlying virtual models.

- We suggest improving or developing guidance for users when documentation or our initial assessment show that a variable's default values should be overridden, but it is not clear in the Tool how to do it. This could be implemented by the Tool developer through updates to the front page (first sheet) of the Tool in MS Excel. This could also be implemented by third parties, like the Tool Trial team, who are conducting training for Tool users. There are five variables that would benefit from additional guidance to users.[6]
  - Project Type: By selecting New Construction for the project type, no existing baseline savings is generated, only code baseline. By selecting Existing Building Alterations, users are allowed to select an older code. The sensitivity analysis showed that this is a critical variable to set correctly. Therefore, we would recommend adding more clarifying

[6] We have considered Proposed Lighting Controls as a single variable for this count, but it refers to all of the variables within proposed lighting controls.

guidance for users to better understand how the project type and permit cycle variables are to be used, how they impact the savings calculations, and how they alter the presentation of the outputs. In the current Tool implementation, it is not clear to users changing the project type clears out the existing building savings output. In addition, the note about types of buildings covers up other notes on the '1 Existing Inputs' tab that are relevant to initial entry.

  - Permit Cycle: In the current Tool implementation, it is not clear to users that the permit cycle is meant to populate the existing building defaults, and that changing the project type clears out the existing building savings output. This means that users must enter these first before making more changes to the details for their project.
  - Occupied Days: The lighting energy use profile curves for weekends are still in place when weekends are occupied, and weekends usually have very low energy use profile curves per the DEER values. If the prototypical facility has very low weekend energy use and the facility under analysis has weekend use similar to weekday use, the user should modify the usage profile in the '3 Detailed Inputs' tab.
  - Proposed Lighting Controls: While the guidance does identify that the user can enter the proposed controls and their details, it does not specify where all of the related items are within the Tool. For example, for users may not realize that the required illuminance by space type (in lux) which is applicable for Daylight Sensor Control, is on the '3 Detailed Inputs' tab, with a default by space type – these defaults appear reasonable compared to ASHRAE 90.1 guidance. In addition, guidance in the Tool does not identify those lighting controls variables (for existing and proposed lighting controls) where the documentation indicates the user must enter the known value, like manual dimming and task tuning percent.
  - Code Trigger Reason: Since the code trigger default is reliant on room size, LPD, window area for certain control types, building types, and space types, it is important to emphasize to the user the importance of inputting those particular values rather than relying on defaults. If the user understands the variables influencing the code trigger, this reason and the code trigger should be able to remain at the default. In addition, a note should be added that changing the reason for the code trigger will change code savings and is not just a documentation reference for the selection of "Yes" or "No".
- We suggest developing a signal of urgency to override defaults when documentation or our initial assessment show that a variable's default values should be overridden, but no indication is given in the Tool that the default value is likely not appropriate for the use case. This could be implemented by the Tool developer through improved guidance for tool users (see above) and through highlighting or commenting on the specific variables in the Tool in MS Excel. This could also be implemented by third parties, like the Tool Trial team, who are conducting training for Tool users.

There are six variables for which we recommend providing the user a signal of urgency to override defaults.[7]

- Building Size (Sq Ft): There can be no expectation for reliable calculations of savings for a project that does not have the appropriate square footage. Users should be strongly urged to modify this value even at their very first screening phase.
- Occupied Start Time: Both the start and end times appear to be medium to highly sensitive variables, indicating that attention should be paid to setting this variable as accurately as possible. We recommend that the tool should flag these variables as critical for user for input as best as possible, even though the default value has a valid source.
- Occupied End Time: (see Occupied Start Time, above)
- Existing LPD: If the user knows these values, the defaults should be overridden because the savings (to baseline) are highly sensitive to the existing LPD, and the defaults are the code maximum which will not be conservative if the facility has more efficient lighting.[8] The code maximum allowable LPDs are assigned to each space type per building type, using the code year specified by the permit cycle selected by the user, which is a required input. For new construction, the most recent version of the code is referenced.
- Existing Lighting Controls: The user may modify the existing lighting controls to select "Yes" or "No" for the full list of control options available. The tool then develops control factors per control strategy that applies to the DEER based lighting energy use profile for each space. We observed large changes in energy savings suggesting that these variables are highly sensitive, although testing them individually showed lower sensitivity. The documentation suggests that the user is expected to enter the control details, but this is not made clear or urgent in the Tool.
- All of the details for Proposed Lighting Controls fall into this category. However, there are two that we can call out as also having medium to high sensitivity to input values:
    - Manual Dim Percent: The documentation indicates that there is not enough data to derive models of the manual dimming percent. Manual percent dim level power reduction value is requested as an input by the user. This input ranges from a minimum of 5% to a maximum of 40%, with a default value of 10%.
    - Task Tuning Dim: Based on the limited number of research studies, the documentation suggests this value cannot be generalized for each space type. Therefore, a task tuning power

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[7] We have considered Existing Lighting Controls and Proposed Lighting Controls each as a single variable for this count, but we refer to all of the variables within lighting controls.
[8] The theory is that the Permit Cycle would be more recent if there had been a lighting upgrade. However, the user may not be aware of the timing of all upgrades, or the extent of upgrades may not have been considered a retrofit.

reduction value is requested as an input by the user. This input ranges available are from a minimum of 10% to a maximum of 50%, with a default value of 20%.

Given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.[9] A meta study from 2012 (which was published under separate cover in 2011) is the primary reference. Lighting controls technology and market share have increased since that time; unfortunately, the literature on controls is not developing rapidly. Additional data is likely published in non-traditional sources for the energy efficiency community, and an extensive search is warranted.

We strongly urge updates of the Tool to shift to a human readable (and commented) lookup method.[10] We found several variables whose impacts could not be traced in the Tool. Ideally, the developer could search for a variable in the code and find all instances. This is not possible when the lookups are based on multiple tables within sheets and identified only by numbers that are not consistent from run to run. We recognize that the Tool is attempting to dynamically represent changing conditions. However, even within MS Excel, reference tables can be created, stored, and accessed within macros. Shifting the Tool to human readable code may take extensive time, but the alternative is a risk that updates to the Tool will not be complete. It is likely that some of the lookup tables could be replaced with formulaic representation.

REVIEW OF THE FORMULAS AND THEORY

We completed the review of formulas and theory in four steps: 1) requested and received the finalized Tool file and detailed documentation, 2) reviewed the documentation, 3) assessed the soundness of formulas, and 4) audited the Tool to determine if the intended approach was reflected in the Tool's programming.

The documentation of the Tool is technical, covering the calculation methodology, building prototype development, and control factor development.[11] This memo does not attempt to repeat the descriptions given in the Tool documentation. Instead, we answer two overarching questions about the Tool design and theory:

1. Is the intended approach sound and consistent with industry best practices?
2. Is the intended approach from the documentation reflected in the Tool programming?

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[9] Related to Finding 3.
[10] Related to Finding 4.
[11] Vistar Energy. 2016. ALCS Energy Savings Calculator: Technical Documentation/ Developers Manual v Sept 30th, 2016. Reference ALCS Calculator version: Beta Version 1.0b6-CA. Developed for Pacific Gas & Electric Company (PG&E) & DesignLights Consortium (DLC)

Is the intended approach sound and consistent with industry best practices?

Short answer: Yes. Fundamentally and purposefully, the approach takes a step away from the accepted industry best practice which requires pre- and post-metering of individual sites to estimate savings from lighting controls. The intended approach in the Tool is to simplify energy savings calculations by setting up a framework for default spaces and buildings; users can modify the defaults to their knowledge and prototypical values are pulled to develop savings estimates. Underlying the defaults and prototypical values are building and lighting data from multiple studies described in the documentation. Therefore, we assessed the documentation for the prototypes, the control factors, and the savings calculations.

Prototypes

The prototypes for the Tool are based off of Database for Energy Efficiency Resources (DEER) and ASHRAE spaces.[12] The version of the Tool that we reviewed, ALCS Calculator 'Beta Version 1.0b6-CA' (finished on 9/30/2016), references DEER 2016 for prototype definitions as well as lighting energy use profiles. The ALCS Prototypes carry over, as-is, building and space level information from 23 building types from DEER 2016 prototypes for: building area, number of floors, ceiling height, window to wall ratio, daily, weekly and yearly occupancy, space types, associated space area fractions. The ALCS Prototypes use a blended lighting energy use profile for each space area rather than use the DEER 2016 profiles as-is, combining the separate profiles for compact fluorescent, linear fluorescent, and high bay lighting.[13] However, the hourly lighting energy use profile is somewhat sensitive to user input. For example, changing the occupancy hours will extend the occupied start and stop values.[14]

The underlying prototype assumptions have been vetted through the California Public Utility Commission (CPUC) and ASHRAE; they are a valid and referenced starting point. The ALCS prototype lighting use profile extension appears reasonable, given the uncertainty in improved output from a more complex adjustment method.

Control Factors

The control factors are corollary to the lighting energy use profiles, in that they are 24-hour curves based off of the expected performance of the lighting control. The documentation highlights that there is a lack of extensive literature for some values of interest and import to developing control factors. The control factor curves are then multiplied by the lighting energy use profiles.[15] We reviewed the approach

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[12] Database of Energy Efficiency Resources (DEER) provided by the California Energy Commission: http://www.energy.ca.gov/deer/ ASHRAE 90.1 standards and guidelines are commercially available via https://www.ashrae.org/resources--publications/bookstore/standard-90-1

[13] Separate lighting energy use profiles are available from http://www.energy.ca.gov/deer/ as 'DEER2016-ComLtgProfilesDevelopment-20May2015.xlsm'

[14] Rather than reproduce the figures here, we invite readers to review Figures 11 through 13 in the documentation and related discussion.

[15] The term 'curves' is used in the mathematical sense, as not all of these control factors result in curved outputs.

taken to account for the method of control based on the information available for each control type.

- For Occupancy Sensors, the Tool relies on three studies: a meta-analysis of lighting controls savings covering 7 building types, a study of occupancy patterns, and a study of the probability that people turn lights on.[16] Essentially, data on expected occupancy settings and savings by building type (for 7 building types) is mapped to the 23 ALCS Tool prototype building types. Partial occupancy reductions are implemented by simple multiplication. The Tool attempts to adjust occupancy sensor savings for the percent of the space that may be impacted by daylight sensors.
- For Daylight Sensors, the Tool relies on a study of daylighting in offices and a study on predicting daylighting irradiance.[17] The general idea is to simulate the amount of available radiance without requiring extensive calculations. The Tool develops an hourly curve for each of three zones (primary, secondary, and not). The curve depends on illuminance (from radiance templates), required illuminance (entered on '3 Detailed Inputs'), and type of lighting. The documentation is not clear, and the Tool is not clear, but it appears that the developers ran 9,270 simulation runs to develop 4 radiance templates. Essentially, based on the amount of daylight illuminance and the required illuminance, the lighting percent required (on the portion of lighting in the daylight space) is adjusted to develop a curve. The documentation refers to separate lighting energy use profiles or impacts by lighting type, but the lighting energy use profile discussed previously is a blended profile. There likely is an interaction with the "enhanced daylighting options". It is not clear what is actually going on within the daylight sensor control factor development.

A note on implementation: The documentation refers to separate calculation for primary, secondary, and not daylight portions of lighting, but the Tool does not have a place to define these regions. The portion of lighting in the daylight zone defaults to 20% for each kind of lighting, and this value is in the '3 Detailed Inputs' tab. Users may not realize where this value is. The other "80%" is not defined as secondary or not daylight. In addition, users may not realize that the lighting type does not have an impact on savings (per our sensitivity analysis), so may expend extra effort trying to identify the type of lighting with each portion of daylighting.[18] Similarly, users may not realize that the required illuminance by space type (in lux)

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[16] Williams A, Atkinson B, Garbesi K, Page E, and Rubinstein F. 2012. Lighting Controls in Commercial Buildings. Leukos. IESNA: 8.6. Chang WK, Hong T. 2013. Statistical analysis and modeling of occupancy patterns in open-plan offices using measured lighting-switch data. Building Simulation: 6.1. D.R.G. Hunt. 1979. Building and Environment. Pergamon Press. 14:22-33.
[17] Saxena, M. (Heschong Mahone Group). 2011. Office Daylighting Potential. California Energy Commission. Publication Number: CEC-500-2013-002 and Saxena M., Ward G., Perry T., Heschong L., Higa R. 2010. Dynamic Radiance – Predicting Annual Daylighting with Variable Fenestration Optics Using BSDFs. Proceedings of 2010 IBPSA SimBuild Conference. New York.
[18] We expected lighting type to matter because there are different assumptions identified in the documentation regarding ballasts and response. However, we did not see an impact of changing the lighting type.

is on the '3 Detailed Inputs' tab, with a default by space type – these defaults appear reasonable compared to ASHRAE 90.1 guidance.

- For Demand Response, there are no cited studies, but the development of the control factor is sound, assuming the user enters appropriate values. The Tool allows modeling of between 3-20 events per year. The number of events called per year depends on the utility, but the user can input the number of events expected, the percent of the wattage impacted (0% to 100%), and the percent that the lighting can be dimmed during an event (0% to 100%). The control factor is based on the utility peak period (which can be modified by the user), assuming an equal distribution of the events across the peak season. During an event, the control factor is based on the multiplicative value between the wattage impacted and degree of dimming. Assuming that 100% of the wattage is covered and the dimming is 25%, and there are 5 events, each event would show a 25% reduction in the lighting energy use profile. The biggest risk here is for users who: incorrectly define the peak period, enter an optimistic number of events (like entering 20 when the typical number is 5), or do not update the portion of wattage and degree of dimming.
- For Task Tuning, the Tool documentation indicates that users must input this value because the literature does not cover enough instances. The Task Tuning control factor is developed as an even reduction in power across operation hours with a default of 20% and a possible range of 10% to 50%. The meta-analysis is cited here again.
- For Manual Dimming, the Tool documentation indicates the same method as Task Tuning and suggests that users must input this value because the literature does not cover enough instances. The Manual Dimming control factor is developed as an even reduction in power across operation hours with a default of 10% and a possible range of 5% to 40%. The meta-analysis is cited here again.
- For the Time Switch, the Tool does not indicate any references. The time switch is implemented in the same way as changing the facility start and end times (described above). The default of one hour before and after is reasonable but may not be conservative.

Given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available. A meta study from 2012 (which was published under separate cover in 2011) is the primary reference. Lighting controls technology and market share have increased since that time; unfortunately, the literature on controls is not developing rapidly. Additional data is likely published in non-traditional sources for the energy efficiency community, and an extensive search is warranted.

Savings Calculations

The Tool presents savings as the difference between the calculated energy consumption of the proposed condition to that of the baseline and the relevant code. There are separate calculations based on annualization of the underlying prototype data for the energy savings and identifying average savings during the peak period for the demand savings. The formulae and concepts employed for the savings calculations are reasonable, straightforward, and not repeated here. However, we will note that this blanket statement is based on the implementation of the savings calculation in the Tool, as the documentation is not clear. The calculated energy and demand consumption values are driven by the underlying building prototypes and control factors. The Tool could be more clear that HVAC interactive savings are not included, as they may be significant in some installations.

Is the intended approach from the documentation reflected in the Tool programming?

Short Answer: Mostly. The Tool is an Excel Workbook which is presented in a locked down version for use; this public version of the Tool hides (for lack of a better word) the underlying prototypes and models which prevents users from accidentally breaking the Tool. The driving engine within the Tool is lookup references which fill key cells with the prototype value based on a match to the user entry. For example, when the user first selects the type of building on the 'Existing Inputs' tab, the Tool automatically populates the building size, ceiling height, floors, operating schedule, type and extent of spaces, and the type of lighting, lighting power density, existing lighting controls, and usage by space.[19] When the user changes the building vintage, the associated lighting values are updated again. The user can then modify the project from the default assumptions.

As noted above, the Tool calculates savings by the difference in energy and demand calculations for three simulated conditions - existing, code, and proposed.[20] The three simulations are based on area (ft²), lighting power density (LPD, in W/ft²), a 24-hour lighting energy use profile, and a 24-hour control factor profile for six lighting control devices (occupancy sensors, daylighting sensors, demand response, task tuning, manual dimming, and time switches). The Tool has default values for all existing conditions; the user must enter the proposed conditions in the 'Proposed Inputs' tab to get an estimate of savings. While the Tool populates defaults based on the building type, the user can specify or override the defaults for all values. The calculated energy and demand consumption values are shown in the '5 Dashboard' for each space type and simulation, along with a summary of the lighting controls included. The calculated energy and demand savings values are shown in the '4 Calculated Savings' tab.

The user can then select 5 additional space type line items to include beyond the default area categories for the building type. When these are added to the building

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[19] The documentation includes reference tables that describe the defaults. For example, spaces and portions for each building type are given in Figure 75; default LPDs for each space by building and code are given in Figure 76; the lighting technology for each space by building is given in Figure 77. Lighting technology does not change by code year.
[20] Title 24-2016 §141.0 refers to these as baseline, code-minimum, and installed.

'1 Existing Inputs' tab, the Tool creates additional entries in the '2 Proposed Inputs' and '3 Detailed Inputs' tabs.[21]
For each space type line item, the user can adjust specific inputs on the '1 Existing Inputs', '2 Proposed Inputs', and '3 Detailed Inputs' tabs. Together, these inputs describe the extent of the retrofit action for each space category. Specifically, the user can:

- change the space category area fraction in the existing and proposed case,
- change the LPD in the existing and proposed case,
- specify advanced lighting control options installed in the existing and proposed case,
- specify the details of advanced lighting controls in the proposed case,
- adjust details of the space, like the required illuminance, window wall ratio, window orientation, etc.

In our assessment of the Tool, the descriptions provided in the documentation were reflected in the Tool. We followed the formulas through the hidden lookup sheets and the prototype identification. In many cases, the documentation suggests that the user input data because the default is questionable, but the user is not urged to do so in the Tool. We highlight these instances throughout this memo.

Our assessment suggests that the approach in the documentation is implemented in the Tool with two exceptions: the savings do not appear to take into account the type of lighting or ballasts as described in the documentation, and the documentation description for daylight zones is not in the model. The implementation is difficult to follow and will remain a logistical challenge for updates, especially if the person (or persons) who developed the Tool are not available. The Tool uses references and lookups to match to prototypes and to adjust the lighting energy use profiles based on user input. These lookups are not coded to be human readable. We strongly urge updates of the Tool to shift to a human readable (and commented) lookup method.

SENSITIVITY ANALYSIS

Sensitivity analysis is a method for identifying the relative importance of a variable in an objective function (in this case annualized energy savings and demand savings). We used the Python programming language to vary the expected user inputs over range of likely values and collect the outputs from the Tool for 23

[21] Usability is beyond the scope of this initial assessment. However, one noted challenge with the implementation is that the user is not prompted for changes that they have made previously within the '3 Detailed Inputs' tab. For example, if a user is working on one project and changes detailed inputs, then changes the Building Type, the detailed inputs remain changed for the order of the space where they were changed. If the change in building type moves "Classroom" from the first type of space to the last, for example, the changes made to "Classroom" space type would stay with the first type of space and not the classroom. This could result in errors if sequential estimates are being made without saving and starting from a clean Tool. The '3 Detailed Inputs' tab does not have a [Reset to Defaults] button implementation like the '1 Existing Inputs' and '2 Proposed Inputs' tabs.

building types.[22] For comparison, we set a "standard" case for all facilities.[23] The standard case and varied cases then result in values that may or may not be reasonable for each facility type, but the point is the responsiveness of the outputs to variation not the absolute value of the outputs.[24] In total, there were 37 user inputs submitted to the Tool over their reasonable range. Note that a single tested user input variable may be entered in multiple cells in the Tool; for example, we speak of existing Lighting Power Density (LPD) as a single user input for the sensitivity analysis, but the tested value is set for all spaces in the building. In some cases, a user input was not valid in the standard case, but required another variable interaction. We addressed these variables by "turning on" the other required variable when testing their responsiveness.

Of the 37 variables tested, 30 were responsive – 8 highly, 10 medium, and 12 low (see Table 1). The remaining seven had no responsiveness to variation over their range. In each case, we considered how the variable was coded and how it is expected to contribute to savings calculations. Those that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all were included in our variable review (below). The overall responsiveness is based on the changes across the four energy and demand outputs for 23 buildings. Some variables were more responsive in particular buildings; this relates directly to the prototype selections and codes underlying the Tool. Some variables are more responsive when comparing energy or demand or to code rather than baseline.

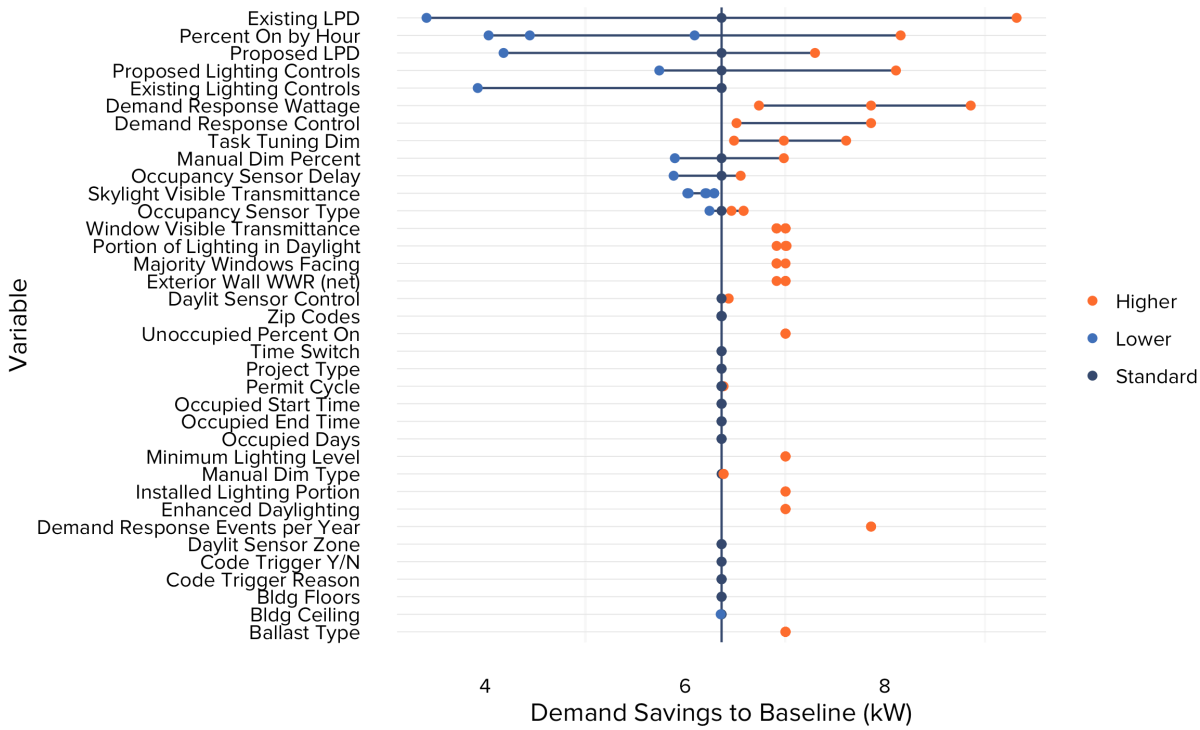
[22] Python Software Foundation, https://www.python.org/ . The code to run these simulations is provided separately to PG&E.
[23] The standard case for the 26 variables tested on the '1 Existing Inputs' and '2 Proposed Inputs' tabs is different and more restrictive than the standard case for the 11 variables tested on the '3 Detailed Inputs' tab.
[24] This note of caution is strong; there is no reason to use the Energy or Demand Savings reported in this Sensitivity Analysis for any purpose. The standard sets values like square footage and lighting power density that are uniform. A 10,000 square foot Office – Large is not likely, just as a 10,000 square foot Relocatable Classroom is not likely. While the variables are varied over a reasonable range for that variable, it is not always reasonable for a particular space, building, or vintage.

Table 1. Overall ALCS Calculator Tool Input Variable Responsiveness

Variable	Relative Responsiveness		Variable	Relative Responsiveness
Building Size (Sq Ft)	High		Building Ceiling	Low
Existing Lighting Controls	High		Daylight Sensor Control	Low
Existing LPD	High		Demand Response Events	Low
Occupied Start Time	High		Exterior Wall WWR (net)	Low
Percent On by Hour	High		Majority Windows Facing	Low
Project Type	High		Manual Dim Type	Low
Proposed Lighting	High		Occupancy Sensor Delay	Low
Proposed LPD	High		Occupancy Sensor Type	Low
Code Trigger Reason	Med		Occupied Days	Low
Code Trigger Y/N	Med		Permit Cycle	Low
Demand Response	Med		Time Switch	Low
Demand Response Wattage	Med		Zip Codes	Low
Manual Dim Percent	Med		Ballast Type	None
Occupied End Time	Med		Building Floors	None
Portion of Lighting in Daylight	Med		Daylight Sensor Zone	None
Skylight Visible Transmittance	Med		Enhanced Daylighting	None
Task Tuning Dim	Med		Installed Lighting Portion	None
Window Visible Transmittance	Med		Minimum Lighting Level	None
			Unoccupied % On	None

The "Office – Small" building variations are shown in Figure 24 through Figure 27; these figures exclude the variation for building size (sq ft) because that variable range dominates. Each figure is laid out in the same way, but the order of the variables changes based on the relative responsiveness to the objective (Energy/Demand Savings to Baseline/Code). The vertical line is the value at the standard values for all variables. The dots represent the value when the variable is set at one of its reasonable values while holding all other variables at the standard, and the horizontal lines represent the range each variable exhibits. When a variable does not have a dark blue dot on the vertical line, it means that another variable had to be adjusted to change that variable for its reasonable values. For example, in Figure 1, the variable "Demand Response Wattage" only has orange dots that are higher than the standard. This is because the standard set of values does not include demand response in the proposed controls but adjusting the wattage would have no influence if the control was not included.[25]

Figure 24. Variations in Demand Savings to baseline for Office-Small



[25] We mention this above in the general description of the approach. In addition, all eleven of the variables on the detailed inputs tab had a separate standard (we did not set the LPD) to allow for changes in the details to lead to changes elsewhere.

Figure 25. Variations in Demand Savings to Code for Office-Small

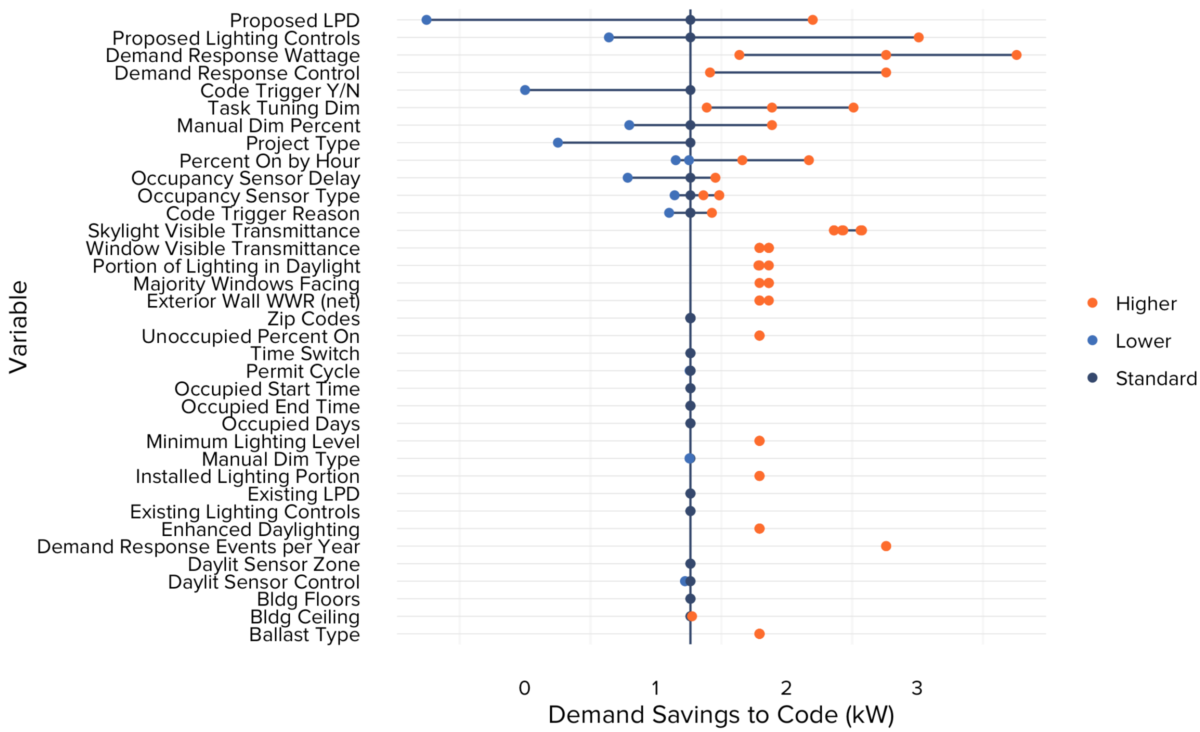


Figure 26. Variations in Energy Savings to Baseline for Office-Small

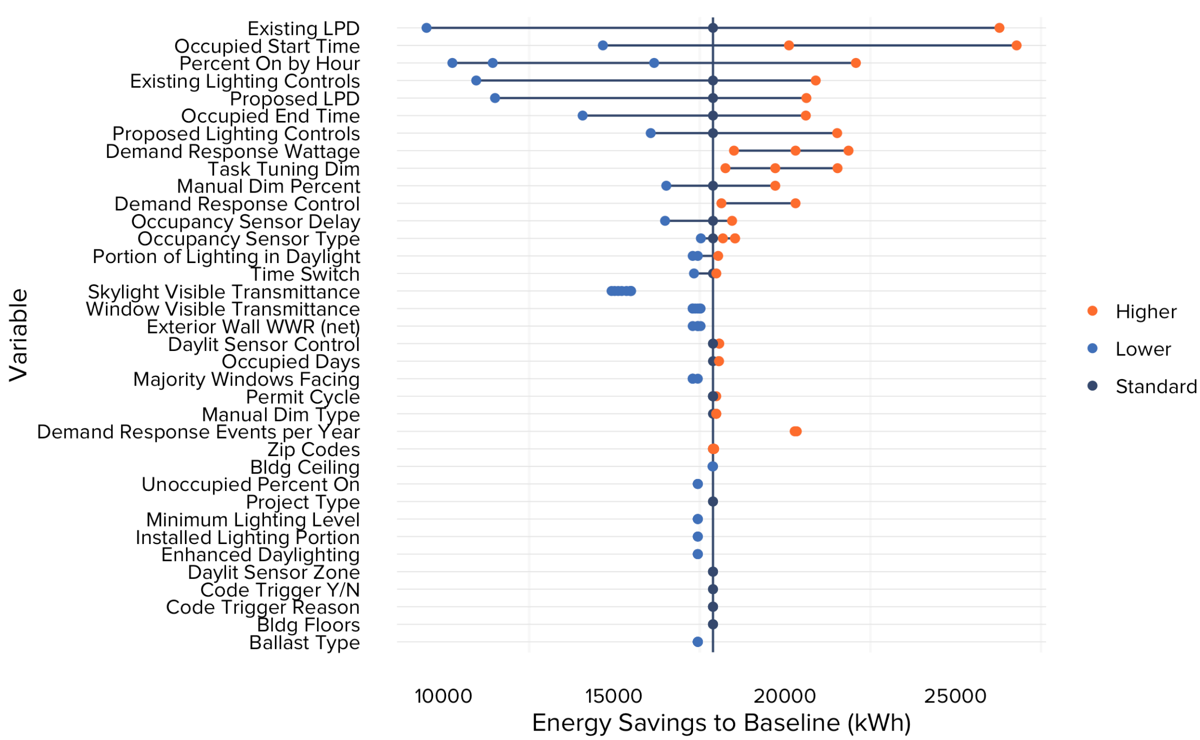
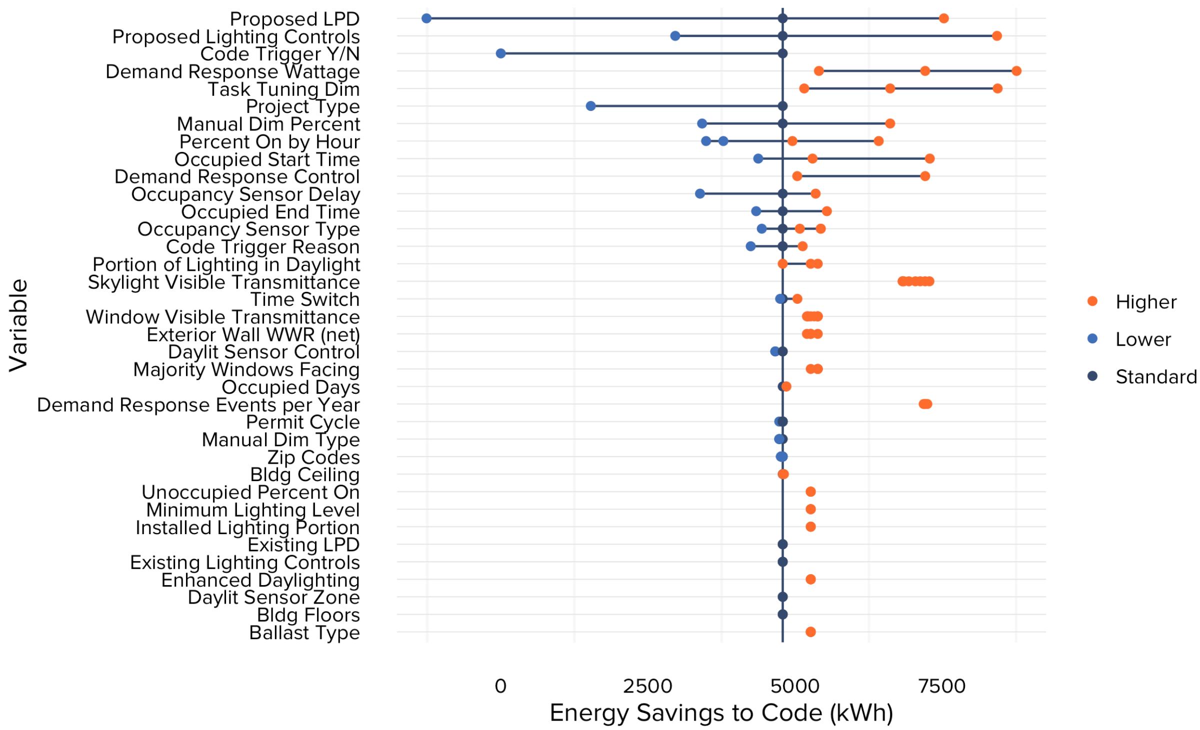


Figure 27. Variations in Energy Savings to Code for Office-Small



VARIABLE REVIEW

For the variable review, we verified the sources of reference, default values, and coding for variables identified in the Sensitivity Analysis. We also checked for proper interpretation and application of Title 24 code requirements.

VARIABLES IDENTIFIED IN THE SENSITIVITY ANALYSIS

Variables that had extremely high responsiveness, were responsive in unexpected ways, or were not responsive at all were included in our variable review. There were 14 unusual or highly responsive variables and 7 with no variation.

First, we discuss 14 variables that showed high responsiveness or were responsive in unexpected ways:[26]

- Building Size (Sq Ft): Very high responsiveness for savings. The demand and energy consumption calculations use matrix multiplication for the control factors, the LPD, and the square footage for each space. The building size is split up across space types in a default manner or as adjusted by the user, but it is still a huge driver of overall consumption and savings. There can be no expectation for reliable calculations of savings for a project that

[26] These variables are listed in alphabetical order.

does not have the appropriate square footage. Users should be strongly urged to modify this value even at their very first screening phase.

- Code Trigger Reason: Medium responsiveness for savings to code, but the reason is not defined as driving a selection in the documentation. The code trigger option activates when changes are entered into the Proposed Inputs tab. The Tool automatically selects lighting controls and a "Yes" or No" in terms of whether the code is triggered for each space type. According to the documentation, similar to LPD, minimum required lighting controls per code are assigned to each space type, which can then be overridden by the user. The documentation also states that the Title 24 lighting requirements are based on code triggers including room size, LPD, window areas, etc. For ASHRAE 90.1, the description is similar but provided as more simplified look-up table against ASHRAE space types. There are sets of ‘Control Trigger Logics’ discussed in detail in the documentation and also found in the tool within the underlying virtual models. The user may override whether the code is triggered, and the reason for the code trigger. Sensitivity analysis testing showed that the "Yes" and "No" override has a medium sensitivity, and only impacts code baseline energy savings which makes sense because changing the code trigger variables only apply to the code baseline development and not the existing baseline development. Since the code trigger default is reliant on room size, LPD, window area for certain control types, building types, and space types, it is important to emphasize to the user the importance of inputting those particular values rather than relying on defaults. If the user understands the variables influencing the code trigger, this reason and the code trigger should be able to remain at the default. In addition, a note should be added that changing the reason for the code trigger will change code savings and is not just a documentation reference for the selection of “Yes” or “No”. Further detail on the Title 24 implementation is below.
- Daylight Sensor Control: Low responsiveness to savings when medium was expected. See "Proposed Lighting Controls" variable review
- Existing Lighting Controls: High responsiveness. The user may modify the existing lighting controls to select "Yes" or "No" for the full list of control options available. The tool then develops control factors per control strategy that applies to the DEER based lighting energy use profile for each space. For the sensitivity analysis, we only tested a combination of Time Switching and Occupancy Sensors in the existing case (more values are tested in the proposed case). We observed large changes in energy savings suggesting that these variables are highly sensitive, although testing them individually showed lower sensitivity. According to the documentation, due to a lack of sufficient study data, the user is expected to enter the type of occupancy sensor (vacancy sensor or occupancy sensor), and the delay off time setting (1 - 30 mins), however currently this expectation isn't made clear enough to the user. The default sensor type does appear to change with space type, however the default for delay time remains 30 minutes regardless of the space and building type. This appears to be a conservative estimate (good) when compared with the few studies mentioned in the documentation that indicate most buildings have 5 to 15-minutes delay time, and only a few are

at 30 minutes. With regards to time switches, according to the documentation, there were no reasonable studies that provided generalized savings for time switches. The default assumptions used may or may not be conservative and thus is a source of risk. Because this is a sensitive variable, we recommend that the user be informed of the backend assumptions, and encouraged and enabled to modify those assumptions. Currently, the tool assumes the lighting system turns on 1 hour before scheduled operation and the override switch is engaged once a weekday in the last hour of operation. Given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.

- Existing LPD: High responsiveness. The code maximum allowable LPDs are assigned to each space type per building type, using the code year specified by the permit cycle selected by the user, which is a required input. For new construction, the most recent version of the code is referenced. The energy savings are determined by taking the difference in existing and proposed LPDs, then multiplying by effective hours of use determined using DEER defined lighting energy use profiles for weekday, Sat and Sun for each space and building type. The implementation is consistent with the documentation and best practices.
- Manual Dim Percent: Medium responsiveness. The documentation indicates that there is not enough data to derive models of the manual dimming percent. Manual percent dim level power reduction value is requested as an input by the user. This input ranges from a minimum of 5% to a maximum of 40%, with a default value of 10%. The Manual Dimming control factor is developed as an even reduction in power across operation hours. Similar to other control factors, given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.
- Occupied Days: Low responsiveness although adding days is expected to have more impact. However, the lighting energy use profile curves for weekends are still in place when weekends are occupied, and weekends have usually very low energy use profile curves per the DEER values. If the prototypical facility has very low weekend energy use and the facility under analysis has weekend use similar to weekday use, the user should modify the usage profile in the ‘3 Detailed Inputs’ tab. Perhaps a flag or guidance to the user could be added to ensure this is communicated.
- Occupied End Time: Medium responsiveness. The occupied start and ends times are typical operational time periods defined by DEER prototypes. The DEER lighting energy use profiles represent an average of many spaces over multiple days, with start and end times that are most typical for that space type. The values before the start time are for times when occupants arrived early and turned on lights, while the values after the end time are times when occupants left late, leaving lights on longer. A user may choose different start and end times for their office building, and the lighting energy use profile is modified, stretched, to meet these times. Both the start and end times appear to be medium to highly sensitive variables, indicating that

attention should be paid to setting this variable as accurately as possible. We recommend that the tool should flag these variables as critical for user for input as best as possible, even though the default value has a valid source. As described in the prototype development above, the approach to modifying these variables appears reasonable.

- Occupied Start Time: See Occupied End Time
- Permit Cycle: Low responsiveness. We conducted additional testing to ensure that this variable was properly coded. The result of low responsiveness in the sensitivity analysis makes sense because the permit cycle is meant to pre-populate the existing condition variables with defaults, but we override these consistently for all cases so the permit cycle would have little impact. On additional testing, we find that changing the permit cycle does update the existing LPD and controls, which impacts the consumption and savings.
- Project Type: High responsiveness. By selecting New Construction for the project type, no existing baseline savings is generated, only code baseline. By selecting Existing Building Alterations, users are allowed to select an older code. The sensitivity analysis showed that this is a critical variable to set correctly. Therefore, we would recommend adding more clarifying guidance for users to better understand how the project type and permit cycle variables are to be used, how they impact the savings calculations, and how they alter the presentation of the outputs. In the current Tool implementation, it is not clear to users that the permit cycle is meant to populate the existing building defaults, and that changing the project type clears out the existing building savings output. In addition, the note about types of buildings covers up other notes on the '1 Existing Inputs' tab that are relevant to initial entry.
- Proposed Lighting Controls: High responsiveness. The user may modify the proposed lighting controls to select "Yes" or "No" for the full list of control options available. The tool then develops controls factor per control strategy that applies to the DEER based lighting energy use profile for each space. For the sensitivity analysis, we tested a combination of Daylight Controls, Demand Response, Task Tuning and Manual Dimming controls. We observed large changes in savings suggesting that these variables are together highly sensitive; individually, Task Tuning and Manual Dimming variables appear the most sensitive. Unfortunately, these are some of the control factors for which the documentation and literature suggest limited information on which to base assumptions. Thus it will be important for the assumptions underlying the control factors and other relevant parameters for these variables to be as accurate as possible. Our review indicates that for the most part, the basis for the Daylight Controls assumptions are adequate. The hourly illuminance is not directly based on studies, but instead are based on four pre-ran Radiance models that are matched based on the user defined inputs, and appear to be a reasonably thorough method for implementation. Also the lux set point and lighting technology mix assumptions appear to be based on best available data. However, for the Demand Response controls, the control factor is based on limited information using the utility peak period, events and wattage provided by

the user. The Tool currently provides default values for control wattage, events per year, and event power reduced, but does not show supporting data for these. Manual Dimming and Task Tuning are sensitive variables, and the default assumptions are based on insufficient data. Therefore, we recommend that the tool should alert the user more clearly that the details about the proposed lighting controls are required input values. As stated for other variables related to the lighting controls, given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.

- Proposed LPD: High responsiveness. Proposed LPDs are required user inputs, so there are no LPD assumptions to verify. The proposed LPD entries all appear to be properly referenced in the underlying virtual models and the savings calculations.
- Task Tuning Dim: Medium responsiveness. Based on the limited number of research studies, the documentation suggests this value cannot be generalized for each space type. Therefore, a task tuning power reduction value is requested as an input by the user. This input ranges available are from a minimum of 10% to a maximum of 50%, with a default value of 20%. The control factor is developed as an even reduction in power across operation hours. Similar to other control factors, given the uncertainty in the literature, the implementation of control factors and the control factor multiplication method should be a priority target for updates as new studies of savings become available.

In addition, we investigated the implementation for 7 variables that exhibited no responsiveness:

- Ballast Type: On the '3 Detailed Inputs' tab, we varied the ballast type for the "On-Off", "2-lvl sw.", "3-lvl sw.", "4-lvl sw.", "2-lvl dim.", "3-lvl dim.", "4-lvl dim.", "cont dim." and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool. All advanced lighting controls were switched "on" in the proposed case with their default detailed values for the testing of this variable.
- Building Floors: The default value varies by the building type. We set the standard value to 2, and we ranged this variable across two additional values (1 and 12) and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. Based on our understanding of the virtual models, there is no reason to include building floors except for a reference to the user, as it is a necessary piece of information for project installation and useful to know in evaluation.
- Daylight Sensor Zone: The documentation does not document how secondary and primary zones are determined for a site. It does describe that savings are calculated separately per daylight zone, but again, it is not stated what assumptions make the basis for how much % space is allocated to each for each space type or building type. There are three kinds of zones

documented in the documentation (daylight, secondary, and none); however, the Tool inputs only show a percentage of each type of installed lighting is in the daylight zone. The default is 20%; it is not clear whether the additional 80% is secondary or not in a daylight zone. The documentation does not describe what is the effect of selecting a Daylighting Zone. Therefore, it is difficult to understand whether the savings should change based on a change in selecting the zone. We suggested developing additional documentation and clarity on this variable.

- Enhanced Daylighting: On the '3 Detailed Inputs' tab, we varied the enhanced daylighting options from the default of 'None' to "Overhang", "Light Redirect Film", and "Automated Shades" and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool. All advanced lighting controls were switched "on" in the proposed case with their default detailed values for the testing of this variable.
- Installed Lighting Portion: On the '3 Detailed Inputs' tab, we varied the installed lighting portion from the defaults to having only 'CFL' and only 'LED' and having 20% of each kind of lighting and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool. Our first thought was that there may be interaction with the ballast operation, but this is not apparent from other testing. The documentation suggests that ballasts matter in the introduction as section 5, "Saving Calculation from LPD change" is referred to in the introduction (erroneously as Section 4) as describing the "calculation method to calculate savings from change in LPD along with change in lighting technology and ballast type." However, review of section 5 and the underlying lighting energy use profiles make no mention of the type of lighting or ballasts. The LPD is the only lighting value that is used in these calculations.
- Minimum Lighting Level: On the '3 Detailed Inputs' tab, we varied the minimum lighting level for each type of lighting from the default of 0 to 0.1, 0.7, and 1.0 and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool.
- Unoccupied Percent On: The default value is 0.05, and we ranged this variable across four additional values: 0, 0.1, 0.5, and 1.0 and observed no response. We followed this variable through the virtual models and the resulting values have no formulas that refer to them. This suggests a coding error, or it was simply impossible to trace due to the complex reference method employed by the Tool.

Application of Title 24 code requirements

kW Engineering reviewed the Tool to see to what extent Title 24 exceptions are captured. Our review of how the tool applies Title 24 code requirements is more global than single variables as in the previous variable review section. This is because the Tool's primary method of treating the Title 24 code applications is through the underlying reference models for required lighting and lighting controls. The version of the Tool that we reviewed is designed to reflect the most recent (2016) Title 24 code.

A card on the 'Proposed Inputs' tab lists the code triggering options. By default, the Tool assumes code is triggered by the following events:

- Adding any control device to space where one does not already exist.
- Populating the proposed LPD (regardless of whether it is different from the existing system)

Generally speaking, the Tool does not handle the following <u>blanket modifications/exceptions</u> to Title 24 lighting control requirements:

1. Entire Luminaire Alterations occurring in a space with 1 or 2 luminaires[27]
2. Luminaire Component Modifications occurring in a space with 1 or 2 luminaires[28]
3. Lighting Wiring Alterations in space affecting 1 or 2 luminaires[29]
4. Lighting Wiring Alterations specifically to accommodate lighting controls with no luminaire modifications[30]

The Tool cannot capture the first three modifications because the spaces are aggregated by space-type line-item. Thus, the specific nuance of these modification is lost. The last modification, however, adding controls to an existing system, is specifically exempt from Title 24 and should be captured in the Tool for maximized utility-claimed savings.

Similarly, the Tool does not handle <u>partial exceptions</u> in the following cases:

- Entire Luminaire Alterations occurring in office, retail, and hotel occupancies achieving 50% LPD reductions[31]
- Entire Luminaire Alterations occurring in other occupancies achieving 35% LPD reductions[32]
- Luminaire Component Modifications occurring in office, retail, and hotel occupancies achieving 50% LPD reductions[33]
- Luminaire Component Modifications occurring in other occupancies achieving 35% LPD reductions[34]

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[27] Title 24-2016 §141.0 (b) I ii Exception 2, grandfathered in to Title 24-2013
[28] Title 24-2016 §141.0 (b) J ii Exception 2, grandfathered in to Title 24-2013
[29] Title 24-2016 §141.0 (b) 2 K Exception 2, grandfathered in to Title 24-2013
[30] Title 24-2016 §141.0(b) 2 K Exception 1 and Title 24-2013 §141.0(b) 2 I iv Exception
[31] Title 24-2016 §141.0 (b) 2 I ii, grandfathered in to Title 24-2013
[32] Title 24-2016 §141.0 (b) 2 I ii, grandfathered in to Title 24-2013
[33] Title 24-2016 §141.0 (b) 2 J ii, grandfathered in to Title 24-2013
[34] Title 24-2016 §141.0 (b) 2 J ii, grandfathered in to Title 24-2013

The Tool does not claim savings or incentives for hardware that is not required by code, given the exceptions for significant reductions in energy through high-efficiency retrofits (evaluated via a reduced LPD). The unclaimed savings include those from daylighting, demand response, task-tuning, and manual dimming.

Further, using the space-type roll-up methodology discussed above, the Tool is unable to identify and thus quantify incentive-eligible control applications that code specifically exempts. We've summarized the exceptions the Tool does not capture below and noted the relevant section of code (note, the citations pertain to Title 24-2016; however, most of these exemptions exist in Title 24-2013).

- Individual Areas > 100 ft² do not require multi-level controls.[35]
- Individual Areas with an LPD ≤ 0.5 W/ft² do not require multi-level controls.[36]
- Classrooms with an LPD ≤ 0.7 W/ft² require only bi-level lighting controls.[37]
- Public restrooms only require bi-level lighting controls.[38]
- Spaces with a single luminaire do not require multi-level controls.[39]
- Areas requiring partial-OFF or full-OFF controls do not require multi-level controls.[40]
    - Warehouse aisle ways and open areas
    - Library book stack aisles
    - Corridors & Stairwells in Commercial buildings
    - Corridors & Stairwells in high-rise residential or hotel areas
    - Parking Garages
- Secondary daylighting zones are not required in existing buildings[41]
- Spaces with less than 0.3 W/ft² that do not require continuous dimming daylighting controls.[42]
- Spaces with fewer than 120 W/ft² in the daylit zone that do not require daylighting controls[43]
- Rooms that have < 24 ft² of glazing do not require daylighting.[44]
- Buildings smaller than 10,000 ft² do not require demand response controls.[45]
- Spaces that use UL924 emergency shunts to turn off emergency lighting at night.[46]
    - Areas with an LPD ≤ 0.5 W/ft² are not counted in the DR load shed calculation and are thus exempt.[47]

[35] Title 24-2016 §130.1 (b)
[36] Title 24-2016 §130.1 (b)
[37] Title 24-2016 §130.1 (b) Exception 1
[38] Title 24-2016 §130.1 (b) Exception 1
[39] Title 24-2016 §130.1 (b) Exception 2
[40] Title 24-2016 §130.1 (b) Exception 3
[41] Title 24-2016 §140.6 (d) is only triggered during additions or new construction.
[42] Title 24-2016 §130.1 (d) 2 D ii
[43] Title 24-2016 §130.1 (d) 2 Exception 1
[44] Title 24-2016 §130.1 (d) 2 Exception 2
[45] Title 24-2016 §130.1 (e) 1
[46] Title 24-2016 §130.1 (a) 1 Exception 1
[47] Title 24-2016 §130.1 (e) 1

Users are allowed to override the code triggering statement (in the Tool) and claim incentives; however, the Tool does not capture specifics, including section of code that describes a useful exception. As such, verifying the accuracy of these inputs will be difficult without reaching-out to the party responsible for populating the Tool.

APPENDIX C: ON-SITE MONITORING DETAILED SITE RESULTS

The following subsections discuss the findings of the detailed data collection. Each section includes a discussion of the calculated and metered power trends for each electrical circuit and a discussion of the energy savings.

SITE 1

This retrofit involved no change in luminaires. The new control system was layered on top of the existing LED lighting. The following section describes the detailed results for Site 1.

Calculated and Metered Power Trends

As this retrofit did not change luminaires, there was no efficacy improvement associated with Site 1.

Circuit 15 (Private Offices 1-4 & Front Open Office)

As the lighting use factor did not change very much from pre-installation to post-installation there was little energy impact in the unaltered spaces (open office, private office 2, and private office 3) using the calculated control factor approach (Table 2). The post-installation data shows the occupants relied more on their occupancy sensors to shut off the lights, versus using the manual switch. The lighting use-factor went up substantially in Office 1, and the newly created Office 4 had a higher use-factor than Office 1.

Circuit 15 was the only circuit in the entire evaluation for which daylighting was a practical recommendation. The Open Office and Private Offices 2 and 3 all had east-facing windows, but neither of the private offices received daylighting controls. While daylighting controls were installed in the open office, they failed to actuate during the study. We suspect the main reason for the poor daylighting performance in the open office was due to the deep overhang over the windows and the solar orientation of the site. The open office only received direct daylighting in the morning hours. However, at that time, the occupants working in the primary daylit zone experienced significant visual discomfort and used the miniblinds to eliminate the daylight exposure, as reported to kW Engineering during data logger retrieval. Once the sun had risen high enough in the sky to eliminate glare concerns, the overhang prevented significant daylighting penetration. While testing sensor locations on-site, a simple functional test was performed on the daylighting sensor and nearby occupants commented that they had never seen that sensor dim the lighting. This indicates that, while the system is functional, the application is not ideal for daylighting performance.

Table 2. Site 1 – Circuit 15 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Daylight	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Office 1	Pre	0.0%	0.0%	0.0%	96.0%	0.0%	0.0%	4.0%
	Post	0.0%	0.0%	0.0%	63.9%	0.0%	24.9%	11.3%
Office 2	Pre	0.0%	0.0%	0.0%	85.5%	0.0%	0.0%	14.5%
	Post	0.0%	0.0%	0.0%	32.9%	0.0%	46.0%	21.1%
Office 3	Pre	0.0%	0.0%	0.0%	61.2%	0.0%	10.9%	27.9%
	Post	0.0%	0.0%	0.0%	9.5%	0.0%	59.2%	31.3%
Office 4	Pre							
	Post	0.0%	0.0%	0.0%	25.5%	0.0%	59.7%	14.8%
Open Office, Front	Pre	0.0%	0.0%	0.0%	54.2%	0.0%	4.1%	41.7%
	Post	0.0%	0.0%	0.0%	54.2%	0.0%	4.1%	41.7%

The power metering data showed energy use on this electrical circuit increased. In the baseline period, Office 1 was rarely occupied. In the post period, Office 1 was divided into two offices and (Office 1 and Office 4). Office 4 was much more frequently occupied and, therefore, the lighting energy use on this circuit went up over all.

Figure 28. Site 1 – Circuit 15 – Pre-Installation Power

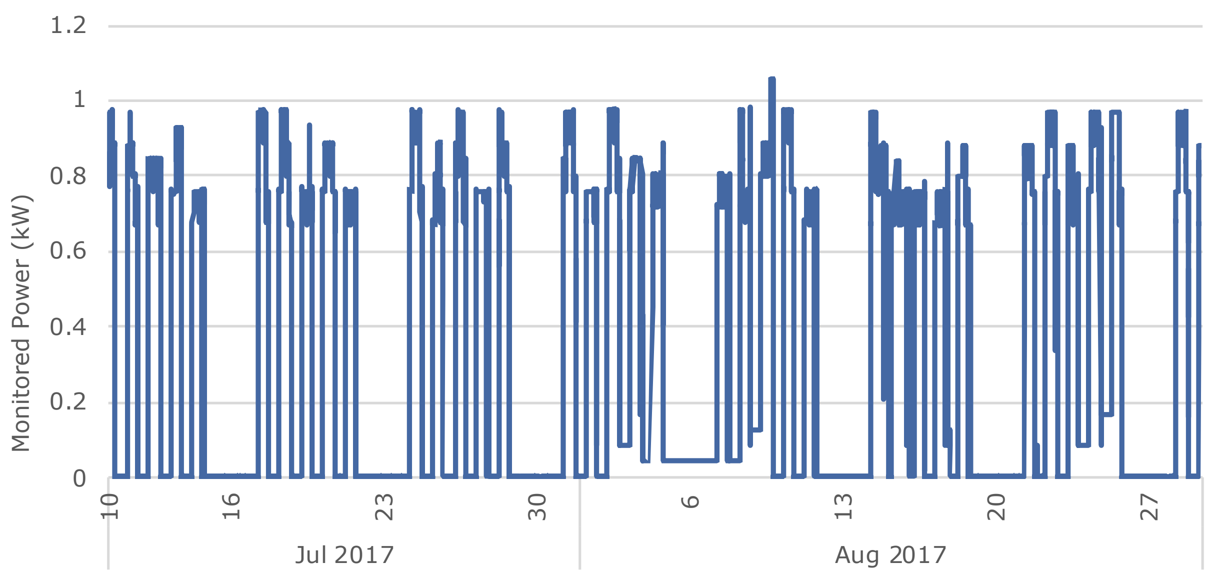
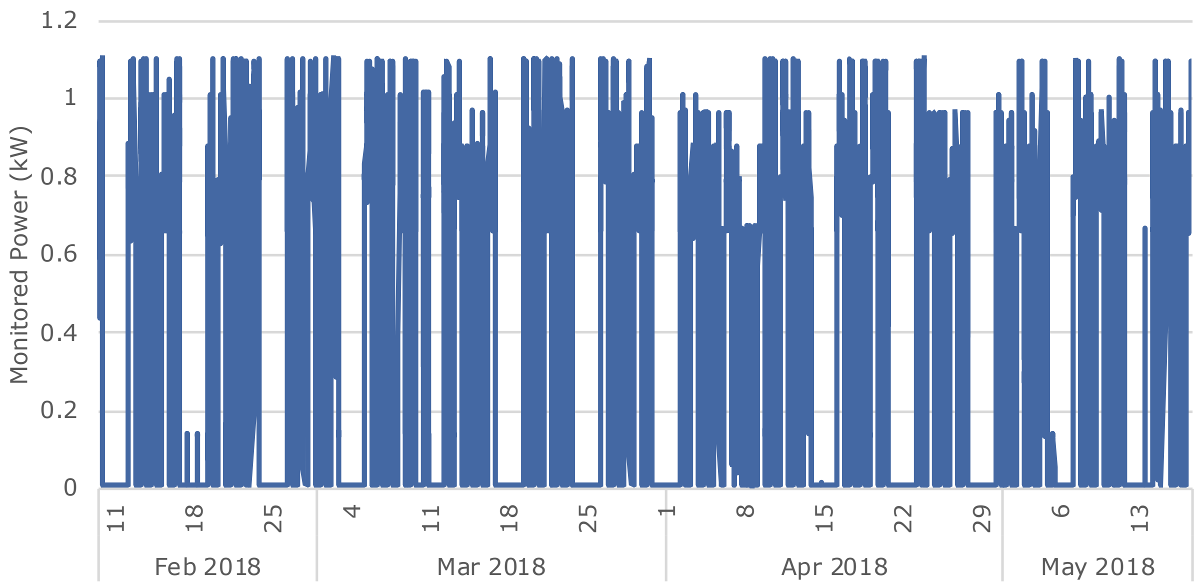


Figure 29. Site 1 – Circuit 15 – Post-Installation Power



Circuit 17 (Middle Open Office)

The overhead lighting was more frequently controlled via the occupancy sensors versus using the switch in the middle open office, as evidenced by the greater reliance on the occupancy sensors shown in Table 3. Using the occupancy sensors likely contributed to the increased lighting use factor; however, the difference was rather small.

Table 3. Site 1 – Circuit 17 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Day-light	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Open Office, Middle	Pre	0.0%	0.0%	0.0%	60.0%	0.0%	5.6%	34.4%
	Post	0.0%	0.0%	0.0%	28.0%	0.0%	33.0%	39.0%

According to site interviews, there was a task tuning effort that occurred in the open office area as part of the installation. During the facility manager interviews, this facility manager discussed completing significant task tuning; down to 43%. However, the power data does not show any task tuning occurred.

Figure 30. Site 1 – Circuit 17 - Pre-Installation Power

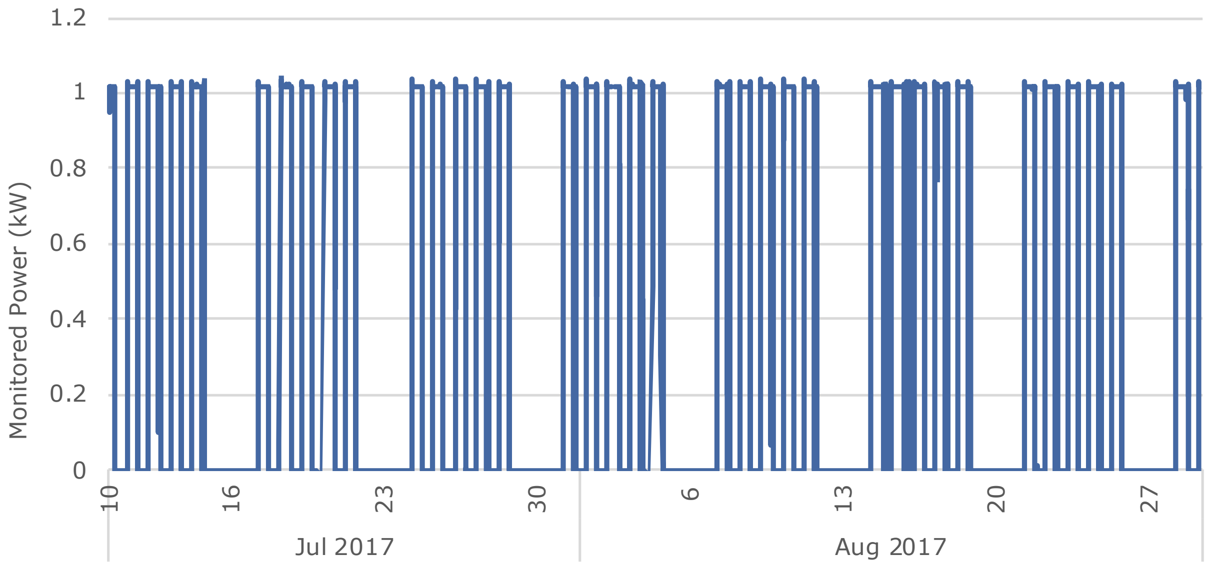
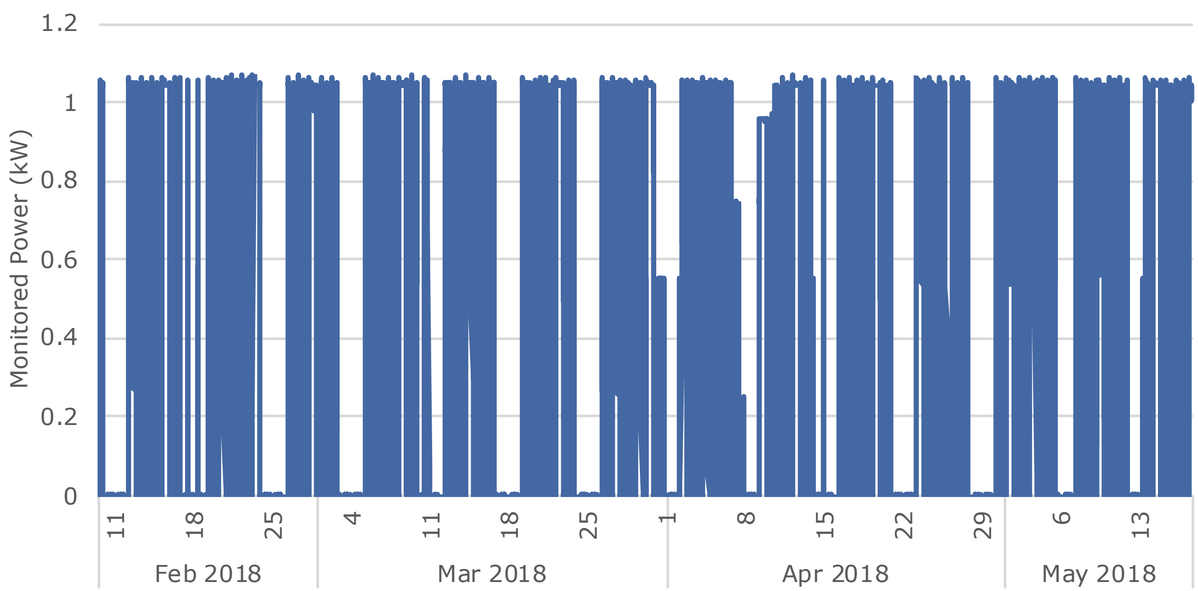


Figure 31. Site 1 – Circuit 17 – Post-Installation Power



Circuit 19 (Rear Open Office)

The overhead lighting in the rear open office was manually controlled in a similar manner between the pre- and post-retrofit data sets, given the small differences in Table 4. Occupancy sensor use went down, but that may have been due to better coverage of the space with higher occupancy sensor density.

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Table 4. Site 1 – Circuit 19 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Daylight	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Open Office, Rear	Pre	0.0%	0.0%	0.0%	40.0%	0.0%	23.9%	36.1%
	Post	0.0%	0.0%	0.0%	44.3%	0.0%	17.0%	38.7%

Looking at the power metering, it appeared there was a week-long period where manual dimming took place for 10 days in March 2018. This data was not supported by the control factor calculations, indicating that perhaps the relative light output meter was not installed in the right location to capture this dip in power. Outside of that 10-day window, no task tuning was evident. The power post-retrofit data aligns very closely to the power data collected prior to the retrofit.

Figure 32. Site 1 – Circuit 19 – Pre-Installation Power

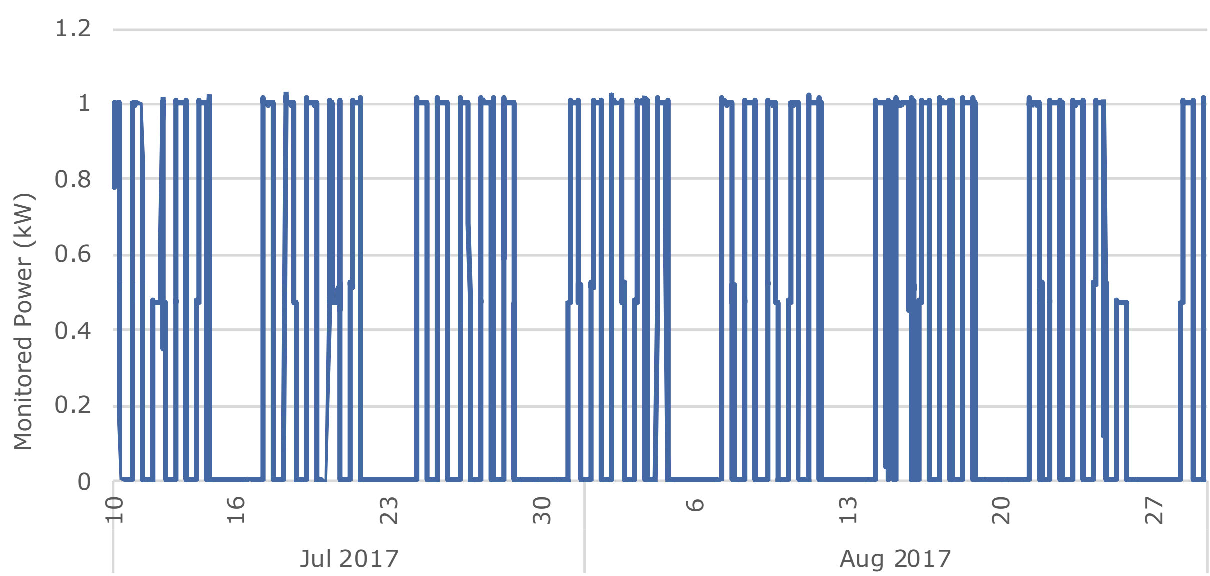
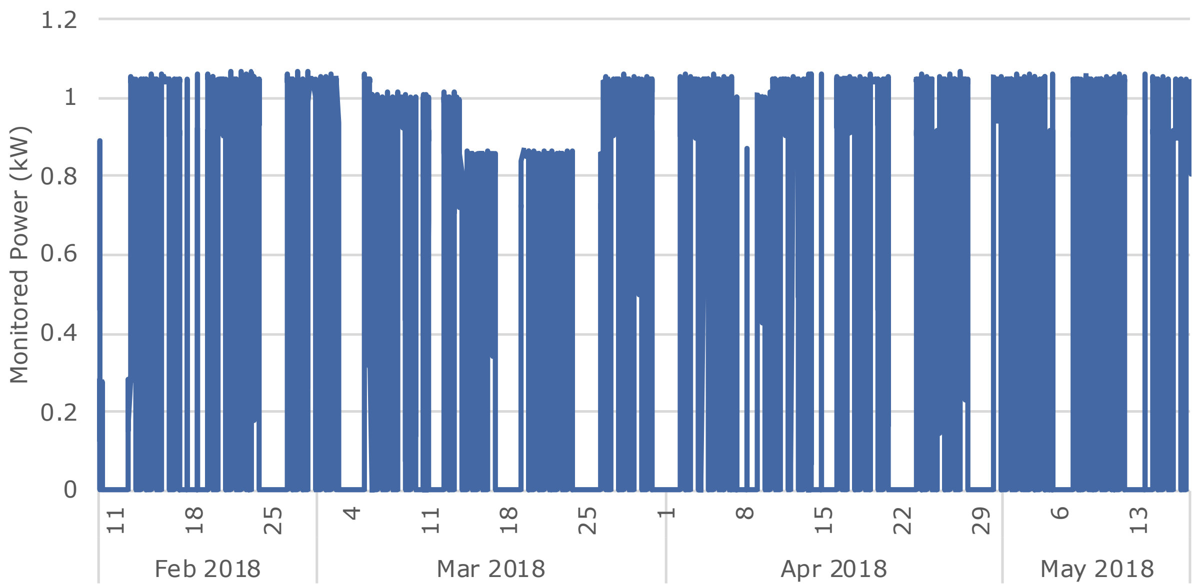


Figure 33. Site 1 – Circuit 19 – Post-Installation Power



Circuit 21 (Conference Rooms)

The data shows that the overhead lighting was manually controlled consistently in the Enos conference room. The Gray conference room had a drop in manual control and a proportionate increase in occupancy sensor reliance, which accounts for some of the increased lighting use in the space. See Table 5 for additional data. In both cases, the preponderance of manual dimming savings came from the incandescent downlights, that idled much of the time at a dimmed state.

Table 5. Site 1 – Circuit 21 – Pre-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Daylight	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Enos	Pre	0.0%	0.0%	13.3%	79.2%	0.0%	0.0%	7.5%
	Post	0.0%	0.0%	12.9%	80.5%	0.0%	0.3%	6.3%
Gray	Pre	0.0%	0.0%	13.4%	78.1%	0.0%	8.2%	0.3%
	Post	0.0%	0.0%	13.2%	53.0%	0.0%	27.9%	5.9%

Looking at the power metering, it appeared there was a week-long period where manual dimming took place for 10 days in March 2018 (Figure 35). This data was not supported by the control factor calculations, indicating that perhaps the light output meter was not installed in the right location to capture this dip in power. Outside of that 10-day window, no task tuning is evident, as the power data aligns very close to the one collected prior to the retrofit. The post-retrofit power data shows only minor changes compared to the pre-retrofit data. The greater apparent density in Figure 36 is likely a visual artifact of showing the on-off cycles.

Figure 34. Site 1 – Circuit 21 – Pre-Installation Power

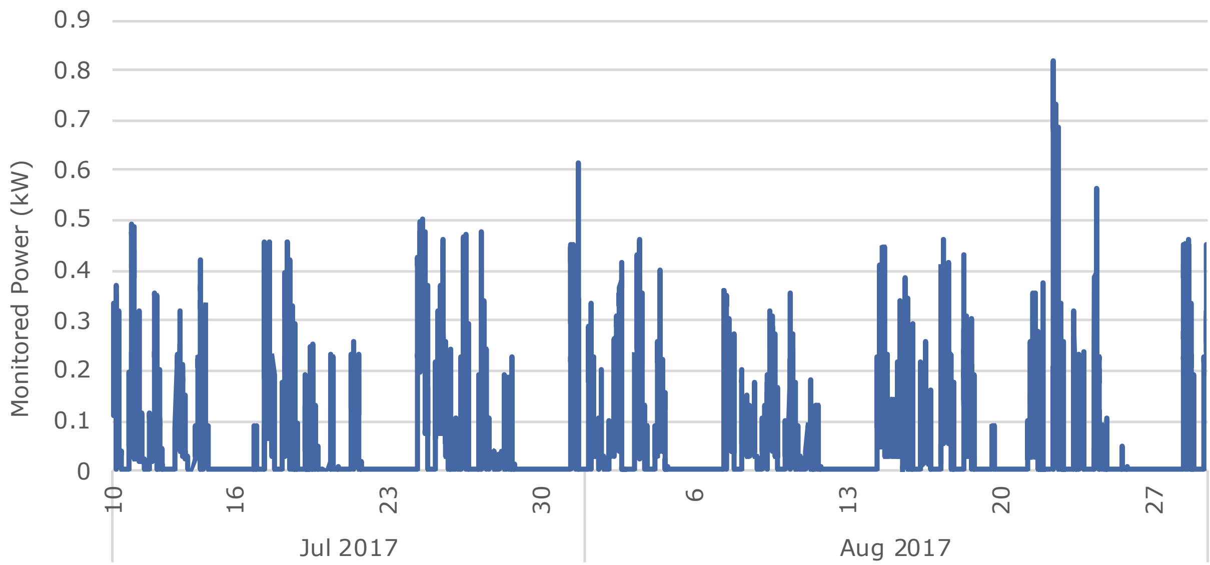
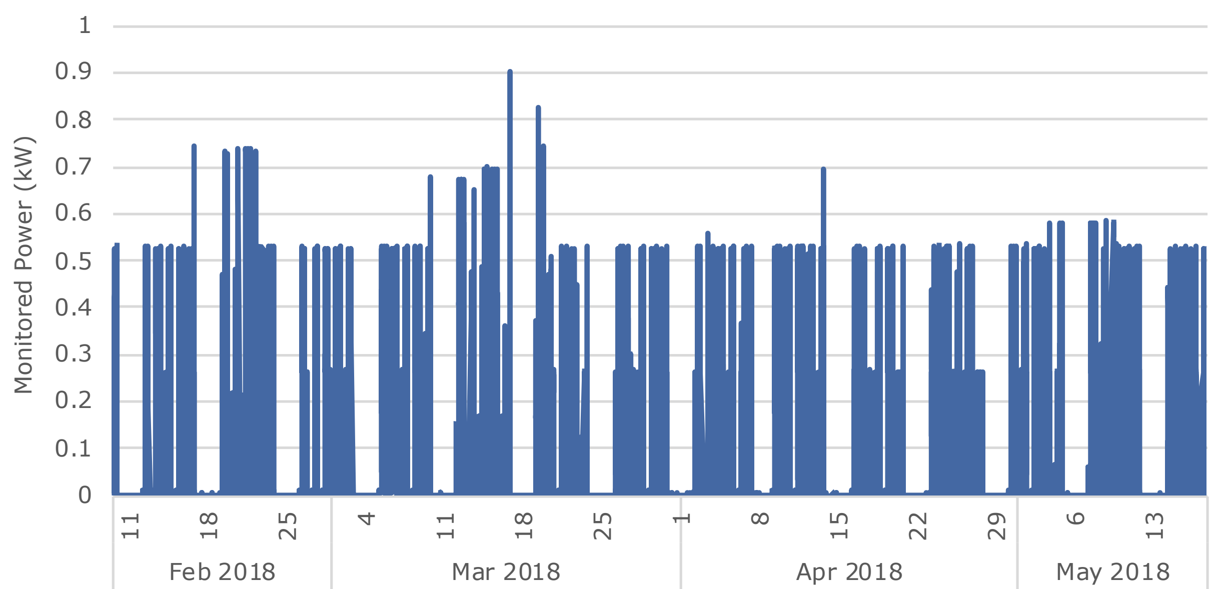


Figure 35. Site 1 – Circuit 21 – Post-Installation Power



Annualized Trend Data

Circuit 15

The calculated control factors were generally consistent with the electric power metering, suggesting that the control factor disaggregation was reasonable. Peak demand variables differed more substantially between the two calculation approaches, likely due to the static power values used in the control factor calculations.

Table 6. Site 1 – Circuit 15 – Calculated Energy Use & Electric Power Metering

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Office 1	0.17	44	0.02	83	**0.81**	**2,803**	**0.88**	**3,128**
Office 2	0.13	157	0.05	235				
Office 3	0.13	308	0.08	349				
Office 4	0.17	0	0.02	109				
Open Office, Front	0.68	2,133	0.50	2,080				
Total	**1.27**	**2,643**	**0.68**	**2,855**				

Circuit 17

The calculated energy consumption was fairly close to the metered energy consumption. However, the peak demand variables were substantially different.

Table 7. Site 1 – Circuit 17 – Calculated Energy Use & Electric Power Metering

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office, Middle	1.06	3,286	0.82	3,617	1.00	3,326	1.03	3,586

Circuit 19

The calculated energy consumption was fairly close to the metered energy consumption. However, the peak demand variables were substantially different.

Table 8. Site 1 – Circuit 19 – Calculated Energy Use & Electric Power Metering

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office, Rear	0.97	3,073	0.76	3,300	0.93	3,031	1.00	3,471

Circuit 21

The calculated energy consumption and peak demand were fairly close to the metered energy consumption.

Table 9. Site 1 – Circuit 21 – Calculated Energy Use & Electric Power Metering

<table>
<tr><th rowspan="3">Zone</th><th colspan="4">Calculated Control Factors</th><th colspan="4">Electric Power Metering</th></tr>
<tr><th colspan="2">Pre-Installation</th><th colspan="2">Post-Installation</th><th colspan="2">Pre-Installation</th><th colspan="2">Post-Installation</th></tr>
<tr><th>Peak Demand</th><th>Energy Use</th><th>Peak Demand</th><th>Energy Use</th><th>Peak Demand</th><th>Energy Use</th><th>Peak Demand</th><th>Energy Use</th></tr>
<tr><td>Enos Conference Room</td><td>0.45</td><td>310</td><td>0.11</td><td>352</td><td rowspan="3">0.11</td><td rowspan="3">438</td><td rowspan="3">0.17</td><td rowspan="3">655</td></tr>
<tr><td>Gray Conference Room</td><td>0.45</td><td>425</td><td>0.07</td><td>262</td></tr>
<tr><td>Total</td><td>0.91</td><td>735</td><td>0.18</td><td>614</td></tr>
</table>

Energy Savings

The energy and demand reductions are discussed by electrical circuit below. The demand increased on every lighting circuit after the controls were retrofitted into the system. While manual dimming controls were provided for each zone, they were not used regularly. Overall, the control retrofit at this site saved no energy. The energy penalty is entirely due to the addition of controls, as the luminaires were not changed as part of the retrofit.

Circuit 15

Of the five zones on Circuit 15, only the open office showed energy savings based on the control factors alone. The private offices showed that the lighting was in use more frequently after the control retrofit, which was entirely due to the specific needs of the user. The electric power metering showed a similar result. When evaluating the power trends, the maximum circuit power was generally higher post-retrofit versus pre-retrofit, which may account for somewhat greater net energy penalty.

Table 10. Site 1 – Circuit 15 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Office 1	0.15	-38	**-0.07**	**-325**
Office 2	0.07	-77		
Office 3	0.04	-42		
Office 4	0.15	-109		
Open Office, Front	0.18	54		
Total	**0.59**	**-213**		

Circuit 17

The middle open office showed both energy and peak demand savings.

Table 11. Site 1 – Circuit 17 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office, Middle	0.23	-331	**-0.03**	**-260**

Circuit 19

The rear open office showed both energy and peak demand savings.

Table 12. Site 1 – Circuit 19 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office, Rear	0.21	-227	**-0.07**	**-440**

Circuit 21

The conference room generated negative power savings on the electric meters, but positive power savings on the calculated control factors. This indicates a possible performance drift in the relative illuminance meter that could have appeared as savings.

Table 13. Site 1 – Circuit 21 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Enos Conference Room	0.35	-41	**-0.05**	**-216**
Gray Conference Room	0.38	162		
Total	**0.73**	**121**		

SITE 2

The Site 2 retrofit included both controls and a luminaire retrofit. The following section describes the detailed results for Site 2.

Calculated and Metered Power Trends

Based on the data shown in Table 14, user behavior remained relatively unchanged based on the manual on/off control factors. Note that there were no manual dimming savings, as manual dimmers were not provided for this project, which does not comply with Title 24. Further, Training Room 250B had no manual control at all, which also does not comply with Title 24.

Since we did not receive luminaire data and were unable to verify the luminaires in the field, most of the energy savings at these sites was attributed to the luminaire retrofit/efficacy upgrade. In practice, some of those energy savings may be more appropriately attributed to task tuning, a control strategy enabled by the lighting control system. Without knowing the exact luminaire wattage, we were unable to disaggregate the control factor associated with task tuning.

In the post-installation data, the occupancy sensor shut off the lighting more frequently, likely due to replacing occupancy sensors that were non-functional.

Table 14. Site 2 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Day-light	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Huddle 252A	Pre	0.0%	0.0%	0.0%	72.5%	0.0%	5.1%	22.4%
Huddle 252A	Post	0.0%	0.0%	0.0%	73.1%	0.0%	4.9%	22.0%
Huddle 252B	Pre	0.0%	0.0%	0.0%	71.1%	0.0%	4.6%	24.3%
Huddle 252B	Post	0.0%	0.0%	0.0%	54.0%	0.0%	26.2%	19.8%
Huddle 252C	Pre	0.0%	0.0%	0.0%	63.8%	0.0%	11.6%	24.6%
Huddle 252C	Post	0.0%	0.0%	0.0%	79.6%	0.0%	0.1%	20.3%
Huddle 252D	Pre	0.0%	0.0%	0.0%	70.8%	0.0%	2.6%	26.6%
Huddle 252D	Post	0.0%	0.0%	0.0%	52.0%	0.0%	27.7%	20.3%
Kitchenette	Pre	0.0%	0.0%	0.0%	35.2%	0.0%	5.4%	59.4%
Kitchenette	Post	0.0%	0.0%	0.0%	22.1%	0.0%	24.9%	53.0%
Storage 250A	Pre	0.0%	0.0%	0.0%	76.6%	0.0%	3.2%	20.2%
Storage 250A	Post	0.0%	0.0%	0.0%	85.5%	0.0%	8.1%	6.4%
Training Rm 250B	Pre	0.0%	0.0%	0.0%	65.0%	0.0%	12.0%	23.0%
Training Rm 250B	Post	0.0%	0.0%	0.0%	0.1%	0.0%	84.4%	15.5%

In the post-installation data, there was a 700W max demand reduction between the existing hardware and installed hardware. The load shape between the pre- and post-installation data sets was very similar (Figure 36 and Figure 37), the magnitude was merely reduced. The exception to the load shape similarity was the change in the baseload pattern, which now persists continuously.

Figure 36. Site 2 – Pre-Installation Power

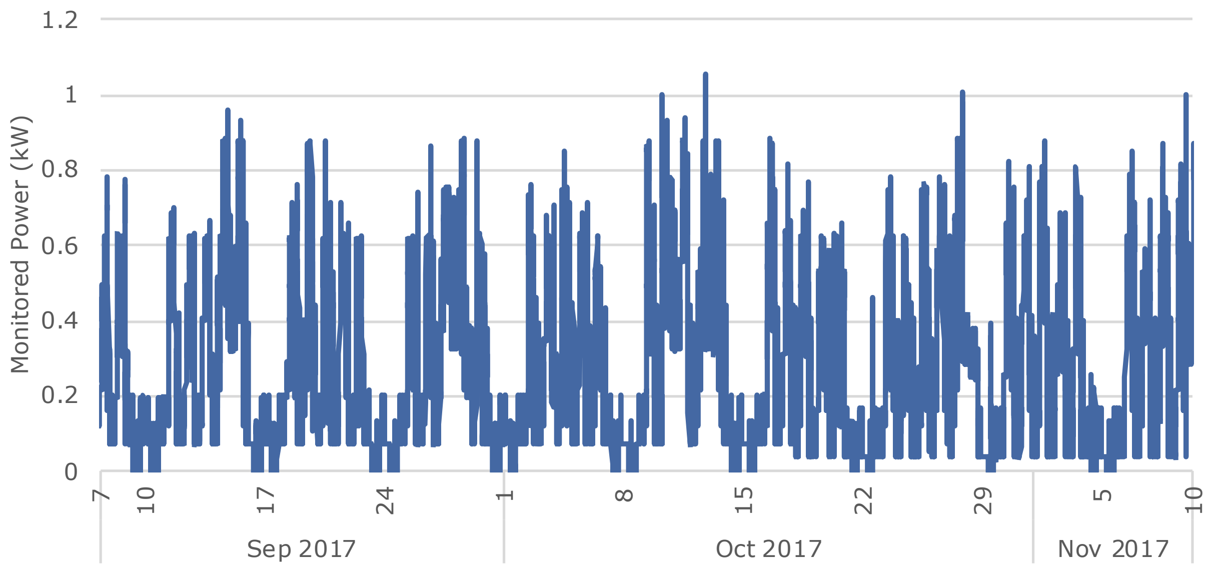
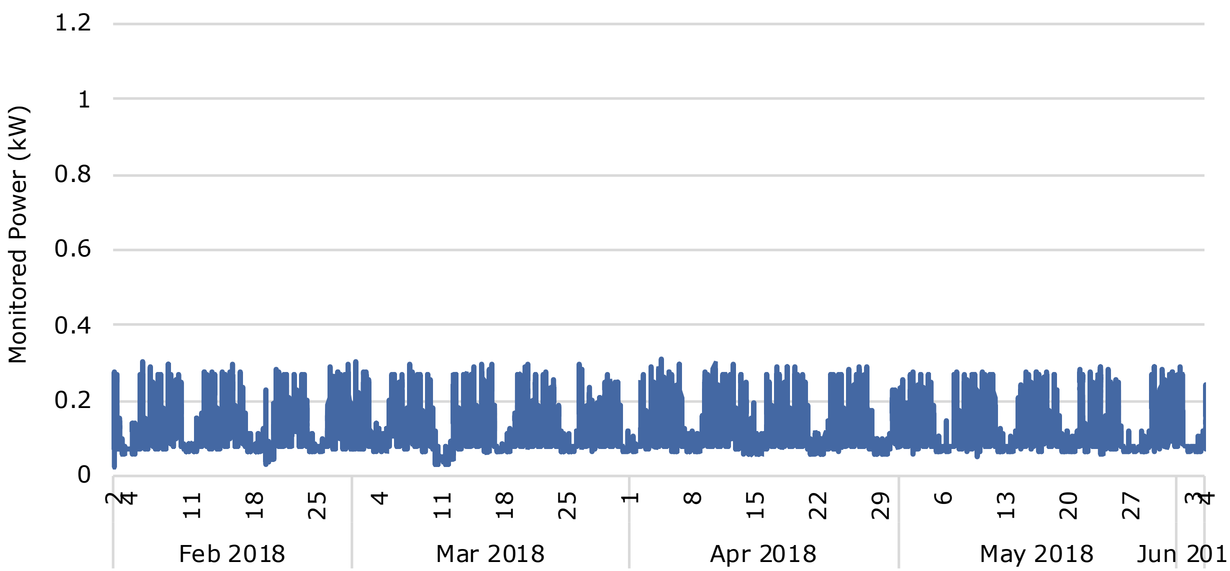


Figure 37. Site 2 – Post-Installation Power



Annualized Trend Data

The pre-installation power meter data does not accurately match the calculated power using the control factors. The key reason for the difference is most likely due to the absence of the observed baseloads in the calculated control factors. Another potential reason for the deviation is the bi-level lighting in the conference rooms. We attempted to meter the fixture-level bi-level lighting using a single meter per luminaire, but the evaluation team cannot definitively say that, in practice, we captured every time the lighting operated at a bi-level state and therefore, we may not have correctly differentiated between the 66% on and 100% on states and underestimated the lighting power.

The deviations in the peak demand likely occurred because the electric power metering captured the coincident peak of all seven zones, while each zone calculated the peak for an individual zone.

Table 15. Site 2 – Calculated Energy Use & Electric Power Metering

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Huddle 252A	0.02	153	0.01	40	**0.54**	**2,341**	**0.20**	**1,081**
Huddle 252B	0.02	171	0.00	29				
Huddle 252C	0.02	173	0.00	28				
Huddle 252D	0.02	187	0.01	29				
Kitchenette	0.05	251	0.03	221				
Storage 250A	0.03	170	0.00	19				
Training Rm 250B	0.08	314	0.02	113				
Total	**0.23**	**1,419**	**0.07**	**479**				

Energy Savings

There was significant energy savings on each circuit. Most of the energy savings was likely due to the efficiency upgrade, replacing ~100W two-by-four troffers with LED luminaires. Furthermore, the storage closet luminaire count was reduced from three luminaires to two luminaires, helping generate additional savings.

However, the calculated energy savings fell approximately 25% below the metered energy savings. This was likely due to inadequately differentiating between the bi-level states in the conference and storage rooms. The difference between the savings results is unlikely to be the pre-retrofit unidentified load, as it is present in both monitoring periods.

Table 16. Site 2 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Huddle 252A	0.01	113	**0.34**	**1,260**
Huddle 252B	0.01	142		
Huddle 252C	0.01	145		
Huddle 252D	0.01	158		
Kitchenette	0.02	29		
Storage 250A	0.03	151		
Training Rm 250B	0.07	201		
Total	**0.17**	**940**		

SITE 3

Site 3 included luminaire retrofits in addition to lighting controls. The following section describes the detailed results for Site 3.

Calculated and Metered Power Trends

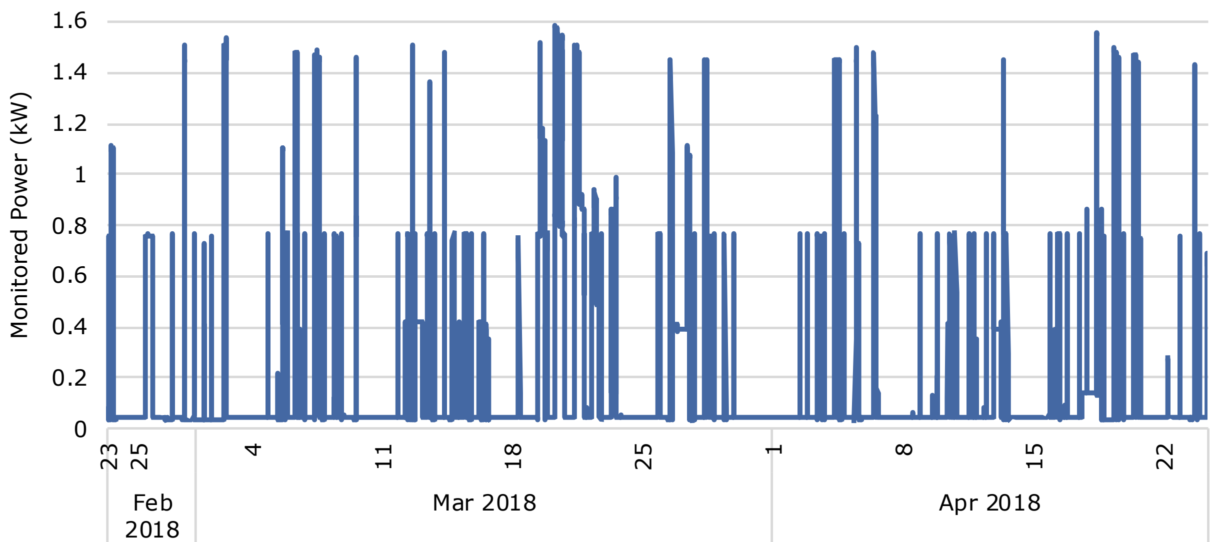
As seen in the summary tables below, the occupancy sensors had very little impact on the post-installation lighting system. The new lighting system task tuning and the manual dimming fraction increased. Based on our review of the data, the manual dimming might be better attributed to task tuning, as the manual dimming fraction stayed relatively consistent day-to-day after implementing a light output adjustment. The lighting use factor went down significantly.

Table 17. Site 3 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Daylight	Manual Dimming	Manual On/Off	Schedule	Occu-pancy	
Training Room	Pre	0.0%	0.0%	0.0%	83.1%	0.0%	0.0%	16.9%
	Post	47.2%	0.0%	30.4%	8.9%	0.0%	3.9%	9.5%
Small ConferencR room	Pre	0.0%	0.0%	0.0%	96.2%	0.0%	0.0%	3.8%
	Post	9.8%	0.0%	83.0%	4.2%	0.0%	0.0%	3.0%

The power metering data for the training room showed a significant drop in peak power (~600W). It appears that the system underwent a significant programming change on December 25, after which the lighting control system appeared to shut off the lighting with greater regularity.

Figure 38. Site 3 – Training Room – Pre-Installation Power



In the post-installation data for this space see significantly more cycling. While on site, we heard from occupants that this centrally located training room often has transient occupancy, as occupants use the three entrances to the space as a short cut to get from one area of the building to another. The occupancy sensors may have been configured in an auto-on configuration and, as a result, turn on the lighting for transient occupancy, which did not happen when manual switches were used in the space.

Figure 39 shows the power logging on training room Circuit 37 in isolation. The approximately 700W loads on the chart were likely due to an overhead projector. The small hip on either end of the project spike on the week of April 15th shows the relative load size (approximately 115W) associated with the two troffers on this circuit. At various times throughout the monitoring period we saw variable loads between the baseload of 42W and the lighting load and projector loads, which we attribute to the lowering of the projector screen, also powered by this circuit.

Figure 39. Site 3 – Training Room – Pre-Installation Circuit 37 Power in Isolation

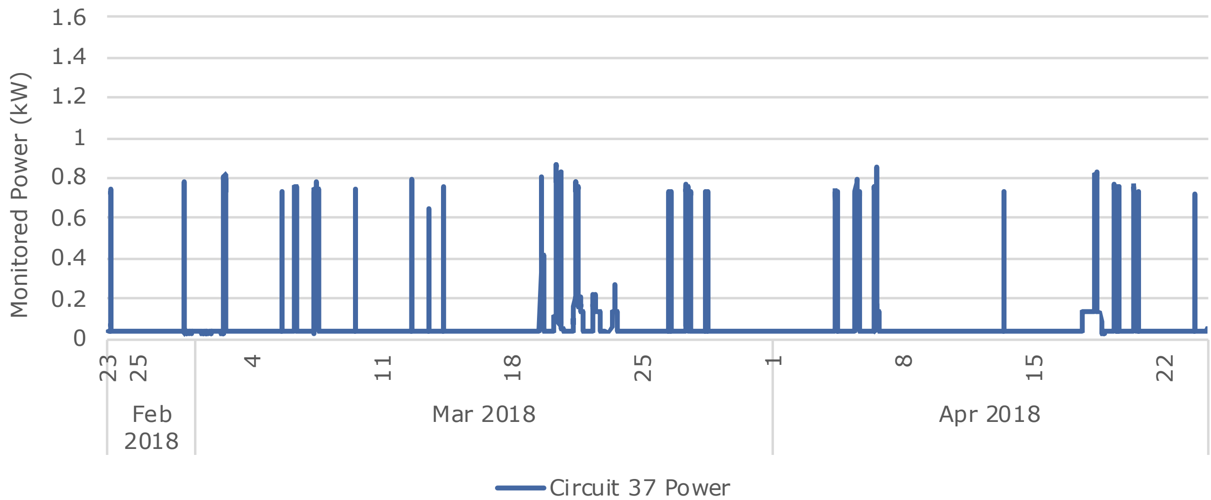
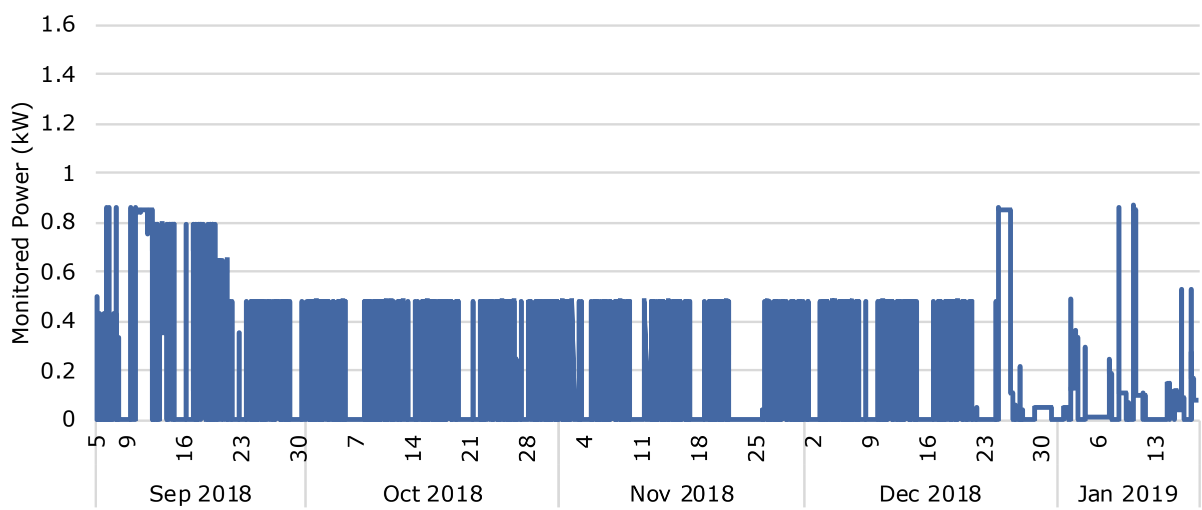


Figure 40. Site 3 – Training Room – Post-Installation Power



In the Small Conference Room, we saw the troffer lighting (590W) cycle on and off, in addition to a lower, sustained load, between 120W and 360W. Presumably the, lower load was due to the downlighting; however, it was unclear how the downlights were controlled in the zone, given that there was no manual switch. After the retrofit, there was a constant baseload (approximately 120W) throughout the monitoring period. The peak demand values exceeded those measured during the pre-retrofit period, possibly because task tuning occurred after monitoring started.

Figure 41. Site 3 – Small Conference Room – Pre-Installation Power

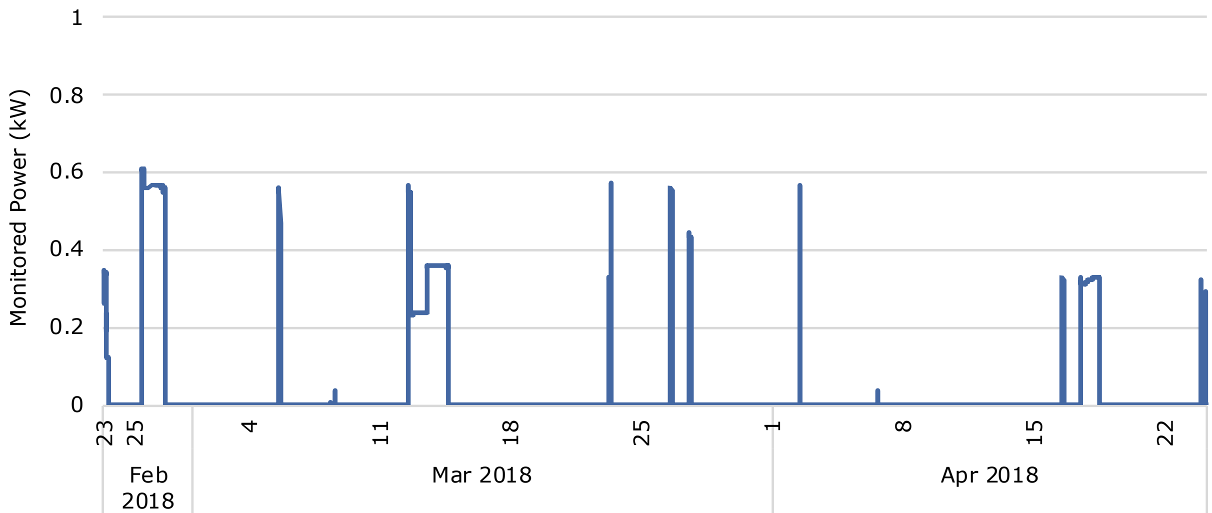
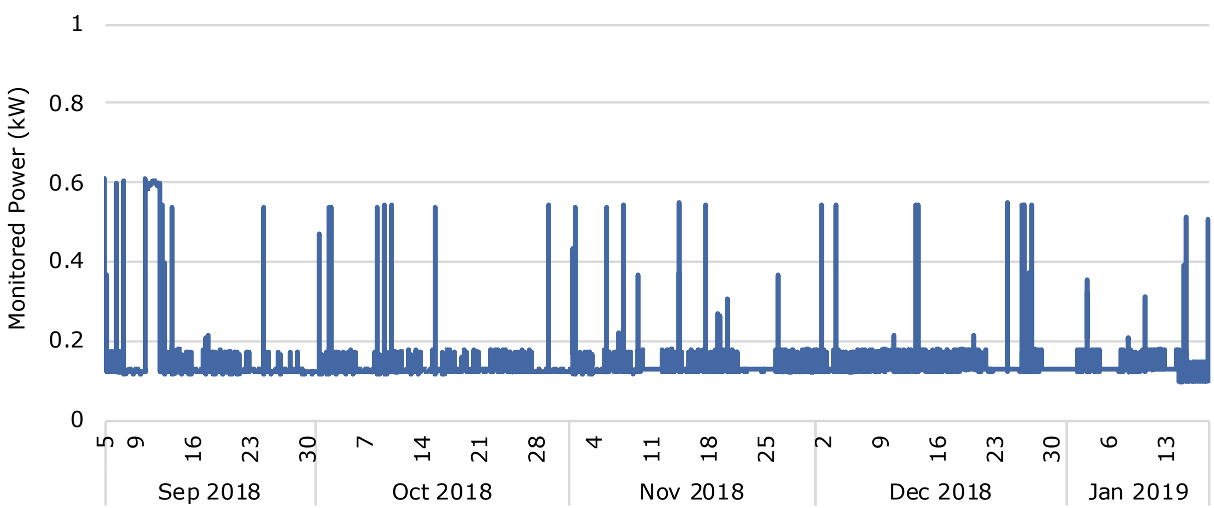


Figure 42. Site 3 – Small Conference Room – Post-Installation Power



Annualized Trend Data

The energy use calculated from the control factors did not align with the savings calculated using monitored energy use, as shown in Table 18. This was likely due to the unidentified electrical loads on the circuit, as noted in the preceding section. We categorized each five-minute interval of data on Circuit 37 based on which loads were operating. Lighting energy use, on an annual basis, accounts for 8 kWh/yr. The remaining loads account for 620 kWh/yr (366 kWh/yr baseload, 27 kWh/yr for projector screen motor, and 227 kWh/yr for the projector). When combined with circuit 41, the total pre-installation lighting power based on the power data is 742 kWh/yr, which compares more favorably with our calculated load (657 kWh).

Table 18. Site 3 – Calculated Energy Use & Electric Power Metering

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Training Room	0.92	657	0.11	636	0.12 0.16	628 734	0.22	1,162
Small Conference Room	0.46	197	0.02	98	0.05	293	0.14	1,204
Total	**1.38**	**854**	**0.13**	**734**	**0.33**	**1,655**	**0.37**	**2,366**

Energy Savings

The savings calculated using the control factors and the metering data differed for the training room, as seen in Table 19. The baseline power metering included electrical loads that were not present in the post power metering, due to electrical recircuiting included in the project scope. As a result, the electric power metering over-estimated savings, as the unknown baseload and the overhead screen were isolated and excluded from the lighting system power metering.

There was a large energy penalty associated with the retrofit on the electric metering for the Small Conference Room due to a baseload that occurred only during the post-retrofit period. This baseload pushed the installed power above the nominal manufacturer power for the luminaires (600W consumed versus 460W expected), indicating that this load might not be associated with the lighting system. We don't know what this baseload is or what device it is associated with; however, based on our experience reviewing the electrical panels and our experience in the training room, it is not unreasonable to assume that the host customer placed an unassociated-electrical load on the circuit without notifying the project.

Table 19. Site 3 – Calculated Energy Savings & Metered Savings

Zone	Calculated Control Factors Savings		Electric Power Metering Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Training Room	0.81	21	0.05	200
Small Conference Room	0.44	99	-0.09	-912
Total	**1.25**	**120**	**-0.04**	**-711**

SITE 4

Site 4 included luminaire retrofits in addition to lighting controls. The following section describes the detailed results for Site 4.

Calculated and Metered Power Trends

After the retrofit of the lighting system, the system was task tuned, resulting in large lighting control savings. Manual dimming and manual on/off control provided the remaining bulk of the lighting control energy savings. While occupancy sensors were installed, they do not appear to have been used. The results are shown Table 20.

Table 20. Site 4 – Pre-/Post-Installation Control Factors

Zone / Period		Control Factors						Lighting Use Factor
		Task Tuning	Daylight	Manual Dimming	Manual On/Off	Schedule	Occupancy	
Open Office	Pre	0.0%	0.0%	0.0%	19.4%	0.0%	0.0%	80.6%
	Post	56.2%	0.0%	7.8%	5.4%	0.0%	1.1%	29.6%

The electrical power trends show a significant drop in energy consumption. Neither the pre-installation nor the post-installation data trends indicate the space had a consistent schedule, indicating that the log operating hours may be related to the nearly continuous (21/7) occupancy period for this facility.

Figure 43. Site 4 – Pre-Installation Power

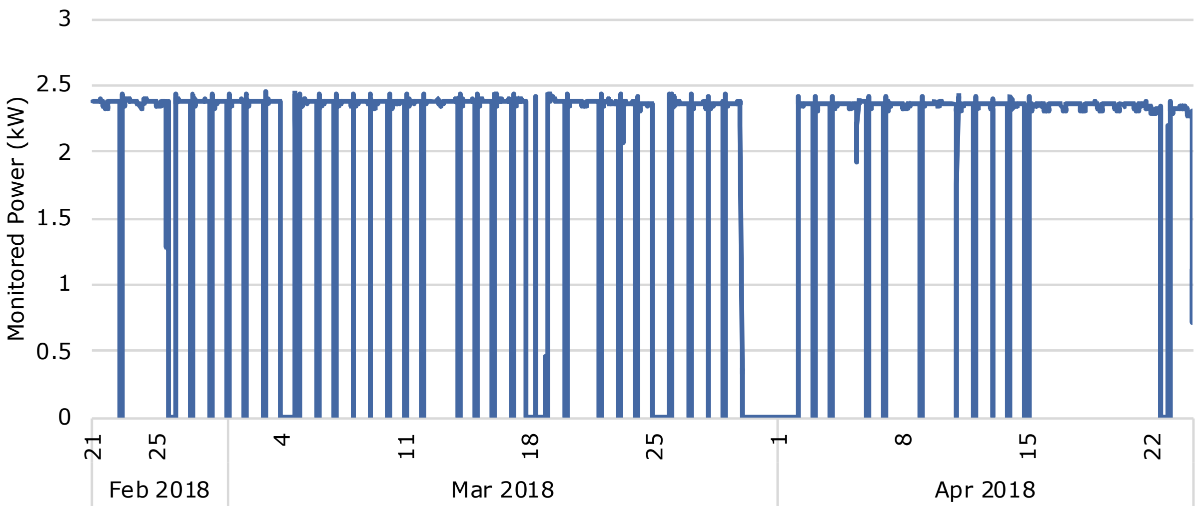
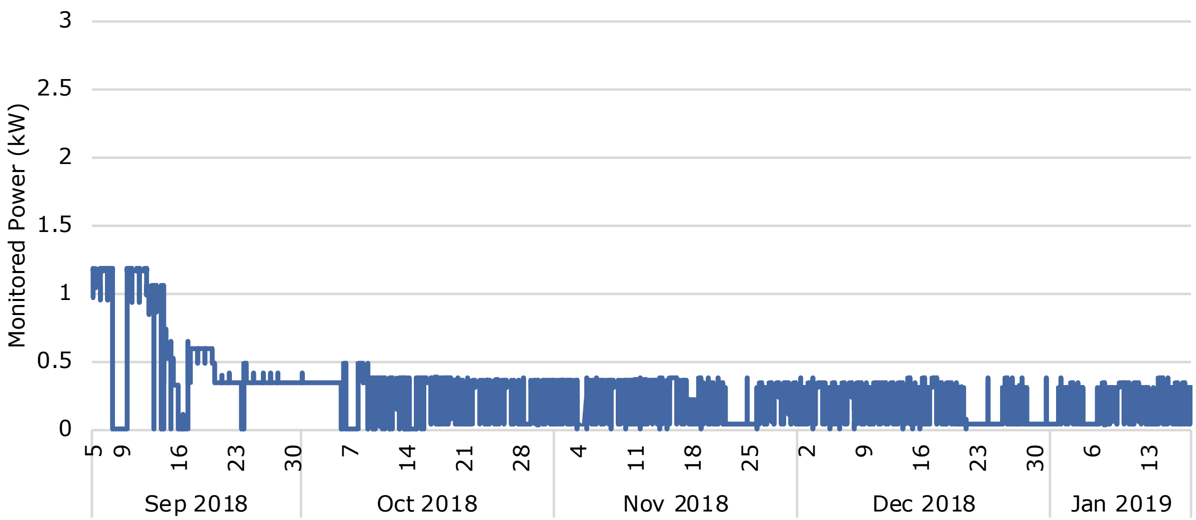


Figure 44. Site 4 – Post-Installation Power



Annualized Trend Data

Both calculation approaches were similar in terms of demand and energy use in the pre-retrofit period. The difference between the post-retrofit energy consumption was, in part, due to a 38W baseload in the new lighting control system.

Table 21. Site 4 – Annualized Trend Data

Zone	Calculated Control Factors				Electric Power Metering			
	Pre-Installation		Post-Installation		Pre-Installation		Post-Installation	
	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office	**1.20**	**16,613**	**0.40**	**3,004**	0.75	5,419	0.27	1,794
					0.56	4,070		
					0.67	4,869	0.26	1,775
					0.33	2,396		
Total					**2.31**	**16,754**	**0.53**	**3,569**

Energy Savings

The savings calculated using the control factors and the savings calculated using metering data were very similar for this site, indicating the control factors were reasonably accurate for this space and project.

Table 22. Site 4 – Energy Savings Data

Zone	Calculated Control Factors		Electric Power Metering	
	Savings		Savings	
	Peak Demand	Energy Use	Peak Demand	Energy Use
Open Office	**0.80**	**13,609**	**1.04**	**7,695**
			0.74	**5,490**
Total			**1.78**	**13,185**

APPENDIX D: SUMMARY OF FINDINGS AND RECOMMENDATIONS

The table on the following pages presents a summary of findings and recommendations for this study.

Summary of Findings and Recommendations

Study Title: PG&E Advanced Lighting Controls System Tool Trial Evaluation
Program: Advanced Lighting Controls
Author: EMI Consulting
Calmac ID: (example) CPU0118.01
ED WO: (example) ED_D_Res_5
Link to Report: (example) http://calmac.org/publications/CPUC_HUP_Focused_Evaluation-FINAL_05-03-16atr.pdf

MANAGEMENT APPROVAL AFTER REVIEWING ALL IOU RESPONSES		
	Name	Date
PG&E		
SCE		
SCG		
SDG&E		

Item #	Page #	Findings	Best Practice / Recommendations (Verbatim from Final Report)	Recommendation Recipient	Disposition	Disposition Notes
				To Evaluator: Be specific, (i.e. "PG&E, SCE and SDG&E" or "Energy Division" or "Commission" or "CEC" or "Future evaluators" To RTR responder: "If incorrect, please redirect and indicate in notes.	Choose: Accepted, Rejected, or Other	Examples: Describe specific program change, give reason for rejection, or indicate that it's under further review.
1	ES-11, 92	**The high cost for ALCS is the primary barrier for increased adoption.** Both participants and near-participants cited the high cost of ALCS as the main barrier for doing more spaces within their facility or for participating in the Trial, respectively. Both facility managers and contractors interviewed reported that customers require a ROI of three years or less to implement a project.	**Consider offering a rebate specifically for the installation of ALCS that is large enough to help meet customers' ROI requirements.** Based on the feedback from facility managers, it appears that the current incentive structure for lighting projects may not be meeting the market's needs. For example, one facility manager reported the deemed incentive allowed the manufacturing portion of their project to proceed quickly, whereas the complicated nature of the office lighting incentive prevented that part of the project from proceeding, because the facility manager was unsure of the final incentive amount. Another respondent said receiving a rebate for their infrastructure upgrades would have brought the ROI for the total ALCS project closer to their ROI requirements. In return for a larger incentive, PG&E should consider making access to system data a participation requirement. Having access to such data has the potential to reduce M&V costs (see Recommendation 3B) and increase savings (see Recommendation 3E). Customers'	PG&E		

			security concerns related to allowing 3rd parties access to their systems could be overcome by downloading data and conducting analysis separately as opposed to viewing real-time data in the ALCS interface. Of course, *this recommendation would have to be taken in context with ongoing changes to the lighting market and California regulatory policy and proceedings.*			
2	ES-11, ES-12, ES-13, 92, 93, 94	**Market actors may be wary of installing ALCS because of previous poor experiences with lighting controls and the fact that ALCS' are still a new and unknown technology.** We heard from multiple interviewees that there is institutional anxiety around installing ALCS. This is due to previous poor experiences with occupancy sensors not working properly, hearing stories of early ALCS installations not working (as experienced with Site 0 in this Trial), and also due to maintenance teams' reservations about switching to systems that are unfamiliar and more complicated than their current system. IT departments also have privacy concerns about ALCS connecting to their internal internet. While many types of ALCS provide similar features and functionality (e.g., daylight dimming, task tuning, remote access), the methods by which they are implemented (e.g., how fixtures are paired to hubs, whether the fixture is integrated or not) can vary significantly. These variations can cause differences in cost, ease of installation, and user experience. As ALCS is still an emerging technology, market actors may have a hard time distinguishing between the products.	**Publish successful ALCS case studies targeted to various audiences.** Trial participants' concerns about lighting control technology were resolved after ALCS installation. They reported high satisfaction with the quality of light, the control strategies, and had not received any complaints from occupants. As ALCS adoption grows, publishing case studies or success stories from customer implementation may help overcome some of the negative perception of lighting control technologies in the market. Providing specific messaging for the different market actors would also be helpful; the information a financial decision-maker needs in a case study is different than the information maintenance staff needs.	PG&E		
			Investigate hosting ALCS trainings for facility managers at IOU energy centers. The trainings could include presentations on the differences between the products, occupant and facility manager experiences and satisfaction, examples of control operation, and information on programs and available incentives.	PG&E		
			Consider conducting bench testing or demonstration projects of different ALCS manufacturers' products. All of the participating facility managers discussed how having results from bench testing various ALCS products, or having a demonstration project, would help increase ALCS adoption. ALCS technologies are complicated, and facility managers found it hard to understand exactly what their lighting would be like after the retrofit, and they reported their ability to see it would have helped their decision-making process. In fact, having a demonstration project is the precise reason why one facility manager, the lighting contractor, installed it in their offices.	PG&E, Future Implementers and/or Evaluators		
			Future pilots or programs could explore the maturity and market-readiness of	PG&E, Future Implementers		

			ALCS technologies. All of the participating facility managers discussed having installation difficulties. For example, one, Site 0, experienced severe enough wide-scale system glitches they chose to uninstall the system. While these experiences may indicate ALCS technology may not be fully matured, this is an extremely small sample size and assessing maturity was not a part of this evaluations' scope. Alongside bench testing or demonstration projects (Recommendation 3B), future research could investigate the technology's maturity and how utilities could partner with manufacturers to further address customers' concerns and barriers.	and/or Evaluators		
3	ES-13, ES-14, ES-15, 94, 95, 96	**If future ALCS pilots are conducted by PG&E, changes to the Trial and evaluation design could improve results.** As with any research, the Trial and this evaluation faced some challenges. If another pilot is undertaken, below are suggestions for improving the design.	**Conduct interviews as project phases are completed.** The interviews were originally designed to have the least impact on participants, meaning one interview was conducted to collect all the needed data. However, the sales cycle and implementation timelines are so long for ALCS that it resulted in interviewees not recalling their experience or staff turnover. As such, data collection should occur immediately after each task is finished. For example, interviews about the sales cycle and completing the Tool should be conducted during the pre-retrofit metering period instead of at project completion. This would also mean staggering the incentives at each interview stage.	Future Evaluators		
			Implement a different monitoring approach. The monitoring approach to verify the output of the Tool, monitoring each control factor in 30 second to five minute intervals in up to ten spaces for Trial sites, used in this evaluation was more complicated and time intensive than the project justified. Due to the combined costs of this approach, limitations on the ability to collect data, and a limited timeframe, only a subsection of spaces in these facilities could be studied. Future efforts would benefit from taking advantage of the monitoring features already built into the lighting control systems (including those listed by the DesignLights Consortium, DLC) which have the ability to monitor the on-going operation of the lighting system, reporting what the system is doing at	Future Evaluators		

			any given time for any given zone (e.g. dimming signal, daylighting signal, occupancy status, etc.). Using the ALCS-generated reports to determine the system behavior would provide higher quality data (no battery failures or occupant interference), reduce assumptions (aligning data with expectations and observations) and lower cost (fewer site visits; potentially no site visits if VPN access is available) compared to the approach taken for this evaluation. One potential barrier to this recommended approach is a lack of trust in the ALCS-generated data. However, it would be feasible to perform a small demonstration project (e.g. a bench-top wiring and programming exercise with short term power monitoring) or a functional test of the system in the field to verify the successful installation and configuration in the field. A small randomly selected field test to verify the system self-reporting is accurate could help utilities and public utilities commissions trust the data, which in turn would build trust in the eventual results when a much larger program relies on ALCS reported data. Fundamentally, the real-time data collected by ALCS could be utilized in Normalized Metered Energy Consumption (NMEC) calculations. Note, this calibration/trust exercise could be avoided if there were an industry-standard test procedure and certification (like the DLC Networked Lighting Controls Program). If the in-depth field monitoring is desired, we recommend utilizing different meters than those that were utilized in this evaluation that would overcome some of the data collection errors experienced by this Trial. These include using meters where remote-download is possible and/or more data can be stored onboard and where there is a warning about failed batteries.			
			Create a financial connection for PG&E contractors between site recruitment and site measurement and verification. For future pilots, the two scopes of work should be closely tied so that the measurement and verification contractor can have access to the hardware on site, a design review, and a single site visit to gather the needed data themselves. Doing so would have avoided the	PG&E		

			needed remote access, which may continue to create security concerns (participants reported they were concerned about the security of allowing external parties access to their control systems) for participants in future projects.			
			Incorporate training for customers on ALCS controls programming into the pilot. The on-site monitoring found efficacy improvements had a much larger impact on energy savings than changes in controls. One possible explanation, based on field observations, was that control programming is often done improperly and that users may not receive adequate training to make use of the advanced control features. While the Trial included training for contractors, the next iteration of an ALCS pilot should also include training for participating customers after installation and commissioning is complete.	PG&E, Future Implementers		
			Consider using ALCS data for opportunity identification. As ALCS adoption increases, there may be an opportunity to analyze the data from across many installations to identify potential lighting controls measures. For example, buildings or areas with high daylight levels and high daytime lighting consumption could be flagged as a potential candidate for daylight harvesting recommissioning. While doing so has the potential to increase projects' savings over what they might achieve without this type of opportunity identification, this type of analysis has been difficult in the past because there is so much variation in each building and area within a building. For example, one of the conference rooms for a participant site in this study is used as a connecting corridor between segments of office areas. When considered as a part of a larger data set, this conference room would show a higher occupancy rate and longer run hours than a typical conference room but result in a non-actionable finding. Repeated unactionable flags may result in lower engagement or burnout of operators, so opportunity identification must take into consideration building nuances and whether operators can take action on the recommendations.	PG&E, Future Implementers		

			The concept of using ALCS data for opportunity identification could also be included in well-established programs such as retrocommissioning and strategic energy management. However, the success of this concept is dependent on gaining access to the ALCS data, which was a barrier experienced in the Trial and discussed in the evaluation report. Recommendation 1 (providing a large incentive for ALCS installation) offers a potential method for overcoming this barrier but would need to be tested with customers to determine its potential effectiveness.			