# Savings for the Program, Savings for the Participant: A Consistent and Scalable Savings Calculation Method for Advanced Lighting Controls

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**ABSTRACT**

Lighting technology has seen tremendous change in the past few years. Along with the growth of solid-state lighting such as Light-Emitting Diodes (LEDs), a new generation of advanced lighting control systems (ALCS) working together with these new lighting technologies offer vast potential for energy savings. By combining and layering multiple lighting control strategies ALCS can be used to provide lighting only when and where it is needed, to optimize energy use. With this potential, some utilities have developed incentive programs to promote ALCS technology, but currently rely on time-consuming and uncertain calculation methodologies, or on-site energy measurements to estimate savings. These calculation methodologies, even when developed, cannot be easily scaled to support aggressive promotion of ALCS by utility programs. Further, the lack of certainty around the accuracy of the calculations often results in conservative program approaches and lower incentives, with most utilities relegating ALCS systems to custom incentive programs. This approach is not market-friendly, creating barriers to participation and limiting aggressive promotion of ALCS technology in utility programs.

To address this need, a new calculation tool has been developed for estimation of savings from ALCS. This new tool utilizes the strengths of simulation based calculations, modified with on-site data collection, to create a quick, consistent, and accurate savings methodology that will allow utilities to scale promotion of ALCS through energy efficiency programs. Along with standardizing a calculation method for ALCS programs, the tool generates savings against both existing and code-minimum baselines. This paper discusses key concepts of the ALCS Calculator, and the implications of developing a standard calculation methodology for the lighting controls industry.

## Introduction

Advanced lighting control systems (ALCS) can be roughly defined as lighting controls with capabilities to reduce lighting energy use through one or more operation modes, namely occupancy sensing, daylighting, demand response, task tuning, manual dimming and scheduled or time switching. These can be used individually or in combination – with programmable logic, generally resulting in higher energy savings.

While ALCS have been in the market for many years, the advent of solid state lighting (LEDs) has been one of the primary enabling technologies for advancements in lighting controls. The combination of ever smaller sensors in lighting controls, combined with wireless communication, and programmable logic has dramatically increased their capability and reach. At the same time, LED lighting's capabilities to continuously dim with minimal loss in efficiency, instant on/off, and ease of digital communications, has provided an unprecedented opportunity for energy savings and controllability.

Alongside these technology developments, building energy codes have evolved to require automatic lighting control in most applications. California's Title 24, ASHRAE 90.1 and IECC energy codes have included requirements for automatic time sweeps (time switches) and/or occupancy sensors for many decades, and more recently, an aggressive requirement for automatic controls. For example, most commercial spaces in California are now required to have either five levels of light output, or continuous dimming, as an available control option from each luminaire. Similarly, new energy codes across the country now require extensive deployment of daylighting controls.

## Need for a Calculation Tool

In spite of the aggressive requirements for lighting controls in energy codes, there are still substantial energy savings to be had from additional lighting control measures, which are an important target for utility run energy efficiency programs. In order to pursue these savings, the programs need a calculation method that can validly and accurately calculate savings, and can also be scaled to accommodate aggressive program expansion and growth. Until now, utility programs have had to rely on either time-consuming custom calculations with uncertain calculation methodologies, on-site energy monitoring, or fall back on oversimplified deemed estimates to calculate energy savings and incentives.

While custom calculations have been used to promote other energy conservation measures, savings from ALCS applications are dependent on highly variable and site-specific inputs such as occupancy patterns, occupant switching behavior, daylight availability, control settings, etc., which make singular engineering calculations very onerous. Given their complexity, a program based on such custom calculations cannot be scaled easily, creating barriers to large-scale program participation.

The other frequently used method is applying deemed savings estimates, which uses a simple one-size-fits-all approach by developing a single savings value for all applications of a given technology. This approach uses so many simplifying assumptions that it compromises on accuracy and severely limits applicability for a technology like ALCS that depend on specific strategies and user defined settings to maximize savings. Without the ability to differentiate between the outcomes of these different strategies in an ALCS application, savings cannot be optimized for a project, leading to overly-conservative estimates and low incentives.

An alternative, non-calculation based option is monitoring on-site energy use, to more directly determine energy savings from a project. This is theoretically the most accurate means of calculating savings from an ALCS project. However, to calculate savings, energy monitoring would be needed for each lighting circuit, for every type of space, over an extended period of time, so as to capture the full range of variability of operating schedules, occupant behavior and weather conditions. Even then, baseline conditions and future conditions have a similar degree of variability, which means uncertainties still remain in the calculated savings. Any monitoring period less than one year would have to be 'annualized' by some calculation, making assumptions about how representative the monitoring period was for a yearly period. This approach also cannot be easily scaled and is thus an expensive approach that still leaves high levels of uncertainty in realized savings.

To support aggressive promotion of ALCS by utility programs, a new calculation mythology was needed that could accurately estimate energy savings, without the need for onerous engineering calculations or extensive on-site monitoring. Towards this goal, the ALCS Energy Estimation Calculator Tool (ALCS Calculator) was developed with funding from Pacific Gas & Electric Company (PG&E) and supporting funding from Northwest Energy Efficiency Partnerships (NEEP). The ALCS Calculator was developed to allow both utility programs administrators and participants to quickly and accurately estimate energy savings from ALCS applications.

## Short and Long Term Vision for the Tool

In order for utility programs to pursue the promotion of ALCS and facilitate market transformation, a calculation tool was needed, that would:

- Allow program managers to estimate the market potential for savings, across various commercial building types, with confidence
- Allow program representatives to screen potential sites for those with the best opportunities for savings
- Allow program participants to easily estimate, and optimize, the value of savings and any available rebates
- Allow program managers to verify and report claimed savings
- Allow program evaluators to easily verify inputs and calculation of program attributable savings

If the calculation tool can usefully and validly differentiate between the performance of different technologies and strategies, then high-performing strategies are more likely to be valued and become competitive in the market. This in turn would influence the industry to innovate towards better performing technologies.

Given the short-term need for an advanced lighting controls calculation tool to support utility programs, and the nascent state of evolution and development of solid state lighting and lighting control technologies, any tool developed would need be to structured such that it can fairly easily evolve over time, as its user-base expands and lighting control capabilities change. It was thus important to establish a clear long-term vision of the ultimate goals and establish a wish list of functional capabilities from a wide range of potential users – before the calculation tool was developed. A group of shareholders spanning a number of nation-wide utilities, utility alliances, and third-party program implementers were consulted during the development of the tool. The goals expressed by the stakeholder group are discussed below. While some of the capabilities discussed were not expected in the first version of the calculation tool, they serve as a guideline for future development:

- **Adaptable**: The tool should be capable of being adapted for use by energy efficiency programs around the country.
    - **Additional Baselines**: The code baseline condition for estimating energy savings should be adjustable to accommodate various regional, local or national codes.
    - **Climate Specific**: The tool should be able to adjust estimate of savings and demand impacts to weather conditions for location other than what the tool was initially designed for.

- **Evolving**: The tool should be periodically updated to new code baseline conditions, new technology capabilities, and new information about observed performance of advanced lighting controls systems.
- **Transparent**: The tool should make the methods and sources of information used to calculated savings easy to track and verify.
- **Multi-purpose**: The tool should be easily used for the purposes of many stakeholders, including:
    - **Programmatic estimates of savings**: Allows estimates of savings from representative populations of buildings
    - **Screening of potential projects**: Allows quick screening of potential projects, to determine savings potential.
    - **Design decisions**: Allows analysis of detailed site characteristics and control system types to facilitate selection of the highest performing options for a given site.
    - **Verification of performance**: Allows realistic comparison with post-occupancy evaluation of system performance, based on observed conditions and/or monitored performance.
    - **Tracking of program experience**: Records history of estimates of savings and observed conditions and performance, to enable comparisons between different phases of a project, especially pre and post estimates. Ideally, also include available information about target populations, including common site conditions and actual performance of lighting control systems.
- **Coordinates with Other Tools**: The tool should facilitate use in coordination with other energy estimation tools in common use by likely users. This may merely imply similarity in formatting inputs and outputs, or it might also include accepting (manual or automated) input from lighting audit tools, and/or enabling output to cost/benefit analysis or whole building energy analysis tools.
- **Expandable**: The tool should have the ability to include retrofit changes to the building that can reduce overall lighting energy use, such as higher surface reflectance or lower partition heights. Likewise, retrofit options that enhance daylight availability, such as window blinds/shades management or daylight redirection systems etc.
- **Ease of use**: The tool should have a shallow learning curve to learn to use, with relatively low investment of time to enter project details and obtain results. It should have convenient formats that facilitate reports, inputs and outputs. Balancing simplicity with accuracy.

## Concept for Calculation Methodology

Theoretically, the most accurate measure of savings from an ALCS project would be obtained by monitoring on-site energy usage for each lighting circuit, for every type of space, over an extended period of time. However, as discussed earlier, there are many reasons that this approach does not work for estimating savings for ALCS technology in a utility program. Alternatively, savings can be estimated using custom engineering calculations, but the accuracy of this approach partially depends on the detail of the modeling inputs. A highly customized answer would require detailed inputs, and a high level of calculation expertise.

For the ALCS energy savings calculation tool, we developed a new calculation methodology based on a hybrid approach. This approach addresses the limitations, and draws on the strengths of both on-site monitoring and detailed engineering calculation. Using this approach, the calculation tool first estimates 'preliminary results' by looking up results from a database of pre-run annual energy simulations, using 'generic prototypes' of various space categories developed using standard default inputs. Looking up pre-run simulation results dramatically reduces calculation time. Moreover, this can be done using relatively few inputs. This output is most useful during the screening phase of a project.

These preliminary results, are then modified based on project-specific inputs. These inputs could be derived from design or compliance documents, or from on-site observations and a detailed lighting audit, or actual monitoring, where possible and feasible to do so. Adding these site-specific details produces the 'final results'.

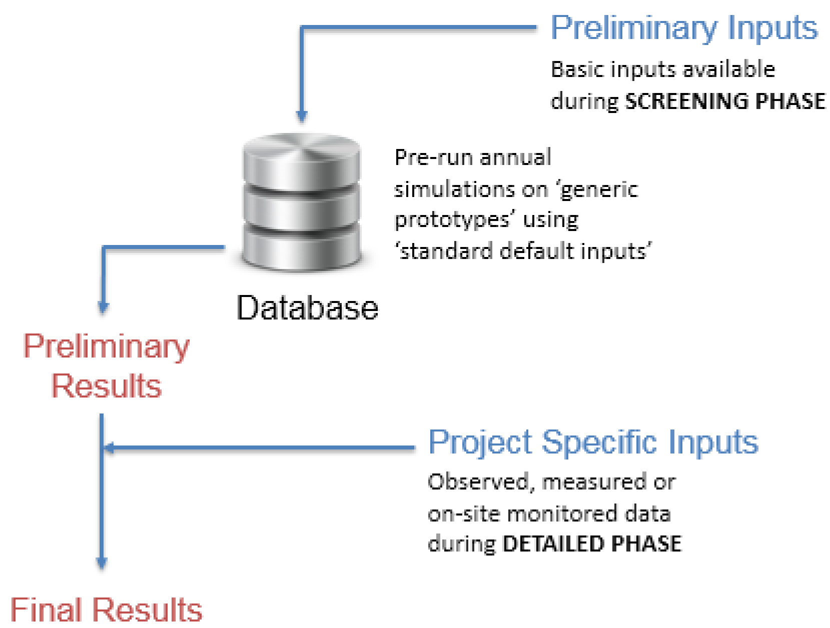


Figure 1: Schematic representation of the calculation methodology concept

This hybrid approach brings the advantages of detailed simulation-based calculation with the ability to improve the accuracy of results based on site-specific data. A key feature of this approach is that savings estimated for projects with little or no site-specific inputs, can be refined over time as site specific data becomes available. This potentially offers a method for program evaluators to verify savings estimates by independently verifying the site data used for tool inputs.

## ALCS Calculator Tool Description

The ALCS Calculator was designed to primarily make it easy for utility program participants to calculate energy and demand savings from advanced lighting controls in commercial buildings. However, its overall structure and modular layout was guided by the long-term vision described earlier. The tool was developed on the MS Excel™ platform, to provide flexibility in tool development and a familiar, easy to use user interface for its users.

At the time of publishing this paper, a beta version of the ALCS Calculator had been released to a limited number of funding utilities and stakeholders, with a full release of the tool expected in the near future.

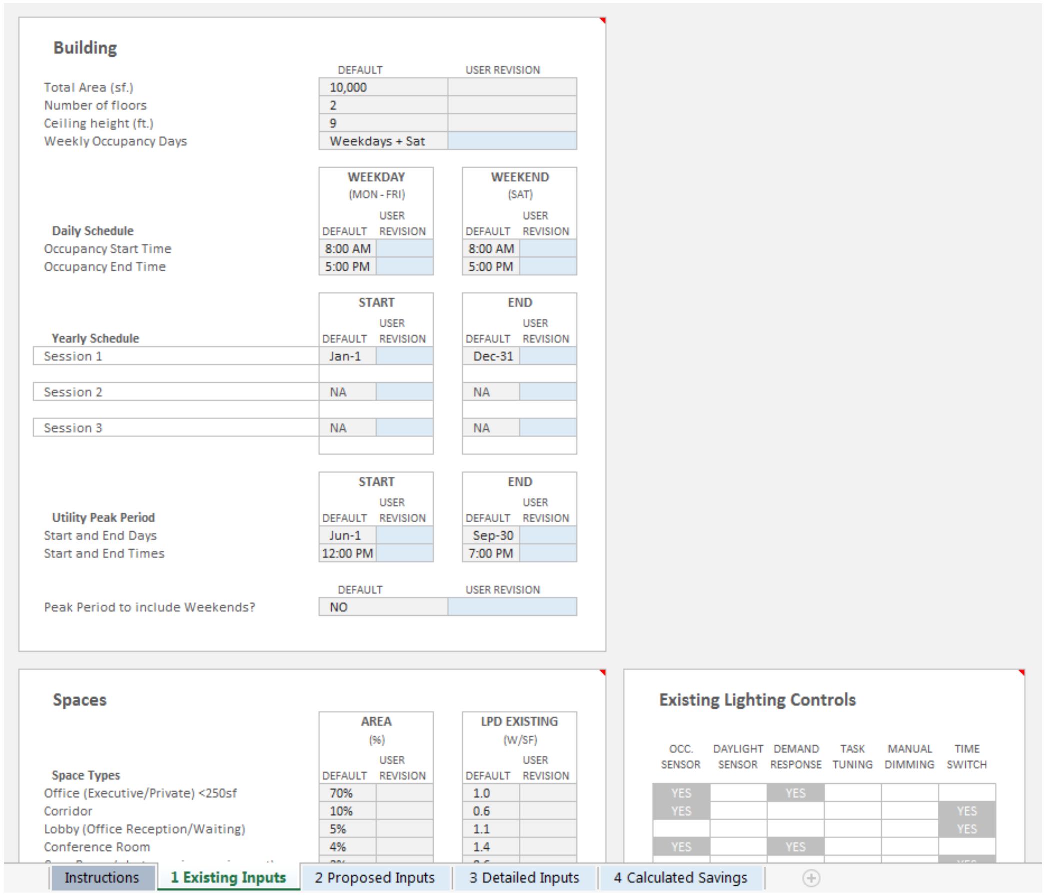


Figure 2: Screenshot of ALCS Calculator Tool

## Building and Space Prototypes

Typically, a project is a building, or a part of a building, with multiple space types within. The ALCS Calculator provides a set of building templates – 23 prototypes of commercial building types and their corresponding space types, based on the California DEER dataset (Itron 2005). A user may choose one of these templates to estimate 'screening-phase' results, when little information on the project is available, using default input values for all or most parameters. Then later, when available, the user can provide their own inputs to replace the defaults, for 'detailed-phase' results and greater accuracy.

The templates provide convenient and well-researched defaults for many of the inputs in the ALCS Calculator, such as a set of 164 unique 'lighting energy-use profiles' corresponding to the 23 typical commercial building types and their space types. These profiles provide users with a reliable baseline energy-use profile on which to base the lighting energy savings. This dataset is derived from historic data from energy measurement and verification (EM&V) studies from 1994 to 2005 (Itron 2005) and thus represents a rich average over multiple spaces and extended time periods. The user may use this default profile as the baseline for their project, or provide site-monitored data based profiles, if available, for greater accuracy.

### Screening-Phase and Detailed-Phase Estimates

Per requests from many stakeholders, the tool was designed to have capabilities of estimating energy and demand savings starting with the simplest first-pass analysis, to quickly screen a project for its suitability for lighting controls. Later, the same analysis may be modified with project-specific inputs for a more detailed calculation.

Based on this, the tool was developed to allow users to simply pick up a template of a commercial building prototype and use it for the 'screening-phase' with default values for all inputs. Every input in the tool clearly shows the values in two columns side-by-side. A 'Default' value, based on the DEER porotype and a 'User Defined' value, which if used, overrides the default value. As the user progressively changes Default inputs to User Defined ones across the tool, the calculation is automatically updated in real-time to refine the calculation results, moving from Screening-Phase results to Detailed-Phase results.

### Calculation Process

The fundamental approach to calculating savings from lighting controls and interaction between individual lighting control modes, is the use of hourly control factor (CF) profiles. These are 24-hour profiles that indicate the savings from a single lighting control type (or control 'mode'). The profiles represent values between zero (0.0) and one (1.0) for each hour in a typical 24-hour day for representative days of the year. A value of 1.0 means the control measure has no effect on the baseline energy of the lighting system for that hour, and 0.7 means that the control measure is saving 30% for that hour.

Control factors were developed in the ALCS Calculator for each lighting control mode, drawing on the best available research on each topic, at times using a novel combination of existing research from multiple prior studies. The innovative methods used in the development of control factors are at the heart of the calculation process, and are a subject of a separate technical publication (Saxena et al., 2016).

Control factors were developed for each of the following lighting control modes:

- Occupancy Sensors
- Daylight Sensors (Climate Dependent)
- Demand Response
- Task Tuning
- Manual Dimming
- Time Switch

A great advantage of developing control factors (CF) as hourly values that represent savings as fractions for each hour, is that these schedules can be simply multiplied as a matrix, with the baseline lighting energy use profile. This allows layering of multiple lighting control modes thus accounting for interactive effects between lighting control modes in the same space.

The diagram in Figure 3 provides a graphical representation of the calculation process showing layering of lighting control factors ($CF_1$ and $CF_2$) over a baseline hourly lighting energy power schedule (bLPS) to develop the modified lighting energy power schedule (mLPS). A space medication factor (SMF) is used in this calculation to customize the results based on user-defined inputs, unique to a particular space.

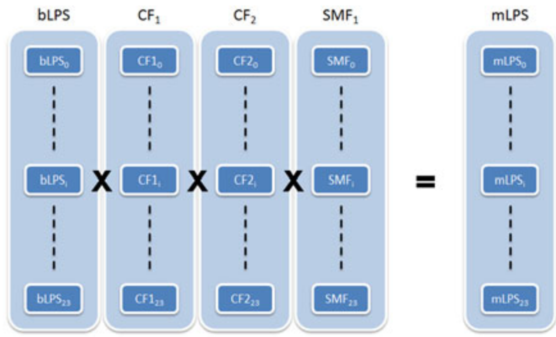


Figure 3: Schematic diagram of calculation process

### Baselines

As codes have become more stringent, and increasingly include lighting controls, the calculation of code-compliant baseline conditions have become increasingly complicated. Whereas lighting operating schedules used to be considered similar to yes/no 'block-shaped' occupancy schedules, now, with options for dimming, plus automatic occupancy controls and daylighting controls, full load equivalent (FLE) hours of operation are likely to present very different patterns than simple 'block-shade' occupancy patterns.

The ALCS calculator provides the unique ability to develop a Title 24 or ASHRAE 90.1/ IECC prescriptive code baseline for any project. The code baseline is a virtual version of the project, with prescriptive lighting power densities by space type, lighting controls that are triggered by code based on described baseline conditions. Since the code baseline is developed internally and automatically, users are not burdened with developing the code baseline. This eliminates the issues of code interpretation and confusion and potential "gaming" of the system by adjusting code baseline, which may otherwise escape administrative inspection by program officials.

## Strengths and Limitations of the ALCS Calculator

The ALCS Calculator has several key strengths that enable users to calculate savings more easily than before, and also limitations that a user needs to be aware of, to avoid using the results from the calculator in a manner inconsistent with the context of the information it provides.

### DEER as a Data Source

The Database for Energy Efficient Resources (DEER) is a compilation of resources to provide information on the energy savings opportunities of various energy efficiency measures, and is based on the results of various prior research studies sponsored by the California Energy Commission and the California Public Utilities Commission.

This database is the most comprehensive source of information on a variety of building factors, including building prototypes, percentages of primary space usage types within these buildings, and lighting use profiles by building type. These are all collected space/time average conditions for a building and hence represent the most defensible starting point for commercial building energy calculation.

The DEER prototypes are accessed from within the ALCS Calculator and can be used to predict a preliminary savings estimate for a building, with relatively little site auditing effort. However, these results – called ‘preliminary or screening results’ – should be considered as such, because the actual conditions of the building (operating hours and breakdown of room areas and types) could vary considerably from the starting assumptions.

The ALCS Calculator allows users to progressively add more detail, as they are provided from building audits, which replace the default inputs used in the screening analysis. This produces the ‘final or detailed results’, which are a more accurate representation of the savings for any specific project.

### Future Predictions Based on Past Performance

Buildings are dynamic systems and the operation of the building can be affected strongly by variables that the past performance of the building has no ability to accurately predict. Weather deviations will impact daylighting performance, but without an extremely detailed analysis of the collected audit information on the building, it isn’t possible to know if the weather that the building experienced during the audit’s logging periods was representative or not, and how that would impact the performance of the building.

Further, changes in the occupant use patterns are likely to occur continually in many building types, and this will add another source deviation in the data. Once again, it is difficult, if not impossible to know whether the occupancy patterns represent a reasonable use of the building and whether that use pattern will continue into the future.

Any calculation tool including the ALCS calculator, is essentially a predictive calculator and cannot account for the future variations in inputs, which are largely unknown or unknowable. This effect is likely to cause variations between predicted energy savings from the ALCS Calculator and any measured on-site energy performance. Such variation however, are expected to stay within acceptable norms of calculation-based approaches for estimating savings for utility programs.

### Daylighting Calculations

The tool makes it possible to predict the energy savings in a typical building associated with daylighting, and in combination with other lighting controls systems, by including an internal database of pre-calculated daylighting savings for a variety of different space conditions. This is a considerable undertaking because it is based on the geometry of the building, so some approximations were used to generalize the spaces for the sake of computational simplicity.

The tool is designed to produce a good prediction of the energy savings in a space while taking into account orientation, window size, window properties and the weather conditions of the building location. This is a particular strength that is currently unique in energy calculators of this type.

### Abstraction

The ALCS Calculator provides predicted energy savings without requiring a large amount of detailed information from the user. This level of abstraction is important to maintain an efficient evaluation process while still maintaining a reasonable level of calculation accuracy, within the context of the tool being a predictive calculator.

While it is possible that a much more detailed audit data can be input into this tool for research or validation purposes, for the purposes of a utility program or for general savings calculations on a lighting retrofit project, a higher level of abstraction for inputs is sufficient.

The user needs to be aware of and identify situations where their actual building conditions are deviating from the building use type averages supplied as default inputs in the tool so that efforts can be expended to collect site-specific details for those inputs. This will produce results that are likely to be more consistent with the actual building savings as a result of a lighting retrofit.

## Implications for Lighting Programs and Market

As noted in the 'Need for a Calculation Tool' section, most existing efforts to estimate and incentivize energy savings from ALCS relied on cumbersome and uncertain custom calculations, creating a barrier to widespread ALCS program implementation. The Excel™-based ALCS Calculator tool, on the other hand, provides a user-friendly, data-driven and project-specific approach to calculating energy savings from ALCS applications. As a result, the tool presents an opportunity to accelerate market adoption of ALCS by providing a standardized calculation methodology to reduce uncertainty in the market, and supporting utility energy efficiency programs to encourage ALCS installations.

### Standardized Calculation Methodology

The ALCS Calculator presents the opportunity for a consistent ALCS calculation methodology, reducing uncertainty and confusion in the market. The calculations in the tool are based on the best-available lighting controls research, combined with climate-specific daylighting simulations, providing rigorous and defensible results. In addition, by utilizing the DEER building prototype data, the tool can quickly provide energy savings estimates using limited project building characteristic data and occupancy schedule information.

By harnessing the results of an extensive survey of research studies on lighting control strategies, the ALCS calculator provides more reliable savings predictions than the many rough "rule-of-thumb" estimates that are often used in the lighting industry. The tool provides control-factor based calculations that ensures that savings from multi-modal controls are not double-counted or over-counted. The DEER building data built into the tool also provides consistent and reliable baseline models, based on data collected from a survey of multiple buildings. Data from the DEER prototypes allows for uniform baselines for easy comparisons across multiple projects, or even between programs. Rather than relying on an inconsistent patchwork of varied calculation methodologies, the ALCS calculator presents the opportunity for a reliable and consistent methodology, and easily comparable, consistent results across multiple programs.

### Support for Utility Energy Efficiency Programs

With an accessible and user-friendly Excel™ platform, the tool provides utility energy efficiency programs the opportunity to significantly reduce the time and effort required to calculate energy savings from ALCS installations, compared to customized program calculations. The Excel™ platform provides the ability for utilities and regulators to easily access and review the algorithms and calculations in embedded in the tool. In addition, the structure of the tool allows a relatively simple process for a desk review to confirm that project installations match program applications that use the tool. This opportunity greatly increases utility program's ability to scale up ALCS programs, and to capture and claim savings from these multi-modal control strategies, without sacrificing calculation details such as climate-specific daylighting models.

As codes and standards become more stringent, and require more and more lighting controls by default, the calculator tool provides utility programs a means to continue to claim and capture energy savings from multi-modal lighting controls. As noted above, in addition to an as-built or existing condition baseline, the tool provides a code baseline to identify how ALCS project savings exceed code requirements.

## Conclusion

The ALCS Calculator makes it possible to reliably estimate energy savings from ALCS applications in a manner that is easy to use and scalable, yet providing a level of detail that can differentiate between the performance of different control strategies. The calculator also produces savings against both an existing, and a code minimum baseline, which make results relevant across all market actors – from the utility programs to program participants, thus addressing a number of key market barriers for promotion of ALCS.

Besides streamlining the energy savings calculation process for programs, the tool also provides an unprecedented opportunity for market research. As utility programs across the country use the calculator to develop savings estimates for their applicants, they will be collecting data on various inputs in the tool. Over time, it should become possible to aggregate this data to perform useful analytics that can inform a variety of decision making. Data such as validated inputs on control settings, user-defined occupancy patterns, lighting energy use profiles existing lighting power densities, and more can be collected over time and across multiple use cases. They can then be analyzed to understand market trends over time as well as provide valuable insight into user behavior with lighting and lighting controls. While the ALCS Calculator currently does not provide a central capability to save multiple datasets from projects, programs can be designed to support such data collection and analysis. Further, these new datasets can also represent better research basis for the tool's calculation engine, which can be improved over time, making calculations more reliable.

The ALCS calculator has been designed keeping in mind that the tool will be improved incrementally, as better data becomes available, and as lighting and lighting controls technologies evolve and energy codes change. These incremental improvements will ensure that the calculator tool remains relevant and increasingly more useful in its role to help transform the commercial lighting controls market.

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