CALCULATION METHODOLOGY FOR THE ADVANCED LIGHTING CONTROL SYSTEMS (ALCS) ENERGY SAVINGS CALCULATOR TOOL

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ABSTRACT

With recent developments in solid state lighting driving much of the current interest in lighting upgrades in existing building, utility programs and codes are beginning to promote advanced lighting controls along with lighting upgrades to ensure that the energy benefit from the investment is maximized. To promote advanced lighting controls in utility programs, a new ‘Advanced Lighting Controls Systems’ (ALCS) energy savings calculator tool has been developed, with funding from Pacific Gas & Electric (PG&E), and DesignLights Consortium (DLC). This Excel™ based calculator allows users easy access to customized calculation of energy savings from lighting controls for their projects, thus removing a key barrier in promotion of lighting controls technology.

For the development of the ALCS Calculator, a new savings calculation methodology was developed that uses the concept of hourly energy use profiles for typical days of a year, and savings control factors. Using this methodology, annual energy and demand savings can be calculated for any commercial building project with different lighting control types, or ‘modes’. The calculation approach accounts for interaction between various lighting control modes applied in a single space.

This paper provides a technical overview of the calculation methodology developed for the ALCS Calculator Tool and discusses key concepts of the tool’s new calculation approach.

INTRODUCTION

The Advanced Lighting Control Systems energy savings calculator tool (hereafter called the ALCS Calculator) is an Excel™ based energy calculation tool designed to make it easy for utility program participants to calculate energy savings from advanced, or multi-modal lighting controls in commercial building projects. The tool also provides a consistent calculation approach based on extensive and accepted research, so that savings can be calculated with confidence and applied consistently across multiple utility programs and the lighting market in general.

CALCULATION METHODOLOGY

One of the goals of developing the ALCS Calculator was to produce a research-based, universal calculation methodology, for use across multiple utility programs and the lighting controls market. Existing custom-calculation methods, used by lighting controls manufacturers, utility programs and other lighting market service vendors, were reviewed and evaluated for their thoroughness and research-basis before developing the final calculation methodology described in this section.

Baseline Lighting Energy Use

To estimate savings from lighting controls applied to any building or space, it is important to start with a realistic assumption of what the baseline lighting energy use is like in that space, before controls are added. This lighting energy use is represented in the ALCS Calculator as 24-hour profiles (Figure 1) for four typical day types:

- Weekday
- Weekend – Saturday
- Weekend – Sunday
- Holiday

![Figure 1: Example of a lighting energy use profile for an office space](image)
These ‘lighting energy-use profiles’ are values between zero (0.0) and one (1.0) representing lighting power consumption for each hour, averaged over time and multiple spaces.

The ALCS Calculator provides a set of 164 unique ‘lighting energy-use profiles’ corresponding to 23 typical commercial building types and their space types, based on the California DEER dataset (Itron 2005). 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.

**Control Factors**

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 of the following lighting control modes:

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

The Daylighting Sensors CF’s are climate dependent and were based on Radiance (Ward 1994) based daylighting simulations, while the rest were calculated using methods based on previously published research studies. The development of control factors for each control mode is described further in a following section.

**Interaction Effects**

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 2 provides a graphical representation of the calculation process showing layering of lighting control factors (CF) over a baseline hourly lighting energy power schedule (bLPS).

**Figure 2: Schematic diagram of calculation process**

Here:

- bLPS is the 24-hour profile of the baseline lighting energy use of the space (from DEER). Each hour for a 24-hour period for a given day, is represented by the subscript “i” going from 0-23.
- CF1 and CF2 represent control factors for two control modes (e.g. daylighting controls and occupancy sensor) layered together in the same space. More control factors can be introduced for spaces with more control modes, as needed.
- SMF is a space modification factor, which is comprised of values between 0 and 1, used to customize the calculation based on user-defined inputs, unique to a particular space. For example to adjust the CF for daylighting due to higher or lower window visible light transmittance, compared to the reference space in the Radiance simulations.
- mLPS is the resulting modified lighting power schedule, a combination of base lighting usage, controls and adjustments based on site-specific inputs.

**Savings Calculation**

As an example let us consider an office space, where two ‘modes’ of lighting controls, daylighting sensors and task tuning are applied. To calculate the energy savings, the ALCS calculator first provides the user with the most appropriate baseline lighting energy use profile from the DEER dataset, shown in Figure 1. If not overridden by the user, this is used as the baseline lighting power schedule (bLPS).

Next the calculator applies two control factor profiles – one for daylighting and another for task tuning. These control factors are calculated based on inputs by the user on various control settings. For task tuning, the user indicates % power reduction, while for daylighting the user provides details of control type such as On/Off or Dimming, and levels or control steps; as well as number of daylighting control zones. Based on these
inputs, control factor profiles CF1 and CF2 are developed shown in Figure 3. Since daylighting is time dependent, the control factor values are lowest in the middle of the day, when the most savings are expected, compared to the morning or evening, and 1.0 at night when the controls do not provide savings. Task tuning is not dependent on time of day, and is hence a constant value across all hours of the day. A combined control factor profile (CF1 x CF2) is shown in green in Figure 3.

The combined control factor profile is finally applied to the base lighting power schedule (bLPS) to develop the modified lighting power schedule (mLPS) as shown in Figure 4. This calculation is done for a number of typical days of a year and then finally combined to calculate annual energy and demand savings.

CONTROL FACTORS DEVELOPMENT

Control factors were developed for each control mode using various methods, based on either previously published research studies, or hourly simulations. These methods and assumptions are described in this section.

Occupancy Controls

Control factors for occupancy sensors were developed, based on a novel combination of existing research from multiple prior studies.

The LBNL study on ‘Lighting Controls in Commercial Buildings’ (Williams et al. 2012) aggregated data on lighting control savings from previous field-studies and reported average % savings by control type and building type. Among other control types, the study
provided savings data for occupancy sensors for seven commercial building types (Figure 5). The data sample (n) referenced for this information consisted of 38 field-studies. While this is the largest study of its kind, the limited number of field-studies referenced (n = 38) meant that further filters could not be applied to the data sample to obtain savings by different control settings such as delay times, sensors type, etc. Instead, typical delay times from the data sample for each building type were noted (Figure 5).

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Occupancy Control Savings</th>
<th>Typical Delay Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>22% (n=23)</td>
<td>15 min</td>
</tr>
<tr>
<td>Warehouse</td>
<td>31% (n=4)</td>
<td>5 min</td>
</tr>
<tr>
<td>Lodging</td>
<td>45% (n=2)</td>
<td>5 min</td>
</tr>
<tr>
<td>Education</td>
<td>18% (n=5)</td>
<td>10 min</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>36% (n=2)</td>
<td>15 min</td>
</tr>
<tr>
<td>Healthcare outpatient</td>
<td>23% (n=1)</td>
<td>15 min</td>
</tr>
<tr>
<td>Other</td>
<td>7% (n=1)</td>
<td>30 min</td>
</tr>
</tbody>
</table>

Figure 5: Average savings by control type and building type (final filter), from LBNL Study (Williams et al. 2012)

To further breakdown the savings by different delay times, a separate study on ‘Statistical Modeling of Occupancy Patterns’ (Chang and Hong 2013) was referenced. The study provides a mathematical model of occupancy patterns from field data captured by lighting-switch data in five-minute intervals for 200 open-plan (cubicle) offices. The authors first identify five typical occupancy patterns that each represent occupancy in an average daily 24-hour day, and then develop probability distributions functions (PDF) and cumulative distribution functions (CDF) for each pattern (Figure 6) indicating the probability for:

- Number of daily absence events
- Absence durations

Using these probability functions, multipliers for different delay times (from a reference delay time value) were developed. These multipliers could then be applied to the data from the LBNL study (Figure 5), to estimate savings from occupancy sensors at various delay times.

To develop delay-time savings multipliers, first ‘Full Load Equivalent Hours’ (FLE Hours) per day that lights are “off” due to occupancy sensors were calculated for each of the five occupancy patterns (p1 – p5) and various delay times (a = 0 – 45 min), using the formula below. The term ‘full load equivalent’ describes the summation of all ‘partial’ and ‘full’ hours that the lights are off in a day.

\[
\text{FLE Hours } p_1 \text{ Delay Time } a = \sum_{i=0}^{165} \left( \frac{|i - \text{Delay Time}_a| + (i - \text{Delay Time}_a)}{2} \right) \times \text{PDF } p_1_i \times \sum_{n=0}^{14} (n \times \text{PDF } p_1_n)/60
\]

Here:

- FLE Hours \( p_1 \text{ Delay Time } a \): The total hours that the lights are off in a day for occupancy pattern 1
- Delay Time \( a \): The delay time setting on the occupancy sensor
- \( i \): Value from 0 to 165 of absence duration in minutes
- PDF \( p_1 \): The probability distribution function for Absence Duration \( i \), for occupancy pattern 1 (Figure 6)


\[
\text{Multiplier} = \frac{(\text{Hrs}_{\text{Req Delay Time}} - \text{Hrs}_{\text{Ref Delay Time}})}{\text{Hrs}_{\text{Ref Delay Time}}}
\]

Here:

- \text{Ref Delay Time: The delay time for which occupancy sensor savings are known}
- \text{Req Delay Time: The delay time for which occupancy sensor savings are required}

To calculate occupancy sensor savings, when savings from a reference delay time are given, the following formula was used.

\[
\text{Occ Sensor Savings}_{\text{Req Delay Time}} = \left( \text{Occ Sensor Savings}_{\text{Ref Delay Time}} \times (1 + \text{Multiplier}) \right)
\]

Multipliers developed using this method are provided in Figure 7. These multipliers were then used with the data from the LBNL study (Figure 5) to develop the occupancy sensor control factors. Occupancy sensor control factors were assumed to be non-time dependent, i.e. having the same value across all hours of the CF profile.

Note that occupancy sensor savings are further distinguished in the ALCS Calculator by type of sensor, namely auto on/off combined with partial on/off or manual on. The research basis for which will be the subject of a separate publication in the future.

**Daylighting Controls**

![Daylighting Controls](image)

\[\text{Figure 8: Examples of two sidelit template spaces for office spaces (Saxena 2011)}\]

A calculation based approach was adopted to develop daylighting control factors using Radiance 3-phase method simulation (Saxena et al. 2010, McNeil and Lee 2012). However, instead of running Radiance simulations for every project, which would be computationally expensive and time-consuming, the ALCS Calculator references a set of pre-simulated results developed using a set of 1,836 ‘template spaces’. These template spaces were carefully designed to represent most common conditions in commercial space types (Figure 8). The large number of templates made it possible to match-up most commercial spaces in a project to a template space and provide a close approximation for daylight availability without having to run a Radiance simulation for each space.

To represent generic commercial space types, the 3-dimensional models of ‘template spaces’ were developed based on the CEC PIER Study on ‘Office Daylighting Potential’ (Saxena 2011). These templates (1,728 sidelit and 108 toplit) were designed to capture...
variations in physical characteristics that impact daylight availability such as, space area, window / skylight area, visible transmittance, window orientation, ceiling height, furniture height etc. using the method developed in the CEC PIER Study.

Demand Response
Demand Response (DR) controls typically dim or switch-off lights in response to a signal during a utility DR event. These events occur during utility peak periods, when a utility is experiencing unusually high electric load on the grid, and can range in occurrence frequency.

To develop daylighting control factors, hourly daylight illuminance data from the Radiance simulations was first used to determine required electric lighting contribution as light level fraction for each hour, for typical days of a year. This takes into account the number of switching steps or dimming settings specified by the user. The light level fraction is then converted to power level fraction based on the light to power relation of each lighting technology to develop the final daylighting control factor profile. Since daylighting is time-dependent, the control factor values differ by time of day, corresponding to the results from Radiance simulations (Figure 9).

Daylighting control factors are calculated separately for primary daylit zone (PDZ) and secondary daylit zones (SDZ), and finally combined proportionally in each space to determine the total lighting energy savings.

Figure 9: Application of Daylighting Control Factor over a baseline lighting schedule

Based on user-provided information about ‘Controlled Wattage’ (the percent of total installed lighting wattage in the space that is connected to the DR controller), ‘Event Power Reduction’ (how much power is reduced for the controlled lighting, during a DR event), and number of expected DR events in a year, the total DR Power Reduction is calculated as:

\[
DR\ Power\ Reduction = \frac{\text{Controlled Wattage}}{\text{Event Power Reduction}}
\]

The DR control factor profile is developed with the calculated ‘DR Power Reduction’ applied during ‘utility peak’ hours to represent power reduction during a DR event. Further, the control factor profile is applied
to a specific number of days in a year, based on what the user input on the expected number of DR events in a year.

**Task Tuning**

Task tuning is a means to reduce lighting energy use by dimming (or “tuning”) the electric lighting such that the lights only produce the required setpoint illuminance, typically set during installation. A tuned luminaire’s maximum power consumption is determined by the task tune level or setting, which is specified in the ALCS Calculator by the user.

**Manual Dimming**

Manual dimming is a strategy that provides users more control over their lighting and visual environment. Research on savings resulting from providing occupants with an option to dim their electric lights manually is very limited. Savings vary highly based on specific use conditions, and hence a simple average across individual studies does not provide a meaningful answer. Studies such as the LBNL study on “Lighting Controls in Commercial Buildings” (Williams et al. 2012) aggregated data from previous studies for Manual Dimming (called Personal Tuning in the study) and reported averages for two building types: Educational 6%, and Office 35%. However individual data points within these averages vary significantly.

To develop control factors for manual dimming, lighting power reduction is assumed to be even across all operating hour, and power reduction is based directly on user inputs on expected savings, instead of the limited previous research on this subject. Further research is needed to allow tools such as the ALCS Calculator to develop control factors for manual dimming that are both time dependent and based on research data.

**Time Switch**

Time Switch, sometimes also referred to as “Scheduling”, is used to program scheduled shut-off times. These are typically programmed to turn lights off after scheduled operating hours to save energy from lights that may be left on by occupants. Override switches are provided to allow occupants to turn lights on during shut off periods.

While individual studies provide savings from scheduling or time switches, in our literature review we did not find any study that provided generalized savings from time switches. This is perhaps because savings are completely dependent on operation schedule, and time switch settings, which vary by individual application.

To develop time switch control factors, lights are assumed to turn ON an hour before the first user-defined scheduled operation hour, and OFF an hour after the last user-defined scheduled operation hour. The control factor acts as a “mask” with values of 0.0 when lights are scheduled to be off, and 1.0 when they are scheduled to be on.

To estimate energy use due to an override switch, two assumptions are made:

1. That the override switch is engaged once every weekday.
2. That the override switch is engaged right after the last hour of occupancy.

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*Figure 11: Application of Task Tuning control factor over a baseline lighting schedule*

The task tuning control factor profile is developed as an even reduction in power across all operation hours. The power reduction is determined by the task tuning setting specified by the user. For example a 20% tuned luminaire will have a maximum power consumption of 80% of its rated power.

**Task Tuning Power Reduction**

\[
\text{Task Tuning Power Reduction} = 1 - \% \text{Task Tuning Setting}
\]
Further research is also needed on factors influencing occupant manual switching and dimming behavior to develop a basis for savings from manual dimming.

The ALCS Calculator uses the DEER dataset of 23 commercial building and its 164 baseline lighting energy profiles to 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 that date back to 1994 CCID study profiles, and updated in 2005 (Itron 2005). Updates to the DEER dataset with more recent EM&V data will provide a more accurate lighting baseline for savings calculation.

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REFERENCES


