Energy Trust of Oregon C&I Lighting Controls Savings and Persistence Study (Draft Final)

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DRAFT REPORT

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APPENDICES

1. EXECUTIVE SUMMARY

Lighting control technologies have been a significant contributor to lighting savings for Energy Trust of Oregon's Production Efficiency (PE), New Buildings (NB) and Existing Buildings (EB) programs.[1] However, much of Energy Trust's information on lighting control savings is becoming increasingly out-of-date. This is especially true when considering the changes and improvements in sensor, communications, and control technology, as well as the significant shift in lighting technologies. Energy Trust commissioned this study to determine the actual savings and persistence of savings associated with the dominant lighting control technologies and their associated applications.

Table 1-1. Summary of Research Objectives and Key Findings

Research Objective	Key Research Finding
1. Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years (2010-2014) and in the future.	Occupancy sensors are the dominant control technology incented by Energy Trust, representing nearly 87% of all control measures. Trends indicate that the relative proportions of fixture-mounted occupancy sensors and custom occupancy sensors have been increasing over time, while the total number of lighting control projects have been declining since 2010.
2. Understand the proportion of C&I lighting savings attributed to lighting efficiency vs lighting controls.	Lighting measures represent 81% of total savings from lighting and lighting control projects.
3. Identify the space types that are associated with specific lighting control technologies/strategies.	Common space types for lighting controls include offices, retail areas, warehouses and industrial areas.
4. Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.	Of program-incentivized controls (program controls) in 2010, 98% are still operational. Overall, of 2010, 2013, and 2014 program-installed controls, 99% are still operational. As shown in Figure 1-1, the majority of program controls that were not operational were not installed (58%) or missing (20%).
5. Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.	36% of lighting-only projects included at least one non-program incentivized control (non-program control), including fixture-mounted controls.[2] A larger percentage of daylighting controls and time clocks were found on projects with controls not incentivized by Energy Trust. A majority (60%) of these controls were installed due to Oregon code or due to an existing energy management system.
6. Estimate the savings from the dominant lighting control technologies/strategies.	The overall calculated reduction factor is 0.38.[3]

EMI Consulting and Michaels Energy established several research objectives for this study. Table 1-1 provides a summary of research objectives and key findings. Overall, the research team found lighting

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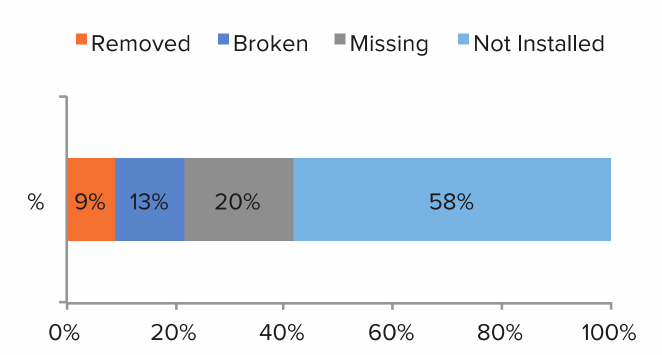
[1] New multifamily fits into the New Building program and existing multifamily fits into the Existing Buildings program.
[2] Energy Trust incentivizes lighting and lighting controls. Some projects only incentivized lighting ("lighting-only"), while others incentivized lighting and controls ("lighting and controls"). However, 36% of lighting-only projects included controls that were not incentivized by Energy Trust.
[3] To estimate savings from lighting controls, a reduction factor was calculated. A reduction factor is the percentage reduction in lighting usage from the installation of lighting controls.

controls to have a reduction factor of 0.38, a notable increase from the existing assumption of 0.25[4] used by Energy Trust when estimating savings.[5] This finding suggests that the actual performance of lighting controls exceeds program expectations. In addition, 99% of program lighting controls installed since 2010 were operational, indicating a high persistence rate for program controls. As shown in Figure 1-1, of the 2% that were no longer operational, the majority of program controls that were not operational were not installed (58%) or missing (20%).

Figure 1-1. Summary of Non-Operational Program Lighting Controls



Overview of Methodology

In order to complete the objectives established for this study, the research team followed a two-part approach to characterize program lighting controls and trends.

First, the research team conducted a comprehensive analysis of data from FastTrack, Energy Trust's project tracking database, and documentation for all C&I lighting and lighting control projects. The database and file review addressed three research objectives:

- **Objective 1**: Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years and in the future.
- **Objective 2**: Understand the proportion of C&I lighting savings attributed to lighting efficiency vs lighting controls.
- **Objective 3**: Identify the space types that are associated with specific lighting control technologies/strategies.

The research team reviewed FastTrack data for information regarding the types of lighting and lighting control projects completed over the past five years. This included finding detailed information about energy savings, measures installed, date of installation, and building or facility type. We also reviewed these data fields for completeness, granularity, and historical trends.

Second, the research team conducted on-site evaluations at 162 sites in order to address the following objectives:

- **Objective 4**: Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.

[4] Although Energy Trust uses a default reduction factor of 0.25, alternative values are often used when adequate information is available. Section 4.6 shows Energy Trust's reduction factor distribution for a sample of projects.
[5] This reduction factor was one of ten scenarios explored by EMI Consulting and Energy Trust. Of the ten scenarios, the reduction factor ranged from 0.24 to 0.39. A full explanation of the methodology can be found in Section 3.3.

- **Objective 5:** Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.
- **Objective 6:** Estimate the savings from the dominant lighting control technologies/strategies.

Sample targets were established in order to understand lighting control characteristics across a range of variables, including project size, type, and age. A summary of the on-site sample design is provided in Table 1-2. In addition to gathering data through on-site observations and participant interviews, lighting loggers were also installed in order to determine annual hours of use for lighting-only projects and lighting control projects. Data from metering are used to inform reductions in lighting hours of use due to the installed controls.

Table 1-2. Summary of Sample Targets for On-Site Metering

Year	Size*	Type	Target Number of Projects	Target Confidence and Precision	Completed Number of Projects
2010	Small	Lighting controls	20	80/22	21
	Small	Lighting-only	20	80/22	18
	Large	Lighting controls	10	80/31	10
	Large	Lighting-only	10	80/31	7
2013-2014	Small	Lighting controls	40	80/16	42
	Small	Lighting-only	20	80/22	21
	Large	Lighting controls	30	80/18	33
	Large	Lighting-only	10	80/31	10
		Total	160	80/15	162

*Small projects are those with annual savings of less than 100,000 kWh. Our team selected 100,000kWh as a clean threshold to distinguish between the majority of projects, and a smaller number of large projects that represent the majority of savings.

Conclusions and Recommendations

A key finding from this study indicates that lighting controls exhibit a greater reduction in lighting hours of use than the default assumptions used by Energy Trust. This and other findings from the study serve as a basis for updating existing assumptions to more closely align with the actual performance of lighting controls deployed.

Furthermore, the analysis of trends and characterization of lighting controls provides Energy Trust with the insights needed to inform future program efforts. For example, results show that the use of lighting controls have been increasing over time in lighting-only projects. This may indicate a shift in the lighting market.

Finally, results by program, building type, and space type may inform efforts to target specific sectors that have greater opportunities for energy savings. For example, targeting sites with very high lighting hours of use may result in deeper energy savings.

EMI Consulting provides several specific recommendations for Energy Trust regarding updates to the reduction factor, quantification of lighting controls measure life, and suggestions for improvement in the program tracking data. These recommendations, outlined below, are based upon analysis results and observations made when conducting this study.

- **Increase default lighting controls reduction factor**. EMI Consulting found the actual reduction factor of program lighting controls to be 0.38, with an uncertainty range of 0.33 – 0.44. The default reduction factor used by Energy Trust is 0.25.[6] While a majority (55%) of projects utilize this default reduction factor, higher reduction factors were also applied when appropriate. EMI Consulting's review of a sample of 276 projects indicated that the average reduction factor used by Energy Trust is 0.35, which is lower than the observed reduction factor of 0.38. As such, EMI Consulting recommends that programs increase reduction factors by 8.5% going forward, reflecting the average observed reduction factor of 0.38 compared to the average program reduction factor of 0.35.
- **Record hours of use by space rather than by project.** The research team found that recorded hours of use generally did not vary by space type within each project's documentation. Metered data show that hours of use vary by space type within each project. EMI Consulting recommends that the reduction factor be calculated using operating or occupancy hours that are recorded on the space-level rather than project-level. This added granularity may also reduce the large variability in program reduction factor accuracy observed.
- **Increase consistency between program tracking data and project documentation.** EMI Consulting observed inconsistencies between program tracking data and project documentation for individual sites. Inconsistencies include: number of lighting measures reported, number of controls reported, and project identification numbers. EMI Consulting recommends that Energy Trust ensures that all data in project documentation is consistent with the program tracking database and that matching identifiers are used for measures in both datasets. Furthermore, implementing a standard template for project documentation will facilitate future evaluation efforts. Current documentation may include paper documents, scanned documents, and spreadsheet-based reports of varying formats and templates.
- **Observe lighting controls measure life for older projects.** EMI Consulting observed that a very large percentage of controls from 2010 (98%) were still operational in 2015, indicating that Energy Trust's current measure life of 15 years for industrial lighting controls and 21 years for commercial lighting controls are well within reason. Given that this study is exploring persistence after only five years, EMI Consulting recommends that Energy Trust revisit this question periodically in the future.

[6] This assumption was informed by a 2012 study by LBNL: "Lighting Controls in Commercial Buildings." (2012). Williams, Alison A., Barbara A. Atkinson, Karina Garbesi, Erik Page, and Francis M. Rubinstein. The Journal of the Illuminating Engineering Society of North America. http://eetd.lbl.gov/sites/all/files/lighting_controls_in_commercial_buildings.pdf

2. INTRODUCTION

Lighting control technologies have been a successful part of Energy Trust of Oregon's strategy and have been a significant contributor to lighting savings for many years. As part of an effort to ensure energy savings assumptions are accurate and up-to-date, Energy Trust commissioned this study to determine the actual performance and persistence of lighting control technologies deployed through C&I programs. Energy Trust worked with the research team at EMI Consulting and Michaels Energy to establish research objectives, collect and analyze data from participant sites, and develop these findings.

Current lighting control savings estimates are generally calculated by assuming that lighting controls reduce the number of hours that lights are on. A key metric to describe the reduction in hours of use is the reduction factor, which is described in more detail in Section 3.3. Energy Trust uses a default reduction factor of 0.25 for most lighting controls measures (meaning lighting hours of use are reduced by 25%).[7] Alternative reduction factors may also be used, depending on the details of a given project. A figure showing the distribution of reduction factors used in evaluated projects is shown later in this report (see Figure 4-9). A key objective of this study is to inform Energy Trust of actual reduction factors based on observations and measurements from lighting controls currently deployed at participant sites. As part of this research, Energy Trust also sought to gain a thorough understanding of lighting control characteristics, including but not limited to factors such as persistence of savings, technology trends over time and the use of non-program controls.

EMI Consulting established several objectives for this research, all aimed at providing Energy Trust with a better understanding of the lighting controls market and the potential to assist Energy Trust in meeting its goals. As listed in Table 2-1, the research team achieved these objectives by completing a project database and documentation review, and through on-site research with program participants at 162 sites. Table 2-1 summarizes the data sources and analysis methods that informed each research objective.

[7] This assumption was informed by a 2012 study by LBNL: "Lighting Controls in Commercial Buildings." (2012). Williams, Alison A., Barbara A. Atkinson, Karina Garbesi, Erik Page, and Francis M. Rubinstein. The Journal of the Illuminating Engineering Society of North America. http://eetd.lbl.gov/sites/all/files/lighting_controls_in_commercial_buildings.pdf

Table 2-1. Overall Approach by Objective

	Research Objective	Data Source	Analysis
1	Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years and in the future.	Project Database Review	Summarized C&I lighting control technologies and strategies in program data and those visited as part of the metering study, looking at trends over time by program and building type.
2	Understand the proportion of C&I lighting savings attributed to lighting efficiency vs lighting controls.	Project Database Review	Calculated savings from C&I lighting projects as well as lighting control projects to understand the percentage of total savings that are attributable to lighting efficiency.
3	Identify the space types that are associated with specific lighting control technologies/strategies.	Project Database Review On-Site Inspection	Summarized C&I lighting control technologies and strategies in program data and those visited as part of the metering study, looking at trends over by space type.
4	Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.	On-Site Inspection Site Personnel Interviews	Described common themes and trends observed in the field regarding the persistence of lighting controls, such as: • Missing controls • Broken controls • Incorrectly installed controls • Controls not working as expected
5	Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.	On-Site Inspection Site Personnel Interviews	Summarized what lighting control technologies and strategies are being used in lighting projects that do not receive incentives for controls. This information was obtained through observation during field visits.
6	Estimate the savings from the dominant lighting control technologies/strategies.	Data Logging Site Personnel Interviews	Calculated a reduction factor from the hours of use and reported hours for the following groupings (and provided estimates of uncertainty): • Lighting-only projects and projects with controls* • Project year and size • Program • Control technology type • Space type

* Projects were categorized as “lighting-only” if there were no lighting control measures in the program tracking database. However, there were some lighting controls found in these projects during the on-site visits.

3. METHODOLOGY

The following section describes the methodology we followed for conducting the C&I Lighting Control Savings and Persistence Study. The research team collected data from Energy Trust's project database and conducted on-site research that included inspections, interviews, and data logging. These methods are described in more detail below.

3.1 Project Database Review

The first portion of the C&I Lighting Control Savings and Persistence Study involved examining data from FastTrack, Energy Trust's project tracking database, and documentation for all C&I lighting and lighting control projects. The database and file review addressed three of the six research objectives:

- **Objective 1**: Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years and in the future.
- **Objective 2**: Understand the proportion of C&I lighting savings attributed to lighting efficiency compared with lighting controls.
- **Objective 3**: Identify the space types that are associated with specific lighting control technologies/strategies.

The research team reviewed data from FastTrack regarding the types of lighting and lighting control projects completed over the past five years. This included detailed information about energy savings, measures installed, date of installation, and building or facility type (in the form of NAICS codes or facility descriptor). We also reviewed these data fields for completeness, granularity, and historical trends.

In addition, the research team examined multiple project files and lighting tools.[8] These files contained information on the reduction factor used for each control measure. We used these reduction factors to compare the current program practices to the on-site data logging results. Our team also extracted contact information from these files for recruiting purposes.

3.2 On-Site Research

Using results from our review of data from FastTrack and other project documentation, the research team worked with Energy Trust to develop sample targets for on-site data collection. On-site data collection efforts helped inform four of the six research objectives:

- **Objective 3:** Identify the space types that are associated with specific lighting control technologies/strategies. Objective 3 is informed by both the database review as well as on-site data collection.
- **Objective 4**: Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.
- **Objective 5:** Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.

[8] Lighting tools are worksheets used by Energy Trust to estimate energy savings for lighting and lighting control measures.

- **Objective 6:** Estimate the savings from the dominant lighting control technologies/strategies.

Sample Design and Recruitment

Below, we outline the sample development and recruitment process we used for the study. It includes detailed information regarding the sample frame, sample stratification, and target number of completed on-site visits. In addition, we present our assumptions in terms of coefficients of variation and the impact those coefficients have on the confidence and precision of our estimates.

Sample Frame and Stratification

The sample for site visits was designed in order to achieve multiple objectives. A primary objective of this study is to determine the overall hours-of-use reduction factor. In order to meter and understand the performance of installed lighting controls, EMI Consulting and Energy Trust chose a quasi-experimental design with a comparison and treatment group approach. This approach involves comparing the lighting hours-of-use between a comparison group (measures with no lighting controls installed) and a treatment group (measures with operating lighting controls) in order to determine the effect of the controls. Details regarding this comparison and calculation of the reduction factor are provided in Section 3.3.

Previous research indicates there is significant variation in lighting hours-of-use across the C&I sector. The research team recently completed a similar study of lighting controls in Michigan and found coefficients of variation between 0.7 and 0.8.[9] Based on this, the research team targeted an overall 80/15 confidence and precision level for all program lighting controls. To achieve this confidence/prevision level, the research team targeted 160 site visits as shown in Table 3-1 below.

In addition to being stratified by lighting and controls, the sample is also stratified by project size and year in order to inform additional objectives. Older projects (completed in 2010), are included in the sample to investigate the persistence of lighting controls over time. Newer projects (completed in 2013 and 2014) are included to understand current lighting controls issues and trends. Note that within each strata, samples were selected randomly.

During the sample design phase of the study, the research team reviewed a small sample (n=13) of building control project files to determine whether or not building control projects should be represented in the sample. All of the building control project files were associated with the Existing Buildings program. The research team observed no lighting controls in the sample of building control project files (controls such as anti-sweat heater controls and other HVAC controls were observed). As such, no building controls projects were included in the final sample design for this study.

[9] Michigan Statewide Commercial and Industrial Lighting Hours-of Use Study. EMI Consulting. July 6, 2014. Available online at: http://www.michigan.gov/documents/mpsc/ci_memd_com_lighting_hou_studydraftrpt_458981_7.pdf.

Table 3-1. Number of Target and Completed On-Site Visits by Sample Strata

Year	Size*	Type	Target Number of Projects	Target Confidence and Precision	Actual Number of Completed Site Visits
2010	Small	Lighting controls	20	80/22	21
	Small	Lighting-only	20	80/22	18
	Large	Lighting controls	10	80/31	10
	Large	Lighting-only	10	80/31	7
2013-14	Small	Lighting controls	40	80/16	42
	Small	Lighting-only	20	80/22	21
	Large	Lighting controls	30	80/18	33
	Large	Lighting-only	10	80/31	10
		Total	160	80/15	162

* Small projects are those with annual savings of less than 100,000 kWh. Our team selected 100,000kWh as a clean threshold to distinguish between the majority of projects, and a smaller number of large projects that represent the majority of savings.

There were a number of projects that were excluded from the sample during the sample development and recruitment processes. To achieve the target of 160 projects, a total of 598 project files were requested. While many projects were removed during the recruitment process due to unavailability or lack of interest, others were excluded for a variety of other reasons, as shown in Table 3-2.[10]

[10] The projects that were excluded from on-site research are still included in the project database review.

Table 3-2. Status of Project Files Requested and Removed

Action	Reason for Removing Project	Number of Projects
Total Project Files Requested		**598**
Removed by Energy Trust	Instant savings measure project*	(57)
	Project at a site currently participating in another evaluation**	(46)
Project Files Received		**495**
Removed during recruitment	Invalid measure (e.g., exterior)	(78)
	Site closed or relocated	(14)
	Invalid contact information	(7)
	Other	(11)
Not Recruited – Refused or No Response		(204)
Not Attempted – Backup Projects		(19)
Total Recruited		**162**

*As part of Energy Trust's Multifamily program, efficient lighting is installed in multifamily facilities at no cost to the facility. These projects typically involve installation of lighting in tenant spaces. If a project was flagged as an instant savings measure, then it was excluded from this study.

**At the time of this evaluation project, a number of other evaluation efforts were taking place. To limit customer fatigue with evaluations, Energy Trust staff decided to remove projects selected for this study if a site was already involved in another evaluation study.

The field engineers (Michaels Energy) visited 162 sites in eight different strata (see Table 3-1); all but two strata targets were met (2010 small lighting-only and 2010 large lighting-only). In order to meet the overall target of 160 sites the research team recruited additional samples from other strata.

Recruitment

Customer recruitment is an extremely important and often overlooked aspect of completing any successful primary data collection effort. Good customer recruitment practices will not only improve the cost-effectiveness of the recruiting process, but also keep customer satisfaction high. The research team recruited study participants via telephone, scheduling sites via electronic calendar and tracking software. The recruitment script for this project can be found in Appendix B:

On-Site Data Collection

The research team completed the majority of the primary data collection through the use of site visits. Site visits involved three primary activities: 1) inspections; 2) data logging; and 3) personnel interviews. These are described below.

On-Site Inspections

The on-site inspections were focused on collecting detailed information regarding the lighting system and its uses at each facility. We utilized a data collection instrument (see Appendix A:), comprising a data input form on a tablet PC for collecting information regarding the building use, lighting equipment, and any lighting controls installed at the facility.

During each site visit, the field engineer from Michaels Energy conducted a thorough walkthrough of the facility, while also working with site personnel to ensure there were no disruptions to their daily operations. While completing the site walkthrough, the field engineer worked with site personnel to determine the lighting and lighting control operating characteristics for each space.

Data Logging

In order to adequately quantify the impacts of lighting and lighting controls, data loggers were installed at sampled sites and collected data for a minimum of three weeks. The purpose of installing the data loggers was to measure the operating hours of the lighting system over a sustained period of time.

Logger Types

The field engineers utilized three types of loggers to meter the operation of the light fixtures:

- On/Off loggers (UX90)
- Light intensity loggers (U12-012)
- Light intensity with AC Current sensor (U12-012 with CT)

Each of the logger types works well in certain scenarios, and the field engineers were trained to select the most appropriate type of logger based on site conditions and limitations. All logger data were time-stamped. Figure 3-1 below is an image that shows the three logger types used.

Figure 3-1. Data Loggers

(From Left to Right: UX90 with Light Pipe, U12-012, U12-012 with CT)

Logger Analysis Methodology

To aid in the analysis of the data loggers, the research team developed a tool that can analyze all three types of loggers used to meter the operation of the lights. In addition, this tool can model the operation of lights that are dependent upon day length, such as photocell-controlled fixtures or spaces with daylighting controls.

For all three logger types, the analysis tool calculates the percent of on-time for each hour during the metering period. This percent on-time is then averaged into hourly profiles to develop an average load shape for the metered lights. If any holidays are observed during the metering period, they are removed and given their own load shape. Any spaces that have "other" profiles (e.g., schools with extended periods of down time) have separate profiles created. The analysis tool generates an average weekday hourly profile and average daily operating hours for weekends and holidays. The research team combines these profiles with the site information collected during the visits, including the facilities' observed holidays and any "other" schedules. Each day type (weekday, weekend, holiday, and other) is multiplied by the corresponding number of days per year for that day type to produce the total yearly operating hours. See A.1.1 1.a.Appendix C: for additional information on logger data and load shapes.

Logger Data Quality Assurance/Quality Control

Quality assurance and control is critical to collecting high quality logger data. Quality control occurred during the logger installation and removal as well as during the logger analysis. The research team developed analysis tools to aid in the calculation of the operating hours, while also identifying potential data issues. The research team identified metered data that included:

- Daylight interference
- Atypical operation
- Tampered loggers
- Flicker

As part of the quality control, the research team flagged any loggers that had any of the above issues. These loggers were reviewed again by the site analyst and by senior staff. Any logger found to have bad data was removed from the sample. Appendix C: provides additional information on logger data.

Site Personnel Interviews

The research team completed interviews with key site personnel to collect information regarding typical building operations and changes, including the operation of the building's lighting system, its occupancy schedule, and any upgrades made since the initial equipment installation. The interview also explored site personnel perspectives on lighting controls to determine how they are used and operated as well as if there were specific issues features or benefits associated with the controls.

During the interview, the field engineer requested pertinent technical information including lighting system specifications, as-built drawings, lighting diagrams, energy management system output, and any lighting contractor-supplied information. These technical documents were used to support and validate the information collected by the field engineers during the site walkthrough.

Finally, the research team interviewed site personnel to identify any areas where the installed lighting and/or lighting controls operate other than as intended or do not meet the needs of the space. Specifically, the research team discussed with site personnel how the needs of the space are being met and what actions they have taken to account or correct for these shortcomings. This includes any spaces where lighting and/or lighting controls had been installed, but have since been removed. See Appendix A: for the data collection instrument.

Summary of On-Site Data

As noted in Table 3-1, visits were conducted at 162 sites. A total of 1,381 loggers were installed at these sites. Table 3-3 shows the number of projects by year and type (lighting vs lighting controls) for each program.

Table 3-3. Number of projects by Energy Trust program

Year	Type	Existing Buildings	New Buildings	Production Efficiency
2010	Lighting controls	19	2	10
	Lighting-only	20	0	5
2013-14	Lighting controls	49	1	25
	Lighting-only	24	1	6
	Total	112	4	46

The research team cleaned and checked the on-site inspection data and logger data to ensure its accuracy and completeness. Each measure was checked to contain valid information on space type, space area, circuit wattage, and controls. Required information for controls included the number of controls, control type, operational status, and whether the controls were incentivized through Energy Trust. Measures with loggers were also checked for valid hours of use data.

We removed a total of 204 loggers from our analysis due to incomplete or erroneous data, leaving a total of 1,177 total valid loggers at 162 project sites. As shown in Table 3-4 below, the loggers were installed in a wide range of space types. The most common space types were warehouses (24%), private office spaces (9%), and storage areas (9%).

Table 3-4. Summary of Space Types Metered

Space Type	Number of Loggers	Percent of Total	Space Type	Number of Loggers	Percent of Total
Warehouse	280	23.8%	Break Room	28	2.4%
Office - Private	110	9.3%	Conference	27	2.3%
Storage	100	8.5%	Restroom	27	2.3%
Industrial	96	8.2%	Process	25	2.1%
Other	77	6.5%	Lobby	24	2.0%
Retail	75	6.4%	Stairs	21	1.8%
Assembly	57	4.8%	Gymnasium	20	1.7%
Technical Area	50	4.2%	Kitchen	9	0.8%
Office - Open	45	3.8%	Computer Room	2	0.2%
Parking Garage	37	3.1%	Dining	2	0.2%
Hallway	32	2.7%	Exterior	2	0.2%
Classroom	30	2.5%	Lodging (Guest Rooms)	1	0.1%

The majority (64%) of metered spaces[11] included in the study contained operating occupancy sensors and many others (31%) had no operating controls. Other control technologies that were metered in the study include daylighting controls, time clocks, bi-level controls, and other[12] controls. Table 3-5 below shows the number and percentage of installed loggers by control technology and by whether or not the controls were incentivized by Energy Trust programs. A full discussion of non-program controls is found in Section 4.5.

Table 3-5. Number of Installed Loggers by Control Technology

	Number of Loggers – Program-Controls	Number of Loggers – Non-Program-Controls	Number of Loggers – Total
Occupancy - Fixture Mount	489	13	502
Occupancy - Other Mount	217	29	246
Other	21	19	40
Stepped	11	3	14
Time Clock	1	13	14
Bi-Level	10	0	10
Continuous	1	3	4
Vacancy - Other Mount	1	0	1
Number of Loggers in Spaces with Operating Control Measures[13]	737	72	809
Number of Loggers in Lighting-Only Spaces or Spaces with Non-Operating Control Measures	0	0	368

3.3 Analysis Methods

After completing the on-site visits and interviews with site personnel, the research team began the analysis of the collected data to inform the research objectives. Savings estimates for lighting control projects are driven by three factors: the watts controlled ($kW_{controlled}$), the estimated hours-of-use (HOU) prior to the adoption of the control strategy (HOU_{pre}), and the estimated reduction factor (RF) associated with the control technology. Equation 3-1 below summarizes this calculation.

Equation 3-1. Lighting Control Electric Energy Savings

$$kWh\ Saved_{lc} = kW_{controlled} * HOU_{pre} * RF$$

Table 3-6 summarizes the data sources for estimating both the pre- and post-HOU values associated with installing lighting controls in C&I facilities.

[11] A metered space is defined as a room or area of a building where a meter was installed. Each metered space included one or more logger.
[12] The research team found that "other" controls consist mostly of computer controls or building management systems.
[13] Some spaces had multiple control types.

Table 3-6. Source of Hours of Use Inputs for Analysis

Analysis Value	Source Description
HOU_{pre}	Aggregated HOU estimates based on metered data from lighting-only sites.
HOU_{post}	Aggregated HOU estimates based on metered data from sites with program lighting controls.

The lighting controls reduction factor is typically calculated using the following equation:

Equation 3-2. Reduction Factor Calculation

$$RF = 1 - (\frac{HOU_{post}}{HOU_{pre}})$$

However, due to the significant differences observed in facility operating hours across all sites (and differences in average operating hours between lighting-only and lighting control projects), the lighting-only sites cannot be considered a directly comparable baseline. The research team adjusted the reduction factor to account for the differences in reported operating hours among all evaluated sites.

To make this adjustment, we first normalized the metered hours for each measure by the site's reported operating hours. Each site's operating hours were determined based on information collected during the on-site interview. Equation 3-3 below shows the metered-to-reported hours ratio formula. This "hours ratio" is expected to be about 1.0 for lighting measures (indicating that lights are on during operating hours) and less than 1.0 for controls measures (indicating that controlled lights are off during some operating hours).

Equation 3-3. Metered-to-Reported Hours Ratio Calculation

$$Hours\ Ratio = \frac{Metered\ Hours}{Site\ Operating\ Hours}$$

Next, the hours ratios were aggregated based on whether or not the measure contained a lighting control. Average hours ratios were weighted by the circuit wattage reported for each measure. Equation 3-4 below shows the revised formula for the reduction factor.

Equation 3-4. Revised Reduction Factor Calculation

$$Reduction\ Factor = 1 - \frac{Average\ Hours\ Ratio_{Controls}}{Average\ Hours\ Ratio_{No\ Controls}}$$

There are a number of ways to aggregate measures into "controls" or "no controls" groupings. Table 3-7 shows the six measure groups that were created for the reduction factor analysis.

The following list defines the terms used in this table.

- "Control Projects" refers to projects in which controls were incentivized. Lighting measures may have also been implemented at controls projects, alongside controls.

- "Lighting-Only Projects" refers to projects in which there are incentivized lighting measures but no program controls.
- "Control Measures" with "Operating Control" refers to program controls that are still operating.
- "Control Measures" with "Non-Operating Control" refers to incentivized controls that are no longer operating or missing.
- "Lighting Measures" with "Non-Program Control" refers to incentivized lights where non-program (unexpected) controls were found.
- "Lighting Measures" with "No Control" refers to incentivized lights where no control was found (as expected).

Table 3-7. Representation of Measure Groupings and Logger Counts per Group

Measure	Control Status	Number of Loggers in Control Projects	Number of Loggers in Lighting-Only Projects
Control Measures	Operating Control	737	-
	Non-Operating Control	40	-
Lighting Measures	Non-Program Control	9	63
	No Control	144	184

EMI Consulting calculated the reduction factor using the operating (n=737) and non-operating (n=40) controls measures at controls projects for the controls grouping and the lighting measures with no control at both controls projects (n=144) and lighting-only projects (n=184) as the no controls grouping. This scenario takes into consideration that some program controls installed may eventually become non-operational. EMI Consulting considers this scenario to be most representative of what Energy Trust can expect from lighting controls going forward. EMI Consulting also calculated reduction factors for other grouping scenarios. Additional details regarding these scenarios can be found in Appendix D:

In addition to calculating the overall reduction factor for all lighting controls projects evaluated, the research team also reported the reduction factor by space type, control technology, year, project size, program controls and non-program controls.

In addition to the reduction factor analysis, the research team determined the operational status of lighting controls as part of the persistence analysis. Possible lighting control issues examined included:

- Missing controls
- Broken controls
- Incorrectly installed controls
- Controls not working as expected
- Mishandling of controls

The research team also explored and characterized lighting control technologies and strategies that did not receive Energy Trust incentives. These observations were analyzed in order to identify any trends regarding current practices in lighting controls.

For a detailed discussion regarding reduction factor scenarios assessed, see Appendix D:

4. RESULTS

This section presents detailed findings for each of the six research objectives established. Each subsection (4.1 through 4.6) corresponds to the research objectives described in Table 4-1. A summary of key findings is provided in Table 4-1.

Table 4-1. Summary of Research Objectives and Key Findings

Research Objective	Key Research Finding
1. Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years (2010-2014) and in the future.	Occupancy sensors are the dominant control technology incented representing nearly 87% of all control measures. Trends indicate proportions of fixture-mounted occupancy sensors and custom oc been increasing over time, while the total number of lighting cont declining since 2010.
2. Understand the proportion of C&I lighting savings attributed to lighting efficiency vs. lighting controls.	Lighting measures represent 81% of total savings from lighting a projects.
3. Identify the space types that are associated with specific lighting control technologies/strategies.	Common space types for lighting controls include offices, retail a industrial areas.
4. Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.	Of program-installed controls in 2010, 98% are still operational. 2013, and 2014 program-installed controls, 99% are still operatio Figure 4-7, the majority of incentive controls that were not operat installed (58%) or missing (20%).
5. Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.	36% of lighting-only projects included at least one non-program fixture-mounted controls.[14] A larger percentage of daylighting co were found on projects with controls not incentivized by Energy (60%) of these controls were installed due to Oregon code or due management system.
6. Estimate the savings from the dominant lighting control technologies/strategies.	The overall calculated reduction factor is 0.38.[15]

4.1 Program Lighting Control Technologies and Strategies

Occupancy sensors accounted for the largest number of lighting control measures and largest lighting control savings in the project database. The controls-related measure categories from the program tracking database contain detailed measure descriptions that were consolidated into six categories. Figure 4-1 and Table 4-2 below show these six control technologies by total project savings and measure count, respectively, across five years. The most measures were completed for "occupancy sensors – other

[14] Energy Trust incentivizes lighting and lighting controls. Some projects only incentivized lighting ("lighting-only"), while others incentivized lighting and controls ("lighting and controls"). However, the lighting-only projects may have included controls that were not incentivized by Energy Trust.

[15] To estimate savings from lighting controls, a reduction factor was calculated. A reduction factor is the percentage reduction in lighting usage from the installation of a lighting control.

mount" which includes ceiling and wall mounted sensors. The measures with the most savings are for fixture mounted occupancy sensors.

Figure 4-1. Project Savings (kWh) by Control Type by Year

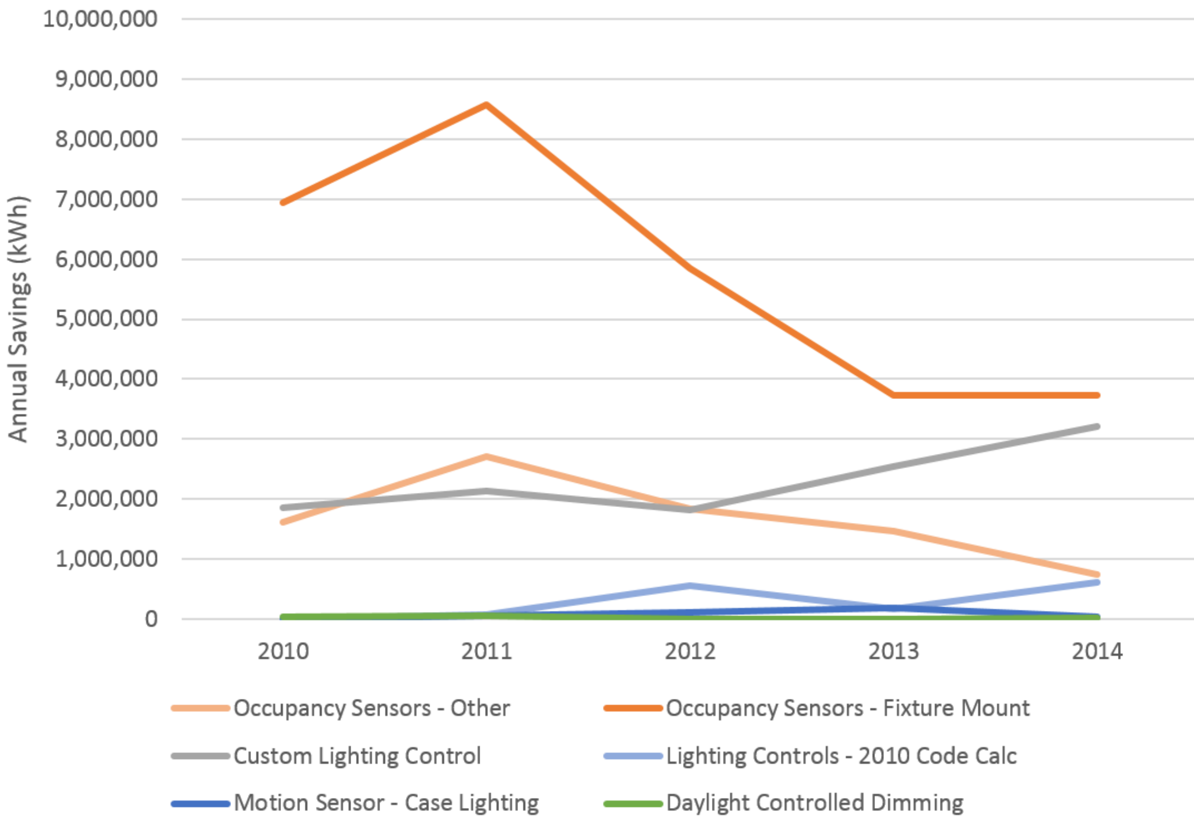
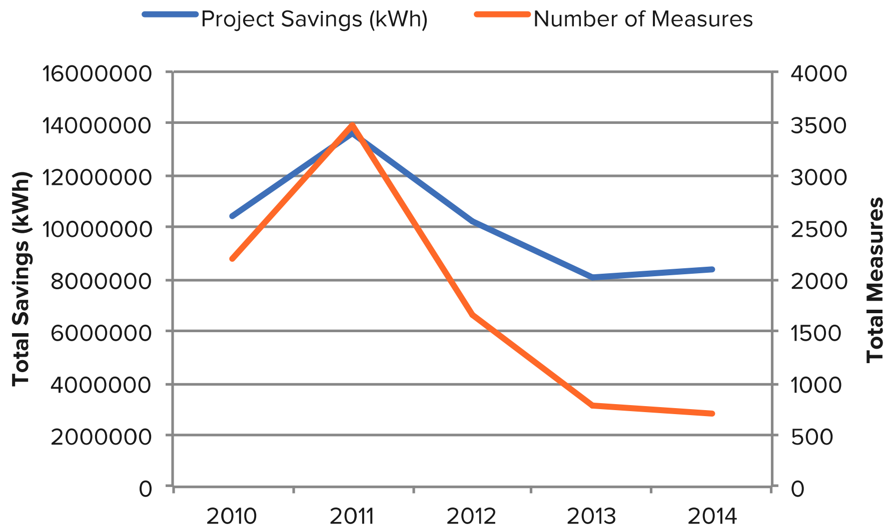


Table 4-2. Number of Measures by Control Type by Year

Control Measure Category	2010	2011	2012	2013	2014	2010-2014
Occupancy Sensors - Other	1,374	2,151	976	380	326	5,207
Occupancy Sensors - Fixture Mount	691	1,101	475	296	268	2,831
Custom Lighting Control	125	216	155	66	86	648
Lighting Controls - 2010 Code Calc	0	6	19	18	13	56
Motion Sensor - Case Lighting	0	10	23	20	6	59
Daylight Controlled Dimming	14	9	3	0	2	28
Yearly Total	2,204	3,493	1,651	780	701	8,829

Occupancy sensors are the dominant control category, representing nearly 87% of all control measures. However, the percentage of lighting controls measures that are occupancy sensors has been decreasing in recent years, while custom lighting and custom building controls measures have been increasing. Figure 4-2 shows the total measures installed annually and the total savings for all control technologies. The total number of measures installed annually has decreased substantially since 2011 while total savings has also declined, but not as rapidly.

Figure 4-2. Number of Control Measures Installed and Project Savings by Year



4.2 Lighting and Lighting Controls Program Savings

In order to determine the percentage of savings for lighting and lighting control projects, these projects were split into three categories: (1) projects with only lighting savings, (2) projects with only lighting controls savings, and (3) projects with both lighting and lighting controls savings. As shown in Figure 4-3 below, projects with lighting only measures make up the majority of projects—out of 14,024 projects from 2010 to 2014, 10,448, or 75%, were lighting only. Controls only projects made up just over 3% of all projects while the remaining 22% had both lighting and controls measures.

Figure 4-3. Energy Trust Database - Number of Projects by Program (2010-2014)

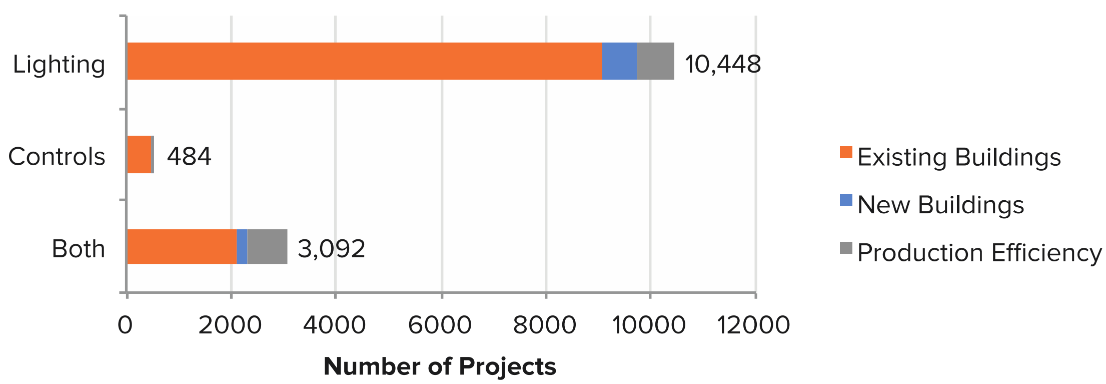
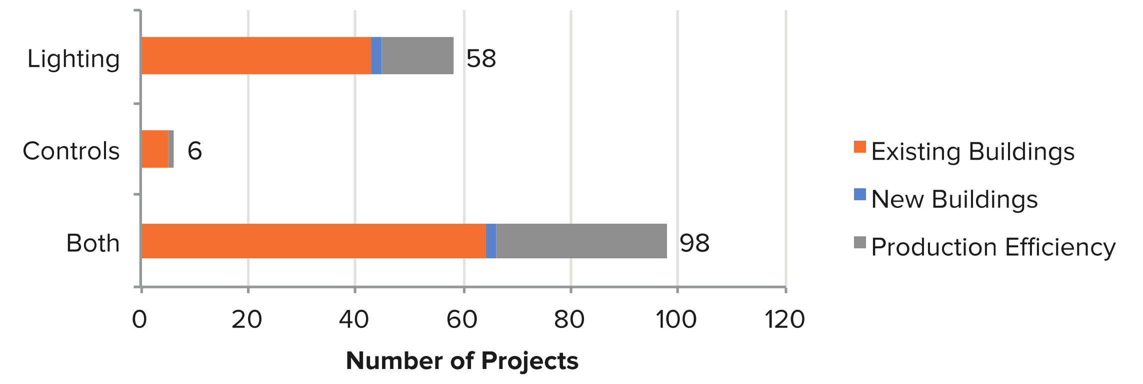


Figure 4-4 shows the number of projects from the same three categories as they are represented in the sample for this project. Projects with both lighting and lighting controls savings make up the bulk of projects in the study (60%).

Figure 4-4. Projects in Sample - Number of Projects by Program (2010-2014)



When comparing all measures, lighting measures represent 81% of total savings from lighting and lighting controls projects. Within projects that include both lighting and lighting controls savings, lighting savings represent 82% of total savings. Table 4-3 below shows the total savings for lighting and lighting controls measures.

Table 4-3. Total Savings for Lighting and Lighting Controls Measures (2010-2014)

	Lighting and Lighting Controls Projects		Lighting Only, Lighting Controls Only, and Lighting and Lighting Controls Projects	
	Total Savings (MWh)	Percentage of Savings	Total Savings (MWh)	Percentage of Savings
Lighting Measures	211,668	82.1%	487,813	81.0%
Controls Measures	46,241	17.9%	114,278	19.0%
Total	257,909	100%	602,091	100%

Lighting and lighting controls savings are split by year and by program in Figure 4-5 below. Projects with only lighting controls are most prevalent in the Existing Buildings program. The New Buildings and Production Efficiency programs more often combine lighting and lighting controls measures within projects, relative to lighting-only and lighting controls-only projects.

Figure 4-5. Annual Savings by Measure Type, Year, and Program

4.3 Lighting Control Building and Space Types

In this study, we analyzed the variation of lighting control technologies installed in different building and space types from both the program tracking data and the on-site inspections. In both cases, occupancy sensors were the most common lighting control technology. However, there was a larger percentage of lighting controls in offices, retail, and other buildings represented in the program database compared to the sites visited, and a larger percentage in warehouses and industrial facilities represented in the on-site inspections compared to FastTrack.

Table 4-4 below shows the number of measures installed by building type and by lighting control category (with the highest value in each column highlighted in orange). Measures were most often installed in "Other" buildings, followed by offices and warehouses. Some control types—like motion sensor case lighting—were much more common in particular building types (grocery and retail).

Table 4-4. Number of Measures by Building Types Associated With Each Control Category –

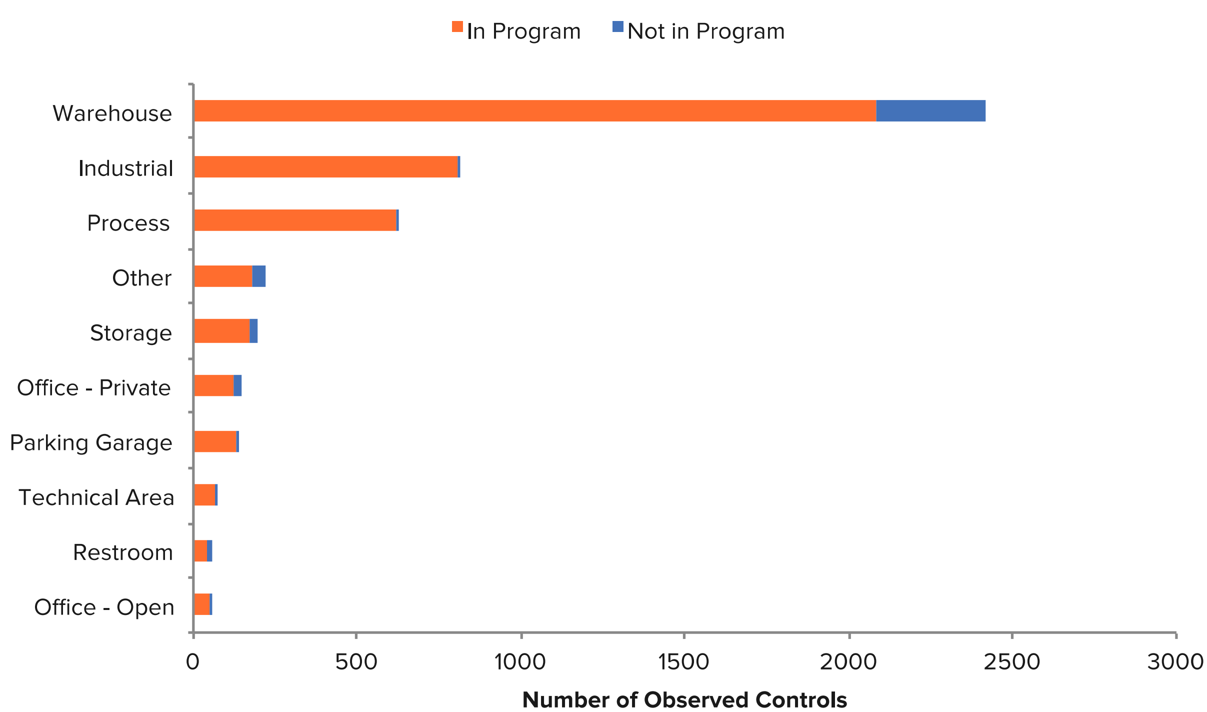
Building Type	Daylight controlled dimming	Motion sensor - case lighting	Occupancy sensors - Fixture mount	Occupancy sensors - Other mount	Custom or Other
Assembly	1	0	65	84	33
Auto Services	0	0	201	287	62
College/University	2	0	14	133	30

Food Products	0	0	62	46	1
Grocery	1	22	104	145	71
Gym/Athletic Club	1	0	17	66	20
Institution/Government	3	0	16	100	4
Office	10	0	241	1,214	279
Other	2	2	837	1,242	165
Other Health	2	0	9	153	38
Religious/Spiritual	0	0	10	130	16
Retail	2	32	328	545	120
Schools K-12	0	0	12	258	52
Warehouse	3	0	725	565	86
Wood Production	0	0	63	64	0

Note: Highest highlighted in orange.

Figure 4-6 below shows the most common space types among all observed lighting controls and that most of the lighting controls found from on-site inspections were in warehouses and industrial spaces. Note that this data from the on-site inspections is by space type, rather than building type. The breakdown of lighting controls by space type is noticeably different for program lighting controls and non-program controls. Warehouses are the most common space type for all controls — and are slightly more common among the non-program controls. The percentage of controls in industrial areas, storage areas, parking garages, and technical areas was higher among program lighting controls, while non-program controls were more common in private offices, restrooms, retail areas, assembly areas, hallways, and other spaces.

Figure 4-6. Program and Non-Program Lighting Controls by Space Type (Sampled Lighting Controls)



4.4 Lighting Controls Persistence

The research team found that there was very high persistence of lighting controls through on-site inspections with facility representatives. A total of 4,259 individual lighting controls were identified in the inspections, 99% of which were operational. Out of the 3,752 program-incentivized lighting controls, 99% were operational. Note that not all of these controls measures were metered.

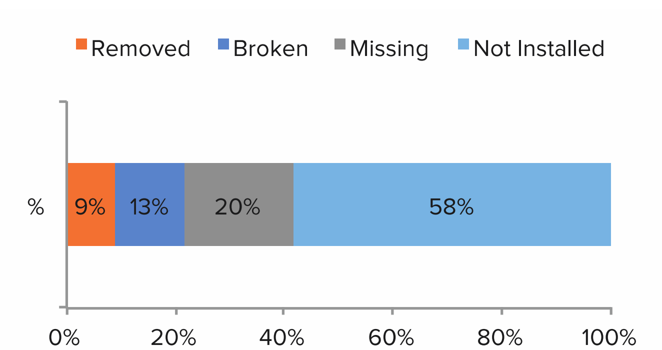
As shown in Table 4-5 below, nearly all program-incentivized lighting controls (98.5%) were operational when inspected by on-site analysts. Interestingly, the percentage of operational lighting controls did not change significantly between 2010 projects and 2013-2014 projects. Most of the lighting controls that were not operational were occupancy sensors.

Table 4-5. Operational Status For Program and Non-Program Lighting Controls

Year	Status	Program Controls (n=3,752)	Non-Program Controls (n=507)	All Controls (n=4,259)
2010	Not Operational	1.6%	0.0%	1.4%
	Operational	98.4%	100.0%	98.6%
2013 - 2014	Not Operational	1.2%	0.5%	1.1%
	Operational	98.8%	99.5%	98.9%
2010, 2013, 2014	Not Operational	1.5%	0.4%	1.4%
	Operational	98.5%	99.6%	98.6%

A total of 55 program lighting controls – out of 3,752 – were no longer operational or were not installed. Of these, most were reported as not installed (58%), missing (20%) or broken (13%), as shown in Figure 4-7. Just over one-third of the 'not operational' program lighting controls (35%) were from 2010 compared with two-thirds (65%) from 2013 or 2014. When field staff asked site personnel about the missing and removed lighting controls, some indicated that they were removed during renovations or because they did not operate as desired (e.g., lights would turn off even when space was occupied). Interviewees noted that some missing controls may have never been installed. Many respondents were unable to provide additional details regarding the missing lighting controls because they were missing or removed prior to the respondents' employment or involvement.

Figure 4-7. Summary of Non-Operational Program Lighting Controls



Based on the few non-operational lighting controls, and even fewer controls that were broken or removed, the research team did not determine a definitive value for the lighting controls measure life. A very large percentage of controls from 2010 (98%) were still operational in 2015, indicating that Energy Trust's current measure life of 15 years for industrial lighting controls and 21 years for commercial lighting controls are well within reason. Given that this study is exploring persistence after only five years, Energy Trust may want to revisit this question periodically in the future.

4.5 Non-Program Lighting Controls Strategies

As mentioned above, there were 507 non-program lighting controls identified on program lighting measures (12% of all controls identified). Most of these lighting controls were installed at sites that completed a lighting-only project in 2013 or 2014 through the Production Efficiency program. Table 4-6 below shows the number of non-program controls by project type, year, and program.

Table 4-6. Number of Non-Program Lighting Controls Observed On-site

Project Type	Year	Existing Buildings (Number of Controls)	Number of New Buildings (Number of Controls)	Production Efficiency (Number of Controls)
Controls[16]	2010	3	0	1
	2013 - 2014	9	0	7
Lighting Only	2010	72	0	4
	2013 - 2014	53	4	353

After reviewing project documentation and conducting on-site interviews, Michaels Energy and EMI Consulting found that 35% of projects included non-program controls due to an existing energy management system, 24% due to code requirements, and the remaining 41% unknown. Some possible reasons for not receiving incentives may also include:

- Fixture-mounted / integrated controls were included (but not recognized by program) in lighting projects
- Controls may have been installed as part of an unknown, subsequent program
- Controls may have pre-dated the lighting installation
- Customers may have been unaware of controls incentives or chose not to participate in the program.

Under the 2010[17] and 2014[18] Oregon Energy Efficiency Specialty Code (OEESC), buildings larger than 2,000 square feet are required to install automatic control devices, which include timers or occupancy sensors. Furthermore, occupancy sensors are required to be installed in specific space types. Examples include, but are not limited to, classrooms, meeting rooms, break rooms, office space, restrooms and storage rooms. A majority (67%) of all non-program controls are found in warehouse spaces, followed by categories such as office (4.1%), storage (3.9%), Assembly (3.2%), and restrooms (2.6%). This aligns with spaces requiring automatic controls due to code.

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[16] The "Controls" project type includes controls-only projects as well as projects with lighting and lighting controls.
[17] 2010 OEESC:
http://ecodes.biz/ecodes_support/free_resources/Oregon/10_Energy/PDFs/Chapter%205_Commercial%20Energy%20Efficiency.pdf
[18] 2014 OEESC: http://ecodes.biz/ecodes_support/free_resources/Oregon/14_Energy/PDFs/Chapter%205%20-%20Commercial%20Energy%20Efficiency.pdf

As shown in Table 4-7 the majority of non-program lighting controls are occupancy sensors (87%). The relative proportions of non-program lighting controls by technology is similar to the proportions for program controls; however, there was a larger percentage of daylighting controls and time clocks for non-program controls.

Table 4-7. Percentage of Program Non-Program Lighting Controls by Control Type

Control Type	Program (n=3,752 controls)	Non-Program (n=507 controls)
Occupancy Sensor	91.8%	87.4%
Other[19]	7.5%	5.9%
Stepped (Daylighting)	0.3%	1.6%
Time Clock	0.0%	4.3%
Bi-Level	0.3%	0.0%
Continuous (Daylighting)	0.0%	0.8%
Vacancy	0.0%	0.0%

4.6 Lighting Controls Savings

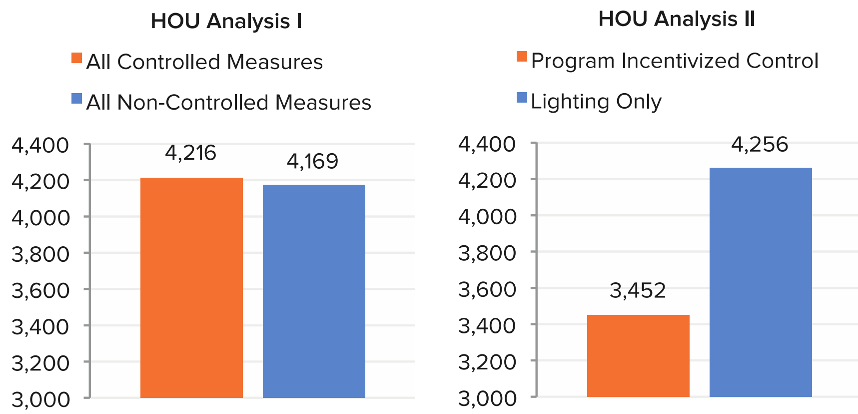
The research team analyzed a total of 1,177 lighting loggers from 160 projects to determine the lighting controls savings below. The hours of use analysis is presented first and shows that controlled measures had higher hours of use than non-controlled measures. Then, after accounting for differences in reported operating hours, the final reduction factor analysis is presented. These savings values were calculated based on the reported building schedule and at least three weeks of metered data as described in the Methodology section.

Reported Hours Analysis

On average, lights that had an operating control had slightly higher average hours of use (4,216 hours per year) than lights with no control (4,169 hours per year), as shown in HOU Analysis I in Figure 4-8. The standard errors of these averages are much larger than the difference between them, indicating that the difference between the two groups is not statistically significant.

[19] Mostly computer-controlled and energy management systems.

Figure 4-8. Comparing HOU Results*



*Note: Axis begins at 3,000 hours

The detailed findings for annual hours of use by control status are shown in Table 4-8. The weighted average across all measures was 4,193 hours.

Table 4-8. Hours of Use for Controlled and Non-Controlled Measures

Control Status of Measure	Number of Loggers	HOU (per year)	Standard Error	Coefficient of Variation	80% CI
Non-Controlled Measure	368	4,216	181.90	0.04	3,983 – 4,449
Controlled Measure	809	4,169	342.74	0.08	3,729 – 4,608
All Measures	1,177	4,193	190.01	0.05	3,949 – 4,436

However, when only considering program measures, controlled measures had lower hours of use as compared to non-controlled measures, as shown in HOU Analysis II in Figure 4-8. Program lighting measures (with no operating controls) had an average hours of use of 4,256 hours per year and operating program controls had an average hours of use of 3,452 hours per year.[20] Average hours of use for these categories are shown in Table 4-9.

[20] This difference is significant at the 95% confidence with less than 1% margin of error.

Table 4-9. Hours of Use by Control Status and by Program Status[21]

Status	Number of Loggers	HOU (per year)	Standard Error	Coefficient of Variation	80% CI
Lighting Only	328	4,256	188.83	0.04	4,014 – 4,498
Operating Controls – Non-Program	72	5,490	652.50	0.12	4,653 – 6,326
Non-Operating Controls – Program	40	3,277	408.08	0.12	2,754 – 3,800
Operating – Program	737	3,452	163.10	0.05	3,243 – 3,661
All Measures	1,177	4,193	190.01	0.05	3,949 – 4,436

Based solely on the hours of use results in Table 4-9, the research team computes a program reduction factor of 0.19 (RF = 1 – 3,452 / 4,256). However, this would not account for any differences in operating hours between the metered projects. For example, it is possible that lighting controls are more likely to be installed in higher usage areas or buildings, which would increase the average hours of use for controlled lights and would reduce the reduction factor for lighting controls. To account for this possibility, the research team computes the reduction factor based on a metered-to-reported hours ratio, as shown in Equation 3-3 and Equation 3-4.

Reduction Factor Analysis

Using the methodology described in Section 3.3, the overall calculated reduction factor was 0.38[22]. This indicates that an average control will reduce a light's hours of use by 38%. This reduction factor value has an 80% confidence interval of 0.33 to 0.44, indicating a relative precision of 13%. In addition, the research team found that controlled lights, on average, have a metered-to-reported hours ratio of 0.72, while non-controlled lights have a ratio of 1.17.

The reduction factor increases slightly to 0.39 when only considering program lighting controls. This occurs because the metered-to-reported hours ratio is smaller for program lighting controls (0.71) compared to non-program lighting controls (0.85). All non-controlled measures were included in this analysis. Note that the equations for the metered-to-reported hours ratios and the reduction factor are shown in Equation 3-3 and Equation 3-4, respectively. The hours ratio, reduction factor, and reduction factor confidence and precision are presented in Table 4-10 by program incentivized control.

[21] Although the research team identified several non-program, non-operating controls, these were not metered and not represented in this table.

[22] This reduction factor is based on EMI Consulting's recommended grouping scenario, as described in Section 3.3. For a complete discussion of all grouping scenarios and their associated reduction factors, please see Appendix D:

Table 4-10. Metered-to-Reported Hours Ratio and Reduction Factor by Program and Non-Program Controls

	Lighting Controls		No Lighting Controls		Reduction Factor			
Control Type	Number of Loggers [23]	Hours Ratio	Number of Loggers	Hours Ratio	Reduction Factor	Std. Error	80% CI	Precision
Non-Program	40	0.85	328	1.17	0.27	0.07	0.19-0.36	0.32
Program	737	0.71	328	1.17	0.39	0.04	0.34-0.44	0.13
All Measures	777	0.72	328	1.17	0.38	0.04	0.33-0.44	0.13

Reduction Factor by Technology and Space Type

In addition to calculating an overall reduction factor, the research team computed reduction factors by lighting control technology and space type to explore potential differences among those groups. The control technologies with the largest reduction factors include bi-level controls (0.90), occupancy sensors (0.40), and daylighting controls (0.30). Table 4-11 presents the reduction factor for all lighting control technologies (including both program and non-program lighting controls). All non-controlled measures were used as a comparison group. Note that all metered bi-level lighting controls were from one project.

Table 4-11. Metered-to-Reported Hours Ratio and Reduction Factor by Lighting Control Technology

	Lighting Controls		No Lighting Controls		Reduction Factor
Control Type	Number of Loggers	Hours Ratio	Number of Loggers	Hours Ratio	Reduction Factor
Time Clock	1	1.02	328	1.17	0.13
Occupancy Sensor	746	0.71	328	1.17	0.40
Daylighting	12	0.87	328	1.17	0.26
Bi-Level	10	0.11	328	1.17	0.91
Other	22	0.69	328	1.17	0.41

The metered-to-reported hours ratio and the reduction factor vary significantly by space type. In general, industrial spaces (warehouses, industrial areas, and technical areas) and closed-type spaces (private offices, storage rooms, classrooms, conferences, and restrooms) had large reduction factors. Open-type spaces (retail spaces, open offices, and hallways) had small reduction factors. Table 4-12 presents the reduction factor by space type.

[23] The *n* represents the number of loggers included in a given group. See Table 3-7 for a summary of lighting controls versus no lighting controls groupings.

Table 4-12. Metered-to-Reported Hours Ratio and Reduction Factor by Space Type

Space Type	Controls		No Controls		Reduction Factor
Space Type	Number of Loggers	Hours Ratio	Number of Loggers	Hours Ratio	RF
Assembly	16	0.52	36	0.78	0.32
Break Room	17	0.86	8	0.67	-0.27
Classroom	18	0.67	11	1.00	0.33
Conference	12	0.27	13	0.45	0.40
Hallway	3	0.84	25	1.06	0.20
Industrial	83	0.87	13	1.54	0.43
Lobby	4	1.01	19	0.97	-0.04
Office - Open	14	0.79	26	1.31	0.39
Office - Private	90	0.50	15	0.71	0.29
Other	35	0.76	36	1.41	0.46
Parking Garage	31	0.43	5	1.00	0.57
Process	10	0.96	12	1.16	0.17
Restroom	16	0.29	8	1.03	0.72
Retail	32	1.03	34	0.99	-0.04
Stairs	10	0.11	11	1.00	0.89
Storage	54	0.69	31	1.14	0.39
Technical Area	45	0.70	5	1.13	0.38
Warehouse	261	0.71	13	1.09	0.35

Reduction Factor by Sample Groupings

The following additional tables present the reduction factor analysis by different groups used in stratifying our sample, including:

- Reduction factor by year (Table 4-13)
- Reduction factor by project size (Table 4-14)
- Reduction factor by program (Table 4-15)

As shown in Table 4-13, the reduction factor for 2013 and 2014 projects (0.43) is higher than 2010 projects (0.33). For larger projects, the reduction factor is considerably higher (0.42) than small projects (0.28) as shown in Table 4-14. Finally, reduction factor by program ranged from a high of 0.48 for the Production Efficiency program to 0.23 for the New Buildings program, as shown in Table 4-15.

Table 4-13. Metered-to-Reported Hours Ratio and Reduction Factor by Project Year

	Lighting Controls		No Lighting Controls		Reduction Factor
Year	Number of Loggers	Hours Ratio	Number of Loggers	Hours Ratio	Reduction Factor
2010	254	0.76	161	1.13	0.33
2013/2014	523	0.70	167	1.22	0.43

Table 4-14. Metered-to-Reported Hours Ratio and Reduction Factor by Project Size

	Lighting Controls		No Lighting Controls		Reduction Factor
Project Size	Number of Loggers	Hours Ratio	Number of Loggers	Hours Ratio	Reduction Factor
Large	378	0.78	108	1.35	0.42
Small	399	0.68	220	0.94	0.28

* Small projects are those with annual savings of less than 100,000 kWh. Our team selected 100,000kWh as a clean threshold to distinguish between the majority of projects, and a smaller number of large projects that represent the majority of savings.

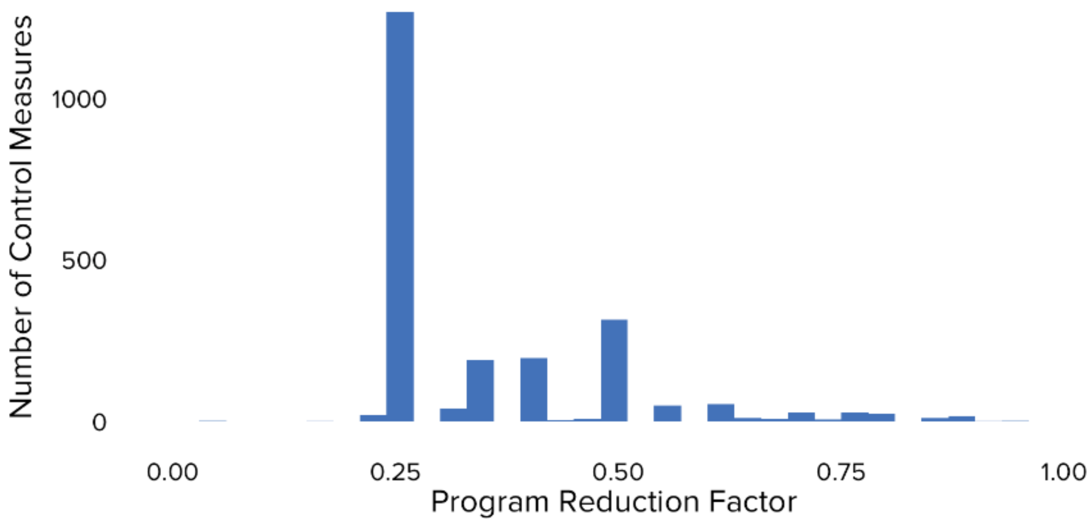
Table 4-15. Metered-to-Reported Hours Ratio and Reduction Factor by Program

	Lighting Controls		No Lighting Controls		Reduction Factor
Project Size	Number of Loggers	Hours Ratio	Number of Loggers	Hours Ratio	Reduction Factor
Existing Buildings	452	0.69	241	0.98	0.30
New Buildings	31	1.04	5	1.36	0.23
Production Efficiency	292	0.75	80	1.43	0.48

Reduction Factor Comparison: Measured vs. Existing Program Assumptions

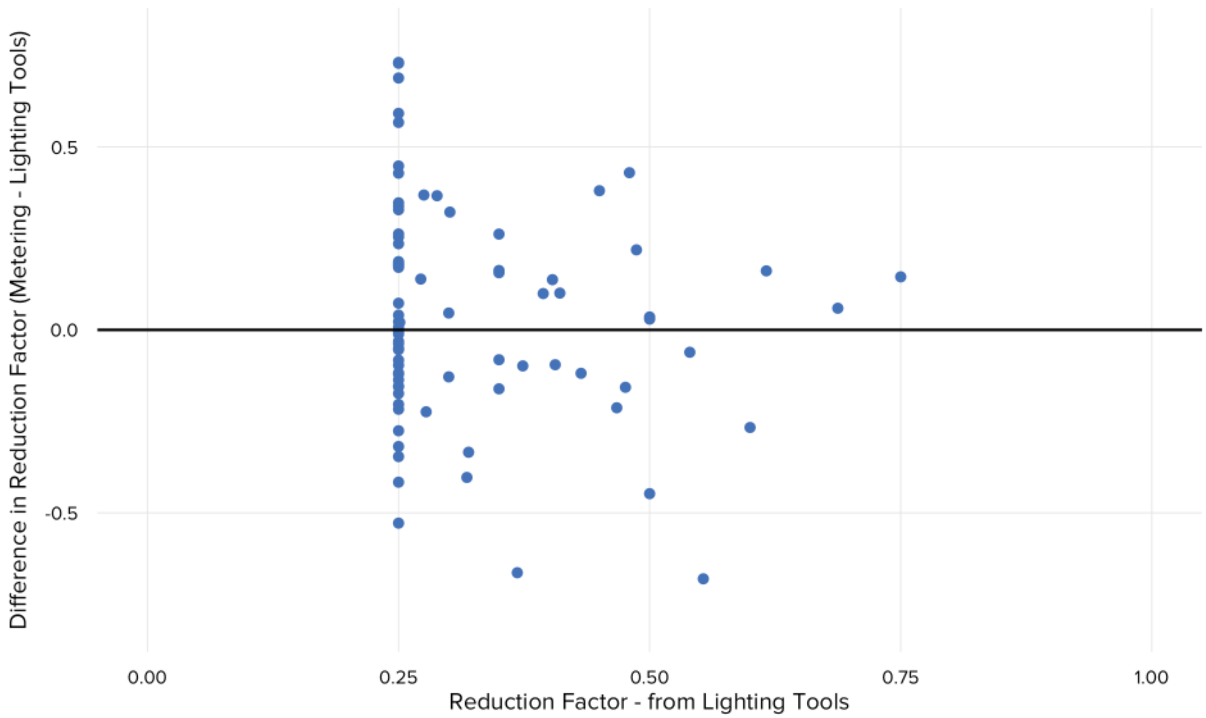
The research team was able to extract program reduction factors from many project files (i.e. lighting tools). The most common reduction factor used was 0.25, as shown in Figure 4-9. However, there were many controls measures with large reduction factors, bringing the average program reduction factor to 0.35. Note that the distribution shown represents only a subset of sites (n=276) for which we had access to the lighting tools (primarily from 2013 – 2014 projects) and may not be representative. Of the 276 sites with data, we reviewed reduction factors for 2,288 lighting controls measures. Of these, just over half (55%) used a default reduction factor of 25%.

Figure 4-9. Histogram of Program Reduction Factors from Lighting Tools



The research team performed a direct comparison of the observed reduction factor and the reduction factor used in the lighting tool at each site where both values were readily available (84 sites – these sites are all in the sample). As seen in Figure 4-10, program reduction factors were generally unable to precisely forecast reduction factors for individual sites. In aggregate, however, the average program reduction factor (0.35) is within the uncertainty range of the observed reduction factor (0.33 – 0.44). This indicates that the program is not systematically underestimating or overestimating reduction factors. If Energy Trust desires to adjust the program reduction factors based on findings from this study, EMI Consulting recommends that programs increase reduction factors by 8.5% going forward, reflecting the average observed reduction factor of 0.38 compared to the average program reduction factor of 0.35.

Figure 4-10. Comparison of Observed Reduction Factor (Metered) to Program Reduction Factor



5. SUMMARY

A key finding from this study indicates that lighting controls exhibit a greater reduction in lighting hours of use than the default assumptions used by Energy Trust. The research team found lighting controls to have a reduction factor of 0.38, a notable increase from the existing default assumption of 0.25 used by the Energy Trust when estimating savings. Findings also show that 98% of evaluated lighting controls installed since 2010 were operational, indicating a high persistence rate for program controls. Table 5-1 provides a summary of research objectives and key findings.

Table 5-1. Summary of Research Objectives and Key Findings

Research Objective	Key Research Finding
1. Determine dominant C&I lighting control technologies and strategies incented through C&I programs over the past five years (2010-2014) and in the future.	Occupancy sensors are the dominant control technology incented by Energy Trust, representing nearly 87% of all control measures. Trends indicate that the relative proportions of fixture-mounted occupancy sensors and custom occupancy sensors have been increasing over time, while the total number of lighting control projects have been declining since 2010.
2. Understand the proportion of C&I lighting savings attributed to lighting efficiency vs lighting controls.	Lighting measures represent 81% of total savings from lighting and lighting control projects.
3. Identify the space types that are associated with specific lighting controls technologies/strategies.	Common space types for lighting controls include offices, retail areas, warehouses and industrial areas.
4. Determine operational status of lighting controls and if issues are due to technology, placement, or user interactions after installation or post-occupancy.	Of program-installed controls in 2010, 98% are still operational. Overall, of 2010, 2013, and 2014 program-installed controls, 99% are still operational. The majority of incentive controls that were not operational were not installed (58%) or missing (20%).
5. Determine what lighting control technologies/strategies are being used in lighting projects that do not receive incentives for controls.	36% of lighting-only projects included at least one non-program control, including fixture-mounted controls.[24] A larger percentage of daylighting controls and time clocks were found on projects with controls not incentivized by Energy Trust. A majority (60%) of these controls were installed due to Oregon code or due to an existing energy management system.
6. Estimate the savings from the dominant lighting control technologies/strategies.	The overall calculated reduction factor is 0.38.[25]

These and other findings from the study serve as a basis for updating existing assumptions to more closely align with the actual performance of lighting controls deployed. Furthermore, the analysis of trends and characterization of lighting controls provides Energy Trust with the insights needed to inform future program efforts. For example, results show that the use of controls have been increasing over time in lighting-only projects. This may indicate a shift in the lighting market, however data from non-program participants are needed before any definitive conclusions can be made.

[24] Energy Trust incentivizes lighting and lighting controls. Some projects only incentivized lighting ("lighting-only"), while others incentivized lighting and controls ("lighting and controls"). However, the lighting-only projects may have included controls that were not incentivized by Energy Trust.

[25] To estimate savings from lighting controls, a reduction factor was calculated. A reduction factor is the percentage reduction in lighting usage from the installation of a lighting control.

Finally, results by program, building type, and space type may inform efforts to target specific sectors that have greater opportunities for energy savings. While findings show that lighting control participants generally have higher lighting hours of use than lighting-only participants (indicating that self-selection is a successfully strategy), targeting sites with very high hours of use may result in deeper energy savings.

5.1 Recommendations

EMI Consulting provides several recommendations for Energy Trust regarding updates to the reduction factor, quantification of lighting controls measure life, and suggestions for improvement in tracking data. These recommendations, outlined below, are based upon analysis results and observations made when conducting this study.

- **Increase default lighting controls reduction factor**. EMI Consulting found the actual reduction factor of program lighting controls to be 0.38, with an uncertainty range of 0.33 – 0.44. The default reduction factor used by Energy Trust is 0.25. While a majority (55%) of projects utilize this default reduction factor, higher reduction factors were also applied when appropriate. EMI Consulting's review of a sample of 276 projects indicated that the average reduction factor used by Energy Trust is 0.35, lower than the observed reduction factor of 0.38. As such, EMI Consulting recommends that programs increase reduction factors by 8.5% going forward, reflecting the average observed reduction factor of 0.38 compared to the average program reduction factor of 0.35.
- **Record hours of use by space rather than by project.** The research team found that recorded hours of use generally did not vary by space type within each project's documentation. Metered data show that hours of use vary by space type within each project. EMI Consulting recommends that the reduction factor be calculated using operating or occupancy hours that are recorded on the space-level rather than project-level. This added granularity may also reduce the large variability in program reduction factor accuracy observed.
- **Increase consistency between program tracking data and project documentation.** EMI Consulting observed inconsistencies between program tracking data and project documentation for individual sites. Inconsistencies include: number of lighting measures reported, number of controls reported, and project identification numbers. EMI Consulting recommends that Energy Trust ensures that all data in project documentation is consistent with the program tracking database and that matching identifiers are used for measures in both datasets. Furthermore, implementing a standard template for project documentation will facilitate future evaluation efforts. Current documentation may include paper documents, scanned documents, and spreadsheet-based reports of varying formats and templates.
- **Observe lighting controls measure life for older projects.** EMI Consulting observed that a very large percentage of controls from 2010 (98%) were still operational in 2015, indicating that Energy Trust's current measure life of 15 years for industrial lighting controls and 21 years for commercial lighting controls are well within reason. Given that this study is exploring persistence after only five years, EMI Consulting recommends that Energy Trust revisit this question periodically in the future.

APPENDIX A: ON-SITE PROTOCOL AND DATA COLLECTION GUIDE

Prior to each onsite visit the field technician will complete the following activities:

- ***Review Participant/Facility Information***. Each of the field technicians will review all information available about each site prior to the onsite visit. This information will include, but is not limited to: the business name and address, the site contact name, the facility type, the various space types, the project type (lighting only or lighting and controls), and any other special instructions noted during the recruitment of that participant.
- ***Inspect and Inventory Lighting Loggers***. Each field technician will test sufficient lighting loggers to meet expected needs for each site visit to ensure each logger is functional and they have an adequate number of functional units to install at each site.
- ***Verify Appointment***. The field technician will call the participant on the day before the onsite visit to confirm the appointment and information collected during recruitment, and to ensure that no conflicts have arisen that would affect the onsite visit or data collection activities. During this call, the field technician will also confirm address, major cross-streets, and a secondary phone number.

A.1 Onsite Protocols

This section provides information on the protocols the field technicians will follow when onsite at the participant facility. This section addresses general protocols, as well as protocols related to the lighting inventory survey and logger installation and removal.

General Protocols

This section covers general protocols to be followed by the field technicians when onsite, including: what to do when arriving at the participant site, appropriate attire, and safety.

Arrival at the Participant Site

If the field technician will be more than 10 minutes late for an appointment, they will notify the participant site contact by phone.

Upon arrival at a participant facility, the field technician will ask for the participant site contact and show their Energy Trust-authorized letter of association and personal legal identification if requested. The field technician will state: “I am here *on behalf* of the Energy Trust of Oregon”—the field technician will never represent themselves as an employee of Energy Trust. They will provide copies of the letter of association and business cards, and will thank them for their participation in the study.

The field technician will verify that this is a good time for the participant. If not, they will try to identify a time to reschedule the onsite. Whenever changes are made, they will communicate the updated schedule to their supervisor as soon as possible.

The field technician will answer any questions for the participant about the purpose of the study or the protocols that will be followed, and explain that the purpose of the visit (see Section 5 for answers to some frequently asked questions).

Attire

Field technicians will wear clean and appropriate clothing for the type of work, including appropriate protective equipment at all times. Personal and company-representative identification sufficient to satisfy participants is also required. Appropriate attire for field technicians includes the following:

- Khaki pants or jeans without holes; no shorts or sweat pants
- Shirts with collars preferred; no logo t-shirts
- Shoes with no-slip soles

Safety

While the objective is to complete the lighting inventory survey and install loggers at every facility selected in the sample, all onsite field technicians have the right to not enter a location or complete the data collection if they feel their safety could be compromised for any reason. Field technicians must ask the onsite representative if there are hazardous conditions that exist and what precautions must be taken before proceeding into a participant facility and will follow all safety protocols for the facility.

If at any point during the onsite visit a field technician no longer feels safe, they will thank the participant for their time and move on to the next location. They will immediately report any incident that resulted in a lighting inventory survey or logger installation not being completed to their supervisor, and document the reason(s) for leaving the facility.

Lighting Inventory

The initial onsite visit will be comprised of a facility lighting inventory survey and the installation of the logging equipment. The lighting inventory survey is used to determine the total number and types of controls installed through Energy Trust, types of lighting fixtures, usage categories, typical hours of use, and operating schedules (and control schedules, where applicable) for each applicable space in the facility covered in the study. Applicable spaces are those that include lighting and lighting control measures installed as part of program. The participant will be interviewed in order to determine any fixture details that cannot be inspected.

The field technician will use the lighting inventory survey form to determine which switches could have loggers installed. The survey form will then randomly assign the eligible switches to be logged.

Logger Installation and Removal

For this study, the field technicians will use Hobo UX90-002 and U12-012 loggers. The UX90-002 logger is a light on/off state logger that registers a change in state based on observed ambient light levels and a user-adjustable sensitivity level. The U12-012 logger is a light intensity (footcandle) logger. The U12-012 logger records the measured light level (footcandles) at a user-defined interval.

Each field technician will be familiar with the loggers installed and be fully trained on the operational characteristics and limitations of each logger. The field technicians will install Hobo UX90-002 loggers in locations that are expected to have minimal variances in ambient light level conditions. Under these conditions a state logger with a user-adjusted sensitivity is expected to capture the operating hours.

The field technicians will install Hobo U12-012 loggers in locations that are expected to have a greater variance in ambient light level conditions, such as rooms with large windows or multiple independent light sources. Additionally, U12-012 loggers will typically be installed in locations with dual-level lighting or dimming capability.

Figure B-5-1 illustrates a typical installation. Each logger will be installed in a manner that will minimize the effects of other light sources. This will include ensuring that the light sensor is aimed toward the light source to be metered and away from any ambient or stray light sources such as lamps and windows. Often this will include installing the logger inside the light fixture. The field technicians will take care to ensure that the maximum temperature rating of the logger (158° F) is not exceeded in the environment where it is placed. For fluorescent lamps, this typically does not need to be considered. These loggers are not recommended for installation in recessed can fixtures. For these fixtures the logger will be installed in an area outside the fixture where it is affected by the light. If no such location is available, the fixture will not be able to be metered for the study.

Figure B-5-1: Example of Appropriate Logger Placement

The loggers will typically be installed using the attached magnet. However, if this is not possible, the logger may be installed using wire, zip-ties, or other forms of attachment. In potentially wet, dirty, or dusty locations, the logger will be placed in a plastic bag. Once installed, the field technician will use the lighting logger installation form to record information on the logger placement, including the time for each logger, the logger serial number and a detailed description of the installed location.

To support logger installation and removal at each participant site, the field technicians will bring the following materials:

- An extra supply of loggers in case, despite pre-testing, some do not work onsite
- Zip-lock plastic bags for storing retrieved loggers or broken lamp cleanup

- Razor blade or sharp pocketknife for slitting painted-over fixtures to allow access to lamps and ballasts
- A variety pack of plastic zip-ties (4", 8", and 14" lengths)
- One inch square 3M double-sided tape (3M-4026) and a glass scraper for removal
- Velcro tape
- Removable/reusable poster putty
- Electrical tape and wire nuts
- Small scissors or wire cutters
- Logger communication cable

A.2 Quality Control and Quality Assurance

This section provides information on protocols to ensure the data is of high quality and that potential conflicts with the participants are adequately resolved. This section covers protocols related to field technician training, data quality, and conflict resolution.

Field Technician Training

All field technicians will be trained to ensure quality and consistency across personnel. During the training process, each field technician will be trained on the content of this protocols document as well as the data entry forms.

A senior evaluation team member will supervise a day of site visits with randomly selected field technicians within 2 weeks of beginning study fieldwork to ensure they are adhering to the protocols. A senior team member will also conduct an additional day of field technician supervision at a later study date (TBD) to ensure technicians continue to adhere to the protocols. The collected data for each supervised site visit will be reviewed to ensure data entry accuracy.

Data Quality

A senior evaluation team member will review all of the data entry forms from each field technician for completeness and consistency. If data from any site is found to be incomplete or inconsistent, the field technician will be interviewed to verify the missing or inconsistent information. If the correct information cannot be determined, the senior evaluation team member will review the site details and make a determination if the site data can be used or if the site will be dropped from the sample.

In a similar manner, a senior evaluation team member will review the technical accuracy of the hours of use calculated for the loggers. During this review, the reviewer will take special care to ensure that hours of use estimates are accurate and will "flag" any loggers that may be providing erroneous data. Typical issues that are assessed include: daylighting obscuring the accurate operation of the logger, loggers stopping during the metering period for unexplained reasons, dramatic changes in profiles that may indicate a logger was moved, loggers that do not indicate light levels changing over a reasonable duration, or very low light levels for the entire duration. Additionally, the field technician will note if a logger had fallen or been removed before data collection was complete. If any loggers are suspected of systematic error, the team member will review each project that used that logger with the analyst and the field technician and drop those data points if warranted.

Conflict Resolution

Every effort will be made to ensure that the inconvenience to the participant is minimized. However, in the case that a conflict does arise with a participant, the evaluation team will work with both the utility and the participant to ensure that the conflict is resolved to the participant's satisfaction.

In the event that a conflict arises during the participant recruitment process, the recruiter will attempt to address the participant concerns. If the recruiter is not able to address the participant concerns immediately, the evaluation manager will be brought into the discussion to discuss any concerns with the participant. At that time, if the concerns have not been addressed, the participant will be thanked for their time, and they will be placed on a "do not call list." A report will be generated documenting the participant interaction, which will be supplied to Energy Trust.

Similarly, in the event that a conflict arises during the on-site inspection, the field technician will attempt to address the participant concerns. If the technician is not able to address the participant concerns immediately, the evaluation manager will be brought into the discussion via telephone to discuss any concerns with the participant. At that time, if the concerns have not been addressed, the participant will be thanked for their time, and the site visit will be ceased. No further inspection will be completed nor will any loggers be deployed. A report will be generated documenting the participant interaction, which will be supplied to Energy Trust.

Additional approaches to addressing specific conflicts are discussed below.

You broke my...

If this is true: Assure the participant that you will report the problem and someone will be in contact with them soon to discuss the next steps.

If it is not true: If the participant will discuss the situation calmly, explain how you are not at fault. If the participant resists this explanation or is otherwise uncooperative, explain that you will report the situation to your manager and someone will be in contact with them soon to resolve the issue.

Regardless of the outcome of this conversation, the technician will take detailed notes on the situation and report it to their manager as soon as reasonably possible.

Scheduling Conflicts

If a field technician will be more than 10 minutes late for an appointment, they will notify the participant by phone. If scheduling no longer works for the participant, the field technician will ask the participant if they are still willing to participate in the study and work with them to determine an alternate date and time.

All contact with the participant will be recorded in a file that includes the date, time, name of parties, and an outline of the discussion or message.

A.3 Frequently Asked Questions

Below are responses to questions that the evaluation team anticipates participants might ask at any point during the field data collection of this study.

Who can I contact to verify this study?

Participants may contact:

Phil Degens
Evaluation Manager
Energy Trust of Oregon
Phone: 503-445-7620

What is the purpose of this study?
The purpose of the visit is to help understand the savings achieved through lighting controls. Energy Trust will use these insights to improve energy efficiency programs.

What should I do if the logger becomes dislodged or disconnected from the lighting equipment?
If a logger becomes disconnected or dislodged from the lighting equipment, please note the date and time as well as the serial number on the logger. Then please report this information to the site engineer or Ryan Kroll of Michaels Energy at 608-785-1900. His contact information is available in the letter provided during the onsite visit. If you think that you can re-install the logger, you may do so, however, you do not have to. If it is convenient for you, we may ask to have somebody stop by to reinstall the logger as well.

Will the data and information on my company be public? Who will have access to the data and company information that is being collected?
Data collected from all participants that participate in this study will be aggregated and summarized before any results are presented to the sponsoring utilities. The summarized results will be publicly available once reviewed by Energy Trust.

Did you learn anything about my facility?
The data will be analyzed once it is aggregated with data collected at other participant sites. If in the process we find any important information that the participant should be aware of, the evaluation team will work with the utility to determine if and how to transmit that information to the participant.

If the technician is pressed for findings, they will explain that the protocols of this study do not allow them to provide any analysis or results directly to the participant. If the participant wishes to have the results, the technician will notify the evaluation team manager and the appropriate utility representative who will determine the appropriate course of action.

A.4 On-site data collection

The evaluation team will gather the following data during the on-site visit, through the technician walk through and through the interview with the participant.

Walk Through

During each site visit, the field engineer will walk through the facility, and record the information into the computer-based data collection tool. This allows for instantaneous recording of the data and eliminates duplicative time scanning and entering paper-based data collection forms. The electronic collection forms also ensure complete and consistent data, as the team will utilize automated checks and set lists of responses, which will significantly reduce the time and money spent cleaning unorganized data.

The research team will conduct a thorough and complete walkthrough of the facility at each site visit, while working with the participant to ensure that there is no disruption to their daily operations during the visits. The field engineers will also be extremely knowledgeable about lighting technologies and lighting controls strategies. All of the research team field staff have the experience, knowledge, and technical expertise to quickly and accurately identify the lighting system type, characteristics, and control strategy to optimize the time spent with the participant.
While completing the site walkthrough, the field engineer will work with site personnel to determine the lighting and lighting controls operating characteristics for each space. Whenever possible, the field engineers will work with site personnel to obtain trended and control strategies from automated lighting control systems such as energy management systems, building automation systems, time clocks, and photocells.

Interview

Site personnel will be interviewed to provide the evaluator with relevant information about building operations and changes, including the operation of the building's lighting system, its occupancy schedule, and any upgrades made since the initial equipment installation. This interview will also touch on the lighting controls to determine how they are used and operated as well as if there are specific issues features or benefits associated with the controls.

Finally, the research team will estimate the measure life for major lighting control technologies by developing failure curves based on the frequency of failed lighting control equipment at historical sites. This research team will likely supplement on-site inspection of equipment with telephone interviews. Given the relative infrequency with which controls fail or are removed, we are unlikely to have a large enough sample of on-sites to inform an accurate estimate of measure life.

Data Fields

The evaluation team will collect the following data:

- Building Type
    - Automotive Repair
    - College or University
    - Exterior 24 Hour Operation
    - Hospital
    - Industrial Plant with One Shift
    - Industrial Plant with Two Shifts
    - Industrial Plant with Three Shifts
    - Library
    - Lodging
    - Manufacturing
    - Office < 20,000 sqft
    - Office > 100,000 sqft
    - Office 20,000 to 100,000 sqft
    - Other Health, Nursing, Medical Clinic
    - Parking Garage
    - Restaurant
    - Retail 5,000 to 50,000 sqft
    - Retail Anchor Store >50,000 sqft Multi-story
    - Retail Big Box >50,000 sqft One-story

    - Retail Boutique <5,000 sqft
    - Retail Mini Mart
    - Retail Supermarket
    - School K-12
    - Street & Area Lighting
    - Warehouse
    - Assembly
    - Other
- Approximate facility age
- Completion date of last major renovation or major lighting project
- Building Hours of Occupancy (daily average)
- Facility Square Footage
- Space Type
    - Assembly
    - Break Room
    - Classroom
    - Computer Room
    - Conference
    - Dining
    - Gymnasium
    - Hallway
    - Hospital Room
    - Industrial
    - Kitchen
    - Library
    - Lobby
    - Lodging (Guest Rooms)
    - Open Office
    - Parking Garage
    - Private Office
    - Process
    - Public Assembly
    - Restroom
    - Retail
    - Stairs
    - Storage
    - Technical Area
    - Warehouses
    - Other, will record
- Space-Type Square Footage
- Space Hours of Occupancy (daily average)
    - If needed, record multiple occupancy schedules

	S	M	T	W	T	F	S	Start Mo.	Start Day	End Mo.	End Day
Schedule 1											
Schedule 2											
Schedule 3											
Schedule 4											

- Holidays Observed, record days affected
    - All Federal Holidays? Or else…
        - New Year's Day
        - MLK Day
        - Presidents' Day
        - Memorial Day
        - Independence Day
        - Labor Day
        - Columbus Day
        - Veterans' Day
        - Thanksgiving Day
        - Christmas Day
        - Other
    - Are the lights in this space turned off during holidays? (Y / N)
- Lighting characteristics
    - Fixture type
    - Lamp type
    - Number of lamps
    - Lamp wattage
    - Controls built in (Y/N)
    - Quantity of controls
- Control Types
    - Manual Light Switch
    - Timeclock
    - Daylight Controls – On/Off
    - Daylight Controls - Continuous Dimming
        - Window Orientation Closest to Daylight Sensor (N, S, E, W)
    - Daylight Controls - Multi-Step Dimming
        - Stepped, # of steps
        - Continuous
        - Window Orientation Closest to Daylight Sensor (N, S, E, W)
    - Occupancy Sensor
        - Strategy: Occupancy or Vacancy[26]
    - Occupancy Sensor w/ Daylight Sensor - Continuous Dimming
        - Strategy: Occupancy or Vacancy
    - Occupancy Sensor w/ Daylight Sensor - Multi-step Dimming
        - Strategy: Occupancy or Vacancy
    - Occupancy Sensor w/ Daylight Sensor - On/Off Operation
        - Strategy: Occupancy or Vacancy
    - Bi-Level Lighting
    - Other controls, record
- Control Schedules

[26] **Occupancy Sensors** turn lights on when motion is detected and off when no motion is detected. **Vacancy sensors** only turn lights off when no motion is detected, but lights must be manually switched on.

Table 5-2. Sample Data Collection Instrument Table

Row Number	Occupancy Sensor Group No.	Selected for Metering?	Room Name/ Number		Room Size		Switch Number	Manual Switch (Y/N)	Occupancy Sensors		Daylighting	
			Name/ Number	Room type	Length	Width			Occupancy Sensor Type	Qty	Daylight Sensor Type	# Dimming Steps (If stepped)
			Description		Area			Bi-Level (Y/N)	Strategy (Occ or Vac)		Window Orientation	
1	-											
					0							
2	-											
					0							

Row Number	Fixture	Fixture Qty	Lamps	Total Switch Watts	Approximate Schedule and Hours	Describe if Control Not working (missing control, broken, not used as intended, programmed incorrectly, etc…)	Do fixtures have built-in controls?	Other Notes (If other controls, or bi-level, describe)
	Type-1		#/ Fixture					
	Type-2		Watts/ Lamp					
1				0				
			0					
2				0				
			0					

EMI CONSULTING

APPENDIX B: RECRUITMENT SCRIPTS

B.1 Participant Recruitment Script

IDENTIFY APPROPRIATE CONTACT

If CONTACT NAME and/or TITLE is available:

Hello, may I speak with [Contact Name or TITLE]?

1. Yes [Introduction]
2. No, not available [Determine appropriate callback time]
3. No, no longer at company [Determine appropriate contact and record contact name and title]

If CONTACT NAME not available:

Hello, my name is _________ calling from Michaels Energy on behalf of Energy Trust of Oregon. This is not a sales call. May I please speak with the facility operations manager or someone that would be familiar with the lighting equipment installed at your facility, or the person who might be familiar with [company name]'s participation in Energy Trust's [program name]?

INTRODUCTION

[repeat as necessary until have correct contact person]

Energy Trust is conducting a study to better understand how lighting controls achieve savings. This information will help Energy Trust provide energy efficiency incentive programs that achieve greater and longer lasting energy savings.

We are contacting participants that previously installed efficient lighting or controls to recruit businesses to participate in the study.

Participation in the study will consist of a walkthrough of your facility with one of our trained field engineers to record the quantity and type of light fixtures and lighting controls in your facility. We will also ask basic information regarding your facilities' hours of use and how any installed controls have affected your lighting use, including control settings. The field engineer will then install a small number of unobtrusive meters to monitor the operating hours of selected lighting in your facility for approximately 3 weeks. Once the metering period is complete, a field engineer will return to your facility to remove the meters.

R1. Are you interested in participating in this lighting metering study?
1. Yes [Skip to R3]
2. No [Skip to END1]
3. (Don't know) [Ask R2]

R2. If you would like, I can give you some time to think about it. Does another time work well for me to call you back?
1. [RECORD DATE AND TIME] [Skip to END3]

2. No [Skip to END1]
3. (Don't know) [Skip to END1]

R3. Great. I need to ask you a few questions to make sure your facility meets the requirements of the study.

Our records indicate your company had [lighting/controls/lighting and controls] installed through a Energy Trust] program in [month/year]. Can you confirm that [lighting/controls/lighting and controls] were installed in your business through the program?

1. Yes [Ask R3a]
2. No [Confirm response, skip to END2]
3. (Don't know) [Confirm response, skip to END2]

R3a

R4. To your knowledge, are the controls still being used as installed?

1. Yes [Skip to R9]
2. No [Ask R5]
3. (Don't know) [Skip to R9]

R5. How has the operation of the controls changed?

[Log response] [Ask R9]

R9. It looks like you are a good candidate for our study. We are currently setting up times for onsite visits and lighting logger installations from [Starting Date] to [Ending Date]. Do you have any specific dates or times that work best for your schedule?

1. Yes [ENTER DATE AND TIME] [Skip to R11]
2. No [Ask R10]
3. (Don't know) [Ask R10]

R10. I currently have an opening at [TIME] on [DATE]. Does this time work for you?

1. Yes [ENTER DATE AND TIME] [Ask R11]
2. No [REPEAT R10 WITH NEW DATE AND TIME]

R11. Is [ADDRESS] in [CITY] still your correct address?

1. Yes [Skip to R13]
2. No [Ask R12]

R12. Can you please give me your correct address and city?

[ENTER ADDRESS AND CITY] [Ask R13]

R13. Can you confirm the best phone number to reach you?

[Record number] [Ask R14]

R14. Did you have any specific safety or other protocols that must be followed while our technician is on site, such as steel-toed boots, hearing protection, or anything else?

1. Yes [Enter response here, note in special instructions for onsite staff]
2. No

If Appointment scheduled read END5, else if read END4;

END1. That is all of the questions I have for you today. Thank you very much for your time.

END2. It looks like your building does not match our current selection criteria. Thank you very much for your time.

END3. That is all of the questions I have for you today. I will plan on calling you back at ______ on _______. Thank you very much for your time.

END4. That is all of the questions I have for you today. I will plan on calling you back at a later date. Thank you very much for your time.

END5. That is all of the questions I have for you today. I will plan on our technician visiting you at [ADDRESS] on [WEEKDAY], [DATE] at [TIME]. The technician will provide you with a letter of association with contact information for the Energy Trust representative, who you can call if you have any questions during or about the site visit. The technician will call you the day before to confirm the appointment. If for any reason this date and time will no longer work for you please feel free to call me at [PHONE NUMBER] to reschedule. My name again is [NAME]. Thank you very much for your time and your participation.

APPENDIX C: LOGGER DATA

In this section, additional information is provided regarding metered data from the lighting loggers deployed at participant sites.

Figures B-1 through B-3 present the metered light level in an open office with no lighting controls. Figure B-1 shows an example of metered data over the entire data collection period. Figure B-2 shows the aggregated hourly profiles for lighting measures (without controls), lights with program controls and lights with non-program controls. Figure B-3 shows an example of hourly profiles for each day of the week.

Figure B-1: Open Office - No Controls

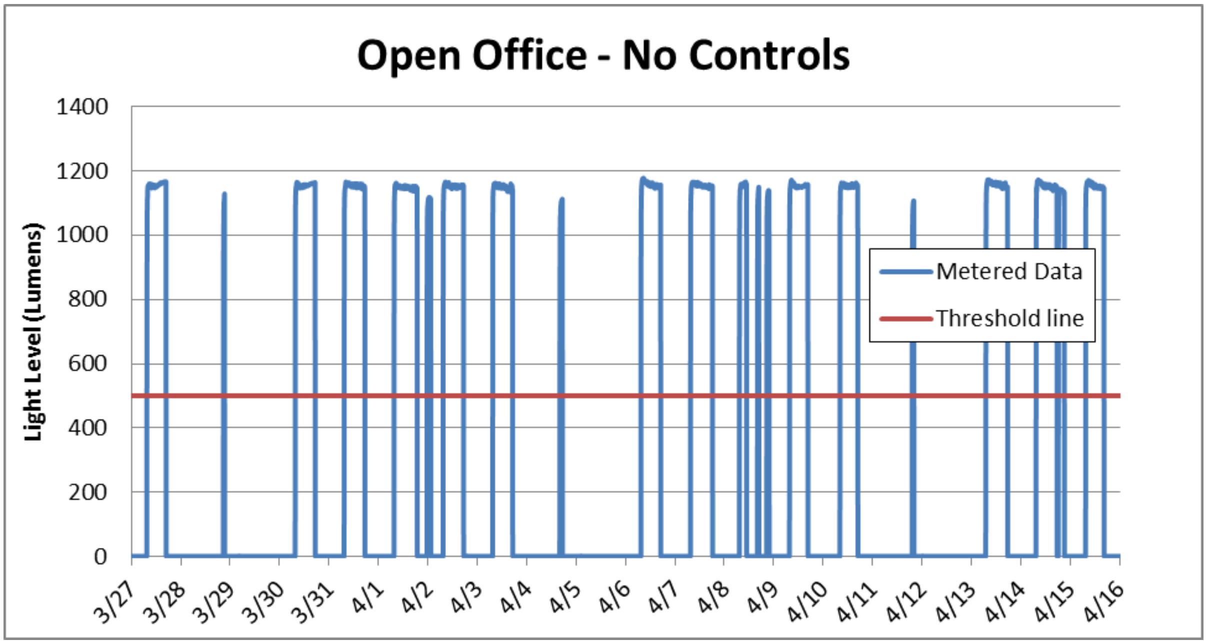


Figure B-2: Hourly Profile for Lighting Measures and Controls Measures

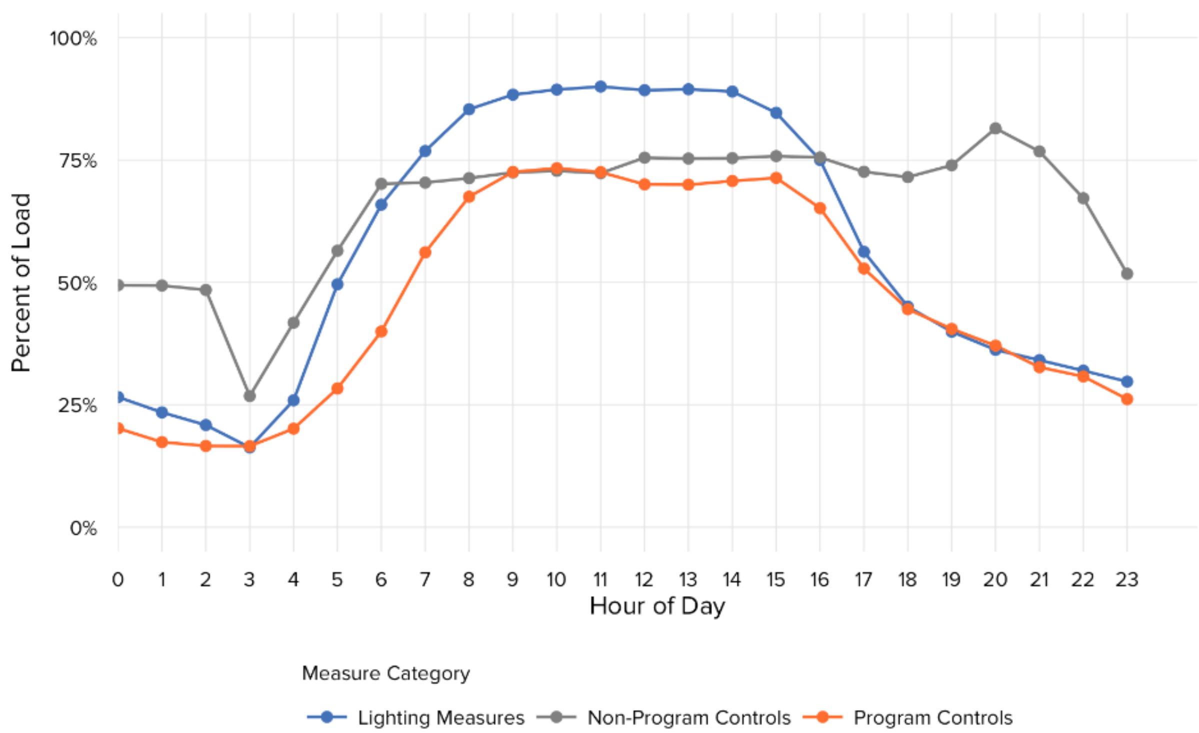
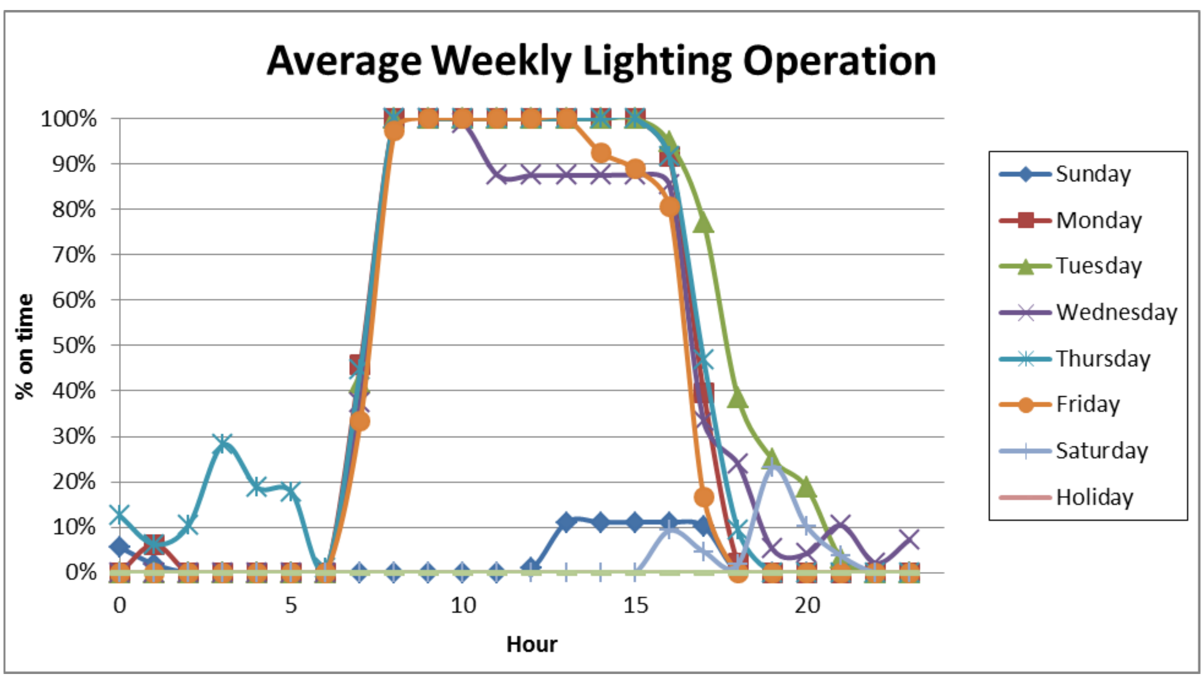


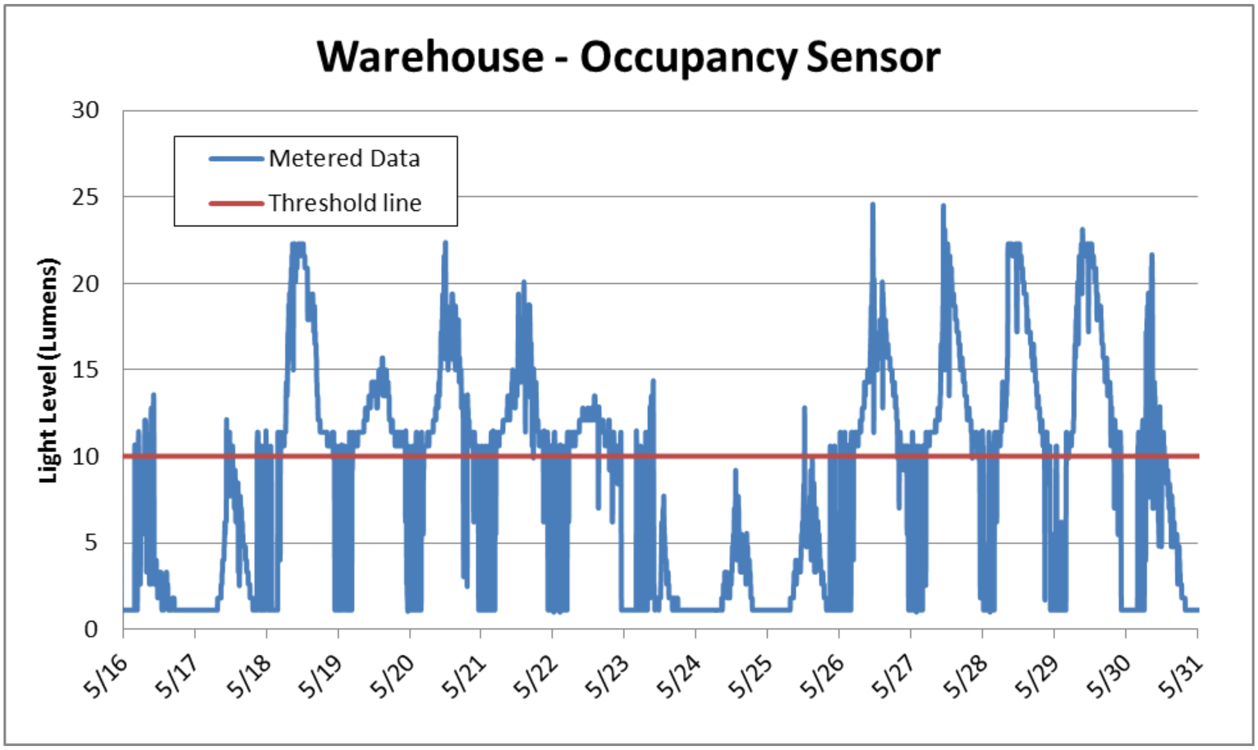
Figure B-3: Open Office - No Controls Weekly Profile



The following figures show possible issues that can occur with the metered data.

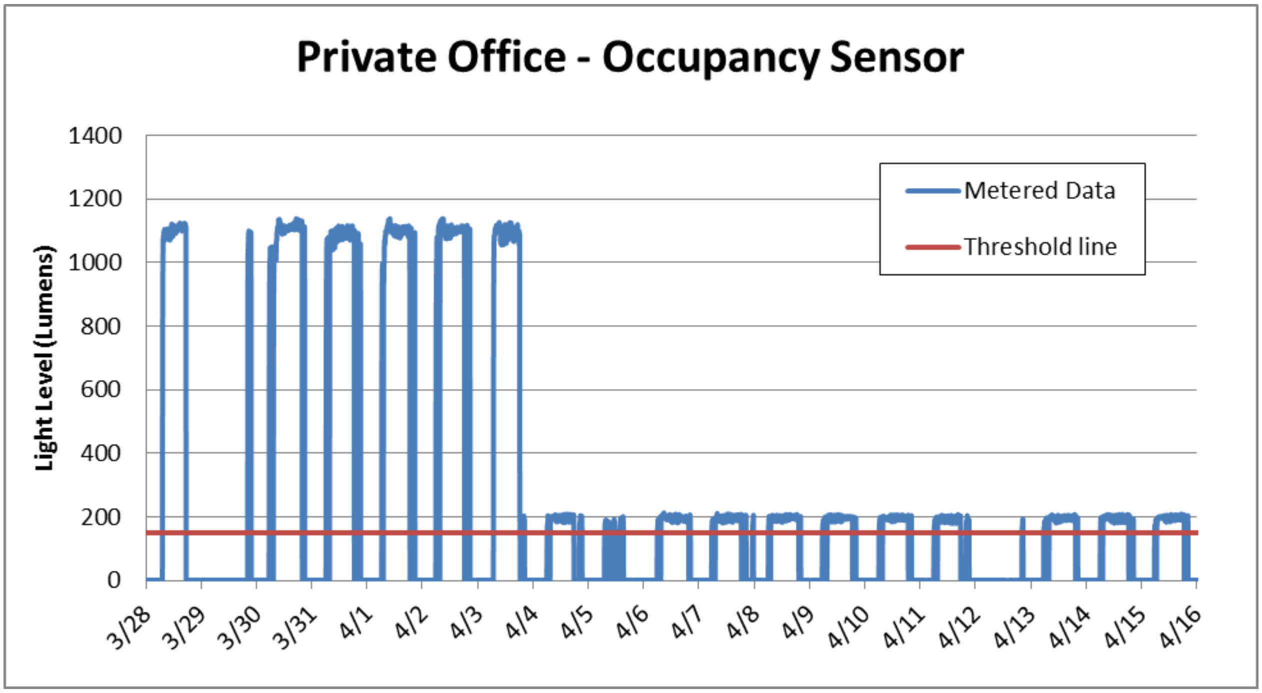
The figure below presents the data from a warehouse with individual occupancy sensors on light fixtures. This logger picked up large amounts of daylight, which appears as the pyramid shapes in the metered data. The pyramid shapes can be seen on the weekends starting at about 1 lumen and increasing up to around 10 lumens. This is also the same point at which the threshold has been set to capture the lights operating. During the weekdays when the lights are on and the sunlight is present, the lumen level increases to over 20 around 3 PM each day. Due to the daylighting lumen levels being brighter or greater than the light fixtures themselves, the fixture operation cannot be reliably determined.

Figure B-4: Warehouse - Occupancy Sensor



The figure below presents the data from a private office with an occupancy sensor. Part way through the metering period, the lumen level intensity sharply reduced. Under further inspection it appears that either one of the two lamps in the fixture burned out or the logger moved. The logger no longer had a direct line of sight to the bulb, reducing the lumen level intensity. The metered data, even at the lower intensity, follows the same profile; therefore, the lighting operation can still be reliably identified.

Figure B-5: Private Office - Occupancy Sensor



APPENDIX D: REDUCTION FACTOR SCENARIOS SUMMARY

This document details how EMI Consulting calculated the reduction factor (RF), the reasons why the RF differs by scenario, and our recommendation on which RF scenario is most representative for Energy Trust.

Ultimately, EMI Consulting recommends **using the "Expected Controls (including non-operating controls) vs. Lighting-Only Measures (without controls)" scenario with a reduction factor of 0.38.** This scenario takes into consideration that some controls installed may eventually become non-operational. This scenario uses lighting hours of use from lighting-only measures that did not have any controls (including unexpected controls). EMI Consulting considers this scenario to be most representative of what Energy Trust can expect from lighting controls going forward.

HOU Analysis and Reduction Factor Calculations

Before discussing hours of use findings and reduction factor calculations, it is best to describe the factors used to classify measures. There were three separate factors that were used to group measures:

- Program incentivized **lighting controls measures** vs. program incentivized **lighting measures**
- Measures with an **operating lighting control** vs. Measures with **no lighting control**
- Measures within **controls projects** vs. Measures within **lighting-only projects**

Note that controls projects include controls-only projects and projects with both controls and lighting measures.

Table 5-3 shows a representation of the six measure groups that were created based on the three factors above. For example, C2 represents the 144 lighting measures that did not have an operating control and that were in control projects. C1 represents the 40 incentivized control measures that did not have an operating control during the metering period (i.e. the controls were removed or broken). A2 and B represent the lighting measures that had a non-program, unexpected control that was operating during the metering period. Table 5-4 shows the distribution of these groups by program.

Table 5-3. Representation of Measure Groupings and Logger Counts per Group

		Control Projects (Number of Loggers)	Lighting-Only Projects (Number of Loggers)
Controls Measures	Operating Control	A1 (n=737)	-
	Non-Operating Control	C1 (n=40)	-
Lighting Measures	Non-Program Control	A2 (n=9)	B (n=63)
	No Control	C2 (n=144)	D (n=184)

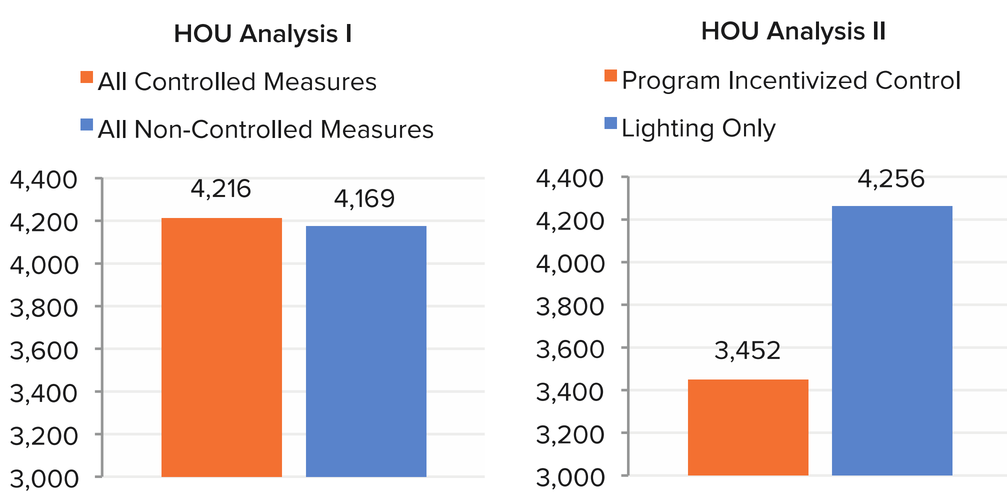
Table 5-4. Number of Loggers by Control Grouping and Program

Control Grouping	Program (Number of Loggers)		
	Existing Buildings	New Buildings	Production Efficiency
A1: Program Operating Controls	425	31	281
A2: Non-program Operating Controls, Control Projects	8	0	1
B: Non-program Operating Controls, Lighting-Only Projects	49	3	11
C1: Program Non-operating Controls	29	0	11
C2: Lighting Only Measures, Control Projects	106	5	33
D: Lighting Only Measures, Lighting-Only Projects	137	0	47

Metered HOU Analysis

As shown in Figure 5-2, controlled measures (A1 + A2 + B) had slightly higher hours of use than non-controlled measures (C1 + C2 + D), although the difference was not large. However, when only considering program measures (A1 for controls and C2 + D for lights), controlled measures had lower hours of use (3,452 hours per year) as compared to non-controlled measures (4,256 hours per year).

Figure 5-2. Comparing Two HOU Results (Note: Axis begins at 3,000 hours and not 0 hours)



Reduction Factor Calculation

First, the research team normalized the metered hours for each measure by the site's reported operating hours, as shown in Equation 5. This "hours ratio" is expected to be about 1.0 for lighting measures (indicating that lights are on during operating hours) and less than 1.0 for controls measures (indicating that controlled lights are off during some operating hours).

Equation 5. Hours Ratio

$$Hours\ Ratio = \frac{Metered\ Hours}{Site\ Operating\ Hours}$$

Next, the hours ratios were aggregated by the measure groupings described above to create different RF scenarios. For each scenario, the groupings were split into "control measures" and "no control" measures. Not all groupings were used for each scenario. Average hours ratios were weighted by the circuit wattage reported for each measure. Equation 6 below shows the revised formula for the reduction factor.

Equation 6. Revised Reduction Factor Calculation

$$Average\ Hours\ Ratio_{Group} = \frac{\sum_i Circuit\ Wattage_i * Hours\ Ratio_i}{\sum_i Circuit\ Wattage_i}$$

$$Reduction\ Factor = 1 - \frac{Average\ Hours\ Ratio_{Controls\ scenarios}}{Average\ Hours\ Ratio_{No\ Controls\ scenarios}}$$

As shown in Table 5-5. Results for Hours Ratio by Measure and Project Groups lighting-only measures within controls projects had a high hours ratio (1.38), indicating that actual lighting hours of use were greater than the site's operating hours. The hours ratio for operating program controls were found to be low (0.71), indicating that the measured hours of use is less than site's operating hours.

Table 5-5. Results for Hours Ratio by Measure and Project Groups

Measure Type	Type of Control Found	Control Projects	Lighting-Only Projects
Control Measures	Operating, Program Control	0.71	N/A
	Non-Operating, Program Control	0.85	N/A
Lighting Measures	Non-Program Control	0.99	0.97
	No Control	1.38	0.94
Overall Hours Ratio		0.89	

Reduction Factor Scenarios

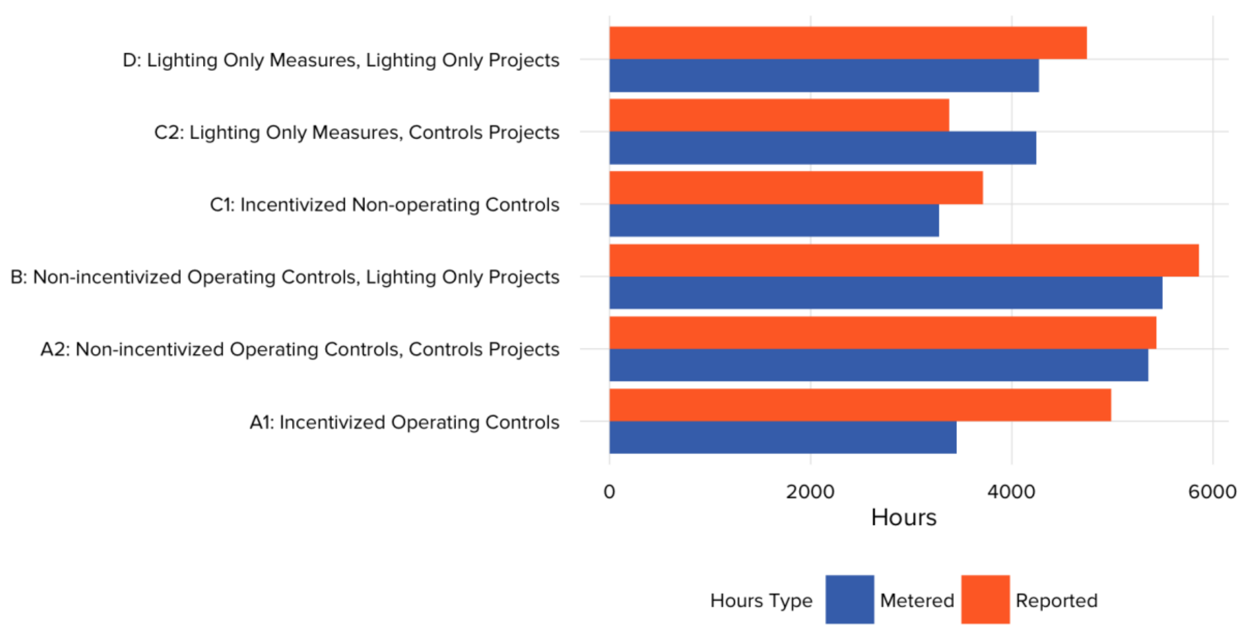
The research team conducted many reduction factor scenarios and found reduction factors in the range of 0.24 to 0.39. For each scenario, the methodology and calculation remained the same; the only changes involved the measure groupings that were included in the controls grouping and no controls grouping. Table 5-6 displays each RF scenario, the measure grouping used, and the overall reduction factor.

Table 5-6. Measure Groupings and Overall Reduction Factor for All Reduction Factor Scenarios

Scenario	Controls Grouping	No Controls Grouping	Reduction Factor
All Controls vs. All Lights	A1 + A2 + B	C1 + C2 + D	0.31
Working Program Controls vs. All Lights	A1	C1 + C2 + D	0.38
Expected Controls vs. All Lighting-Only Projects	A1 + C1	A2 + B + C2 + D	0.36
Working Program Controls vs. All Lighting-Only Projects	A1	A2 + B + C2 + D	0.36
Working Program Controls vs. Lighting-Only Measures	A1	C2 + D	0.39
Working Program Controls vs. Lighting-Only Measures	A1	D	0.24
Expected Controls vs. Lighting-Only Projects	A1 + C1	B + D	0.24
Working Program Controls vs. Lighting Measures w/ no Control OR in Lighting-Only Project	A1	B + C2 + D	0.37
Working Program Controls vs. Lighting-Only Measures in Lighting-Only Projects OR Expected Controls w/ no Operating Control	A1	C1 + D	0.24
Expected Controls (including non-operating controls) vs. Lighting-Only Measures (without controls) **[EMI Consulting Recommended Scenario]**	A1 + C1	C2 + D	0.38

Note that any scenario that did not include the C2 group generally has a lower reduction factor. As shown in Figure 5-3, the C2 grouping (lighting measures with no operating control in controls projects) generally had higher metered HOU but low reported HOU, indicating that lights were operating for significantly more hours than was expected. This is particularly true for Production Efficiency participants.

Figure 5-3. Comparison of Metered to Reported Hours of Use by Control Groups



Including C2 in the no controls grouping results in higher reduction factors because the calculation adjusts for the fact that these participants have lights that are turned on for much longer than the reported operating hours. Because inclusion of the C2 group impacts overall reduction factor results, EMI Consulting reviewed C2 for any possible explanation or bias that would warrant its exclusion from overall results. For example, Table 5-7 shows a comparison of the distribution of space types for measure group C2 and measure group D (lighting measures with no control). EMI Consulting did not observe significant tendencies towards space types that are required to have lights on all the time. EMI Consulting also carefully reviewed the data for consistency and outliers and determined that the C2 group results are reliable and should not be removed from the analysis.

Table 5-7. Space Type Distribution by Control Groups C2 and D

Space Type	C2	D
Office - Open	12%	5%
Storage	12%	8%
Hallway	10%	5%
Lobby	9%	3%
Stairs	8%	0%
Conference	6%	2%
Industrial	6%	2%
Other	6%	15%
Office - Private	6%	4%
Warehouse	4%	4%
Parking Garage	3%	0%
Restroom	3%	2%
Retail	3%	16%
Process	3%	4%
Break Room	2%	3%
Classroom	2%	4%
Technical Area	1%	2%
Assembly	1%	19%
Kitchen	1%	2%
Lodging (Guest Rooms)	1%	0%
Dining	0%	1%

Reduction Factor Scenario Recommendations

EMI Consulting understands that the RF is intended to inform a best estimate for the average lighting hours of use reduction that can be expected when the program incentivizes a lighting control. As such, the research team recommends using the "Expected Controls (including non-operating controls) vs. Lighting-Only Measures (without controls)" scenario with a reduction factor of 0.38. This scenario takes into consideration that some controls installed may eventually become non-operational. This scenario uses lighting hours of use from lighting-only measures that did not have any controls (including unexpected controls).