Pennsylvania Statewide Act 129 2014 Commercial & Residential Light Metering Study

Prepared for:

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research into action

APEX ANALYTICS

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LIST OF ACRONYMS

CF	Coincidence factors
C_v	Coefficient of variation
DUQ	Duquesne Light Company
EDC	Electric distribution companies
EE	Energy efficiency
EFLH	Equivalent full load hours
˚F	Degrees Fahrenheit
GWh	Gigawatt Hours
HID	High Intensity Discharge
HOU	Hours of use
IF	Interactive Factors
kW	Kilowatt
kWh	Kilowatt Hour
Met-Ed	Metropolitan Edison Company
MWh	Megawatt Hour
NAICS	North American Industry Classification System
PECO	PECO Energy Company
Penelec	Pennsylvania Electric Company
Penn Power	Pennsylvania Power Company
PPH	People per household
PPL	PPL Electric Utilities Corporation
PUC	Public Utility Commission
RBS	Residential Baseline Study
RLS	Residential Light Metering Study
SAS	Statistical Analysis System
SFD	Single Family Detached
SIC	Standard Industrial Classification
SWE	Statewide Evaluators
The Act	Act 129 of 2008
The Baseline Study	Non-Residential End-Use & Saturation Study
TRC	Total Resource Cost
TRM	Technical Reference Manual
TUS	Technical Utility Services
WPP	West Penn Power Company

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1 EXECUTIVE SUMMARY

1.1 OVERVIEW

GDS Associates, Inc. (GDS), Nexant, Inc. (Nexant), Research Into Action, Inc.(Research Into Action), and Apex Analytics LLC (Apex Analytics) – collectively known as the Statewide Evaluation (SWE) Team – have been contracted by the Pennsylvania Public Utility Commission (PUC) to perform a light metering study for the State of Pennsylvania and its seven largest electric distribution companies (EDCs). The EDCs included as part of this study are listed below:

- Duquesne Light Company (DUQ)
- Metropolitan Edison Company (Met-Ed)
- Pennsylvania Electric Company (Penelec)
- Pennsylvania Power Company (Penn Power)
- West Penn Power Company (WPP)
- PPL Electric Utilities Corporation (PPL)
- PECO Energy Company (PECO)

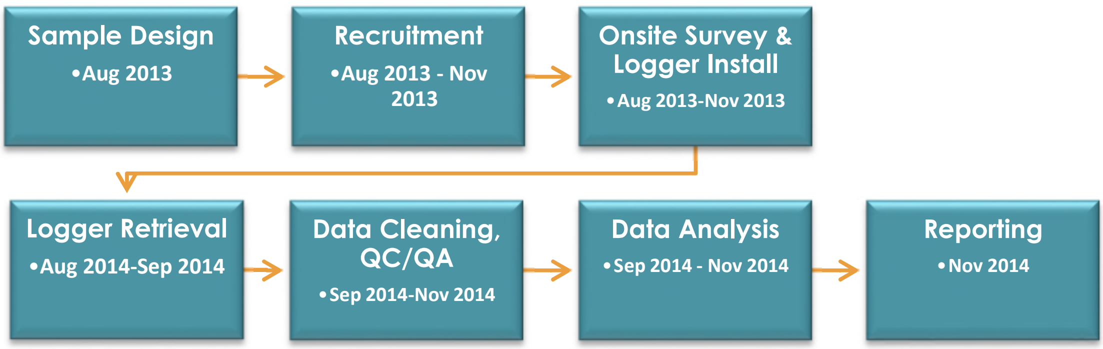
The purpose of this study was to provide updated lighting load profile information to the PUC to assist in the calculations of electric peak demand and energy savings for lighting energy efficiency (EE) programs in Pennsylvania. Specifically, this report presents lighting load shapes, coincidence factors (CFs), hours of use (HOU), and HVAC interactive factors (IFs).

This study is designed to serve as a stand-alone study, supplying information useful for EE program development, system planning, program evaluation and obtaining a general understanding of the lighting equipment present in Pennsylvania. To accomplish these goals, the SWE conducted a lighting metering survey of Pennsylvania residential and non-residential customers to gather accurate lighting load profile data that is specific to Pennsylvania and the seven EDC service territories included in this study.

1.1.1 Residential Light Metering Overview

Figure 1-1 shows the main tasks completed during the conduct of the Residential Light Metering Study.

Figure 1-1: Residential Light Metering Study Key Tasks



Sample design consisted of determining the number of participating homes and light loggers that would be necessary to achieve the goals of the Study. Recruitment was conducted by using a stratified sampling approach with a recruitment frame of 2,100 residential consumers from each EDC. Participants were recruited via email and telephone over a four month period. A total of 216 homes were recruited to participate in the Study. An $80 incentive was offered for participation split into two $40 payments. The participant received the first half at the time of logger installation and the second half at the time of logger retrieval, assuming at least one logger was retrieved.

Once onsite, SWE field technicians completed a detailed survey of lighting sockets. They collected counts of bulbs by room type, bulb type (CFL, incandescent, tube fluorescent, etc.) control type (e.g., dimmer switch), and wattage. Light sockets were randomly selected to be metered using a randomization algorithm programmed into a tablet carried by the field technicians. Loggers were carefully installed to ensure the meters measured the status of the light of interest but did not receive interference from ambient light. Finally additional data was collected on the specific lights metered in the Study including homeowner estimates of the hours they use each metered light socket per day. A total of 1,482 loggers were installed in the 216 participating homes, an average of 6.9 loggers per home.

Logger retrieval began a year after initial onsite visits began. On average, the loggers were left in participating homes for ten months. Multiple efforts were taken to achieve maximal success in recovering the loggers. The SWE team was able to recover some or all of the loggers from 206 (95%) of the 216 participating homes. Of the 1,482 loggers originally installed by the SWE team, 92% or 1,368 were successfully recovered.

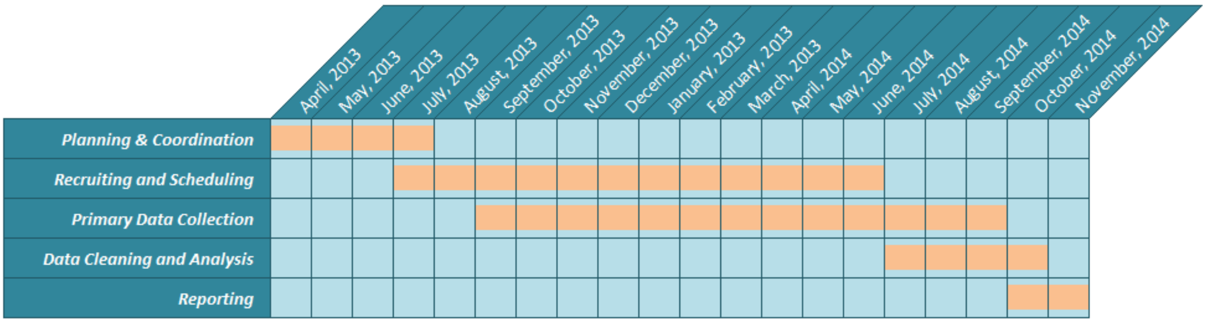
Data cleaning consisted of downloading all logger data, evaluating if the data on the loggers was fit for use, and examining outliers. Of the 1,368 loggers recovered, a final database of 1,191 loggers was used for analysis. Details on the number of loggers excluded for various reasons are provided in Chapter 3 of the report.

Data analysis consisted of generating weighted HOU and CF estimates by room type and for the total home. Weights were created for each logger that takes into account home type, room type, bulb efficiency, and EDC. For HOU estimating, a sinusoidal model was developed for each logger to annualize the usage data. Then, a hierarchical linear model was run to account for covariance in in-home lighting consumption between loggers installed in the same home. This model was used to estimate HOU by room type. For CF estimation, no sinusoidal annualization of data was necessary, since most loggers captured information for most of the on-peak summer hours. Like the model for estimating HOU, a hierarchical model was developed to estimate CF.

1.1.2 Commercial Light Metering Overview

The five main tasks of the Commercial Light Metering Study were completed according to the timeline shown in Figure 1-2.

Figure 1-2: Commercial Light Metering Study Timeline of Key Tasks



Planning and coordination consisted of the EDC data request and selection of a sample frame. From the sample, prospective participants were contacted via mail, email, and phone to solicit their inclusion in the Study. Recruiting and scheduling of participants was a rolling process that typically occurred two to three weeks ahead of the allotted site visit time.

Primary data was collected from September, 2013 through September, 2014. The data collection involved the installation of over 2,300 light loggers at 498 facilities across the state. Each participating site received a general survey and a complete lighting inventory using Nexant's iEnergy® Onsite, a mobile energy assessment and data collection application. Up to six loggers were installed at each site for a minimum of 45 days, at which point the loggers could be mailed back, or manually retrieved by a field engineer.

Once all loggers were retrieved, the SWE team calculated the targeted values of this Study using Statistical Analysis System (SAS) software in conjunction with Microsoft Excel. Data was evaluated within a statewide context and the context of each building type. The calculated values included lighting and controls technology trends, lighting load shapes, HOU, CF, and IF.

The information gathered from the Residential and Commercial Light Metering Study will be used to update assumptions tied to energy and demand savings calculations in the 2016 Technical Reference Manual (TRM). Furthermore, the data will help shape future programs by serving as a new holistic resource for Total Resource Cost (TRC) tests, as well as the "2014 Technical Economic Achievable Potential Study", a tool designed and used to inform the planning and implementation of Phase III of Pennsylvania's Act 129 energy efficiency goals.

1.2 STATEWIDE FINDINGS AND RESULTS

This section provides a basic overview of the findings and results that will be presented in detail throughout this report.

1.2.1 Residential Findings

Key results of the Residential Light Metering Study are summarized in Table 1-1 and Table 1-2. Overall, residents of Pennsylvania use lights an average of 2.5 hours per day. HOU are highest for exterior lights, kitchen lights, and living room lights. Closets observed the lowest HOU out of all room types by far, with less than one hour of use per day. The statewide CF for a residential home is 0.101, with kitchens, dining rooms, and exterior lights having the highest CF.

Efficient bulbs, defined as CFL and LED lights, have a statistically higher average HOU than all bulbs, but not a statistically different CF. Efficient bulbs are used an average of 3.0 hours per day statewide while non-efficient bulbs are used an average of 2.3 hours per day.

Table 1-1: Residential Statewide Average Hours of Use Per Day

Room Type	No. Loggers	Average HOU	90% CI
Basement	80	1.7	(1.0 , 2.4)
Bathroom	151	2.3	(1.8 , 2.8)
Bedroom	147	1.8	(1.4 , 2.2)
Closet	77	0.6	(0.4 , 0.9)
Dining Room	114	2.7	(2.2 , 3.2)
Exterior	58	3.9	(3.1 , 4.7)
Hall/Foyer	125	1.9	(1.4 , 2.4)
Kitchen	142	3.9	(3.3 , 4.5)
Living Room	147	3.7	(3.1 , 4.2)
Other	150	1.7	(1.4 , 2.0)
Home - All Bulbs	***206***	***2.5***	***(2.4 , 2.6)***
Efficient Bulbs	***518***	***3.0***	***(2.7 , 3.2)***
Non-Efficient Bulbs	***673***	***2.3***	***(2.1 , 2.5)***

Table 1-2: Residential Statewide Average Coincidence Factor

Room Type	No. Loggers	Average CF	90% CI
Basement	80	0.066	(0.042 , 0.091)
Bathroom	151	0.096	(0.073 , 0.119)
Bedroom	147	0.064	(0.044 , 0.085)
Closet	77	0.029	(0.011 , 0.046)
Dining Room	114	0.108	(0.080 , 0.136)
Exterior	58	0.265	(0.192 , 0.338)
Hall/Foyer	125	0.076	(0.050 , 0.101)
Kitchen	142	0.142	(0.115 , 0.170)
Living Room	147	0.098	(0.073 , 0.123)
Other	150	0.061	(0.044 , 0.079)
Home	***206***	***0.101***	***(0.097 , 0.105)***
Efficient Bulbs	***518***	***0.106***	***(0.095 , 0.116)***
Non-Efficient Bulbs	***673***	***0.099***	***(0.086 , 0.112)***

1.2.2 Commercial Findings

Key results of the commercial component of the Light Metering Study are summarized below in Table 1-3.

Table 1-3: Commercial Light Metering Study Key Results

	Hours of Use (HOU)		Coincidence Factor (CF)		Interactive Factor (IF)	
Building Type	Screw-Based Bulbs	General Service Ltg.	Screw-Based Bulbs	General Service Ltg.	Energy	Demand
Education	2,944	2,371	0.39	0.45	1.84%	12.34%
Grocery	7,798	6,471	0.99	0.93	-1.36%	19.24%
Health	2,476	2,943	0.47	0.52	-2.17%	19.41%
Institutional/Public Service	1,456	1,419	0.23	0.23	2.68%	16.57%
Lodging	2,925	3,579	0.38	0.45	-7.12%	19.63%
Miscellaneous	2,001	2,830	0.33	0.58	-0.08%	21.61%
Office	1,420	2,294	0.26	0.48	3.14%	22.64%
Restaurant	3,054	4,747	0.55	0.77	-7.15%	19.32%
Retail	2,383	2,915	0.56	0.66	-2.56%	21.53%
Warehouse	2,815	2,545	0.50	0.48	2.65%	19.89%

Throughout this report, key results and findings will be presented on both the statewide and building-type levels. Section 4.2 presents the details of the findings evaluated statewide, which include:

- Lighting equipment saturations
- Lighting controls saturations
- Comparison of 2014 and 2016 HOU values
- Comparison of 2014 and 2016 CF values

Section 4.3 presents the details of the findings evaluated per building type, which include:

- Lighting equipment trends
- Lighting controls prevalence
- Building type-specific load shapes
- HOU for both screw-in and other general service fixtures
- CFs for both screw-in and other general service fixtures
- IFs for both energy and demand

2 INTRODUCTION

2.1 ACT 129 BACKGROUND

On October 15 of 2008, Governor Rendell signed HB 2200 into law as Act 129 of 2008 (the Act), with an effective date of November 14 of the same year. The Act imposed new requirements on EDCs, with the overall goal of reducing energy consumption and demand. Under the Act, all EDCs with at least 100,000 customers were directed to develop and deliver energy efficiency programs that reduce their electric load. The Phase II Implementation Order is the current governing iteration of the Act, with the PUC currently considering energy and demand reduction targets for the possible implementation of Phase III of Act 129, slated to start June 1 of 2016. Phase II specifically required the costs and benefits of the developed programs to be evaluated via the TRC test by November 30 of 2013 and every five years thereafter.

2.2 STUDY OVERVIEW

As part of Act 129, the PUC supplies all EDCs bound by the Act with a TRM which is used to identify energy efficiency measure offerings, and to quantify their associated energy and demand savings. Since the programs' inception in 2009 the savings assumptions for lighting measures, such as HOU values and coincidence with system peak have been taken from secondary research based on studies conducted in other jurisdictions with several daisy-chained references. As the SWE team, GDS and Nexant were asked to perform a light metering study in order to update the measure assumptions used in the calculation of savings. Using primary data collection coupled with detailed load shape analyses, the SWE team developed Pennsylvania-specific results for inclusion in the 2016 TRM.

2.3 STUDY GOALS

This Light Metering Study aims primarily to serve as a stand-alone end use study, supplying information useful for EE program development, TRM improvement, system planning, and obtaining a general understanding of the lighting equipment presently in use across Pennsylvania. With consideration for these ultimate uses of this research, the following goals have been identified for this Study:

- Create unique load shapes for residences and common commercial building types in Pennsylvania.
- Update the lighting HOU for residences and common commercial building types.
- Update the lighting CFs for residences and common commercial building types.
- Update the HVAC IFs for comfort cooled spaces in common commercial building types.

In addition to supplying information for EE program development, the Study will also provide reasonable, defensible results to inform the potential study and facilitate improved system planning.

2.4 ORGANIZATION OF THE REPORT

The remainder of this report includes the following sections:

- **Section 3** – Residential Light Metering Study Methodology & Findings
- **Section 4** – Non-Residential Light Metering Study Methodology & Findings
- **Section 5** – Concluding Remarks
- **Appendices** – The appendices at the end of this report include detailed inputs into the calculation of energy and demand interactive factors as well as 8760 load shapes created for the residential sector, and all ten building types detailed in the commercial component of this Study.

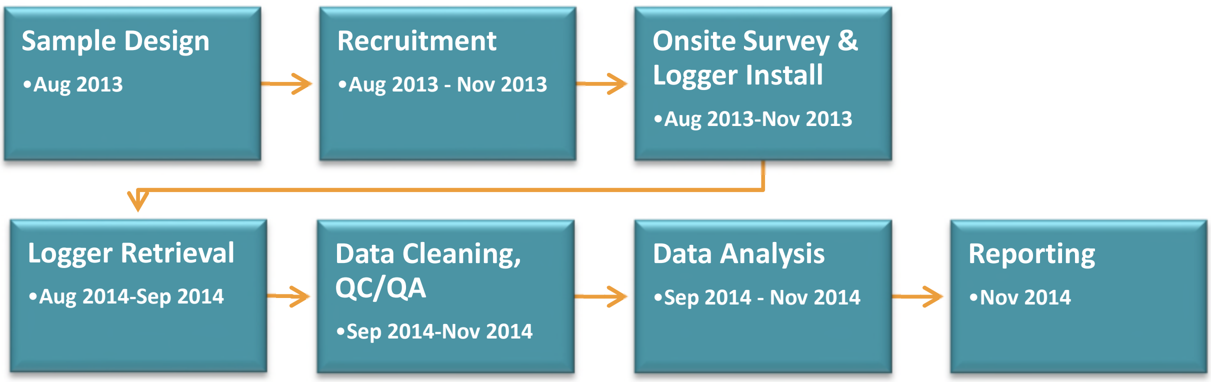
3 RESIDENTIAL LIGHT METERING STUDY

3.1 RESIDENTIAL STUDY OBJECTIVES AND METHODOLOGY

At the request of the PUC, the SWE has conducted a Residential Light Metering Study (RLS). The findings from the lighting study will serve to inform TRM assumptions and algorithms in support of TRM revisions for residential-sector lighting measures. The RLS will provide more accurate values for HOU and CF than the current values in the TRM that are based on secondary research. Furthermore, the measured HOU and CF values developed from the RLS will be used to inform lighting assumptions in the Residential Energy Efficiency Potential Study for Pennsylvania.

Figure 3-1 below presents a high-level overview of the key tasks that have been undertaken to complete the RLS. The process spans 15 months since project inception to release of the report. For several of the early steps in the Study, the SWE team elected to coordinate the efforts for the RLS with the Residential Baseline Study (RBS) as many of the tasks could be shared to maximize project efficiency and reduce the possibility of customer fatigue or confusion related to contacting them multiple times for two independent projects.

Figure 3-1: Overview of Steps for Residential Light Metering Study



3.2 SAMPLE DESIGN

The RLS sample design was a clustered data design, in which each participating home was recruited from a stratified random sample and then individual lighting sockets within the home were randomly selected to be metered. In such a clustered approach, the design parameter is the home and not the light meter. This means that, if a single home has 8 light meters deployed, the sampling unit is still one home when measuring HOU or CF. Given cost constraints associated with the amount of time the loggers were in the field, the SWE team designed a sample that provides 90% confidence with ±15% precision. The SWE team assumed a coefficient of variation (C_v) of 1.0 for lights within a given room type and a C_v of 1.3 for the total home, since lighting HOU were expected to vary more between room types rather than within a room type.

Equation 3-1: Required Sample Size Calculations

$$n_0 = \left(\frac{z * C_v}{D}\right)^2$$

Where:

n_0 = The required sample size before adjusting for the size of the population
Z = A constant based on the desired level of confidence. Equal to 1.645 for 90% two-tailed test
C_v = Coefficient of variation (standard deviation/mean)
D = Desired relative precision

The sample included a total of 200 homes, split between single family and multifamily residences. Assuming slightly fewer than 8 loggers per home (to allow for some homes with few fixtures or the site evaluator's inability to enter rooms), the plan called for 1,560 loggers to be installed. The SWE team identified a wide array of room types in which to target logger installations, with a higher design precision being used for higher socket saturation rooms. The sample design by room type is displayed in Table 3-1. Given that the loggers would be in homes for nearly a year, the SWE team built in a 15% attrition rate into the design sample sizes by room.

Table 3-1: Proposed Sample Size and Confidence/Precision by House and Room Type

Room Type	Estimated Socket Saturation[1]	Number of Homes	Precision (at 90% Confidence)[2]
Media/Bonus Room	6%	120	16%
Bathroom	13%	160	14%
Bedroom	15%	160	14%
Closet	3%	100	17%
Dining Room	6%	100	17%
Foyer/Hallway	7%	120	16%
Garage	5%	100	17%
Kitchen	11%	160	14%
Living Room	11%	160	14%
Office/Den	4%	100	17%
Unfinished Basement/Attic/Other	10%	140	15%
Exterior	10%	140	15%
Total Number of Homes	**100%**	**200**	**15%**
Total Number of Loggers		***1,560***	

1 - Based on the 2012 Pennsylvania Statewide End-Use Saturation Study, GDS Associates, with Nexant and Mondre Energy.
2 - Assumes a C_v of 1.3 for the home (total line) and a C_v of 1.0 per room type.

3.3 RECRUITMENT

As described above, several tasks of the RBS and RLS were performed concurrently, including recruitment. A single recruitment list of 2,100 randomly selected residential accounts from each EDC was used for recruitment for both studies. The sample frame was selected by sorting a full 2013 residential customer billing history by home type and 2013 average monthly kWh usage. Then, 2,100 customers for each EDC were selected from the full list using a random skip pattern. With seven EDCs, then, a total recruitment frame of 14,700 customers was developed.

The next step in the recruitment process was to design a letter to inform customers in the initial recruitment frame that an energy survey was to be performed in their area and that a SWE team representative would potentially contact them to request participation in the study. The primary recruitment letter was sent under the name and letterhead of each representative EDC. Next, a phone recruitment script was designed to introduce the study to the residential homeowner, explain the process and demands of the onsite and light metering surveys, and ask for participation in either or both of the studies.[1] In order to facilitate recruitment, the SWE team offered an $80 incentive to homeowners who participated in the RLS.

In order to ensure a representative mix of housing types and electricity usage in the study sample, the SWE team stratified each EDC's recruitment sample by housing type and monthly energy usage and divided the sample into bins for recruitment. Once a homeowner from a given bin agreed to participate in the light metering study, the SWE team did not actively recruit the remaining residences in that bin. The SWE team would attempt to contact customers a maximum of three times before considering an account a non-participant in the study. For the RLS, there were no difficulties in recruiting a representative from each of the recruitment sample bins.

As an example, a total of 29 participating homes were required in DUQ's service territory. First, DUQ's 2,100 customer recruitment frame was sorted by home type (single family attached, single family detached, multifamily, and manufactured) and then by average 2013 kWh usage. The stratified sample design called for 18 of those 29 homes to be single family detached homes. There were 1,290 single family detached homes in the recruitment frame, therefore, each bin for the single family detached segment of DUQ's recruitment frame included 1,290 ÷ 18 = 71 customers (with 12 bins having 72 customers). The recruiters then focused on securing participation from 1 of the 71 customers in each bin, ensuring both a representation by home type and by average usage. As shown in the example below, one participant from Bin 1 was recruited ensuring a participant with a single family detached home and average usage in the range of 213 to 442 kWh per month. One participant was also recruited from Bin 2 to represent a single family detached home with usage between 475 and 626 kWh per month.

Table 3-2: Example Recruitment Frame with Bin Identifiers

No. in Bin	Customer Name	Telephone	Address	Home Type	Average Usage (kWh)	Bin No.
1	Jane Doe	999-999-9999	123 XYZ Ave.	SFD	312	1
2	Joe Smith	888-888-8888	456 MAIN St.	SFD	315	1
3	Alex James	111-111-1111	732 WEST Rd.	SFD	378	1
71	Mike Jones	444-444-4444	182 MIGGS Dr.	SFD	442	1
1	Sally Beth	333-333-3333	888 ROSE Blvd.	SFD	475	2
2	Tom Shu	777-777-7777	7183 13TH St.	SFD	477	2
3	Jamie Dill	666-666-6666	418 JUNIPER SE	SFD	492	2
71	Scott Dukes	555-555-5555	101 RED OAK Rd.	SFD	626	2

In order to fulfill the sample requirements for both the RBS and the RLS, a total of 6,010 (41%) of the 14,700 customers in the recruitment frame were contacted across the state. Recruitment and onsite visits were conducted within a week of each other. Because of this timing design, recruitment and onsite

[1] A sample of the initial recruitment letter and the telephone recruitment script were provided in the Appendices to the *2014 Pennsylvania Statewide Act 129 Residential Baseline Study*, GDS Associates, Inc., April 2014.

surveys were conducted one EDC at a time, with a three week focus spent on each EDC before moving to the next. During this EDC-by-EDC process, not all bins were filled for the RBS but were filled for the RLS. After the first recruitment and onsite sweep across the state, a second round of recruitment was conducted to fill the missing bins in all EDCs for the RBS. During this secondary recruitment phase, the SWE team elected to allow any of those remaining homes to participate in the RLS if they wished to do so in order to allow for installation of more loggers. As a result, participation in the RLS exceeded the original design of 200 homes by 8%, totaling 216 participating homes.

Table 3-3: Survey Recruitment Results

EDC	Customers Contacted	Lighting Metering No. Homes	No. of Light Loggers Installed
DUQ	576	32	200
Met-Ed	1,207	32	226
Penelec	791	31	206
Penn Power	802	25	184
WPP	827	32	222
PECO	797	31	217
PPL	1,010	33	227
Total	***6,010***	***216***	***1,482***

3.4 Onsite Survey and Logger Installation

Data was collected onsite for both the RBS and RLS from August through November of 2013. A site visit in which the homeowner participated in both studies entailed five steps:

- Primary data collection
- Random selection of logger placement
- Additional data collection for lights metered in the RLS
- Installation of loggers
- Incentive payment

This section provides details on the initial data collected during the onsite visits and installation of the light loggers.

3.4.1 Primary Data Collection

The primary data collection process collected all the data necessary to complete the RBS. The SWE technician performed an exhaustive inventory of energy using equipment, home characteristics, demographics, and customer attitudes on specific topics and recorded the information in tablets. The data was then automatically backhauled to the SWE team's survey databases any time the tablet was connected to a wireless signal (at least daily).

The primary data collection included an accounting for all lighting sockets and light bulbs inside and external to the home. Specific information included socket type, type of bulb (incandescent, CFL, tube fluorescent, etc.), any kind of control for the light (such as a dimmer switch or occupancy sensor), and wattage. Once this step of the survey was completed, the tablet's internal database had an accounting of rooms and light types that could be eligible for metering in the RLS.

3.4.2 Randomized Selection of Rooms and Sockets for Loggers

Once all of the primary data was collected, a randomization algorithm selected specific room and light types to meter for the RLS. The randomization algorithm took into account the number of loggers needed for each room type from the sample design phase and produced a random assignment of sockets for metering. If the technician was unable to meter the selected light due to physical constraints or homeowner refusal, then the technician had the ability to have the algorithm select a new randomly assigned socket for metering. Each day, as the RBS and RLS data was backhauled to the SWE database, the probabilities for selecting rooms were adjusted to reflect the counts attained to that point. The algorithm was adaptive to allow for selection of rooms based on the sample design and the number of loggers already installed to that date by each room type.

Rooms were assigned based on use of the space in which the light resides. For instance, a desk lamp in a kitchen nook would be assigned as an office if that nook was used as an office by the homeowner. Furthermore, finished basements were recorded as separate rooms based on usage by the homeowner as well.

One of the goals of the RLS was to determine if HOU and/or CF were significantly different for efficient versus non-efficient bulbs. Therefore, in order to ensure a large enough sample of efficient bulbs, the algorithm attempted to select efficient bulb types for at least four of the six to ten light loggers installed within a home. The goal was to have approximately half of the meters recording data on efficient bulbs when in fact efficient bulbs make up 25% of the statewide socket count.

As the installation process unfolded, it became obvious that some room types would not be encountered often enough within the 200 homes in order to meter the number of lights from that room type from the sample design. Specifically, bonus rooms, garages, and offices were not being metered at a rate that would result in achieving the original sample targets for those room types. Therefore, technicians were directed to continue to log those room types as much as possible and the algorithm was adjusted to call for more of the higher saturation room types such as kitchens, living rooms, bedrooms, and bathrooms to ensure enough total loggers were installed within the budget constraints of the project. As shown in Table 3-4, the actual number of meters installed for media/bonus rooms and garages were much lower than the design target. The SWE team recognized that these rooms would have to be grouped into an “other” category during the data analysis stage of the study.

Table 3-4: Logger Installations by Room Type

Room	Design Sample Size	No. Installed	% of Design
Media/Bonus Room	120	35	29%
Bathroom	160	179	112%
Bedroom	160	186	116%
Closet	100	89	89%
Dining Room	100	130	130%
Foyer/Hallway	120	152	127%
Garage	100	53	53%
Kitchen	160	172	108%
Living Room	160	177	111%
Office/Den	100	75	75%
Unfinished Basement/Attic/Other	140	120	86%
Exterior	140	114	81%
TOTAL	1,560	1,482	95%

3.4.3 Data Collection Specific to the RLS

Once the specific sockets to meter had been selected, additional data collection was required specific to the lights being metered. The technicians recorded the logger serial number, specific instructions on where to find the logger to make retrieval more efficient, bulb type, wattage, and asked the homeowner to estimate how many hours a day they think they use that specific socket. As will be described later in the chapter, the estimates on hours of use were used during data analysis as a means to assess potential outliers in the database.

3.4.4 Installation of the Loggers

Figure 3-2: Light Logger used in the Study

The SWE team used Dent Instruments' LIGHTINGlogger 4G devices for metering lighting usage in the RLS. The loggers are non-intrusive and fairly simple to install using either the logger's magnets or an electrical tie. The loggers have a photosensitive cell on the front of the device with a sensitivity dial to adjust how sensitive the device is to reception of light. Although easy to install, the biggest concern was ambient light could be picked up by the logger, inappropriately recording the light status of the bulb under study. To remedy this concern, all SWE field technicians were carefully trained with hands-on demonstrations and printed material on the proper installation of the loggers and testing for sensitivity to ambient light. Furthermore, fiber optic light pipes were available to use for certain situations in which it was difficult to eliminate the possibility of all ambient light entering the photocell. Furthermore, technicians were trained to be careful about placing loggers too close to bulbs that radiate heat, as that can cause the loggers to burn and melt. For external lights, the loggers were placed in zip lock bags to help protect from the elements.

3.4.5 Distribution of Incentive Payment

Once the loggers were deployed and the data collected, the field technician concluded with providing the homeowner with a $40 VISA reward card. The technician recorded the card number and had the participant sign acknowledging receipt of the card. Finally, the technician left a letter with the homeowner that included SWE team contact information and a request that, should the homeowner move prior to the conclusion of the study, that they contact the SWE so that arrangements could be made to collect the loggers and pay the second half of the $80 incentive.

3.5 LOGGER RETRIEVAL

The light loggers were retrieved from the homes in late August and early September 2014. As described in the sample design section, the SWE team expected a relatively high level of attrition due to the loggers being left in the field for nearly a year. However, several steps were taken to ensure the highest recovery rate possible:

1) Half, or $40, of the incentive for participating in the Study was held until after successful collection of the loggers
2) During the initial site visit, the installing technicians left a letter with the homeowner that included contact information of SWE team project managers and representatives of Market Decisions, who performed the recruitment function. The letter also instructed the participants to contact the SWE team if they were moving so that arrangements could be made to recover the loggers.
3) Approximately one month prior to scheduling for retrieval, a letter was mailed to all participants from the Project Manager reminding participants that the loggers were in place and that we would

be making arrangements to retrieve the loggers for the remaining $40 incentive. Furthermore, the letter reiterated that participants who would be moving should contact the SWE team. This letter resulted in recovery of loggers from ten homes.

4) In two instances, in which a participant had moved without having contacted the project team, efforts were made to make contact with new tenants or the building superintendent to gain access to the home to determine if loggers were still present. This effort resulted in recovery of loggers in both cases.

5) The SWE team continued to attempt to make contact, in some instances making more than five calls to try to reach a participant and schedule a time for retrieval.

6) Technicians stopped by homes in which we were unable to schedule a time for retrieval when they were close enough to do so. This approach allowed for successful collection of loggers in several homes in which contact information had changed or the scheduling team was unable to reach participants. This approach allowed us to recover an additional 179 loggers from 27 participants.

During installation, 1,482 loggers were installed in 216 homes. These loggers remained in place for nine to eleven months. Given the efforts made to ensure successful recovery of loggers, a very high percentage of loggers were recovered. A total of 1,368 loggers were recovered from 206 homes, representing a recovery rate of 92% of loggers.

Of the 114 loggers not retrieved, 62 were from the 10 homes in which the SWE team was unable to recover any loggers. For those 10 homes, multiple attempts to contact the homeowner were made and a technician stopped by the home and left a letter asking for the homeowner to contact the SWE team to make arrangements for recovery of the loggers.

Table 3-5: Logger Installation and Retrieval

EDC	No. of Homes in Study	No. of Homes Retrieved	Percent of Homes Recovered	No. Loggers Installed	No. Loggers Retrieved	Percent of Loggers Recovered
DUQ	32	32	100%	200	197	99%
Met-Ed	32	30	94%	226	206	91%
Penelec	31	31	100%	206	200	97%
Penn Power	25	25	100%	184	183	99%
WPP	32	31	97%	222	209	94%
PECO	31	26	84%	217	165	76%
PPL	33	31	94%	227	208	92%
Total	***216***	***206***	***95%***	***1,482***	***1,368***	***92%***

3.6 DATA CLEANING AND OUTLIER DETECTION

3.6.1 Quality Control and Assurance

Once the loggers were collected, data extraction and cleaning could commence. Considerable effort was undertaken to review data files and perform quality control and assurance checks on the data. Loggers with extremely frequent on/off records of short duration (flicker) were removed from the analysis database. In other instances, if flicker was apparent in only short periods of time, the flicker data was removed but other valid data for the logger was kept. With loggers in the field for such a long period of time, some loggers also had battery issues that in some instances caused the date time in the loggers to be reset to 2001, making the data useless for analysis since the date stamps were no longer valid. Thirteen loggers had heat damage from their close proximity to the bulb. Of those thirteen, six still had usable data that was retrievable. Finally, some loggers came back with no data and were therefore unsuitable for analysis. Table 3-8 below accounts for the logger attrition from installation to the final analysis database.

3.6.2 Room Type Consolidation

As described above, the SWE team had difficulty installing enough loggers in several room types because a high enough number of rooms of that type were simply not encountered in the Study. Therefore, for the analytical phase of the project, the SWE elected to condense the room types and create a more robust “Other” category. The “Media/Bonus Room”, “Garages”, “Office/Dens”, and “Other” room types were condensed into a single “Other” category. The SWE also gave consideration to including closets in the “Other” category, but decided that there were enough closets that adding them to the other category would cause closets to have too much weight in that group.

3.6.3 Outlier Detection and Handling

During logger installation, homeowners were asked to estimate how many hours a day they used each of the lights that were metered within their home. This estimation data was only used to help determine if outliers should be considered for removal from the analysis database. A comparison of the measured HOU versus homeowner estimates for loggers within three times the interquartile range of HOU shows that homeowners had an average estimation error of 85%. Roughly 40% of the estimates made by homeowners were lower than measured usage and 60% higher than measured usage.

A total of 33 loggers metered usage that was higher than three times the interquartile range, indicating a possible problem with ambient light or a faulty logger. The SWE team removed these potential outliers only if the estimated hours of use were more than 85% different than the measured hours of use. Six loggers met this criterion and were removed from the analysis.

Table 3-6: Table of High Use Outliers Removed from Analysis

Logger Number	Measured Hours Use	Estimated Hours Use	Absolute % Estimation Error
11100346	11.4	0.5	95.6%
13040533	14.1	2.0	85.8%
13040547	15.0	1.0	93.3%
13070289	11.8	1.0	91.5%
13070544	21.0	1.0	95.2%
13080097	11.6	0.0	100.0%

A total of 37 loggers were identified as potential outliers on the low usage end, having zero or near zero hours of average use. The SWE team determined that a logger in which the homeowner estimated more than half an hour a day of usage for these lights was sufficient to remove the logger from the analytical database. At half an hour a day, the homeowner would have estimated over 180 hours of use per year, but the meter recorded nearly zero usage. This criterion resulted in removal of 18 loggers.

Table 3-7: Table of Low Use Outliers Removed from Analysis

Logger Number	Measured Hours Use	Estimated Hours Use
11100049	0.0	0.5
11100187	0.0	1.0
11100192	0.0	0.5
11110042	0.0	0.5

Logger Number	Measured Hours Use	Estimated Hours Use
13070028	0.0	0.5
13070039	0.0	0.5
13070048	0.0	1.0
13070090	0.0	0.5
13070341	0.0	1.0
13070418	0.0	0.5
13070426	0.0	1.0
13070442	0.0	0.7
13070472	0.0	2.0
13070545	0.0	1.0
13070599	0.0	1.0
13080007	0.0	2.0
13080043	0.0	2.0
13080082	0.0	4.0

The final analysis database consisted of 1,191 loggers. With 1,482 loggers installed that equates to an effective attrition rate of 20%. Table 3-8 identifies the attrition attributable to the inability to recover loggers (8%) and the inability to use data due to various reasons (12%). As will be shown, this database of 1,191 is still sufficient to provide reasonable estimates on HOU and CF with precise enough confidence intervals to validate the Study.

Table 3-8: Logger Attrition

Item	No. Loggers	Percent of Total Installed
Installed	**1,482**	**100%**
Unrecovered	114	8%
Recovered	***1,368***	***92%***
Excessive Flicker	25	2%
No Data	47	3%
Battery Reset Dates	81	5%
Outliers Removed	24	2%
Final Analysis Database	***1,191***	***80%***

3.7 COMPARISON OF MEANS ANALYSES

As a first step in exploratory data analysis, three simple comparisons of means tests were conducted to test if the raw, unweighted average usage data was statistically different along different attributes: efficient versus non-efficient bulbs, home type, and EDC. The results of these comparisons of means were useful in determining both weighting factors and independent variables for inclusion in the statistical models used to estimate HOU and CF.

3.7.1 Efficient versus Non-efficient Bulbs

The pairwise means comparison with 90% confidence by room type for efficient and non-efficient bulbs indicates a statistically significant difference in mean HOU for basement, bathroom, kitchen, living room, and other room types. These room types represent over 50% of the socket saturation in the state. As shown in the table, efficient bulb usage was measured to be higher in most of the rooms, even though not high enough to conclude they are statistically different. Differentiating between efficient and non-efficient bulbs was maintained in both weighting and modeling. In the final analysis for the total home, efficient bulbs were used with a higher average hours of use at a statistically significant level.

Table 3-9: Comparison of Means Results – Efficient vs. Non-Efficient Bulbs

Room	Efficient Mean HOU	Non-Efficient Mean HOU	Tukey Pairwise Test p-Value	Statistically Different @ 90% Confidence
Basement	1.58	0.57	0.0488	✓
Bathroom	2.90	1.80	0.0479	✓
Bedroom	2.25	1.68	0.2368	
Closet	0.46	0.47	0.9737	
Dining Room	3.02	2.58	0.4941	
Exterior	2.64	3.64	0.2798	
Hall/Foyer	2.05	1.40	0.1479	
Kitchen	4.41	3.01	0.0329	✓
Living Room	3.96	2.93	0.0810	✓
Other	1.90	1.32	0.0920	✓

3.7.2 Home Type

Data from four home types was collected during the RBS on-site surveys: single family detached, single family attached, multifamily, and manufactured homes. Pairwise comparisons of means by room and home type indicated very few room/home type combinations in which mean HOU is statistically different from other home types. There is therefore no indication that the statistical models to estimate HOU should include variables for home type. However, as described in the section below about weighting, the raw logger data should continue to be weighted by home type since the sampling purposely over-weighted multifamily homes to ensure representation of that home type in the two studies.

Table 3-10: Comparison of Means Results – Home Type

Note: The cells indicate the p-value from a Tukey Pairwise Comparison of Means Analysis, cells with a check mark and shaded orange indicate a statistically different mean at 90% confidence.

Room	SFD vs SFA	SFD vs MF	SFD vs MA	SFA vs MF	SFA vs MA	MF vs MA
Basement	0.5311	n/a	n/a	n/a	n/a	n/a
Bathroom	0.4251	0.4974	0.6297	0.9262	0.9265	0.9867
Bedroom	0.4127	0.1671	0.4976	0.6234	0.2785	0.1507
Closet	0.7985	0.5396	0.6944	0.7524	0.7574	0.8536
Dining Room	0.6492	0.6417	0.8381	0.9848	0.9261	0.9151
Exterior	0.5818	0.6258	0.1873	0.4499	0.3238	0.1640
Hall/Foyer	0.8402	0.6575	0.9700	0.8322	0.9306	0.8040
Kitchen	0.5111	0.8061	0.4602	0.7474	0.2919	0.4283
Living Room	0.5184	0.1469	0.8616	0.1117	0.7676	0.2727
Other	0.9844	0.8662	0.0120 ✓	0.8727	0.0242 ✓	0.0885 ✓

SFD = Single Family Detached *SFA=Single Family Attached* *MF = Multifamily* *MA = Manufactured*

3.7.3 EDC

The pairwise comparison of means analysis indicates a significant difference in HOU by EDC for several room types. It is not clear from the data the SWE collected what might be driving the difference. One demographic variable that may impact lighting usage is the number of people in the home. Census data for each EDC service territory was used to estimate the average people per household (PPH) by EDC, as shown in the table below. This indicates that DUQ may have lower PPH than other utilities and Met-Ed and PECO may have higher PPH. However, the people per household was not collected during the RBS and RLS for study participants, so further analysis of this hypothesis cannot be conducted using the metering data. EDC differences were not included in the statistical modeling but were taken into account via the weighting procedure as described in Section 3.8. By including EDC weights, the SWE is using the total number of customers served by each EDC as a substitute to modeling specific demographic or geographical characteristics that may be driving lighting usage differences between EDCs.

Table 3-11: Census Estimates for Average People per Household in Service Territories by EDC

EDC	Census Mean People per HH
DUQ	2.24
Met-Ed	2.55
Penelec	2.38
Penn Power	2.37
West Penn Power	2.36
PECO	2.54
PPL	2.47

Table 3-12: Comparison of Means Results – EDC

Note: The cells indicate the p-value of a Tukey Pairwise Comparison of Means Analysis, cells with a check mark and shaded orange indicate a statistically different mean at 90% confidence.

Room	DUQ vs Met-Ed	DUQ vs Penelec	DUQ vs Penn Power	DUQ vs WPP	DUQ vs PECO	DUQ vs PPL
Basement	0.0035 ✓	0.0271 ✓	0.0009 ✓	0.0019 ✓	0.0033 ✓	0.0015 ✓
Bathroom	0.5043	0.9742	0.3229	0.6820	0.4037	0.7534
Bedroom	0.3079	0.4667	0.7127	0.4386	0.3340	0.2803
Closet	0.5732	0.7524	0.9411	0.4092	0.6213	0.5733
Dining Room	0.3441	0.6695	0.6626	0.2988	0.3018	0.8215
Exterior	0.0252 ✓	0.4816	0.4752	0.5711	0.0304 ✓	0.1552
Hall/Foyer	0.2822	0.9655	0.5312	0.3230	0.7250	0.8790
Kitchen	0.8054	0.4453	0.1305	0.0606 ✓	0.7742	0.9984
Living Room	0.3643	0.3227	0.3983	0.4944	0.4230	0.1966
Other	0.8799	0.9998	0.6253	0.3657	0.9719	0.8252

Room	Met-Ed vs Penelec	Met-Ed vs Penn Power	Met-Ed vs WPP	Met-Ed vs PECO	Met-Ed vs PPL
Basement	0.7299	0.6310	0.6578	0.8063	0.5034
Bathroom	0.4761	0.6820	0.7774	0.8070	0.7065
Bedroom	0.7192	0.4928	0.7973	0.0327 ✓	0.9557
Closet	0.3750	0.5800	0.1268	0.2604	0.9651
Dining Room	0.2006	0.1622	0.0543 ✓	0.0616 ✓	0.4998

Room	Met-Ed vs Penelec	Met-Ed vs Penn Power	Met-Ed vs WPP	Met-Ed vs PECO	Met-Ed vs PPL
Exterior	0.0087 ✓	0.0044 ✓	0.0187 ✓	0.8217	0.3597
Hall/Foyer	0.2095	0.0661 ✓	0.8644	0.1328	0.1895
Kitchen	0.3129	0.0827 ✓	0.0361 ✓	0.9681	0.8119
Living Room	0.0352 ✓	0.9159	0.0805 ✓	0.0684 ✓	0.6689
Other	0.8850	0.7103	0.4177	0.9160	0.6943

Room	Penelec vs Penn Power	Penelec vs WPP	Penelec vs PECO	Penelec vs PPL
Basement	0.4563	0.0019 ✓	0.5930	0.0015 ✓
Bathroom	0.2900	0.6730	0.3753	0.7532
Bedroom	0.7167	0.9299	0.0612 ✓	0.6733
Closet	0.6767	0.6434	0.8763	0.3859
Dining Room	0.9620	0.5985	0.5797	0.5407
Exterior	0.9291	0.9522	0.0102 ✓	0.0545 ✓
Hall/Foyer	0.5070	0.2371	0.7264	0.9004
Kitchen	0.4222	0.2398	0.2934	0.4553
Living Room	0.0356 ✓	0.7421	0.8838	0.0118 ✓
Other	0.6371	0.3817	0.9731	0.8319

Room	Penn Power vs WPP	Penn Power vs PECO	Penn Power vs PPL
Basement	0.9992	0.8439	0.7997
Bathroom	0.5074	0.8821	0.4577
Bedroom	0.6687	0.1561	0.4550
Closet	0.3154	0.5326	0.5831
Dining Room	0.5123	0.5013	0.5219
Exterior	0.9892	0.0048 ✓	0.0361 ✓
Hall/Foyer	0.0697 ✓	0.7814	0.6119
Kitchen	0.7248	0.0758 ✓	0.1405
Living Room	0.0850 ✓	0.0721 ✓	0.5823
Other	0.6850	0.6656	0.4749

Room	WPP vs PECO	WPP vs PPL
Basement	0.8538	0.8126
Bathroom	0.6194	0.9216
Bedroom	0.0625 ✓	0.7532
Closet	0.7480	0.1481
Dining Room	0.9515	0.2317
Exterior	0.0229 ✓	0.0926 ✓
Hall/Foyer	0.1476	0.2140
Kitchen	0.0327 ✓	0.0675 ✓
Living Room	0.8716	0.0310 ✓
Other	0.4060	0.2541

Room	PECO vs PPL

Room	PECO vs PPL
Basement	0.6805
Bathroom	0.5629
Bedroom	0.0270 ✓
Closet	0.2789
Dining Room	0.2361
Exterior	0.4591
Hall/Foyer	0.8288
Kitchen	0.7815
Living Room	0.0269✓
Other	0.8063

3.8 DEVELOPMENT OF WEIGHTS

A fairly complex weighting scheme was deployed by the SWE team to control the analysis for home type, room type, bulb type, and EDC. Although the comparison of means analysis indicated no statistical differences between home types, weights were deployed by home type to refine the analysis because the recruitment efforts purposely oversampled multifamily homes to ensure collection of enough data to provide significance. The weights were computed in two steps. The first step incorporates room, bulb type, and home type. The second weight accounts for the EDCs.

Equation 3-2: Weighting Formula for RLS

$$W = W_1 \times W_2$$

Where:

$W_1 = \frac{(N_{h,r,b}/\sum_h \sum_r \sum_b N_{h,r,b})}{(n_{h,r,b}/\sum_h \sum_r \sum_b n_{h,r,b})}$

$W_2 = \frac{(C_e/\sum_e C_e)}{(p_e/\sum_e p_e)}$

W = weight

N = statewide weighted number of sockets from RBS

n = number of light loggers in the RLS sample

C = number of residential customers in 2013

p = number of homes in the RLS sample

h = home type

r = room type

b = bulb type – efficient (CFL and LED) or non-efficient

e = EDC

The population socket count data was developed from the RBS. The following tables show the weights developed for W_1 and W_2. With 4 home types, 10 room types, 2 bulb types, and 7 EDCs, 560 different weighting factors were computed for the RLS.

Table 3-13: Development of Weights for Home, Room, and Bulb Types (W1)

POPULATION PERCENTAGE	Efficient	Non-Eff.	Total	SAMPLE PERCENTAGE	Efficient	Non-Eff.	Total	Efficient Weight	Non-Eff. Weight
Manufactured Home				**Manufactured Home**					
Basement/Attic	0.00%	0.04%	**0.04%**	Basement/Attic	0.00%	0.00%	**0.00%**	0.000	0.000
Bathroom	0.12%	0.36%	**0.47%**	Bathroom	0.17%	0.67%	**0.84%**	0.688	0.534
Bedroom	0.14%	0.29%	**0.43%**	Bedroom	0.25%	0.50%	**0.76%**	0.548	0.583
Closet	0.01%	0.04%	**0.05%**	Closet	0.00%	0.08%	**0.08%**	0.000	0.462
Dining Room	0.08%	0.08%	**0.17%**	Dining Room	0.34%	0.17%	**0.50%**	0.249	0.489
Exterior Lighting	0.08%	0.17%	**0.24%**	Exterior Lighting	0.00%	0.17%	**0.17%**	0.000	0.993
Foyer/Hallway	0.05%	0.10%	**0.14%**	Foyer/Hallway	0.34%	0.34%	**0.67%**	0.137	0.286
Kitchen	0.11%	0.24%	**0.36%**	Kitchen	0.42%	0.42%	**0.84%**	0.265	0.583
Living Room	0.14%	0.26%	**0.40%**	Living Room	0.67%	0.25%	**0.92%**	0.204	1.045
Other	0.04%	0.25%	**0.29%**	Other	0.34%	0.08%	**0.42%**	0.118	2.981
Multifamily Home				**Multifamily Home**					
Basement/Attic	0.03%	0.22%	**0.26%**	Basement/Attic	0.00%	0.00%	**0.00%**	0.000	0.000
Bathroom	0.29%	0.92%	**1.21%**	Bathroom	0.59%	1.09%	**1.68%**	0.497	0.839
Bedroom	0.53%	0.84%	**1.38%**	Bedroom	1.26%	0.34%	**1.60%**	0.424	2.511
Closet	0.04%	0.15%	**0.19%**	Closet	0.42%	0.50%	**0.92%**	0.089	0.302
Dining Room	0.11%	0.42%	**0.53%**	Dining Room	0.50%	0.59%	**1.09%**	0.220	0.718
Exterior Lighting	0.11%	0.38%	**0.49%**	Exterior Lighting	0.17%	0.17%	**0.34%**	0.640	2.269
Foyer/Hallway	0.19%	0.42%	**0.61%**	Foyer/Hallway	0.59%	0.76%	**1.34%**	0.324	0.558
Kitchen	0.25%	0.65%	**0.90%**	Kitchen	0.76%	0.92%	**1.68%**	0.333	0.702
Living Room	0.38%	0.82%	**1.20%**	Living Room	1.09%	0.67%	**1.76%**	0.346	1.224
Other	0.10%	0.29%	**0.38%**	Other	0.08%	0.34%	**0.42%**	1.131	0.862
Single Family Attached Home				**Single Family Attached Home**					
Basement/Attic	0.18%	0.92%	**1.10%**	Basement/Attic	0.34%	0.50%	**0.84%**	0.525	1.830
Bathroom	0.50%	1.57%	**2.07%**	Bathroom	0.34%	1.34%	**1.68%**	1.474	1.167
Bedroom	0.63%	1.63%	**2.26%**	Bedroom	0.92%	0.92%	**1.85%**	0.680	1.760
Closet	0.06%	0.31%	**0.37%**	Closet	0.17%	1.01%	**1.18%**	0.383	0.304
Dining Room	0.16%	0.65%	**0.81%**	Dining Room	0.34%	0.84%	**1.18%**	0.478	0.769
Exterior Lighting	0.20%	0.60%	**0.80%**	Exterior Lighting	0.42%	0.42%	**0.84%**	0.471	1.422
Foyer/Hallway	0.25%	1.01%	**1.26%**	Foyer/Hallway	0.50%	1.18%	**1.68%**	0.501	0.854
Kitchen	0.29%	1.14%	**1.44%**	Kitchen	0.76%	0.92%	**1.68%**	0.389	1.238
Living Room	0.52%	1.07%	**1.58%**	Living Room	0.67%	0.76%	**1.43%**	0.767	1.409
Other	0.32%	0.85%	**1.17%**	Other	0.34%	1.01%	**1.34%**	0.943	0.842
Single Family Detached Home				**Single Family Detached Home**					
Basement/Attic	1.67%	5.97%	**7.64%**	Basement/Attic	2.77%	3.11%	**5.88%**	0.603	1.919
Bathroom	2.30%	7.57%	**9.86%**	Bathroom	3.19%	5.21%	**8.40%**	0.719	1.453
Bedroom	2.83%	8.36%	**11.20%**	Bedroom	4.37%	3.95%	**8.32%**	0.648	2.118
Closet	0.34%	1.97%	**2.31%**	Closet	0.84%	3.45%	**4.29%**	0.406	0.570
Dining Room	0.68%	4.51%	**5.20%**	Dining Room	2.18%	4.62%	**6.81%**	0.312	0.977
Exterior Lighting	1.41%	6.60%	**8.01%**	Exterior Lighting	1.01%	2.69%	**3.70%**	1.394	2.454
Foyer/Hallway	1.22%	5.44%	**6.66%**	Foyer/Hallway	2.61%	4.20%	**6.81%**	0.468	1.295
Kitchen	2.29%	6.04%	**8.33%**	Kitchen	3.19%	4.37%	**7.56%**	0.717	1.382
Living Room	2.48%	4.49%	**6.97%**	Living Room	5.04%	3.19%	**8.24%**	0.492	1.406
Other	2.22%	9.02%	**11.25%**	Other	5.13%	5.13%	**10.25%**	0.433	1.761
	23.33%	76.67%	**100.00%**		43.11%	56.89%	**100.00%**		

Table 3-14: Development of Weights for EDC (W_2)

EDC	No. Customers in 2013	% of Total	No. of Homes in RLS	% of Total	EDC Weight
DUQ	526,736	10.6%	32	15.5%	0.684
Met-Ed	487,974	9.8%	30	14.6%	0.671
Penelec	503,617	10.2%	31	15.0%	0.680
Penn Power	141,060	2.8%	25	12.1%	0.231
WPP	619,531	12.5%	31	15.0%	0.833
PECO	1,445,232	29.2%	26	12.6%	2.317
PPL	1,231,452	24.8%	31	15.0%	1.653
Total	4,955,602	100.0%	206	100.0%	

3.9 HOURS OF USE MODELING

Two analytical steps were taken by the SWE to develop estimates of HOU. First, the logger data was annualized since a full year of data was not captured. Next, a weighted hierarchical linear model was developed for HOU to estimate statewide HOU estimates by room type.

3.9.1 Annualized HOU Estimates

In the Pennsylvania RLS, the loggers were installed for a long time relative to other recent studies, with some loggers in the home for nearly a complete calendar year (on average, loggers were installed for about ten months). However, not all loggers were installed for a full year as some loggers were not deployed until November 2013 and general logger collection took place in August to September of 2014. Furthermore, some homeowners mailed loggers to the SWE earlier than August because of impending moves. Therefore a sinusoidal model was used to estimate daily HOU for missing dates for each logger.[2] A sinusoidal model, as described by the formula below, was fit to each logger's weekend and weekday measured HOU data.

Equation 3-3: Sinusoidal Model Specification

$$HOU_d = \beta_0 + \beta_1 \sin(\theta_d) + \varepsilon_d$$

Where:

- HOU = hours of use
- θ = an angle, in radians, representing the amount of sunlight on the day. θ is 0 for the spring and autumnal equinoxes, $\pi/2$ for the winter solstice, and $-\pi/2$ for the summer solstice
- d = the day of the year
- β_x = regression coefficients
- ε = error term.

[2] The approach is consistent with the Uniform Methods Project for estimating lighting efficiency savings.

Figure 3-3: Independent Variable Sin(θ_d) for Sinusoidal Modeling

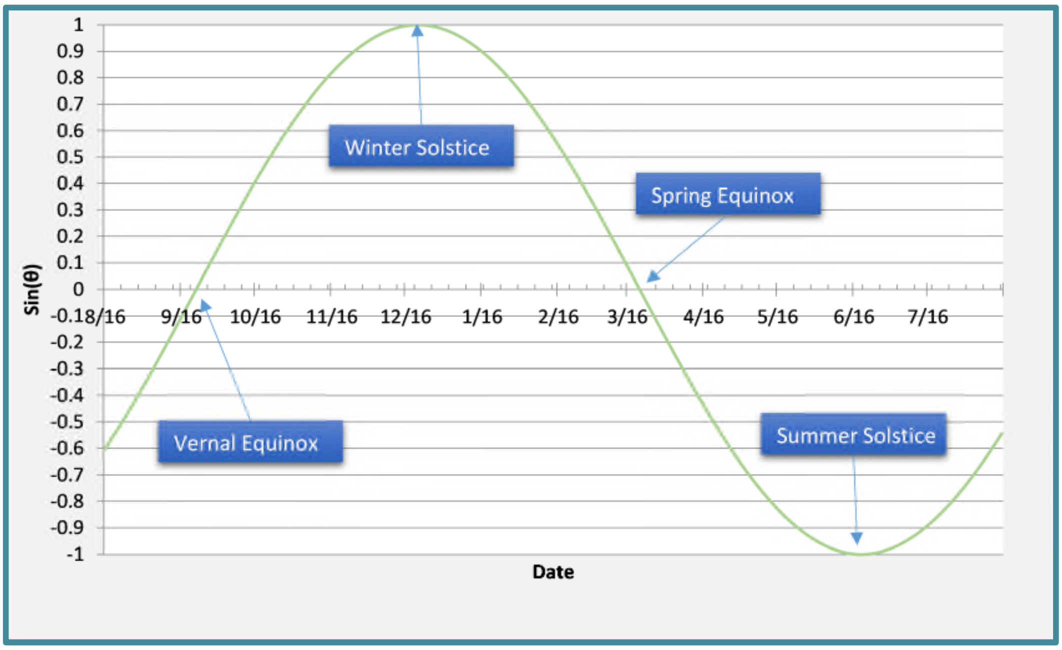
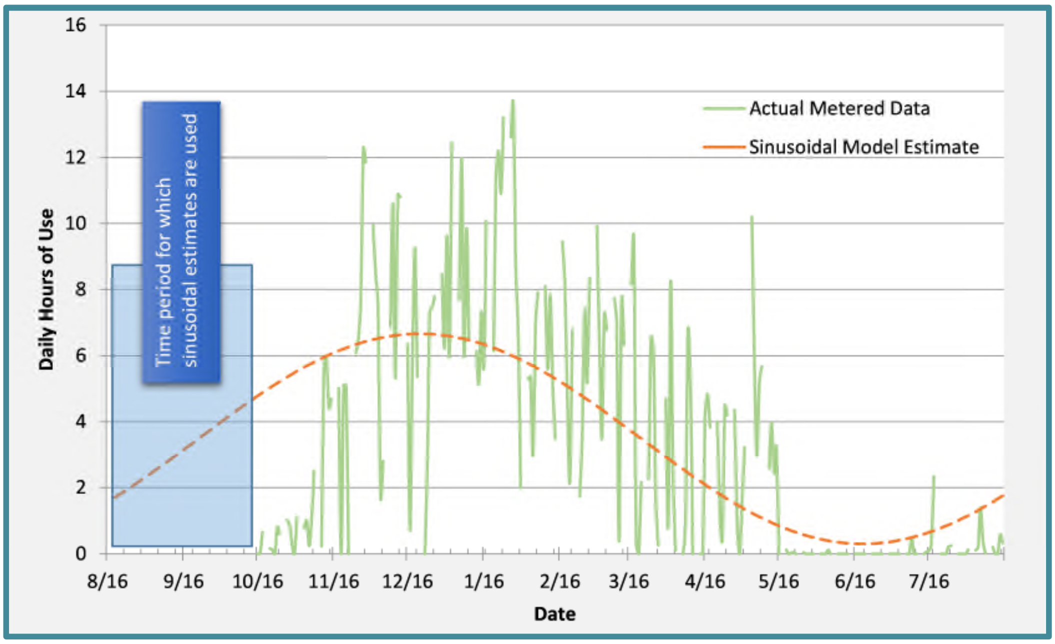


Figure 3-4 demonstrates how the sinusoidal model functions for a specific logger as an example. This logger metered lighting usage in a living room. The green line represents actual metered usage per day for weekdays only. The sinusoidal model fit produces an R^2 value of 0.41 with β_0 = 3.4837 and β_1 = 3.1783. This equation generates the orange line. The sinusoidal model estimates, then are used only to represent weekdays in the period for which no data was collected for this logger, shown in the figure as the shaded time frame.

Figure 3-4: Example of Sinusoidal Model Estimate and Actual Logger Data



Consistent with the criteria set forth in the California Upstream Lighting evaluation[3] and the Northeast Residential Lighting HOU Study[4], sinusoidal models were deemed to be a poor fit if one of the following criteria were met:

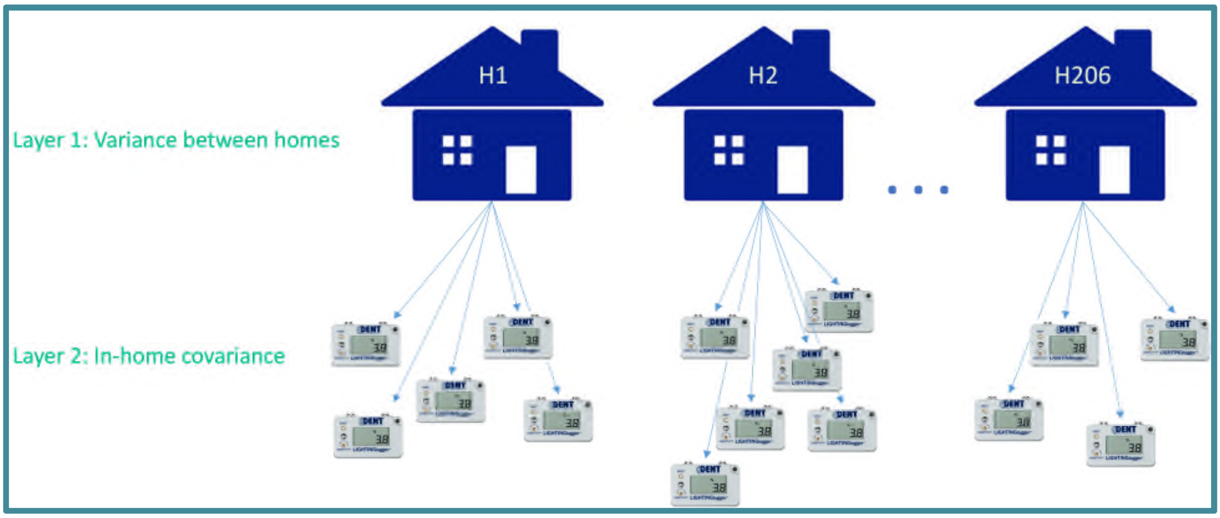
- $\beta 1$ coefficient has an absolute value greater than 10
- The standard error for $\beta 1$ is greater than 1
- $\beta 0$ is less than or equal to zero
- $\beta 0$ is greater than 24

With these criteria, only 31 of the 2,382 sinusoidal models were deemed to have a poor fit. For those loggers, many of which were closets and basements with very erratic use, the average weekend HOU from the measure data was used to estimate weekend HOU for dates not in the sample and the average weekday HOU from the measure data was used to estimate weekday HOU for dates not in the sample.

3.9.2 Hierarchical Model

A weighted hierarchical (or multilevel) model was developed to estimate average statewide HOU by room type and for the home.[5] The key advantage of the hierarchical approach is that the model takes into account in-home lighting usage covariance in estimating coefficients. This is important as lighting across multiple loggers in the same home are likely to have some covariance associated with the usage behavioral patterns of the home's occupants. For instance, during an extended vacation, nearly all of the lights in the home may be off, and all of those loggers would record zero usage during those same dates.

Figure 3-5: Hierarchical Model Construct



[3] KEMA, Inc. and the Cadmus Group, Inc. *Final Evaluation Report: Upstream Lighting Program Volume I*. Prepared for California Public Utilities Commission, Energy Division. February 8, 2010.
[4] NMR Group, Inc. and DNV GL. *Northeast Residential Lighting Hours-of-Use Study*. May 5, 2014.
[5] Hierarchical models are described very briefly here. For further details, several good sources can be found, including: Woltman, Feldstain, MacKay, and Rocchi, *An introduction to hierarchical linear modeling*; Goldstein, Harvey, *Multilevel Statistical Models*; Singer, Judith D., *Using SAS PROC MIXED to Fit Multilevel Models, Hierarchical Models, and Individual Growth Models*; and Sullivan, Dukes, and Losina, *Tutorial in Biostatistics: An Introduction to Hierarchical Linear Modeling*.

The model includes fixed effects variables for room type and efficient bulb type and random effects for the intercept and room type at the household level. The random terms account for correlation among loggers within the home. The form of the HOU hierarchical model is shown below.

Equation 3-4: Hierarchical Linear Model for HOU

$$HOU_{h,i} = (\beta_0 + b_{0,h}) + \beta_1 I_{EFF} + \sum_r (\beta_r + b_{r,h}) I_r + \varepsilon_{h,i}$$

Where:

$b_{o,h}$ ~ $N(b_h, \sigma^2_{b_h})$
$b_{r,h}$ ~ $N(0, \sigma^2_h)$
HOU = average daily hours of use
h = index for home
i = index for logger
r = index for room type
I_{EFF} = indicator variable for efficient bulb type
I_r = indicator variable for room type
β_x = fixed effects coefficients
$B_{x,h}$ = random effects coefficients
ε = error term.

3.10 COINCIDENCE FACTOR MODELING

CF estimates were developed by constructing a hierarchical linear model. The CF represents the average percent of the hour lights are on during the defined on-peak period of non-holiday weekdays from June through August between 2:00 PM and 6:00 PM.

Since the loggers were in place for nearly an entire summer period, sinusoidal model estimates were not used in the development of estimated CF. Average CF was computed for each logger and then a hierarchical model was developed to estimate CF by room and bulb type. The model includes fixed effects variables for room type and efficient bulb type and random effects for the intercept and room type at the household level. The random terms account for correlation among loggers within the home. The form of the HOU hierarchical model is shown below.

Equation 3-5: Hierarchical Linear Model for CF

$$CF_{h,i} = (\beta_0 + b_{0,h}) + \beta_1 I_{EFF} + \sum_r (\beta_r + b_{r,h}) I_r + \varepsilon_{h,i}$$

Where :

$b_{o,h}$ ~ $N(b_h, \sigma^2_{b_h})$
$b_{r,h}$ ~ $N(0, \sigma^2_h)$
CF = coincidence factor
h = index for home
i = index for logger
r = index for room type
I_{EFF} = indicator variable for efficient bulb type
I_r = indicator variable for room type
β_x = fixed effects coefficients
$B_{x,h}$ = random effects coefficients
ε = error term.

3.11 UNCERTAINTY

As with any survey or statistical analysis, the results in this report are subject to a certain degree of uncertainty. Practical and monetary constraints make it impossible for the SWE to survey the entire population of Pennsylvania residential electrical accounts, necessitating the selection of a small sample population from which to collect data. When using a sample to make predictions about a population, factors of uncertainty are introduced, primarily based on the size of the sample and the existence of biases within the sample.

Equation 3-6: Margin of Error

$$Margin\ of\ Error = z * \frac{\sigma}{\sqrt{n}}$$

Where:

z = 1.645 for 90% confidence

σ = The standard error

n = The sample size

With considerations for sample size it is important to note that the more general findings (such as statewide lighting and controls technology details) in this report have the highest precision, while the precision decreases as results become more specific (i.e. CFs and hours of use per room type). While findings are presented for all residences at the statewide level, the level of precision differs by room type since some room types received fewer samples than others (e.g., basements had 80 loggers whereas kitchens had 142 loggers).

Another factor that can influence the uncertainty of the results is the extent to which the sample is representative of the population as a whole. Though samples are selected randomly, it is possible that the sample contains some type of bias that can influence the overall results. One example could be a sample that has many households with at least one member of the household who stays at home on a regular basis.[6]

Where possible, the SWE took steps to ensure that biases were minimized in the sample. Samples were selected randomly from the customer database in a manner which minimized the potential for human error or other biases.

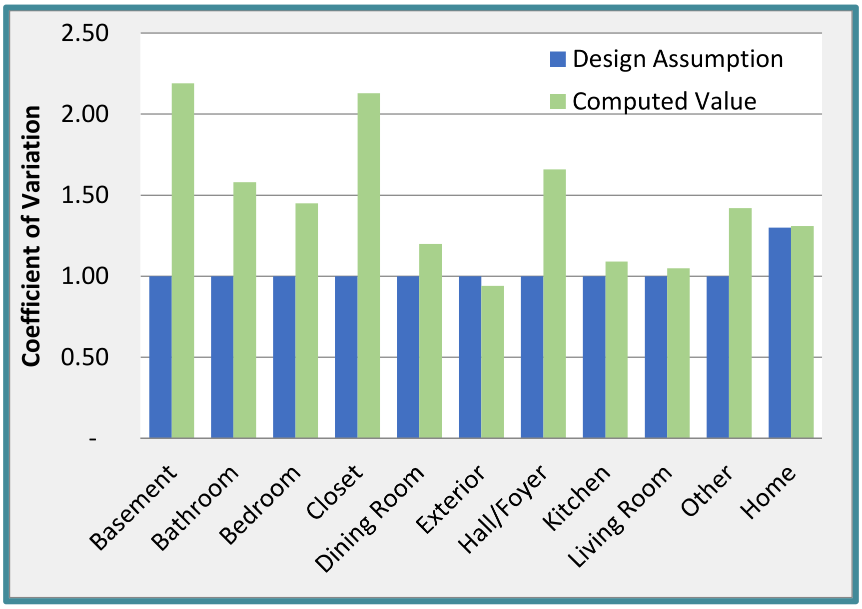
3.12 RESULTS

3.12.1 Sample Coefficients of Variation

During sample design, the SWE team used a coefficient of variation (C_V) of 1.0 for lights within a room and 1.3 for lights throughout the home. The sample data collected indicated higher variation for most room types, but nearly 1.0 for some of the higher usage and socket saturation rooms (kitchen, living room, and exterior lights). A very high Cv was computed for basements and closets, which would be expected given how vastly different behavioral tendencies may drive lighting use in those room types. For the home overall, the realized sample C_V was computed as 1.3, consistent with the original estimate from the sample design phase of the project.

[6] The SWE attempted to control for this particular form of bias by performing site visits in evenings and on weekdays and targeting a representative mix for the age of the head of household relative to census estimates.

Figure 3-6: Sample Design and Sample Computed C_v by Room Type



3.12.2 Hours of Use

Hours of use are highest for exterior lights, kitchen lights, and living room lights. As would be expected, closet hours of use are the lowest use room type. Efficient bulbs were found to have a statistically higher average hours of use than non-efficient bulbs, as shown in the table below. Overall, residents in Pennsylvania use lights an average of 2.5 hours per day, or 912.5 hours per year. At 90% confidence, the estimated overall home average usage is between 2.4 and 2.6 hours per day, or 876 and 949 hours per year. Efficient bulbs are used an average of 1,095 hours per year and non-efficient bulbs, an average of 839.5 hours per year. The results of this study should be used to inform both the potential study and future iterations of the Pennsylvania Technical Reference Manual (TRM). Note that the selected values should differ depending on the purpose. The potential study should use the all bulbs number, reflecting the energy savings potential for replacing every socket in a home with an efficient bulb. Future versions of the TRM, however, should assume selected socket replacement and continue to use higher hours of use for upstream programs, but use the all bulbs number for programs (e.g., direct installation programs) that replace the majority of bulbs in a home with efficient bulbs.

Table 3-1512: Average Hours of Use

Room Type	No. Loggers	Average HOU	90% CI
Basement	80	1.7	(1.0 , 2.4)
Bathroom	151	2.3	(1.8 , 2.8)
Bedroom	147	1.8	(1.4 , 2.2)
Closet	77	0.6	(0.4 , 0.9)
Dining Room	114	2.7	(2.2 , 3.2)
Exterior	58	3.9	(3.1 , 4.7)
Hall/Foyer	125	1.9	(1.4 , 2.4)
Kitchen	142	3.9	(3.3 , 4.5)
Living Room	147	3.7	(3.1 , 4.2)
Other	150	1.7	(1.4 , 2.0)
Home - All Bulbs	***206***	***2.5***	***(2.4 , 2.6)***
Efficient Bulbs	***518***	***3.0***	***(2.7 , 3.2)***
Non-Efficient Bulbs	***673***	***2.3***	***(2.1 , 2.5)***

Figure 3-7: Average Hours of Use with 90% Confidence Limits by Room Type

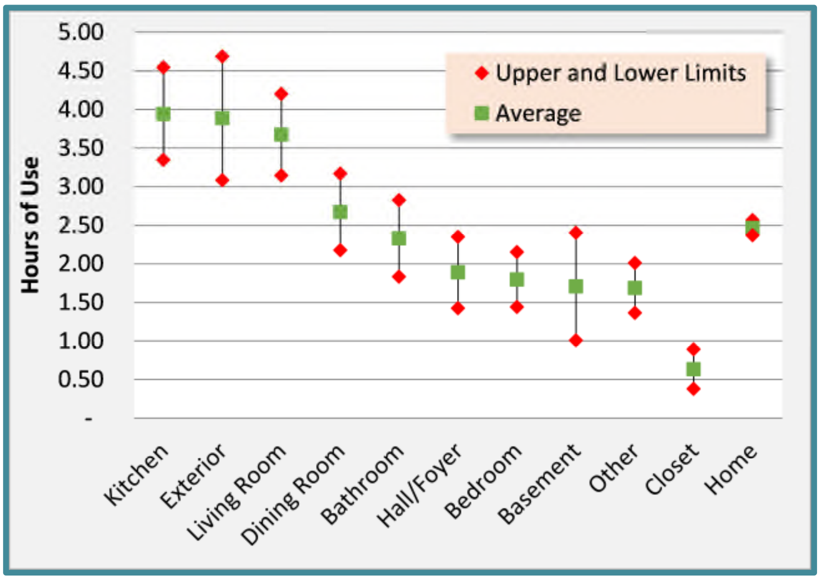
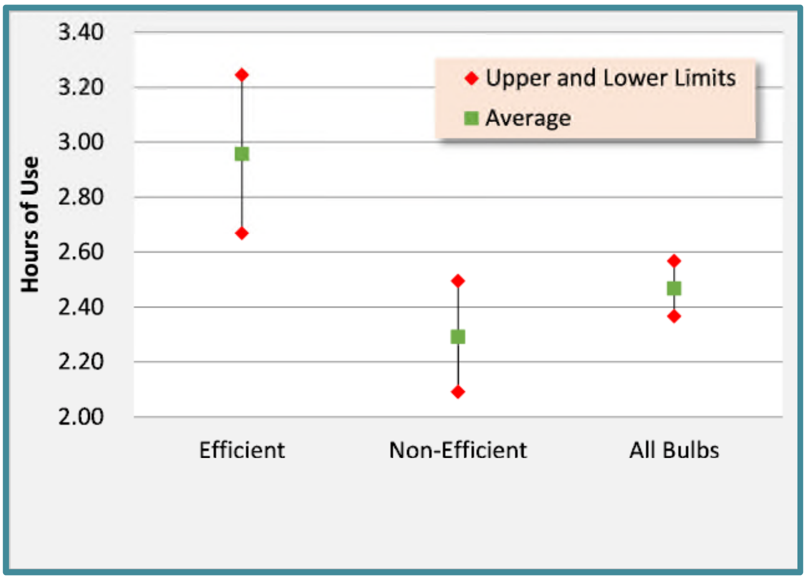
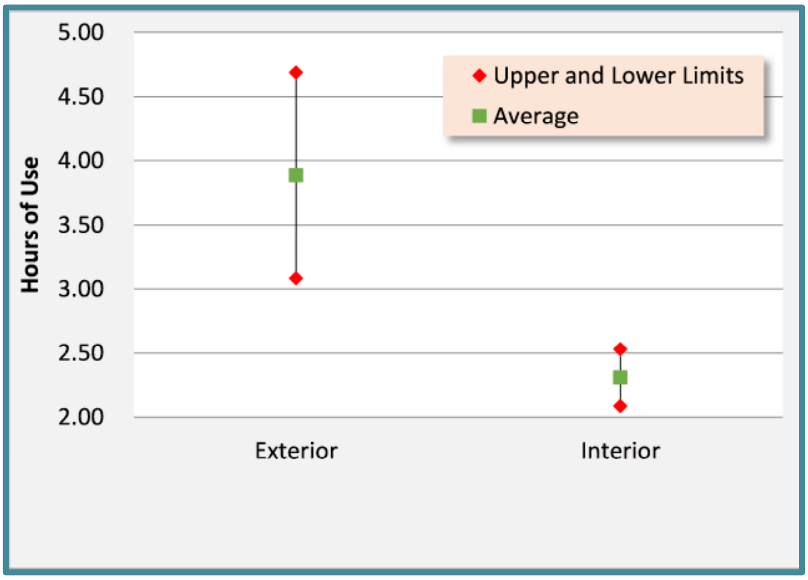


Figure 3-8: Average Hours of Use with 90% Confidence Limits by Bulb Efficiency



The SWE team was also interested in the average HOU between exterior and all interior lights as information useful for the EE Potential Study. Interior lights average 2.3 hours of use per day with a 90% confidence interval ranging from 2.1 to 2.5 hours per day. Exterior lighting ranges from 3.1 to 4.7 hours per day, with an average of 3.9. The difference between all interior and exterior lights is statistically significant at 90% confidence.

Figure 3-9: Interior vs. Exterior Average HOU



3.12.3 Coincidence Factors

The statewide CF for the home is estimated to be 0.101. This is the percent of on-peak hours lights are on in the home. On-peak hours are non-holiday weekdays, June through August, 2:00 p.m. to 6:00 p.m. The CF for kitchens, dining rooms, living rooms, and exterior lights are higher than other room types. There is no statistical difference in CF between efficient and non-efficient bulb types.

Table 3-16: Coincidence Factors

Room Type	No. Loggers	Average CF	90% CI
Basement	80	0.066	(0.042 , 0.091)
Bathroom	151	0.096	(0.073 , 0.119)
Bedroom	147	0.064	(0.044 , 0.085)
Closet	77	0.029	(0.011 , 0.046)
Dining Room	114	0.108	(0.080 , 0.136)
Exterior	58	0.265	(0.192 , 0.338)
Hall/Foyer	125	0.076	(0.050 , 0.101)
Kitchen	142	0.142	(0.115 , 0.170)
Living Room	147	0.098	(0.073 , 0.123)
Other	150	0.061	(0.044 , 0.079)
Home	***206***	***0.101***	***(0.097 , 0.105)***
Efficient Bulbs	***518***	***0.106***	***(0.095 , 0.116)***
Non-Efficient Bulbs	***673***	***0.099***	***(0.086 , 0.112)***

Figure 3-10: CF with 90% Confidence Limits by Room Type

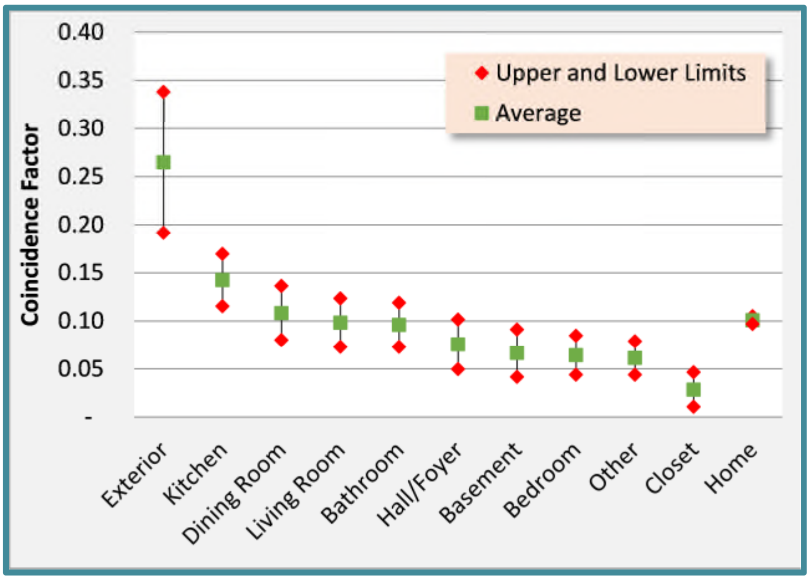
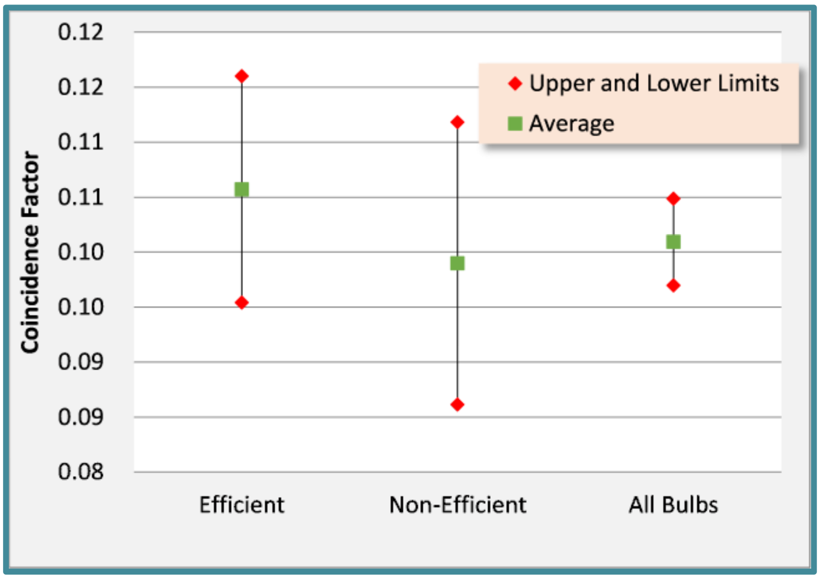


Figure 3-11: CF with 90% Confidence Limits by Bulb Efficiency



3.12.4 Load Curves

The figures below present typical weekly load shapes for residential lighting by season. Further details are presented in the Appendix.

Figure 3-12: Winter Load Shape for Residential Lighting – All Bulbs

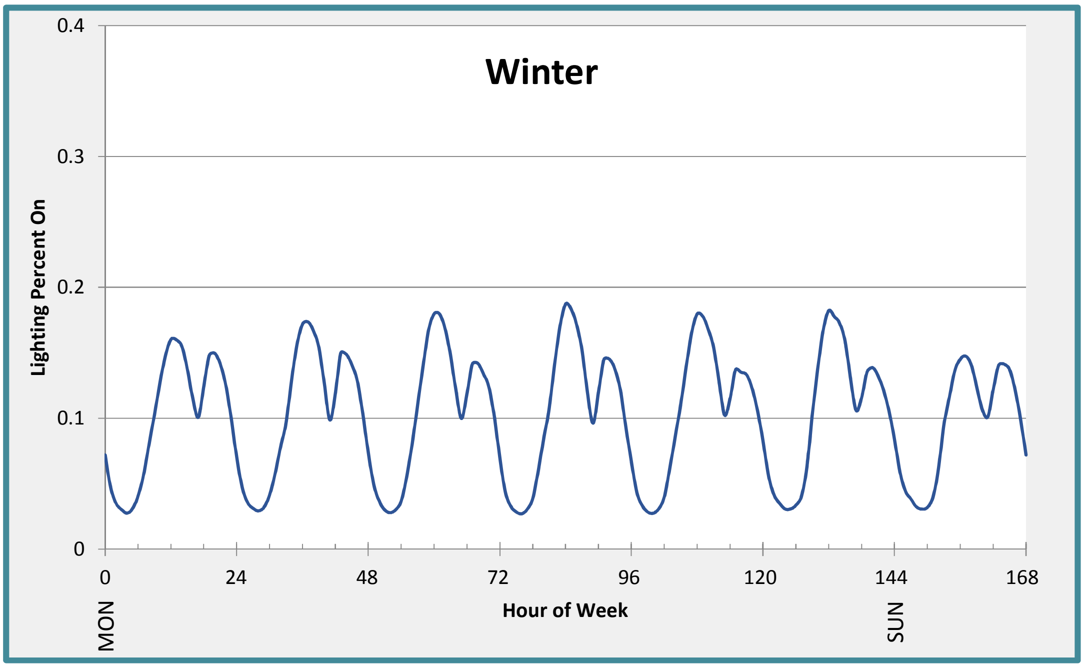


Figure 3-13: Spring Load Shape for Residential Lighting – All Bulbs

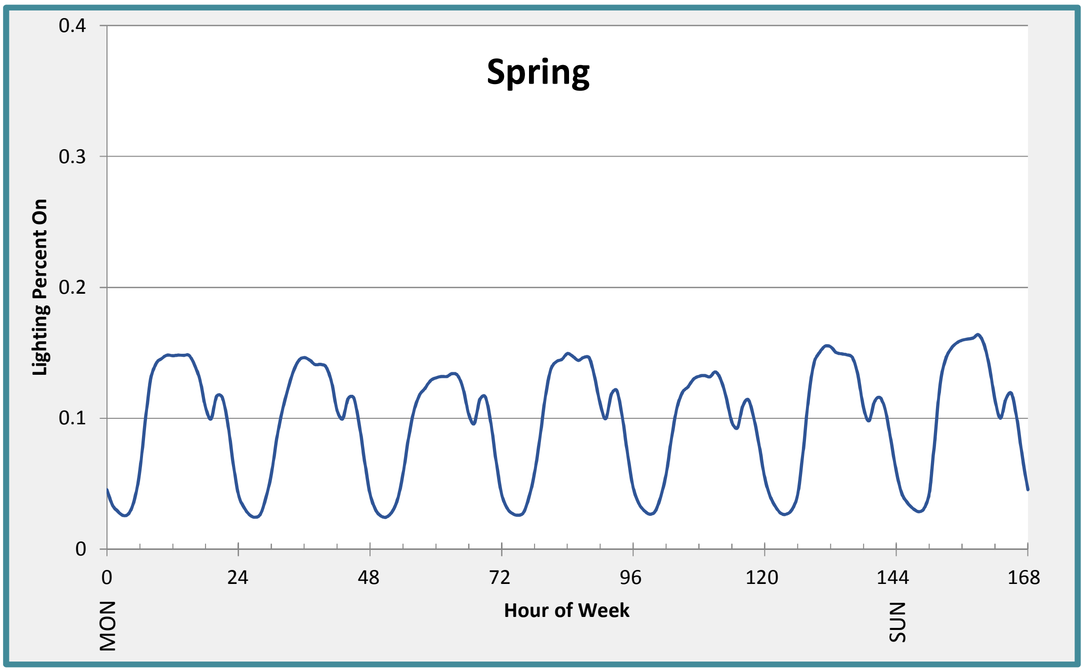


Figure 3-14: Summer Load Shape for Residential Lighting – All Bulbs

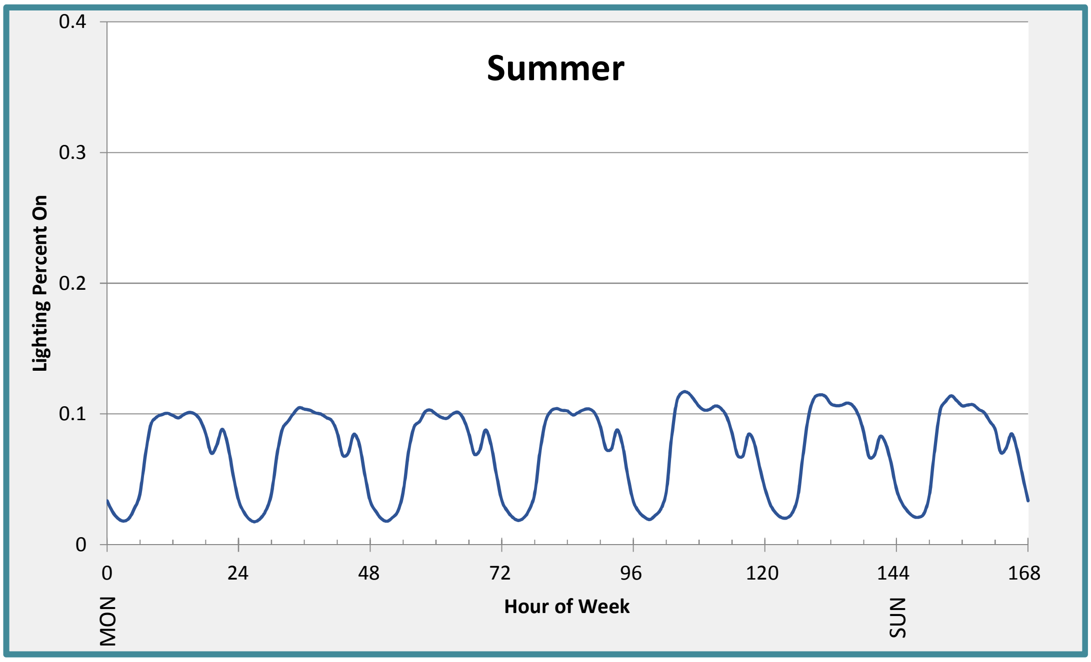
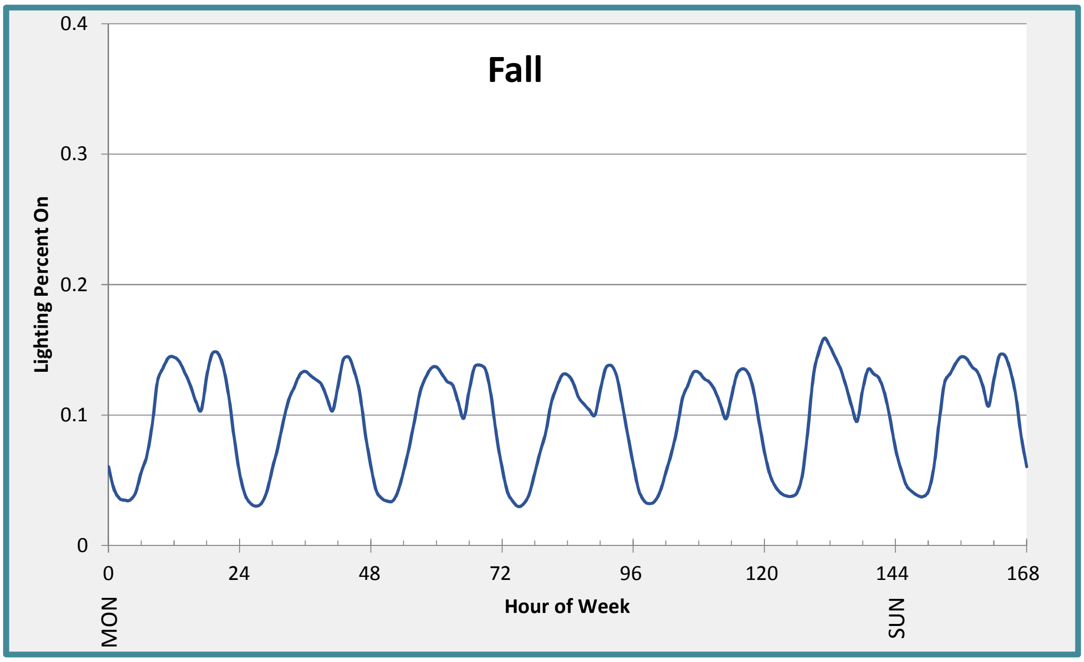


Figure 3-15: Fall Load Shape for Residential Lighting – All bulbs

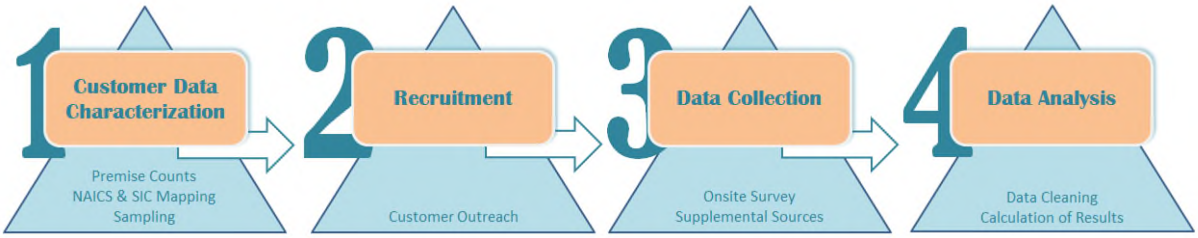


4 COMMERCIAL LIGHT METERING STUDY

4.1 COMMERCIAL STUDY METHODOLOGY

This section details the SWE's methodology to manage the four key tasks that needed to be undertaken to complete the Study. Figure 4-1 provides an overview of these tasks.

Figure 4-1: Overview of Tasks Involved in the Commercial Light Metering Study



4.1.1 Customer Data Characterization

The SWE was provided with customer billing databases of all non-residential accounts within the seven participating EDCs. The first step in this study was to evaluate these datasets in order to appropriately structure the study's research so a representative sample could be drawn. The databases included rate codes, 2012 annual sales[7], North American Industry Classification System (NAICS) codes, and Standard Industrial Classification (SIC) codes for non-residential customers.

4.1.1.1 Premise Counts

To accurately describe lighting usage patterns, it was important to remove non-premise accounts from each EDC customer database. The SWE found that when samples were initially selected, a large number of non-building, closed and inactive accounts were selected. These accounts were linked to end uses such as fire pumps, street lights, railroad signals and other small miscellaneous items. To remove these from the sample, the SWE removed the following accounts:

- All accounts with 2012 annual consumption lower than would be reasonably expected for a building. This cutoff level was set at 2,000 kWh for non-residential accounts.
- All but the top tenth-percentile of Transportation, Communication & Utilities accounts based on kWh consumption.
- Unclassified accounts after SIC mapping and engineering analysis. This represented a small share of consumption for most EDCs. The non-residential customer database PECO provided to the SWE had only approximately 40% of accounts classified so this filter was not possible. Instead the SWE team assumed the 60% of unclassified accounts followed a similar segment distribution as the 40% of classified accounts.
- All closed or inactive accounts in 2012.

[7] May 2012 through April 2013 was used for West Penn Power due to the company's acquisition by First Energy and subsequent customer account record transition.

Consumption values for these removed accounts represented a relatively small share of the total consumption across the state.

4.1.1.2 NAICS and SIC Mapping

The NAICS and SIC codes provided by the EDCs designate the business type of the customer. For the purposes of this study, each specific address needed to be classified by building type rather than a business type. Because of this inconsistency in data, the SWE had to map each SIC or NAICS code to its corresponding building type within the study. For example, while an SIC or NAIC code may categorize an office headquarters for a restaurant chain as restaurant, our study would classify that building as an office to match the specific use of the facility. To bridge this gap, the SWE assigned each NAICS and SIC code to a building type by adopting the building type mapping used by the *California Commercial End Use Survey*.[8] This mapping key was adjusted to ensure that building types are consistent with the definitions used in this study. Further work was done by the SWE to adjust the mapping, primarily concerning the Institutional/Public Service building types. Extensive research was performed on the highest energy consuming accounts along with various random accounts to verify, and in some cases correct, the mapping exercise.

4.1.1.3 Sampling Approach

The SWE considered the Phase I savings contribution and the variability of HOU and CF values reported by TRMs from other jurisdictions to estimate the relative uncertainty associated with each building type listed in Table 3-4 of the 2013 PA TRM. The 2010 statewide electricity consumption for commercial segments, lighting load shares, lighting power density and saturations of various lighting technologies from the Phase I C&I End-Use and Saturation Study were used to further refine the list of high-impact facility types in the Commonwealth. The SWE identified the building types with the greatest relative uncertainty and used a value-of-information approach to allocate sample points to these various building types and focus resources on the building types with the largest uncertainty contribution.

Equation 4-1 was used to estimate the sample size required to achieve the desired levels of precision at the 90% level of confidence. Note that a finite population correction factor was not used due to the large scale of the study.

Equation 4-1: Required Sample Size Calculations

$$n = \left(\frac{z * C_v}{D}\right)^2$$

Where:

n = The required sample size before adjusting for the size of the population

z = A constant based on the desired level of confidence, equal to 1.645 for 90% two-tailed test

Cv = Coefficient of variation (standard deviation/mean), equal to 0.4 for the purposes of this study

D = Desired relative precision

[8] See *California Commercial End Use Survey* prepared by Itron, Inc. March, 2006.

The coefficient of variation term was of central importance to this sample design. Due to the very homogeneous nature of operating hours of lighting fixtures within a given building type, a coefficient of variation of 0.4 was used in the sample design. To achieve the goal of 500 sites, a sample population of at least 1,000 customers per EDC was pulled for recruitment. This design was intended to produce findings that satisfied the statistical requirement of 10% precision at the 90% confidence level for each building type. The confidence levels were reduced to 85/15 for the restaurants, lodging, and miscellaneous building types, as these three types contributed very minimal consumption and uncertainty in the 2012 statewide electricity consumption.

Industrial sites were not included in this study as the HOU values among industrial and/or manufacturing facility types tend to vary widely depending on the type of industry, number of shifts in the facility, and space types within a facility. Although industrial and manufacturing facility types were identified as an important building type, the SWE recommends that these HOU values be estimated using site-specific information.

Because commercial customers may opt to purchase efficient lighting discounted through the Act 129 upstream lighting programs, the commercial lighting survey was designed to determine unique HOU and CF values for medium screw base CFLs and LEDs. In order to estimate an average HOU and CF for screw based CFLs and LEDs by building type that are statistically valid, the SWE assigned a larger sample size to those commercial building types where a significant percentage of CFLs and LEDs were expected. Building types such as Offices, Retail, Small Groceries, and Restaurants made up a large portion of building types in which the majority of the screw based CFLs and LEDs were expected to be metered.

Table 4-1 shows the final target and achieved sample sizes by building type for the commercial metering study.

Table 4-1: Allocation of Sample Sites by Building Type

Building Type	Target	Achieved
Education	60	69
Retail	69	65
Healthcare	55	61
Office	65	61
Warehouse	44	53
Grocery	56	47
Institutional/Public Service	45	37
Restaurants	35	35
Lodging	38	35
Miscellaneous	33	32
Total	**500**	**495**

Table 4-2 shows the final target and achieved sample sizes by EDC for the commercial metering study. Note that in accordance with sample design, EDCs showing higher sales received larger portions of the targeted site visits.

Table 4-2: Allocation of Sample Sites by EDC

Building Type	2012 Sales (GWh)	Target	Achieved
PECO	30,419	198	187
PPL	21,015	118	118
West Penn Power	11,569	57	20
Penelec	9,286	42	35
Duquesne	9,832	40	52
Met-Ed	8,022	35	53
Penn Power	2,769	10	30
Total	**92,912**	**495**	**2,347**

4.1.2 Recruitment

The first step in the survey process was to recruit participants. This section details the methods used and success rates of customer outreach efforts.

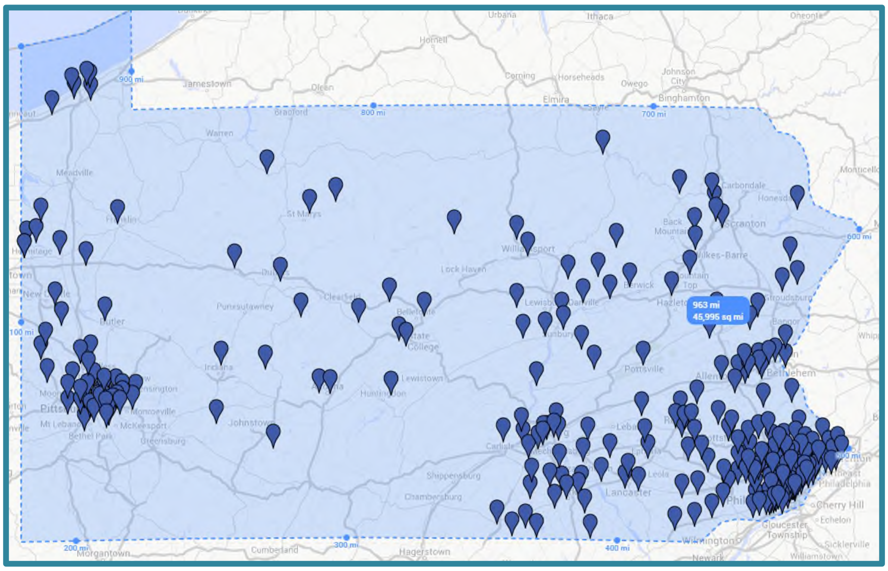
4.1.2.1 Customer Outreach Methods

A letter was drafted and sent to inform customers in the sample that an energy survey was to be performed in their respective territory and that a SWE representative would potentially contact them to ask for their participation in the study. The letter was sent out under the name and letterhead of each respective EDC. All customers with a valid email address on file also received the letter electronically, prompting them to contact the SWE directly for participation. Once the letters were sent out, customers were given a short period of time to volunteer their participation. When voluntary interest seemed to wane, a phone recruitment script was designed to introduce the study to the customer, explain the on-site surveys, and ask for participation. Potential participants that had received letters but had not responded were called by a SWE representative to solicit participation. Once a customer volunteered to participate, SWE callers would place them on the schedule, allotting two hours for each install visit and a half hour for each retrieval visit. The SWE would attempt to contact customers a maximum of three times via phone before considering an account not part of the study. In the unusual event that any EDC or building type saw greater interest than the targeted values, prospective participants were put on a wait list. The wait list was used to supplement EDCs and building types that were unable to reach the targets with their sample's customers.

4.1.2.2 Customer Outreach Results

The SWE garnered a total of 498 site visits retrieving loggers from 495, attaining 99% of the targeted 500 sites. The distribution of participating sites is shown in Figure 4-2, with heaviest participation in the Philadelphia, Pittsburgh, and Allentown regions.

Figure 4-2: Distribution of Participating Sites by Zip Code



A total of 2,347 loggers were installed across the state for an average of 4.75 loggers installed per site. Table 4-3 details the distribution of participants and installed loggers by building type.

Table 4-3: Distribution of Participants and Retrieved Loggers by Building Type

Building Type	Participants	Loggers
Retail	69	312
Office	65	302
Education	61	309
Institutional/Public Service	61	306
Health	53	257
Grocery	47	229
Miscellaneous	37	159
Restaurant	35	155
Lodging	35	166
Warehouse	32	152
Total	**495**	**2,347**

Install visits were initiated in August, 2013 and were completed in July, 2014. Retrieval visits were initiated in October, 2013 and were completed in September, 2014. Details on site activity as well as total loggers in place by month are shown in Figure 4-3 and Figure 4-4, respectively.

Figure 4-3: Site Activity by Month

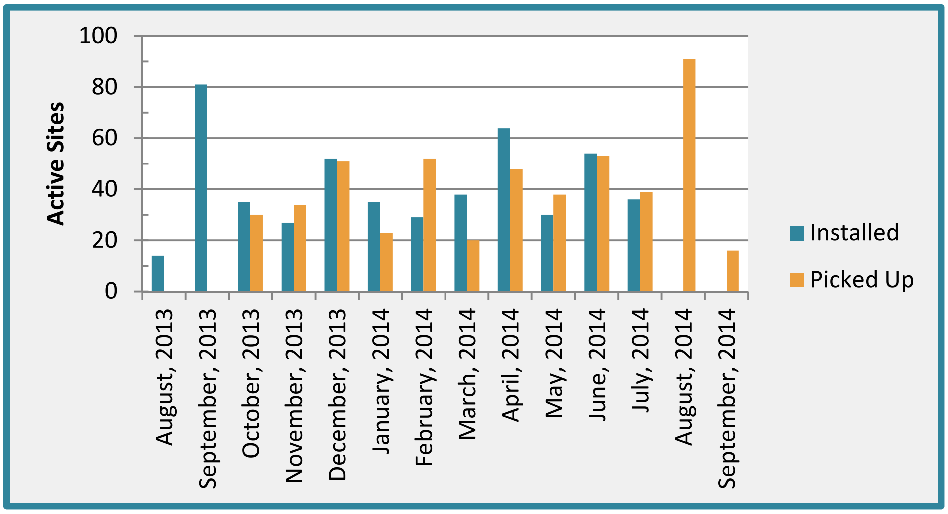
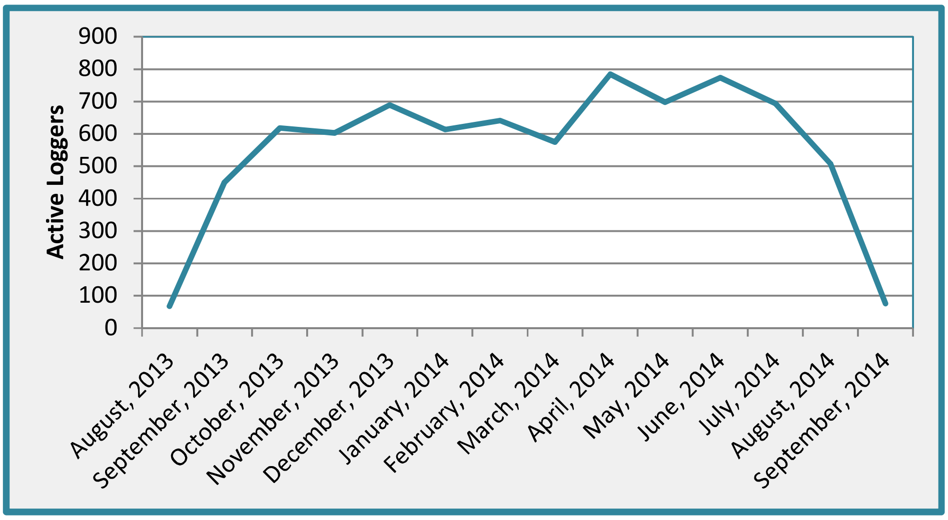
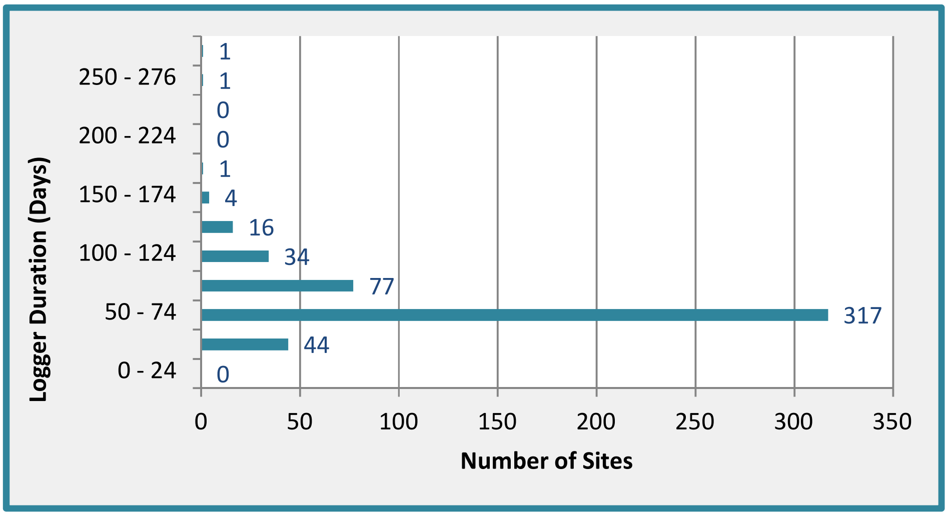


Figure 4-4: Quantity of Loggers in Place by Month



Loggers remained onsite for a period of time anywhere between 45 and 300 days, depending on seasonality and location of the facility in question. An overview of logging durations is presented in Figure 4-5.

Figure 4-5: Logging Durations



4.1.3 Data Collection

Primary data was collected for this study from August, 2013 through September, 2014. Data accrual was completed in three steps:

- Record lighting equipment inventory
- Install light loggers
- Remove light loggers

Each participating site received an initial site visit in which the engineer obtained a detailed lighting inventory and installed a predetermined number of lighting loggers. Loggers were left on site for a minimum of 45 days and a maximum of 300 days. Once the logging duration ended, customers had the option to mail the equipment back or to have an engineer retrieve the equipment onsite.

This section provides a more detail into the methodology for collecting the primary data summarized in this report.

4.1.3.1 Onsite Survey

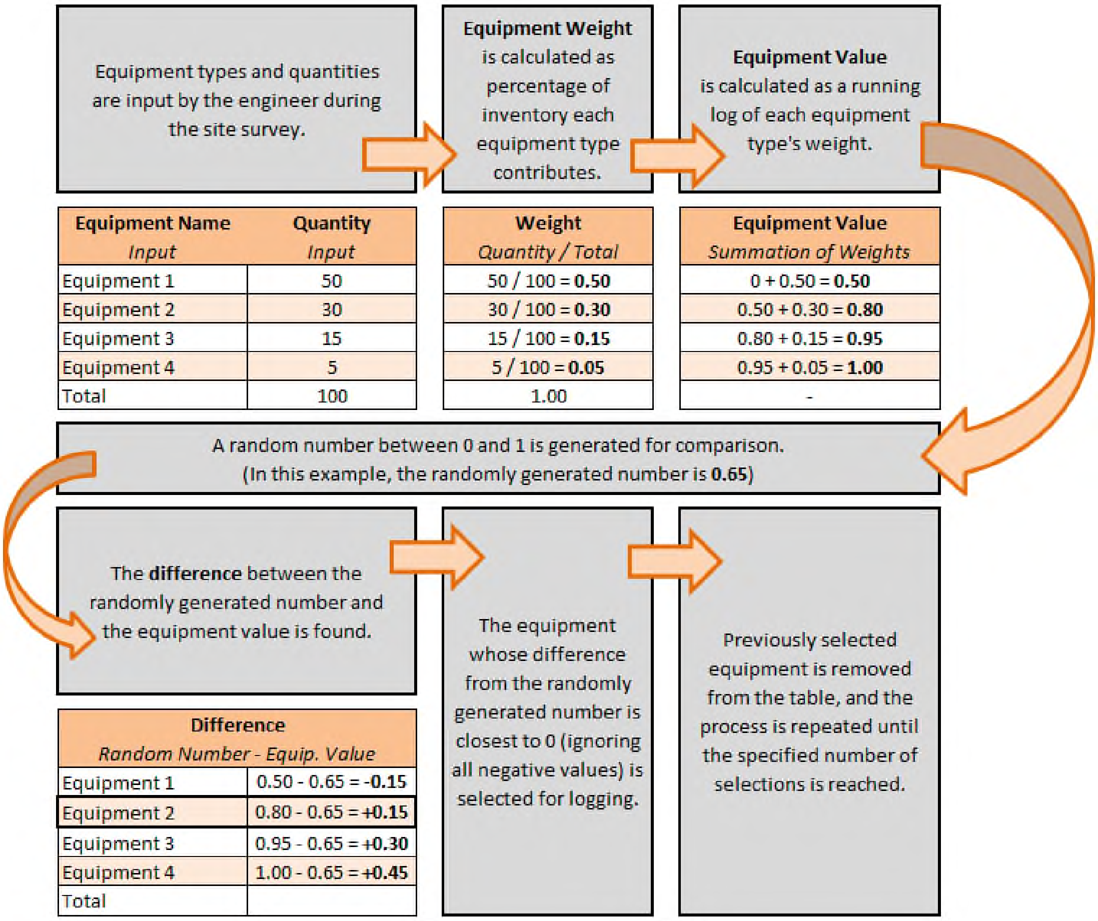
Data was collected on-site electronically via Nexant's iEnergy® Onsite[9].

[9] More details on Nexant's iEnergy® Onsite can be found at http://www.nexant.com/products/nexant-ienergy/ienergy-onsite.

Figure 4-6: Select Images of Nexant's iEnergy® Onsite Energy Assessment and Data Collection Tool

While in the field, engineers used this application to record basic information regarding the facility as well as all lighting and controls equipment observed in the facility. Once the engineer recorded the full lighting inventory, the engineer selected the "random" button, which initiated the sampling process to determine which fixtures would be logged. The application randomly selected fixtures from the inventory for logging. As a default, 5 fixtures were selected. The engineer also had the option to specify the number of fixtures that must be sampled by the application. The sample was randomly selected according to the following process:

Figure 4-7: Random Equipment Selection Process



Once fixtures for logging had been selected, the engineer could opt to install any one of three logger types:

- HOBO® U9-002 light on/off
- HOBO® U12-012 light intensity logger
- HOBO® U9-006 occupancy meter/light logger

The HOBO® U12-012 light intensity loggers were used mostly in high-bay applications and in instances where natural light was unavoidable. A small amount of HOBO® U9-006 occupancy meter/light loggers were installed specifically to log fixtures not attached to any controls in order to try to estimate the savings that could be achieved by the addition of an occupancy sensor. The vast majority of the equipment logged however was logged using the HOBO® U9-002 light on/off logger.

All of the engineers' recorded responses and notes within the iEnergy® Onsite application were stored in a relational database. Exports of the database were extracted as needed for post-processing. The data was organized in two tables: "Assessments" and "Equipment". The "Assessments" table shows one line item (i.e., row) for each site visited. This tab contains general site information associated with each unique site including the customer name, site address, date and time of site visit, building type and age, general heating and air conditioning overview, detailed operating schedule, and responses to the willingness to pay battery. The "Equipment" table displays one line item for each unique lighting equipment entry (space/technology combination). Each line item displays the space type where the fixture is located, as well as the square footage, estimated hours of use, and air conditioning details associated with the space. If loggers were installed to meter a specific lighting fixture, the logger's information is also displayed on the record for that space/equipment combination.

4.1.3.2 Supplemental Sources

Parallel to the Light Metering Study, the SWE also performed a *Non-Residential End Use & Saturation Study*[10] (the Baseline Study). Data collection for the Baseline Study started in August of 2013 and concluded in December of the same year. As many customers participated in both studies, information gathered from the Baseline Study was applied to all applicable fields for all customers also participating in the light metering study once the baseline study was completed.

Appendix C of the 2014 PA TRM was used to estimate wattages of linear fluorescent fixtures in order to calculate load and create load shapes. All other fixture types required manual input of fixture wattage into Nexant's iEnergy® Onsite application.

4.1.4 Data Analysis

Following the collection of primary data, the SWE calculated HOU, peak CFs, and HVAC interactive effects using SAS software in conjunction with Microsoft Excel. Data was evaluated within a statewide context and the context of each building type.

4.1.4.1 Data Review & Cleaning

The following sections outline the data cleaning techniques employed to ensure accuracy of collected data.

4.1.4.1.1 Data Presentation

Each of the three logger types records and presents the collected data differently. For the purposes of this study, all of the data obtained was converted into one common format specifying hourly intervals and the associated percentage of time the logged light was on within each hour.

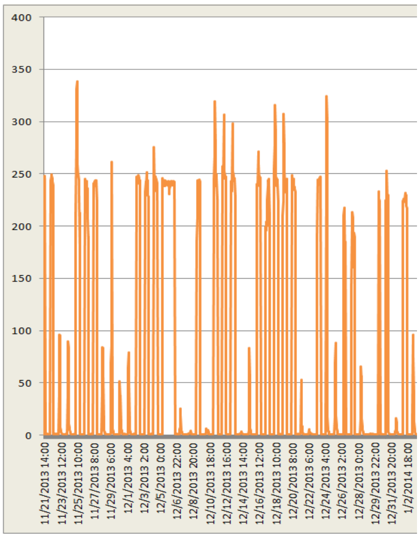
The HOBO® U9-002 Light On/Off Data Logger records light on and off status. The determination of the fixture's on/off status is dictated by calibration performed by the engineer at the time of installation and is adjustable from 10 to 100 lumens/m^2. Each time the state changes from "off" to "on" a value of 1 is recorded and each time the state changes from "on" to "off" a 0 is recorded. Average values are then calculated from the recorded data to get a "percent on" value for each hour of the logging duration.

Unlike the HOBO U9-002, the HOBO U12-012 is programmed to take readings at set intervals (i.e. 5 minutes for this study) at which time the logger will record the light intensity in lumens/ft^2. Figure 4-8 shows the data collected by an intensity logger. From a visual inspection of the data, an analyst would determine a lighting power density threshold above which the light will be considered "on". In the example in Figure 4-8, the threshold was set at 50 lumens/ft^2. The recorded values were then evaluated against the determined threshold in order to tabulate the hourly "percent on" chart for each logger.

[10] The *Non-Residential End Use & Saturation Study* Report is available at: http://www.puc.pa.gov/filing_resources/issues_laws_regulations/act_129_information/act_129_statewide_evaluator_swe_.aspx

Figure 4-8: Sample Intensity Logger Data

...	...
3/13/2014 9:00	231.8
3/13/2014 10:00	244.3
3/13/2014 11:00	236.9
3/13/2014 12:00	225.9
3/13/2014 13:00	221.6
3/13/2014 14:00	212.8
3/13/2014 15:00	215.7
3/13/2014 16:00	216.4
3/13/2014 17:00	217.2
3/13/2014 18:00	237.7
3/13/2014 19:00	1.1
3/13/2014 20:00	1.1
3/13/2014 21:00	1.1
3/13/2014 22:00	1.1
3/13/2014 23:00	1.1
3/14/2014 0:00	1.1
3/14/2014 1:00	1.1
3/14/2014 2:00	1.1
3/14/2014 3:00	1.1
3/14/2014 4:00	1.1
3/14/2014 5:00	1.1
3/14/2014 6:00	231.1
3/14/2014 7:00	232.5
3/14/2014 8:00	228.9
3/14/2014 9:00	1.1
3/14/2014 10:00	1.1
3/14/2014 11:00	1.1
3/14/2014 12:00	1.1
3/14/2014 13:00	1.1
3/14/2014 14:00	1.1
3/14/2014 15:00	1.1
3/14/2014 16:00	1.1
...	...



The HOBO U9-006 occupancy meter/light logger records the operating hours in the same way as the Hobo U9-002 logger with an added column describing the occupancy status based on an infrared motion sensor. As with the on/off logger, a value of "1" is recorded each time the state changes from "off" to "on" and a value of "0" is recorded each time the state changes from "on" to "off". In the case of these loggers, average values were calculated from the recorded data to get a "percent on" value for each hour of each day.

4.1.4.1.2 Time Zone Inconsistencies

As the installation and removal of light meters spanned several months, loggers were sometimes launched in Daylight Savings Time and read out in Eastern Standard Time. The loggers are programmed to record data in GMT -5. Once all data was compiled, all loggers were adjusted to Eastern Prevailing Time in SAS.

4.1.4.1.3 Noise

The next step was to remove spurious observations that may have been recorded during installation and removal of the logger. Depending on when the engineer launched the logger and how long the installation took, it is possible for the logger to record information during transport and installation that is not representative of the actual site operation. All data recorded during the entire day of installation and removal as recorded in the scheduling database was discarded. This also ensured that partial day data did not skew the results.

4.1.4.1.4 Hours of Use Irregularities

Collected logger data was compared to the customer supplied "Estimated hours of use" field noted in the assessment for the space that was logged. Special consideration was given to logger data showing more than a 25% difference from the customer reported hours of use. Similarly, logger data files showing either 0% or 100% operation throughout the entire logging period were analyzed on a case by case basis to determine whether or not they should be discarded.

4.1.4.1.5 Seasonality

In cases when a customer reported their facility operated seasonally, the engineer requested detailed operation schedules from the customer including dates of seasonality, and operating hours associated with each date range. Logger data from sites marked in the database as having seasonal operation were then individually analyzed to make sure the annualization of the logger data appropriately reflected the site's operation. This was done by applying ratios to seasonal date ranges based on the percentage of operation during the date range in question with respect to the logged date range. Table 4-4 provides an example of an education facility that was logged from November 13, 2013, through March 12, 2014, with noted decreased hours during the period of June 6, 2015, through August 20, 2015. The adjustment factor is based on the hours of operation the customer provided for the seasonal time frame as compared to the logged data. In the example shown, the customer noted that the facility operates 7:00

a.m. to 6:00 p.m. on weekdays and 8:00 a.m. to 12:30 p.m. on Saturdays in the summer, which was found to be 24% less and 5% more respectively than the logger data.

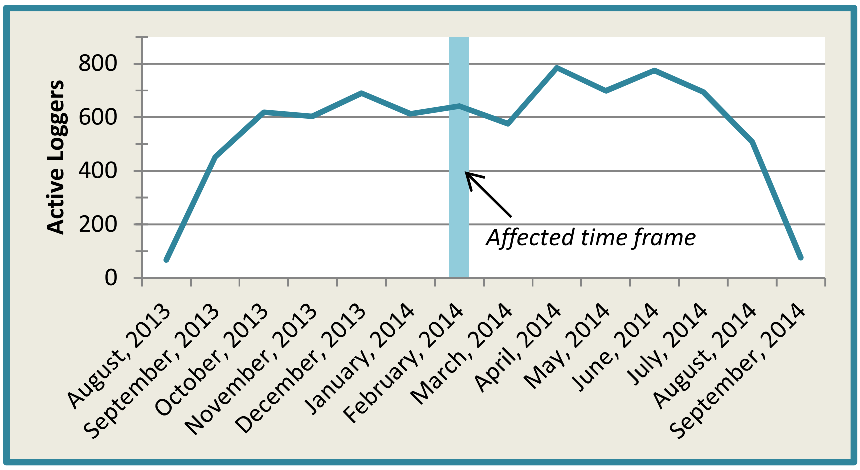
Table 4-4: Sample Seasonality Adjustment Table

Project ID	PECO_xxxx
Install Date	**11/13/2013**
Removal Date	**3/12/2014**
Season 1 Start Date	1/1/2015
Season 1 End Date	6/5/2015
Season 1 Weekday Action	Logged
Season 1 Saturday Action	Logged
Season 1 Sunday Action	Logged
Season 2 Start Date	**6/6/2015**
Season 2 End Date	**8/20/2015**
Season 2 Weekday Action	**-24%**
Season 2 Saturday Action	**+5%**
Season 2 Sunday Action	**=**
Season 3 Start Date	8/21/2015
Season 3 End Date	12/31/2015
Season 3 Weekday Action	Logged
Season 3 Saturday Action	Logged
Season 3 Sunday Action	Logged

4.1.4.1.6 Inclement Weather

During the week of February 3, 2014, through February 7, 2014, heavy snow, ice, and wind caused widespread power outages and school closings across the PECO, PPL, and Met-Ed territories. The unusual lack of power, or lack of occupancy in the case of school closings, caused the lights to be powered down when they may typically be operational. The data from this period was discarded as it was not representative of the typical operation. During this period, loggers were deployed at 30 sites in Met-Ed territory, 75 sites in PECO territory, and 31 sites in PPL territory. These loggers were left in the field one week longer than anticipated to make up for the week of lost data.

Figure 4-9: Loggers Affected by Inclement Weather



4.1.4.1.7 Lighting Controls

A portion of the fixtures logged were found to have lighting controls installed. Section 3.2.2 of the 2014 Pennsylvania TRM defines the following equations for calculating savings attributed to lighting upgrades:

Equation 4-2: Lighting Savings Calculations per Section 3.2.2 of the 2014 PA TRM

For all lighting fixture improvements (without control improvements)

$$\Delta kWh = (kW_{base} - kW_{EE}) * \left[HOU * (1 - SVG_{base}) * \left(1 + IF_{energy}\right)\right]$$

$$\Delta kW_{peak} = (kW_{base} - kW_{EE}) * [CF * (1 - SVG_{base}) * (1 + IF_{demand})]$$

For all lighting control improvements (without fixture improvements)

$$\Delta kWh = kW_{con} * HOU * (SVG_{EE} - SVG_{base}) * \left(1 + IF_{energy}\right)$$

$$\Delta kW_{peak} = kW_{con} * CF * (SVG_{EE} - SVG_{base}) * (1 + IF_{demand})$$

Where:

kW_{xx} = Rated kW of the fixture
kW_{con} = Total kW of all fixtures controlled
HOU = Hours of use
CF = Coincidence factor
SVG = Savings factor associated with employed controls techniques
IF_{xx} = HVAC interactive factor

Table 3-6 of the TRM defines the HOU based on building type and Table 3-8 of the TRM defines the SVG factor assumptions based on lighting control type. In order to determine HOU values consistent with Table 3-6 (i.e., only manual controls), HOU values for logged fixtures with controls were increased by a factor using estimated savings percentages of controls technologies outlined in Table 3-8. Otherwise, the effect of controls would be incorporated into Table 3-6 and then again in the savings algorithm – leading to an artificially low savings values. For example, Table 3-8 of the 2014 TRM defines the SVG factor for an occupancy sensor as 24%. If a logger recorded the operating hours of a lighting fixture attached to an occupancy sensor to be 3,000 hours, our analysis used an input of 3,947 hours according to the equation below:

Equation 4-3: Sample Adjustment for Lighting Controls

$$Adjusted\ HOU = \frac{Logged\ HOU}{1 - SVG} = \frac{3{,}000}{1 - 24\%} = \mathbf{3{,}947\ Hours}$$

4.1.4.2 Hours of Use Calculations

The data collected over the logging duration was tabulated per hour per week to create an average 192-hour operation schedule reference table (as pictured below in Table 4-5) for each logger. The 192 hours correspond to 24 hours of each of eight distinct day types (Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and holiday). Annual hourly load shapes were created for each logger by mapping each hour of each day in the 2015 calendar to the 192-hour reference table. This method of analysis assumed that the average Monday throughout the logged period is representative of all Mondays throughout the year (and likewise for each Tuesday, Wednesday, etc.).

Table 4-5: Sample 192-Hour Reference Table

	Hour Ending Value										
Day Type:	...	10	11	12	13	14	15	16	17	18	19	...
(1) Sunday	...	76%	86%	86%	86%	86%	86%	85%	40%	4%	< 1%	...
(2) Monday	...	55%	72%	85%	100%	100%	100%	94%	56%	9%	< 1%	...
(3) Tuesday	...	83%	92%	100%	100%	100%	100%	90%	78%	30%	14%	...
(4) Wednesday	...	84%	84%	99%	100%	100%	100%	100%	73%	9%	< 1%	...
(5) Thursday	...	94%	100%	100%	100%	100%	100%	91%	64%	21%	14%	...
(6) Friday	...	100%	100%	100%	100%	96%	82%	76%	58%	4%	< 1%	...
(7) Saturday	...	77%	86%	86%	86%	86%	86%	86%	76%	6%	< 1%	...
(8) Holiday	...	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	...

1. Table abridged due to size.

2. Percentages shown represent the percentage of each hour lights were found on.

Operating characteristics from logged holiday data were applied only to any day noted as an observed holiday in each site's assessment. In the assessment, the engineer was able to specify if the site is closed or if it observes only reduced operation for each specific holiday. For sites metered during a holiday, the collected data will be applied to any day marked as a holiday. For facilities that were not metered during a holiday, holiday hours will be taken from the assessment information provided by the customer to the engineer onsite and recorded in the tablet.

The annualized HOU obtained by mapping the 192-hour reference table to the 2015 calendar from various spaces within a facility were weighted by the relative contribution to the lighting load of the facility. Each fixture type recorded in the lighting inventory was assigned a wattage as found in the Wattage Table in the Appendix C calculator of the Pennsylvania TRM. The lamp types and fixture counts collected during the site visit in conjunction with their assigned assumed wattages were used to determine the total lighting load as well as the connected load per specific space type for each assessment submitted. The percentage of connected load each space type contributed to the total connected load was calculated per site and averaged to create space type weighting factors to be applied to all loggers collected from a building of the matching building type. Table 4-6 shows the weighting factor results of a sample 20 restaurant sites evaluated.

Table 4-6: Calculation of Restaurant Space Type Weighting

Assessment ID:	100048	100130	...	100144	100145	100343	100371	Avg.
Total Connected Load (W):	2,175	9,044	...	18,540	3,682	3,600	1,211	-
Dining Area	47%	88%	...	49%	42%	62%	21%	47%
Kitchen/Food Preparation	0%	6%	...	20%	33%	6%	32%	24%
Restrooms	6%	6%	...	13%	3%	2%	48%	9%
Storage	5%	0%	...	2%	17%	29%	0%	7%
Other	36%	0%	...	0%	0%	0%	0%	4%
Sales Floor	0%	0%	...	0%	0%	0%	0%	4%
Interior Office	6%	0%	...	2%	0%	0%	0%	3%
Hallways	0%	0%	...	10%	3%	0%	0%	1%
Exterior Office	0%	0%	...	0%	0%	0%	0%	< 1%
Lounge/Break Room	0%	0%	...	0%	0%	0%	0%	< 1%
Lobby/Reception	0%	0%	...	2%	0%	0%	0%	< 1%
Mechanical Room	0%	0%	...	0%	2%	0%	0%	< 1%
Meeting/Conference Area	0%	0%	...	2%	0%	0%	0%	< 1%
Shipping and Receiving	0%	0%	...	0%	0%	0%	0%	< 1%

1. Table abridged due to size.
2. The "Avg." column represents the straight average across each row and is not weighted by size of the facility.
3. Shaded rows represent space types which were not logged.

Because the study design called for five loggers per site, most assessments contained more space types than were logged. The random selection algorithm in the iEnergy® Onsite application was configured to favor spaces with higher contributions to connected load. For example, Assessment 100144 included lighting equipment from 8 space types, but only 5 were logged.

Of the 20 sites included in the example above, no loggers were installed in the space types shaded in blue which are labeled as sales floor, interior office, exterior office, lounge/break room, lobby/reception, mechanical room, meeting/conference area, or shipping and receiving. In aggregate these 8 space types accounted for only 7% of the load observed. The weighting of the logged spaces was then redistributed across only those space types with accompanying logger data. Table 4-7 shows how the final HOU were calculated from the logger data collected and the redistributed weighted space types.

Table 4-7: Calculation of Restaurant HOU

Space Type	Weight		Annualized HOU		Weight*HOU
Dining Area	0.49	x	2,304	=	1,129
Kitchen/Food Preparation	0.25	x	3,058	=	765
Restrooms	0.09	x	4,353	=	392
Storage	0.10	x	713	=	71
Other	0.05	x	6,596	=	330
Hallways	0.01	x	2,452	=	25
Total	**1.00**				**2,711**

Note that each sampled site within a given building type was weighted equally. Data collected from a logger installed in the hallways of 500,000 square foot hospital was given equal weight as data from a 5,000 square foot dentist's office.

4.1.4.3 Coincidence Factor Calculations

The Pennsylvania 2014 TRM defines the peak CF as the fraction of the connected load that occurs during the peak demand window (from 2 p.m. to 6 p.m. for all non-holiday weekdays in the months of June through August). From the 192-hour reference table created for each logger, the average percentage displayed on non-holiday weekdays from hours ending 15 to 18 in June, July, and August was calculated as the CF for that logger. Table 4-8 illustrates the CF calculation for a logger installed in an interior office within a miscellaneous building.

Table 4-8: Calculation of Coincidence Factor

	Hour Ending Value											
Day Type:	...	10	11	12	13	14	15	16	17	18	19	...
(1) Sunday	...	76%	86%	86%	86%	86%	86%	85%	40%	4%	< 1%	...
(2) Monday	...	55%	72%	85%	100%	100%	100%	94%	56%	9%	< 1%	...
(3) Tuesday	...	83%	92%	100%	100%	100%	100%	90%	78%	30%	14%	...
(4) Wednesday	...	84%	84%	99%	100%	100%	100%	100%	73%	9%	< 1%	...
(5) Thursday	...	94%	100%	100%	100%	100%	100%	91%	64%	21%	14%	...
(6) Friday	...	100%	100%	100%	100%	96%	82%	76%	58%	4%	< 1%	...
(7) Saturday	...	77%	86%	86%	86%	86%	86%	86%	76%	6%	< 1%	...
(8) Holiday	...	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	< 1%	...

1. Table abridged due to size.

2. Percentages shown represent the percentage of each hour lights were found on.

In this example, the average percentage of time the light spent on within the shaded cells is 67%, so the CF for this logger is 0.67. The aggregated CF per building type to be presented in the TRM was ultimately calculated by applying the same space type weighting as was defined in the HOU calculations.

The calculation of the CF in this fashion assumed that the operation observed from 2 p.m. to 6 p.m. during the weeks of logging consistently represents the operation observed from 2 p.m. to 6 p.m. in June through August, unless seasonal operation was otherwise noted in the assessment.

4.1.4.4 HVAC Interactive Effects Calculations

A reduction in lighting load affects the cooling and heating requirements of a building. Energy efficient lighting technologies typically expel less heat than their standard counterparts; this creates cooling benefits in the summer as less heat has to be removed from the space, and heating penalties in the winter as more heat needs to be added. To account for these impacts in areas with electric cooling and/or electric heating, energy and demand savings from lighting retrofits are adjusted by the HVAC Energy Interactive Factor (IF_{energy}) and the HVAC Demand Interactive Factor (IF_{demand}), respectively. IF_{energy} is the summation of cooling benefits and heating penalties attributed to electric heating and cooling equipment divided by the total lighting savings. IF_{demand} is the ratio of the peak kW reduction for summer cooling to the demand savings from a lighting project, where the peak kW reduction is the average hourly kW reduction during PJM summer coincident peak hours[11]. These equations are noted below.

Equation 4-4: Interactive Factor Equations

$$IF_{energy} = \frac{Cooling\ Benefits + Heating\ Penalties}{Gross\ Lighting\ Savings\ (kWh)}$$

[11] Coincident peak hours are 2:00 pm through 6:00 pm on non-holiday weekdays during June, July and August.

$$IF_{demand} = \frac{Peak\ Cooling\ Benefits}{Gross\ Lighting\ Demand\ Reductions\ (kW)}$$

A supplemental Excel-based tool was developed in order to calculate the two interactive factors based on the data collected from the metering and baseline studies in addition to PECO's tracking data for the most recent available four quarters. The tracking data was analyzed to calculate the sensible heat gain of all observed lighting retrofit combinations according the ASHRAE 90.1 equation below.

Equation 4-5: Sensible Heat Gain

$$\Delta Heat\ Gain = \frac{\sum Qty * HOU * \left(W_{post} - W_{pre}\right) * F_{ul} * F_{sa}}{1000} * SF$$

Where:

- Qty = Fixture quantity
- HOU = Hours of use of the fixture
- W_{post} = Wattage of the efficient fixture
- W_{pre} = Wattage of the removed fixture
- F_{ul} = Lighting Use Factor, assumed to be 1 for all fixtures
- F_{sa} = Special allowance factor
- SF = Space fraction, or percentage of heat gain that will need to be cooled

Using savings values from the same tracking data, energy savings and demand reduction profiles were created proportionately to the annual lighting load shapes observed in the metering study for each building type. Building occupancy was determined based on the probability that lights would be active. A building type was assumed to be "occupied" whenever the probability of the lights being on was greater than 40%.

Building type-specific cooling load shapes were created from the eQuest modeling runs used to develop equivalent full load hours (EFLHs) for cooling systems, while building type-specific heating and cooling set point trends were taken from the Phase II baseline study. Data was compared to the average statewide temperatures in order to understand HVAC operation schedules.

Electric cooling benefits and electric heating penalties were calculated for each building type as a function of the percentage of electrically cooled space, the percentage of space with electric heating, and the HVAC equipment efficiencies. Interactive factors were then calculated for all building types from the heating and cooling benefits. The key factors affecting the calculations as well as the calculated cooling benefits and heating penalties are presented in Appendix C.

The resulting interactive factors showed the influence from the percentage of electrically heated space, which ranged from a low 0.1% for warehouse to a high of 61.1% for restaurants. [12] A lower percentage of electrically heated space resulted in a smaller heating penalty and a higher IF_{energy} while a higher percentage of electrically heated space resulted in a larger heating penalty and a lower IF_{energy}.

[12] Percentages are based on a weighted average of Phase 1 and Phase 2 Baseline data. The two studies were combined due to the great differences in the Phase 1 and Phase 2 values.

Table 4-9: Share of Electrically Heated Buildings

Building Type	Percentage of Space Heated by Electricity
Education	0.1%
Grocery	24.6%
Health	30.4%
Institutional/Public Service	2.9%
Miscellaneous	21.6%
Lodging	53.7%
Office	6.7%
Restaurant	61.1%
Retail	36.9%
Warehouse	0.1%

4.1.5 Uncertainty

As with any survey or statistical analysis, the results in this report are subject to a certain degree of uncertainty. Practical and monetary constraints make it impossible for the SWE to survey the entire population of Pennsylvania non-residential electrical accounts, necessitating the selection of a small sample population from which to collect data. When using a sample to make predictions about a population, factors of uncertainty are introduced, primarily based on the size of the sample and the existence of biases within the sample.

Equation 4-6: Margin of Error

$$Margin\ of\ Error = z * \frac{\sigma}{\sqrt{n}}$$

Where:

z = 1.645 for 90% confidence

σ = The standard error

n = The sample size (500)

With considerations for sample size it is important to note that the more general findings (such as statewide lighting and controls technology details) in this report have the highest precision, while the precision decreases as results become more specific (i.e. CFs and hours of use per building type).While findings are presented for all commercial buildings at the statewide level, the level of precision differs by building type since some building types received fewer samples than others (e.g., warehouses received 32 surveys vs. 65 surveys completed in office buildings). Additional margins of error were also introduced into the study as the logged equipment was only a sample of equipment from the sample of sites.

Another factor that can influence the uncertainty of the results is the extent to which the sample is representative of the population as a whole. Though samples are selected randomly, it is possible that the sample contains some type of bias that can influence the overall results. One such example is a sample with a high prevalence of retail customers who are busy during the holidays, and thus unavailable for a site visit, potentially resulting in a lower than average energy consumption.

Where possible, the SWE took steps to ensure that biases were minimized in the sample. Samples were selected randomly from the customer database in a manner which minimized the potential for human error or other biases. After gathering data, the SWE then analyzed the sample and compared the customers with known statistics about the population in an attempt to verify and calibrate the survey results. This comparison is explored by building type further in Section 4.3.

The relative precision of the key results of this study are presented graphically in Figure 4-10 and Figure 4-11. From the graphs, the largest amounts of uncertainty are introduced in the Warehouse and Lodging building types for general service lighting, and in the education and grocery building types for screw-base CFL & LED applications.

Figure 4-10: Margins of Error in HOU at 90% Confidence Level

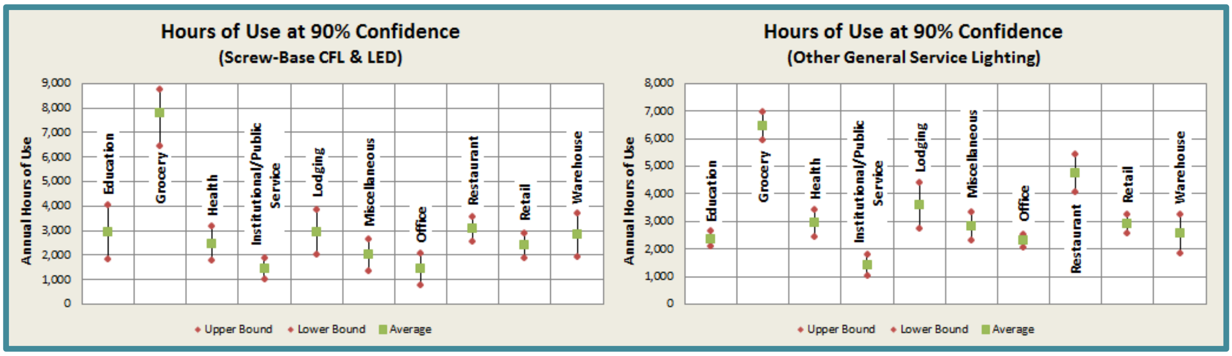
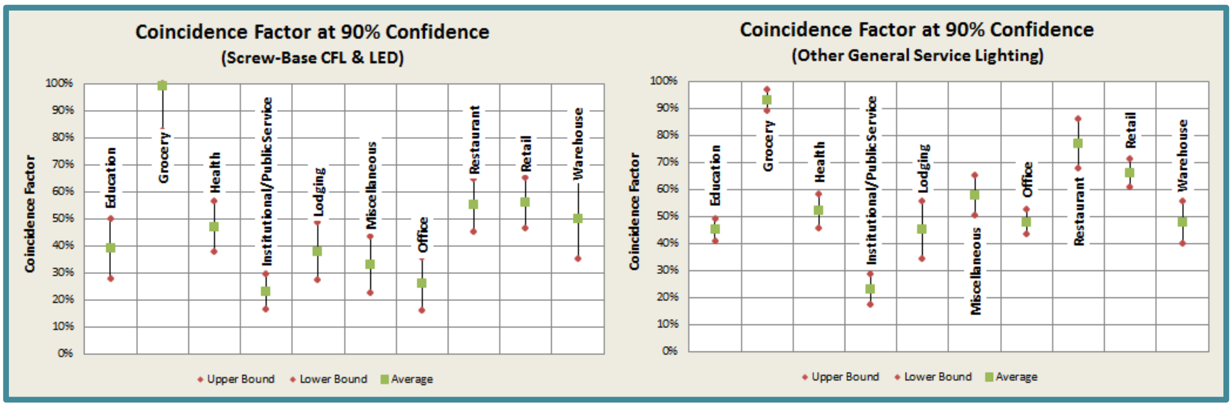


Figure 4-11: Margins of Error in CF at 90% Confidence Level



4.2 STATEWIDE COMMERCIAL FINDINGS

This section provides detailed findings relevant to the lighting equipment found onsite, and the accompanying calculated HOU, CF, and IF.

4.2.1 Statewide Lighting Equipment Findings

Table 4-10 shows the statewide representation of different lighting system technologies as a function of connected load.

Table 4-10: Non-Residential Lighting Technology Representation by Percent of Connected Load

Lighting Technology	Connected Load (kW)	Percent of Total Connected Load
T12	2,649	26%
T8	4,410	44%
T5	687	7%
Incandescent	754	7%
Halogen	226	2%
CFL	502	5%
LED	75	1%
HID	70	1%
Metal Halide	699	7%
Total	**10,072**	**100%**

Figure 4-12: Statewide Linear Fluorescent Lighting Share

Linear fluorescent lighting accounts for more than three quarters of the connected lighting load of all commercial buildings in Pennsylvania. While T5s are predominantly found in high-bay applications, for the purpose of this study they will be included with the linear fluorescent lamps. T8 lamps dominate the linear fluorescent market statewide, and across most building types. Sites within building types experiencing lower operating hours, such as Institutional/Public Service and Miscellaneous, were found to rely more heavily on T12 lamps. T5 lamps account for only 7% of the statewide lighting load and were most commonly found throughout the Health, Grocery, Miscellaneous, and Warehouse building types.

Figure 4-13: Statewide Other Non-High-Bay Lighting Share

Other non-high-bay lighting consists of incandescent, halogen, CFL, and LED lamps of both the screw-in and hardwired variety. This category contributes 15% to the statewide lighting load. Edison-base bulbs make up the majority of this category, with only 12% of other non-high-bay lighting being attributed to hardwired bulb types. The CFL is the most prevalent technology within this category, accounting for 5% of the statewide lighting load and 24% of the load from this category. Hardwired CFL lamps consist of 3-pin, 4-pin, and biax lamps, and are most commonly found in offices and education facilities as recessed can fixtures. Hardwired LED lamps were more popular than screw-in LED lamps statewide with prevalence in grocery and retail establishments as refrigerated display case lighting, and also in health facilities as retrofitted linear fluorescent fixtures.

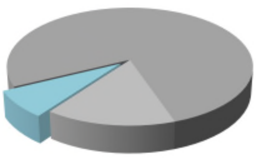


Figure 4-14: Statewide High-Bay Lighting Share

High-bay lighting accounts for only 8% of the statewide lighting load. This category includes high-intensity discharge and metal halide lamps. The more common of the two technologies is the metal halide lamp, which contributes 7% to the statewide lighting load and 91% of the load from high-bay applications. High-bay technologies are most commonly found in grocery and warehouse site.

The density of each lighting technology as a factor of connected load with respect to building type is summarized in Figure 4-15 with highest representation in the darkest cells and diminishing with decreased intensity. These trends are explored further in Section 4.3.

Figure 4-15: Representation of Lighting Technology by Building Type

	T12	T8	T5	Incandescent	Halogen	CFL	LED	HID	Metal Halide
Education	24%	52%	8%	4%	1%	4%	0%	1%	5%
Grocery	11%	60%	7%	1%	5%	2%	4%	0%	10%
Health	23%	38%	9%	17%	3%	10%	1%	0%	0%
Institutional	42%	26%	8%	14%	4%	3%	1%	0%	1%
Lodging	19%	18%	0%	25%	3%	31%	2%	0%	1%
Miscellaneous	46%	20%	9%	11%	4%	6%	1%	3%	1%
Office	39%	43%	5%	4%	2%	3%	0%	1%	2%
Restaurant	15%	39%	1%	34%	6%	3%	1%	0%	0%
Retail	19%	61%	4%	4%	3%	1%	1%	0%	6%
Warehouse	34%	30%	5%	1%	0%	2%	0%	0%	28%

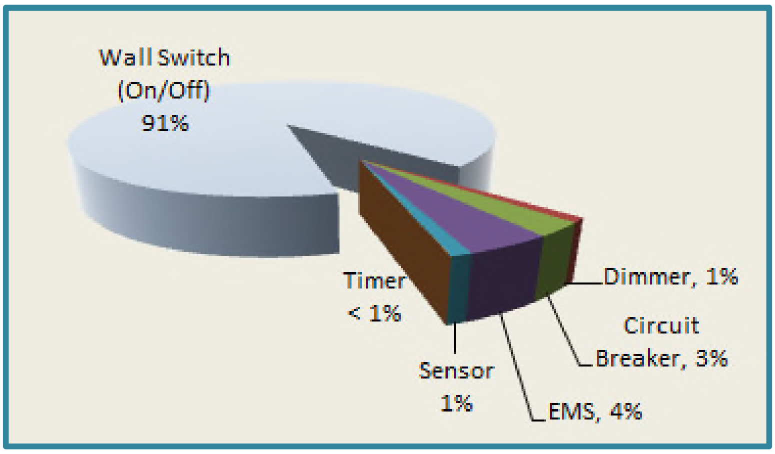
Table 4-11 shows the penetration of automatic lighting controls across the state by building type. This table reflects sites that had implemented at least one lighting control strategy. Overall, 26% of the visited sites had at least one lighting control strategy in place.

Table 4-11: Percentage of Sites Utilizing Lighting Controls by Building Type

Building Type	Sites Surveyed	Sites Utilizing Controls	Percent of Controlled Sites
Retail	69	6	9%
Office	65	16	25%
Education	61	24	39%
Institutional/Public Service	61	20	33%
Health	53	9	17%
Grocery	47	15	32%
Miscellaneous	37	8	22%
Restaurant	35	11	31%
Lodging	35	13	37%
Warehouse	32	7	22%
Statewide	**495**	**129**	**26%**

The majority (94%) of the lighting load was found to be controlled by manual switches, including direct control from circuit breaker and on/off switches. Implemented control strategies found include sensors, dimmers, timers, and energy management systems. The popularity of lighting controls strategies by percent of controlled load is summarized in Figure 4-16.

Figure 4-16: Lighting Controls Strategies by Controlled Load



4.2.2 Statewide HOU and CF Findings

HOU and CF findings were analyzed discretely for Interior Screw-Base Bulbs (Incandescent, Halogen, CFL, and LED) and Other General Service Lighting (Linear Fluorescents, HID bulbs, and Metal Halide bulbs). Table 4-12 shows the sampling of logged fixture types contributing to the final HOU and CF values.

Table 4-12: Overview of Logged Lighting Technologies

Application	Lighting Technology	Connected Load (kW)	Saturation (by Load)	Fixtures Logged
Interior Screw-Base CFL & LED	Incandescent	753.76	7%	234
	Halogen	225.74	2%	50
	CFL	502.30	5%	269
	LED	75.35	1%	55
Other General Service Lighting	T12	2,649.20	26%	694
	T8	4,410.33	44%	936
	T5	686.67	7%	87
	HID	70.39	1%	5
	Metal Halide	699.22	7%	17

The unweighted average annual HOU value across all 495 sites is 3,069. The unweighted average CF is 0.51. A comparison of these values across building types with associated margins of error is presented in Table 4-13 and explored further in Section 4.3.

Table 4-13: Hours of Use and Coincidence Factors by Building Type

Application	Building Type	HOU	*MOE*[†]	CF	*MOE*[†]
Interior Screw-Base CFL & LED	Education	2,944	*± 1,120*	0.39	*± 0.11*
	Grocery	7,798	*± 1,335*	0.99	*± 0.16*
	Health	2,476	*± 704*	0.47	*± 0.09*
	Institutional/Public Service	1,456	*± 427*	0.23	*± 0.07*
	Lodging	2,925	*± 904*	0.38	*± 0.11*
	Miscellaneous	2,001	*± 664*	0.33	*± 0.10*
	Office	1,420	*± 646*	0.26	*± 0.10*
	Restaurant	3,054	*± 519*	0.55	*± 0.10*
	Retail	2,383	*± 488*	0.56	*± 0.09*
	Warehouse	2,815	*± 894*	0.50	*± 0.15*
Other General Service Lighting	Education	2,371	*± 261*	0.45	*± 0.04*
	Grocery	6,471	*± 520*	0.93	*± 0.04*
	Health	2,943	*± 498*	0.52	*± 0.06*
	Institutional/Public Service	1,419	*± 381*	0.23	*± 0.06*
	Lodging	3,579	*± 840*	0.45	*± 0.10*
	Miscellaneous	2,830	*± 518*	0.58	*± 0.07*
	Office	2,294	*± 228*	0.48	*± 0.05*
	Restaurant	4,747	*± 688*	0.77	*± 0.09*
	Retail	2,915	*± 343*	0.66	*± 0.05*
	Warehouse	2,545	*± 689*	0.48	*± 0.08*

[†]*Margins of error presented at the 90% confidence level.*

In general, the HOU and CF values decreased from the values represented in the 2014 TRM, with the outliers being the Restaurant and Grocery building types, which both saw increases of more than 30% in HOU. The change in HOU and CF values is presented in Table 4-14. Note that the 2014 TRM did not distinguish between "Interior Screw-Base CFL & LED" and "Other General Service Lighting", and as such, only the updated values for "Other General Service Lighting" are presented for comparison.

Table 4-14: Change in HOU and CF Values from 2014 TRM to 2016 TRM

	2016		2014		△	
Building Type	HOU	CF	HOU	CF	HOU	CF
Education	2,371	45%	2,190	56%	8%	-20%
Grocery	6,471	93%	4,660	87%	39%	7%
Health	2,943	52%	4,185	72%	-30%	-27%
Institutional/Public Service	1,419	23%	3,155	62%	-55%	-63%
Lodging	3,579	45%	4,399	50%	-19%	-9%
Miscellaneous	2,830	58%	4,056	62%	-30%	-6%
Office	2,294	48%	2,567	61%	-11%	-21%
Restaurant	4,747	77%	3,613	65%	31%	18%
Retail	2,915	66%	2,829	73%	3%	-10%
Warehouse	2,545	48%	2,868	58%	-11%	-17%

4.2.3 Statewide IF Findings

The 2014 PA TRM presented interactive effects solely as a factor of a space conditioning type (i.e. comfort cooled space, freezer space, unconditioned space, etc.). However, this is an oversimplification of a much more complicated calculation. The interactive effects observed by a lighting retrofit are affected by the following factors:

- Lighting Load Shape
- Installed and Removed Lighting Specifications
- Heating and Cooling Efficiencies
- Heating and Cooling Setpoints
- Heating Fuel Type
- Dry Bulb Temperature

The interactive factor is the summation of heating penalties and cooling benefits occurring as a result of a lighting retrofit. Negative interactive factors signify that the heating penalties outweigh the cooling benefits (i.e. the reduction in heat that will need to be added mechanically to the space when the building is in heating mode is greater than the reduction in heat that the air conditioning will not need to compensate for in cooling mode). A high saturation of electric heating leads to increased heating penalties.

After many trial runs of individually adjusting variables, it was determined that the heating fuel type contributed most substantially to the IF results. The Phase I and II Baseline Studies[13] revealed variations in the average saturation of electric heat by building type. These heating fuel saturations were used to indicate the probability of the presence of electric heat in the calculation of average IF values for each building type. Each building type was separately analyzed at both 100% and 0% electric heat as well in order to develop values for the 2016 TRM. This is explored further in Appendix C.3.

The updated demand and energy interactive factors by building type are summarized in Table 4-15 and explored further in Section 4.3. The average saturation of electric heating for building types with positive energy interactive factors is 8% while the average for types with negative factors is 40%.

Table 4-15: Interactive Factors by Building Type

Building Type	IF Demand	IF Energy
Education	12.3%	1.8%
Grocery	19.2%	-1.4%
Health	19.4%	-2.2%
Institutional/Public Service	16.6%	2.7%
Lodging	19.6%	-7.1%
Miscellaneous	21.6%	-0.1%
Office	22.6%	3.1%
Restaurant	19.3%	-7.1%

[13] Table 4-4 of the Phase I Baseline Study Report and Table 4-5 of the Phase II Baseline Study Report show the space heating fuel share by building type for the separate phases. The reports are available on the PUC website at http://www.puc.state.pa.us/filing_resources/issues_laws_regulations/act_129_information/act_129_statewide_evaluator_swe_.aspx.

Building Type	IF Demand	IF Energy
Retail	21.5%	-2.6%
Warehouse	19.9%	2.7%

4.3 COMMERCIAL FINDINGS BY BUILDING TYPE

The following sections present observations and trends noted by building type. Figure 4-17 (below) details how businesses were classified by building type. Retail has been left out of the figure as retail consisted of all sites where all non-grocery goods are sold for money and did not have any subtypes.

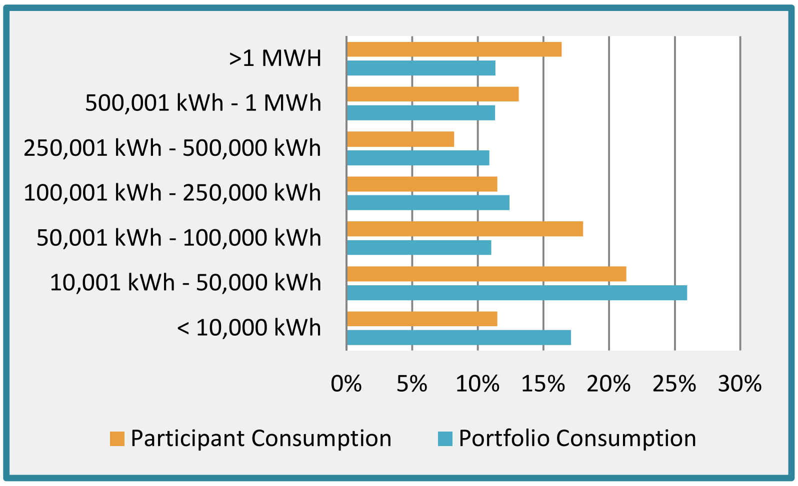
Figure 4-17: Building Types and Subtypes

4.3.1 Education

Education Overview	
Sites Logged:	61
Hours of Use:	2,944 (Screw-in LED & CFL) 2,371 (Other General Service)
Coincidence Factor:	0.39 (Screw-in LED & CFL) 0.45 (Other General Service)
Interactive Factors:	12.3% (Demand) 1.8% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	9 sites, 15%

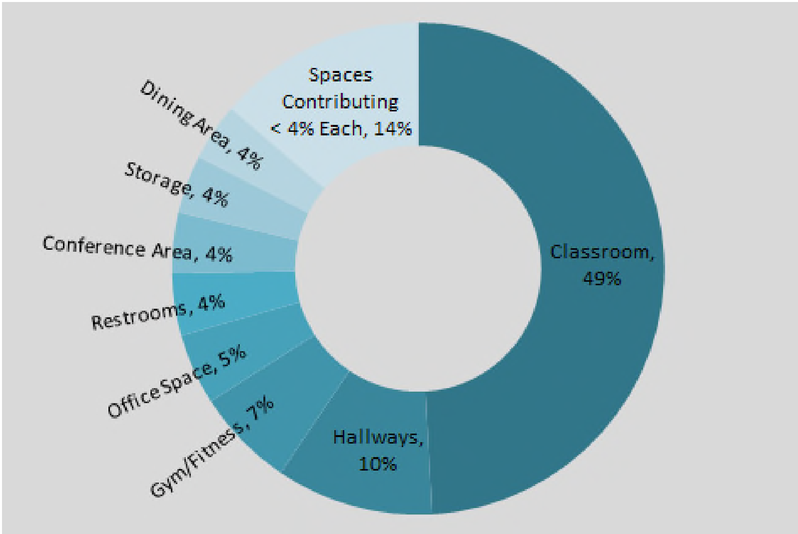
Sites included within the education building type consist of universities, high schools, intermediate schools, elementary schools, preparatory schools, daycare centers, and one fireman training facility. Sizes of participating education sites ranged from facilities consuming as little as 2,000 kWh to as much as 5.8 MWh in 2012. The spread of site sizes by 2012 consumption is tabulated in Figure 4-18.

Figure 4-18: 2012 Consumption of Portfolio and Participant Education Facilities



Contributing space types to the education building type are described in Figure 4-19. Spaces contributing less than 4% of the total education square footage were assembly and auditorium, lobby and reception, kitchen and food preparation, lounge and break rooms, and mechanical rooms.

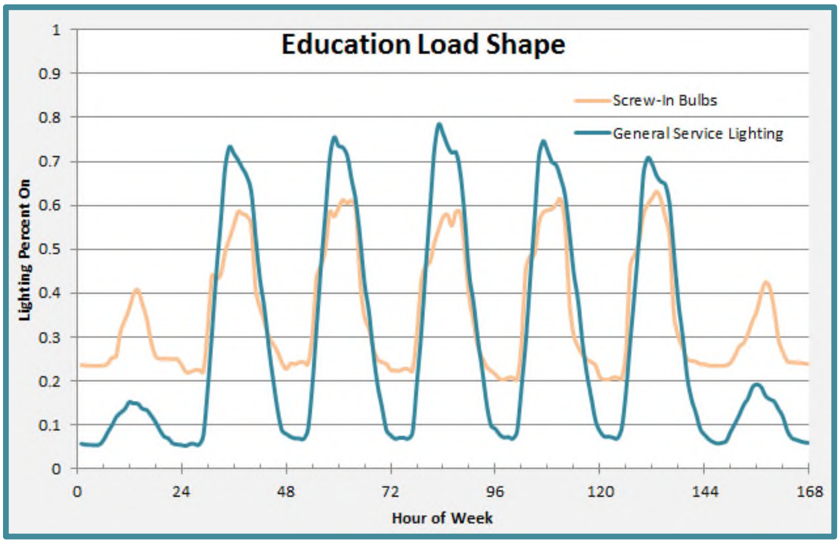
Figure 4-19: Contributing Space Types for Education Facilities



The predominant lighting technology across the education building type is the T8 followed by the T12. Education facilities generally tended toward hardwired CFL lamps as opposed to screw-in bulbs. These were generally found in hallways, bathrooms, and offices as 4-pin bulbs in recessed can fixtures. Lighting controls were not prevalent in education facilities. Of the 23 sites utilizing controls, the Energy Management System was the most popular type with respect to controlled wattage.

The typical load shape of a standard Sunday-through-Saturday week free of holidays for education facilities is shown in Figure 4-20. The HOU value for this building type increased by 8%, while the CF factor decreased by 20% when compared to the values in the 2014 TRM. This was to be expected as many education facilities observe decreased observation over the summer months. Thirty-seven of the 61 logged education facilities were marked as having seasonal operation, all of which noted decreased operating hours from June through August.

Figure 4-20: Standard Education Weekly Lighting Load Shape



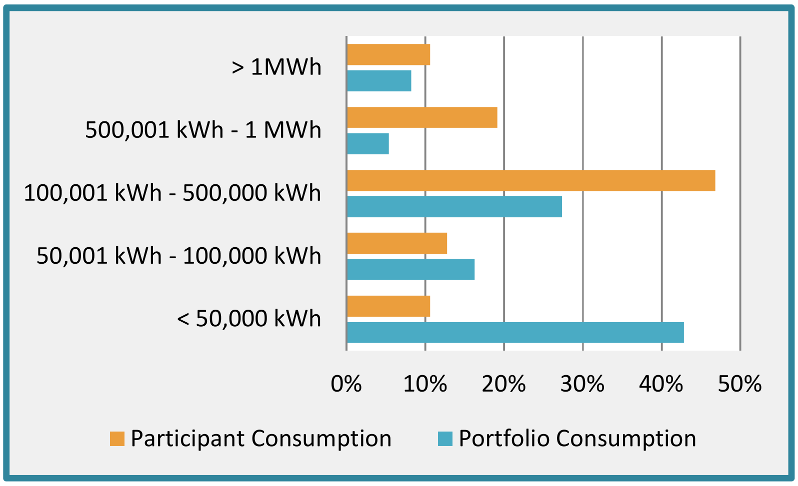
Demand and energy interactive factors for education buildings were found to be 12.3% and 1.8% respectively. This was the lowest observed value for demand interactive factors, occurring primarily because of the seasonal nature of education facilities.

4.3.2 Grocery

Grocery Overview	
Sites Logged:	47
Hours of Use:	7,798 (Screw-in LED & CFL) 6,471 (Other General Service)
Coincidence Factor:	0.99 (Screw-in LED & CFL) 0.93 (Other General Service)
Interactive Factors:	19.2% (Demand) -1.4% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	8 sites, 17%

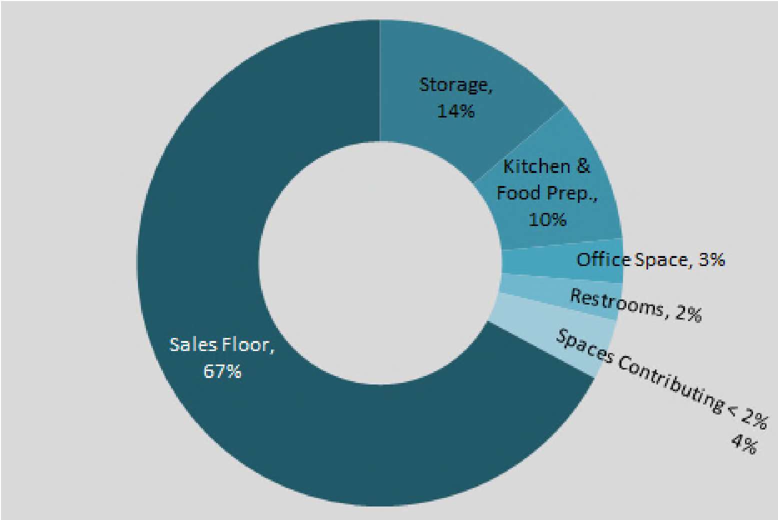
Sites included within the grocery building type consist of convenience stores, supermarkets, and delis. Sizes of participating grocery sites ranged from facilities consuming as little as 2,000 kWh to as much as 2.6 MWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-21.

Figure 4-21: 2012 Consumption of Portfolio and Participant Grocery Facilities



Contributing space types to the grocery sector are depicted in Figure 4-22. Spaces contributing less than 2% were condensed in the chart and consist of hallways, lobby and reception, lounge and break rooms, mechanical rooms, dining areas, conference spaces, and shipping and receiving.

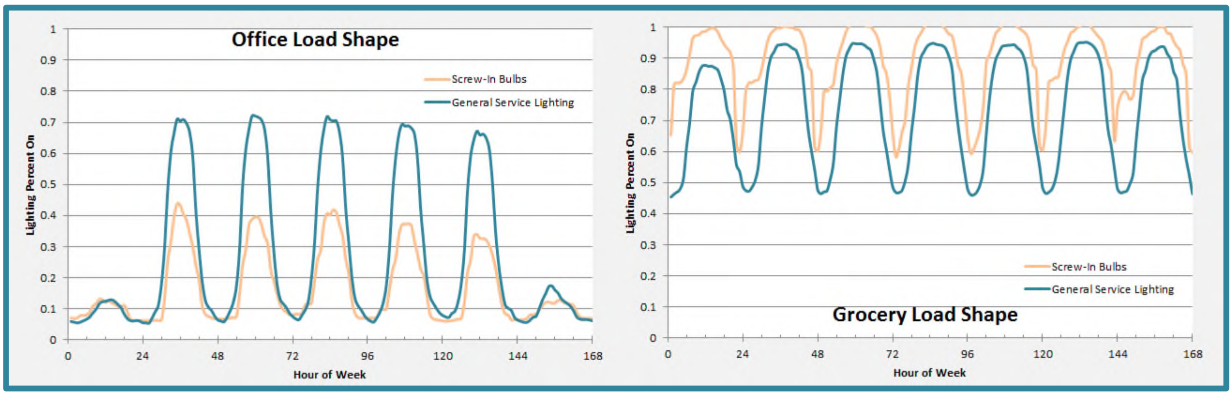
Figure 4-22: Contributing Space Types for Grocery Facilities



The predominant lighting technology across the grocery building type is also the T8 followed by the T12 and Metal Halides. Grocery sites generally tended toward screw-in CFL lamps, but hardwired LEDs, which are most common in refrigerated display case lighting. Grocery facilities also saw a low penetration of lighting controls (17%) with only 6 sites utilizing controls. The most common lighting control strategy by wattage controlled was the occupancy sensor. Sensors were most commonly found in the stock room areas.

The HOU value for grocery sites saw the greatest increase of all building types (39%) when compared to the values in the 2014 TRM. The CF also presented a modest increase of 7%. Grocery sites saw the highest HOU, which is attributed to many of the sites being operational 24 hours per day, 7 days per week. The grocery building type presented a rare case in which the HOUs and CFs for the interior screw-in CFL & LED bulbs were significantly greater than the HOU and CF for the general service lighting. The difference is depicted graphically in Figure 4-23, where the left side shows a standard Sunday through Saturday week, with no holidays, in an office, and the right side shows the same week in a grocery store.

Figure 4-23: Comparison of Standard Lighting Load Shapes in Office and Grocery Facilities



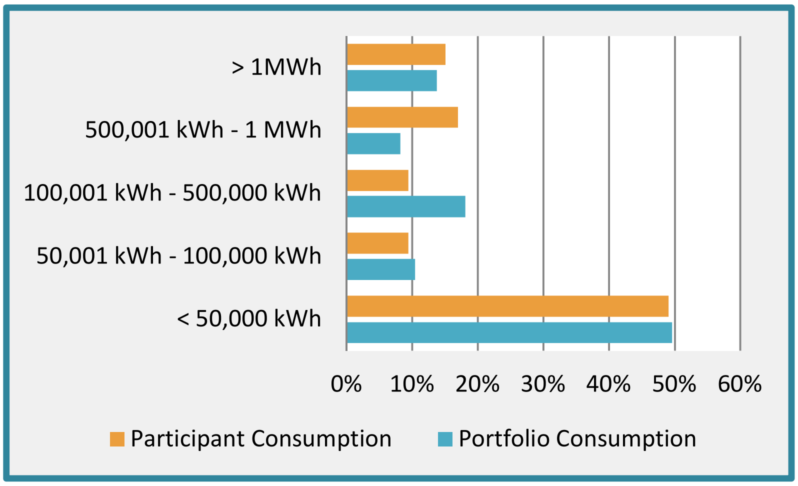
Demand and energy interactive factors for grocery facilities were found to be 19.2% and -1.4% respectively. Grocery sites incurred the least amount of heating penalties because of the large heat output of refrigeration equipment present coupled with the characteristically low heating setpoint requirements of most grocery stores.

4.3.3 Health

Health Overview	
Sites Logged:	53
Hours of Use:	2,476 (Screw-in LED & CFL) 2,943 (Other General Service)
Coincidence Factor:	0.47 (Screw-in LED & CFL) 0.52 (Other General Service)
Interactive Factors:	19.4% (Demand) -2.2% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	11 sites, 21%

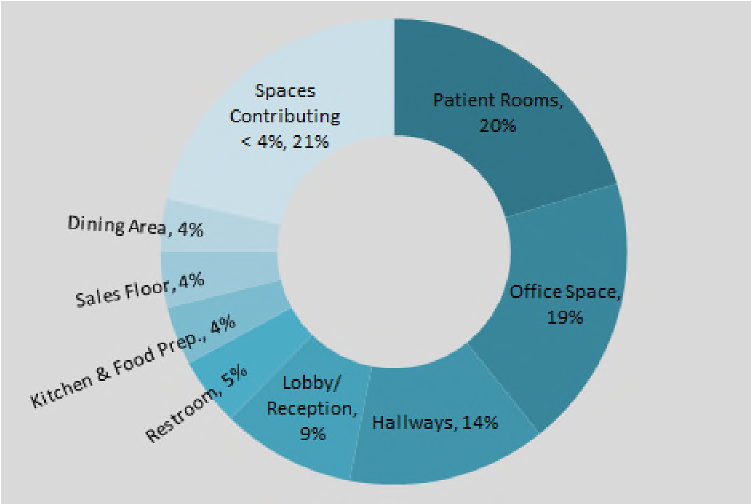
Sites included within the health building type consist of doctor and dentist offices, assisted living centers, nursing homes, hospices, hospitals, rehabilitation centers, medical laboratories, veterinarian offices, and gymnasiums. Sizes of participating health facilities ranged from buildings consuming as little as 2,000 kWh to as much as 3.5 MWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-24.

Figure 4-24: 2012 Consumption of Portfolio and Participant Health Facilities



Contributing space types to the health sector are detailed in Figure 4-25. Spaces contributing less than 4% to the health square footage were storage areas, assembly rooms and auditoriums, classrooms, conference areas, operating and exam rooms, lounge and break rooms, gym and fitness centers, laboratories, mechanical rooms, and shipping and receiving.

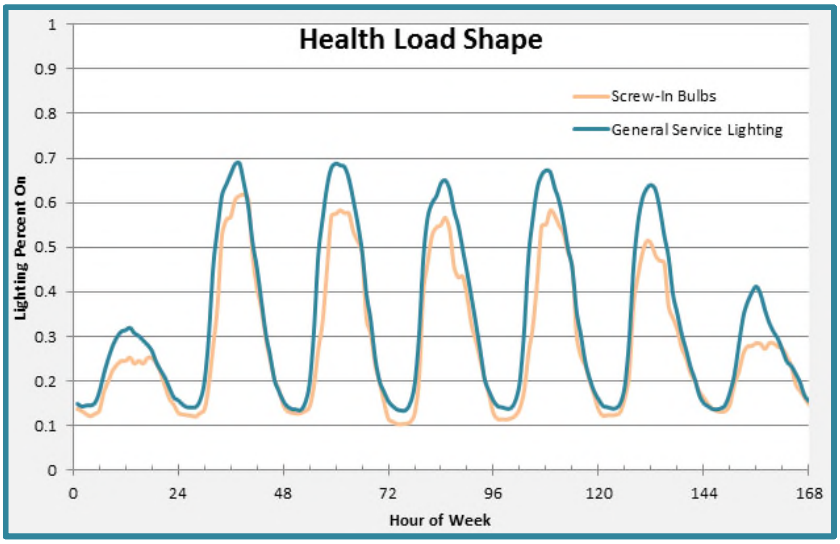
Figure 4-25: Contributing Space Types for Health Facilities



The predominant lighting technology across the health building type is the T12 followed by the T8 and incandescent lamps. Health facilities generally tended toward screw-in CFL and LED lamps as opposed to hardwired bulbs of the same type. Penetration of lighting controls was moderate with 11 of 53 sites utilizing controls.

The typical load shape of a standard Sunday-through-Saturday week free of holidays for health facilities is shown in Figure 4-26. The HOU value for health facilities fell 30% with a decrease in CF of 27% compared to the values in the 2014 TRM.

Figure 4-26: Standard Health Facility Weekly Lighting Load Shape



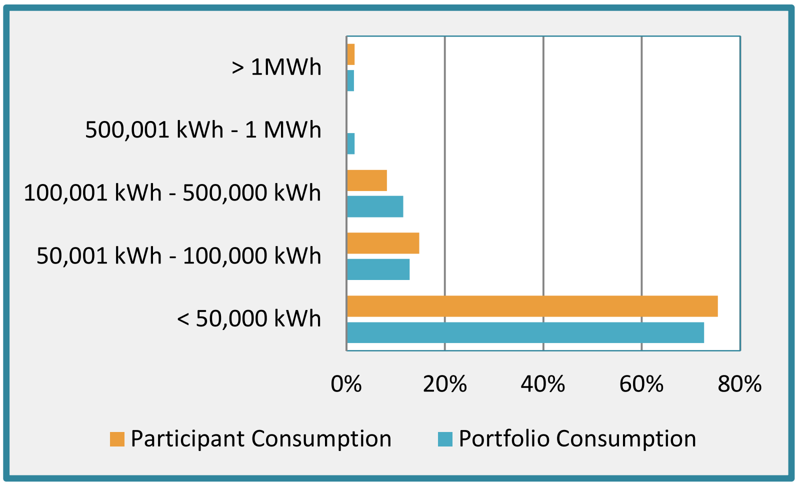
Demand and energy interactive factors for health facilities were found to be 19.4% and -2.2% respectively.

4.3.4 Institutional/Public Service

Institutional/Public Service Overview	
Sites Logged:	61
Hours of Use:	1,456 (Screw-in LED & CFL) 1,419 (Other General Service)
Coincidence Factor:	0.23 (Screw-in LED & CFL) 0.23 (Other General Service)
Interactive Factors:	16.6% (Demand) 2.7% (Energy)
Predominant Lighting:	T12
Sites Utilizing Controls:	20 sites, 33%

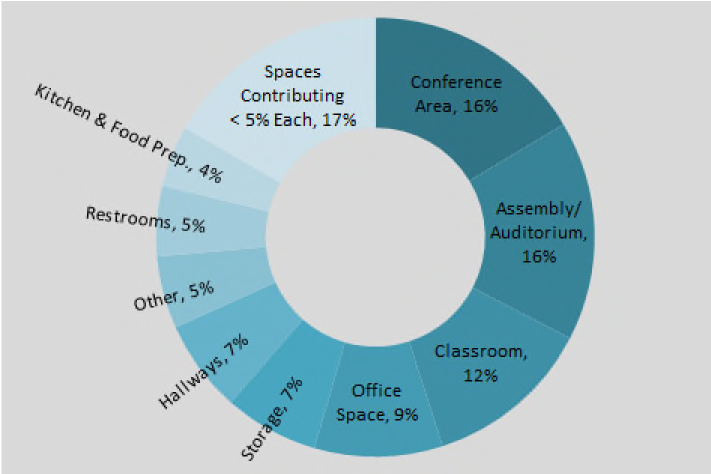
Sites included within the institutional/public service building type consist of cemeteries, churches, shelters, community centers, EMT stations, fire departments, township buildings, train stations, and public libraries. Sizes of participating institutional and public service facilities ranged from buildings consuming as little as 2,000 kWh to as much as 1.0 MWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-27.

Figure 4-27: 2012 Consumption of Portfolio and Participant Institutional Facilities



Contributing space types to institutional and public service facilities are described in Figure 4-28. Spaces contributing less than 5% of the total square footage were condensed in the chart for clarity and consist of lobby and reception spaces, dining areas, lounge and break rooms, parking areas, sales floors, gym and fitness centers, mechanical rooms, and production floors.

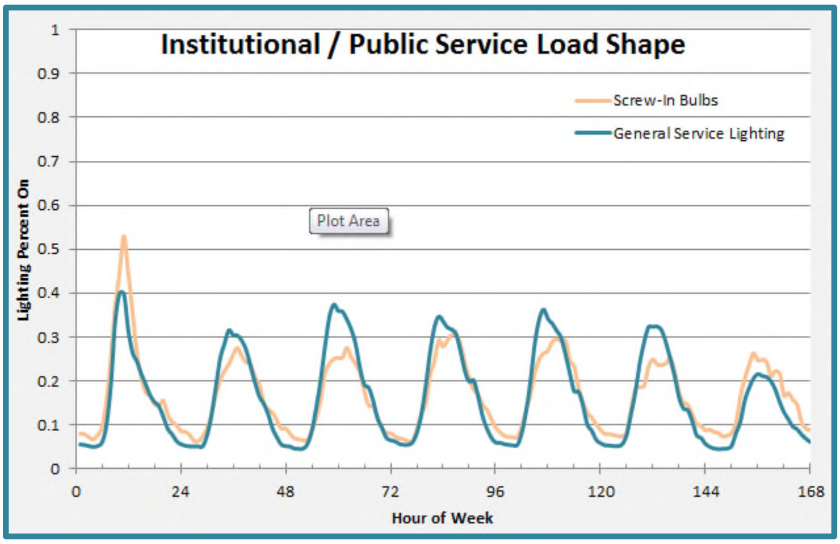
Figure 4-28: Contributing Spaces for Institutional and Public Service Facilities



The predominant lighting technology across the institutional and public service facilities is the T12 followed by the T8. These sites generally tended toward screw-in CFL and LED lamps as opposed to their hardwired counterparts. Institutional and public service facilities saw a relatively high penetration of lighting controls (33%) with the predominant methods of control being the dimmer and occupancy sensor. A high penetration of controls is expected in this building type as it includes many buildings with very minimal usage, and also a high concentration of non-profit customers who would be more inclined to employ energy saving equipment.

The typical weekly load shape for institutional and public service facilities is shown in Figure 4-29. These building types had the lowest HOU and CF values across the study. They also saw the highest drops in value since 2014 with 55% and 63% decreases respectively. The extremely low operating hours explains the prevalence of T12 lamps as replace-on-burnout situations arise far less frequently in these buildings as compared to other building types with higher HOU values.

Figure 4-29: Standard Institutional/Public Service Weekly Lighting Load Shape



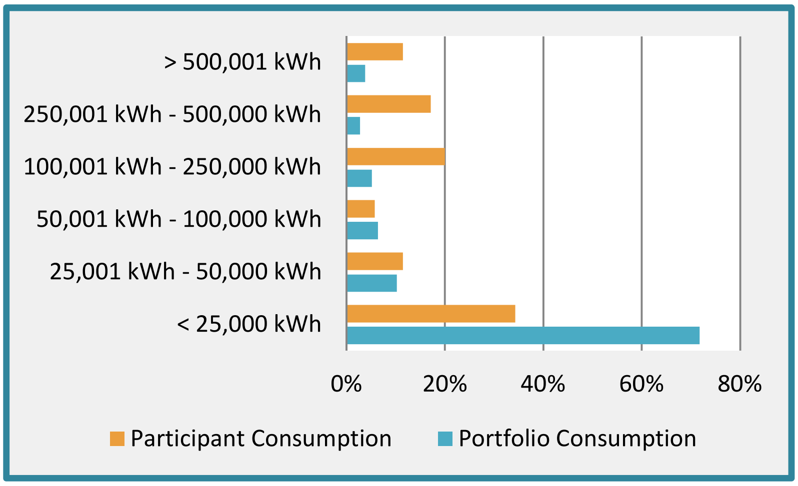
Demand and energy interactive factors for institutional and public service facilities were found to be 16.6% and 2.7% respectively. Facilities within this building type observed the lowest hours of use leading to larger periods of time without space conditioning needs. They also observed higher proportions of unconditioned spaces and very low saturations of electric heating.

4.3.5 Lodging

Lodging Overview	
Sites Logged:	35
Hours of Use:	2,925 (Screw-in LED & CFL) 3,579 (Other General Service)
Coincidence Factor:	0.38 (Screw-in LED & CFL) 0.45 (Other General Service)
Interactive Factors:	19.6% (Demand) -7.1% (Energy)
Predominant Lighting:	CFL
Sites Utilizing Controls:	6 sites, 17%

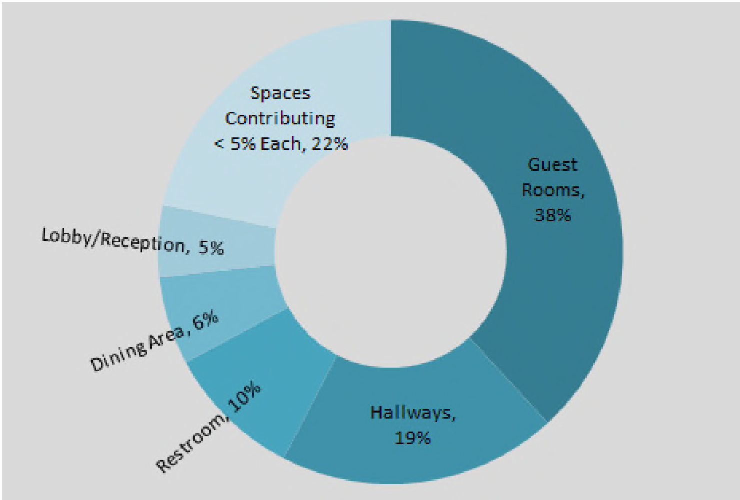
Sites included within the lodging building type consist of apartment and condominium buildings, foster care facilities, retirement homes, and hotels and motels. Sizes of participating lodging sites ranged from facilities consuming as little as 2,000 kWh to as much as 7.7 MWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-30.

Figure 4-30: 2012 Consumption of Portfolio and Participant Lodging Facilities



Contributing space types to the lodging sector are depicted in Figure 4-31. Spaces contributing less than 5% were storage areas, office spaces, conference areas, kitchen and food preparation areas, lounge and break rooms, gym and fitness centers, and mechanical rooms.

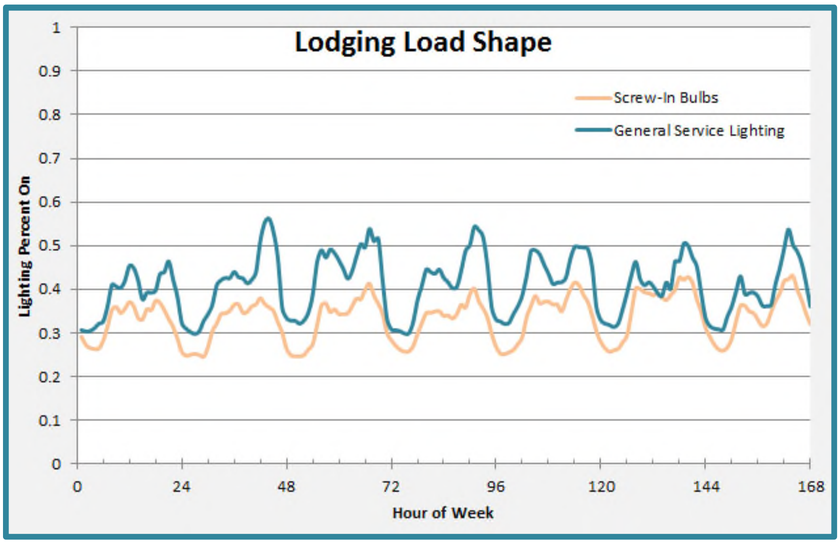
Figure 4-31: Contributing Space Types for Lodging Facilities



The predominant lighting technology across the lodging sites is the CFL followed by the incandescent lamp. This can be largely attributed to the increased amount of Edison-base desk and floor lamps encountered in guest rooms. These sites generally tended toward screw-in CFL and LED lamps as opposed to their hardwired counterparts. Lodging facilities saw a low penetration of lighting controls (17%) with the predominant methods of control being the energy management system and occupancy sensor. The lack of controls can most likely be attributed to the fact that the common areas generally operate 24 hours per day, 7 days per week.

The typical load shape of a standard Sunday-through-Saturday week containing no holidays for lodging facilities is shown in Figure 4-32. In general, these facilities showed decreases in HOU and CF of 55% and 63% respectively over the numbers presented in the 2014 TRM.

Figure 4-32: Standard Lodging Weekly Lighting Load Shape



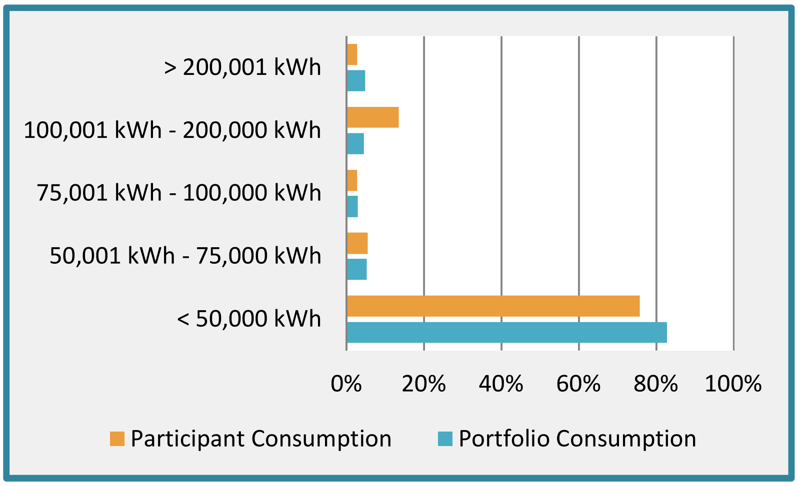
Demand and energy interactive factors for lodging sites were found to be 19.6% and -7.1% respectively. Facilities within this building type observed an average heating setpoint of 70° and an average cooling setpoint of 71°, leaving very little threshold where no space conditioning is needed. These facilities also saw the second highest saturation of electric heating, leading to increased heating penalties.

4.3.6 Miscellaneous

Miscellaneous Overview	
Sites Logged:	37
Hours of Use:	2,001 (Screw-in LED & CFL) 2,830 (Other General Service)
Coincidence Factor:	0.33 (Screw-in LED & CFL) 0.58 (Other General Service)
Interactive Factors:	21.6% (Demand) -0.1% (Energy)
Predominant Lighting:	T12
Sites Utilizing Controls:	16 sites, 43%

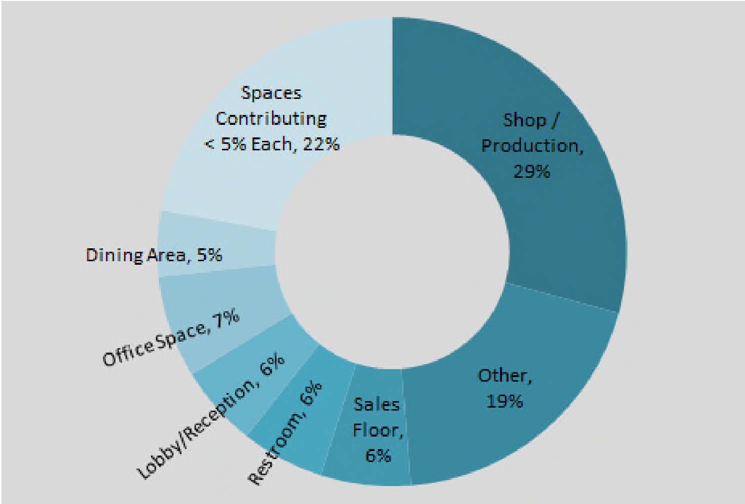
Sites included within the miscellaneous building type consist of auto body and repair shops, car washes, drycleaners, funeral homes, HOA buildings, laundromats, printing shops, recreation centers and swim clubs, salons, theaters, and meeting halls (such as a VFW or American Legion). Sizes of participating miscellaneous facilities ranged from buildings consuming as little as 2,000 kWh to as much as 215,000 kWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-33.

Figure 4-33: 2012 Consumption of Portfolio and Participant Miscellaneous Facilities



Contributing space types to the miscellaneous sector are detailed in Figure 4-34. Spaces contributing less than 5% to the total square footage were storage areas, hallways, conference areas, lounge and break rooms, kitchen and food preparation areas, and mechanical rooms.

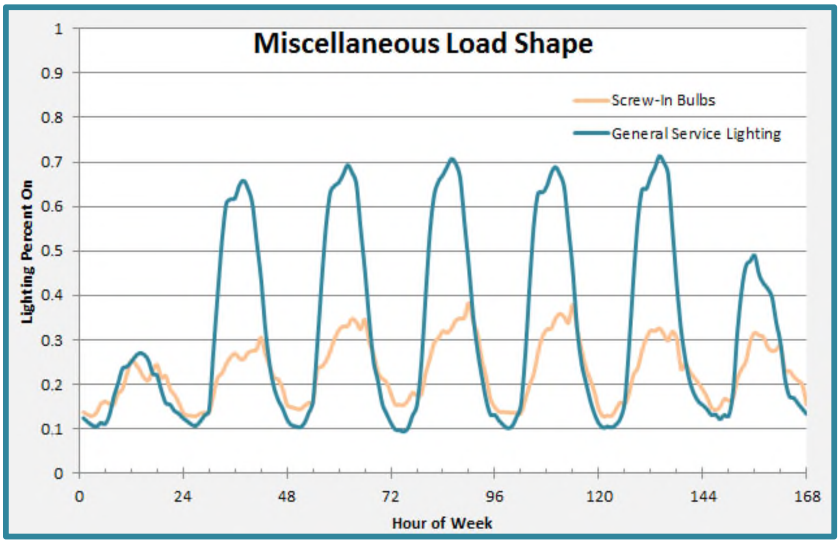
Figure 4-34: Contributing Space Types for Miscellaneous Facilities



The predominant lighting technology across the miscellaneous facilities is the T12 followed by the T8. These sites generally tended toward screw-in CFL and LED lamps as opposed to their hardwired counterparts. Miscellaneous buildings saw the highest penetration of lighting controls (43%) with the predominant methods of control being the dimmer and occupancy sensor.

The typical load shape of a standard Sunday-through-Saturday week free of holidays for miscellaneous facilities is shown in Figure 4-35. These buildings generally showed decreases in HOU and CF of 30% and 6% respectively.

Figure 4-35: Standard Miscellaneous Weekly Lighting Load Shape



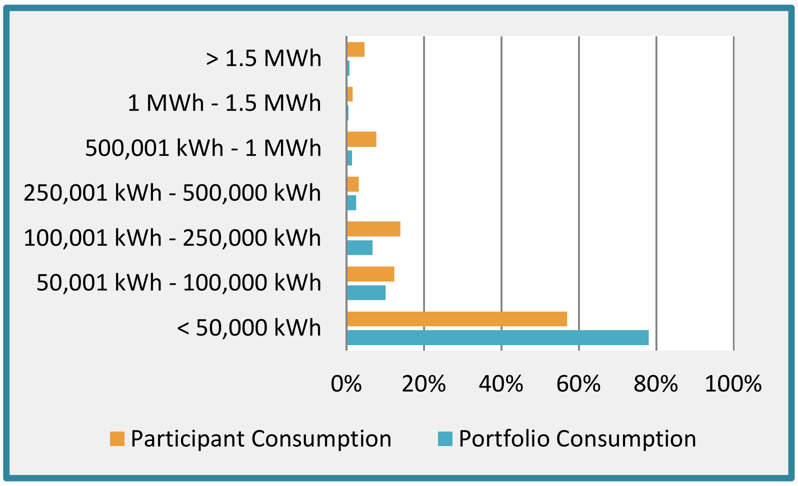
Demand and energy interactive factors for miscellaneous facilities were found to be 21.6% and -0.1% respectively, which are slightly above average values for both factors across all building types.

4.3.7 Office

Office Overview	
Sites Logged:	65
Hours of Use:	1,420 (Screw-in LED & CFL) 2,294 (Other General Service)
Coincidence Factor:	0.26 (Screw-in LED & CFL) 0.48 (Other General Service)
Interactive Factors:	22.6% (Demand) 3.1% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	15, 23%

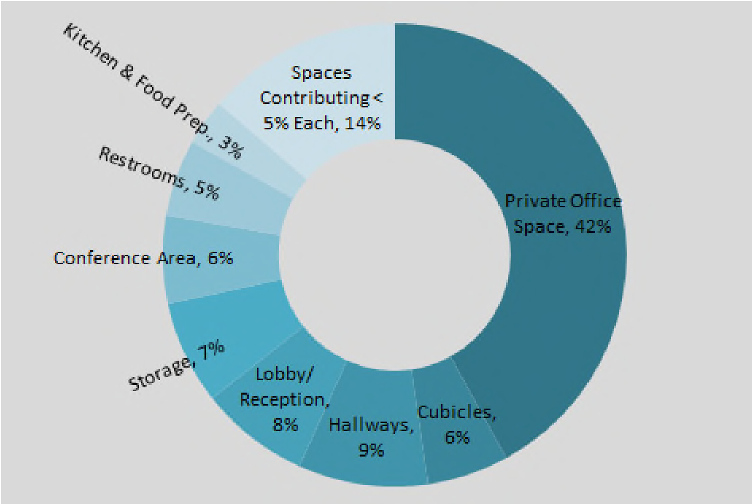
Sites included within the office building type consist of general office spaces and banks. Sizes of participating office facilities ranged from buildings consuming as little as 2,000 kWh to as much as 16.5 MWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-36.

Figure 4-36: 2012 Consumption of Portfolio and Participant Office Facilities



Contributing space types to office facilities are described in Figure 4-37. Spaces contributing less than 5% of the total square footage were condensed in the chart for clarity and consist of dining areas, gym and fitness centers, lounge and break rooms, production floors, mechanical rooms, and server and data centers.

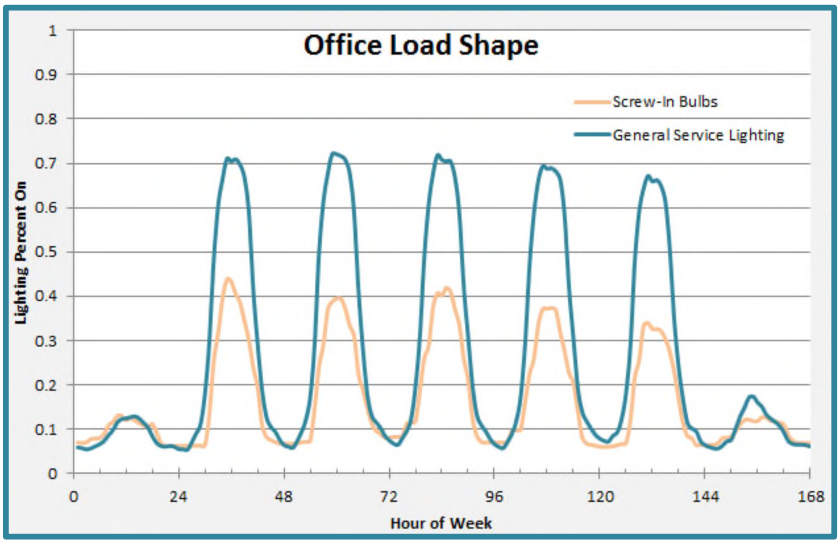
Figure 4-37: Contributing Space Types for Office Facilities



The predominant lighting technology in these facilities is the T8 followed by the T12. Office buildings generally tended toward screw-in LED lamps but hardwired CFL lamps. Hardwired CFLs were particularly common in office spaces and hallways as 4-pin CFLs in recessed fixtures. Office buildings saw a moderate penetration of lighting controls (23%) with 15 sites utilizing controls. The most common lighting control strategy by wattage controlled was the occupancy sensor. Sensors were most commonly found in the restroom areas.

Office buildings showed decreases in HOU and CF of 11% and 21% respectively over the values in the 2014 TRM. This presents a rare case where the CF dropped significantly more than the HOU, signifying that the operating hours shifted considerably in addition to the decrease in operation. The typical weekly lighting load shape of office buildings is presented in Figure 4-38.

Figure 4-38: Standard Office Weekly Lighting Load Shape



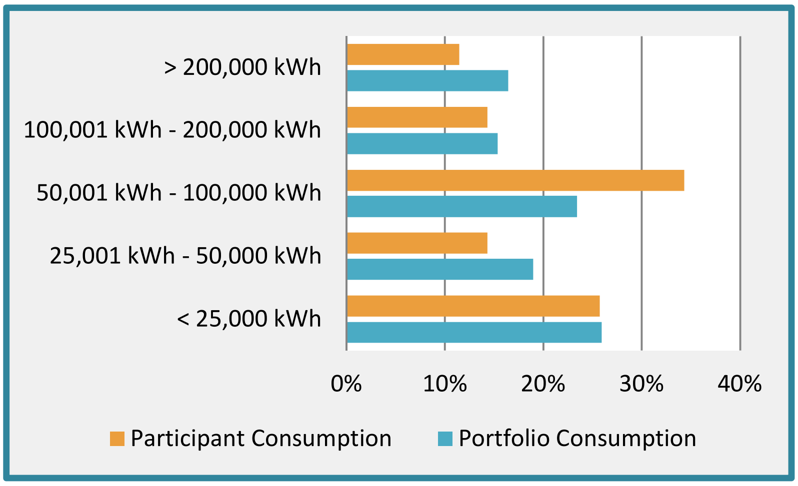
Demand and energy interactive factors for office buildings were found to be 22.6% and 3.1% respectively, which are the highest values observed for either category.

4.3.8 Restaurant

Restaurant Overview	
Sites Logged:	35
Hours of Use:	3,054 (Screw-in LED & CFL) 4,747 (Other General Service)
Coincidence Factor:	0.55 (Screw-in LED & CFL) 0.77 (Other General Service)
Interactive Factors:	19.3% (Demand) -7.1% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	13 sites, 37%

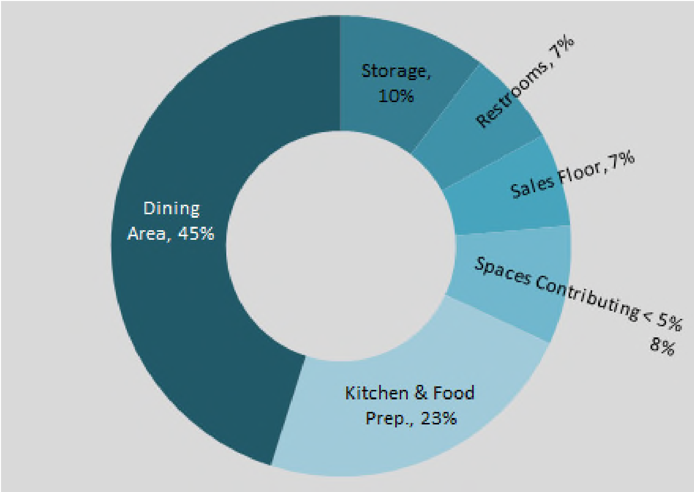
Sites included within the restaurant building type consist of bars, catering facilities, family restaurants, quick-serve restaurants, country clubs, and highway rest stops. Sizes of participating restaurants ranged from facilities consuming as little as 3,000 kWh to as much as 412,000 kWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-39.

Figure 4-39: 2012 Consumption of Portfolio and Participant Restaurant Facilities



Contributing space types to restaurant establishments are depicted in Figure 4-40. Spaces contributing less than 5% were office spaces, hallways, lobby and receptions areas, and lounges and break rooms.

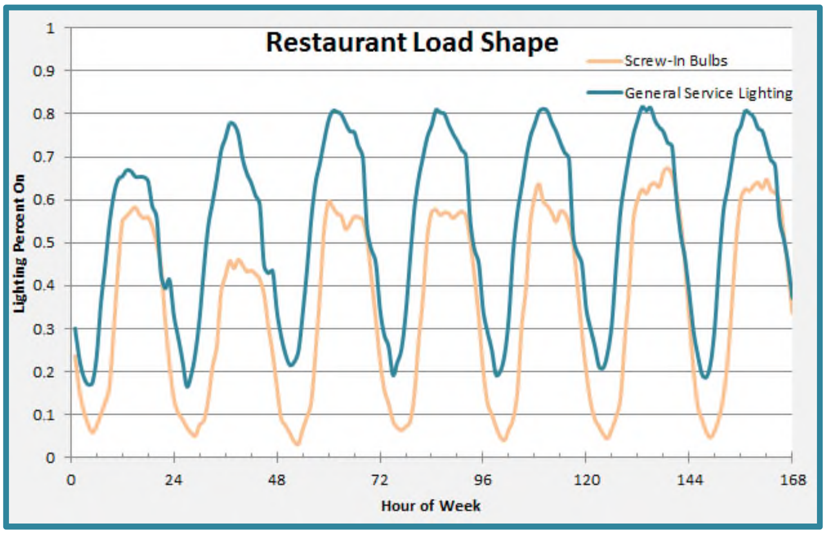
Figure 4-40: Contributing Space Types to Restaurant Facilities



The predominant lighting technology across the surveyed restaurants is also the T8 followed closely by the incandescent lamp. Restaurants saw minimal quantities of LEDs and CFLs compared to the stock of incandescent lamps found, but generally tended toward screw-in LED lamps and CFL lamps. Some hardwired LEDs were found again in refrigerated display cases. Restaurants saw the second highest penetration of lighting controls (37%) with the most common lighting control strategy by wattage controlled being the dimmer. Dimmers were most commonly found in the dining areas.

The typical weekly lighting load shape of restaurant facilities is presented in Figure 4-41. Restaurants showed increases in HOU and CF of 31% and 18% respectively as compared to the values in the 2014 TRM. These facilities saw the largest differences in HOU and CF between interior screw-based CFL & LED bulbs compared to other general service lighting. In this case, the HOU and CF of the general service lighting is more than 150% of that of the screw-based bulbs. While higher HOU and CF values for general service lighting are the statewide trend, the magnitude of the difference observed in restaurant facilities is far greater than that in any other building type. This can generally be attributed to the very segregated nature of having only screw-based bulbs in customer areas versus only linear fluorescent lighting in staff only and preparation areas that experience longer operating hours.

Figure 4-41: Standard Restaurant Weekly Lighting Load Shape



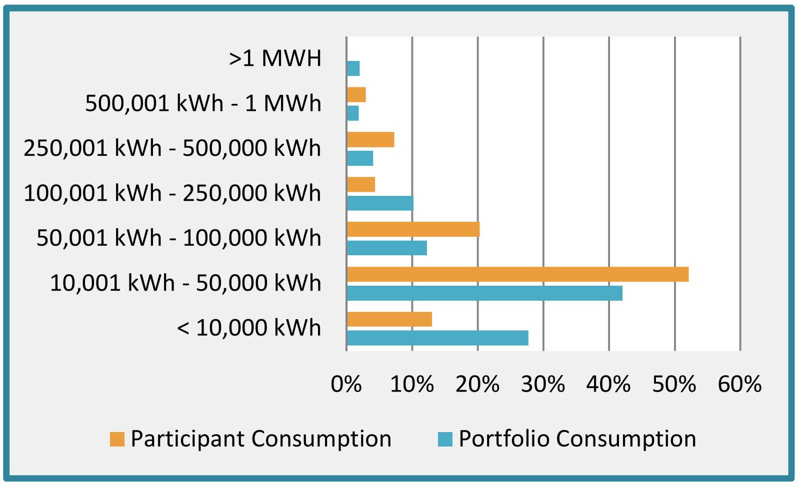
Demand and energy interactive factors for restaurants were found to be 19.3% and -7.1% respectively. This was the lowest observed value for energy interactive factors, occurring primarily due to the unusually high saturation of electric heating coupled with a relatively high average heating setpoint.

4.3.9 Retail

Retail Overview	
Sites Logged:	69
Hours of Use:	2,383 (Screw-in LED & CFL) 2,915 (Other General Service)
Coincidence Factor:	0.56 (Screw-in LED & CFL) 0.66 (Other General Service)
Interactive Factors:	21.5% (Demand) -2.6% (Energy)
Predominant Lighting:	T8
Sites Utilizing Controls:	24 sites, 35%

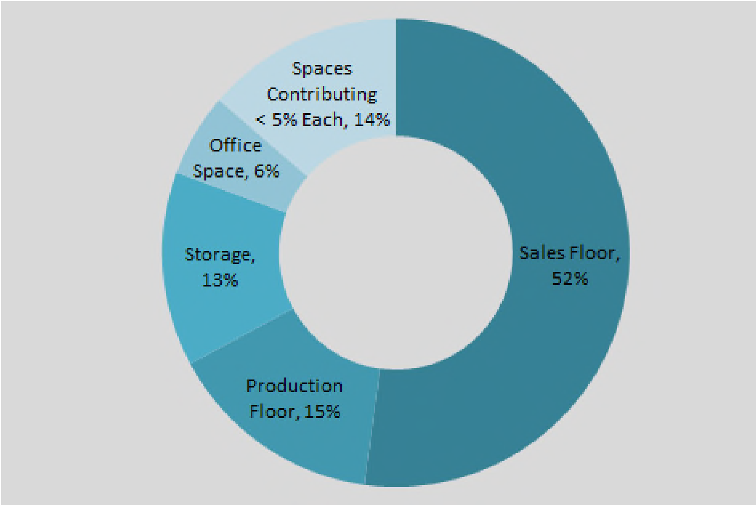
Sites included within the retail building type consist of any non-grocery sites where goods are sold for money, including but not limited to establishments selling apparel, appliances, beer, books, wholesale meats, cars, equipment, flowers, hardware, pharmaceuticals, supplies, and videos. Sizes of participating retail establishments ranged from facilities consuming as little as 2,000 kWh to as much as 716,000 kWh in 2012. The spread of sites by 2012 consumption is tabulated in Figure 4-42.

Figure 4-42: 2012 Consumption of Portfolio and Participant Retail Facilities



Contributing space types to the restaurant sector are detailed in Figure 4-43. Spaces contributing less than 5% to the total square footage were hallways, kitchen and food preparation areas, lobby and reception areas, mechanical rooms, restrooms, server and data centers, and shipping and receiving.

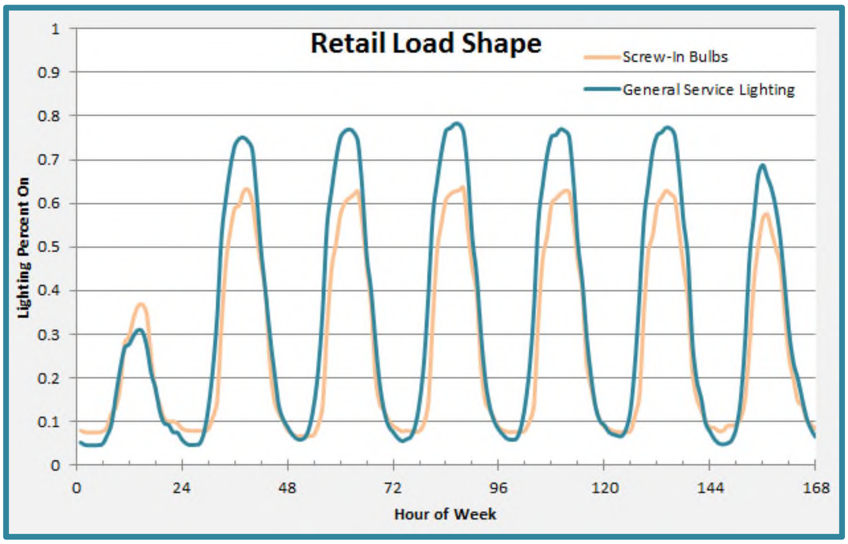
Figure 4-43: Contributing Space Types to Retail Facilities



The predominant lighting technology across the surveyed retail sites is the T8 followed closely by the T12. Retail sites generally tended toward hardwired LED lamps, predominantly in refrigerated display cases, and screw-in CFL lamps. Lighting controls were largely prevalent in retail facilities with 24 sites utilizing controls. The most common lighting control strategies by wattage controlled were the energy management system and the occupancy sensor, with sensors being most prevalent in stock rooms and offices.

The standard operating hours of a typical Sunday-through-Saturday week free of holidays for retail establishments is shown in Figure 4-44. Retail facilities showed an increase in HOU of 3% with a decrease in CF of 10% as compared to the values in the 2014 TRM, signifying again that the operating hours shifted considerably in addition to the slight increase in operation.

Figure 4-44: Standard Retail Weekly Lighting Load Shape



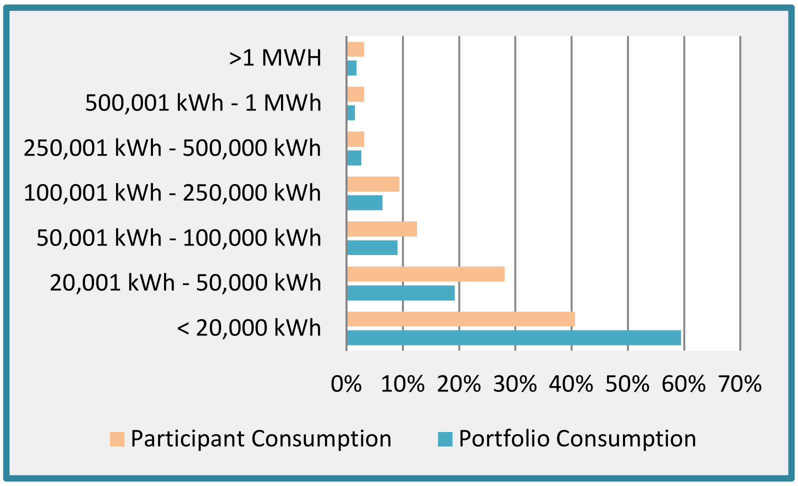
Demand and energy interactive factors for retail establishments were found to be 21.5% and -2.6% respectively. Facilities within this building type typically had larger areas of unconditioned spaces and relatively high cooling setpoints creating decreased cooling benefits to outweigh heating penalties.

4.3.10 Warehouse

Warehouse Overview	
Sites Logged:	32
Hours of Use:	2,815 (Screw-in LED & CFL) 2,545 (Other General Service)
Coincidence Factor:	0.50 (Screw-in LED & CFL) 0.48 (Other General Service)
Interactive Factors:	19.9% (Demand) 2.7% (Energy)
Predominant Lighting:	T12
Sites Utilizing Controls:	7, 22%

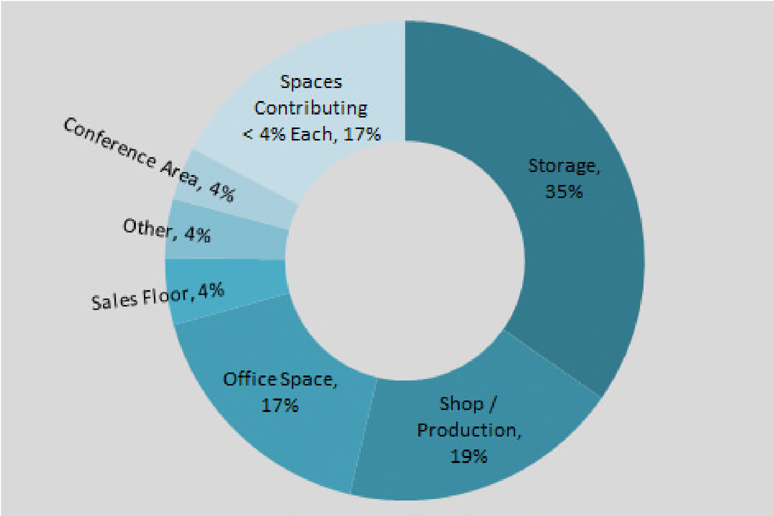
Sites included within the warehouse building type consist of light manufacturing, shipping facilities, showrooms, distribution centers, donation centers, storage facilities, airport hangars, and one bingo hall. Sizes of participating warehouses ranged from facilities consuming as little as 2,000 kWh to as much as 1.8 MWh in 2012. The spread of sites by 2012 consumption is tabulated in

Figure 4-45: 2012 Consumption of Portfolio and Participant Warehouse Facilities



Contributing space types to warehouse facilities are described in Figure 4-45. Spaces contributing less than 4% of the total square footage were condensed in the chart for clarity and consist of shipping and receiving areas, kitchen and food preparation areas, mechanical rooms, restrooms, lobby and reception areas, hallways, lounges and break rooms, and dining areas.

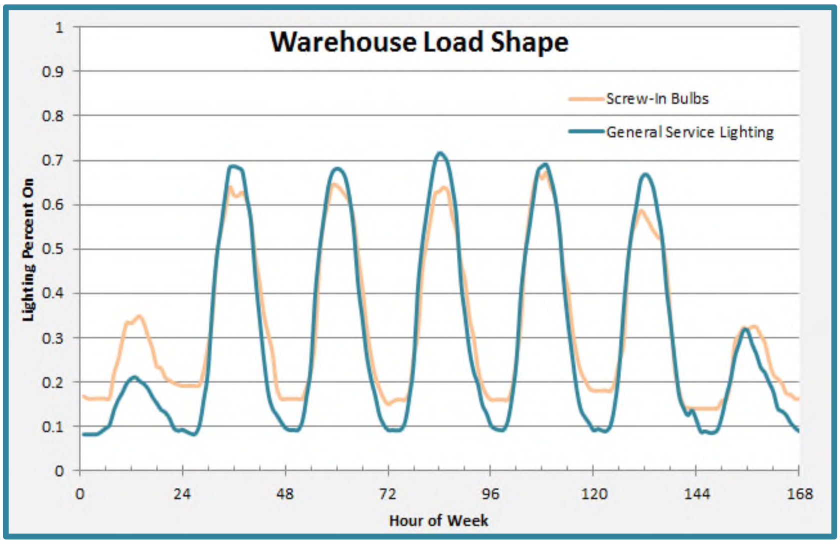
Figure 4-46: Contributing Space Types for Warehouse Facilities



The predominant lighting technology across these facilities is the T8 followed by the T12 and metal halides. Warehouses saw very minimal amounts of lighting that were not linear fluorescents or metal halides as the majority of sites utilized high bay fixtures. There was a moderate penetration of lighting controls (22%) with the most common lighting control strategy being the occupancy sensor.

Warehouse sites showed decreases in HOU and CF of 11% and 17% respectively as compared to the values in the 2014 TRM. A graph of the typical weekly load shape is portrayed in Figure 4-46.

Figure 4-47: Standard Warehouse Weekly Lighting Load Shape



Demand and energy interactive factors for warehouse facilities were found to be 19.9% and 2.7% respectively. Facilities within this building type saw little to no areas of unconditioned spaces and typically kept relatively high heating setpoints. However, the high heating setpoints were of little consequence as less than one percent of warehouse facilities were found to have electric heating.

5 CONCLUDING REMARKS

Since the inception of Pennsylvania's Energy Efficiency market in 2009, the savings assumptions for lighting measures have been borrowed from other jurisdictions without concern for regional differences in climate and typical operating schedules. The impetus for updated assumptions is validated with differences of up to 63% and 55% in CF and HOU values observed respectively. This study enabled the SWE team to develop, across the seven largest EDCs in the Commonwealth of Pennsylvania, contemporary Pennsylvania-specific information regarding key parameters that influence energy and demand savings calculations. In the short term, these findings are intended to inform the 2016 TRM. Long term, however, this study will serve as a valuable resource for upcoming TRC tests as well as the "Electric Energy Efficiency Potential Assessment for the State of Pennsylvania."

APPENDIX A: RESIDENTIAL LOAD SHAPES

The file embedded below presents the 8760 load shapes for Residential lighting. The file contains load shapes for all bulbs within the home, efficient bulbs, and non-efficient bulbs.

Appendix A -
Residential Load Shap

APPENDIX B: COMMERCIAL LOAD SHAPES

The file embedded below presents the 8760 load shapes for all 10 facility types included in the Commercial Light Metering Study. The file contains two tabs, one for load shapes of screw-based bulbs, and one for load shapes of general service lighting.

Appendix B -
Commercial Load Sha

APPENDIX C: HVAC INTERACTIVE EFFECTS FACTORS

C.1 HVAC INTERACTIVE EFFECTS CALCULATOR INPUTS

As discussed in Section 4.2.3, the interactive effects observed by a lighting retrofit are affected by the following factors:

- Lighting Load Shape
  The lighting load shape is a function of building type, and was a key deliverable of this Commercial Light Metering Study.

- Installed and Removed Lighting Specifications
  Installed and removed lighting specifications affected the sensible heat gain. Reductions in sensible heat gain were calculated for each lighting retrofit project listed in PECO's tracking data from the most recent four quarters as a function of the baseline and post-retrofit lighting equipment specifications.

- Heating and Cooling Efficiencies
  The heating and cooling efficiencies were analyzed by building type in the Phase I and II Baseline Studies and are presented in Table C-1.

Table C-1: Baseline Study Results, Percentage of Conditioned Space and HVAC Efficiencies

Building Type	HVAC Equipment Efficiency (kW/ton)
Education	1.17
Grocery	1.09
Health	1.03
Institutional/Public Service	1.25
Lodging	1.02
Miscellaneous	1.36
Office	1.25
Restaurant	1.14
Retail	1.12
Warehouse	1.48

- Heating and Cooling Setpoints
  The heating and cooling setpoints were analyzed by building type in the Phase I and II Baseline Studies and are presented in Table C-2.

Table C-2: Baseline Study Results, Heating and Cooling Setpoints

Building Type	Unoccupied Cooling Setpoint (°F)	Occupied Cooling Setpoint (°F)	Unoccupied Heating Setpoint (°F)	Occupied Heating Setpoint (°F)
Education	79.5	73.0	61.1	70.3
Grocery	76.0	70.0	61.7	66.0
Health	75.8	71.3	63.8	69.8
Institutional/Public Service	78.6	71.9	60.1	68.9
Lodging	79.0	71.0	64.0	70.0
Miscellaneous	76.5	70.7	60.4	68.8
Office	78.3	71.8	64.3	70.6
Restaurant	78.9	72.0	61.4	70.8
Retail	78.0	73.2	60.6	68.7
Warehouse	81.5	72.3	60.0	71.7

- Heating Fuel Type

  The heating fuel type by building type was analyzed in the Phase I and II Baseline Studies and is presented in Table C-3.

Table C-3: Baseline Study Results, Percent Saturation of Electric Heating

Building Type	Electric Heating	Non-Electric Heating
Education	0.1%	99.9%
Grocery	24.6%	75.4%
Health	30.4%	69.6%
Institutional/Public Service	2.9%	97.1%
Lodging	53.7%	46.3%
Miscellaneous	21.6%	78.4%
Office	6.7%	93.3%
Restaurant	61.1%	38.9%
Retail	36.9%	63.1%
Warehouse	0.1%	99.9%

- Dry Bulb Temperature

  The historical dry bulb temperature was recorded by weather station and presented by NOAA. Although seven weather stations were analyzed, the variance in dry bulb temperature appeared to produce little to no change in IF values. Because of this, statewide average historical weather data was used for the IF calculations presented in this report.

C.2 TRM APPLICATION OF INTERACTIVE EFFECTS

After many trial runs of individually adjusting variables, it was determined that the heating fuel type contributed most substantially to the IF results. Table C-4 presents the variation in IF values as the saturation of electric heating changes.

Table C-4: IF Results Tabulated by Electric Heat Saturations

	Building-Type Specific Saturations		0% Electric Heat		100% Electric Heat	
Building Type	**IF Energy**	**IF Demand**	**IF Energy**	**IF Demand**	**IF Energy**	**IF Demand**
Education	1.8%	12.3%	1.9%	12.3%	-16.0%	12.3%
Grocery	-1.4%	19.2%	3.0%	19.2%	-14.8%	19.2%
Healthcare	-2.2%	19.4%	3.1%	19.4%	-14.2%	19.4%
Institutional/Public Service	2.7%	16.6%	3.2%	16.6%	-13.9%	16.6%
Lodging	-7.1%	19.6%	2.6%	19.6%	-15.5%	19.6%
Miscellaneous	-0.1%	21.6%	3.6%	21.6%	-13.6%	21.6%
Office	3.1%	22.6%	4.3%	22.6%	-12.7%	22.6%
Restaurant	-7.1%	19.3%	3.4%	19.3%	-13.8%	19.3%
Retail	-2.6%	21.5%	3.6%	21.5%	-13.1%	21.5%
Warehouse	2.7%	19.9%	2.7%	19.9%	-14.5%	19.9%
Average	***-1.0%***	***19.2%***	***3.1%***	***19.2%***	***-14.2%***	***19.2%***

Section 4.2.3 of this report presents the Building-Type Specific IF values as presented in the first two columns of the table above. These numbers were calculated using an electric heat saturation value equivalent to that of the corresponding building type as dictated by the Phase I and II Baseline Studies and previously presented in Table C-3. This saturation value attempts to predict the probability that the site will be using electric heat based on historical data linked to the building type. However, as applications are filled out on a per-site basis, and the heating fuel source will be known, there is no need to predict the probability of the presence of electric heat. Because of this, the 2016 TRM and Appendix C calculator will use different IF values than presented above and in Section 4.2.3 of this report.

The IF_{demand} remains constant regardless of the heating fuel type. This is because the IF_{demand} is only a factor during the peak period, when heating is not in use. The IF_{energy} however varies drastically as the electric heat saturation is changed. Because of this, the SWE proposes that the IF values be calculated for each lighting application as a function of both building type and primary heating fuel in the 2016 TRM Appendix C calculator. In the event that electricity is the primary fuel source, the 100% electric heat values will apply to the entirety of the application; similarly, if any other fuel source is the predominant fuel source, the 0% electric heat values will be applied. In the event that fuel source is unknown, or otherwise left blank, a default value of 0% will be used for the IF_{energy} value with the building type specific IF_{demand} value. The SWE believes this assumption is fair as the state average for electric heating saturation was found to only be 12%, so it is likely that electricity is not the predominant heating fuel; however, the onus will be on the customer to do the additional legwork to achieve the additional savings that result in selecting a non-electric heating source.