

BUILDING *performance* LAB

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Measurement Guide: Lighting on Dedicated Panelboards with Automatic Controls

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Acronyms

AHU	air handling unit
BAS	building automation system
Btu	British thermal unit
CUNY BPL	CUNY Building Performance Lab
DCAS DEM	NYC Department of Citywide Administrative Services Division of Energy Management
DTC	distributed control
FELL	CUNY BPL Field Equipment Lending Library
kW	kilowatt
kWh	kilowatt hour
IoT	Internet of Things
IPMVP	International Performance Measurement and Verification Protocol
ITC	integrated control
OAT	outdoor air temperature
M&V	measurement and verification
MW	megawatt
PNNL	Pacific Northwest National Lab
PV	photovoltaic
RTU	rooftop unit
true power	true RMS power
VAV	variable air volume
VFD	variable frequency drive
NOAA CNY	National Oceanic and Atmospheric Administration Climate Normal Year

Purpose of Guides

This guide is one of a series developed with the goal of implementing consistent, simple, purpose-driven measurement processes to help quantify the impact of projects designed to further New York City's greenhouse gas (GHG) reduction goals. These guides are designed for use by internal and external stakeholders to facilitate comprehensive characterizations of building energy consumption and promote standardized and reasonable reporting of avoided energy use, through the collection of energy-related system data in buildings owned or operated by the City. Stakeholders include personnel at the NYC Department of Citywide Administrative Services Division of Energy Management (DCAS DEM), NYC Agency Energy Personnel, and third-party consulting engineers and/or other measurement and verification (M&V) providers. These measurement guides may also provide direction to other municipalities or private sector organizations that are looking to quantify avoided energy use for applicable energy conservation measures (ECMs).

General Overview of NYC GHG Reduction Goals

As the hub for energy management for the City's fixed infrastructure, DEM plays a critical role in supporting NYC agency partners' progress toward major emissions reduction and energy objectives. These goals include:

- **80x50**, focuses on achieving an 80% reduction in total economy-wide emissions in NYC by 2050 from a 2005 baseline. NYC also has an 80 x 50 goal relative to an FY06 baseline. OneNYC 2050 extended this goal by committing to net-zero greenhouse gas (GHG) emissions Citywide by 2050. This will require 100% clean energy and offsetting sources of irreducible emissions.
- **50x30**, a new target created by the Climate Mobilization Act (NYC Local Law 97 of 2019) that focuses on achieving a 50% reduction in emissions by 2030, relative to an FY06 baseline. This includes all operations, facilities, and assets that are owned or leased by the City and for which the City pays all or part of the annual energy bills.
- **40x25**, a new interim target on path to 50x30 that was also included in the Climate Mobilization Act and applies to all City government operations.
- **Solar Target of 100MWx25**, focuses on installing 100 Megawatts (MW) of solar photovoltaic (PV) at City government facilities by 2025.
- **Energy Storage Target of 100MWhx20**, focuses on installing 100 Megawatt hours (MWh) of energy storage at both private and public facilities by 2020.

Why Take Measurements?

Documenting consistent measurement techniques and reporting standards for DEM-funded energy efficiency projects is a vital step in facilitating judicious project selection and efficient program management. In agency applications for DEM project funding, the use of measurements (as opposed to general assumptions) yields more accurate estimates for baseline consumption and avoided energy use. Measurements promote a verifiable methodology that enhances the validity of the application and a best practice that is aligned with the City's goals.

Prioritizing Appropriate, Necessary Measurements

The primary goal of collecting measurements is to establish a reasonable characterization of the system before and after the retrofit in a simple, non-invasive, and replicable manner. This involves collecting data that reasonably document the operational patterns and energy consumption using tools available

from the [CUNY BPL Field Equipment Lending Library \(FELL\)](#). This guide is appropriate for a project where the International Performance Measurement and Verification Protocol (IPMVP) Option A or Option B for retrofit isolation is being used. Option A and B require direct or proxy measurements of some or all of the key variables associated with the implementation of an ECM.

An engineering problem, such as measuring the amount of energy used by a piece of equipment or a system, can be solved using many different techniques. These guides provide a primary recommendation for direct or proxy measurements of key system variables. It is understood that other techniques may be more appropriate for specific situations and that the user can adjust these recommendations based on the specific details of the project they are undertaking.

The measurement processes outlined in this guide were established to meet four key criteria and to standardize GHG reduction reporting across City facilities and agencies. Measurements should be:

1. **Reasonable:** These measurements will not reflect the exact annual energy consumption of a device or system. Rather, they are expected to represent a reasonable characterization of the annual energy consumption and are generally normalized either by measured operation or weather-dependent variables such as outdoor air temperature (OAT). When measurements are being taken before and after a retrofit, the measurement techniques may change based upon the characteristics of the ECM, but both techniques are expected to provide equally reasonable results.
2. **Replicable and Consistent:** A key goal is to provide methodologies that are easily replicable by a wide range of users who have varying degrees of familiarity with the facility's operations and system configuration. This guide has multiple measurement strategies with differing levels of accuracy, however the results from any of these strategies are consistent enough to enable comparison across ECMs or facilities.
3. **Simple:** The measurement strategies and processes in this guide are intended to be as minimally invasive as possible, and relatively easy to set up. Setup time for most measurements should be less than an hour; however, in some cases, specialized personnel such as electricians or operating engineers should be engaged to assist with the installation of measurement equipment. This guide highlights methods of data collection that do not interfere with regular system operation and that are not excessively difficult to perform. All necessary tools used for measurements can be borrowed from FELL. The guides also provide standardized demonstrations for equipment setup, data collection protocols, and post-processing of the data to develop estimates of annual energy consumption.
4. **Purpose-driven:** While there may be different reasons for collecting these measurements (conducting full M&V, identifying preliminary avoided energy estimates, fault detection diagnostics, etc.), all methodologies represent the intent to estimate annual energy consumption and associated emissions.

Taking measurements provides verification of the two key variables associated with energy consumption in facilities: 1) operating schedule; and 2) energy used by the system when operating. Measuring operational variation in energy consumption over time, and other variables like OAT, allow for short term measurements to be extrapolated to a seasonal or annual estimate of energy consumption. For example, measuring a boiler can reveal the general time of day when the boiler is used in the facility, and how often it operates with respect to OAT. Given a range of measurements under varying temperatures, a reasonable model of operation can be developed and applied to all times that the boiler is used over the course of an entire heating season.

Application, Baseline, and Post-Retrofit Measurements

Given the typical timeline of DEM-funded projects, measurements can be taken at three different stages:

1. **Project identification and scoping:** These measurements help to generally characterize the system operation and energy consumption and can be used with other engineering calculations to develop estimates of avoided energy use for a given ECM. Depending on the timing of the project development and the season, these measurements might only encompass several weeks of a year.
2. **Project approval and implementation:** Once the decision has been made to proceed with the project, a more comprehensive baseline measurement may be appropriate. The measurement technique and tools will likely be identical, but measurement duration is extended to verify the assumptions that went into the initial analysis. Longer measurement periods can provide more accurate estimates of annual energy consumption, especially in systems that vary due to changes in a key variable such as OAT.
3. **Post-implementation:** Post-retrofit measurements provide verification that the ECM is installed and operating as designed and are used to estimate avoided energy use. The measurement techniques may differ from the application or baseline measurements, especially if the ECM changed key system characteristics. For example, a lighting retrofit that added a lighting control system to some fixtures, yielding a change in their hours of operation, may require a different set of sensors to quantify this change compared to lighting fixtures without controls.

Direct and Proxy Measurements

There are two types of measurements used in this guide:

1. **Direct Measurement:** A direct measurement specifies a quantity of the exact item being measured. For example, a current transducer provides a direct measurement of the current through a wire. The coincident voltage and power factor can also be directly measured to calculate the true RMS power (kW) being used by the system or device.
2. **Proxy Measurement:** A proxy measurement provides an indication of the system operation but does not directly measure the quantity in question. For example, a motor runtime logger on the draft fan of a boiler provides a proxy measurement for the actual firing of the boiler. The draft fan motor typically runs before the fuel valve opens (for a series of internal safety checks), while the boiler is firing and for a short period after the fuel valve has shut off. By subtracting the pre- and post-firing runtime, a proxy measurement for the actual firing time can be calculated.

Measurement Uncertainty

Sources of measurement uncertainty can include the accuracy of measurement devices, translation of the measured data into models that are used to project longer term energy consumption, and measurement of a non-representative sample of ECMs.

Measurement accuracy is improved by using high quality and properly calibrated equipment. Typically, the recommended measurement equipment yields measurement errors of less than 2% and may often be significantly lower than 1%. As such, measurement error is typically negligible. CUNY BPL has worked to develop robust measurements and associated models that further reduce error. CUNY BPL has not developed tools to develop statistically valid sample sizes to achieve a desired error at a specific

confidence interval; therefore, the recommended approach is to identify measurement points in the applicable system to capture the largest percentage of the total connected load as possible. This will allow for quantification of both the peak power draw of the system and operational variations that exist in the system.

General System Overview

This guide describes the measurement approach for quantifying avoided energy use associated with retrofitting lighting systems with automatic controls, which are on panelboards that serve lighting loads only. The system may either have integrated control (ITC) at the panelboard or distributed control (DTC), where controls replace manual wall switches in the occupied space and are frequently coupled with wireless occupancy sensors.

Safety

This guide does not cover health and safety aspects of the collection of measurements at facilities. There are many hazards that exist in facilities surrounding the collection of measurements, including but not limited to: electrical safety, fall protection, personal protective equipment, control of hazardous energy (lock out/ tag out), confined space, respiratory protection, and machine safeguarding. Part of the measurement planning process must include the identification and mitigation of these and other hazards. The implementation of a measurement strategy and installation of measurement equipment should be performed by qualified personnel.

Description of System

The following sections provide background information on the components of lighting systems with automatic controls. **If you are already familiar with the system, you may skip to the *Measurement Description for System* section.**

System Overview

A general lighting system, as shown in Figure 1, comprises a main electrical switchgear, possibly a secondary switchgear, a panelboard with circuit breakers that serves multiple circuits, the light fixtures and may include manual controls (i.e., light switches) or automatic controls (occupancy, timer or light level controls) in each space on each circuit.

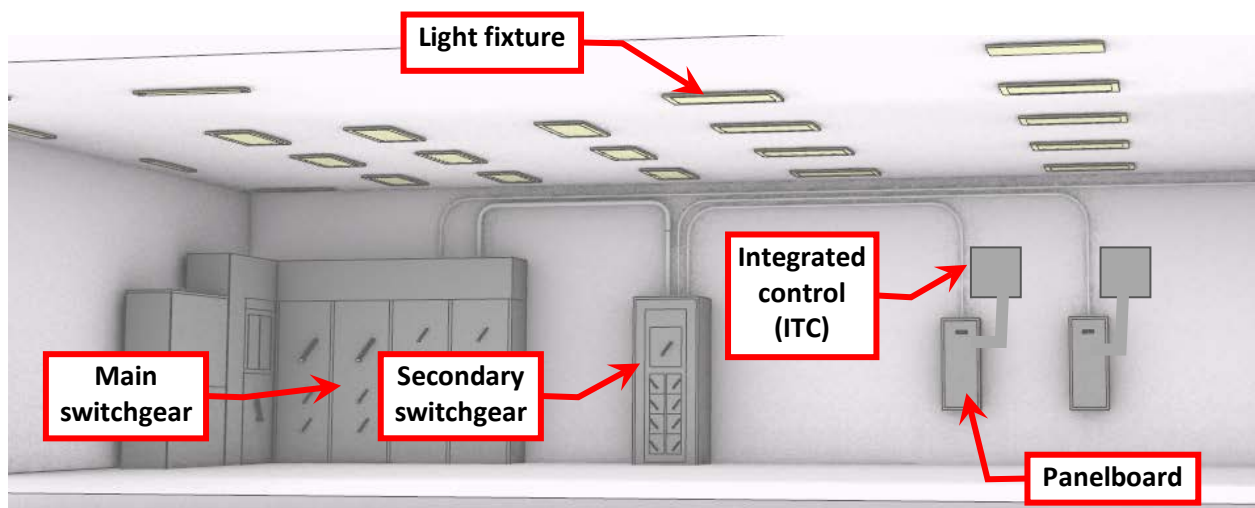


Figure 1. Lighting system components

For the purposes of measuring lighting system energy consumption, lighting systems have been divided into four general categories. Because the components for the system and evaluation process vary for each system which impacts the measurement techniques, separate guides were developed, as follows:

- Lighting on panelboards that serve only lighting loads without an automatic control system (Lighting on Dedicated Panelboard without Automatic Controls)
- Lighting on panelboards that serve only lighting loads with an automatic control system (Lighting on Dedicated Panelboard with Automatic Controls)
- Lighting on panelboards that serve lighting and other loads (e.g., receptacles, office equipment, etc.) without an automatic control system (Lighting on Mixed Panelboard without Automatic Controls)
- Lighting on panelboards that serve lighting and other loads (e.g., receptacles, office equipment, etc.) with an automatic control system (Lighting on Mixed Panelboard with Automatic Controls)

Interior lighting affects both heating and cooling system energy consumption because waste heat generated by lights increases the cooling load and reduces the heating load. A more efficient lighting system will reduce cooling energy consumption and increase heating energy consumption because less waste heat is put into the space. Measurement of the change in heating and cooling loads associated with a lighting retrofit are not discussed in this guide.

This document was designed to provide guidance for measuring lighting on panelboards that serve only lighting loads with an automatic control system as illustrated in Figure 2.

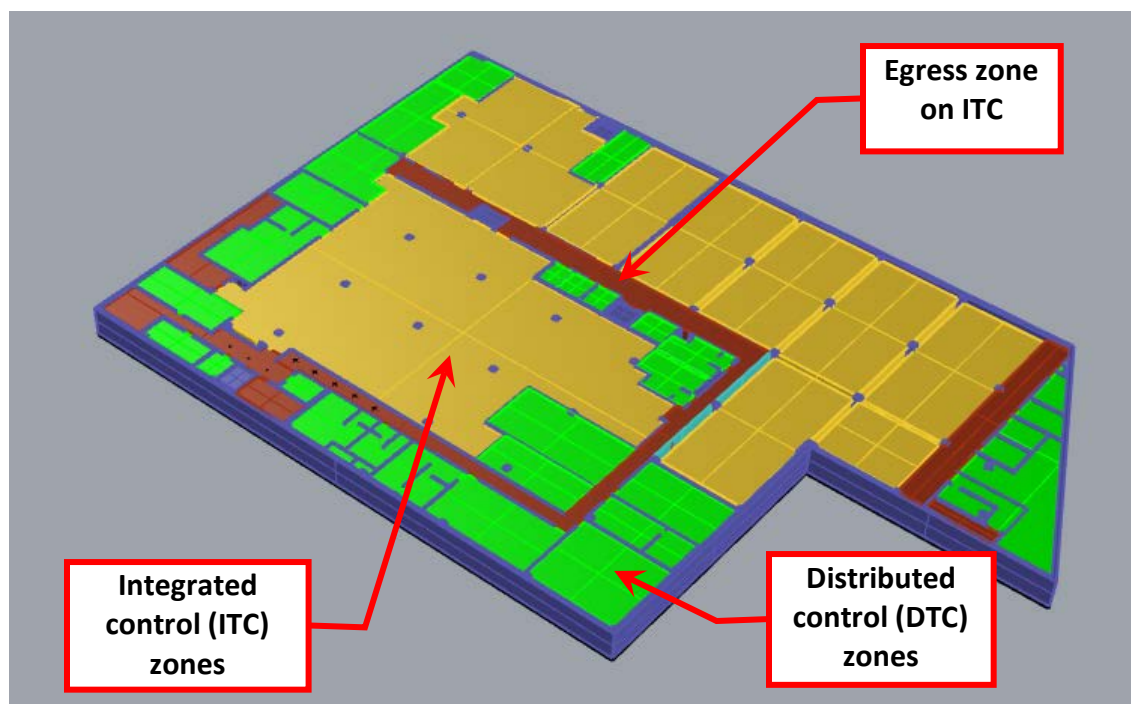


Figure 2. Diagram of lighting on a single panelboard with different automatic control zones

The flowchart in Figure 3 should be used to determine which system is present in your facility and, as a result, which measurement guide and process flow to use.

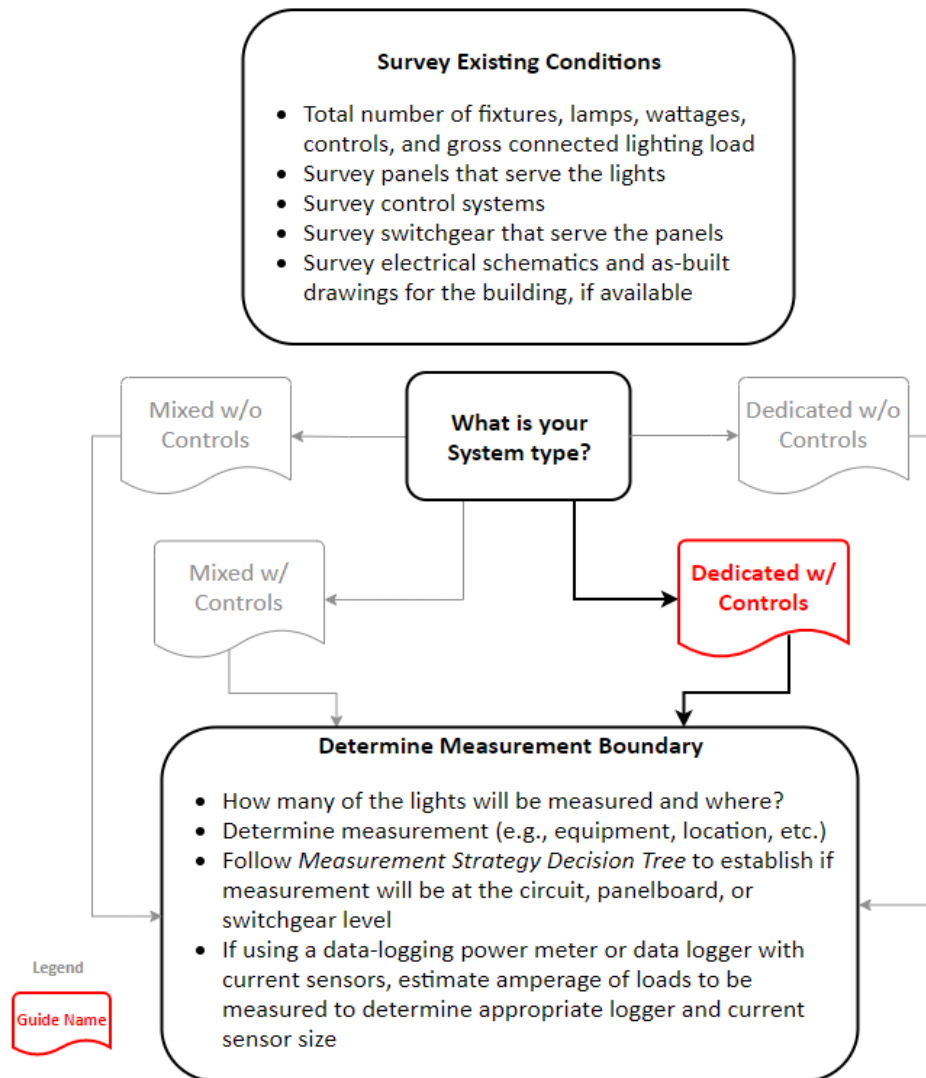


Figure 3. Decision tree for Lighting Guide selection

This document does not provide guidance on measuring and quantifying the interactive effects of heating or cooling energy consumption associated with replacing inefficient lamps or ballasts. The calculation tools that accompany this guide generate an estimate of average hourly kWh for lighting for each day of the week. This can be used to calculate interactive effects separately, based on occupancy, season, percentage of lighting waste heat attributed to spaces, and heating and cooling system efficiencies.

Key Variables Associated with Calculating Energy Consumption

The energy source for a lighting system is electricity, which is measured in kWh. The relevant variables used to characterize the electricity consumption of a lighting system are:

- Hours of operation
- Total connected load in kW, which is a function of
 - Number of fixtures
 - Wattage per fixture

Operating Characteristics – Dedicated Panels with Automatic Controls

Lighting is solely needed when spaces are occupied, to provide adequate illumination for the tasks being performed. The Illuminating Engineering Society has developed task-based recommendations for lighting levels, and it is the designer's responsibility to select fixtures, lamps and fixture locations to appropriately meet these light levels.

A lighting system on a dedicated panel is typically found on higher voltage 227V/480V panels. Smaller facilities may use 120/208V panels, however these panels frequently have other circuits that serve receptacles or other equipment.

The control system can have a variety of operating characteristics and levels of functionality. These include, but are not limited to, lighting operation by time, by occupancy or vacancy, emergency or night-lighting functions, and the ability for occupants to manually override the control system. This is discussed in greater detail in the Occupancy Characterization section below.

Scope of This Guide

The profile of energy consumption and savings associated with the following ECMs can be characterized using this guide:

1. Installation of an automatic control system, which may or may not also include:
 - a. Replacement of low-efficiency lamps and ballasts in existing fixtures
 - b. Wholesale replacement of fixtures (including lamps and ballasts)

This document is designed to assist in gathering either pre- or post-retrofit data for the electricity consumption of a lighting system. As such, a primary goal is to describe the data that should be collected through measurements and the appropriate equipment to perform those measurements. Guidance is provided for specifically measuring lighting systems connected to dedicated panelboards with automatic controls. The other systems outlined earlier (including systems connected to mixed lighting panelboards or without automatic controls) are not covered in this guide.

Because of the many permutations that exist with automatic control systems, a number of decisions need to be made as part of the system characterization undertaken during the initial site survey mentioned in Figure 3. It is also important to evaluate pre- and post-retrofit measurements to determine if routine or non-routine events took place that need to be accounted for in the calculations. Routine events include holidays or vacation weeks that may occur during the measurement period; non-routine events include unscheduled shutdowns or emergency 24-hour operations.

Measurements

Measurement Approach

The measurement boundary¹ of a lighting system on a dedicated panel with automatic controls will differ based on the configuration of the lighting system in the specific facility. Figure 4 illustrates a decision tree that can be used to identify the measurement boundary and general approach that should be used for the system being assessed.

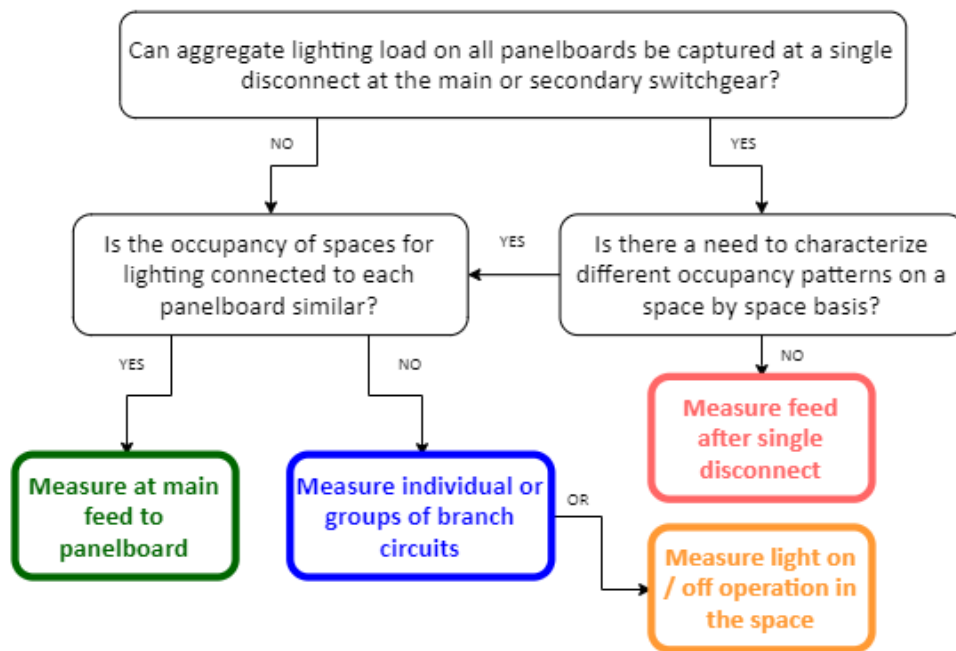


Figure 4. Decision tree to determine the measurement boundary of a lighting system

Occupancy Characterization

A major consideration when measuring a lighting system with automatic controls is the level to which characterization of occupancy patterns is needed. Generally, measurement at a panel or switchgear level is likely adequate to simply estimate the avoided energy between pre-and-post retrofit periods. If the purpose of conducting measurements is to gain an understanding of pre-retrofit occupancy patterns in a specific facility to better estimate savings, measurement at the panel, circuit, or space is likely more appropriate. Another factor to consider is the scale of the retrofit and the occupancy variation in the

¹ Chapter 3 of IPMVP Core Concepts, 2016 defines the measurement boundary as “notational boundaries drawn around equipment, systems or facilities to segregate those which are relevant to savings determination from those which are not.”

spaces where the retrofit is taking place. Measurement at the switchgear or panel level in a large single use facility with small percentage of office space, like a warehouse, is probably appropriate. When measuring a large facility with a mix of spaces and uses (e.g., school, courthouse, fire station) it may be desirable to measure at the panel, circuit, or space level, especially if a sampling plan is being implemented (see Sampling section below). Detailed measurements may also be desirable in a small set of buildings with similar use types (e.g., fire or police stations, schools, etc.), to develop standardized occupancy schedules for different space types that can then be used to estimate savings in a larger population of buildings, in conjunction with switchgear- or panel-level measurements.

Another consideration is the degree to which the lighting controls are integrated with the building automation system (BAS) or can log the operation of different circuits or spaces. The Internet of Things (IoT) has ushered in a vast number of control capabilities, including fixtures within a space that can be individually controlled by an occupant using a smartphone app. This level of control is beyond the scope of this guide, but many mainstream LED fixtures now offer IP-based connectivity.

Evaluating the data-capturing capabilities of the control system is an important aspect of the functional requirements for the design team or implementation contractor. The incremental cost of integrating data-logging capabilities in some systems is nominal or may simply be a function that is built in but needs to be activated during commissioning. Some systems will internally measure and record energy consumption in real time. Some control system can record on/off states and when coupled with a simple circuit-by-circuit one-time measurement of power draw using a clamp meter, reflects a relatively simple measurement approach.

Ultimately, a mixed approach may be needed: spaces in the building with intermittent occupancy may require detailed measurements; while, spaces where lighting is provided regardless of occupancy can use measurements at the panel or switchgear. Pacific Northwest National Lab² (PNNL) recommends that at least 75% of the total lighting load be measured to reasonably capture the operational characteristics of the facility.

Sampling

Lighting hours may vary seasonally depending on the amount of daylight available to the spaces being illuminated. Small spaces such as conference rooms or private offices may operate with inconsistent schedules. To establish the best estimate of avoided energy use, measurements should be taken for as much of the lighting to be replaced as possible, to capture both the energy consumption and the occupancy patterns. If only a sample of fixtures can be measured, the sample should be chosen carefully

to reasonably represent all of the operational conditions and fixture types included in the upgrade, not simply the highest wattage fixtures or those with the largest number of operating hours. If a more rigorous sampling plan is needed, Bonneville Power Administration³ has developed an excellent resource for guidance.

Measurement Boundaries and Types

Two examples of possible measurement boundaries for lighting on a dedicated panel with automatic

² https://www.energy.gov/sites/prod/files/2016/03/f30/mv_lighting_control_wireless.pdf

³ https://www.bpa.gov/EE/Policy/IManual/Documents/2_BPA_MV_Sampling_Reference_Guide.pdf

controls and differing occupancy characteristics are shown in Figures 5 and Figure 6.

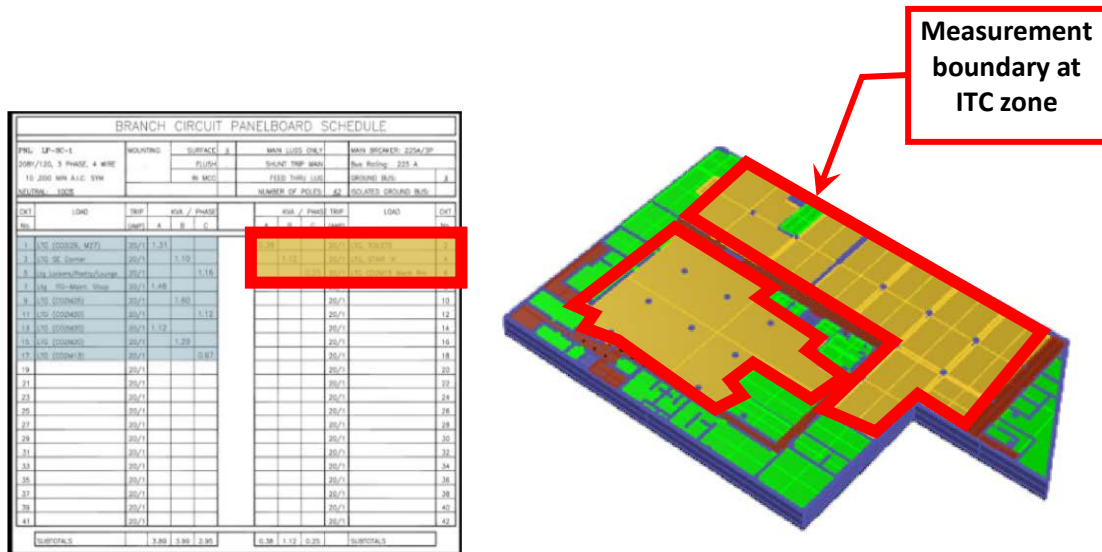


Figure 5. Diagram illustrating measurement boundary of one zone of lights with automatic controls

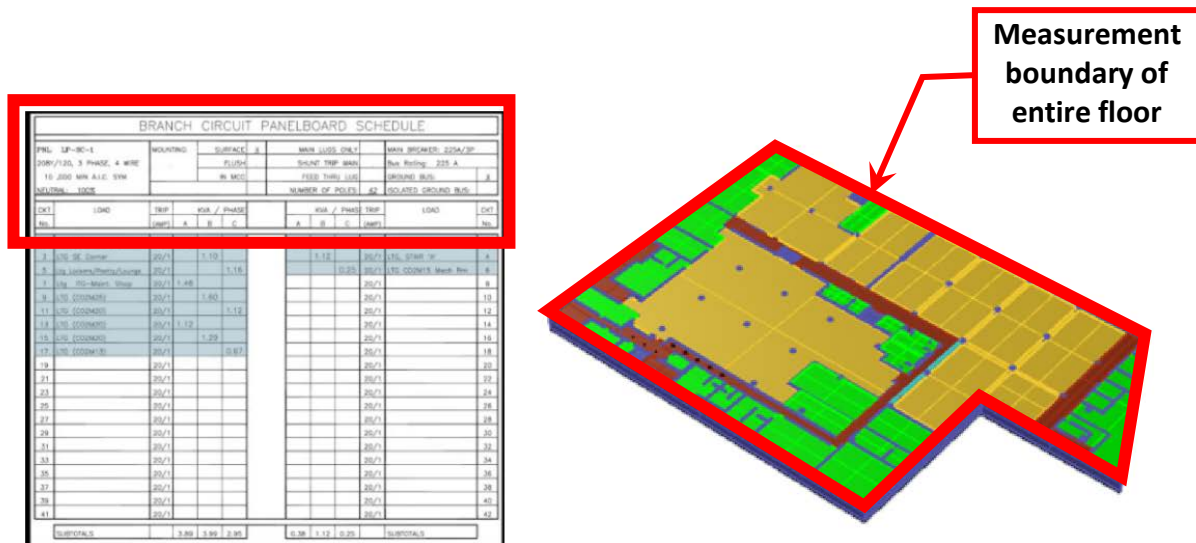


Figure 6. Diagram illustrating the concept of measurement boundary of whole floor measured at the panelboard

Measure Feed After Single Disconnect

This strategy, represented in Figure 7, is appropriate when multiple panelboards are served from a single piece of switchgear and the main feed to those panelboards can be de-energized to install measurement equipment. True RMS power and operating hours can be captured using the same equipment that would be used to measure at the main feed.

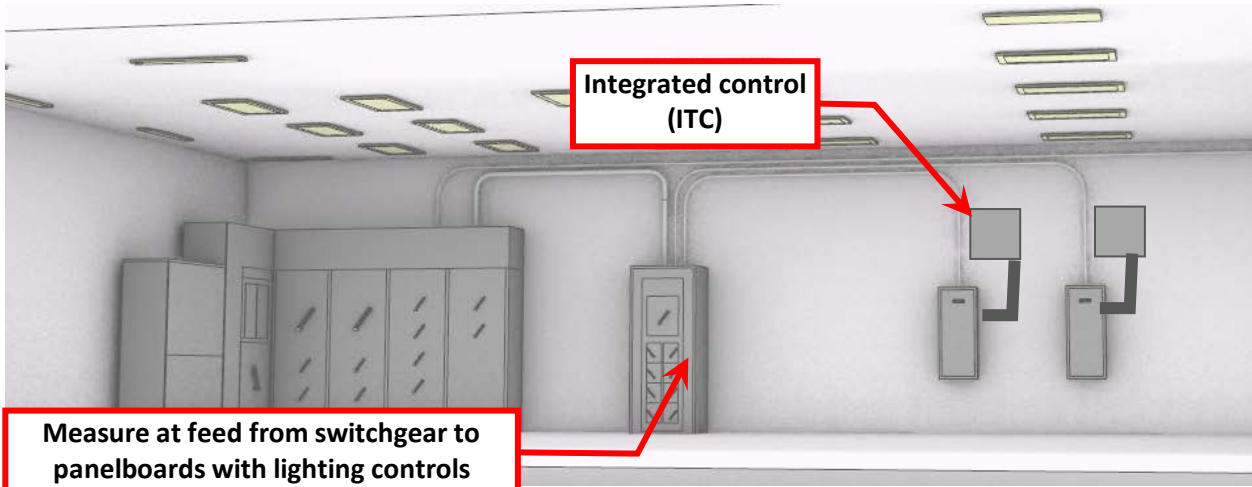


Figure 7. Measurement point for collecting data after single disconnect

Measure at Main Feed to Panelboard

This strategy, represented in Figure 8, is usually the easiest measurement to take, though it typically requires de-energizing the panelboard at the associated switchgear. True RMS power can be measured using a data-logging power meter, or a one-time reading using a clamp meter can be used with a long-term measurement of apparent AC current that is then correlated to true RMS power.

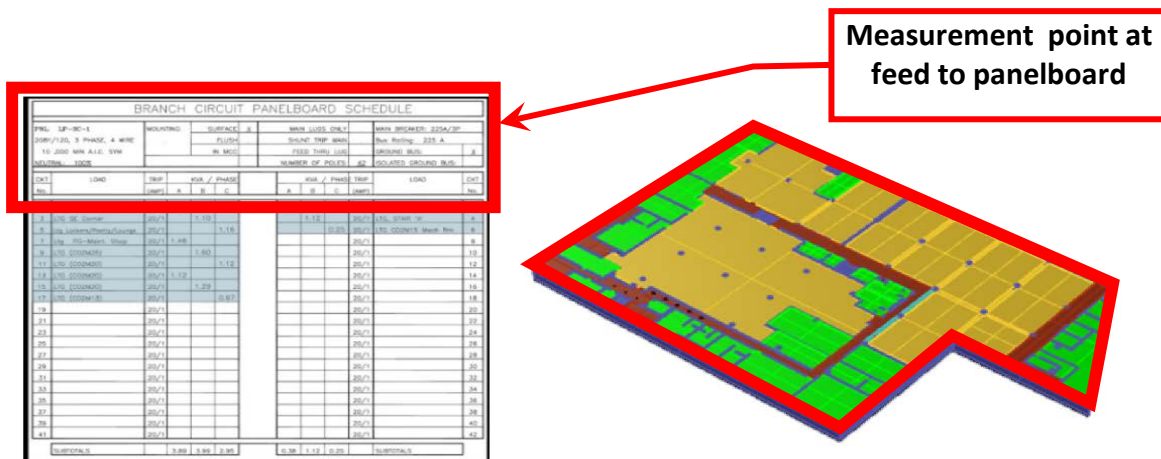


Figure 8. Measurement point at panelboard for lights with automatic controls

Measure Individual or Groups of Branch Circuits

This strategy, represented in Figure 9, is most appropriately used to evaluate the lighting operation where the circuits serve more than 75% of the lighting in the space(s) of interest. True RMS power and operating hours can be captured using the same equipment that would be used to measure at the main feed, and occupancy patterns can be developed based on the hourly energy consumption.

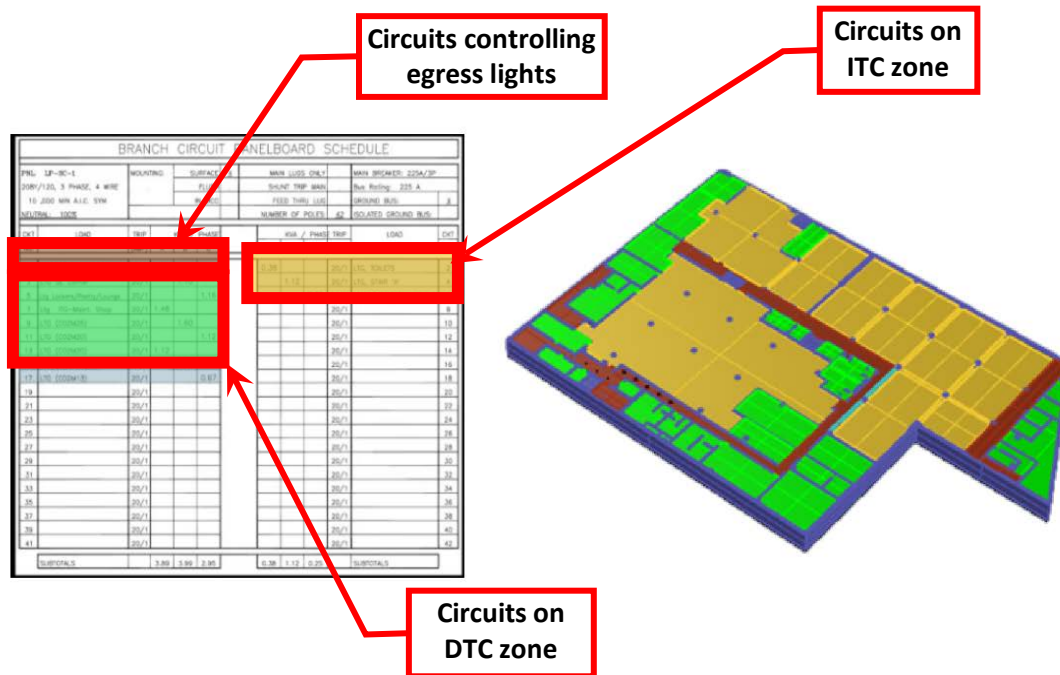


Figure 9. Measurement point for collecting data at individual or groups of branch circuits

Measure Light On/Off Operation

This strategy, represented in Figure 9, may be used where measurement of detailed occupancy patterns in highly localized spaces is desired, such as when characterizing lighting use by space type to apply to a sampling plan. However, a thorough fixture inventory is required to reasonably develop estimates of avoided energy. This strategy may also be helpful in improving predictions of post-retrofit lighting operation and in confirming sensor locations prior to design of an automatic control system. The hours of operation are measured with light on/off data loggers, which should be placed in close proximity to the fixture types that are expected to constitute over 75% of the total connected load in kW.

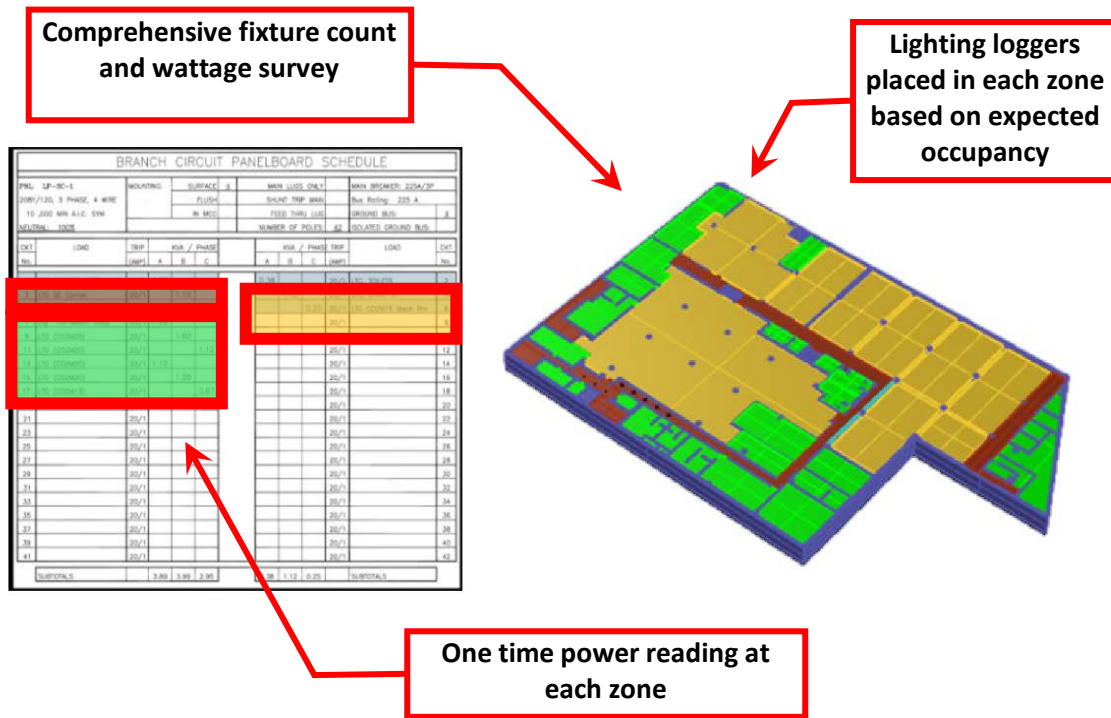


Figure 10. Measurement points for collecting data for on/off operation






Measurement Tools and Equipment

The measurements in this guide can be performed with the equipment listed in Table 1; more detailed descriptions have been provided in Table 2. NYC agency employees can borrow the recommended equipment from CUNY BPL’s FELL, and have it delivered to their facility. Third-party M&V consultants and others can use this equipment list as guidance, recognizing that many manufacturers make comparable equipment. Inclusion on the list in Table 1 or Table 2 should not be construed as an endorsement of these manufacturers.

Table 1. List of measurements and associated tools

Measurement	Units	Tool	FELL Equipment
True RMS Power	kW	Clamp Meter	Fluke 345 Power Quality Clamp Meter
Apparent Current	Amperes	Current Sensor and Data Logger	Onset Split-core AC Current Sensor (CTV-A, CTV-B, Or CTV-C) Onset HOBO 4-Channel Analog Data Logger (UX120-006M)
True RMS Energy	kWh	Data-logging Power Meter and Current Transducers	DENT ELITEpro XC Portable Power Data Logger (EXCUNC) DENT 16” RoCoil Flexible Rope Current Transformers (CT-R16-A4-U)
Hours of Operation	Seconds	Light Data Logger	Onset HOBO (UX90-002) Light On/Off Logger)

Table 2. Detailed descriptions of measurement tools

Tool Image	Tool Name	Description
	Fluke 345 Power Quality Clamp Meter (Fluke 345)	Multi-purpose electrical measurement tool used to take true RMS power readings over a short period of time.
	Onset Split-core AC Current Sensor (CTV-A, CTV-B or CTV-C)	Provides a measurement of the current flowing through a conductor. Converts measurement to a signal which the U12- or UX120-series data logger can record. The sensors are rated for specific amperage ranges - CTV-A for 2-20 Amps, CTV-B for 5-50 Amps, or CTV-C for 10 – 100 Amps). The sensor should be selected based on the maximum or minimum amperage anticipated to be measured to avoid out of range readings.
	HOBO 4-Channel Analog Data Logger (UX120-006M)	Used in conjunction with the CTV series of sensors. Records measurements from up to four CTV sensors. Requires HOBOWare software and a USB connection cable for programming and downloading data files.
	DENT ELITEpro XC Portable Power Data Logger (EXCUNC) DENT 16" RoCoil Flexible Rope Current Transducers (CT-R16-A4-U)	Provides a measurement of true RMS power from voltage and current inputs and records long-term power (kW) and energy (kWh) measurements. Requires ELOG19 software and a USB connection cable for programming and downloading data files.
	HOBO Light on/off Data Logger – (UX90-002)	Records light on and off conditions using an internal sensor. Requires HOBOWare software and a USB connection cable for programming and downloading data files.

Measurement Strategies

The following instructions have been developed for each measurement strategy discussed in this guide. While these instructions are reasonably detailed, certain aspects of each strategy may need to be modified based on the specific system configuration at each facility. Early surveying of the facility is recommended when tailoring each strategy to unique site conditions.

The measurement recommendations reference supplementary equipment guides, which can be found in Appendix A.

- A.2: Fluke 345 Clamp Meter
- A.3: DENT ELITEpro XC Power Meter
- A.4: Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor
- A.5: Onset HOBO Light On/Off Data Logger (UX90-002)

Measure Feed After Single Disconnect OR Measure at Main Feed to Panelboard Using Data-Logging Power Meter

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
2. Obtain measurement equipment from FELL:
 - a. DENT ELITEpro XC Power Meter – (EXUNC)
 - b. 16” Flexible Current Transducers (CTs) (DENT CT-R16-A4-U)
3. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - a. Set up and initialize the DENT logger per the instructions in section A.3.1.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - a. Install the ELITEpro XC power meter and CTs at the main feed lines of the panelboard per the instructions in sections A.3.2 to A.3.3.
3. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - a. Confirm that the logger is collecting data and that system operation is being recorded. The steps are included in the instructions in section A.3.5. **Be careful not to stop the logger when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.

2. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - a. Confirm that the logger has collected the required operational data per the instructions in section A.3.5. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.3.5.
4. Remove the data logger and return to FELL.

Measure Feed After Single Disconnect OR Measure at Main Feed to Panelboard Using Clamp Meter, Current Sensors, and an Analog Data Logger

This approach should be used as an alternate method to measuring after a single disconnect or main feed with a data-logging power meter if the DENT ELITEpro XC Portable Power Data Logger (or equivalent) is not available or cannot be installed due to space or other constraints.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
2. Obtain measurement equipment from FELL:
 - a. Fluke 345 Power Quality Clamp Meter (Fluke 345)
 - b. ONSET 4-Channel Analog Logger (UX120-006M)
 - c. ONSET Amp Split Core AC Current Sensors (CTV-A, B, or C)
3. Refer to *Appendix A.4 Onset HOB0 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Set up and deploy data logger per the instructions in sections A.4.1 to A.4.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *A.2: Fluke 345 Clamp Meter*
 - a. Take a one-time measurement of true RMS power draw at the main feed lines of the panelboard per the instructions in section A.2.1
 - b. Take a screenshot of the reading per the instructions in section A.2.2 (or, alternatively, a photograph using a cell phone).
3. Refer to *Appendix A.4 Onset HOB0 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Install the current sensors and analog logger using section A.4.4 as guidance.
4. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.4 Onset HOB0 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger is collecting data and that system operation is being recorded per the instructions in section A.4.5. **Be careful not to stop the logger when downloading data.**

4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.4 Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger has collected the required operational data per the instructions in section A.4.5. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.4.6.
4. Remove the data logger and sensors and return to FELL.

Measure Individual or Groups of Branch Circuits Using Clamp Meter, Current Sensors, and an Analog Data Logger

This approach should be used when measuring a main feed is not feasible, and individual circuits or groups of circuits can be measured using up to four current sensors to capture the lighting load in the panel. This measurement is similar to the above description, however an assessment of the loads on each circuit or group of circuit may required the use and configuration of different current sensors.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
2. Obtain measurement equipment from FELL:
 - a. Fluke 345 Power Quality Clamp Meter (Fluke 345)
 - b. ONSET 4-Channel Analog Logger (UX120-006M)
 - c. ONSET Amp Split Core AC Current Sensors (CTV-A, B, or C)
3. Refer to *Appendix A.4 Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Set up and deploy data logger per the instructions in sections A.4.1 to A.4.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *A.2: Fluke 345 Clamp Meter*
 - a. Take a one-time measurement of true RMS power draw at the main feed lines of the panelboard per the instructions in section A.2.1
 - b. Take a screenshot of the reading per the instructions in section A.2.2 (or, alternatively, a photograph using a cell phone).
3. Refer to *Appendix A.4 Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Install the current sensors and analog logger using section A.4.4 as guidance. Verify that the appropriate sensor is being used based on the different range of amperage being measured.
4. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.4 Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger is collecting data and that system operation is being recorded per the instructions in section A.4.5. **Be careful not to stop the logger when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.4 Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger has collected the required operational data per the instructions in section A.4.5. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.4.6.
4. Remove the data logger and sensors and return to FELL.

Measure Long-Term Light On/Off Operation and Take Fixture Inventory

This approach should be used when other measurement strategies are not appropriate, or where it is desirable to characterize different occupancy patterns based on space types.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
2. Obtain measurement equipment from FELL:
 - a. Light On/Off Data Logger (UX90-002)
3. Refer to *Appendix A.5: Onset HOBO Light On/Off Data Logger (UX90-002)*
 - a. Set up and deploy data logger per the instructions in sections A.5.1 to A.5.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.5: Onset HOBO Light On/Off Data Logger (UX90-002)*
 - a. Install the light on/off loggers in the appropriate spaces and be sure the loggers pass calibration with the lights on as per the instruction in section A.5.4 and A.5.5.
3. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.5: Onset HOBO Light On/Off Data Logger (UX90-002)*

- a. Confirm that the logger is collecting data and that system operation is being recorded per the instructions in section A.5.6. **Be careful not to stop the logger when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.5: Onset HOBO Light On/Off Data Logger (UX90-002)*
 - b. Confirm that the logger has collected the required operational data per the instructions in section A.5.6. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.5.7.
4. Remove the data logger and return to FELL.

Calculation Methodology

Total annual energy (in kWh) is calculated using the general equation, below:

$$E \left[\frac{kWh}{year} \right] = \sum_{i=1}^N T_i [Hours] * P_i [kW] \quad (1)$$

Where,

E = Electricity use of the system, in kWh/year

T_i = Total amount of time that the system is operational for a given operational bin, in hours/year

P_i = Average power draw for each operational bin, in kW

N = Number of operational bins

Four Microsoft Excel workbooks have been developed along with this guide to facilitate the calculation of total annual energy consumption from the measured data:

1. **Long-term true power measurements using a power logger** – This workbook calculates annual consumption using average hourly power draw (in kW) as measured by a DENT power logger. This workbook is primarily designed for measurement of the main feed at the panel or groups of main feeds to lighting panels at the switchgear.
2. **AC current measurement at main feed with current sensors** – This workbook calculates annual consumption using hourly average current (in amperes), as directly measured by current sensors, and spot measurements for true power. This workbook is primarily designed for measurement of the main feed at the panel or groups of main feeds to lighting panels at the switchgear.
3. **AC current measurement at one or more circuits with current sensors** – This workbook calculates annual consumption using hourly average current (in amperes), as directly measured by current sensors, and spot measurements for true power. This workbook can be used with measurements of individual circuits or groups of circuits.

4. **Fixture inventory and long-term light on/off measurements** - This workbook calculates annual consumption using a physical count of the fixture types and wattage in each space and lighting on/off loggers to generate an operational schedule. Where possible, a one-time measurement of true power on the lights in the spaces being measured is encouraged. This workbook is based on fixture types and grouped by space/occupancy.

Instructions are included in each workbook that detail how to input data and how to interpret and make use of the results. Specific calculation methodologies can be found in Appendix A.20: Lighting on Dedicated Panelboards With Automatic Controls Calculations and are captured in the workbooks. All spreadsheets assume all days measured are representative of typical occupancy. Manual adjustments may need to be made if some days are atypical (e.g., a holiday on a weekday).

Reporting Recommendations

As part of the documentation of expected avoided energy use, the integration of measurements and calculation methodology discussed in this guide will serve to enhance these projections. To facilitate transparency and data quality control, the following pieces of information should be documented to accompany expected savings calculations:

1. Measurement tool information and dates of measurement. The HOBOWare application records logger information (such as product, serial number, and version number) as well as deployment and measurement dates. To export this information, use the software to open the logger data file, then select “Export Details” from the File menu; this will produce a text file like the one shown in Figure 10. Repeat for all data loggers that were deployed and include all files with the funding application.

```
Details
Series: FAn
  Devices
    Device Info
      • Product: HOBO UX90-004M Motor On/Off
      • Serial Number: 10939612
      • Version Number: 3.07
      • Manufacturer: Onset Computer Corp.
      • Device Memory: 524288
      • Header Created: 11/30/11 01:37:05 PM GMT-07:00
    Deployment Info
      • Full Series Name: FAn
      • Launch Name: AC-1-07_Fan
      • Deployment Number: 11
      • Wrap Enabled: Yes
      • Wrap Count: 0
      • Launch Time: 05/24/18 09:37:51 AM GMT-07:00
      • Launch GMT Offset: -7 Hr 0 Min
      • Battery at Launch: 2.87 Volts
      • Launching Program: HOBOWare Pro-3.7.13_0928_1253_Windows
    Series Statistics
      • Samples: 16
      • Total time on: 31:30:23 HMS
      • Total time off: 329:20:35 HMS
      • Percent time on: 8.73
      • Percent time off: 91.27
      • Number of transitions to on: 7
      • Number of transitions to off: 7
      • First Sample Time: 05/24/18 11:00:00 AM GMT-07:00
      • Last Sample Time: 06/08/18 11:50:58 AM GMT-07:00
```

Figure 11. Example of Device Information Export from HOBOWare

2. If a building automation system (BAS) was used to collect any of the information discussed in this guide, submit a brief description of the system, including:
 - a. BAS manufacturer and model
 - b. BAS software and version number
 - c. Measurement dates
 - d. Most recent date of sensor calibration (if a sensor was used)
3. The completed workbook(s) containing measured data.

It is expected that the user will be responsible for measuring the system of interest and compiling the data input to the calculation tools. The output of these tools can be directly used to satisfy reporting requirements.