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Standard Measurement and Verification Plan for Lighting Retrofit Projects for Buildings and Building Sites

EE Richman

October 2012

Pacific Northwest NATIONAL LABORATORY

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Richland, Washington 99352

Abstract

This document provides a framework for standard measurement and verification (M&V) of lighting retrofit and replacement projects. It was developed to provide site owners, contractors, and other involved organizations with the essential elements of a robust M&V plan for lighting projects. It includes details on all aspects of effectively measuring light levels of existing and post-retrofit projects, conducting power measurement, and developing cost-effectiveness analysis. This framework M&V plan also enables consistent comparison among similar lighting projects, and may be used to develop M&V plans for non–lighting-technology retrofits and new installations.

Abbreviations

amp	ampere(s)
fc	footcandle(s)
CIE	International Commission on Illumination
ft	foot, feet
HVAC	heating, ventilating, and air conditioning
in.	inch(es)
kw	kilowatt(s)
kwh	kilowatt-hour(s)
M&V	measurement and verification
PF	power factor
RMS	root mean square

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1.0 Background and Plan Summary

This document provides a framework for a standard measurement and verification (M&V) plan for lighting projects. It was developed to support cost-effective retrofits (partial and complete replacements) of lighting systems and is intended to serve the following purposes:

- Provide a foundation for M&V plans for lighting retrofits following a “best practice” approach that considers engineering accuracy as well as practicality. This document may need to be customized for individual applications.
- Provide site owners, contractors, and other involved organizations with the essential elements of a robust M&V plan for lighting projects, including examples such as the calculation of expected energy savings.

This framework M&V plan also enables consistent comparison among similar lighting projects. Although intended for lighting retrofit applications, this document may also be used to develop M&V plans for non–lighting-technology retrofits and new installations.

The M&V approach outlined herein contains many parameters. The prescribed methodologies were developed considering technical accuracy and practicality. This approach is suitable for lighting fixture retrofits and/or replacements. The approach is also useful for projects that include changes to control systems for additional energy savings. Capturing control savings typically requires additional monitoring and calculation. This M&V plan especially applies to projects in which the parties involved seek consistent verification of savings among different projects and technologies.

Table 1.1 summarizes the key elements associated with M&V activities for lighting equipment retrofits based on three types of activities: baseline M&V activities, post-installation M&V activities, and annual/periodic M&V activities.

Table 1.1. Key Elements in Standard Measurement and Verification Plan for Lighting Retrofits

Activities	Elements
Baseline M&V activities	• Obtain fixture counts from documented lighting audit. • Measure baseline fixture power for lamp + driver/ballast combinations representing a total of 75% of the baseline connected load. – This may be done by measuring a minimum of 75% of the circuit load or at least six individual fixtures of each type and then calculating total load from these representative measurements. Failed light sources must be addressed as described later in this document. – HVAC interactions are assumed to be negligible. • Measure or document baseline operating hours based on control timers or schedules. • Calculate baseline energy use based on product of the baseline fixture power consumption, operating hours, and fixture quantities for each line item in the lighting audit OR product of total circuit load and operating hours. • Calculate baseline demand based on product of the baseline fixture power consumption and fixture quantities for each line item in the inventory OR total circuit load.
Post-installation M&V activities and energy-use savings calculations	• Audit and inspect lighting installation to confirm final fixture counts. • Measure fixture power for lamp + driver/ballast combinations representing a total of 75% of the baseline connected load (i.e., a minimum of 75% of the circuit load or 75% of the individual fixtures). • Assume that operating hours are the same as baseline operating hours for direct lamp technology comparisons assuming standard dawn to dusk on-off control. If controls have been added or modified that affect energy savings, the operating hours should be measured or estimated based on documented research or case studies. • Verify post-installation energy use based on product of the verified post-installation fixture power consumption, operating hours, and fixture quantities for each line item in the inventory OR product of total circuit load and operating hours. • Verify post-installation demand based on product of the verified post-installation fixture power consumption, and fixture quantities for each item in inventory OR total circuit load. • Calculate savings as the difference between the baseline and post-installation energy use and power demand.
Annual or periodic M&V activities	• Inspect approximately 10% of the area or fixtures retrofitted. • Report deficiencies that affect performance and/or energy savings to facility representative.

2.0 Measurement and Verification Activity Details

This section provides details on each of the primary elements of a useful and effective M&V plan. Specific guidance on application of the plan in varying field conditions is included to accommodate commonly expected differences in project applications.

2.1 Basic Considerations

For measurements to provide a useful comparison of different lighting technologies, the standard M&V plan assumes several conditions, as follows.

- Operating hours are identified during the initial energy survey and are assumed to be the same before and after the equipment retrofit for the purpose of energy-savings calculations. Savings associated with different facility operating hours are not part of the energy-savings methodology detailed here.
- If controls have been added or modified as part of the installation, the associated energy savings should be separately calculated. If modifications or additions incorporate timed controls such as on-off schedules, the calculation can be based on measurement of the new operating hours or on an estimate based on timer or schedule settings.
- For new controls that are not time-based (e.g., occupancy sensors and dimming controls), capturing operating hours will not support an accurate calculation. In these cases, circuit energy use needs to be measured for representative periods (minimum of 2 weeks) to capture representative energy use, which replaces the calculation of load multiplied by operating hours.
- Interactive effects on heating and cooling systems from the lighting baseline and post-installation equipment are not considered for interior or exterior installations. Although heating and cooling will be affected for interior installations, in most cases the heating and cooling interactions at least partially offset each other or are relatively minor.
- Electricity demand and associated charges are not considered for exterior installations. Exterior lighting rarely affects demand and associated charges for most utilities because utility power rarely peaks at night.
- Lighting levels (photopic illuminance) are assumed to be appropriate for the task in both the baseline condition and the post-installation condition. If baseline lighting levels are too low for the task, the lighting should be repaired, refreshed, or modified as needed for an appropriate comparison.

2.2 Site Selection and Setup

An effective comparison of lighting technologies requires an environment and conditions that eliminate unnecessary variables that could invalidate the results. All installations and real-world conditions are unique; however, equivalent conditions are needed for a reasonable comparison. Each of the setup conditions described below should be evaluated and emulated as closely as possible.

2.2.1 Fully Operational Baseline

The baseline lighting system should be fully functioning in the same manner as a lighting system that has recently been installed or refreshed. If possible, the system should be cleaned before testing with a damp cloth and refreshed with new lamps that have been seasoned for 100 hours. For an optimum comparison, the light levels in the baseline condition should be set equal to the appropriate levels for the task, if possible. This should also match closely with the target light levels for the retrofit technology.

If refreshing the system lamps is not possible, it is important to complete power and light level measurements on portions of the system that are fully functioning. Note, however, that this will not necessarily provide a true comparison of two technologies because of natural degradation of the baseline lamps. In this situation, the age of the lamps used for measurement should be recorded where possible. Computer models of the lighting can be used when equipment status and/or degradation do not permit reasonable assessment of existing conditions.

2.2.2 Stable Conditions for Measurement

The test site should be located where the surrounding conditions will be the same for both the baseline and the post-installation retrofit testing. Changes in surrounding structures, occupants, weather, or other conditions could affect the results and may make comparative measurements difficult.

2.2.3 Measurement Access

The test site should provide easy access to the circuits serving the test lighting system. The illuminated area should be available for light level measurements during periods when potential obstructions can be avoided (e.g., vehicles, occupants, customers, and temporary materials or equipment).

2.3 Instrumentation Requirements

This standard M&V plan recommends minimum accuracy requirements for the instruments used to take measurements. Table 2.1 provides instrument specifications appropriate for use in the types of measurement applications covered in this M&V plan. Specific brands or manufacturers are provided as examples only and do not represent an all-inclusive list. Testing documentation should include the actual specifications and measurement accuracies of any equipment used. If the accuracy is significantly less than the values listed in Table 2.1, the measurements may not be suitable because they would introduce additional error into the energy calculations.

2.4 Power Measurement

There are two primary methods for measuring baseline and post-installation power: 1) measure the entire electrical circuiting encompassing the replacement project (circuit measurement method) or 2) measure a sample of representative fixtures (sampling measurement method). The circuit measurement method is generally preferred because it captures the true power consumption without calculation or use of average values, and it is often easier to implement.

Table 2.1. Examples of Instrumentation Specifications

Equipment Type	Purpose	Measurement Uncertainty and Range	Meter Characteristics	Brand Name[(a)] Examples
Illuminance meter	Establish functional performance of baseline and new lighting equipment	Uncertainty: ±3% Range: ≤0. 1 fc (0.01 lux) to ≥10,000 fc (100,000 lux)	<3% deviation from cosine function for reported single value or ≤10% at incidence angle of 60° for multiple angle reported values. Spectral response within 10% of the CIE spectral luminous efficiency function	Minolta Photo Research Cooke Extech Amprobe Solar Light
Power meter	Establish true RMS power draw of baseline and new lighting equipment	Uncertainty: ±3% Decimal precision of 0.01 amp	Power factor (PF) calculation	Fluke 39/41/41B Extech 4KC20 AEMC 3910
Light on/off data logger	Measure run time of lighting fixtures	Uncertainty: ±1 minute per week; Light threshold adjustment range: 1–100 fc (10–1,000 lux)		Onset Computer Hobo Loggers Dent Instruments SmartLogger Omega OM-53

(a) Brand names listed are examples only. Associated products **may not** meet all of the requirements in this table. Verification of the individual equipment is required.

2.4.1 Circuit Measurement Method

The circuit measurement method involves identifying the circuit(s) that serve the baseline and post-installation lighting systems (typically they are the same circuit) and measuring the power to at least 75% of the total load. This provides a direct representative measurement of actual power for the project. If all fixtures are not included in the measurement, the total load can be calculated from this representative measurement by prorating to the total quantity of fixtures. **It is important to ensure that the circuits identified and measured do not have other loads on them**; however, if the loads constitute a small percentage of the total lighting load (less than 10%) and can be separately measured, the circuit can still be used. In this case, measure the non-lighting load separately at the same time as the circuit measurement and subtract to determine the lighting-only load.

2.4.2 Sampling Measurement Method

The sampling measurement method involves measuring the power draw of a sample of each type of fixture (existing and replacement) and calculating an average of these measurements for use as a per-fixture power rating. The total project power is then calculated as the product of the average fixture power and the fixture quantities. The sample size to be measured for each separate fixture type shall be a total of six fixtures of that type or the entire set if less than six. It is important to note that a consistent comparison of technologies should assume normal operating conditions for both cases. Therefore, identify and measure only normally operating fixtures for the baseline (and post-installation) test.

2.4.3 Equipment Burn-in and Warm-up

For newly installed retrofit or replacement equipment, power measurements should be made after at least 100 hours of burn-in operation to avoid measurement of any equipment power anomalies typically associated with initial operating periods. Fixtures for both baseline and post-installation must also be allowed to warm up to typical operating conditions prior to measurement. Appropriate warm-up periods will vary depending on the technology, but 1 hour should cover all interior and exterior situations.

2.5 Basic Exterior and Interior Light Level Measurement Protocols

Light level (i.e., illumination) measurements are critical to comparing the capabilities of different lighting technologies. It is important to measure only the light being provided by the technologies being tested, which represents the actual illumination provided by the system being measured. The following guidelines will help to ensure accurate and representative light level data.

Follow these guidelines for all measurements (exterior and interior) as applicable:

- Where possible, use the same calibrated illuminance measurement meter (see Section 2.1). If the same meter is not available, use the same make and model of calibrated meter to minimize underlying differences in accuracy and internal meter spectrum correction characteristics.
- When taking measurements, verify that occupants and objects/materials are not blocking any light to the meter head. The use of a remote meter head cabled to the meter body is recommended to prevent the operator from blocking the meter's "view" of the lighting system being measured. Measurement points that are shaded, even partially, by obstructions that are not moveable should be noted for potential elimination.
- Identify the appropriate task plane at which to take the measurements. For most outdoor areas and indoor corridors, gathering spaces, and warehousing or manufacturing spaces, this plane will be the ground or floor surface (where walking is the primary task). For most other indoor areas, the task plane will be a typical office desk height (30 inches above the floor).
- Identify the measurement locations by marking and/or mapping. It is important to measure the same locations for the baseline and post-installation lighting systems, or the same representative type of locations if fixtures are relocated for the retrofit. Therefore, it is necessary to provide some permanent record of measurement point locations.
  - For interior areas, mapping (e.g., using a sketch or marked-up plans with dimensions) is usually the best option because marking on measurement surfaces will often not be allowed or will not be retained between measurements. Make sure to reference the measurement points to some permanent features of the space because desks and other furniture may be moved between the baseline and post-installation measurements.
  - For exterior areas such as parking lots, it may be possible to mark locations with dots or numbers using striping or other paint (durable but non-permanent), subject to site representative approval. Otherwise, a map of the measurement grid referenced to permanent site features can be developed

such that the same measurement locations can be identified later. It is advisable to map the measurement points even if marking is possible in case the exterior area is resurfaced or otherwise cleaned of all markings.

- Photographs of the test site conditions, meter setup, and measurement layout are recommended to provide a record of the conditions to be applied for repeated sets of measurements. These will help identify obstructions and other conditions that may affect readings. Note that using photos for color comparisons of baseline and retrofit installations may not provide accurate results because camera model settings including white (color) balance and exposure may vary. If photos are to be used for comparison purposes, the camera color accuracy should be assessed and appropriate caveats noted.
- Record time and ambient temperature at start and finish of measurements.

Additional detailed guidance on precautions, methods and appropriate techniques for taking effective light level measurements is provided in Appendix A.

2.6 Specific Exterior Light Level Measurement Activity

In addition to the guidelines in Section 2.5, follow these guidelines for exterior area measurements:

Set Up Measurement Grids

- Identify a horizontal grid of measurement points on the site surface that contains the expected minimum and maximum of each different exterior area for both baseline and post-installation conditions (see sample layouts in Appendix B).
- Locate measurement points on gridlines covering the test measurement area. Ensure that the spacing between measurement points is uniform in both directions and is less than one-half the pole height or less than 15 feet, whichever is smaller. For installations with lights spaced less than 15 feet apart, locate measurement points no farther apart that one-half the pole height, with at least three points between poles in both directions.
- Record the location of all measurement grids and point layouts with dimensions from surrounding poles or other structures. Provide this information, including a sketch or rendering of the grid layouts, to the site owner such that the measurement points can be reused for future verification measurements.
- For open areas such as main parking, make the measurement grid large enough to completely encompass at least four poles that represent typical layout and spacing of poles (or the complete installation if fewer than four poles). See Appendix B, Figure B.1, for an example.
- For site perimeter open areas or areas adjacent to a building edge or façade (e.g., front drive aisle, rear drive, pallet/loading), establish the test area measurement grid in a typical perimeter or building edge area. The depth of the test area should extend from the paved site boundary or building edge inward to the nearest line of light poles that are at least 15 feet from the boundary or building edge. The width of the test area must cover at least two of the poles in the line that is at least 15 feet from the boundary or building edge. See Appendix B, Figure B.2.

- For areas that include separate or main entry drives, establish the measurement grid across the entire drive or other area and extending the typical distance between two adjacent light poles. See Appendix B, Figure B.3.
- For each separate horizontal grid, also identify a vertical plane representative of the lighting in the area (typically the gridline directly between two light poles). On this vertical plane, set a grid (line) of points at 5 feet above the site surface at each of the corresponding horizontal measurement points. See Appendix B, Figure B.4.
- **Note that in some exterior applications, the layout of the lighted area and location of luminaires will be inconducive to uniform grids of measurements**. In these cases, follow the intent of the grid layout as closely as possible. In cases where all luminaires are not arranged in a uniform grid pattern, identify a row of luminaires, preferably parallel to the site boundary or drive, to use as the basis for setting a measurement grid. Use a reasonably typical spacing of luminaires at the site to identify the grid spacing. Use this spacing, starting with the initially identified row, to develop a grid of measurements without regard to existing luminaire locations that do not match the grid. Extend the grid to ensure that enough clear, unobstructed points will be available to provide adequate characterization when the obstructed point data is eliminated.

Measure and Record Illuminance

- At each measurement point on each grid, measure and record the horizontal illuminance on the ground or finished surface. See Appendix A for more guidance on producing repeatable and accurate measurements. Also measure and record the vertical illuminance at 5 feet above the site surface at the points identified in the vertical plane. See Appendix B, Figure B.4.
- Schedule and take all measurements so as to minimize the effects of other light sources and weather conditions on the results.
  - When possible, schedule measurements for both baseline and post-installation when the moon phase is at half or less to eliminate moon glow as a variable in the measurements. Record a background measurement of ambient lighting (e.g., moonlight, sky glow) in an area shielded from all site lighting and subtract it from other measurements if it is determined to be significant.
  - Ensure that rain, fog, or winds that might introduce particulates into the air, or other conditions that might obscure the light between the fixtures and the meter, are not present for the measurements.

2.7 Specific Interior Light Level Measurement Activity

In addition to the guidelines in Section 2.5, follow these guidelines for interior area measurements:

Set Up Measurement Grids

- Identify a set of measurement points that sufficiently represents the overall lighting of the space for both baseline and post-installation conditions. See Appendix B, Figure B.5.
- For each different set of lighting conditions (i.e., different space types or lighting layouts), locate at least 12 measurement points at easily identifiable points. It is commonly very difficult to identify a rigid grid of measurements because of the many variations in layout and obstructions at desk height

(workplane) in office environments. Therefore, select a sampling of measurement points both below and between fixtures, in both 90-degree directions and diagonally. Include at least two measurements of each location type and in the most uniform grid pattern possible.

- For circulation-type spaces such as corridors and gathering spaces, establish a measurement grid on the task surface (floor) that includes representative points both directly beneath and between fixtures.
- For office and other task areas, identify a set of measurements points on desktops and other work surfaces that best represents lighting conditions in the space. It may not be possible to develop a uniform spacing grid, but points should be chosen that represent the various lighting conditions across the space.
- For each separate horizontal grid, identify a vertical plane representative of the lighting in the area (typically the gridline directly between two light fixtures). On this vertical plane, set a grid (line) of points at 5 feet above the site surface at each of the corresponding horizontal measurement points. See Appendix B, Figure B.4.

Measure and Record Illuminance

- Schedule and take all measurements so as to minimize the effects of other light sources and location conditions on the results. See Appendix A for more guidance on producing repeatable and accurate measurements in both horizontal and vertical planes.
- Schedule measurements for both baseline and post-installation when there is no daylight in the space. This typically requires taking measurements after sunset. Adjacent electric lighting need not be blocked or turned off as long as it is noted and remains the same for both the baseline and the post-installation measurements.
- Ensure that potential temporary obstructions such as occupants, temporary materials, and furniture are removed for both the baseline and the post-installation measurements.

2.8 Proposed Energy and Demand Savings Calculation Methodology[1]

Lighting-energy savings (kilowatt-hours) are based on the difference between the baseline and post-installation luminaire power (watts), the fixture quantities, and the hours of operation. The application of additional controls will further affect the energy savings. It is strongly recommended that lamp technology and any control savings be separately calculated where possible. This can be important in making future retrofit decisions. This standard M&V plan assumes that the operating hours remain constant during the performance period. Simple fixture demand savings are calculated as the difference between the baseline and post-installation power (watts). For most interior technology comparisons, the lighting will be on during peak conditions and the hours of operation will be the same for both cases. Therefore, demand will not need to be adjusted for any coincidence with utility peak conditions.

The proposed annual lighting energy and demand savings are calculated for each set of fixtures using Equations (2.1) and (2.2):

[1] The approach described assumes a simple electric rate. If the rate uses time-of-use periods, the approach shown can be modified by calculating the energy and demand savings separately for each time-of-use period. More complex rates, such as demand ratchets, may require additional calculations.

$$ES = [(FP_{Base} \times N_{Base}) - (FP_{Post} \times N_{Post})] \times H \tag{2.1}$$

$$DS = [(FP_{Base} \times N_{Base}) - (FP_{Post} \times N_{Post})] \times 12 \tag{2.2}$$

where	ES	=	annual electric energy savings (in kWh)
	DS	=	annual electric demand savings (in kWh)
	FP_{Base}	=	baseline fixture power consumption (in kW/fixture)
	FP_{Post}	=	post-installation fixture power consumptions (in kW/fixture)
	N_{Base}	=	number of baseline fixtures
	N_{Post}	=	number of post-installation fixtures
	H	=	annual operating hours (this term may be different for baseline and post-installation if time-based controls are to be evaluated as part of the energy savings)
	12	=	typical number of months of demand charges in a year.

Note that if the effects of non–time-based controls installed in the post-installation case (occupancy sensors, dimming) are to be included in the calculation, the **calculated** energy use (i.e., $FP_{Post} \times N_{Post} \times H$) in the energy savings calculation (ES) is replaced by a representative **measured** yearly energy use for the post-installation system (see Section 2.4). Note that demand savings may also be diminished, but determination of the effect requires matching monitored hourly loads with utility peak timing information.

The total annual cost savings can be determined using Equation (2.3):

$$ECS_{Total} = ES_{Total} \times ER + DS_{Total} \times DR \tag{2.3}$$

where	ECS_{Total}	=	total annual energy cost savings (in dollars)
	ES_{Total}	=	the sum of energy savings for all sets of luminaires
	ER	=	electric energy rate (in \$/kWh)
	DS_{Total}	=	the sum of energy demand savings for all sets of luminaires
	DR	=	electric demand rate (in \$/kW).

2.9 Operations and Maintenance and Other Cost Savings

Operations and maintenance and related savings are determined separately from energy savings. These savings can involve many variables, including

- lamp replacement policy – replacement on failure vs. group lamp replacement
- control calibration and maintenance/repair requirements
- lighting system cleaning policy
- labor hourly rates and daily output values or similar contracted lighting maintenance/cleaning cost structures.

Often, these developed savings can be part of an overall evaluation of project viability. In other cases, these savings are not considered for programmatic or conservative analysis reasons. Because of the wide variety of characteristics, applications, and policy approaches associated with the variables involved, a full treatment of costing these potential savings is not provided in this document. Spreadsheet and other format systems and methodologies for calculation of these savings may be available from lighting manufacturers and distributers or other sources online.

2.10 Post-Installation Measurement and Verification Activities

Upon completion of the retrofit installation, an as-built inventory of post-installation lighting fixtures should be supplied to building owners and/or operators. The inventory should include the lighting drivers/ballasts and lamps actually installed, as well as the lighting illumination levels (footcandles) in the areas specified.

Once per year, a minimum of 10% of the installation should be inspected to ensure that it is operating as installed and commissioned, and that it continues to have the potential to generate the expected savings. This inspection should include measurements of horizontal light levels (illuminance) at a minimum and, where practical, energy consumption. Discrepancies in equipment function and or performance should be documented, and contract arrangements reviewed to determine appropriate contractual responsibilities.

Appendix A

Additional Guidance on the Accurate and Repeatable Measurement of Illuminance

Appendix A

Additional Guidance on the Accurate and Repeatable Measurement of Illuminance

Accurate and repeatable illuminance measurements can be influenced by many factors, including characteristics of the measurement instrumentation as well as the setup and execution of the actual measurements. This appendix provides detailed guidance on two major areas that require special consideration: measurement accuracy at low light levels and test site obstructions.

A.1 Measurement Accuracy at Low Light Levels

Low light levels create particular accuracy and comparability problems for measurements taken using standard field light measurement equipment. This is due, in part, to the typical variability among sensors and measurement electronics, which may produce different readings of the same lighting source. Ambient temperatures can also affect illuminance readings by up to 1% per 10°C and typically 3% over the equipment operating illuminance range. These effects can occur during any measurement but are most noticeable with low light levels, where small actual differences can represent a large percentage difference.

To reduce the effects of meter accuracy and differences in sensors, the following practices should be considered:

- Use a meter with the highest overall accuracy possible that meets the specifications in Table 2.1 (Examples of Instrumentation Specifications).
- Set the meter to the lowest available measurement range if not auto-adjusted.
- Use the same meter—or at least the same make and model of meter—for pre and post measurements as well as measurements between sites, to ensure comparability of readings.
- Where possible, avoid extreme temperatures (toward the limits of the meter's stated operating temperature range). If extreme temperatures cannot be avoided, ensure that similar temperatures exist for pre and post measurements.

The test setup for the measurements (including handling of the meter) will also affect readings—particularly at low light levels. Careful test setup and measurement procedures can reduce potential variances from the handling and placement of the meter. When multiple measurements are taken and averages calculated for comparisons, minor variations in placement of the meter should have minimal effect. However, in critical areas such as perimeters and special areas where fewer measurements are taken and/or perimeter conditions are being verified, the measurement placement will be important.

To reduce the effects of test setup and meter handling, follow these guidelines:

- Ensure that critical measurement locations are marked and easily identifiable (e.g., "X" or small dot) such that the centerpoint of the identifying mark can be accessed for each measurement.

- Ensure that the sensor head is placed parallel to the horizontal or vertical task plane (typically the paved surface or ground for horizontal exterior measurement). Many exterior surfaces are not perfectly flat, and placing the sensor in a slightly different location can tilt the sensor and produce a potentially large difference in reading. For rough surfaces, it is recommended that the sensor head be placed on a platform (e.g., a 12-in. × 12-in. square of plywood) to eliminate the effect of small surface differences on the small meter head. When using a platform, it is suggested that the sensor head be attached at the edge of the platform so that it can be more easily centered over the measurement location mark.
- For vertical measurements, a tripod is recommended to provide consistent height and angle of orientation. With particularly rough locations, a leveling bubble may be needed to ensure that the apparatus is level to the ground and that the meter head is vertical. Placing the tripod on a platform (e.g., a 3-ft × 3-ft square of plywood) may also reduce this error.
- Ensure that all measurements are made with no obstructions blocking the direct light from surrounding luminaires. Also ensure that objects such as cars and persons are not close enough to the measurement point to reflect light onto the sensor head. For this same reason, dark clothing is recommended when taking exterior nighttime measurements. However, a reflective vest may be necessary for safety.
- For exterior areas, ensure that measurements are not affected by sources of ambient light that are not part of the typical operating conditions, which could include any of the following:
  - daylight – Take measurements well after sunset; even a modest amount of daylight on the horizon can effect the measurements.
  - temporary construction lighting
  - vehicle lights
  - lighting for neighboring structures – For neighboring lighting controlled by occupancy sensors, conduct all measurements while this lighting is off. For neighboring lighting on timer controls, take all measurements either with or without this lighting.

A.2 Test Site Obstructions

Basic considerations for avoiding obstruction of the light to be measured are covered in the measurement section of this document (Section 2.5). However, additional issues that may not be obvious or clear are discussed here. Obstructions include both objects that block the light being measured and objects that reflect unwanted light. When preparing to take light measurements at a site, it is important to identify permanent obstructions that should not be adjusted or moved. However, temporary obstructions should be moved to create repeatable site configuration for light measurements. When future measurements are taken, temporary obstructions should again be moved to replicate the original site configuration.

In some cases, semi-permanent or permanent obstructions are added between sets of measurements. In these cases, the obstructions should be evaluated to determine actual effect on readings and action taken where possible. Examples are detailed here:

- temporary piles of material, plants, and desk objects – If objects are near the test point, temporarily move them to take the measurement. To minimize these issues, test points should be located away from partitions and other nearby surfaces where materials might accumulate.
- overhead signage and banners – Hanging interior signs and exterior pole banners are often added to locations as general improvements or for holiday events. If these will block the light for a reading, they should be removed if practical; otherwise, their presence should be noted.

Obstructions can also cause unwanted reflection of lighting that will affect the readings. In many cases, objects both reflect and obstruct light. As described above, these objects should be moved if possible. Some temporary or newly installed objects (between sets of readings) may not obstruct light but may reflect it into the sensor's field of view. These might include

- vehicles
- pedestrians
- material stockpiles
- temporary furniture
- added wall treatments such as whiteboards.

When these are encountered and are considered detrimental to light measurements, removal is preferred. Vehicles, pedestrians, and furniture are easily removed; however, more permanent items such as whiteboards may not be. In such cases, the location of the item relative to the test point should be noted. Photographs of the initial site conditions are useful for identifying changes for subsequent sets of measurements.

Appendix B

Sample Measurement Point Layouts

Appendix B

Sample Measurement Point Layouts

The following figures provide sample layouts for selecting horizontal measurement points for typical areas where lighting measurements are taken.

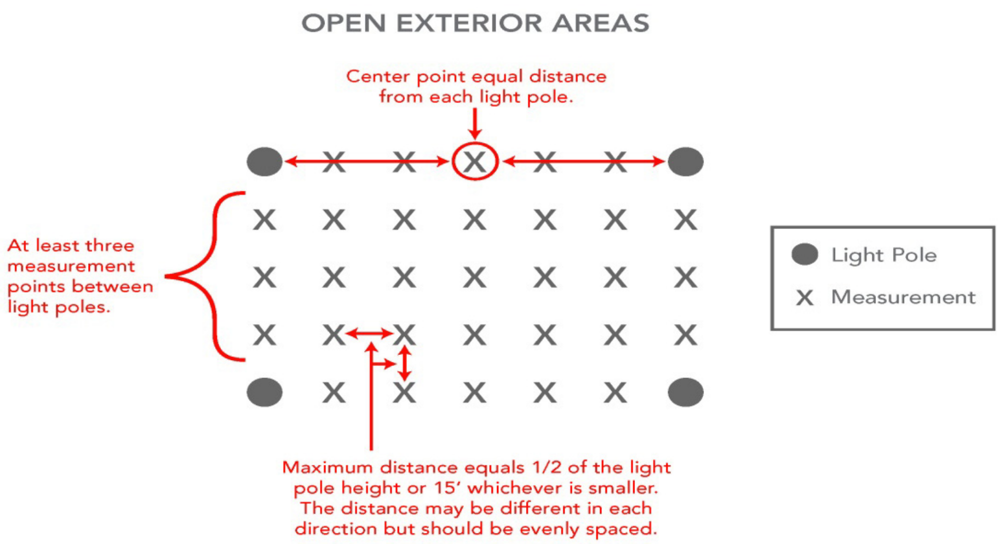

Figure B.1. Open Exterior Areas such as Parking Lots or Storage Yards

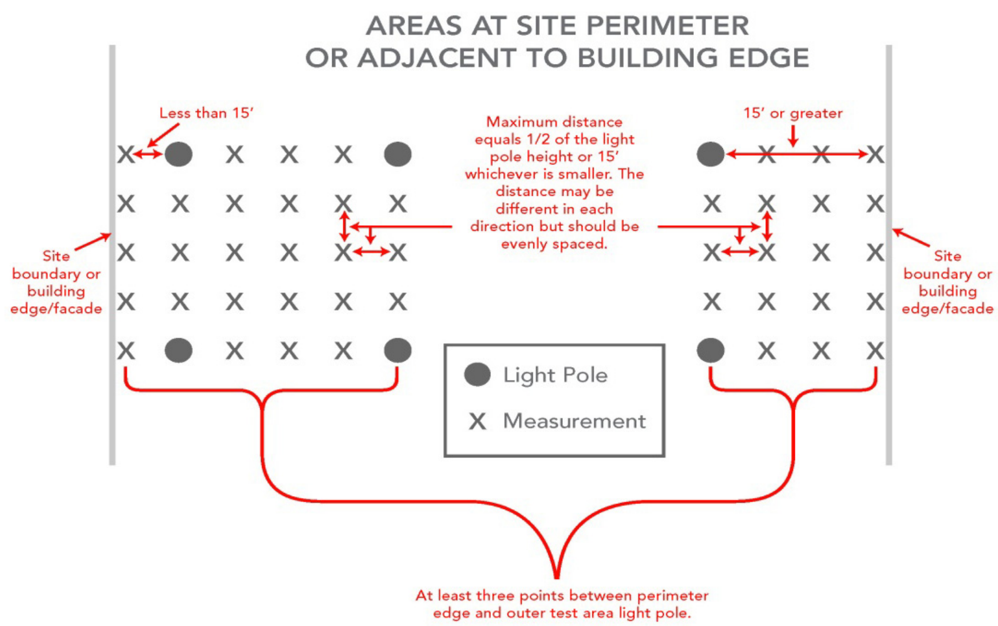

Figure B.2. Site Perimeter or Adjacent to Building Areas

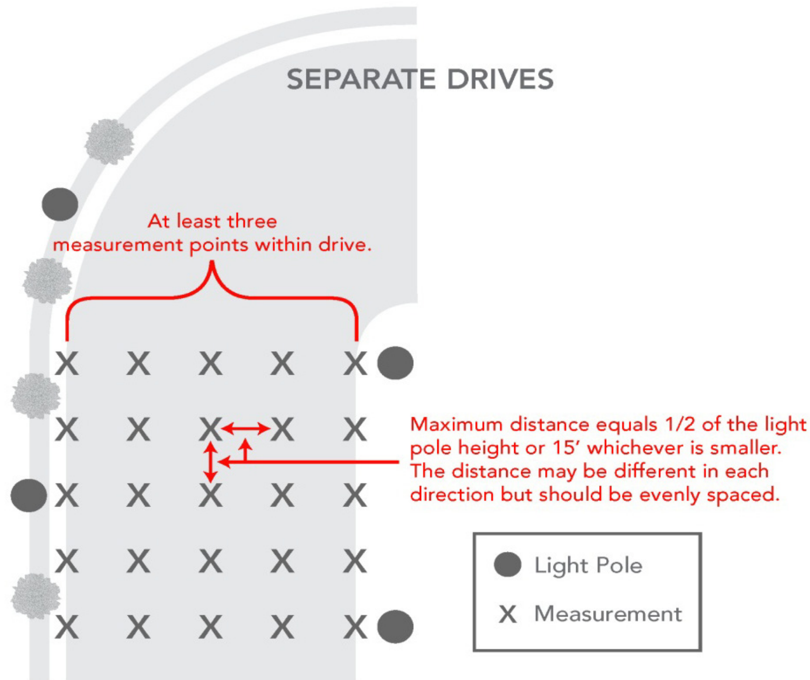

Figure B.3. Separate or Main Entry Drives

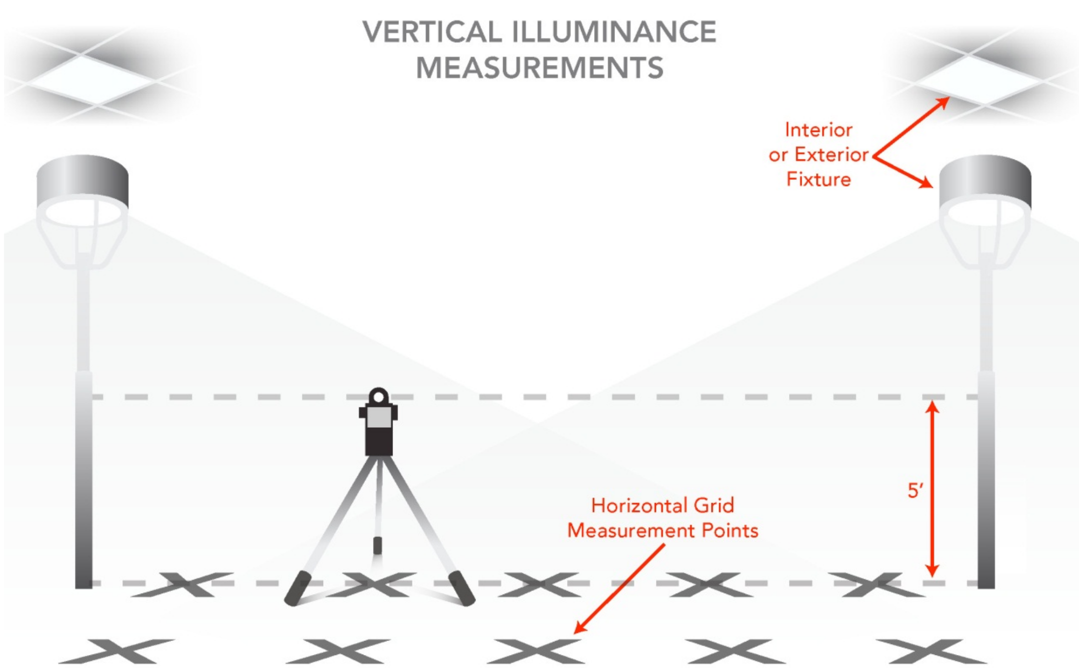

Figure B.4. Typical Vertical Measurements. Exterior application shown. Use a similar approach for interior applications with points along a horizontal gridline between fixtures and taken directly above the horizontal grid point at 5 feet above the floor.

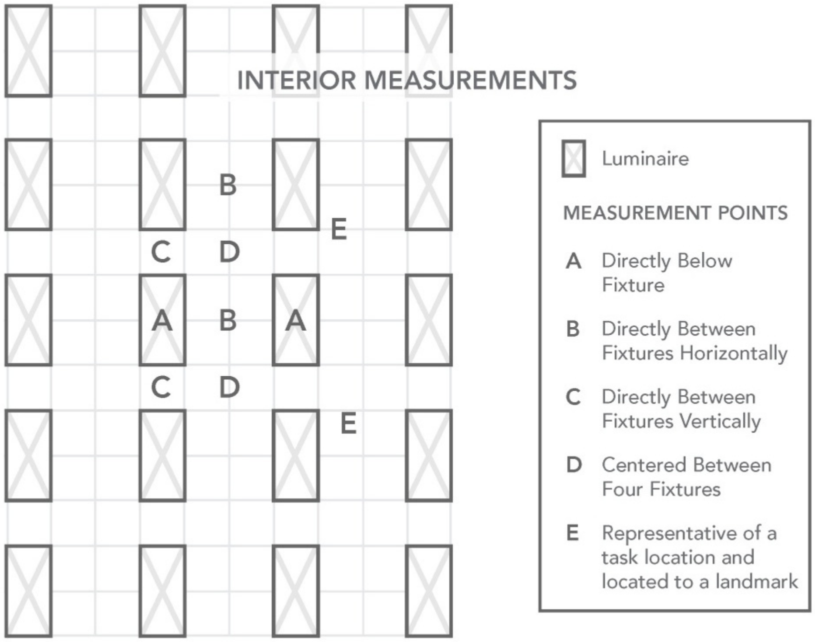

Figure B.5. Typical Interior Measurements

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