Measurement and Verification Operational Guide

Lighting Applications

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ISBN 978 1 74293 961 2
OEH 2012/0995
December 2012

Printed on environmentally sustainable paper

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1 Your guide to successful M&V projects

The Measurement and Verification (M&V) Operational Guide has been developed to help **M&V practitioners, business energy savings project managers, government energy efficiency program managers and policy makers** translate M&V theory into successful M&V projects.

By following this guide you will be implementing the International Performance Measurement and Verification Protocol (IPMVP) across a typical M&V process. Practical tips, tools and scenario examples are provided to assist with decision making, planning, measuring, analysing and reporting outcomes.

But what is M&V exactly?

M&V is the process of using measurement to reliably determine actual savings for energy, demand, cost and greenhouse gases within a site by an **Energy Conservation Measure** (ECM). Measurements are used to verify savings, rather than applying deemed savings or theoretical engineering calculations, which are based on previous studies, manufacturer-provided information or other indirect data. Savings are determined by comparing post-retrofit performance against a 'business as usual' forecast.

Across Australia the use of M&V has been growing, driven by business and as a requirement in government funding and financing programs. M&V enables:

- calculation of savings for projects that have high uncertainty or highly variable characteristics
- verification of installed performance against manufacturer claims
- a verified result which can be stated with confidence and can prove return on investment
- demonstration of performance where a financial incentive or penalty is involved
- effective management of energy costs
- the building of robust business cases to promote successful outcomes

In essence, Measurement and Verification is intended to answer the question, "how can I be sure I'm really saving money?[1]"

1.1 Using the M&V Operational Guide

The M&V Operational Guide is structured in three main parts; Process, Planning and Applications.

Process Guide: The *Process Guide* provides guidance that is common across all M&V projects. Practitioners new to M&V should start with the *Process Guide* to gain an understanding of M&V theory, principles, terminology and the overall process.

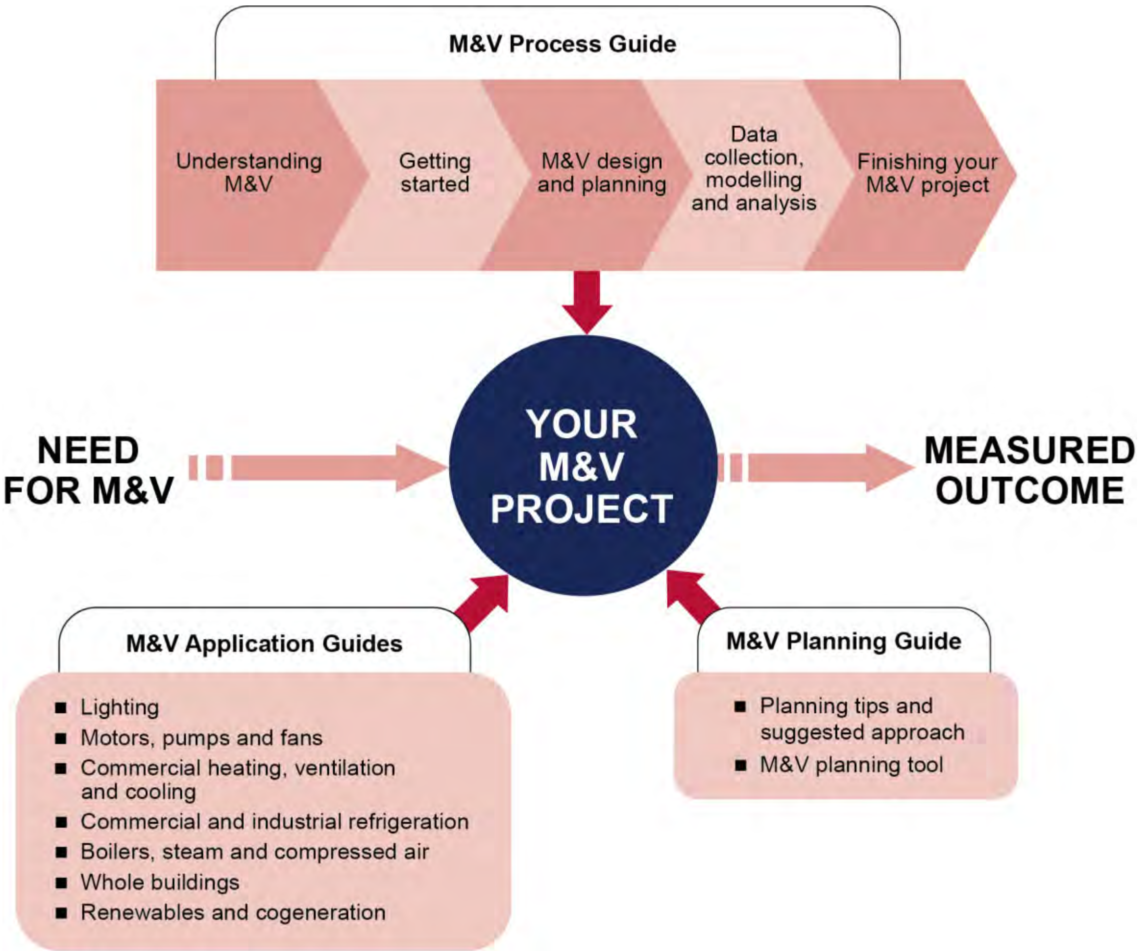
Planning Guide: The *Planning Guide* is designed to assist both new and experienced practitioners to develop a robust M&V Plan for your energy savings project, using a step-by-step process for designing a M&V project. A Microsoft Excel tool is also available to assist practitioners to capture the key components for a successful M&V Plan.

Applications Guides: Seven separate application-specific guides provide new and experienced M&V practitioners with advice, considerations and examples for technologies found in typical commercial and industrial sites. The *Applications Guides* should be used in conjunction with the *Planning Guide* to understand application-specific considerations and design choices. *Application Guides* are available for:

[1] Source: www.energymanagementworld.org

- Lighting
- Motors, pumps and fans
- Commercial heating, ventilation and cooling
- Commercial and industrial refrigeration
- Boilers, steam and compressed air
- Whole buildings
- Renewables and cogeneration

Figure 1: M&V Operational Guide structure



1.2 The Lighting Applications Guide (this guide)

The *Lighting Applications Guide* provides specific guidance for conducting M&V for lighting projects. It is designed to be used in conjunction with the *Process Guide*, providing tips, suggestions and examples specific to lighting projects.

The *Lighting Applications Guide* is presented as follows:

▪ Understanding M&V concepts	Section 2 presents a high level diagram of the best practise M&V process.
▪ Getting started	Section 3 provides a discussion on key things that need to be considered when getting your M&V project started.
▪ M&V design and planning	Section 4 provides guidance on how to design and plan your lighting M&V project and key considerations, potential issues and suggested approaches.
▪ Data collection, modelling and analysis	Section 5 provides guidance on data collection, modelling and analysis for your lighting M&V project.
▪ Finish	Section 6 provides a discussion on reporting M&V outcomes, ongoing M&V and ensuring savings persist over time.
▪ References to examples of M&V projects	Section 7 provides a reference list of example projects located within the IPMVP and throughout this guide.
▪ Example lighting scenario A	Appendix A illustrates the M&V process by assessing a lighting fixture replacement within an office tenancy.
▪ Example lighting scenario B	Appendix B illustrates the M&V process within a lighting fixture and control upgrade at a function centre
▪ Example lighting scenario C	Appendix C illustrates the M&V process using a worked example involving a lighting fixture retrofit incorporating daylight control.

2 Understanding M&V concepts

2.1 Introducing key M&V terms

The terms listed in Table 1 below are used throughout this guide and are introduced here to assist with initial understanding. Refer to Section 4 within the *Process Guide* for a full definition and explanation.

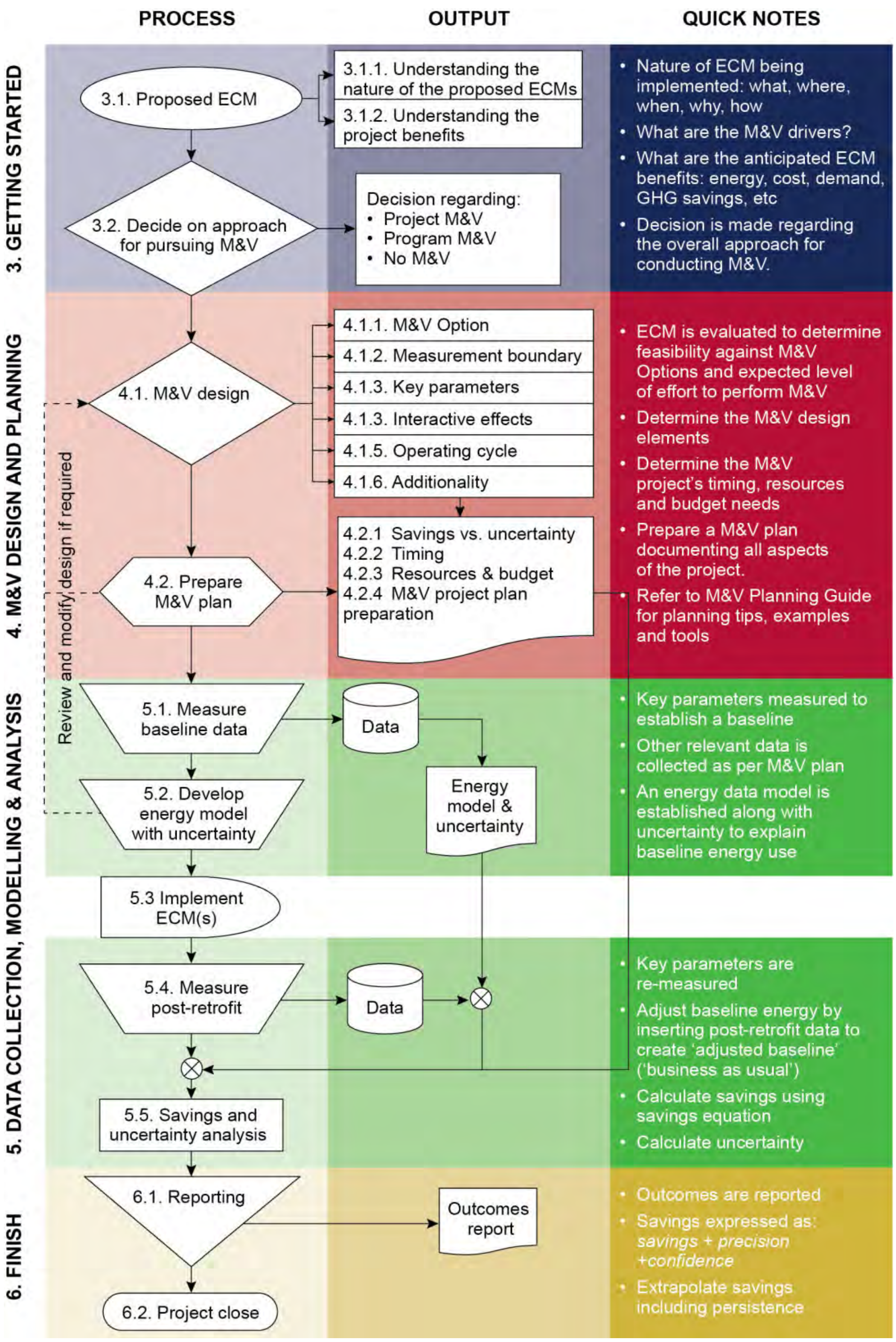
Table 1: Key M&V terms

M&V Term	Definition	Examples
Measurement boundary	A notional boundary that defines the physical scope of a M&V project. The effects of an ECM are determined at this boundary.	Whole facility, sub facility, lighting circuit, mechanical plant room, switchboard, individual plant and equipment etc.
Energy use	Energy used within the measurement boundary.	Electricity, natural gas, LPG, transport fuels, etc
Key parameters	Data sources relating to energy use and independent variables that are measured or estimated which form the basis for savings calculations.	Instantaneous power draw, metered energy use, efficiency, operating hours, temperature, humidity, performance output etc.
M&V Options	Four generic approaches for conducting M&V which are defined within the IPMVP.	These are known as Options A, B, C and D.
Routine adjustments	Routine adjustments to energy use that are calculated based on analysis of energy use in relation to independent variables.	Energy use may be routinely adjusted based on independent variables such as ambient temperature, humidity, occupancy, business hours, production levels, etc.
Non routine adjustments	Once-off or infrequent changes in energy use or demand that occur due to changes in static factors	Energy use may be non routinely adjusted based on static factors such as changes to building size, facade, installed equipment, vacancy, etc. Unanticipated events can also temporarily or permanently affect energy use. Examples include natural events such as fire, flood, drought or other events such as equipment failure, etc.
Interactive effects	Changes in energy use resulting from an ECM which will occur outside our defined measurement boundary.	Changes to the HVAC heat load through lighting efficiency upgrades, interactive effects on downstream systems due to changes in motor speed/pressure/flow, etc.
Performance	Output performance affected by the ECM.	System/equipment output (e.g. compressed air), comfort conditions, production, light levels, etc.

2.2 Best practise M&V process

The following figure presents the best practise M&V process which is reflected in the structure of *Lighting Applications Guide*. Refer to the *Process Guide* for detailed guidance on the M&V processes.

Figure 2: Best practise M&V process with references to M&V Process Guide



3 Getting started

3.1 Proposed lighting ECM(s)

3.1.1 Lighting projects

Lighting Energy Conservation Measures (ECMs) aim to reduce lighting demand and/or energy use through:

1. reducing power draw by:
   a. installing/retrofitting existing lighting systems with more energy efficient fixtures, lamps or ballasts
   b. removing unnecessary fixtures and/or lamps
   c. reducing supply voltage
2. introducing or adjusting lighting controls to limit operating times
3. combinations of 1 and 2 above.

3.1.2 Key points to note

When considering M&V, it is important to understand the nature of the site and proposed ECM(s) (what, where, when, why, how much) and the project benefits (e.g. energy, demand, greenhouse gas and cost savings). Key points to note when getting started are:

- All options are available, however typically, lighting projects use M&V Option A or B, which treat the project in isolation, thus avoiding the need to deal with the effects of other systems.
- Identify independent variables that may affect before and after comparison including changing operating hours/patterns, seasonality, human behaviour.
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.
- The length of measurement is determined by the operating cycle of the energy system, chosen option, and the desired level of uncertainty.

Section 4.2 provides detailed information on other M&V considerations for lighting projects.

3.2 Decide approach for pursuing M&V

Once the nature of the M&V project is scoped and the benefits assessed, the form of the M&V can be determined. Decide which M&V approach you wish to pursue:

1. Conduct project-level M&V.
2. Conduct program-level M&V using a sample based approach incorporating project level M&V supplemented with evaluation within the program ‘population’.
3. Adopt a non-M&V approach in which savings are estimated, or nothing is done.

4 M&V design and planning

4.1 M&V design

4.1.1 M&V Option

Use the matrix below to assist with identifying your project's key measurement parameters and guidance on choosing the appropriate M&V Option.

Table 2: Guidance on choosing the appropriate M&V Option

Typical projects	**M&V Option**	**Key parameters**		
		To measure	**To estimate or stipulate**	**To consider**
Changes in power draw: ▪ Fixture replacement or retrofit (e.g. upgrade to T5 fluorescents, induction lighting or LEDs) ▪ Lamp replacement (compact fluoro for incandescent, LED for dichroic replacement, downsizing lamp wattage) ▪ Removing excess lamps/fixtures (delamping) ▪ Voltage reduction/optimisation units	**OPTION A**	Changes in power draw	Operating hours Interactive effects	Lighting levels Interactive effects
Changes to lighting controls: ▪ Photovoltaic control (daylight control) ▪ Movement detectors ▪ Manual switching ▪ 'Auto-Off' master switching/reset or BMS control		Operating hours	Changes in power draw Interactive effects	Lighting levels Interactive effects
Combination of lighting control and lighting efficiency initiatives above		Measure the parameter with the biggest impact or uncertainty on the accuracy of the outcome. **If both are unknown or uncertain, then Option A cannot be used.** Choose between changes in power draw and Operating hours	Estimate or stipulate the remaining key parameters, including: ▪ Changes in power draw ▪ Operating hours ▪ Interactive effects	

Typical projects	M&V Option	Key parameters		
		To measure	**To estimate or stipulate**	**To consider**
All lighting project types	OPTION B	Operating hours and Changes in power draw	Interactive effects	Lighting levels Interactive effects
	OPTION C	Metered energy use	Non-routine adjustments	All independent variables within the measurement boundary, including those from other energy systems
Projects with no metered baseline	OPTION D	Post-retrofit *operating hours* and *power draw* (In this case baseline parameters cannot be measured, and so both must be post-retrofit and used to recalibrate the developed baseline model	Non-routine adjustments	All independent variables within the measurement boundary, including those from other energy systems

4.1.2 Measurement boundary

For M&V Option A or B, this is the part(s) of the lighting system affected by the project.

- For complex projects, the lighting system may be divided into functional areas or sections (sub-projects), where differing initiatives or operating patterns can be assessed individually.
- Similarly, for ease, the measurement boundary can be:
  - divided into sections (sub-projects), or
  - expanded to include non-lighting loads (e.g. connected power) if power draws, usage patterns and independent variables can be ascertained.

For Option C, this is typically the whole facility, or a large segment covered by a utility meter or sub-meter.

- Using Option C may result in reduced data collection cost. However the boundary covered by the meter usually includes additional loads, which may introduce undue data analysis complexity.
- In addition, the predicted savings from the lighting project should be 10% or more of the total meter usage, in order to use Option C.

Option D may be considered in the following situations:

- New building design – evaluating the difference between average efficiency and high efficiency designs
- Retrofit in the absence of a measured baseline.

4.1.3 Key parameters

The table below lists the key parameters to be considered when conducting M&V for a lighting efficiency project.

Table 3: Key parameters to be considered when conducting M&V for lighting projects

Parameter	Description
Power draw	This comprises the fixtures, including lamps, ballasts, controls, transformers within the lighting system. A fundamental component of lighting efficiency projects is reducing the power draw. Through retrofit, components may be added or removed, and therefore it is important that the measurement boundary and point of measurement are defined to include all components, before and after the project. For lighting efficiency retrofit projects, the change in power draw is a key parameter to measure. For simplified M&V within lighting control projects, power draw may be assumed to be unchanged (constant). Power draw is usually expressed in watts (W) for individual fixtures or components, and kilowatts (kW) for entire circuits, systems or projects.
Operating hours	This is simply the amount of time during which the lighting system operates. Whether estimated or measured, they are an important factor to consider for each area within a site. Operating hours may be controlled manually by staff, or through the use of automated controls that are responsive to ambient light, movement, time clocks, etc. Operating hours are dictated by the installed controls and subsequent operating patterns of the lighting system, which are influenced by one or more of the following: ▪ Lighting type – general office, emergency/security, decorative or task lighting ▪ Site occupancy times – business hours, 24/7 operation, seasonality, public holidays ▪ Segmentation of circuits / ‘down the line’ switching ▪ Type, placement and use of controls ▪ Seasonality – changes in daylight times ▪ People movement (manual or movement based controls) ▪ Staff culture and behaviour. For lighting control projects, the change in operating hours is a key parameter to measure. For simplified M&V within lighting efficiency retrofit projects, operating hours may be assumed constant, depending on their variability and associated uncertainty.

4.1.4 Interactive effects

Lighting projects typically have a well defined measurement boundary with few or negligible *interactive effects.* Verifying projects is usually a straightforward M&V exercise, utilising Option A or B with relatively short-term measurements. Option C is available for large-scale lighting projects.

The main interactive effect typically encountered with lighting projects is due to reduce heat loads of light fittings which may reduce cooling demand and increase heating demand.

4.1.5 Operating cycle

The length of measurement is determined by the operating cycle of the energy system(s), chosen Option, and the desired level of accuracy. The table below outlines the suggested measurement timeframes for baseline and post-retrofit periods.

Table 4: Suggested measurement timeframes for baseline and post retrofit periods

Option	Measured parameter		
	Power draw	Metered energy use	Operating hours
A (power draw is key)	Short/instantaneous power draw during relevant time periods	Not required unless load varies, then between one week and one month	
A (operating hours is key)			Typically between one week and one month or periodic. Repeat periodically if seasonality is an issue (e.g. school terms)
B	Short/instantaneous power draw during relevant time periods	Typically between one week and one month	Typically between one week and one month or periodic. Repeat periodically if seasonality is an issue (e.g. school terms)
C		At least one site operation 'cycle', that includes changes in other energy systems. For example, 12 months baseline data is required where seasonality is a factor. Typically require at least three months of post-retrofit data	At least one site operation 'cycle', that includes changes in other energy systems. For example, 12 months baseline data is required where seasonality is a factor. Typically require three months of post-retrofit data
D	For the baseline typically one site operation 'cycle' is modelled. *Operating hours* is the key parameter in this scenario, and so short-term electrical measurement is sufficient.	For the baseline typically one site operation 'cycle' is modelled. *Operating hours* is the key parameter in this scenario, and so short-term electrical measurement is sufficient.	For the baseline typically one site operation 'cycle' is modelled. Within a lighting project, a 'cycle' is typically two weeks or more. Post-retrofit measurements are used to re-calibrate the baseline model, and so both *operating hours* and *power draw* must be measured.

The following table may also provide guidance for planning the length of measurement using Option B in the following building types:

Table 5: Suggested measurement period for selected building types[2]

Building Type	Measurement Period
Retail	Three weeks
Office	Three weeks
Schools with reduced or no summer occupancy[3]	Four weeks (two weeks in session and two weeks out of session)
Year-round schools	Three weeks
Hospital	Three weeks
Industries with constant production	Three weeks
Industries with seasonal production*	Four to eight weeks (two weeks each season with a change in operating hours)

4.1.6 Additionality

Savings determined from multiple ECM projects may not be mutually exclusive. In other words, the combined savings of multiple ECMs implemented together will be less than the sum of the individual savings from ECMs if implemented in isolation from each other.

Below lists the suggested approaches to managing additionality which are described in detail in the *Process Guide*:

1. Adjust to isolate
2. 'Black box' approach
3. Ordered summation of remainders

4.2 Prepare M&V plan

The next step of the M&V process is to prepare an M&V plan which is based on the M&V design and the time, resources and budget necessary to complete the M&V project.

Refer to the *Process Guide* and the *Planning Guide* for further guidance on preparing an M&V plan.

The table below outlines issues commonly found when conducting M&V on lighting projects and provides suggested approaches for addressing them in your M&V plan and when executing the M&V project.

[2] source: San Diego Gas and Electric – Measurement and Verification

[3] seasonal variation in operating hours of fixtures

Table 6: Considerations, issues and suggested approach for lighting projects

Consideration	Issue	Suggested Approach
Mixed usage measured by a meter or within a circuit	The chosen measurement point (circuits, distribution board, installed electrical meter, etc) encompasses both lighting and additional power loads. Initially this situation presents barriers to conducting M&V using the chosen measurement point. *For example: this may arise when attempting to measure load across a whole distribution board, containing light and power.*	Determine if the metering point will result in the capture of additional loads. One way to do this is to review available 'circuit charts', which describe the loads on each circuit. Evaluate the additional loads to determine if they are variable and/or can be predicted. If the additional load is predictable, then its effects can be ignored – apart from calculating percentage savings. If the load varies, then depending on the relative cost and effort, it may be easier to: a. conduct measurements at a suitable number of individual lighting fixtures within the project and extrapolate b. expand the measurement boundary to include the foreign loads and allow for any additional independent variables that impact their energy use c. conduct measurements on the foreign loads, and then subtract from the whole circuit to determine the load within the measurement boundary.
Mixed use and controls	The M&V boundary includes areas (circuits, rooms, functional areas) that may have different operating patterns and controls. *For example: an office tenancy is fed from a single lighting circuit, and contains both open-plan office space and meeting rooms. Individual rooms have local switches.*	The various areas should be identified in the M&V plan, along with a strategy for incorporating the variability in operating patterns. Depending on the option chosen, this may involve: a. reviewing the measurement strategy to identify ways to calculate operating hours (e.g. review load profiles) b. changing the measurement strategy to make operating hours the key parameter (i.e. Option A where load is key parameter) c. changing to Option B and measure both load and operating hours. d. conducting additional measurement aligned with functional areas (Option A or B where operating hours is measured) e. estimating operating hours more accurately for each area (e.g. Option A where load is key parameter), by referencing available information such as equipment control settings, behaviour patterns, and contextual information (e.g. sunrise/sunset times).
Mixed fittings	The lighting project involves a mix of changes to the power draw due to the range of fittings installed before and after.	Two approaches are: a. simply, to treat the mix of changes as a 'black box' and conduct measurements at the boundary b. to categorise the types of changes, and conduct sample-based measurement for each case, then extrapolate to the number of fixtures within the project.

Consideration	Issue	Suggested Approach
Rewiring	The lighting project includes major changes to circuits and wiring. *For example: during a building lighting upgrade, the number of circuits used within the measurement boundary was reduced from 10 to 8. The remaining 2 were used for new lighting to be installed in an adjoining area.*	The circuits are a proxy for functional spaces, and rewiring complicates the task of measuring 'like-for-like' to directly determine project savings on a circuit basis. It is important to understand the fixtures attached to each circuit (before and after), and then: a. plan where measurements are conducted to minimise effects (e.g. measure rooms or fixtures rather than circuits) b. use post-measurement data analysis to align before and after, generally by combining measured areas to the point where 'like-for-like' is achieved. This may only occur at the project boundary.
Power factor	Potential changes in power factor, which might affect demand and thus cost savings. *For example: incandescent lamps have a power factor of 1, linear fluorescents are typically around 0.95 whilst compact fluorescents can be as low as 0.5.*	Technology retrofits may affect the power factor within the M&V boundary, which may impact demand savings. The proposed approach is: 1. Estimate the power factor before and after the retrofit by conducting measurements or reviewing equipment specifications. If the change is minor, then its affects can be ignored. If the change is material, then: 2. Determine if the change in power factor is likely to affect overall site maximum demand (if this is an energy cost item). *Does the lighting system operate at peak demand times?* *Will an existing power factor correction unit negate this issue?* 3. If maximum demand is affected, then apply the appropriate demand cost rates to calculate the financial impact.
Lighting levels	The lighting project results in changes to the observed lighting levels. Examples include installing skylights, delamping, fixture replacement, dimming.	Managing the impact of changes to lighting levels is important within lighting projects. Some projects specifically target excess lighting, and savings are directly attributable to reductions in lighting levels. With other projects, reduced or improved lighting levels are a side effect. The key requirement is that the resulting outcome is fit for purpose and meets customer needs and regulatory standards. If lighting levels are impacted as a result of an ECM, it is important that budget is allocated to measure and calculate the new lighting levels and ensure the relevant Australian standards are met. If these conditions have been met, then minor changes in lighting levels can be ignored, apart from noting the changes.

Consideration	Issue	Suggested Approach
Interactive effects of heat	Lighting operation produces both light and heat. Higher efficiency lighting fixtures produce higher amounts of light output per input watt, and lower amounts of heat.	In office environments, the lower heat output resulting from a control or efficiency project may have an *interactive effect* with the building air conditioning system. This may have a positive effect where cooling is required, or a negative effect where heating is required. Changes in heat output should be considered within M&V of lighting projects. Typically these changes are considered minor and are ignored; however the effects should at least be estimated to determine their impact. Estimate the amount of heat created by the lighting system, and apply a 'coefficient of performance' to convert that into the electrical load required to remove that heat by an air conditioning system.
Persistence and extrapolation	The savings calculated from short-term measurements often extrapolated to 'estimate' annual project savings. It is important to incorporate additional factors, which may include: ▪ reliance on human behaviour ▪ seasonal effects (daylight savings, holidays, etc) ▪ calibration changes/failures ▪ likelihood of future changes within measurement boundary.	When extrapolating the savings verified during the post-retrofit period to estimate annual savings, it is important to identify influencing factors and assess their impact. If minor, they can be ignored. If material, the M&V plan should document how they are to be addressed. Examples include: a. repeating M&V at various times throughout the year b. collecting appropriate data (such as site closure dates and public holidays) and adjusting accordingly c. combining short-term measurement of load with more periodic measurement of control (e.g. human behaviour) d. occasional spot measurements to verify assumptions.

5 Data collection, modelling and analysis

5.1 Measure baseline data

5.1.1 Determine existing lighting inventory

If not already done, catalogue the baseline lighting inventory, including:

- Number of lamps and fixtures
- Type of ballast in fluorescent lamps
- Operation times
- Controls, such as sensor or time switches, dual switching
- Areas under common circuits
- The number of burnt-out or de-lamped fittings.

5.1.2 Measurement data sources, measurement tools and techniques

The following provides guidance on measurement and data collection:

- Conduct the baseline measurement in line with the prepared M&V plan.
- Ensure appropriate records are kept including the placement of measuring equipment.
- Collect any associated data required for calculating baseline energy use or adjustments for independent variables.
- Measurement should consider period demand and, where applicable, measurement should be made during any and all relevant demand periods.
- Measurement should include only lighting fixtures. Circuits with non-lighting loads should be avoided or accounted for in the measurement.

The following sources may be used to provide data as input to an M&V exercise:

Table 7: Potential M&V data sources

Data Type	Source	Comments
Power draw	Instantaneous measurement using true rms power meter, or by separately measuring voltage, current and power factor	Appropriate for Option A where hours are estimated. Use calibrated equipment and measure instantaneous power in order to evaluate energy and demand savings.
	Manufacturers' product specifications	Can be used when power draw is estimated (as it is not being measured).
Energy usage	Utility bills	Typical frequency of one to three months. Can be used for Option C, and are considered 100% accurate, when not estimated by the supplier.
	Revenue meter – interval data	Typically 30 minute data intervals, which can be used to accurately calculate savings across a day, week or longer. Can also be used to estimate operating hours based on profile changes. Data provided by a Meter Data Agent is used for billing and is considered 100% accurate.
	Permanent sub-meter – interval data	Similar characteristics to the revenue meter above. Data quality will be high, but may not be revenue quality. Data should be reviewed for

Data Type	Source	Comments
		meter 'drop outs'.
Energy usage	Temporary energy logger	Similar to a sub-meter, an energy data logger is connected to a circuit and acts as a temporary meter. Data quality depends on the quality, range and an accuracy of the logger and associated CTs. Some units experience difficulties capturing large changes in loads. Be careful to size the CTs for the load to be measured. A tong reading will assist with sizing, however all operating loads should be considered.
	Manual meter readings (e.g. hourly/daily)	Periodic manual readings of a revenue/sub-meter. Take care to read the meter in the correct way and apply any meter multiplier 'k factor' to the values if stated on the meter. Contact the electricity supplier if unsure how to read the meter.
Operating hours	Security system records (access swipe cards)	Time stamped records may be available from security systems, which may assist with tracking occupancy and operating patterns.
	Occupancy and light logger	Typically small, a battery operated unit which measures the amount of time a person is in the area, and the amount of time the lights are on. The unit is unobtrusive and can be left on a desk. Be careful to appropriately adjust the light sensitivity.
	Lighting control schedules/settings (e.g. time clocks, building management systems, run on time settings)	Fixed or logic based time schedules that are in place for the lighting system. This simply involves interrogating the lighting control equipment to extract the operating schedules.
	Timed observations	Manual readings taken periodically to approximate the occupancy or an area or control patterns for a lighting circuit. This is time intensive, but may be achieved using a data log sheet filled in by various staff as they come and go.
	Sunrise/sunset times from Bureau of Meteorology	Historical weather data including sunrise and sunset times are available from the Bureau of Meteorology, and may be used to estimate operating hours for lighting controlled by photo electric sensors.
	Light level meter/sensor	A light level sensor may be used to record ambient light levels for projects where photo electric sensors are involved.
	Business hours of operation schedules	Published business schedules, such as stated hours of operation, including public holidays or non-occupancy periods.
	Discussions with staff/custodians	In conjunction with business schedules, staff may provide a more realistic estimate of operating hours, which may include after-hours occupancy and cleaning schedules.

5.1.3 Conducting measurements

Electrical measurements can be conducted in a variety of ways as per the table below.

Table 8: Methods for conducting electrical measurements

Technique	Placement	Guidance
Direct measurement of whole measurement boundary	Energy meter or data logger that covers all energy use within the measurement boundary	This provides highly accurate project measurements.
Various direct measurements at selected switches or circuits	Energy meter or data logger connected to relevant switches/circuits	This approach may be necessary for large, complex or distributed projects. Logging selected switches/circuits enables different functional areas to be segregated and savings can be calculated separately and in aggregate. Consistent results may be extrapolated across the project.
Direct measurement using a sample based approach using selected fixtures	Temporary data logger (for energy use) or instantaneous power meter (for power draw) measures selected fixtures	Measuring instantaneous power load for mixtures before and after retrofit may be very cost effective. A wide range of samples should be taken to minimise uncertainty. It is important that the number of fixtures involved (before and after) is known to correctly calculate savings. This may be supplemented with measurements elsewhere within the project to ensure all system losses are captured.

Should a meter or logger be placed where it covers several areas with different operating patterns, then an instantaneous 'load test' could be conducted where each area is operated separately to determine the power draw, from which the relevant operating hours could be applied. Measurements for operating hours can be conducted as per the following table.

Table 9: Methods for conducting measurements of operating hours

Technique	Placement	Guidance
Direct measurement by occupancy meter	The placement is dependent on the space to be measured and the functionality of the meter. Refer to product instructions.	It is important to ensure the meter collects data as accurately as possible. As such, the position and configuration of the meter should be carefully considered to avoid failures to register a person's presence or alternatively register false readings (such as someone walking past an open door in which a meter has been placed).
Indirect measurement using energy load profile data	Data is derived from electrical measurement	Depending on the situation, switching of lights is clearly visible on load profiles. The observed on/off times can be used to create an operation schedule. Please note: Typical revenue meter data summates in 30 minute intervals, and rapid or complex switching may not be accurately observed. Interval data may include a variety of loads or circuits and deciphering the correct operating patterns with certainty may not be possible.

5.2 Develop energy model and uncertainty

Typically for lighting projects, the energy model will take on the following form:

$$Energy\ consumption(kWh) = \frac{qty.fittings\ \times wattage\ per\ fitting\ \times operating\ hours}{1000}$$

and the lighting demand model will take on the following form:

$$Electrical\ demand\ (kW) = \frac{qty.fittings\ \times wattage\ per\ fitting}{1000}$$

Where: ‘wattage per fitting’ represents the total connected load including lamp, ballast, transformer and any other components.

More complex energy models may be developed using regression and analysis for lighting projects, typically where:

- the operating hours are highly variable and suitable independent variable(s) can be identified e.g. swipe card access records, meeting room booking records etc.
- lighting levels can be adjusted through dimming using automated or manual controls. In this case the M&V approach may need to incorporate data collection for power draw for various light levels or control setting, and then operating hours are specified for each mode of operation

Uncertainty can be introduced into the energy model due to inaccuracies of measurement equipment, sampling errors and regression modelling errors. These inaccuracies need to be quantified as an overall uncertainty statement which includes a precision and confidence level. Refer to the *Process Guide* for further guidance on calculating and expressing uncertainty.

5.3 Implement ECM(s)

During the implementation phase of ECM(s), no M&V baseline or post retrofit data should be collected. Measurement and collection of post retrofit data can commence after ECM(s) have been installed and commissioned, preferably allowing for a period of time for the ECM(s) to be “embedded” into normal operations.

5.4 Measure post retrofit data

Conduct post-retrofit measurement in line with the prepared M&V plan using the same techniques as for the baseline (section 5.1). Position the measurement equipment in the same place where possible. Ensure appropriate records are kept.

Collect any associated data required for calculating post-retrofit energy use or adjustments based on independent variables (e.g. changes in trading hours). Confirm data integrity and completeness.

Post-retrofit performance should not be measured immediately post-retrofit, but allow for a “bedding-in” period prior to measurement.

5.5 Savings analysis and uncertainty

Analyse the data and calculate savings according to the prepared M&V plan. Analyse post-retrofit performance against baseline to:

1. Calculate savings, adjusting for independent variables
2. If included, adjust savings for interactive effects such as the impact on air conditioning
3. Estimate the savings uncertainty

5.5.1 Savings equations

The general equation for energy savings is:

$$Energy\ Savings = (Baseline\ Energy - Post\text{-}Retrofit\ Energy) \pm Adjustments$$

In the case of lighting projects, energy savings can be calculated as:

$$kWh_{savings} = (kW_{base}\ x\ OH_{base}) - (kW_{post}\ x\ OH_{post}) \pm Adjustments$$

Where:

$kWh_{savings}$ = *total energy savings, measured in kilowatt-hours (kWh)*

kW_{base} = *the kilowatt (kW) demand of the existing fixtures*

kW_{post} = *the kilowatt (kW) demand of the retrofit fixtures*

OH_{base} = *operating hours during the baseline period*

OH_{post} = *operating hours during the post-retrofit period*

Source: San Diego Gas and Electric

For lighting efficiency projects with minimal adjustments and unchanged operating hours, this may be simplified to:

$$kWh\ savings = (kW_{base} - kW_{post})\ x\ OH$$

Whilst for lighting control projects with minimal adjustments and unchanged power draw, this may be simplified to:

$$kWh\ savings = (OH_{base} - OH_{post})\ x\ kW$$

Lighting efficiency projects usually result in reduced demand. Demand savings are calculated as follows:

$$kW\ savings = (Baseline\ demand - Post\text{-}retrofit\ demand) \pm Adjustments$$

For lighting efficiency projects, this may be simplified to:

$$kW\ savings = kW_{base} - kW_{post}$$

Cost savings are determined by multiplying the energy and demand savings by the appropriate cost rates.

$$\text{Annual Cost Savings (\$)} = \text{Demand Saving} + \text{Energy Saving}$$

$$= ([\text{kW savings}] \times [\text{monthly demand cost rate}] \times 12)$$

$$+ ([\text{kWh savings}] \times [\text{energy cost rate}])$$

5.5.2 Extrapolation

If a sample-based approach is used (selected fixtures or circuits), then extrapolate across the project's measurement boundary.

Extrapolate the calculated savings for the measured period as required.

5.5.3 Uncertainty

Estimate the savings uncertainty, based on the measurement approach, placement, impact of variables, length of measurement and equipment used. Refer to the *Process Guide* for further guidance on calculating and expressing uncertainty.

6 Finish

6.1 Reporting

Prepare an outcomes report summarising the M&V exercise. Ensure any extrapolated savings are referred to as estimates, as the ‘actual’ savings only apply to the measurement period.

6.2 Project close and savings persistence

Periodic performance review of the retrofit may also be undertaken to confirm ongoing savings. This may not require the measurement of power usage but may be limited to:

- An inspection of the area to ensure equipment remains consistent with that specified in the installation
- Review of lighting levels
- Review of tube replacement levels.

7 M&V Examples

Both the IPMVP and this guide contain several worked example M&V projects. These are provided to assist readers with applying M&V concepts in real world situations, and to demonstrate the design and analytical components of successful M&V projects.

7.1 Examples from the IPMVP

The table below lists the example M&V projects that can be found within the IPMVP.

Table 10: Example M&V projects from the IPMVP

M&V Project Name	IPMVP Option	Location
Pump/Motor Efficiency Improvement	A	Volume 1: Appendix A – A-2
Pump/Motor Demand Shifting	B	Volume 1: Appendix A – A-2-1
Lighting fixture upgrade	A	Volume 1: Appendix A – A-3
Lighting control	A	Volume 1: Appendix A – A-3-1
Lighting – new fixtures and dimming	B	Volume 1: Appendix A – A-3-2
Compressed-Air Leakage Management	B	Volume 1: Appendix A – A-4
Turbine/Generator Set Improvement	B	Volume 1: Appendix A – A-5
Boiler Efficiency Improvement	A	Volume 1: Appendix A – A-6
Multiple ECMs with metered baseline data	C	Volume 1: Appendix A – A-7
Whole facility energy accounting relative to budget	C	Volume 1: Appendix A – A-7-1
Multiple ECMs in a building without energy meters in the baseline period	D	Volume 1: Appendix A – A-8
New building designed better than code	D	Volume 1: Appendix A – A-9
Solar water heating test	A	Volume 3: Renewable Energy
Direct measurement centralised solar hot water heater	B	Volume 3: Renewable Energy
Indirect measurement residential solar hot water heater	B & D	Volume 3: Renewable Energy
Building integrated photovoltaic system	D	Volume 3: Renewable Energy
Solar Water Heating	D	Volume 3: Renewable Energy

7.2 Examples from this guide

The table below lists the example M&V projects that can be found within this guide.

Table 11: Example M&V projects from the M&V Operational Guide

M&V Project Name	IPMVP Option	Location
M&V design examples	A, B, C, D	Process: Appendix A
Demand and cost avoidance calculation example	n/a	Process: Appendix A
Regression modelling and validity testing	n/a	Process: Appendix E
Lighting fixture replacement within an office tenancy	A	Applications: Lighting – Scenario A
Lighting fixture and control upgrade at a function centre	A	Applications: Lighting – Scenario B
Lighting fixture retrofit incorporating daylight control	B	Applications: Lighting – Scenario C
Pump retrofit and motor replacement	A	Applications: Motors, Pumps and Fans – Scenario A
Car park ventilation involving CO monitoring and variable speed drive on fans	B	Applications: Motors, Pumps and Fans – Scenario B
Replacement an inefficient gas boiler with a high efficiency one	C	Applications: Heating, Ventilation and Cooling – Scenario A
Upgrade freezer controls within a food processing plant	B	Applications: Commercial and Industrial Refrigeration – Scenario A
Compressed air leak detection within a manufacturing site using sampling analysis	B	Applications: Boilers, Steam and Compressed Air – Scenario A
Steam system leak detection within a food processing site using regression analysis	B	Applications: Boilers, Steam and Compressed Air – Scenario B
Multiple ECMs involving compressed air and steam system optimisation, combined with lighting controls at a cannery	C	Applications: Whole Buildings – Scenario A
Commercial building air conditioning central plant upgrade	C	Applications: Whole Buildings – Scenario B
Evaluate performance efficiency of a newly installed cogeneration unit at a school	D	Applications: Renewables and Cogeneration – Scenario A
Installation of a cogeneration plant at a hospital	C	Applications: Renewables and Cogeneration – Scenario B
Use of solar hot water system on a housing estate	B	Applications: Renewables and Cogeneration – Scenario C

Appendix A: Example scenario

The scenario below provides details of how **Option A** is used to measure and verify the savings from a lighting efficiency project.

A small IT organisation wants to reduce its energy use. The company works from a single floor of a multistorey building.

Their electrical contractor has recommended they replace:
- all existing twin T8 fluorescent troffers with high performance single T5 troffers
- the existing 50W halogen lamps with 11W compact fluorescent lamps
- the existing T12 fluorescent troffers with high performance single T5 troffers.

The electrical contractor has not recommended any lighting control options. She has, however, guaranteed at least a 50% savings in lighting electricity from the measures above.

The T12 lamps are only in the toilet areas, which are on the common building circuits.

The 50W halogen lamps are only in the foyer.

During the design stages of the project, desktop analysis determined that the project would result in estimated savings of $8,500 per annum.

The IT firm requires validation that these changes have resulted in improved energy efficiency of at least 50%.

Getting started

Budget

The required output from the M&V exercise was to confirm the level of savings being achieved from the lighting efficiency project is greater than 50%. Using the savings as a guide, an M&V budget of $1,000 was established (12% of annual savings). With such a small budget available, M&V Option A was chosen.

Key Parameter(s)

Given that the project involves the replacement of fixtures, power draw was determined to be the key measurement parameter. Operating hours would be stipulated, based on discussions with staff and cleaners.

Measurement Boundary

The measurement boundary was chosen to be twelve circuits within two distribution boards that supply the existing lighting to be retrofitted.

Approach for Conducting Measurement

The chosen approach for measuring power draw was to conduct instantaneous real power readings on each of the twelve circuits when fully loaded. The tenancy consists of a number of functional areas, each with their own hours of operation. In order to correctly attribute operating hours for each functional area to the relevant lighting circuit, it was determined that each circuit would be tested separately. The distribution board circuit ‘schedule’ was examined and confirmed by switching the lights on in each area, measuring the power draw for each circuit and noting the functional space served by each circuit.

Timing

Measurement is to be conducted by the electrician prior to the retrofit, and once again after the new fixtures have been installed and tested. The estimated time for conducting measurements was 30 mins each time.

Lighting Inventory

During the design phase of the project, the existing and proposed lighting inventories were developed. This contains the types and quantities of fixtures with their estimated load based on visual inspections of selected fixtures.

Operating Hours

The lighting controls will not be altered and so operating hours will not be greatly affected. The baseline and post-retrofit period are stipulated. In order to confirm this, occupancy schedules were reviewed and confirmed with staff as part of the baseline determination.

Lighting Levels

Current lighting levels are satisfactory and are at minimum standards. Lighting levels are to be maintained and confirmed post-retrofit to ensure legal compliance.

Interactive effects with air conditioning

The application of the new technology will impact the air conditioning. T5 lamps produce less heat than T12 or T8 lamps and hence in summer there may be a reduction on the air conditioning load, and potentially an increase in the winter heating requirements. It is estimated that additional savings of around 20% may be seen from reduced air conditioning load and therefore this interactive effect should be considered.

However, as a tenant in the building, the IT firm receives conditioned air as part of its lease with the building owner. Although the lighting upgrade will reduce demand on the air conditioning system, the IT firm will not directly benefit as it pays a fixed monthly fee. Therefore the interactive effects have been ignored for this M&V project.

Summary of M&V Plan

The key elements of the project's M&V plan in summary are:

Item	Plan
Project summary	Lighting retrofit for a 2 storey commercial office building, involving the replacement of halogen downlights with compact fluorescents and linear twin T8 and T12 fluorescents with single T5s Lighting controls remain unaffected.
Required outcome	To confirm that savings of 50% or more are being achieved from the lighting efficiency project.
Budget	$1,000

Item	Plan
M&V Option	A – Project Isolation Key Parameter Measurement
Measurement boundary	Twelve electrical circuits across two distribution boards that feed the lighting fixtures to be retrofitted.
Key measurement parameters	Power draw
Other parameters to consider	Operating hours Lighting levels
Potential interactive effects	Reduced heat load and its effect on air conditioning energy use.
Approach for conducting measurement and collecting data	Power draw: Instantaneous real power readings are to be measured of the fully loaded circuits prior to and post-retrofit. Operating hours: to be estimated following discussion with staff Lighting Levels: to be measured post-installation to ensure they meet minimum standards.
Measurement equipment required	An AC digital power meter will be used to measure the real power in watts/kW.
Measurement period	Instantaneous measurement conducted prior to retrofit, and repeated once new lighting has been installed.
Approach for calculating results	Savings are to be estimated by multiplying the estimated operating hours for each functional area by the change in power draw for each circuit that is measured before and after the retrofit. Cost savings will be calculated by applying the following cost rates: All energy - $0.18 / kWh Demand - $4 / kW / month

Conducting measurements

The baseline and post-retrofit power draws were measured by the electrician using a digital power meter. The power was measured at each circuit by ‘clamping’ the meter around the single phase circuit wire when the circuit was in full operation (i.e. all lights were connected and running), whilst simultaneously measuring voltage. Each measurement was held for approximately 15 seconds to ensure a steady-state reading was obtained.

Given that the installation was being conducted outside normal business hours when other equipment was not in use, the issue of accidently causing a major spike in demand by operating the entire lighting system was avoided.

The dates and times when the readings were taken were recorded.

The measured readings were:

Current Point of Measurement	Measured Value (kW)	
	Baseline	Post-retrofit
DB 1, Cct 21	0.72	0.25
DB 1, Cct 22	2.17	0.87
DB 1, Cct 2	3.30	1.36
DB 2, Cct 5	3.40	1.99
DB 2, Cct 14	3.40	1.31
DB 2, Cct 20	3.40	1.69
DB 2, Cct 9	1.84	0.62
DB 2, Cct 11	2.43	0.87
DB 1, Cct 6	1.09	0.38
DB 1, Cct 9	0.36	0.13
DB 1, Cct 7	1.23	0.38
DB 2, Cct 3	1.24	0.37

Light levels were measured before and after to confirm compliance.

A discussion was held with key staff, to confirm the operating hours of the lighting system. Staff reviewed the initial estimate used to in the business case for the opportunity, and mentioned that there is often additional occupancy on Level 1, including some weekend use, and that the toilet lights are generally left on. Meeting room use was lower than estimated and these lights are controlled regularly.

Functional Area	Initial estimate – operating hours	After discussion with staff
Foyer	2,500	2,500
Open office area (Level 1 East Side)	2,500	3,150
Open office area (Level 1 West Side)	2,500	3,150
Open office area (Level 2 East Side)	2,500	2,500
Open office area (Level 2 East Side)	2,500	2,500
Large Conference Room	800	800
Meeting Rooms 1, 2 and 3	1,000	400
Kitchen	2,500	2,500
IT Server Room	2,500	2,500
Toilets - Level 1	3,500	8,760
Toilets - Level 2	3,500	8,760

Calculating savings

Savings were calculated by determining the power draw for the baseline and post-retrofit installed lighting. The energy savings were calculated by applying the equation to each circuit, in order to allow for the operating hours of each functional area:

$$Baseline\ Energy\ usage\ (kWh_{base}) = kW_{base}\ x\ OH$$

$$Post\text{-}retrofit\ Energy\ usage(kWh_{post}) = kW_{post}\ x\ OH$$

And:

$$Energy\ savings\ (kWh) = kWh_{base} - kWh_{post}$$

Or directly using:

$$Energy\ savings\ (kWh) = (kW_{base} - kW_{post})\ x\ OH$$

The table below summarises the savings calculations.

Circuit	Measured		Estimated	Calculations	
	Power draw P_{base} (kW)	Power draw P_{post} (kW)	Annual Operating Hrs (OH)	Demand Saving (P_{saving}=P_{base} – P_{post}) (kW)	Est. Energy Savings =(P_{saving} x OH) (kWh)
DB 1, Cct 21	0.72	0.25	2,500	0.47	1,181
DB 1, Cct 22	2.17	0.87	2,500	1.30	3,241
DB 1, Cct 2	3.30	1.36	3,150	1.94	6,119
DB 2, Cct 5	3.40	1.99	3,150	1.41	4,455
DB 2, Cct 14	3.40	1.31	2,500	2.09	5,237
DB 2, Cct 20	3.40	1.69	2,500	1.71	4,277
DB 2, Cct 9	1.84	0.62	800	1.22	972
DB 2, Cct 11	2.43	0.87	400	1.56	622
DB 1, Cct 6	1.09	0.38	2,500	0.72	1,795
DB 1, Cct 9	0.36	0.13	2,500	0.24	590
DB 1, Cct 7	1.23	0.38	8,760	0.85	7,474
DB 2, Cct 3	1.24	0.37	8,760	0.87	7,578
			Total	**14.37**	**43,541**

Note the demand ‘saving’ achieved is 14.37 kW. This demand savings represents the like-for-like potential reduction that would be realised if all lights within the lighting system are operating at the same time before and after.

It can be seen that the majority of circuits operate more than 2,500 hours per annum, or around 50 hours per week. However there are two circuits that operate 400 and 800 hours per annum;

on average 8 and 16 hours per week respectively. Without measuring operating hours for each functional area, we cannot reliably predict that all circuits will be operating at full load at the same time, and hence that all demand reduction will coincide.

In order to calculate a more conservative estimate of the demand saving, it was decided to calculate the demand savings from the circuits that operate 2,500 hours or more. Thus the demand savings for circuits 9 and 11 from DB 2 will be ignored, resulting in a demand reduction of 11.60 kW.

Cost savings are determined by multiplying the energy and demand savings by the appropriate cost rates. Using rates of $4/kW per month for demand, and $0.18/kWh for energy, the cost savings are:

$$\begin{aligned}\text{Annual Cost Savings (\$)} &= (\text{kW}_{\text{saved}} \text{ x } \$4/\text{kW x } 12) + (\text{kWh}_{\text{saved}} \text{ x } \$0.18/\text{kWh}) \\ &= (11.6 \text{ x } \$4 \text{ x } 12) + (43{,}541 \text{ x } \$0.18) \\ &= \$556.97 + \$7{,}837.39 \\ &= \$8{,}394.36\end{aligned}$$

Reporting results

Estimated annual energy savings are reported as:

Component	Baseline	Post Retrofit	Savings
Energy	73,061 kWh	29,500 kWh	43,541 kWh
Maximum Demand	24.59 kW	10.22 kW	14.37 kW
Demand for circuits operating more than 2,500 hours p.a.	20.32 kW	8.72 kW	11.60 kW
Cost	$14,331	$5,804	$8,527
Cost savings (using conservative demand estimate)			$8,394

The conservative savings are more appropriately quoted as 43,500 kWh and $8,400, for the operating hours stipulated in the table earlier. The savings represent approximately 59% energy and cost savings against the baseline, which exceeds the 50% guarantee provided by the electrical contractor.

Note: uncertainty has not been calculated for this example.

Appendix B: Example scenario

The scenario below provides details of how **Option A** is used to measure and verify the savings from a lighting efficiency project.

A conference and function centre, originally built in the 1970's is interested in improving its energy efficiency and reducing its operating costs. The venue consists of a number of discrete rooms capable of handing both large and small functions.

An energy audit was conducted at the site, which identified significant potential energy savings could be achieved by replacing the existing incandescent lighting within its 'Banksia' and 'Waratah' function rooms with modern, high efficient LED alternatives.

Unlike a typical office environment, the lighting within both rooms must be capable of being controlled in sections, with each section being able to be dimmed between 0% and 100%.

The Building Manager was coordinating the works and was seeking to confirm the energy savings to management in order to validate the project and improve the likelihood of other projects proceeding.

Formal measurement and verification was only considered at the last minute and date for installation was fast approaching. For this reason an Option A approach for conducting M&V is to be used.

Getting started

Budget

A budget amount of $2,500, based on labour, has been allocated for M&V of the lighting upgrade.

Key Parameter(s)

Given that the project involves the replacement of fixtures, power draw was determined to be the key measurement parameter. In addition, lighting Lux levels have been deemed to be a key parameter, given the need to dim the lights at various levels based on the type of function. Differing light levels should impact the amount of power draw or energy use consumed during any given function.

Operating hours would be stipulated, based on discussions with function coordination staff.

Measurement Boundary

Two separate measurement boundaries will be applied to this project. The first boundary relates to the 'Banksia' function room in which lighting is supplied from ten circuits located at a single distribution board.

The second boundary relates to the 'Waratah' room in which lighting is supplied from nine circuits at a single distribution board.

Should the number of circuits change during the installation, all additional circuits are to be included in the post-retrofit data collected, so as to create a like-for-like comparison of each functional space.

Approach for Conducting Measurement

The chosen approach for measuring power draw is conduct instantaneous real power readings on each circuit.

For each circuit, steady-state measurements are to be taken whilst the lighting is controlled at four levels of dimming, namely 0%, 25%, 50%, and 75%.

Light level readings will be taken concurrently with the power draw measurements for the circuits so that the relationship between power draw and light output from a common reference point can be established.

This approach is to be conducted before the lighting was replaced and once again post-retrofit.

Timing

Measurement is to be conducted by the electrician prior to the retrofit, with Lux readings to be taken by the Building Manager, and once again after the new fixtures have been installed and tested. The estimated time for conducting measurements was 60 mins each time.

Operating Hours

The operating hours of the lighting varies significantly based on the type and number of functions that occur within each room. Given the lack of time prior to the retrofit combined with the high variability, the operating hours will be stipulated based on data provided by the Function Coordinator.

In addition to the reported hours, the Building Manager has stated that the lighting operates for 1 hour before and 1 hour after each function for set up and pack up.

Interactive effects with air conditioning

It is recognised that the new lighting will result in less heat output, which will impact the amount of mechanical heating or cooling required. However for the purposes of this exercise these interactive effects will be ignored.

Summary of M&V Plan

The key elements of the project's M&V plan in summary are:

Item	Plan
Project summary	Lighting upgrade from incandescents to LEDs within 'Banksia' and 'Waratah' function rooms. The old and retrofitted lighting systems can be dimmed from 0% to 100%.
Required outcome	To quantify the savings being achieved from the lighting efficiency project using formal M&V methods.
Budget	$2,500
M&V Option	Option A – Project Isolation Key Parameter Measurement

Item	Plan
Measurement boundary	Separate boundaries for the 'Banksia' and 'Waratah' function rooms. Each boundary encompasses all electrical circuits that feed the lighting fixtures to be retrofitted.
Key measurement parameters	Power draw Lighting levels
Other parameters to consider	Operating hours
Potential interactive effects	Reduced heat load and its effect on air conditioning energy use.
Approach for conducting measurement and collecting data	Power draw: Instantaneous real power readings are to be measured of the fully loaded circuits prior to and post-retrofit. Lighting Levels: to be measured pre and post-installation concurrently with power draw. Power draw and lighting levels will be measured at dimming levels of 0%, 25%, 50%, and 75%. Operating hours: to be estimated following discussion with staff
Measurement equipment required	An AC digital power meter will be used to measure the real power in watts/kW.
Measurement period	Instantaneous measurement conducted prior to retrofit, and repeated once new lighting has been installed.
Approach for calculating results	For each measurement boundary, separate pre and post-retrofit lighting models will be developed. Power draw will be correlated with lighting levels. Then for various function types and durations (i.e. hours), a lighting profile will be stipulated in which lighting is operated between 0% and 100% dimming. Hours of operation at various levels of dimming will be combined with the energy models for power draw to determine baseline and post-retrofit usage. Total monthly operating hours will be estimated based on data to be provided by the site's Function Coordinator. Energy use will be determined by multiplying the estimated operating hours for each functional area by the change in power draw for each circuit that is measured before and after the retrofit. Savings are to be estimated by subtracting post-retrofit usage from baseline usage. Cost savings will be calculated by applying an electricity cost rate of \$0.15 / kWh.

Conducting measurements

The baseline and post-retrofit power draws were measured by the electrician using a digital power meter. The power was measured at each circuit by 'clamping' the meter around the single phase circuit wire when the circuit was in full operation (i.e. all lights were connected and running), whilst simultaneously measuring voltage. Each measurement was held for approximately 15 seconds to ensure a steady-state reading was obtained.

At the same time, the Building Manager recorded the corresponding light level observed using a lighting meter. The Building Manager operated the lights to dim them between 0% and 100% and data was captured at each stage.

The measured readings for the 'Banksia' function room were:

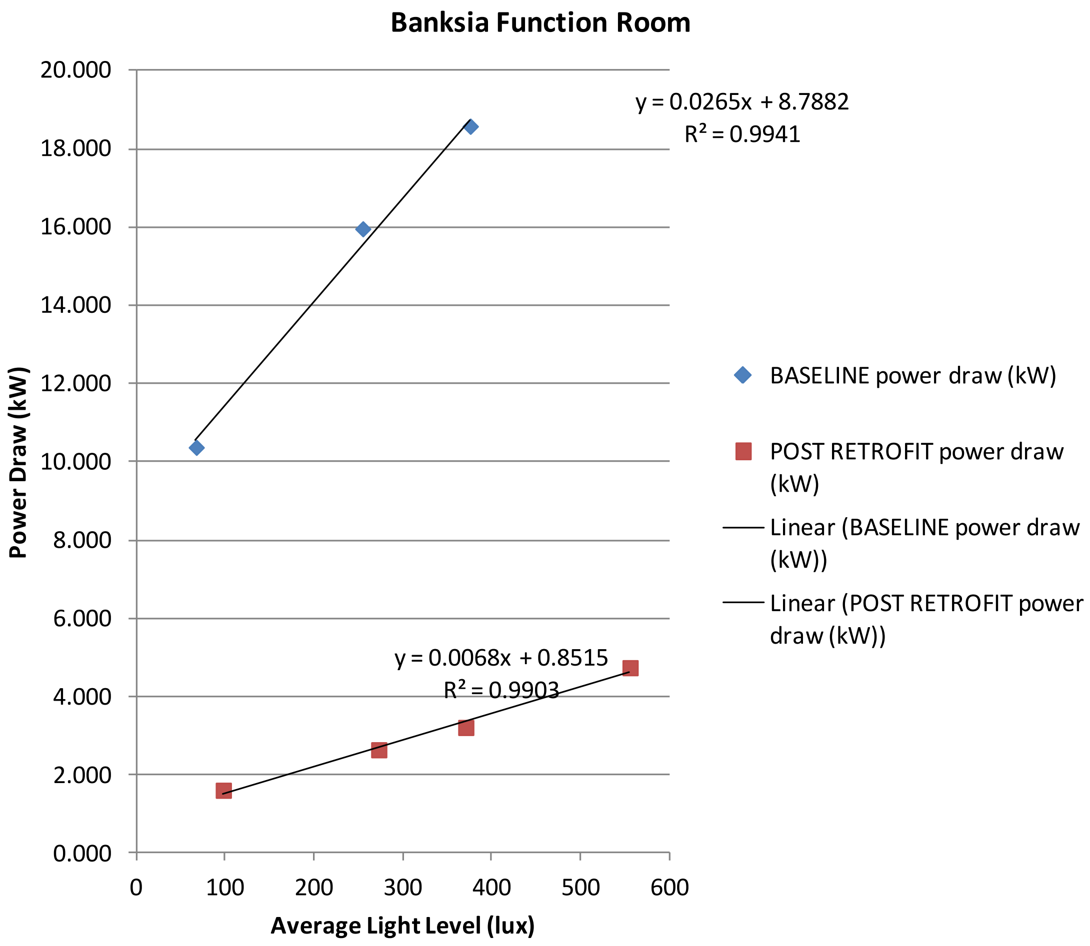
Table 12: Baseline and post-retrofit measurements

BASELINE lighting levels (Lux)					POST-RETROFIT lighting levels (Lux)				
Dimming level	**0%**	**25%**	**50%**	**75%**	**Dimming level**	**0%**	**25%**	**50%**	**75%**
Measured light level (Lux)	375.0	375.0	254.0	66.5	Measured light level (Lux)	555.0	370.0	272.0	97
BASELINE power draw (kW)					**POST-RETROFIT power draw (kW)**				
Circuit 1	0.000	0.000	0.000	0.000	Circuit 1	0.616	0.388	0.319	0.205
2	2.850	2.622	1.824	1.368	2	0.502	0.342	0.274	0.160
3	1.824	1.482	1.254	0.798	3	0.228	0.137	0.114	0.068
4	3.078	2.850	2.166	1.482	4	0.274	0.182	0.137	0.091
5	2.964	2.850	2.394	1.710	5	0.502	0.319	0.274	0.160
6	2.736	3.078	2.964	1.482	6	0.502	0.319	0.251	0.160
7	1.026	1.368	2.508	0.798	7	0.046	0.046	0.023	0.014
8	1.824	1.254	1.254	1.368	8	0.502	0.319	0.251	0.160
9	0.912	1.824	0.456	0.798	9	0.502	0.319	0.251	0.160
10	1.368	1.254	1.140	0.570	10	0.319	0.205	0.160	0.091
					11	0.547	0.456	0.433	0.205
					12	0.205	0.182	0.160	0.137
Total Baseline power draw (kW)	**18.582**	**18.582**	**15.960**	**10.374**	**Total Post-retrofit power draw (kW)**	**4.742**	**3.215**	**2.645**	**1.610**

A similar set of data was obtained for the 'Waratah' room. Note that the number of circuits has increased, and as have the maximum (undimmed) light levels. This may lead to issues in being able to correlate the before and after dimming levels.

Before and after energy models

The chart below shows the energy models that were developed from the combined data above:



It can be seen that highly linear energy models were obtained from the data. Ideally, additional dimming levels (e.g. 40%, 60%, etc) would have been collected to expand the number of data points.

From the models above we can see that the change in power draw and hence consumption varies depending on the level of dimming, as the slope of the trend lines are different.

Operating Hours

Discussions were held with site staff to understand how the lighting systems were operated, and to obtain details of the number of functions that occur. As we are seeking to report normalised savings, data from the baseline period was not required. We can simply apply operating hours and details of dimming control obtained from the post-retrofit period to the baseline to obtain a like-for-like comparison.

The table below lists the indicative number of hours of operation of the lighting system within the Banksia Room across a typical month.

Table 13: Lighting Control % of total hours of use at various dimming levels

Control (lux level)	Days per month	% of total hours	BASELINE light levels (Lux)	POST-RETROFIT light levels (Lux)
75%	2	6.7%	67	97
50%	16	53.3%	254	272
25%	8	26.7%	375	370
0% - no dimming	4	13.3%	375	555
Weighted average light level (Lux			**289.9**	**324.2**

Following five months of post-retrofit operation, data for the number of functions that were held was collated. Two hours per function has been added for set up and dismantling. This is described in the table below:

Table 14: Monthly hours of operation

Month	Monthly Function Days	Monthly Hours of Operation (for functions)	Monthly hours for setup/dismantling	Total Hours
Jan-12	21	238.75	42	280.75
Feb-12	23	227	46	273
Mar-12	23	224.5	46	270.5
Apr-12	9	63	18	81
May-12	25	261	50	311
Total for 5 months	**101**	**1014.25**	**202**	**1216.25**
Estimated for 12 months	**242.4**	**2434.2**	**484.8**	**2919**

Calculating savings

Savings were calculated by applying the power draw models for the baseline and post-retrofit against the stipulated operating hours.

Monthly energy use for the baseline and post-retrofit periods was calculated by combining the two tables above. The baseline model for power draw is:

$$baseline\ power\ draw\ (kW) = 0.0265 \times Lux + 8.7882$$

$$baseline\ energy\ use\ (kWh) = baseline\ power\ draw\ (kW) \times operating\ hours\ (hours)$$

Where:

$$baseline\ energy\ use\ (kWh) = function\ energy\ use\ (kWh) + setup/dismantle\ energy\ use\ (kWh)$$

Using January 2012 as an example, we apply the weighted average light level of 289.9 Lux to the function power draw model, and apply the maximum light level of 375 Lux for the set up and dismantle hours:

$$Baseline\ energy\ use\ for\ Jan12\ (kWh)$$
$$= (0.0265 \times 289.9 +\ 8.7882) \times 238.75 + (0.0265 \times 375 +\ 8.7882) \times 42$$
$$= 16.471 \times 238.75 + 18.726 \times 42$$
$$= 3{,}932.34 + 786.49$$
$$= 4{,}719\ kWh$$

A similar method was used for the post-retrofit data using the post-retrofit model:

$$post\ retrofit\ power\ draw\ (kW) =\ 0.0068 \times Lux\ +\ 0.8515$$

Thus for January 2012, we obtain:

$$Post\ retfofit\ energy\ use\ for\ Jan12\ (kWh)$$
$$= (0.0068 \times 324.2 +\ 0.8515) \times 238.75 + (0.0068 \times 555 +\ 0.8515) \times 42$$
$$= 3.056 \times 238.75 + 4.626 \times 42$$
$$= 729.63 + 194.27$$
$$= 924\ kWh$$

Note that the full light level of 555 Lux has been used here, even though the old system could only produce light levels of 375 Lux. It has been assumed here that both systems have been controlled using the same step ratios, which means that the resulting light levels observed will be higher for each step within the post-retrofit period.

An alternate view is that the lights are controlled to similar light levels pre and post-retrofit, which means that the step changes are different. The savings from this approach can also be calculated using the models above, but applying different light levels and hours of operation.

It is most likely that actual operation is a combination of both situations. However the approach used here will result in a more conservative savings estimate.

Energy use for baseline and post-retrofit periods were calculated. The savings were then obtained by subtracting the post-retrofit figures from their corresponding baseline figures.

The table below summarises the savings calculations.

Month	BASELINE Energy Usage (kWh)	POST-RETROFIT Energy Usage (kWh)	Savings (kWh)	Savings %
Jan-12	4,719	924	3,795	80.4%
Feb-12	4,600	906	3,694	80.3%
Mar-12	4,559	899	3,660	80.3%
Apr-12	1,375	276	1,099	79.9%
May-12	5,235	1,029	4,206	80.3%
Total for 5 months	**20,488**	**4,034**	**16,454**	**80.3%**
Estimated for 12 months	**49,171**	**9,682**	**39,489**	**80.3%**

The 12 month estimate is simply a pro-rating of an average monthly saving as data regarding operating hours was not available.

$$Annual\ energy\ savings\ (kWh) = \ baseline\ energy\ (kWh) - post\ retrofit\ energy\ (kWh)$$

$$= \ 39{,}489\ kWh$$

Cost savings are determined by multiplying the energy savings by the appropriate cost rate. The cost savings are:

$$Annual\ cost\ savings\ (\$) = \ annual\ energy\ savings\ (kWh) \times electricity\ cost\ rate\ (\frac{\$}{kWh})$$

$$= \ 39{,}489 \times \$0.15$$

$$= \$5{,}923$$

Estimating uncertainty

The savings calculation makes use of regression models for estimating the baseline and post-retrofit power draw based on light levels. Therefore the savings uncertainty will incorporate modelling errors from both models.

The standard error of baseline regression model SE_b is calculated as follows:

$$SE_b = \sqrt{\frac{\Sigma(\hat{Y}_i - Y_i)^2}{n - p - 1}}$$

Where:

$\hat{Y}_i$ is the model-predicted baseline power draw for light level i,

Y_i is the baseline power draw for light level i, n is the number of data points (4 light levels used in regression model), and

$p = 1$ is the number of independent variables in the regression model.

The table below illustrates the process for the baseline model:

Actual (kW) Y_i	Light level (Lux)	Modelled (kW) $\widehat{Y_i}$	$(\widehat{Y_i} - Y_i)^2$
18.5820	375	18.7176	0.0184
18.5820	375	18.7176	0.0184
15.9600	254	15.5137	0.1992
10.3740	66.5	10.5490	0.0306
Total			0.2666

Using the value above:

$$SE_b = \sqrt{\frac{\Sigma(\hat{Y}_i - Y_i)^2}{n - p - 1}} = \sqrt{\frac{0.2666}{2 - 1 - 1}} = 0.3651$$

A similar process was followed to determine the standard error for the post-retrofit model, yielding:

$$SE_{pr} = 0.1579$$

The standard error for the power savings can now be calculated as a function of the standard errors from the baseline and post-retrofit models, as shown below:

$$SE(reduced\ power\ draw) = \sqrt{{SE_b}^2 + {SE_{pr}}^2}$$

$$SE(reduced\ power\ draw) = \sqrt{0.3651^2 + 0.1579^2} = 0.39776$$

The standard error above applies to the reduction in power draw. As the energy saving is a combination of the power draw and operating hours, the overall standard error for the energy saving would be expressed as:

$$SE(monthly\ savings) \approx mean\ monthly\ savings \times \sqrt{\left(\frac{SE(reduced\ power\ draw)}{reduced\ power\ draw}\right)^2 + \left(\frac{SE(hours)}{hours}\right)^2}$$

In this case, however, we are calculating 'normalised' savings based on stipulated operating hours. Therefore for this case we assume the standard error for operating hours is nil. As a result the standard error for the monthly energy savings is calculated as follows:

$$SE(savings) \approx 3{,}291 \times \sqrt{\left(\frac{0.39776}{\frac{3{,}291}{243.25}}\right)^2 + \left(\frac{0}{243.25}\right)^2}$$

Where:

0.39776 is the standard error for reduced power draw

0 is the standard error for operating hours

3,291 kWh is the average monthly energy saving

243.25 is the average total hours across the 5 months

This is simply:

$$SE(monthly\ savings) \approx 0.39776 \times 243.25 = 96.76\ kWh$$

Extrapolating across the 12-month savings period:

$$Total\ SE(savings) = \sqrt{SE(savings_1)^2 + SE(savings_2)^2 + \ldots + SE(savings_n)^2}$$

$$Total\ SE(savings) = \sqrt{12} \times 96.76 = 335.17\ kWh$$

We need to associate our uncertainty or precision with reference to a level of confidence. For this exercise we will determine the absolute and relative precision at 95% confidence.

Absolute precision (AP) can be calculated using the t-value for 4 readings, or DF = 4 -1 – 1 = 2 degrees of freedom. The t-value can be found within Table 27 of Appendix G within the *Process Guide*.

The t-statistic for 2 degrees of freedom at 95% confidence is 4.30.

The absolute precision is found by:

$$AP = t \times SE$$

$$= 4.30 \times 335.17$$

$$= 1{,}441\ kWh$$

Relative precision (RP) is then calculated to be:

$$RP = \frac{AP}{Estimate}$$

$$= \frac{1{,}441}{39{,}489}$$

$$= \pm 3.6\%$$

Reporting results

Finally, the energy savings can be expressed as:

The estimated annual energy savings are 39,489 kWh ±3.6% at 95% confidence, based on stipulated annual operating hours of 2,919 hours.

The above analysis would be repeated for the Waratah Room to obtain the combined saving figure.

Appendix C: Example scenario

The scenario below provides details of how **Option B** is used to measure and verify the savings from a lighting efficiency project.

A regional performing arts centre provides the city with a world class opera theatre. The venue consists of concert halls, theatres, and studios encompassed within a 'masterpiece' of modern architecture.

An energy audit was conducted at the site, which identified significant potential energy savings could be achieved by replacing the existing incandescent lighting throughout the building with modern, high efficiency fixtures.

Implementation is to be staged, and formal verification of the savings achieved from the pilot retrofits is required to ensure that the upgrade is rolled out across the building.

Getting started

Budget

A budget amount of $1,500, based on labour, has been allocated for M&V of the lighting upgrade. Although it is estimated that this will exceed 10% of the anticipated energy savings, it is an important step in the project and the cost was deemed justifiable.

Key Parameter(s)

Given that the project involves the replacement of fixtures as well as introduction of automated controls, power draw and operating hours were determined to be the key measurement parameters.

The lighting within the measurement boundary is controlled using a combination of manual switches, as well as a photoelectric cell that controls the lights based on available ambient light. As a result the hours of operation will vary according to staff behaviour as well as seasonal changes in sunrise/sunset times.

Measurement Boundary

IPMVP Option B will be used to determine savings for a selected area being retrofitted, known as the central corridor.

The approach is to measure baseline and post-retrofit energy use using a data logger for the lighting circuit that serves the central corridor.

Approach for Conducting Measurement

Savings will be determined for the post-retrofit period by aligning days (length and weekdays versus weekend) and adjusting for changes in sunrise/sunset times due to photoelectric cell control of lighting.

An energy model will be developed based on the average hourly usage for day and night periods. Daily data for sunrise/sunset periods will be used determine the hours of operation which will then be applied to the model to extrapolate the 2 weeks of measured data across 12 months. Steady state operation on every day of the year is assumed.

Timing

The baseline period is continuous twelve day period prior to the upgrade of the lighting. This was the period between 12th July and 24th July 2011.

Due to delays in finalising the retrofit, the post-retrofit performance measurement did not occur until the period between 25th October and 6th November 2011.

Operating Hours

The operating hours of the lighting varies significantly based manual control by site staff as well as daylight control via a photoelectric cell. Following the baseline data collection, the data will be examined with site staff to gain an understanding and note the observed changes in usage due to lighting control, noting where the manual and daylight controls take effect.

Annual data for solar exposure will be used for estimating the seasonal changes in lighting control due to the photoelectric control.

Interactive effects with air conditioning

It is recognised that the new lighting will result in less heat output, which will impact the amount of mechanical heating or cooling required. However for the purposes of this exercise these interactive effects will be ignored.

Summary of M&V Plan

The key elements of the project's M&V plan in summary are:

Item	Plan
Project summary	Lighting upgrades involving lamp/fixture replacement and introduction of controls.
Required outcome	To demonstrate that savings are being achieved from the lighting efficiency project using formal M&V methods in order for next phases to commence as planned.
Budget	$1,500
M&V Option	Option B – Project Isolation Full Parameter Measurement
Measurement boundary	Electrical circuit which serves lighting within the central corridor
Key measurement parameters	Power draw Operating Hours
Other parameters to consider	Light levels Ambient available light
Potential interactive effects	Reduced heat load and its effect on air conditioning energy use.
Approach for conducting measurement and collecting data	A power data logger will be installed on the relevant circuit to continuously measure real power draw (and hence energy use). Operating hours will be examined from the logged data and correlated by discussion with staff to determine the changes in control. Data relating to solar exposure will be obtained from the Bureau of Meteorology.

Item	Plan
Measurement equipment required	An AC digital power meter will be used to measure the real power in watts/kW.
Measurement period	Approximately two weeks for baseline and two weeks for post-retrofit period.
Approach for calculating results	An energy model will be developed to determine the power draw from the circuit when the lights are in operation and when they are controlled. Operating hours will be determined by reviewing the load profiles to determine the staff controlled events, as well as any changes in operating hours due to daylight control. These will be combined to estimate the annual baseline and post-retrofit energy use. Savings are to be estimated by subtracting post-retrofit usage from baseline usage. Cost savings will be calculated by applying an electricity cost rate of $0.15 / kWh.

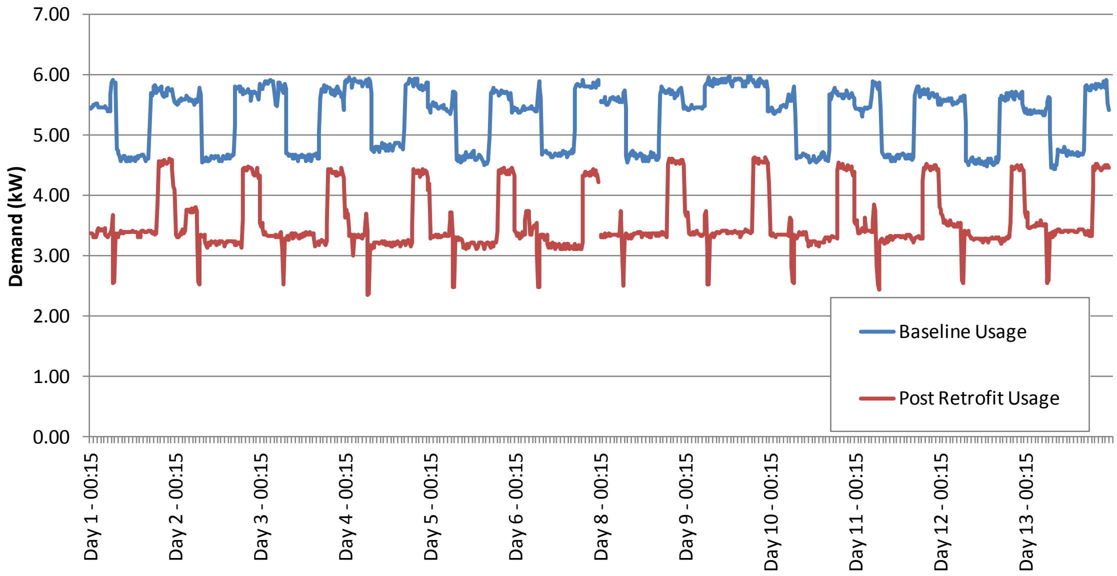
Conducting measurements

The baseline energy use was measured using the power meter in the latter part of July 2012. The load profile was reviewed with staff to determine the control events.

Following the retrofit, the data collection was repeated for the post-retrofit period, which occurred between late October and early November 2012.

The time periods were aligned so that each contained complete days of data, and that days of the week were aligned.

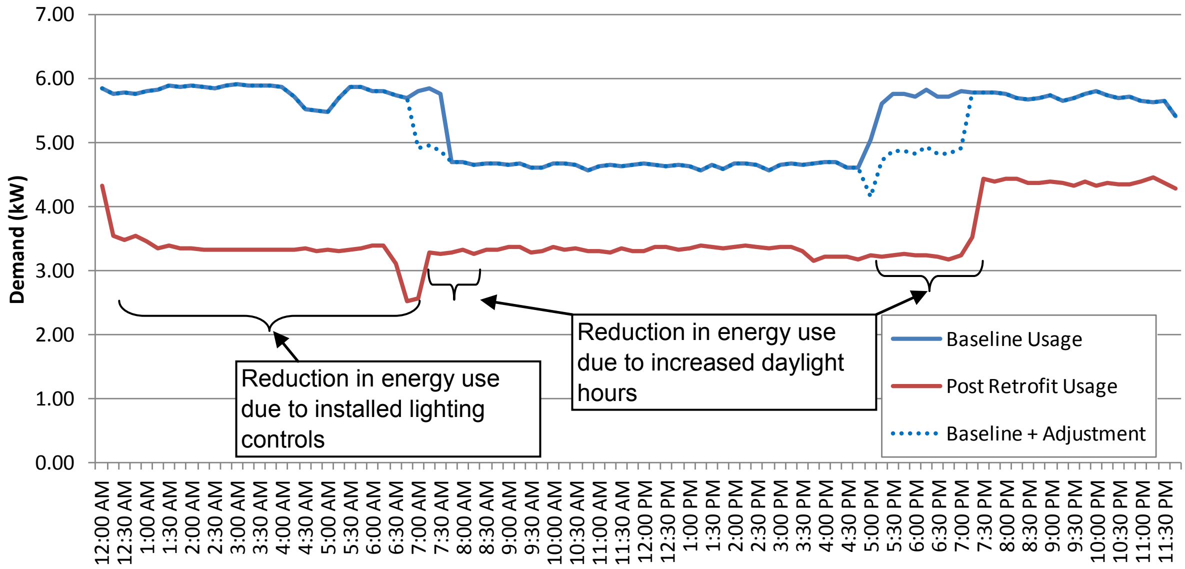
The chart below illustrates the measured baseline and post-retrofit usage.



The overall step change in power draw can be seen. The changes in lighting load due to controls can also be seen.

The change operating hours is partially due to the introduction of lighting controls, which involves switching off the lights just after midnight. Operating hours is also affected by the change in ambient light.

The chart below shows the load profile for a single day.



Within our M&V savings analysis we wish to adjust the baseline energy use to incorporate the seasonal changes in ambient daylight (i.e. extended hours in summer months). At the same time we want to include any savings resulting from the introduction of automated lighting controls.

To this end, the data was analysed to identify the time periods when the lighting was being controlled due to the PE cell. The baseline energy model was then ‘adjusted’ accordingly. This can be seen by the dotted line in the chart above.

Note that there has been no adjustment between midnight and 7:00 am as the change in usage arises from the automated controls and hence we wish to claim these savings.

Using this approach, the winter baseline data was adjusted (in time, not in amplitude) to estimate the usage that would have occurred in October/November.

Calculating savings

Now that a like-for-like comparison has been achieved, savings were calculated by subtracting the post-retrofit measured usage from the adjusted baseline.

$$Energy\ savings\ (kWh) = \ adjusted\ baseline\ energy\ (kWh) - post\ retrofit\ energy\ (kWh)$$

The table below summarises the daily amounts for baseline, adjusted baseline, post-retrofit and energy savings across 12 like-for-like days.

Weekday	Baseline Usage (measured) (kWh)	Baseline Adjustments (kWh)	Adjusted Baseline (kWh)	Post Retrofit Usage (measured) (kWh)	Savings (kWh)
Tuesday	497.65	-10.67	486.98	341.15	145.84
Wednesday	503.87	-10.67	493.20	340.08	153.12
Thursday	511.32	-10.67	500.65	337.59	163.06
Friday	522.42	-11.55	510.87	333.25	177.62
Saturday	499.15	-11.55	487.60	332.90	154.70
Sunday	505.79	-11.55	494.24	332.79	161.45
Tuesday	493.03	-11.55	481.48	335.45	146.03
Wednesday	554.55	-11.55	543.00	346.81	196.19
Thursday	499.81	-11.55	488.26	337.22	151.04
Friday	502.95	-12.44	490.51	340.75	149.76
Saturday	498.23	-12.44	485.79	338.26	147.53
Sunday	501.33	-11.55	489.78	346.96	142.82
Total (12 days)	**6,090.10**	**-137.77**	**5,952.33**	**4,063.21**	**1,889.12**

Thus the measured energy savings across the 12-day measurement period is 1,889 kWh.

Extrapolating the savings

In order to estimate the annual savings, we need to develop an energy model based on power draw for different periods of each day. Reflecting on the daily load profile seen earlier, the lighting operates at two different demand levels.

One demand level corresponds with overnight and daytime usage, when a section of lights is not required to operate. The other demand level corresponds to the morning and evening periods where lights in the corridor are required to operate.

The 15-minute interval data was revisited and each time period was categorised as being either ‘in use’ or ‘’controlled’.

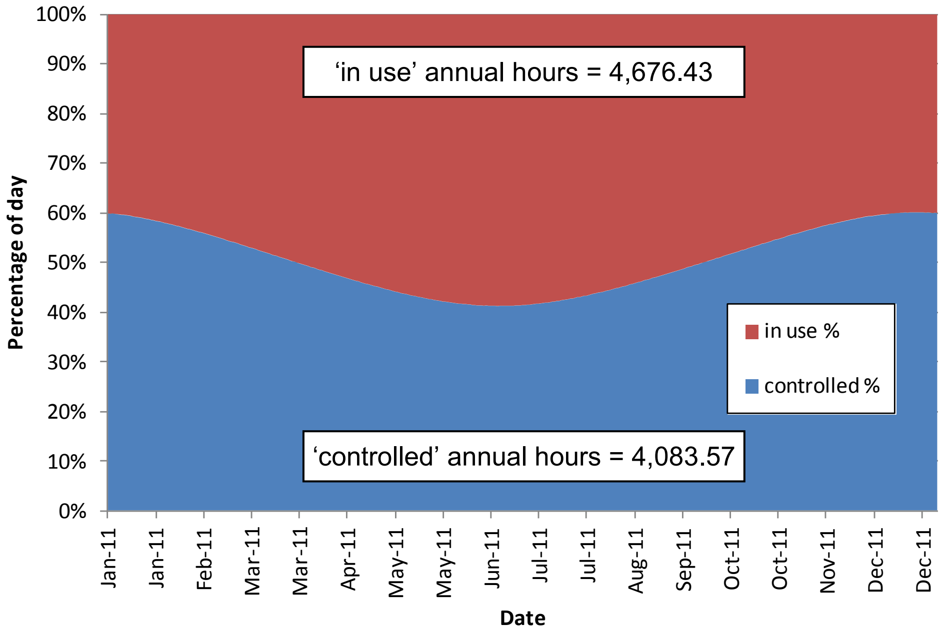
Average hourly energy use figures were then calculated for each category.

	Pre-retrofit		**Pre-retrofit**	
Category	**‘Controlled’**	**‘In use’**	**‘Controlled’**	**‘In use’**
Total Usage (kWh)	2861.27	3102.30	1958.23	2113.66
Total Hours	150	138	150	138
Average Hourly Use (kWh/hr)	19.08	22.48	13.05	15.32

Next, the annual hours of 'controlled' and 'in use' hours must be determined. To achieve this, 12 months of daily data for solar exposure was obtained from the Bureau of Meteorology and reviewed. Data for the calendar year 2011 was used so that it could be overlayed against the measurement periods.

The data relating to the post-retrofit period was examined to determine the timing in relation to daily sunrise and sunset which causes the PE cell to control the lights. Once this was known, the 12 months of data was segmented into 'controlled' and 'in use' categories.

The results are shown in the chart and data below.



Finally the 12-month extrapolated energy savings are:

$$Annual\ energy\ savings(kWh)$$

$$= 'controlled'\ average\ saving\ \left(\frac{kWh}{hour}\right) \times 'controlled'\ hours + 'in\ use'\ hourly\ saving\ \left(\frac{kWh}{hour}\right) \times 'in\ use'\ hours$$

$$= (19.08 - 13.05) \times 4{,}083.57 + (22.48 - 15.32) \times 4{,}676.43$$

$$= 58{,}017\ kWh$$

Cost savings are determined by multiplying the energy savings by the appropriate cost rate. The cost savings are:

$$Annual\ cost\ savings\ (\$) = \ annual\ energy\ savings\ (kWh) \times electricity\ cost\ rate\ (\frac{\$}{kWh})$$

$$= \ 58{,}107 \times \$0.15$$

$$= \$8{,}716$$

Reporting results

Estimated annual energy savings are reported as:

Component	Baseline	Post Retrofit	Savings
Energy	183,041 kWh	124,934 kWh	58,107 kWh
Cost	$27,456	$18,740	$8,716
Savings %			31.7%

The conservative savings are more appropriately quoted as 58,000 kWh and $8,700. The savings represent approximately 31% energy and cost savings against the baseline.

Note: uncertainty has not been calculated for this example.