Measurement and Verification Operational Guide

Best practice M&V processes

Contents

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) [1] 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?" [2]

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:

- 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
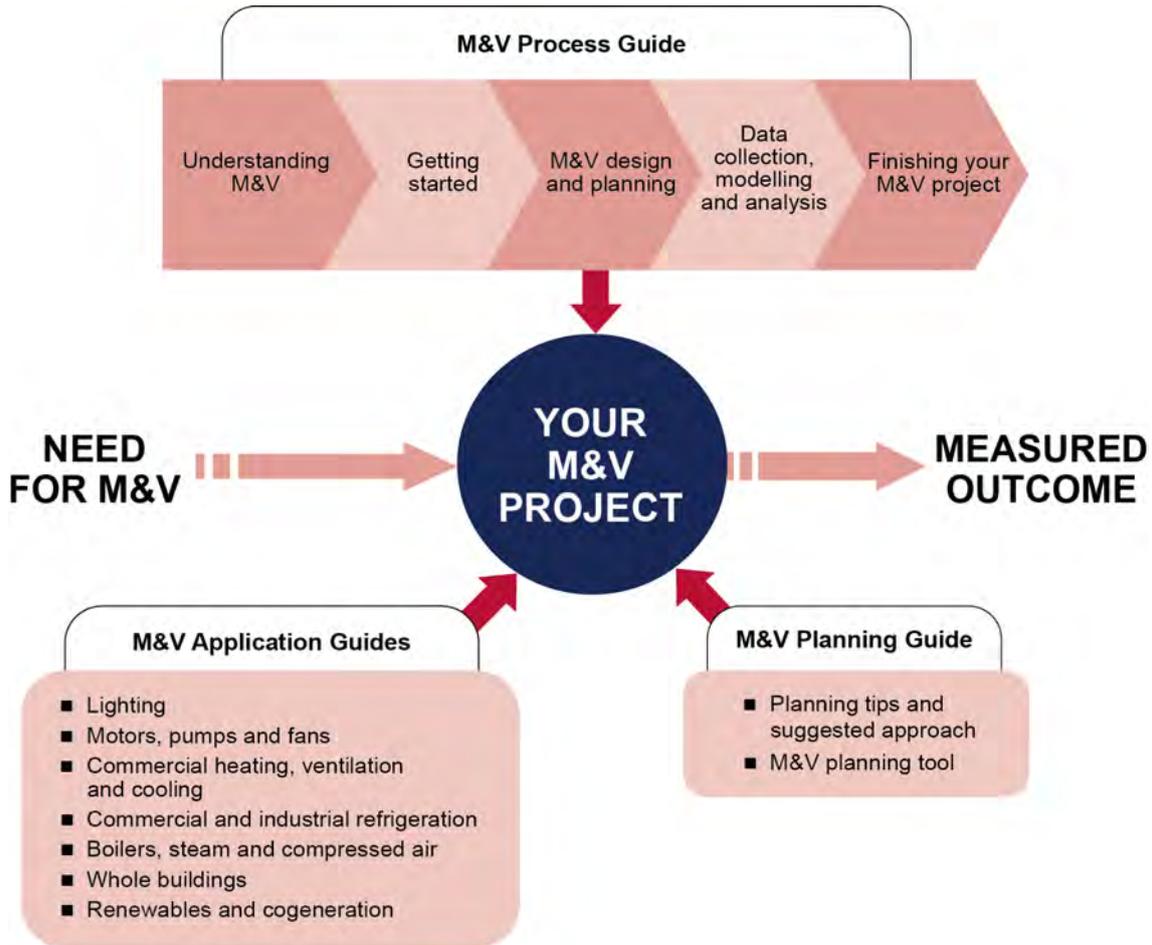
1.2   The Process Guide (this guide)

The *Process Guide* opens with a chapter introducing and describing key concepts, before providing an outline of a typical M&V process. The chapters that follow describe the stages in the M&V process and the elements that need to be considered to ensure a result that stands up to audit and management scrutiny.

2   Understanding M&V key concepts

While users of this guide should possess a basic knowledge of energy use in industrial and commercial applications, it is important to familiarise yourself with the foundational concepts and key terms used in M&V before commencing your M&V project. This chapter discusses the following concepts:

- measuring energy and demand savings,
- determining cost avoidance and greenhouse gas emissions reduction,
- key terms,
- calculating and reporting savings,
- developing an energy model, and
- addressing uncertainty.

Section 2.6 of this chapter outlines a typical M&V process: from understanding the nature of the energy conservation measure to be implemented, designing and planning, through to the post-retrofit analysis, modelling and reporting.

All subsequent chapters in the M&V Operational Guide directly map to the stages described in the M&V process.

2.1   Measuring energy, demand and cost 'savings'

Energy, water or demand savings cannot be directly measured since savings represent the absence of energy/water use or demand. Instead, savings are determined by comparing measured use or demand before and after implementation of an Energy Conservation Measure, making suitable adjustments for changes in conditions [1].

The effect of an ECM is best understood against the energy usage that would have occurred in a 'business as usual' situation had the ECM not been implemented. The chart below illustrates this concept.

Figure 2: Implementation of an ECM: measuring the savings achieved
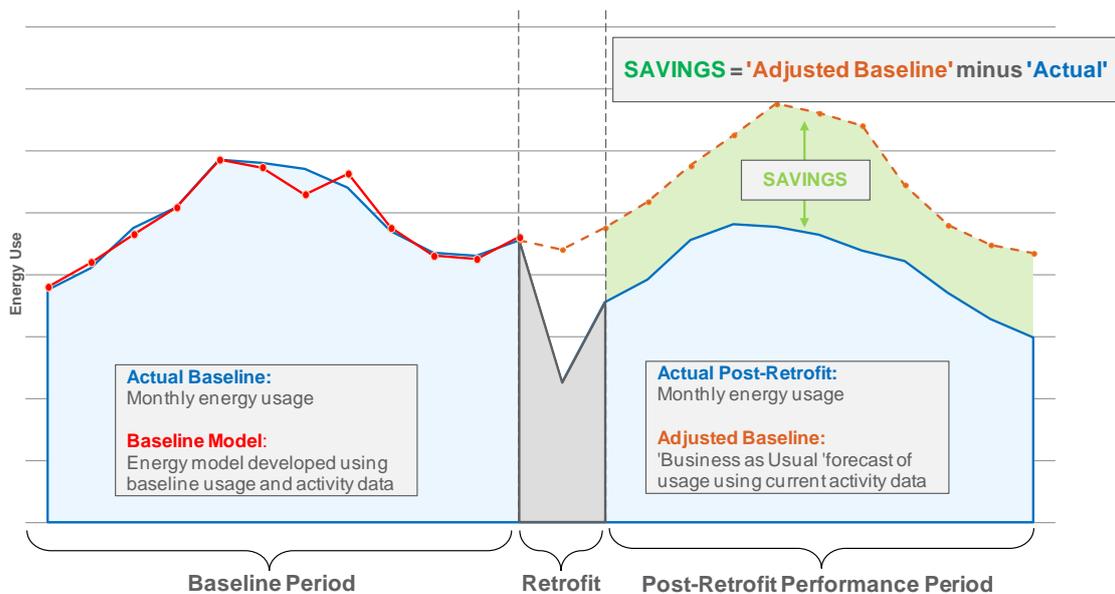
To understand the process described in the chart above:

Before the ECM is implemented

1. A period of time prior to the ECM implementation is selected and measured – this is the 'baseline period'.
2. During the baseline period, data is also collected for 'independent variables', which change on a regular basis, and have a direct effect on baseline energy usage patterns. Examples of such variables include changes in weather.
3. An energy model is developed to describe the relationship between baseline energy use, and the independent variables affecting energy use.

After the ECM is implemented

1. Once the ECM is implemented, data over a suitable period is once again selected and measured. This is called the **'post-retrofit' performance period**.
2. Data is also collected for the same independent variables for the post-retrofit period.

Calculating savings

1. A 'business as usual' forecast of energy use or demand is determined by adjusting the developed baseline energy model with data for independent variables from the post-retrofit period. This is known as the **'adjusted baseline'**.
2. Finally, savings are determined by subtracting the measured actual usage from the adjusted baseline.

Adopting structured M&V techniques is a powerful approach to verifying the impact of ECMs in the areas of energy and demand savings, as well as cost. Other areas of savings, such as reduced maintenance costs, are usually determined using other methods and data, and are not considered within this guide.

2.2   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 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,

M&V Term	Definition	Examples
		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.

2.3   Calculating and reporting savings

Formal M&V techniques are adopted to provide confidence in the accuracy of reported savings. As we will explore in this guide, by applying formal M&V techniques, practitioners are able to:

- Provide a savings figure that is based on a rigorous measurement process
- Incorporate adjustments for changes in site energy usage patterns to enable a 'like-for-like' comparison
- Demonstrate the uncertainty in that figure

As we have seen, the standard M&V practice includes a baseline within the post-retrofit period through adjustments. A standard savings equation is used for calculating savings from energy projects, which is shown below.

$Energy\ Savings\ =\ Adjusted\ Baseline\ Energy\ -\ Actual\ Energy$

AND

$Adjusted\ Baseline\ Energy\ =\ Baseline\ Energy$
$$\pm\ Routine\ Adjustments$$
$$\pm\ Non\ Routine\ Adjustments$$

where:

$\boldsymbol{Actual\ Energy} =$	Energy consumption measured during the post-retrofit performance period.
$\boldsymbol{Baseline\ Energy} =$	Energy consumption measured during the baseline period.
$\boldsymbol{Routine\ Adjustments} =$	Adjustments due to regular changes in independent variables (e.g. changing weather conditions, varying production levels).
$\boldsymbol{Non\ Routine\ Adjustments} =$	Once-off or infrequent changes in energy use or demand that occur due to changes in static factors (e.g. building facade changes, extreme weather events, building extensions and changes to equipment).

The inclusion of **adjustments is one of the critical elements of the M&V process**. This is the step often overlooked or ignored by practitioners seeking a quick and low cost outcome. The M&V process outlined within the IPMVP, on which this guide is based, aims to guide practitioners to consider and incorporate these adjustments.

For another view of the **standard savings calculation**, see the diagram below.

2.3

Figure 3: Process diagram of standard savings calculation
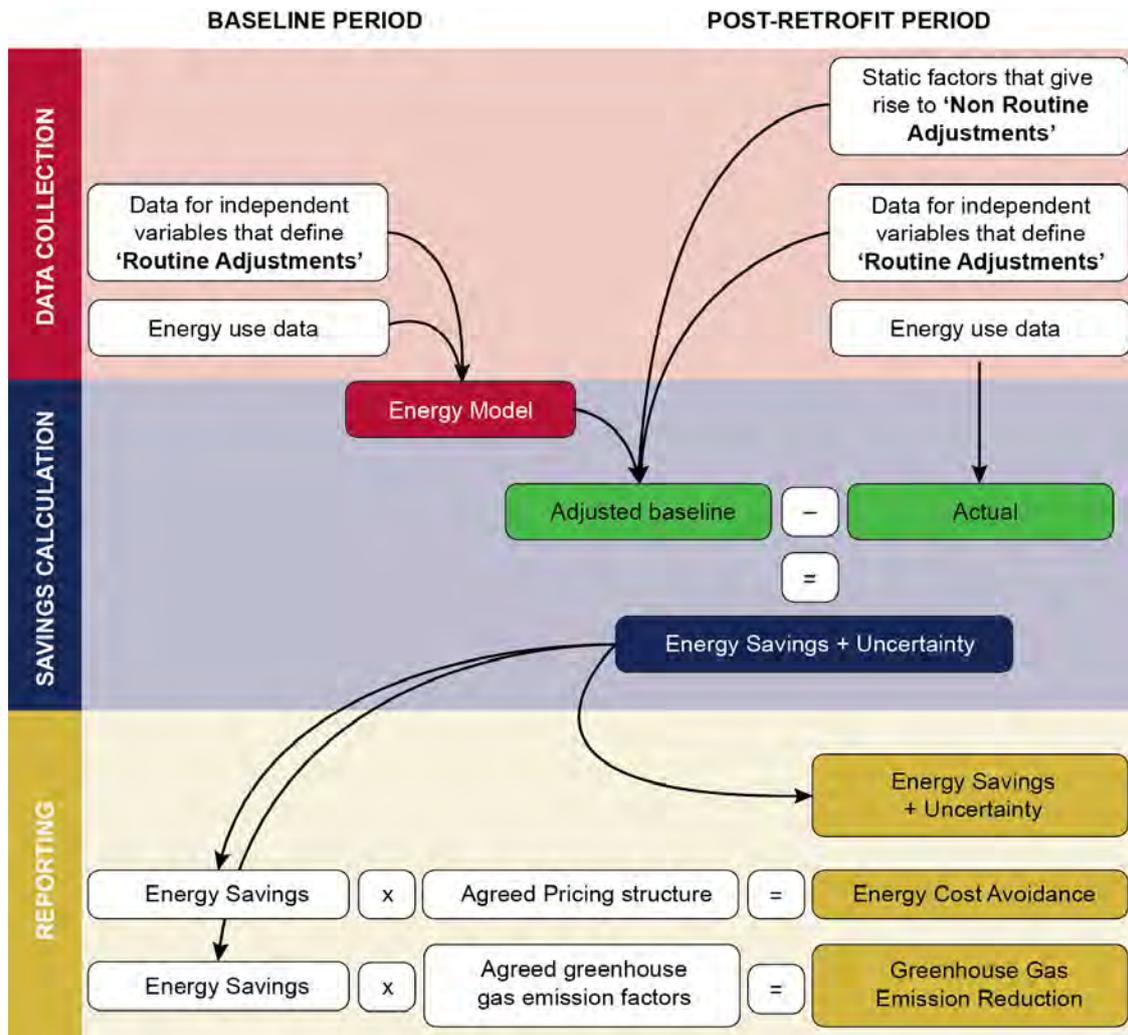
2.3.1 Cost avoidance and price risk

In nearly all cases an energy conservation measure's success is evaluated based on its financial returns as well as the energy that has been saved. A successful ECM will result in a financial benefit due to reduced energy use. This benefit is referred to 'cost avoidance'. Often a project will realise 'other financial benefits' which also help with improving the ECM's payback. Total project savings will often be expressed by its components, as follows:

$Project\ savings\ (\$) = Cost\ Avoidance\ (\$) + Other\ Financial\ Benefits\ (\$)$

Where:

$Cost\ avoidance\ (\$) =$ avoided energy costs due to the ECM

$Other\ financial\ benefits\ (\$) =$ include other areas of project savings, either once off or ongoing. Examples include reduced maintenance costs, avoided future equipment replacement, etc

Non-financial benefits may also be evaluated in order to determine the success of an ECM. Non-financial benefits may include improved comfort conditions, better product quality, increased productivity, improved reliability / reduced risk of failure, positive staff/customer impact, etc.

The focus of M&V (and this guide) is to accurately determine the energy cost avoidance. Within Figure 3 above we can see that the cost avoidance associated with an ECM is derived from the measured energy savings by applying an agreed pricing schedule.

The standard equation for cost avoidance is:

$$Cost\ avoidance\ (\$ = pricing\ structure \times (energy\ use_{adjusted\ baseline} - energy\ use_{actual})$$

In the equation above it is important to note:
- A baseline energy model has been adjusted for post-retrofit conditions (i.e. the adjusted baseline and the actuals span the same time period.
- The same energy pricing structure is applied to the adjusted baseline as well as the actual usage

In essence, this equation determines that amount of money saved through implementation of the ECM against the business as usual forecast had the ECM not been implemented.

Cost avoidance should not be confused with cost savings. The term 'cost savings' infers that energy costs post-retrofit will be lower than those within the baseline period. This simplistic view does not take into account:
- Changes in factors that determine energy use (e.g. changes in site activities, effects of independent variables such as production or weather, etc)
- Price risks such as changes to energy contracts, structures or tariff rates

The effects of these factors may result in a situation where energy costs rise despite a reduction in energy use. In this case there are no 'cost savings' however we can still justifiably claim 'cost avoidance'.

As the equation above highlights, cost avoidance is determined by applying an energy pricing structure to the measured energy savings, and results in the amount of money that the site has avoided spending on energy due to the ECM.

Refer to 5.5.4 for further explanation and suggested approaches for calculating cost avoidance.

2.3.2 Greenhouse gas emissions reduction

Another key driver for determining the success of an ECM is the achievement of greenhouse gas emission reductions. As with cost avoidance we seek to determine the like-for-like reduction in greenhouse gas emissions through direct measurement of greenhouse gas emissions, or more typically through indirect means involving emissions factors.

Refer to section 5.5.5 for guidance for estimating greenhouse gas emissions reductions.

2.4   Developing an energy model

An energy model is a method of describing the energy consumption patterns of a site or an energy system in the context of the independent variables affecting it.

An energy model is used for calculating adjustments to the measured baseline, so the effects of an ECM can be compared with this baseline on a like-for-like basis. To illustrate this idea, consider the diagram below:

2.4

Figure 4: Like-for-like comparison of actual vs. adjusted baseline energy use

1. The situation without adjustments …

Baseline ? Actual

What's happened?
On first inspection, it appears that both demand and usage have increased.

2. An energy model is developed to 'explain' and adjust baseline use …

Baseline

ENERGY MODEL
Increased operating hours
Higher occupancy

Adjusted baseline

By analysing independent variables it is clear that other factors have changed.
An energy model is developed to adjust for site changes

3. The 'adjusted baseline estimates BAU to enable like-for-like comparison …

Adjusted baseline Like-for-like Actual

A like-for-like comparison can now be made …

Savings

… and the difference is the savings

An energy model is very effective in providing a sound basis for a savings claim. Energy models may be simple or complex depending on the site's energy usage patterns and the variables that affect them.

2.5   Uncertainty

2.5.1   Addressing uncertainty

A key element of the M&V process is the desire to determine and express uncertainty, in addition to determining a savings figure. This may add extra effort and cost to a M&V project, yet quantifying the uncertainty enables the reader of a M&V report to understand the confidence behind a stated savings figure.

Quantifying savings uncertainty involves estimating the range of the inherent inaccuracy of the savings figures that have been developed within the M&V project, which are built upon various data sources, each with their own individual uncertainty. Uncertainty arises from physical limitations in our ability to determine the correct figure for a data item. These errors occur in data obtained from modelling, sampling and measurement and are due to equipment inaccuracies, sampling procedures and adjustment procedures. Uncertainty is a statistical estimate of the deviation from the stated value to its true value.

Estimating overall uncertainty involves understanding and calculating the uncertainty of individual data elements and combining them in a structured way by applying statistical methods.

2.5.2 Expressing uncertainty with precision and confidence

Uncertainty is represented by two elements; precision and confidence. The M&V process aims to minimise uncertainty through awareness and proper planning, as well as quantifying the remaining uncertainty of claimed savings so that the reader is aware of the accuracy of the figure. M&V savings expressions should include:

$$savings + precision + confidence$$

Precision is defined as "the amount by which a measured value is expected to deviate from the true value". Precision is expressed as a ± tolerance (e.g. ±2.7% or ±340 kWh).

Confidence level is defined as "the probability that any measured value will fall within a stated range of precision". That is, our confidence that the true value lies within the stated tolerance. Confidence is expressed as a percentage (e.g. 95%)

Example savings statements with uncertainty

Achieved savings are 55,000 MJ ± 3,200 MJ with 95% confidence

Achieved savings are 96,280 kWh ± 5.8% with 90% confidence

For the majority of examples and scenarios presented this guide uncertainty has been calculated in order to demonstrate the process.

Please refer to Appendix G for further guidance regarding the key concepts of uncertainty, key terms and parameters and equations to assist practitioners to calculate uncertainty. Examples of uncertainty calculations can be found within the scenarios in the various *Application Guides*.

2.6   The M&V process

Figure 5 below outlines a typical M&V process. To ensure that your M&V project meets best practice standards, the chapters that follow in this guide are organised according to the stages of the M&V process.

2.6

Figure 5: M&V process flow chart
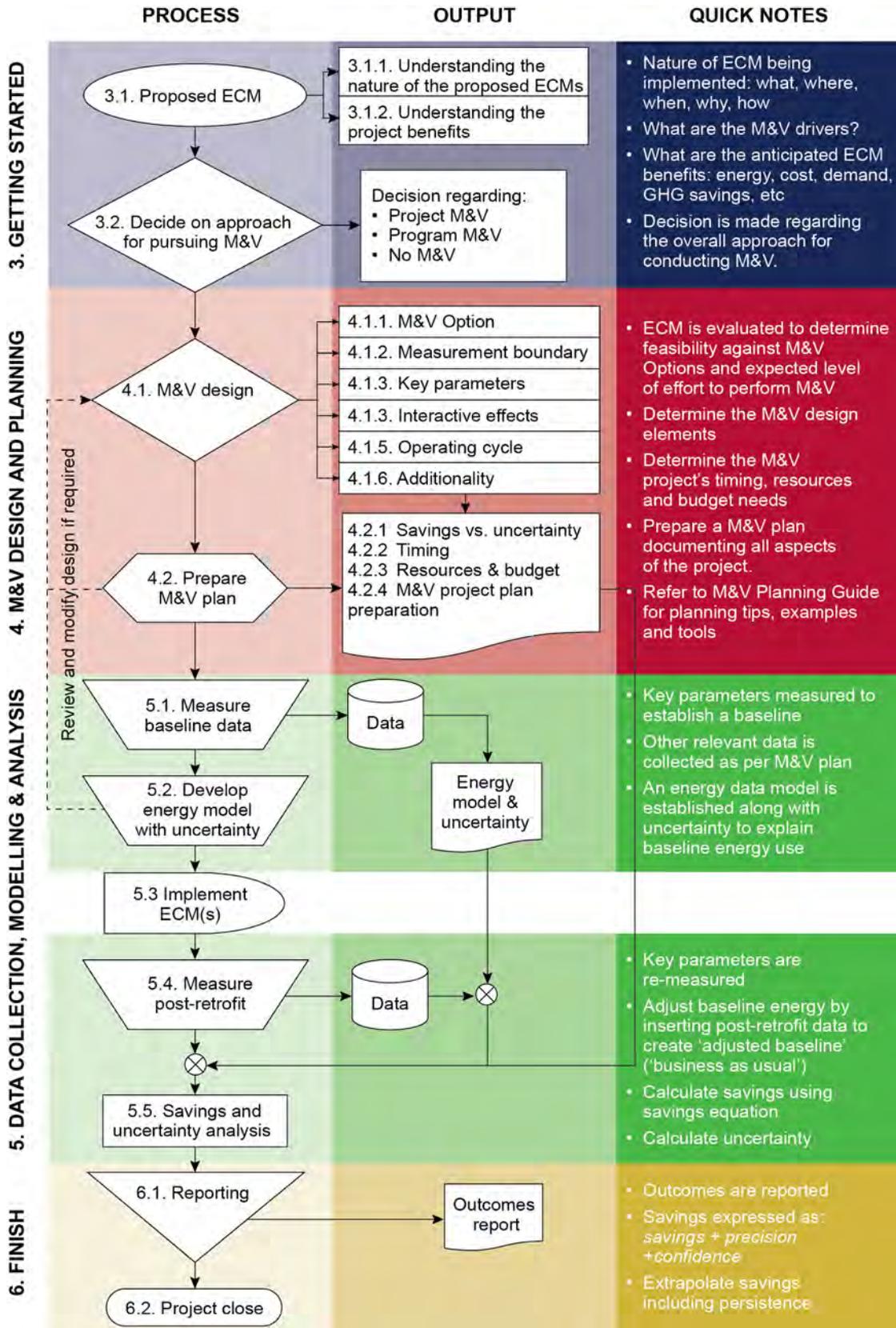
The elements within the flow diagram above are expanded in the table below:

Table 2: M&V process elements

3.1 Proposed Energy Conservation Measure (Start)	The process starts with a proposed ECM, which is typically identified during an energy audit or similar exercise. Available ECM details will include a description of the project, where it will be implemented and why. The expected outcome including estimated energy and demand savings should be known, and these will form the basis for M&V planning.
3.2. Decide on approach for pursuing M&V	The project is evaluated at a high level in order to determine the M&V drivers, whether M&V should be pursued, and if so what form should it take. Usually there are compelling reasons that prompt this decision and all that remains is to decide how to proceed. It may be necessary to spend time preparing an initial M&V design and plan so that the cost and timing can be evaluated within the decision to proceed.
4.1. M&V design	The proposed ECM and desired M&V outcome is reviewed to determine feasibility and expected level of effort to perform M&V. The ECM is evaluated against the available M&V Options (four generic approaches for conducting M&V as defined within the IPMVP) and potential constraints in order to determine the preferred approach. Other key M&V design elements for consideration include measurement boundary, key parameters, interactive effects, operating cycle and additionality. The selected M&V design will determine the project's resource needs in terms of equipment, personnel, budget, tasks and timing and may need to be reviewed to fit within the M&V constraints.
4.2 Prepare M&V plan	A M&V plan, similar to any other project plan is prepared. This plan documents the process and outcomes from the initial M&V planning stage, in a structured format, ensuring that the key details are captured. M&V plans contain: ▪ a description of the intended approach ▪ the M&V 'Option' and measurement boundary ▪ a description of how measurements will be conducted (parameters to be measured, when and how) ▪ details of any assumptions or stipulations ▪ details of variables that affect energy use and how adjustments will be calculated ▪ description of savings calculation methods and energy cost rates to be applied ▪ other basic project details (resources, timing, budget, inputs, and desired outcomes). M&V plans act as a guide for conducting M&V for the ECM and are very useful when preparing business cases or undergoing audit and verification.
5.1 Measure baseline data	The agreed M&V plan is put into action. The first step is to measure and collect the nominated data in order to determine the baseline, prior to ECM implementation. Measurement equipment is installed and calibrated as required, and measures the nominated 'key parameters' for the required 'baseline' measurement period. Data is reviewed and corrective action is taken for data errors or omissions.

2.6

5.2 Develop energy model and associated uncertainty	A baseline energy model is developed which relates the independent variable(s) to energy consumption. The inherent uncertainty of the energy model is quantified.
5.3 Implement ECM(s)	The ECM is implemented and commissioned, and steady state operation is achieved.
5.4 Measure post-retrofit data	The data measurement and collection process is repeated as per the M&V plan. This will typically be a repeat of the same measurements however it will depend on the nature of the ECM.
	As before, measurement equipment is installed and calibrated as appropriate and measurements are conducted for the 'post-retrofit' performance period. Data quality is reviewed and corrective action taken where errors or omissions are found.
5.5 Savings analysis and uncertainty	The baseline and post-retrofit datasets are analysed as per the M&V plan and the energy and demand savings are calculated. Components of uncertainty are combined and calculated to support the overall savings claim.
	Where actual savings are sought, the baseline is 'adjusted' by applying the developed energy model with post-retrofit data from independent variables to forecast an 'adjusted baseline' across the post-retrofit period. This is known as 'business as usual' forecasting. Actual data is subtracted from the adjusted baseline to determine savings.
	Alternatively, both the baseline and post-retrofit datasets are adjusted to the same set of conditions and 'normalised savings' are calculated.
	Adjustments may also be made to baseline or post retrofit data to account for non-routine adjustments, due to temporary or permanent changes in conditions. In many cases these are made through engineering calculations. Where these adjustments are complex and/or will significantly impact the savings analysis, then further measurement may be required.
	Savings may be extrapolated outside the measured period as defined in the M&V plan (e.g. to cover a full 12 months). This may be required where a short-term or sample based approach has been used to determine measured savings. This may involve the use of additional data, such as annual weather patterns, or historical production values.
6.1 Reporting	The savings results are reported as per the M&V plan. It is important that reports contain the savings result, as well as precision and confidence. Reporting may be once-off or ongoing depending on the plan and approach.
	Outcome reports may require a statement of an annual savings or similarly, results from a sample set may be extrapolated across a population.
6.2 Finish	The M&V project is closed out. Periodic review or further M&V may be conducted where there is uncertainty around the ongoing size or persistence of savings.

2.7   Timing, budget and resources

A M&V project runs in parallel with its corresponding ECM implementation project. From a timing perspective it is important that:

- Decisions to implement ECM and conduct M&V are aligned where possible to enable early planning and incorporate into overall design
- Adequate time is set aside for collecting baseline data and developing an energy model
- A valid energy model is established prior to the ECM being implemented. Failure at this stage may require additional data collection or a new M&V design.

Refer to Section 4.2 for further guidance regarding M&V project timing.

Like any project, a M&V exercise requires budget and resources. These are identified during the M&V design phase and costed as part of the planning process; as described in Sections 4.1 and 4.2. Required resources may include labour, equipment, software, or external specialists.

There is flexibility within the M&V design options to cater to varying budgets through choices of M&V Option and parameters to be measured.

2.7

3 Getting started with your M&V project

3.1 Proposed Energy Conservation Measure(s)

3.1.1 Understanding the nature of the proposed ECM(s)

It is important to review your proposed ECM(s) to understand the key elements so they can be incorporated into your M&V planning. Use the questions below as a guide for gathering information regarding the What, Where, When, Why and How as they relate to the site and the proposed ECM(s).

Table 3: Questions to answer to understand the nature of the proposed ECM(s)

	SITE	ECM	M&V IMPACT
WHAT?	What is the primary function of the site?	What type of ECM is proposed? In what way will it reduce energy, cost, and demand?	▪ M&V design ▪ Parameter selection ▪ Choice of boundary and M&V Option
WHERE?	Where is the site located and does it have a defined site boundary?	Where within the site will the ECM be implemented, and which systems/processes will be affected?	▪ Site access ▪ Choice of measurement boundary and M&V Option
WHEN?	When is the best time for collecting baseline data that fully represents the site?	When will the ECM be implemented?	▪ Timing ▪ Resourcing ▪ Availability to collect baseline data ▪ Frequency/time interval of collected data
WHY?	Why is M&V being sought? What are the drivers and intended outcomes?	Why is the ECM being implemented and what are the expected benefits?	▪ Inform M&V planning ▪ Tailored outcome ▪ Accuracy ▪ Record keeping
HOW MUCH?	How much does the site spend on energy?	How much can be spent on M&V based on expected savings, project costs or approved budget?	▪ M&V Budget ▪ Overall approach and option

3.1.2 Understanding the project benefits

The matrix below lists project types with examples, and indicates the energy, demand, cost and other environmental benefits that may result.

3.1

Table 4: Project types and expected benefits

Project type	Project benefits				
	Energy savings	Energy cost savings	Electrical demand savings	Electrical demand cost savings	Other benefits
Efficiency improvement Example: ▪ Lighting retrofit/dimming ▪ Chiller replacement ▪ Gas burner replacement	Yes Improved efficiency for performing the same task	Yes Based on energy reduction x tariff based unit prices	Largely yes	Perhaps Consider the coincidence of ECM demand savings in context of overall site demand profile	Greenhouse savings
Time/demand based control Example: ▪ Lighting occupancy control (movement, PE) ▪ HVAC time schedules ▪ Car Park CO control ▪ VSDs on motors ▪ Compressed air leak reduction	Yes Reduced operating hours	Yes Based on energy reduction x tariff based unit prices	Perhaps Only when equipment is not operating	Perhaps Consider the coincidence of ECM demand savings in context of overall site demand profile	Greenhouse savings
Load shifting Example: ▪ Moving batch processes to off peak periods ▪ Chilled water storage	No Simply moving loads does not save energy	Yes Based on relative tariff based unit prices for different usage periods	Typically yes Moving loads to after hours, when demand is generally lower	Typically yes Demand charges may only apply within 'peak periods'	Improved load factor Ability to downsize equipment Reduced strain on electrical infrastructure
Fuel switching Example: ▪ Cogeneration, Solar hot water ▪ LPG fuel conversion	Yes or no Dependent on fuel energy content per input unit Dependent on view towards renewable as being 'free'	**Yes or no** Dependent on relative fuel pricing and fuel quantities	Yes Removing electrical loads	Yes Removing electrical loads	Greenhouse savings
Increased throughput Example: ▪ Increasing the output of a boiler that loses heat with a constant flux (W/m^2) will result in lower losses per unit of production	No Energy use is unchanged	No Energy use is unchanged	No Demand is unchanged	No Demand is unchanged	Lower cost per unit output

3.1

3.2   Deciding on an 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. Project managers have three choices when pursuing M&V:

1. Conduct project-level M&V using approaches outlined in this guide
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.

on the following page can be used as a decision making tool to decide on the form of the M&V project.

Certainly, where there is no need to prove results, or the outcome can be predicted with a high degree of certainty, then M&V may not be required. As the case example below highlights, many 'typical' ECMs cannot necessarily be predicted with certainty, and the business case for M&V at a project and/or program level is often compelling.

Case example

A major retailer engaged a contractor to implement an Energy Conservation Measure (ECM) involving the installation of new controls for its refrigeration display cabinets at a pilot site, prior to rolling out across its portfolio. The contractor completed the installation and informed the retailer.

In preparation for a broader roll out, the retailer was interested to verify how the ECM performed against the initial engineering estimates, and so embarked on a M&V exercise. M&V was conducted on the ECM, and no savings were found. After initially questioning the data collection techniques, further data was reviewed with the same result.

The retailer requested that the contractor investigate further, and it was found that the controller had not been commissioned properly, and usage patterns had not changed, as verified via M&V. Remedial work was carried out and a second round of post-retrofit data demonstrated the expected 15% site saving.

Although the M&V exercise had to be repeated, it achieved a valuable outcome, and highlights the value of evidence over assumption.

Figure 6: Decision tree to determine the form of the M&V project cost

M&V Context, Considerations and Understanding

Site / Project	**Drivers**	**Cost / Resources**
Size, complexity, calculated savings and associated uncertainty, timing, data availability	What do you need to know, why is M&V important, what additional driver or external requirement is prompting M&V?	Are resources and equipment available and accessible to conduct M&V? What M&V budget is available; is this adequate?

Project level M&V Justification

Project level M&V may be justified when:

- External requirements or internal drivers exist
- Supports contract evaluation or business case
- M&V is a need-to-know
- Need to reduce risk and uncertainty for large projects
- M&V funding is accessible
- M&V costs is 10% of first year savings or less

Justified

Not justified

Program level M&V Justification

Program level M&V may be justified when:

- Applies for EE program managers / ECM implementers
- Large, multi-site organisations
- A 'population' can be established
- Long-term implementation timeframe
- M&V program can be adequately resourced and coordinated
- M&V costs can be apportioned across the population
- M&V costs is 10% of first year savings or less across the population
- Policy significance/strategic benefit to justify M&V costs greater than 10%

Not justified

Justified

Project Level M&V

- Evaluate ECM and site
- Understand M&V process
- Use this guide to plan M&V
- Review available M&V Options
- Conduct M&V and report

Program Level M&V

- Select sample projects
- Use this guide for each project
- Conduct M&V and report as per project level M&V
- Conduct further analysis on population
- May require additional data
- Report outcomes in relation to population

No M&V

- Confirm that ECM is operating via commissioning
- Use indirect data to 'deem' savings
- Use engineering calculations to estimate savings

3.2

4   M&V design and planning

There are four available M&V Options, or methodologies, for performing M&V under the IPMVP. The most appropriate Option is chosen by reviewing the proposed Energy Conservation Measure to determine the feasibility and expected level of effort to perform M&V. Other key M&V design elements require decisions on the project's measurement boundary, key parameters, interactive effects, operating cycle and additionality.

Once the design is finalised, a plan should be developed. The selected M&V design will determine the project's resource needs in terms of equipment, personnel, budget, tasks and timing and may need to be reviewed to fit within the M&V constraints.

4.1   M&V design

4.1.1 M&V Option

Standard approaches for using measurement to verify the savings results of energy conservation projects have emerged following years of trial, testing and application. These are specified within the International Performance Measurement and Verification Protocol. The IPMVP specifies four generic approaches from which practitioners can choose when planning and conducting M&V. These are known as Options A, B, C and D.

Options A and B isolate the energy use of a piece of equipment, process or functional area and are used in conjunction with an ECM-based measurement boundary. Options C and D are used to measure the effects of one or more ECMs on total site energy usage, and are used in conjunction with a facility boundary.

The four Options provide M&V practitioners with flexibility based on particular ECMs, desired accuracy, data requirements, timing and M&V costs. The nature of the four Options, including appropriate use and best applications, are explored throughout this guide.

The table below describes the four M&V Options available.

Table 5: Available M&V Options

| Option	Title	Savings determination	Measurement	Considerations
A	Key parameter measurement	Savings are determined by measuring the performance parameters that will have the *most* influence on the savings calculation. Savings are calculated by combining measured values with estimates.	Measurement frequency ranges from short-term to continuous depending on the expected variations in the measured parameter and the length of the reporting period. Measurements of the same parameter must occur in the baseline and post-retrofit periods.	Any remaining parameters are estimated, using historical data, manufacturer's specifications or engineering judgement.
B	Full parameter measurement	Savings are determined by measuring energy use and all variables affecting energy use within the measurement boundary.	Measurement frequency ranges from short-term to continuous depending on the expected variations in the savings and the length of the reporting period.	Option B provides greater certainty of savings versus Option A.

Option	Title	Savings determination	Measurement	Considerations
C	Whole facility	Savings are determined by measuring energy use at the whole facility or sub-facility level. Actual cost savings can also be determined. Option C is for ECMs where expected savings are high compared to site energy use, and where measurement periods are long.	Continuous measurements of the entire facility's energy use are taken throughout the reporting period. This option typically makes use of existing utility meters and/or energy invoices and the combined effect of all ECMs is determined. An energy model using techniques such as regression is developed spanning the baseline period, which is adjusted for the post-retrofit period.	The primary challenges with Option C are to identify and incorporate all routine and non-routine adjustments, as well as ensuring that the savings are large enough (10% or more) when compared to the site's energy use.
D	Calibrated simulation	Savings are determined through simulation of the energy use at the whole facility or sub-facility level.	Simulation routines are demonstrated to accurately model actual energy performance measured at the facility. Computer simulation software is used to predict energy use once detailed information is entered covering building facade, installed equipment, operating patterns and external variables such as weather. ECMs can be evaluated as a group, or individually, where multiple simulations are run. The simulation needs to be calibrated against actual monthly energy use and demand. Matching annual totals is insufficient.	Option D is useful where baseline data does not exist or is unavailable. The primary challenges are to develop an accurate simulation and to calibrate it against measured energy data. Specific software modelling skills and careful documentation is required.

Choosing the most suitable M&V Option will depend on a range of factors. Considerations include the following.

- Baseline data exists or can be made available.
- Expected savings are greater than 10% of total energy use within the measurement boundary.
- Continuous energy use measurements are available through utility metering and/or energy invoices.
- The ECM(s) can be isolated within the measurement boundary using appropriate measurement equipment.
- Energy use within the measurement boundary and all variables affecting energy use can be measured.
- There is a single or multiple key parameters that will have the most influence on the savings calculation.
- Parameters not measured directly can be estimated with an acceptable level of uncertainty.

4.1

Figure 7 illustrates the M&V Option decision flow chart which can be used as a guide when determining the most appropriate M&V Option to use when verifying savings from ECM projects.

Figure 7: M&V Option decision flow chart
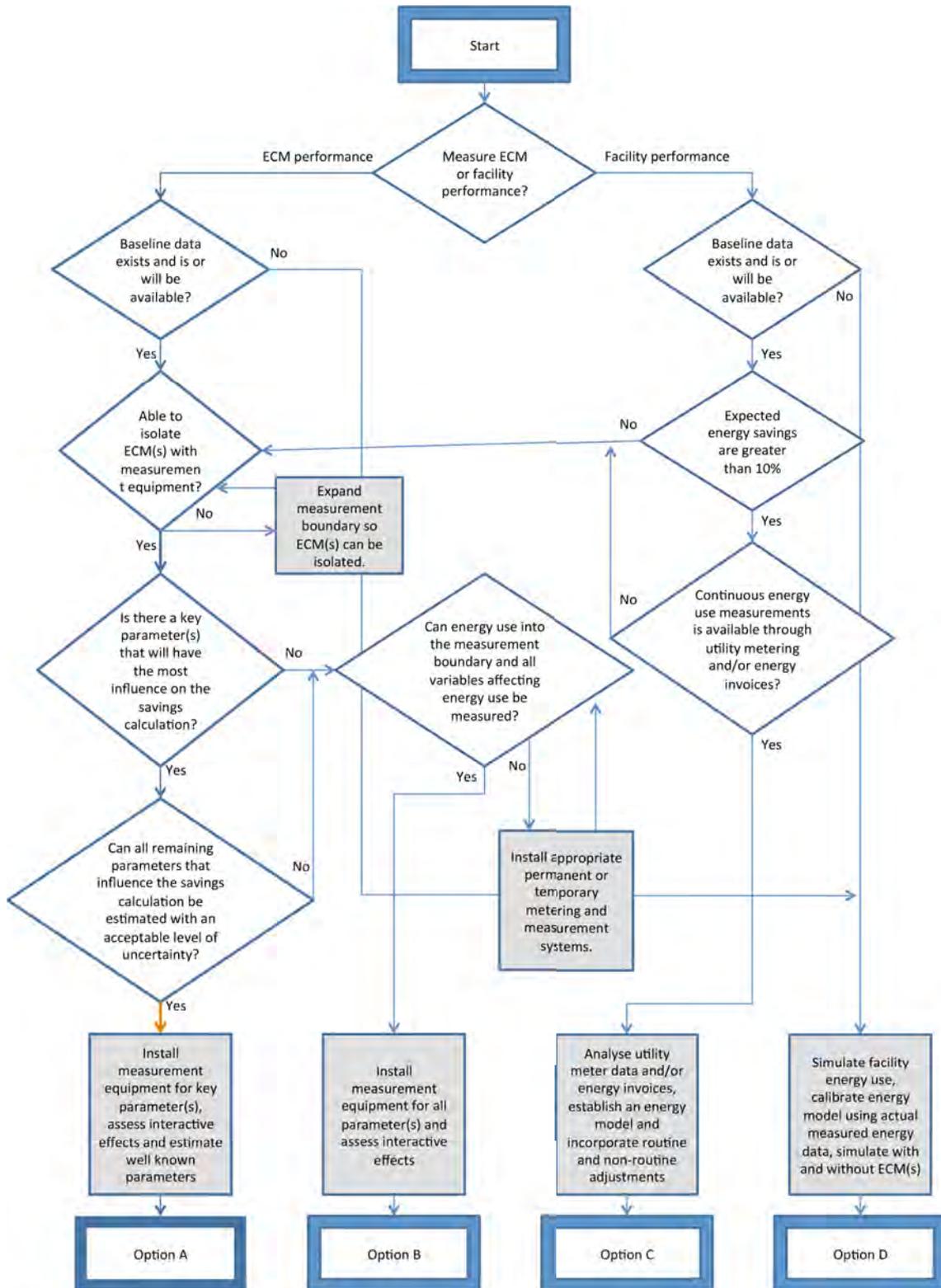
(Adapted from IPMVP volume 1, 2012, Figure 4)

4.1

4.1.2 Measurement boundary

Savings projects implemented at sites often apply to a portion of a site; usually a specific functional area, energy system or piece of equipment. In order to employ M&V techniques to effectively evaluate the *before* versus *after* effects of an ECM, we need to establish a consistent boundary which serves as a common reference point for conducting measurement and for claiming savings. This is defined as a measurement boundary.

> A **measurement boundary** is a notional border drawn around equipment and/or systems that are relevant for determining the savings achieved by an ECM.

Measurement boundaries are defined to include site areas affected by an ECM for the purpose of conducting M&V and to isolate or segregate unaffected areas. Excluding those areas which may introduce uncertainty enables us to focus on the specific effects of the ECM.

In summary, a measurement boundary is used to:

- define the metering points – all energy use within the boundary should be measured
- define the scope of any adjustments – all independent variables and static factors can be identified
- exclude energy use or influencing variables not affected by the ECM – remove the unnecessary complexities to simplify the process and results calculations
- provide a reference point in order to calculate savings based on a like-for-like comparison

Once the measurement boundary is defined, the M&V exercise is performed on the energy system within it, and the savings are calculated and reported.

Measurement boundaries as applied to the four M&V Options

Within M&V practice there are two measurement boundary choices available, which are described below. These are linked to the four IPMVP Options as follows:

Table 6: Measurement boundary and available M&V Options

Measurement boundary	Available M&V Options
ECM boundary using retrofit isolation	Options A and B
Facility boundary	Options C and D

Facility and sub-facility boundaries

A facility boundary is as simple as it sounds. Energy use within the entire facility or a large portion of it is assessed, usually involving readily available data from a utility meter, energy invoices or sub-meter.

Facility boundaries may also extend beyond a single address to encompass a precinct of buildings (e.g. ECM(s) involving district heating or cooling, or street lighting upgrades).

ECM boundaries, defined using retrofit isolation

Retrofit isolation involves the narrowing of the measurement boundary to wrap tightly around the system, area or equipment affected by an ECM. The purpose is to reduce the effort required to understand and incorporate independent variables and static factors that affect site energy use but are unrelated to the ECM. Tightening the measurement boundary typically requires additional metering at the boundary edge which may lead to increased M&V cost. In contrast a more accurate result may be obtained by avoiding sometimes complex and unrelated energy usage.

4.1

ECM related boundaries are generally defined in reference to:
  I. a piece of equipment (e.g. a pump or fan, compressor, lighting circuit).
 II. a physical space (e.g. room, floor, production line)
III. an energy system (e.g. ventilation system, condenser water loop)
IV. a combination of i. to iii.

Selecting a measurement boundary

The selection of a measurement boundary is achieved by reviewing the nature of the ECM being implemented. M&V planners will typically consider the following:

- where it will be implemented (e.g. a circuit, room, pump, etc)
- the equipment or system affected (e.g. crusher, condenser loop, etc)
- the expected outcome (e.g. reduced hours, higher efficiency, higher output, etc)
- the variables that may impact the outcome (e.g. production, occupancy, weather, etc)
- the size of the expected savings
- the metering requirements and available data sources
- the available M&V Options
- the M&V project aims and budget.

More than one choice may be available. An evaluation should be made in the context of broader M&V planning.

A boundary is practically determined to single out the physical aspects of the site impacted by an ECM. For example, an ECM may result in savings that represent a high proportion of overall site energy use, even with a small boundary. Where an ECM affects more than one system or area, we need to include those within the measurement boundary.

The table below summaries the best applications for ECM and facility boundaries:

Table 7: Boundary types and applications

Boundary type	Best applied when...
Retrofit isolation – ECM boundary	- the focus is on the ECM only - interactive effects can be easily estimated or ignored - the facility is complex and difficult to analyse - multiple ECMs fit within the same boundary or can be totally separated - independent variables can be easily monitored - sub meters already exist to isolate and monitor energy use - measurement of parameters is less costly than modelling or attempting to calculate facility adjustments - short term M&V is sufficient - savings will be small when compared with the overall site energy use - cost savings can be estimated rather than being reconciled to invoices
Facility boundary	- the focus is on the whole facility - multiple ECMs across different energy systems are being implemented - ECMs involve activities where energy use is difficult to separately measure e.g. glazing or shading, operator training) - savings are large when compared with the overall site energy use - various ECMs are being implemented across a long period of time - M&V of individual ECMs is not required - non-routine adjustments can be easily identified, estimated and incorporated - a suitable correlation between energy use and independent variables can be established.

Example boundary statements

When documenting a measurement boundary, we wish to describe the physical border within which to conduct our M&V exercise, using words and/or diagrams, in a manner that should be clear to a casual reader who has a basic familiarity with the site.

The table below provides four example boundary statements for four separate M&V projects:

Table 8: Example measurement boundary types and statements

Measurement boundary type	Example boundary statement
Equipment	"The measurement boundary consists of the two 11kW pumps and associated motors that supply the irrigation system. These pumps are located in the pump room B2, within the maintenance building."
Energy system	"The measurement boundary consists of the tenant condenser water loop, which includes the following components: ▪ Condenser Water Pumps 3 & 4 and associated motors ▪ Cooling Tower B ▪ The condenser water loop, which is a closed loop between the Level 18 plant room and the basement with access points at each floor. The following components are excluded from the measurement boundary: ▪ Cooling Tower A - it is an emergency back up only ▪ Tenant air conditioning units connected to the condenser water loop."
Functional area	"The measurement boundary is the gymnasium (room W2-21), located on Level 2 of the Winchester Building on the main campus."
Facility or sub-facility	"The measurement boundary is the commercial office building located at 921 Arthur Street, Greystanes. The building consists of 9 storeys of A-grade office space, with a basement level car park. The building is supplied with electricity via a single utility meter located within the main switch room, supplied with natural gas via a single utility meter located at the north-east corner of the property boundary."

Examples of measurement boundaries can also be found in Appendix A and the scenario examples included within each M&V *Applications Guide*.

4.1.3 Key parameters

To effectively apply the savings formula we need to measure and sometimes estimate data. The data types we collect for this purpose are known as key parameters.

Key parameters refer to the data types that are measured or estimated in relation to a defined measurement boundary for measuring and verifying the impact of an ECM and calculating savings.

Key parameters are the data types which will be measured or estimated to:

1. calculate baseline and post-retrofit energy use
2. determine the size of adjustments, and
3. calculate energy savings.

In the context of performing M&V, key parameters consist of:

1. **Energy usage** – the amount of energy used within the measurement boundary, before and after.
2. **Independent variables** – the variables that cause routine changes in energy use, which must be incorporated as routine adjustments in a M&V savings calculation.
3. **Static factors** – the factors related to infrequent events that may cause a material change in energy consumption.
4. **Performance outputs** – the measures by which the usefulness or efficiency of the energy system can be judged.

Note that we are only interested in the parameters that relate to the energy use within the measurement boundary. We don't need to monitor parameters that only have scope outside the chosen boundary.

Decisions regarding choices for key parameters and independent variables overlap with decisions regarding choices for measurement boundaries and the M&V Option. Decisions may also be influenced by the availability of relevant data.

Energy use

Energy use is measured or estimated to determine baseline and post-retrofit energy use of the system within the measurement boundary. It is usually measured, as it is the change in energy use that is most relevant.

Energy use parameters include:

- metered energy use for each fuel type
- a combination of power draw (instantaneous power) and duration (operating hours).

Other parameters to consider within this category include demand and power factor, which may be specifically required for particular ECMs (e.g. demand management or power factor correction projects).

In principle it is the net energy use at the measurement boundary that is important. This may involve measuring not only energy consumption, but also energy production.

By treating the energy system within the measurement boundary as a 'black box', energy transformations and interactions within the boundary may be disregarded[1].

Independent variables

Independent variables refer to regularly changing parameters affecting a site's energy use. These may be environmental or operations based, including:

- nature based – e.g. ambient temperature, humidity, rainfall, wind speed/direction
- site specific – occupancy, operating hours, visitors/customers
- system specific – production line output, raw materials (purity, moisture, etc).

From a M&V perspective, identifying and incorporating independent variables is an important step to ensuring a like-for-like comparison.

The impact of the variables on energy use may be random, cyclical or changing according to predetermined patterns. The location of the variables may be external to a site or within the site, though not necessarily within the measurement boundary.

---

[1] Energy flows within the boundary are considered during an energy audit or assessment process undertaken to quantify the ECM.

To identify independent variables, consider the following:
- nature of the energy system within the measurement boundary
- the energy system's historical energy consumption patterns
- primary function of the energy system and how energy use is controlled. This may involve manual or automated controls involving sensors that provide feedback to adjust outputs from the system, and energy use (e.g. movement, temperature, pressure sensors).

Collecting data for independent variables and relating this data to the corresponding energy consumption enables us to construct an energy model that explains changing energy consumption patterns. Further collection of data enables us to calculate the size of routine adjustments for the 'adjusted baseline' energy use for comparison with 'post-retrofit' energy use.

When data for an identified independent variable is difficult to obtain, surrogate/proxy data can be used.

Independent variables should be measured over the same period of time as the energy use measured, to ensure the correct adjustment of energy usage. For example, energy use in September should be compared to production output in September.

Static factors

Static factors refer to less regular changes or events that may affect a site's energy use temporarily, periodically or permanently.

Static factors may be internal or external. Examples of static factors include:
- extreme weather events – e.g. flooding, cyclone
- planned maintenance schedules – e.g. planned shutdown
- changes in the nature of a site due to project phasing – e.g. construction
- change in site behaviour
- site additions, renovations or refurbishments – e.g. facade, additional space
- equipment changes.

The presence of static factors may require non-routine adjustments to enable like-for-like comparison. If their effects on energy use are temporary, they may be avoided by adjusting the baseline or post-retrofit measurement period.

Performance outputs

Performance outputs refer to the energy services (e.g. lighting levels) produced by the energy system within the measurement boundary. These parameters need to be considered in different ways depending on the nature of the ECMs.

- If an ECM seeks the same performance from an energy system using less energy – once this has been verified during implementation and commissioning, the performance aspects of the ECM can be ignored within the M&V scope. For example, lighting retrofits aim to replicate or improve lighting levels whilst reducing consumption. Once satisfactory lighting levels are confirmed, they are typically ignored from a M&V perspective.
- If an ECM seeks to eliminate excess consumption due to 'wastage', the reduction in performance output should be measured and the acceptability of the reduced level output should be verified. Looking at lighting once again, an ECM may involve delamping selected fittings. The overall effect is less light output for less energy use with no efficiency improvement in system performance. However this project is reducing *excess* lighting, and becomes a valid savings project, assuming that the post-retrofit lighting levels are acceptable.

4.1

- If an ECM aims for an increase in performance outputs with or without a reduction in energy use – the change in performance output should be included within the M&V scope. An example of this is an ECM that may result in higher production throughput, rather than a direct energy saving. In this case, the production data becomes a key parameter and is used to adjust the baseline energy usage to estimate the usage for the higher production levels.

Example

Consider the parameter 'lighting levels' within the following lighting projects:

- **Fixture replacement or delamping:** The ECM involves replacing inefficient or removing excess lamps/fixtures. Baseline and post-retrofit light levels are fixed (although potentially different). Lighting levels will be assessed as part of the implementation to ensure adequate conditions are met. In this case, the ECM may or may not have affected lighting levels; however observed light levels are not a variable affecting energy use.
- **Occupancy based controls:** The ECM involves installing movement detectors, to switch off lights when rooms are unoccupied. Fixtures and light levels have not changed, and this is not a variable affecting energy use.
- **Dimming and daylight control:** The ECM involves controlling light fixtures by either dimming or switching off according to the available ambient light levels. In this case, the amount and duration of available natural light directly affects the need for artificial lighting. Fixtures and artificial light levels have not changed, and this is not a variable to consider. Rather, available natural light is the variable affecting energy use and should be considered as a key parameter.

As can be seen above the nature of the ECM has a direct effect on the choice of key parameters.

4.1.4 Interactive effects

Site energy use usually occurs through several energy systems or processes. Some systems may operate in isolation whilst others interact with each other or are affected by the same independent variables.

Example

- Within a commercial building, interior lighting produces heat as well as light, which the air conditioning system may be required to remove or augment. Similarly, both the lighting and air conditioning systems are dependent on the size and positioning of windows, affecting the amount of available natural light and solar heat gain.
- Within a manufacturing site, the output from one production line may be an input to another.

When we conduct M&V for an ECM, we define a measurement boundary which forms the basis for assessment, as described in Section 4.1.2. Ideally this boundary is straightforward to define as the effects of the ECM rest entirely within a single piece of equipment or energy system.

In other cases, we need to consider where energy systems overlap and the corresponding effects of the ECM across affected systems.

The effect that an ECM will have on energy use outside the defined measurement boundary is described as an 'interactive effect'.

4.1

'**Interactive effects**' refer to the effects on energy usage **outside the M&V measurement boundary** which occur as a result of implementing an ECM.

Addressing interactive effects

When planning a M&V exercise, we can address interactive effects in the following ways:

- Ignore – if the effect is minor and results in an added benefit, it may be ignored.
- Estimate – if the effects are small to moderate and can be estimated using available data or previous studies. This must be flagged in reports.
- Include within the M&V exercise – if the effects are moderate to large or are difficult to determine then consideration should be given to expanding the measurement boundary to include the affected system, so they are no longer an interactive effect.

The final choice should be made on the basis of relative size and uncertainty of the interactive effect, as well as the impacts on the M&V project by expanding the measurement boundary to incorporate them. If the measurement boundary can be expanded to encompass interactive effects there is no need to estimate them.

One available approach is to adopt a facility boundary, which is far less susceptible to the presence of interactive effects.

The examples below highlight the need to assess interactive effects in the context of the ECM, the measurement boundary and the site.

Example 1: Lighting retrofit – conference room

An ECM is proposed in which a conference room fitted with 50 watt dichroic downlights is retrofitted with 9 watt LED downlights. The M&V measurement boundary has been chosen to be the lighting circuits that feed the conference room. The building itself is located in a moderately warm climate and has a central air conditioning system that operates year-round to remove excess heat.

In this situation, the inefficient incandescent lights have been replaced with higher efficiency lights that produce more light per watt and hence less heat. In addition to the energy savings from the reduction in lighting load, the air conditioning will also benefit from a reduced cooling load, yielding further savings.

This reduction in heat will affect the energy use of the air conditioning system, reducing cooling loads, but potentially increasing heating requirements. Due to the choice of measurement boundary, the energy savings associated with the air conditioning are considered to be an interactive effect.

Should these savings be significant, there is the option of creating a second M&V project for the air conditioning system, or expanding the original measurement boundary to incorporate both.

Example 2: Lighting retrofit – car park access

Suppose the site above carries out a similar retrofit within the staff access-way to the basement car park. As before, the M&V measurement boundary has been chosen to be the lighting circuits that feed the lights.

In this situation, although there has been a reduction in heat load due to higher efficiency lighting, the area is not air conditioned, so there is no interactive effect to consider

4.1

Interactive effects should be incorporated within the measurement boundary where feasible.

4.1.5 Operating cycle

In all but the most stable situations, changes in energy usage patterns within a site or energy system are due to the presence of independent variables, which often occur in cycles. The time period over which one full cycle occurs is known as an 'operating cycle'.

> An **operating cycle** refers to the average time period for a site or energy system to witness one complete cycle of energy usage patterns due to the effects of key influencing variables.

From a M&V perspective, it is important to understand these cycles as this will affect the period over which measurements are taken.

A site may have several operating cycles each for a different functional area or energy system. Some example operating cycles are listed below.

Table 9: Example operating cycles

System	Independent variable	Typical operating cycle
Commercial building air conditioning	Weather conditions / ambient temperature	12 months
Interior lighting	Occupancy, business hours	2-4 weeks
Swimming pool	Weather conditions / ambient temperature Patronage	12 months
Compressed air system	Plant production	Up to 2 weeks

The IPMVP stipulates the baseline measurement period should span a full operating cycle to fairly represent all normal operating conditions.

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 typically be less than the sum of the individual savings from ECMs if implemented in isolation from each other.

> **Additionality** refers to the extent to which the measured energy savings from multiple ECMs can be added together to provide aggregated energy savings figures.

Consideration of additionality applies to sites that implement 2 or more energy ECMs, either concurrently, or over a period of time. More accurately, this applies when 2 or more projects are implemented with overlapping measurement boundaries. These projects effectively 'compete' for the same savings.

Additionality should not be confused with interactive effects. The former describes the situation where multiple ECMs affect each other *within* shared or overlapping measurement boundaries, whilst the latter describes changes in usage that occur *outside* the measurement boundary.

In the diagram below, each circle represents the savings from an ECM. On the left, each project has its own measurement boundary. On the right, the projects share parts of the same measurement boundary.

Figure 8: Additionality diagram

No additionality issues between ECMs	Additionality issues between ECMs
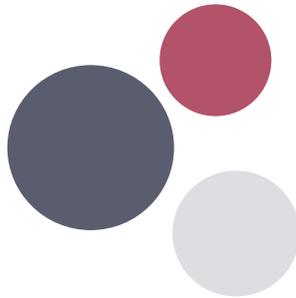
We have 3 projects with separate measurement boundaries. Savings from each ECM can be added together.
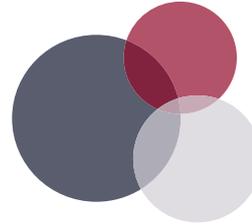
We cannot simply add the 3 ECM savings figures as this would result in double counting of the overlapping areas.

Tips for managing additionality

1. Ensure that additionality is considered when planning M&V, and that potential ECM overlaps are identified
2. Review each ECM and determine where and to what extent they influence each other
3. Choose between the 'Adjust to Isolate', 'Black Box' and 'Ordered Summation of Remainders' methods described below to resolve remaining additionality issues.

Suggested approaches for resolving additionality Issues

There are 3 approaches for managing additionality:

1. **Adjust to isolate**
   Adjust your measurement boundary to separate overlapping ECMs (for evaluating separately). This would resolve the issue as the ECMs can be evaluated in isolation. This may not always be possible due to the physical nature of the measurement boundary or the ECM.

2. **'Black box' approach**
   Treat all ECMs within the measurement boundary as a single project and measure the combined savings as a single M&V exercise. The additionality issue is resolved by expanding the measurement boundary to include all ECMs and evaluating as a group.

   This approach may lead to reduced costs as we are effectively evaluating a single (albeit more complex) project. Conversely we may need to develop a more complex energy model incorporating data for additional independent variables. Typically this may also involve changing from an Option A approach to either Option B or C, which may lead to longer measurement periods.

3. **Ordered summation of remainders**
   ECMs are assessed in a specific order and the post-retrofit data for one ECM forms part of the baseline data for the next ECM. In effect we progressively assign each overlap to a particular ECM, and calculate the reduced savings for all preceding ECMs based on their overlap. This approach may be useful for ECMs implemented over a period of time. Some combinations of ECMs may not be suitable for this type of approach as the effects of one ECM in isolation cannot be determined. This concept is illustrated in the following diagram:

4.1

Figure 9: Resolving additionality issues through ordered summation of remainders

Where: ECM #1 savings are claimed in full (i.e. claims all overlaps). ECM #2 savings are reduced by the influence of ECM #1. ECM #3 savings are reduced by the influence of both ECMs #1 and #2.

4.2   Prepare M&V plan

4.2.1   Estimated savings versus uncertainty

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

If the current M&V design does not fit within any fixed constraints imposed on the M&V project in terms of timing, resources and budget, then section 4.1 may be revisited to adjust the M&V design into a more suitable form that may involve a higher level of estimation or stipulation of key parameters over measurement, provided the level of uncertainty will be acceptable.

In determining an initial budget, and therefore approach, consider the relationship between the predicted amount of savings, and the associated uncertainty.

As a guide to managing uncertainty the figure below is reproduced from the Australian Best Practice Guide for Measurement and Verification [3]. This figure illustrates the relationships between savings uncertainty, magnitude of savings, and whether stipulation of parameters is recommended.

Figure 10: Guide to M&V approach: estimated savings vs. uncertainty

4.2
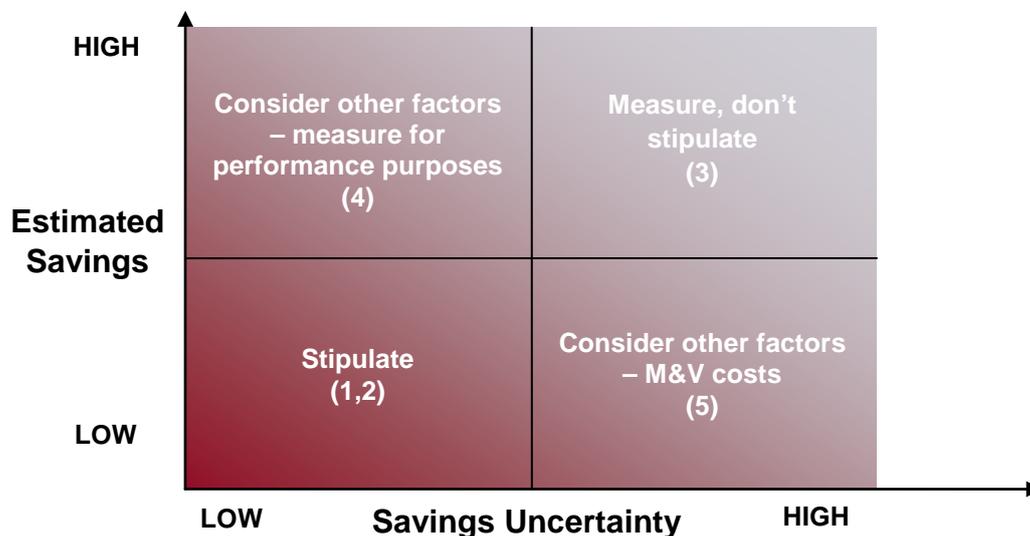
Several "rules of thumb" that flow from these relationships as noted by the numbers (#) in the figure above are as follows:

1. The most certain and predictable parameters can be estimated and stipulated without significantly increasing uncertainty.
2. Stipulating parameters that represent a small degree of uncertainty in overall savings will not significantly increase uncertainty.
3. Parameters that represent a higher percentage of project savings and uncertainty should be measured.
4. If estimated savings are high but uncertainty is low, measurement may not be necessary.
5. If estimated savings are small and uncertainty is high, stipulation would only shift risk to the facility owner/manager and consideration of whether the ECM is worthwhile might be warranted. In these cases an ECM's other financial and non-financial benefits, such as reduced maintenance, better quality or customer satisfaction may decide if the project proceeds.

Stipulation of parameters will result in less measurement and lower costs, but may lead to higher uncertainty.

4.2.2 Timing

It is important to fully consider the timing requirements for conducting M&V and factor them into the ECM implementation plan. It is critical that M&V planning occurs early so the necessary baseline data can be collected. Without an adequate baseline, developing a model may be difficult, or could result in a high uncertainty in the final figure.

Just as important, the length of time for conducting measurement within the baseline period should cover at least one site 'operating cycle' so that a complete cycle of variations in energy use can be incorporated into the energy model. In some cases the baseline period will be 12 months, and so adequate lead time should be factored in.

Figure 11 below provides an overview of the relative timing between the lifecycle of an ECM and its corresponding M&V project.

Figure 11: ECM and M&V lifecycle timing
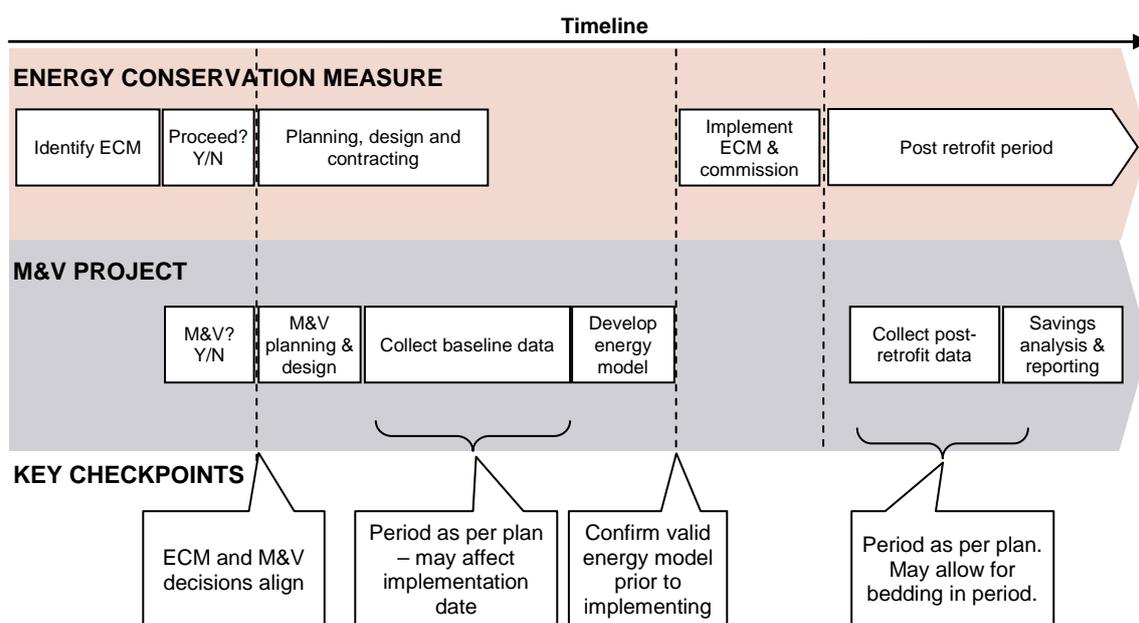
Appendix B also provides a more detailed insight into the typical lifecycle of an ECM and associated M&V project, from identification, approval, implementation and evaluation. Note that the project timelines for implementation and M&V run in parallel, with M&V design and planning, and baseline data collection occurring prior to the ECM being implemented.

4.2.3 Resources and budget

Prior to undertaking more detailed planning it is recommended that an initial M&V budget is determined and evaluated. Typically a M&V budget should be less than 10% of the first year savings from a project, typically in the range of 3-5%. When estimating M&V project costs we need to consider the following:

Labour costs:

- for project management and liaison with ECM implementation team
- for M&V planning, conducting measurements, analysing data and calculating results, and preparing reports and presenting outcomes

Data collection and analysis costs, including:

- data acquisition costs – including hire/purchase of equipment, or purchase of data
- modelling software (if required)

External fees and other project costs, including:

- consultant fees (if required)
- travel and other expenses.

4.2.4 M&V project plan preparation

A well-defined and implemented M&V plan provides the basis for documenting performance in a transparent manner that can be subject to independent, third party verification. A good M&V plan balances the savings uncertainty associated with energy improvement projects against the cost to execute the plan [4].

Like any project, success depends on careful planning. M&V plans come in all shapes and sizes and reflect the following:
- complexity of the project
- underlying purpose of M&V (e.g. funding assistance, energy performance contract)
- explanations required for management sign-off
- the size of the available savings and available M&V budget
- audit and verification needs

M&V planning covers the following areas, and is essential for a successful and meaningful outcome.

Table 10: M&V planning areas and considerations

Area	Why is this important?
People	To ensure key stakeholders are known and appropriate people are involved
Timing	To integrate M&V within the overall project implementation timeline, rather than considering M&V as an afterthought.
	To ensure that the baseline period and conditions are known and evaluated and that adequate baseline data is collected in order to accurately measure, rather than estimate the project benefits

Area	Why is this important?
Resources	To determine the people and equipment needs and forecast when required.
Cost	To understand the anticipated M&V costs so that agreement and funding can be obtained. To facilitate a cost/benefit analysis to determine the level of M&V that should be conducted, if at all.
Approach and process	To methodically evaluate the project being considered and develop a suitable baseline from which savings can be claimed. To enable the various M&V approaches to be considered and evaluated so that the preferred approach can be adopted. To define a suitable physical boundary within which the project will be implemented, which will be used as the reference point for ensuring like-for-like comparison. To identify the variables that affect energy use so that appropriate data types can be measured. To provide a well thought out and documented methodology for manipulating data to calculate savings.
Outcomes	To ensure that the aims and desired outcomes of each stakeholder are known and incorporated into the planned approach. To provide a written document that can form the basis of a savings agreement or guarantee.
Audit and verification	To provide a documented methodology based on an international standard that will support audit and verification

Contents of a M&V plan

A complete M&V plan should include the following key components:

Table 11: Recommended M&V plan table of contents

Element	Description
Project description	Site and the project details including information about the size and nature of the project, how it will affect site energy usage and demand, implementation plan, key contacts, etc.
Expected project benefits	Describe the anticipated benefits to be derived from the project. This will include the estimated energy savings, cost avoidance and greenhouse gas emission reduction that have been forecast for the project. Include other financial and non-financial benefits, which may be observed or evaluated in conjunction with conducting M&V to verify the savings associated with reduced energy use.
M&V project team and manager	List the project team with roles and responsibilities, and contact details including the nominated project manager.
Budget and resources	The agreed M&V budget including the resources required and associated costs covering initial set up costs and ongoing costs throughout the post-retrofit reporting period.

4.2

Element	Description
Chosen M&V Option	Nominate the chosen approach for determining savings. Under the IPMVP, this will be a choice between the four available options, A, B, C and D.
Measurement boundary	Describe using words and/or diagrams the chosen measurement boundary. The boundary may be as narrow as a single piece of equipment or as broad as the total energy use across one or more buildings.
Baseline and post-retrofit measurement periods & key dates	Describe the measurement periods for baseline and post-retrofit listing the start and end dates. Where data is available include the baseline energy data from within the measurement boundary. This data may be available from a completed energy audit or feasibility study.
Operating cycle	Describe the operating cycle of the savings that are expected to be achieved and whether or not the measurement period will cover a full cycle. If the measurement period does not cover a full operating cycle, explain how this will be addressed by stipulating or using standard or normalised data sets e.g. standard 10-year average weather file.
Baseline conditions	Describe any baseline conditions and variables that do not include independent variables. These will be factors that are more static in nature, such as internal comfort conditions or lighting levels within a commercial building, or production shifts and details of product line set points in an industrial or manufacturing context. List any conditions that fall short of required conditions, such as low lighting levels or inadequate air flow.
Key measurement parameter(s)	List the key parameters that will be measured, including the data source, and type and frequency of measurement.
Estimated parameter(s) and justification for estimates	List additional parameters that will be estimated. For each, describe the data source, type and frequency of data, and provide a justification for the estimate.
Independent variables and the basis for adjustments	List all independent variables that have been identified as having an effect on baseline energy use. For each, describe the data source, type and frequency of data, and provide a description of how they will be used to adjust the baseline data for the post-retrofit period.
'Interactive effects'	Describe any interactive effects that have been identified where the implementation of the project will have effects on energy use outside the boundary.
Additionality	If multiple projects are planned for implementation and additionality is an issue, describe the approach that will be used to manage additionality.
Methods for collecting data, equipment requirements and metering specifications	Describe the process to be used for collecting measurements, including type, specification and placement of measurement equipment where known. Where Option D has been used, this should describe the modelling software that is used, and all inputs and outputs.
Analysis procedure for calculating results and uncertainty	Specify the data analysis process to be used, and list all significant calculations and assumptions. Where Option D is used, this should describe how the energy model is to be calibrated using measured data.

4.2

Element	Description
Energy prices for cost savings calculations	Specify the overall approach and specific cost rates that will be used for calculating energy and demand cost savings, noting any mechanisms for future adjustment.
Expected uncertainty	The expected uncertainty of the energy savings results which will include precision and confidence.
Report format	Specify how results will be reported with a sample output.
Quality assurance	Nominate quality assurance procedures that will be used within the data collection, and preparation of analysis and reports. This may include: ▪ Measurement system commissioning ▪ Measurement equipment re-calibration frequency ▪ Reviewing measured data to spot gaps or out of range conditions ▪ Identifying qualified personnel to review draft reports
Ongoing monitoring and periodic inspections	Assign responsibilities for reporting and recording the energy data, independent variables and static factors within the measurement boundary during the reporting period.
Adherence with international protocols	IPMVP adherent plans also include the following details. ▪ The person responsible for approving the site-specific M&V plan and for ensuring that the plan is followed for the duration of the reporting period ▪ The date of publication is clearly stated, or the version number of the IPMVP edition and volume being followed ▪ Terminology that is consistent with the cited IPMVP edition ▪ All required M&V plan elements ▪ Approval is obtained from all parties interested in adherence with IPMVP ▪ Consistency with the principles of M&V

Suggested M&V planning process

To develop an effective M&V approach, we need to understand:

- the nature of the project being implemented
- basic approach and design for conducting M&V
- elements of a robust M&V plan, including tasks, resources, timing and cost; and
- desired outcomes and limitations (e.g. budget).

The suggested M&V planning process listed in Figure 12 below can be used as a basis for developing a M&V plan. A full description of this process and suggested tasks and tips can be found within the *Planning Guide*.

4.2

Figure 12: Suggested M&V planning process

STEP 1: Identify stakeholders and select project team	Identify the key people who will prepare and implement the M&V plan.
STEP 2: Understand your site and ECM	Understand the nature of the site involved and the proposed ECM. Find out the implementation timeframe.
STEP 3: Determine M&V requirements and outcomes	Determine the M&V requirements and desired outcomes (e.g. agreed accuracy, multiple ECMs, 3rd party verification).
STEP 4: Establish an initial budget	Establish an initial M&V budget figure as a basis for planning decisions.
STEP 5: Evaluate M&V options and select preferred approach	Use budget and requirements to select preferred approach for: a. M&V Option b. measurement boundary c. key parameters/ independent variables d. determining suitable operating cycle e. managing additionality if required
STEP 6: Determine measurements & calculations	Identify the measurement requirements and calculation methods.
STEP 7: Develop project task list and timeline	List the tasks to be completed and nominate resources. Nominate task completion dates to develop the overall M&V project timeline.
STEP 8: Finalise M&V budget	Finalise the M&V budget based on tasks and equipment needs.
STEP 9: Review M&V Design	Review the M&V design against requirements. Review budget against initial estimate. Look at alternative approaches if unsatisfactory.
STEP 10: Document your M&V Plan	Document your M&V plan and obtain sign off as required.

Example M&V plans

The table below provides links to examples of M&V plans for a variety of projects that range in nature and complexity. Each is presented in its own style however they all share similar characteristics and key elements.

4.2

Table 12: Example M&V plans

Example	Reference
Standard M&V Plan for lighting retrofit Chiller replacement projects – standard M&V Plan	Berkley Lab: http://mnv.lbl.gov/qato
M&V Plan template	Federal Energy Management Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy [5] http://www1.eere.energy.gov/femp/pdfs/6_3_reviewingmvplans.pdf
Appendix B – M&V Plan outline	Australian Best Practice Guide for Measurement and Verification (ABPG) – Australasian Energy Performance Contracting Association, 2004 [3] www.eec.org.au/Best%20Practice%20Guides
Appendix A – 12 example cases which include M&V design (available for separate download)	Efficiency Valuation Organization http://www.evo-world.org/index.php?option=com_content&view=category&layout=blog&id=655&Itemid=513&lang=es

M&V Excel planning tool

A M&V planning tool has been developed in conjunction with this guide to assist M&V planners incorporate the various design elements. The template is presented in a spreadsheet for ease of calculations with the following contents:

Table 13: M&V Excel planning tool contents

Worksheet Tab	Purpose
ECM Project Background	To capture details for the site and ECM, including the estimated project benefits, implementation plan and key stakeholders
M&V Requirements	To capture the M&V requirements key considerations, desired outcomes and success criteria, as well as the M&V project details.
M&V Design	To capture the essential elements of the M&V Plan. This includes preferred M&V Option, measurement boundary definition, details of key parameters, and process information relating to conducting measurements, calculating saving and uncertainty.
M&V Budget	To prepare a project budget, based on the tasks, resources, equipment and other needs. The final figure is measured against the ECM project costs and savings as a sanity check.
M&V Tasks	To capture the step-by-step list of tasks, and allocation of resources
M&V Timing	A Gantt Chart based timeline, where tasks are given a start and completion date, so that the overall project timeline can be developed.

4.2

5 Data collection, modelling and analysis

The M&V plan will describe the parameters to be measured, the data to be collected and the assumptions that will be made. We now need to implement the plan and collect the data required for our M&V savings calculation for the baseline and post-retrofit periods.

This section provides general guidance for conducting measurements and collecting data, developing the energy model and analysing findings.

5.1 Measure baseline data

The first step in the data collection, modelling and analysis process is to measure, collect and process the baseline data in accordance with the measurement process and task timeline specified in your M&V plan.

Considerations when measuring, collecting and processing baseline data (which also applies to post retrofit measurements) include:

- Key parameters to measure (e.g. energy consumption, power draw, temperature)
- Measurement approach (e.g. continuous, periodic, sampling, once-off)
- Measurement equipment and placement (e.g. data loggers, utility meter, sensors etc)
- Measurement interval (e.g. 1 month, 1 week, 1 day, 1 hour, instantaneous)
- Measurement start/finish dates
- Measurement duration (e.g. instantaneous readings, 2 weeks, 1 month, 12 months)
- Data collection, processing and integrity (e.g. software, format, completeness)
- Calculating uncertainty (e.g. measurement equipment, sampling, standard errors)

Table 14 presents four measurement examples detailing the considerations above. Please refer to Appendix C (Data measurement and collection principles) and Appendix G (Uncertainty) for further guidance.

Table 14: Measurement examples

Key parameter	Facility electricity use	Chiller current (Amps)	Average light fitting instantaneous current	Pump motor kW power draw
Approach	Continuous	Periodic	Sampling	Once-off
Equipment and placement	Utility meter already installed on incoming electricity mains	Electrical data logger installed on the chiller circuit at the mechanical switch board	Clamp on current meter at the light fitting including lamp and ballast (for selected fittings within the sample)	Existing sub meter installed on the pump circuit at the mechanical switch board.
Interval	Monthly	1 hour	Instantaneous	Instantaneous
Start/finish dates	January to December 20XX	1/5/XX to 14/5/XX	11:00am, Wed 16/5/XX	3:00pm, Tue 7/2/XX
Duration	12 months	2 weeks	Instantaneous	Instantaneous

5.1

Data collection, processing and integrity	Data extracted from utility invoices into spreadsheet.	Software used to extract data into spreadsheet format. Visual check for missing and out of range data.	Transfer written notes into spreadsheet and conduct a statistical analysis to determine the average light fitting load.	Visual reading on sub meter and record in spreadsheet for future analysis.
Uncertainty	Utility meter therefore can be considered 100% accurate	A regression model will be established relating chiller Amps and ambient temperature. The regression model uncertainty will be quantified.	Uncertainty associated with sampling errors will need to be calculated	Uncertainty associated with sub meter precision (as per manufacturers specifications)

5.2   Develop an energy model and associated uncertainty

Once all baseline data has been measured, collected and checked for data integrity, completeness and acceptable uncertainty, the next step is to develop an energy model and quantify the associated uncertainty. As we have seen, calculating baseline adjustments is critical for comparing like-for-like in a M&V exercise.

Assuming we have identified the parameters upon which adjustments will be made to the baseline energy data, we need to develop an energy model which can be applied to calculate baseline adjustments.

An energy model may be as simple as adding a fixed step adjustment.

More commonly, adjustments will depend on a number of factors or variables. The best way to deal with this is to develop an energy model, which combines baseline data collected for energy and independent variables to express energy use as a function of those variables.

The model may be based on engineering calculations, simulation software, or may use techniques like regression analysis to determine the relationship.

Organising data with non-uniform time periods

An important first step in developing a sample-based or regression energy model is to establish uniformity in time intervals for energy bills and independent variables. In cases where the dates between energy meter reads vary (and hence the billing periods are different length), this can lead to errors in the analysis. Just as importantly, measurements for independent variables must align with those of corresponding energy bills.

To fix this it is recommended that invoices with adhoc bill-periods are pro-rated into calendar months. Data for independent variables should be treated in a similar way to align with billing periods. This issue should also be considered during the data collection phases so that data is collected at regular intervals.

To pro-rata non-calendar month energy data into calendar months we:

1. Calculate the length (number of days) for each invoice.
2. Determine the average daily consumption
3. Determine the number of days applicable within each month for period that each invoice spans and multiply by the average daily consumption for the corresponding invoice.
4. Sum up the amounts for all invoices in each month

Pay particular attention to the relationship between the start date of an invoice and the end date of its predecessor to ensure that the date periods don't overlap.

On some energy invoices, the dates shown relate to 'read date' and 'previous read date', whereas on others the dates shown relate to 'start date' and 'end date'. In the case of read dates, the actual start date of the invoice is the 'previous read date' + 1 day, as the 'previous read date' is actually the last day of the previous invoice.

We want to make sure that when calculating the number of days for each invoice (step 1 above) we don't count the same day in two separate invoices. The simple way to check is to line the invoices up in date order and compare the dates of each invoice with its adjacent ones.

Example: pro-rating non-calendar month invoice data

Suppose we have the following three invoices:

	Start Date	End Date	Energy Use (kWh)
Invoice 1:	12-Aug-11	17-Sep-11	6410
Invoice 2:	18-Sep-11	14-Oct-11	5440
Invoice 3:	15-Oct-11	12-Nov-11	7080

The pro-rating into calendar months is as follows:

5.2.1 Simple energy model

A simple energy model for a lighting ECM may look like:

$$Energy\ use\ (kWh) = fittings\ (quantity)$$
$$\times\ power\ draw\ per\ fitting\ (Watts)$$
$$\times\ operating\ hours\ (hours)$$
$$\div\ 1000\ (Watts/kW)$$

This may have been determined using a M&V Option A approach where either operating hours or power draw per fitting is measured and the other parameters are estimated.

The model can now be applied with varying figures for each variable as required to adjust the baseline figure for the post-retrofit period.

Example

Suppose we have 50 fittings with an estimated power draw of 90 watts per fitting including ballasts. Our ECM involves installing movement-based occupancy controls. Baseline operating hours have been measured to be 65 hours across a week. Using our energy model:

Baseline energy use (kWh)	*= 50 x 90 x 65 / 1000*
	= 293 kWh

Now suppose that during the post-retrofit period, 10% of the fittings are removed unexpectedly. We need to adjust for the change in load. Using the model with 45 remaining fittings:

Adjusted baseline energy use (kWh)	*= 45 x 90 x 65 / 1000*
	= 263 kWh

We can now use the measured operating hours (48 hours of operation) during the post-retrofit period to calculate is energy use:

Post-retrofit energy use (kWh)	*= 45 x 90 x 48 / 1000*
	= 194 kWh

Refer to Appendix G for standard statistical definitions, terms and uncertainty calculations that can be applied to a set of data (e.g. measured samples of occupancy hours).

A more complex model where a whole building's energy use is to be expressed as a function of temperature is presented in the section below.

5.2.2 Regression analysis energy model

Regression analysis is a statistical technique for establishing the relationship between a dependent variable (e.g. energy use) and a series of independent variables (e.g. production, weather, occupancy).

This relationship can be described using a mathematical equation. Example forms include:

Simple Regression: $\quad Y = a + bX + u$

Multiple Regression: $\quad Y = a + b_1 X_1 + b_2 X_2 + \ldots + b_t X_t + u$

where:

Y = the variable that we are trying to predict during a specific time period (e.g. 30 days)

X = the variable that we are using to predict Y (e.g. production, weather, occupancy)

a = the y-intercept coefficient

b = the slope coefficient for the particular independent variable

u = the regression residual that remains unexplained

Regression takes a group of random variables, thought to be predicting Y, and tries to find a mathematical relationship between them. This relationship is typically in a straight line (linear regression) that best approximates all individual data points.

Example

A manufacturing plant produces 'widgets'. A regression model has been established which relates monthly electricity consumption to a single independent variable: number of widgets produced in a month.

The regression model is expressed as follows:

$monthly\ electricity\ use\ (kWh) = 96{,}000 + (45 \times qty.\ of\ widgets\ per\ month)$

In this example, each additional widget manufactured will consume 45 kWh. If 20,000 widgets are produced in one month, the electricity use associated with widget production will equal 900,000 kWh.

Also, irrespective of how many widgets are manufactured, the plant will consume 96,000 kWh per month which may be due to static (non-variable) loads such as plant lighting, standby equipment power, standby hot water energy consumption and the like.

Within M&V practice, regression can be used to determine a range of relationships including:
- performance curves for equipment based on data sampling
- energy use as a function of independent variables
- marginal energy prices based on varying energy usage patterns

Further guidance for creating weather corrected energy models can be found in Appendix E. Readers are also strongly encouraged to review the Australian Best Practice Guide for M&V for further guidance in developing weather corrected energy models.

Further comments regarding regression models

In addition to the linear models presented above, regression models may be based on other equation types as per the following:

Polynomial: $\quad Y = a + b_1 X + b_2 X^2 + b_3 X^3 + \ldots + b_t X^t + u$

Exponential: $\quad Y = a + b e^{cX} + u$

Logarithmic: $\quad Y = a + b \ln X + u$

5.2

Power: $Y = a + bX^c + u$

There are numerous software packages and spreadsheet applications available that can perform regression modelling functions on a set of data.

It is important to ensure that you review the data in order to select the most appropriate modelling relationship. The diagram below highlights the potential pitfalls with developing models without visual inspection. Originally proposed by Frank Anscombe [6], each of the four charts below result in the same key statistics when analysed using a linear regression, yet each trend represents a unique relationship that is better served by a non-linear equation or none at all.

Figure 13: Different data sets which produce the same key statistics when using a linear regression
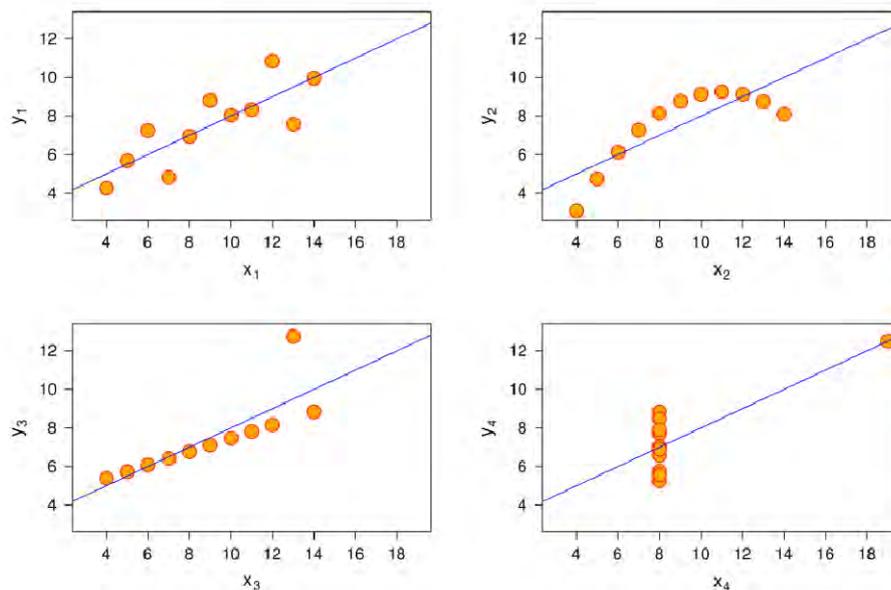
Key tips for conducting regression analysis:
- ensure the data set has a suitable number of data points.
- eliminate outliers where justifiable if the reason is temporary.
- think about the big picture when using a model to forecast outside the data range.
- consider segmented or stepped regression.
- examine residuals (differences between actual values and the trend line) to see if there are patterns (specific seasons, production periods, etc) to see if additional variables need to be considered.
- avoid adding unnecessary variables, or those that relate to each other, as they may attempt to cancel each other in the resulting equation,
- avoid adding variables that are related to energy use as regression analysis is based on the assumption of independence,
- use a XY scatter diagram or a plot of actual energy use against the modelled energy use from the regression analysis help identify overall trends, functional form and issue patterns.

Statistical validity tests and uncertainty

In order to evaluate how well a particular regression model explains the relationship between energy use and independent variable(s), a number of tests outlined below should be performed.

5.2

Coefficient of determination (R^2)

The coefficient of determination (R^2) is used to test the goodness of fit of the model. It is expressed as a value between 0 and 1. A value of 1 indicates a perfect fit, and therefore, a very reliable model for future forecasts. A value of 0, on the other hand, would indicate that the model fails to accurately model the dataset.

As a rule of thumb, an R^2 of 0.75 or greater is often considered a reasonable indicator of a good causal relationship between the energy and independent variables. R^2 values of 0.9 or above are very good and R^2 values below 0.7 represent a poor correlation, indicating that the relationship between energy use and the independent variable is not strong. This may be due to incorrect choices for independent variables, or simply that the relationship is weak or does not exist.

The coefficient of determination is calculated by:

$$R^2 = \frac{\sum(\hat{Y}_i - \overline{Y})^2}{\sum(Y_i - \overline{Y})^2}$$

where:

$\hat{Y}_i$ is the model predicted energy value for a particular data point i by inputting the actual independent variable(s) into the regression model equation.
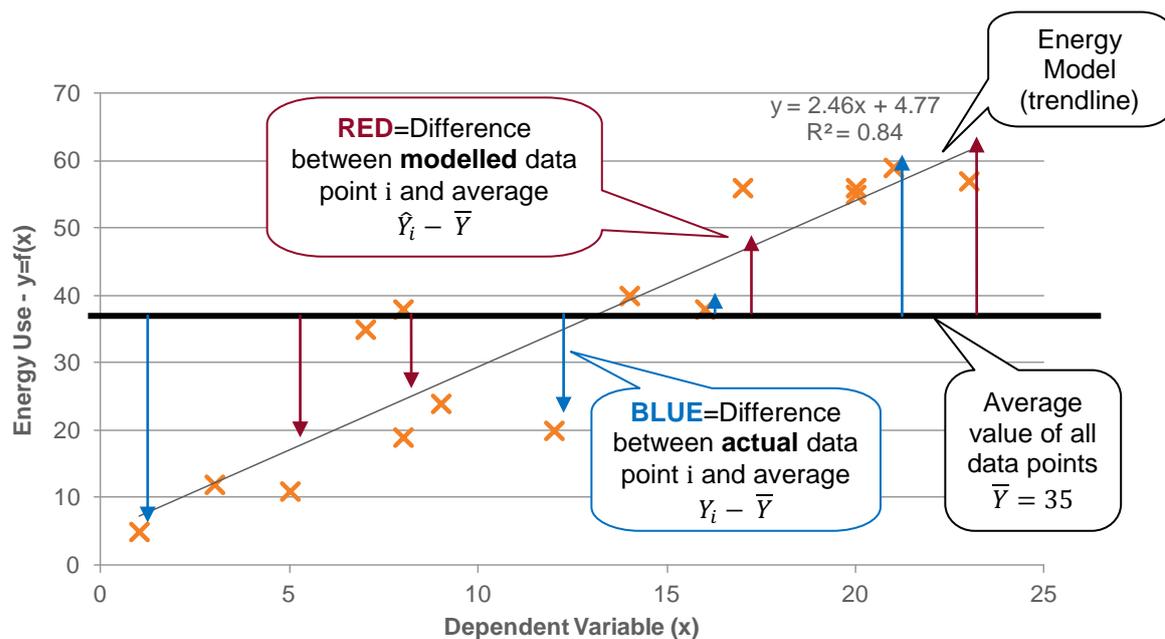
$\overline{Y}$ is the mean of the n actual observed or metered energy values.

Y_i is the actual observed or metered energy use value for data point i.

These variables are illustrated in <u>Figure 14</u>.

Put simply, this may be viewed as the 'explained' error in the sample or regression model.

Figure 14: Variables used to calculate the Coefficient of Determination (R^2)

Coefficient of variation (CV(RMSE))

Dividing the RMSE[2] above by the average energy use produces the coefficient of variation of RMSE, or the CV(RMSE). Acceptable limits for monthly CV(RMSE) are less than 0.25 for energy and less than 0.35 for demand when 12 to 60 months of base year data are used.

$$CV(RMSE) = \frac{SE_{\hat{Y}}}{\overline{Y}}$$

where $SE_{\hat{Y}}$ is the standard error of the regression model (estimate). Refer to Appendix G for further information on uncertainty and how to calculate standard errors.

Mean bias error (MBE)

The MBE is a good indicator of overall bias in the regression model estimate. Positive MBE indicates that regression estimates tend to overestimate the actual values and vice versa. The acceptable limit for MBE is less than 0.005% and is calculated by the following:

$$MBE = \frac{\Sigma(\hat{Y}_i - Y_i)}{n}$$

Standard error of the coefficient

Since regression model coefficients $(b_1, b_2, ..., b_t)$ are statistical estimates of the true relationship between an individual X variable and Y, they are subject to variation. The accuracy of the estimate is measured by the standard error of the coefficient and the associated value of the t-statistic. The t-statistic (t) of the coefficient(s) provides a test to determine whether a model has statistical significance. The standard error of each coefficient is computed by regression software and spreadsheet applications however the following equation applies for the case of one independent variable:

$$SE_b = \sqrt{\frac{\Sigma(Y_i - \hat{Y})^2/(n-2)}{\Sigma(X_i - \overline{X})^2}}$$

For cases with more than one independent variable, the equation provides reasonable approximation when the independent variables are truly independent (i.e. not correlated). Otherwise, the equation gets very complex and software packages and spreadsheet tools would be more suitable to calculate the standard errors of the coefficients.

The standard error of the coefficient b (SE_b) is used to calculate the t-statistic which will determine whether the calculated coefficient is statistically significant or simply a random calculation. The t-statistic is calculated by the following equation:

$$t = \frac{b}{SE_b}$$

Therefore the range within which the true value of the coefficient b falls within is calculated as:

$$b \pm t \times SE_b$$

2 Root Mean Squared Error -This is a measure of the 'typical' error of a modelled data point.

5.2

> **Tip**
>
> A rule of thumb states that the t-statistic of 2 or more implies that the estimated coefficient is significant relative to its standard error and therefore that a relationship does exist between Y and the particular independent variable X related to the coefficient (95% confidence that the coefficient is not zero). However, at a t-statistic of 2, the precision in the value of the coefficient is about $\pm100\%$ and to obtain a precision of say $\pm10\%$, the t-statistic must be around 10.

The following considerations can be given to improve the t-statistic of the coefficient(s);
- Select independent variable(s) with the strongest relationship to energy use.
- Select independent variable(s) whose values span the widest possible range.
- Gather and use more data points to develop the model.
- Select a different functional form for the model (e.g. polynomial, exponential etc).
- Consider segmented or stepped regression.

Other statistical validity considerations

Other validity tests [7] include:
- The model makes intuitive sense; e.g., the independent variables are reasonable, and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude)
- The modelled data is representative of the population
- The form of the model conforms to standard statistical practice
- The number of coefficients is appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations)
- The model is tested for possible statistical problems and, if present, appropriate statistical techniques are used to correct for them
- All data input to the model are thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.
- The base load constant (i.e. y-intercept) should not be negative
- If using weather related independent variable (e.g. ambient temperature), the weather related coefficient should not be negative
- Use "Bill Matching" if the regression is not statistically significant

Statistical validation summary

The table below provides a summary of the statistical validity tests presented above and their associated acceptable limits.

Table 15: Regression model statistical validity summary and acceptable limits

Statistical validity test	Equation	Acceptable limit
Coefficient of determination (R^2)	$$R^2 = \frac{\sum(\hat{Y}_i - \overline{Y})^2}{\sum(Y_i - \overline{Y})^2}$$	> 0.75
Standard error of the estimate ($SE_{\hat{Y}}$)	$$SE_{\hat{Y}} = \sqrt{\frac{\sum(\hat{Y}_i - Y_i)^2}{n - p - 1}}$$	Dependent on the M&V project requirements for precision and confidence.

Coefficient of variation (CV(RMSE))	$CV(RMSE) = \dfrac{SE_{\hat{Y}}}{\overline{Y}}$	Monthly values < 0.25 for energy and < 0.35 for demand when 12 to 60 months of base year data are used.
Mean bias error (MBE)	$MBE = \dfrac{\sum(\hat{Y}_i - Y_i)}{n}$	< 0.005%
Standard error (SE_b) of the coefficient (b) and associated t-statistic (t)	$SE_b = \sqrt{\dfrac{\sum(Y_i - \hat{Y})^2/(n-2)}{\sum(X_i - \overline{X})^2}}$ $t = \dfrac{b}{SE_b}$	$t > 2$ Note: the precision in the coefficient is approximately: $\pm 100\%\ t = 2$ $\pm 10\%\ t = 10$
Base load i.e. y-intercept	a	>= 0. A Value less than zero may still be acceptable however it places restrictions on the usability of the model
Weather related coefficients	$b_1, b_2, ..., b_t$	>0

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.

Some ECMs require no embedding such as lamp efficiency upgrades, while other ECMs will require an amount of time after installation and commissioning to remove transient behaviour until a 'normal' level operation is achieved

For example, a chiller replacement project may require tweaking of set points and control parameters after installation and commissioning until a desired level of operation is achieved. Or a new lighting control system may take tenants an amount of time to understand how to operate the lighting controls properly.

5.4   Measure post retrofit data

Once the ECM(s) have been implemented and embedded into normal operations, the post retrofit data will need to be measured and collected in accordance with the process and task timeline specified in your M&V plan.

The same measurement principles from the baseline measurement period will be applied to the post retrofit measurement period. Refer to section .

The post retrofit data will provide the input required to adjust the energy model and calculate the predicted energy consumption during the post retrofit period (business-as-usual) which will then be compared to the actual energy consumption to determine the estimated savings.

5.5   Savings analysis and associated uncertainty

5.5.1 Adjusting the model for post-retrofit or normalised conditions

Adjusting the energy model for post-retrofit or normalised conditions simply involves inputting the data for the relevant independent variables into the model to determine the resultant energy use. This value becomes the adjusted baseline.

The data required, and the variables, will be defined from the baseline data analysis and will relate to a particular ECM.

When making adjustments we have the option of adjusting for post-retrofit 'actual conditions' or for a defined set of 'fixed conditions'. This choice will lead to our savings result being defined as 'actual' or 'normalised'.

To represent actual conditions, we use data from independent variables that has been collected during the post-retrofit period, covering the same period as actual energy use.

To represent fixed conditions, we select the data for independent variables to be used for making adjustments. These conditions may be those of the baseline period (requiring adjustment of the post-retrofit data), or some other period or set of conditions (e.g. 10-year average weather normalisation curve).

5.5.2 Calculating energy savings

With the adjusted baseline and post-retrofit data collected and quality checked, we can now calculate energy savings. Use the equations below to calculate energy savings.

Basic savings equation for Options A, B and C[3]

Savings   = Baseline Usage

– Post-Retrofit Usage

± Routine Adjustments

± Non-Routine Adjustments

Basic savings equation for Option D (when using model only)[4]

Savings   = baseline energy from the calibrated model without ECMs

– reporting period energy from the calibrated model with ECMs

Basic savings equation for Option D (when using actual post-retrofit energy data)[5]

Savings   = baseline energy from the calibrated model without ECMs

– actual energy with ECMs (during calibration period)

± calibration error in the corresponding calibration reading

---

[3] Source: IPMVP 1:2012, page 13, Equation 1a

[4] Source: IPMVP 1:2012, page 31, Equation 1f

[5] Source: IPMVP 1:2012, page 31, Equation 1g

Considerations

Ensure that:
- the time periods for the adjusted baseline and the post-retrofit data are of the same length and aligned
- units of measure are the same

The result of the calculation is the measured energy saving for the measurement boundary for the time period specified by the post-retrofit data.

5.5.3 Calculating peak demand savings

Peak demand, or simply demand savings are calculated by using a similar approach to energy savings. For some ECMs demand savings are easily calculated, whilst for others it may be difficult to determine.

Basic demand savings equation

$$\begin{aligned}
\textit{Demand Savings} \quad &= \textit{Baseline Demand} \\
&\quad - \textit{Post-Retrofit Demand} \\
&\quad \pm \textit{Routine Adjustments} \\
&\quad \pm \textit{Non-Routine Adjustments}
\end{aligned}$$

For example:

$$\begin{aligned}
\textit{Connected Lighting Load Reduction (kW)} \quad &= \textit{Baseline Lighting Demand (kW)} \\
&\quad - \textit{Post-retrofit Lighting Demand (kW)}
\end{aligned}$$

Changes in demand need to be assessed separately from changes in energy. It is important to understand the nature of the ECM and its effect on demand. Consider the charts below, which illustrate before (red) versus after (blue) load profiles for three ECMs:

ECM #1

e.g. Lighting efficiency upgrade

The ECM results in an improvement in efficiency (energy use vs. task performed), and demand will be directly proportional to the energy savings.

Demand savings will be realised at all times where the system is operating.
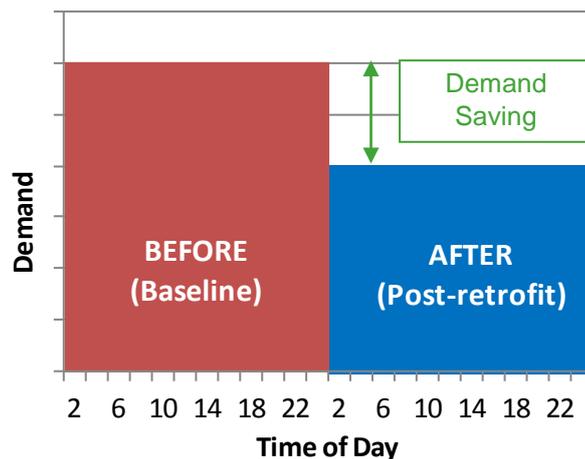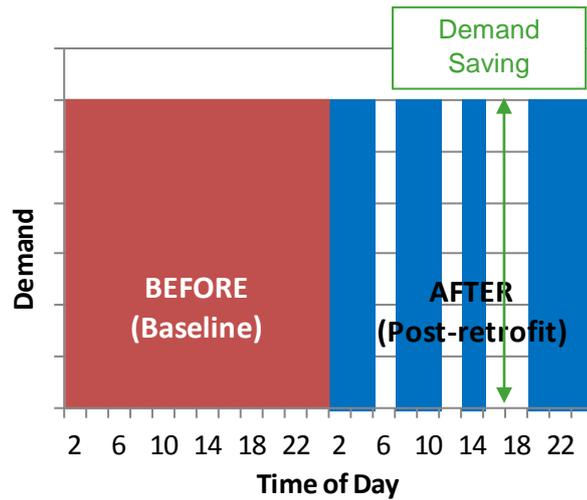
ECM #2

e.g. Lighting occupancy control

The ECM results in reduced operating hours of the same equipment with no change in efficiency.

Demand savings are realised only when the ECM is controlling usage. No demand savings when the system is running.
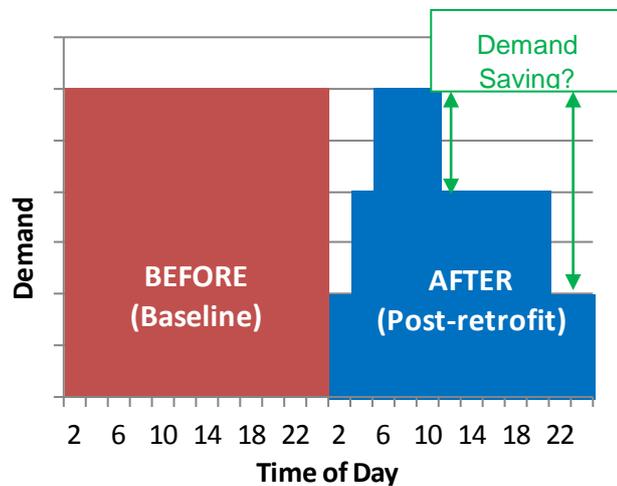

ECM #3

e.g. VSD on car park exhaust

Demand savings are a combination of efficiency and timing.

The specific demand reduction is dependent on:
1. The change in efficiency at peak loads
2. When peak load occurs

From the examples above, the demand savings may be any value between zero and the total power draw from the measurement boundary.

Typically ECM#1 will be the most straightforward to estimate demand, as power draw is likely to be measured as a key parameter, and we don't have to worry too much about timing.

Demand savings for ECM#2 should also be straightforward to calculate, assuming we can determine when savings occur.

The most difficult situation occurs with ECM#3 as the demand savings varies according to the work that the system with the ECM is performing. Where Option B is used, this may be as simple as reviewing before and after load profiles. With Option C, additional analysis may need to be conducted in relation to load factors.

As with energy, regression analysis can be a powerful tool to estimate demand savings. An example of calculating demand savings of a chiller replacement project using regression analysis is provided in Appendix A.

5.5.4 Calculating cost avoidance

In Section 2.3.1 we introduced the term 'cost avoidance' which is a financial figure derived from the measured like-for-like energy savings that represents the avoided energy costs due to the ECM.

When determining cost avoidance, the following equations are equivalent:

$$\text{Cost avoidance (\$)} = \text{Cost}_{\text{adjusted baseline}} - \text{Cost}_{\text{actual}}$$

$$= \text{pricing structure} \times (\text{energy use}_{\text{adjusted baseline}} - \text{energy use}_{\text{actual}})$$

$$= \text{pricing structure} \times \text{energy savings}$$

Example: Cost Savings versus Cost Avoidance

A bank branch implements a lighting retrofit and is told by the lighting contractor that project will reduce site energy use by 15% and they will recoup their investment within three years. The Branch Manager reviews the first three months of energy bills and cannot see any reduction in cost. In frustration she asks the lighting contractor to explain.

After some initial investigations, the lighting contractor confirmed that the new lighting was performing as expected. Following further discussion with the Branch Manager it was discovered that the bank branch has begun opening on Saturdays. This has increased the weekly hours of operation by 16%.

The lighting contractor used cost avoidance to justify the initial claim as follows:

	Old conditions: 50 hours per week		New conditions: 60 hours per week	
	Annual Energy Use (kWh)	Annual Cost (@16c/kWh)	Annual Energy Use (kWh)	Annual Cost (@16c/kWh)
Old Lighting System	150,000	$24,000	180,000	$28,800
New Lighting System	127,500	$20,400	153,000	$24,480
Difference	22,500	$3,600	27,000	$4,320

Although the Branch Manager could not see any 'cost savings', the cost avoidance actually increased from $3,600 to $4,320 per annum. In addition the payback dropped from 3 years to 2.5 years.

Energy tariffs and price risks

Typically, energy costs are calculated by applying an energy tariff to a site's energy usage based on energy usage volumes and other tariff items. Energy tariffs can be simple or very detailed, involving a range of fixed and variable charges for usage and/or demand, including energy commodity prices, network infrastructure and demand fees, metering costs, and government and environmental fees.

Given that tariff structures and rates within supply agreements will change over time, 'price risks' are introduced which we must manage in order to successfully calculate cost avoidance.

The key question becomes:

> *"What prices should be used for the conversion of energy savings to energy cost savings and how should any price risks be managed?"* [3]

It may be one of the methods described above and below, or it may be an arbitrary, yet realistic pricing structure.

The choice of pricing structure is made during the M&V planning and design. Considerations include:

- **Documenting the agreed pricing structure:** The energy pricing structure is agreed and documented within the M&V Plan upfront. This is critical where multiple parties are involved (e.g. EPCs). By doing so, price variation risk is removed.
- **Nominating pricing period(s):** It is important to define the period covered by the pricing structure and any structure/rate changes over time, if any.
- **Impacts on M&V design:** The choice of pricing structure may alter the complexity of data collection and analysis. When planning the M&V design, the energy pricing structure should be reviewed so that the appropriate data collection and analysis can occur to successfully apply the pricing structure (e.g. time of use pricing, demand components, etc)

Methods for calculating cost avoidance

Cost avoidance is determined using one of three approaches:

1. applying an agreed average price
2. applying a marginal price
3. applying an energy tariff schedule

Basic cost avoidance equation using average price

$Cost\ avoidance\ (\$) = energy\ savings\ (units) x\ average\ price\ (\$/unit)$

Basic cost avoidance equation using marginal price

$Cost\ avoidance\ (\$) = energy\ savings\ (units) x\ marginal\ price\ (\$/unit)$

Basic cost avoidance equation using energy tariff schedule

$$Cost\ avoidance\ (\$) = \sum_{i=1}^{tariff\ line\ items} line\ item\ qty_i\ (units) \times line\ item\ rate_i\ (\$/unit)$$

where:

$line\ item\ qty_i$ = the savings (energy or demand) that are defined as per the rules for the line item i (e.g. peak period between 12pm and 8pm)

$line\ item\ rate_i$ = the tariff schedule for the line item i, expressed in $/unit

Applying an agreed average price

The simplest approach for estimating cost avoidance is to apply an average energy price to the calculated savings. The average energy price is determined by simply dividing the total cost of the invoice by the total energy, as follows:

$Average\ energy\ price = total\ bill\ cost\ /\ total\ bill\ energy$

then:

$Cost\ avoidance\ (\$) = average\ energy\ price \times energy\ savings$

Typically the average price is determined by considering cost and energy use across a full year of energy consumption using 12 monthly or four quarterly invoices.

Considerations and limitations

Although simple to calculate, this method has the following limitations and considerations:

- reduction in energy use will usually cause the average energy price to increase due to the presence of fixed charges
- the average price incorporates a number of variables which may or may not change, including load factor, peak demand, power factor, time of use break ups, etc
- this method is not appropriate for load shifting projects where cost avoidance is realised from differences in Peak and Off Peak rates
- where time-of-use pricing is involved, savings from reductions in Peak energy use will be under-reported, and savings from Off Peak use will be over-reported
- demand savings cannot not be calculated, but are implied within the energy savings.

Applying an agreed marginal price

A second approach for estimating cost avoidance is to apply a marginal energy price to the calculated savings. The marginal price is the price paid for the last units of energy used, which become the first units saved from an ECM. Marginal prices reflect a change in a consumer's bill divided by the corresponding change in the amount of energy consumed.

The marginal price can be thought of as the price difference that would result from adding or subtracting one energy unit from an energy bill.

The marginal price is dependent on:

- the tariff structure and line items under which the account is billed
- the energy volumes
- relationship between fixed and variable costs

In many cases, a marginal price can be easily read or estimated with satisfactory accuracy from a bill. In more complex cases regression can be used to develop a pricing model. The chart below shows 12 months of price and usage data for three sites within the same business and network area.

Figure 15: Monthly energy use vs. cost for 3 separate sites within the same business and network area
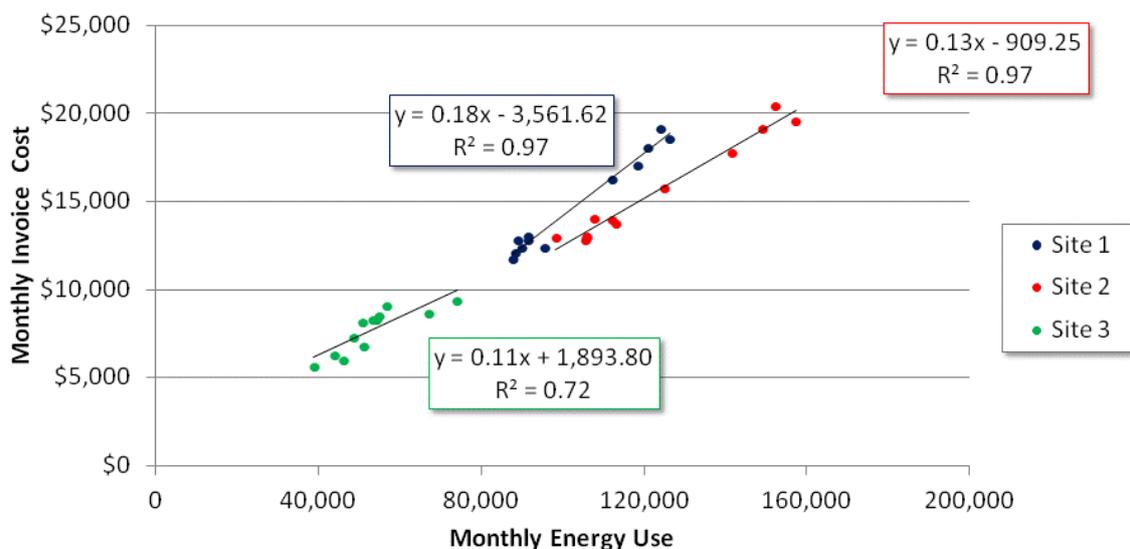
The marginal price is the slope of the trend line. The table below compares the marginal price against the average price (calculated over 12 months) for these sites.

5.5

Table 16: Comparison between average and marginal electricity price

Site	Average Price ($/kWh) (total cost / total use over 12 months)	Marginal Price ($/kWh) (slope of regression trend line)	Difference (marginal – average)	% difference (difference / average)
Site 1	$0.1430	$0.1776	$0.0346	24%
Site 2	$0.1264	$0.1338	$0.0074	6%
Site 3	$0.1449	$0.1094	-$0.0355	-25%

From the table, we can see that there can be substantial differences between the average and marginal prices. In the case of Site 3, the R^2 value is less than 0.75 which indicates a less than satisfactory correlation.

Using a marginal price effectively separates the effects of fixed and variable charges.

Considerations and limitations

Overall marginal pricing enables us to provide a more accurate estimation of cost avoidance. However the limitations and considerations outlined below, apply.

- The average price incorporates a number of variables which may or may not change, including load factor, peak demand, power factor, time of use break ups, etc.
- This method is not appropriate for load shifting projects where cost avoidance is realised from differences in Peak and Off Peak rates.
- Where time of use pricing is involved, savings from reductions in Peak energy use will be under-reported, and savings from Off Peak use will be over-reported.
- Demand savings cannot not be calculated, but are implied within the energy savings.
- Developing a price model for accounts with adhoc usage may not be feasible.
- Changes in network or retail tariff rates may cause a step change in a price model. Where possible use the current data as it is most relevant.

Applying an energy tariff schedule

Calculating cost avoidance using a relevant energy tariff schedule will provide an accurate estimate. Energy bills vary in detail according to the nature of the fuel type, and may include:

- commodity charges (energy use, commodity weight, volume, etc)
- transportation (or transmission and distribution) charges (network charges, demand charges)
- metering charges
- environmental charges
- taxes
- bundled fees incorporating some or all of the above.

Cost avoidance is calculated from an energy tariff by applying each tariff line item. Depending on the ECM, some tariff items may apply and others may not. An important first step is to review each item to understand the rules and calculations that apply. Once this is known, ECM savings are reviewed in the context of those rules to determine the inputs for each tariff line.

Finally, once the tariff line item inputs are known, cost savings are calculated from the input quantities by applying the tariff unit rates and rules.

It should also be noted that unit price rates found on invoices can be stated with certainty (therefore there is no uncertainty to consider).

Considerations and limitations

When using an energy tariff schedule to calculate cost avoidance, the key considerations and limitations are listed below.

- Apply the schedule that applies to the post-retrofit reporting period
- Only the components that have changed need to be evaluated. For example, if we can state with confidence that a control project won't result in a billed demand reduction due to timing issues, demand does not need to be calculated.
- Align energy and demand savings figures with the time brackets and 'block steps' within the tariff. For example, a saving of 8,000 kWh may need to be split into two blocks (say first block = 6,500 kWh and remainder = 1,500 kWh) so the correct rates can be applied.
- Aligning with time brackets and block steps may increase the complexity of the analysis and modelling required and will lead to higher M&V costs.
- Understand when the tariff (or parts thereof) is scheduled to change. LNSPs typically revise network tariffs annually in either January or July. Retail contract rates may also change annually on an agreed anniversary.
- Understand the seasonal nature of the tariff. Check for items in the tariff that may be added or undergo a change rate.
- Where rates are sourced from an energy bill, make sure that the rates are free from transmission and distribution losses and taxes.

Refer to Appendix E for example cost avoidance calculations using the three methods described above.

5.5.5 Calculating greenhouse gas emissions savings

About greenhouse gas emissions

The term 'greenhouse gases' refers to a set of naturally occurring and synthetically created gases that exist in the atmosphere and trap the sun's heat and keep the planet at an inhabitable temperature. Scientific evidence has concluded that the release of additional greenhouse gases by humans is causing increased amounts of heat to be trapped within the atmosphere thereby raising global temperatures, a phenomenon known as global warming.

Often ECMs will result in greenhouse gas emissions reductions, which for some projects may be the underlying driver for proceeding with the project. Greenhouse gas emissions are divided into following categories or 'scopes', according to the level of control a business exercises over the generation of emissions:

- **Scope 1 emissions:** Direct emissions where a business activity involves the direct release of greenhouse gases. The business directly controls energy use and the release of greenhouse gases.
- **Scope 2 emissions:** Indirect emissions from energy use where a business activity involves direct energy use where greenhouse emissions are released off-site in order to provide the energy to the site. The business directly controls energy use, but is not responsible for the emissions released from generating the energy source.
- **Scope 3 emissions:** Indirect emissions from business activities where a business activity involves the indirect use of energy through use of a product or service. The business does not control energy use nor the release of greenhouse gases.

Within commercial and industrial businesses greenhouse gas emissions typically arise from the following activities:

Table 17: Summary of activities and greenhouse gas emissions

Emission source	Example business activities	Scope 1	Scope 2	Scope 3
▪ Combustion of fossil fuels (either stationary or in vehicles) ▪ Leakage of synthetic gases often used in air conditioning and refrigeration	▪ Combusting natural gas, diesel, wood, coal for energy ▪ Charging/recharging air conditioning refrigerants	Yes	No	Yes (depending on boundary)
▪ Industrial processes ▪ Fugitive emissions ▪ Storage and treatment of waste	▪ Chemical processes that release GHGs ▪ Coal seam methane ▪ On-site waste to landfill or sewerage treatment	Yes	No	No
▪ Use of electricity that is purchased from the grid ▪ Purchased steam, heat or chilled water	▪ Electricity from grid ▪ Imported fuel sources	No	Yes	Yes (depending on boundary)
▪ Use of 3rd party products and services ▪ Emissions associated with extraction, transportation and distribution of energy commodities consumed in Scopes 1 and 2 above	▪ Use of hire care and taxis ▪ Business air travel ▪ Off-site disposal of waste to landfill ▪ Outsourced telecommunications and data centres ▪ Emissions associated with base building energy use where a business is a tenant ▪ Electricity transmission and distribution losses ▪ Natural gas extraction and transportation losses	No	No	Yes (depending on boundary)

As shown above some activities may result in emissions within more than one scope, depending on the measurement boundary that is chosen and the context in which emissions savings are to be claimed.

For energy-related ECMs, greenhouse gas emission savings arise from:
- Reduced energy use
- Switching from a fuel to an alternative with lower greenhouse emissions
- Harnessing renewable energy sources that are emission free

Calculation methods

Greenhouse gas emissions are determined using one of the following approaches:
1. Calculation based on default emissions factors
2. Determination of greenhouse content of fuels using laboratory testing, combined with fuel use
3. Direct measurement through continuous or periodic monitoring

Approaches 2 and 3 are usually adopted by businesses where emissions are large, difficult to quantify, or where required by government. These approaches require additional preparation

5.5

and effort, which is beyond the scope of this guide. Further information regarding these approaches can be found at:

- The Greenhouse Gas Protocol [8]: www.ghgprotocol.org
- National Greenhouse and Energy Reporting Act (NGER), administered by the Clean Energy Regulator [9]: www.cleanenergyregulator.gov.au

For most businesses, greenhouse gas emissions are calculated from default emissions factors, which are published following extensive trial and analysis.

Factors covering energy use within Australia can be found in the following publications:

1. **National Greenhouse Accounts (NGA) Factors** [10]

   The NGA Factors Workbook is prepared by the Department of Climate Change and Energy Efficiency and is designed for use by companies and individuals to estimate greenhouse gas emissions. It contains default energy content and emissions factors, and provides guidance for calculating greenhouse emissions from energy use.

   The NGER factors workbook is available at www.climatechange.gov.au.

2. **National Greenhouse and Energy Reporting (NGER) Act** [9]

   The NGER Act is a legislated national framework for businesses to report to government regarding corporate energy use, energy production and greenhouse gas emissions.

   Aside from the compliance and corporate structure elements, the NGER Act prescribes methods for calculating greenhouse gas emissions, including approaches a), b) and c) mentioned earlier.

   The Act includes a document titled 'National Greenhouse and Energy Reporting (Measurement) Determination' which is the technical reference guide for calculating emissions. This 'Determination' specifies the methods available to companies for calculating greenhouse emissions.

   Although intended for calculating corporate greenhouse gas inventories, the contents of the Determination can assist with calculating emissions savings from M&V projects.

   Schedule 1 contains a list of default energy content and emission factors.

   Part 8 provides default uncertainty factors and guidance for calculating emissions uncertainty.

   Information about the NGER Act can be found at www.cleanenergyregulator.gov.au.

Note that the NGA Factors Workbook contains factors covering Scopes 1, 2 and 3, whilst the NGER Act is only concerned with Scope 1 and 2 emissions.

Considerations

When calculating greenhouse gas emission savings from M&V projects, consider the following:
- understand the 'scopes' of emissions to be reported
- preferably use existing approaches and factors used within your business
- if using default factors, be aware that publications are updated annually. Ensure that current factors are being used.
- in both your M&V plan and reports, state the approach used and list any relevant details
- determine if it is necessary to adjust calculated figures to reflect voluntary green energy purchases or other purchased offsets

5.5

■ consider other elements of the project that may result in greenhouse savings (e.g. switching refrigerants).

5.5.6 Savings extrapolation

The savings results obtained from our M&V exercise are only valid for the post-retrofit performance period for the measurement boundary we selected. We cannot claim 'actual' savings for a longer period or outside the boundary as they are not based on evidence gathered from measurement.

Typically savings are extrapolated in one of two ways:
1. Extrapolation over an extended period of time
2. Extrapolation outside the measurement boundary to a larger population

Extrapolation over time

Suppose we use Option B for measuring the effects of an ECM, with a post-retrofit measurement period of four weeks. In this case we can claim that the saving achieved over the four week period as being actual. If we wish to report savings for a longer period of time, say 12 months, we can only report figures as being an estimate as we have not collected data covering the period in which we are claiming.

Extrapolation outside the measurement boundary

Suppose we install solar hot water systems in three university buildings. We conduct M&V using Option B for one building and determine the actual savings across 3 months. If we wish to reports savings across all three buildings, we can only report figures as an estimate as the remaining two buildings were not part of our original measurement boundary.

Extrapolation over time

Our ability to extrapolate, and the mechanisms for doing so, is dependent on the M&V Option chosen. For example, if we conduct short term measurement using Option A, extrapolation is still possible by using data such as annualised demand curves under normalised conditions within our estimated parameters. Extrapolation beyond the post-retrofit period will involve additional data collection and analysis, perhaps from additional sources, or accounting for additional variables.

Example

Consider the ECM where a Variable Speed Drive is fitted to a condenser water pump to control water flow based on demand. Using Option B we may simply measure the baseline and post-retrofit periods, with actual savings claimable for the measurement period. Extrapolating beyond this to create a 12 month savings estimate, may involve the following additional effort:
1. Develop an energy model between energy and demand for condenser water (or a proxy)
2. Forecast an annual demand profile for condenser water, which may incorporate factors such as seasonality, public holidays, vacancy and site usage patterns
3. Extrapolate the actual savings across 12 months by applying the annual demand profile to the energy model we developed.

In this scenario, the 12 months savings figure is an estimate. In order to claim actual savings for this period, we would need to conduct continuous measurement for 12 months.

Extrapolation across a population

This section extends beyond project based M&V as defined within the IPMVP.

Using the savings obtained from a M&V exercise to forecast savings across similar projects is another common M&V outcome. Both ECM implementers and Government Program Managers have an interest in estimating the success of ECMs across a number of sites without the effort of conducting M&V for each one. The diagram below illustrates the relationship between policy/strategy, program management and site level project implementation.

Figure 16: Relationship between energy policy, energy programs and projects
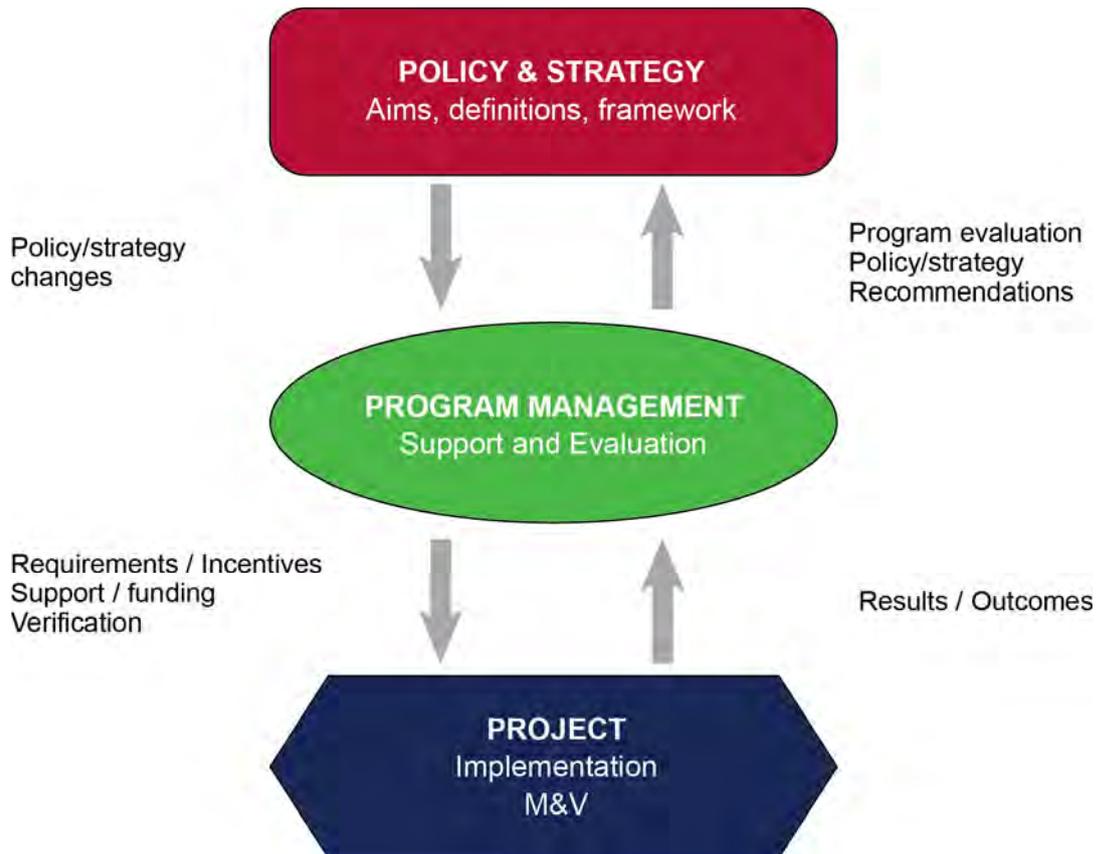
This type of extrapolation could be referred to as a 'representative assessment', in which:
1. a population of similar sites is created
2. M&V is conducted for a sample number of sites and the actual savings are determined
3. The outcome is extrapolated across the population based on sampling techniques, combined with contextual information for each site within the population.

Focusing on the program management and project implementation levels, the following approach may be considered.

Figure 17: Program management and project implementation
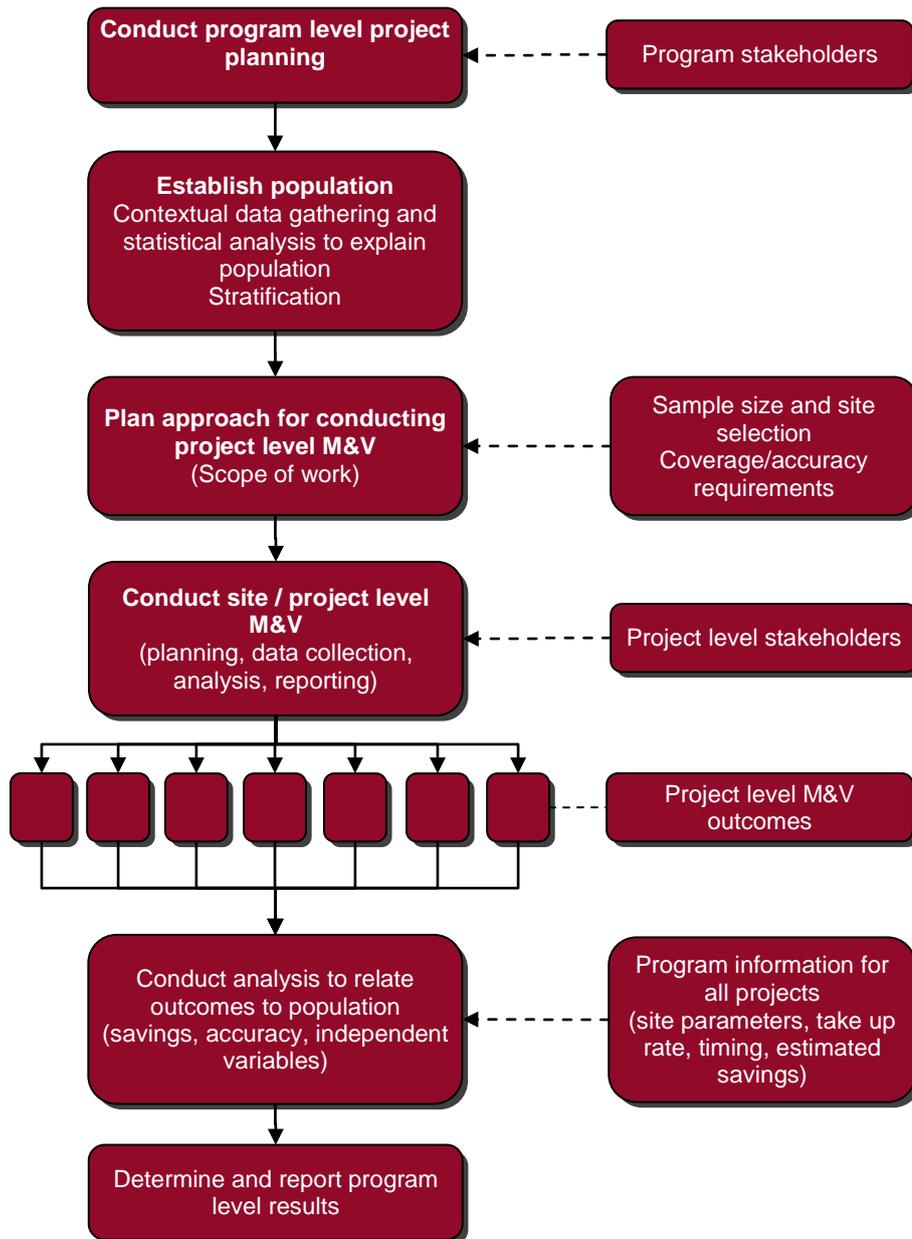
Further guidance can be found via a Representative Assessment Guide published by the Department of Resources, Energy and Tourism. This comprehensive guide covers planning and conducting representative assessments in the context of the federal government's Energy Efficiency Opportunities (EEO) program. [11] This guide is available at:

http://www.ret.gov.au/energy/Documents/energyefficiencyopps/PDF/newsletters%2010/EEORepAssessGuide-FINAL.pdf

5.5.7 Calculating uncertainty

The overall savings uncertainty should be determined at the time the energy and/or demand savings have been calculated. Multiple components of uncertainty (i.e. uncertainty associated with measured parameters, sampling and/or energy modelling) may need to be combined to calculate the overall uncertainty inherent in the total savings figure.

Additional uncertainty will be introduced when extrapolating savings over time, extrapolating savings over a population or translating energy and/or demand savings into cost and greenhouse gas savings.

Refer to Appendix G for information on uncertainty topics including statistical methods and equations, regression modelling, sampling, measurement equipment and combining components of uncertainty.

5.5

6   Finishing your M&V project

6.1   Reporting

In writing up the outcomes of the M&V project, this section provides assistance with preparing M&V reports, as well as covering other issues such as persistence.

6.1.1   M&V savings reports

A M&V report is a document that summarises the M&V project and the outcomes achieved. M&V savings reports typically include:

- overview of the site and the ECMs
- list of installed equipment and/or technology
- summary of the approach as per the M&V Plan
- the M&V Option that has been used - with reference to the IPMVP edition
- list of project team members
- performance measurements
- process for calculating savings
- expected savings for the first year
- savings uncertainty

Savings reports may take several forms, including presentations, case studies, as well as formal and informal written reports. Length, writing style and level of detail will vary for each of these formats.

Reporting tips

The following tips may assist when preparing M&V savings reports:

1. Consider the audience of the report. Use appropriate language and provide background details to put findings into context.
2. Use the details within your M&V plan to shape your report, including goals, expected outcomes and measures for success
3. Use both words and diagrams to demonstrate the savings
4. Add pictures which demonstrate the ECM in-situ and the process for conducting measurements
5. Describe step-by-step the data analysis and savings calculations. Add equations with explanations if they are unfamiliar to the audience.
6. Report savings figures using an appropriate number of significant digits
7. Note that 'actual' savings can only be stated for the post-retrofit measurement period. Any extrapolation beyond this is considered an estimate.
8. Acknowledge key stakeholders and project champions.

6.1.2   Example M&V reports

The table below provides links to examples of M&V reports and case studies for a variety of projects:

Table 18: Example M&V reports and case studies

Example	Reference
M&V case studies	Berkley Lab: http://mnv.lbl.gov/keyMnVDocs/mnvreports
Sample final report	Nexant: "Commercial/Industrial Performance Program (CIPP) Pilot Risk Analysis" http://www.nyserda.ny.gov/en/Page-Sections/Program-Evaluation/NYE$-Evaluation-Contractor-Reports/2007-Reports/Measurement-and-Verification.aspx?sc_database=web
Example Option C and Option D Reports	**7Group: "M&V Reports"** Cambria – Chapter 6 contains M&V findings based on Option D Southern York County Library – example of Option C report http://www.sevengroup.com/r-project-reports/energy/mv-reports/
Example of program level M&V using sample group and control group	Power Systems Engineering as independent verifier for Opower: http://opower.com/uploads/library/file/14/power_systems_engineering.pdf
Case study style M&V Reports	Energy Efficiency Council: http://www.eec.org.au/M%2526V

6.1.3 Rounding and significant digits

The IPMVP framework has adopted standard engineering practice for rounding figures in savings calculations so that reported figures reflect the accuracy of their underlying data. This involves rounding measurements and calculated values according to an appropriate number of significant digits.

Rules for significant digits (significant digits are bolded in examples):
1. Digits from 1-9 are always significant (e.g. **134.6**, **56**,000**)**.
2. Zeros between two other significant digits are always significant (e.g. **2,049**)
3. One or more additional zeros to the right of both the decimal place and another significant digit are significant (e.g. 0.**290**)
4. Zeros used solely for spacing the decimal point (placeholders) are not significant (e.g. **24,56**0 or 0.00**654**)

When combining figures in calculations we need to report the results using the correct number of significant figures.

Table 19: Applying the correct number of significant digits in arithmetic operations

Arithmetic Operation	Example (significant digits in bold)
For multiplication and division, the result should have as many significant digits as the measured number with the smallest number of significant digits	3,240 x 5.1 / 0.755 = 21,886.09272 = **22**,000 (reported to 2 significant figures)
For addition and subtraction, the result should have as many decimal places as the measured number with the smallest number of decimal places (i.e. the lowest unit where all numbers share a digit.	664.4 + 87.98 + 528.240 - 0.0079 = 1,280.612 = 1,280.6 (reported to 5 significant figures as 664.4 has the least decimal places)

Tips for managing significant digits

- When performing a calculation, do not follow these guidelines for intermediate results. Instead, keep as many digits as is practical to avoid rounding errors.
- When doing multi-step calculations, keep at least one more significant digit in intermediate results than needed in your final answer
- Do not apply rounding to special numbers such as published utility rates or key constants such as *pi*.

6.2   Project close and savings persistence

Once a M&V project has been completed and closed off, how do we know what the savings for an ECM will be in one year's time? Three years? Ten years? The truth is we don't. We can only give our best estimate.

6.2.1 Savings persistence

The ability of an ECM to sustain savings over its useful lifetime is an important consideration when evaluating potential projects. This is referred to as the "savings persistence" and is influenced the factors described below.

Savings persistence refers to the savings from an ECM continuing or persisting over its useful time.

Strictly speaking, savings persistence is not an issue for M&V, as M&V is only concerned with measuring actual results, rather than forecasting results. However savings persistence is highlighted within this guide so that practitioners understand the potential implications when:

- extrapolating M&V outcomes beyond the measurement period
- evaluating paybacks or making funding decisions based on M&V results
- long term forecasting of savings (e.g. within Marginal Abatement Cost Curves – MACC)
- evaluating the success of energy efficiency programs.

6.2.2 Factors affecting savings persistence

It is important that the "test measure lifetime" of equipment, often based on manufacturers' data, is considered in conjunction with the effects of maintenance, cycling patterns and other factors listed below, to determine the lifespan and energy savings achievable under typical operating conditions.

The effects of each of the items below is dependent on the type of ECM being considered, as well as the organisation's approach to factors such as staff awareness and training and maintenance procedures.

Table 20: Factors affecting savings persistence

Factor	Consideration
Equipment technical lifetime	Equipment technical lifetime provides an outer boundary for estimating lifetime savings. This information should generally be available from equipment manufacturers, and is based on testing conducted using fair to good conditions and assumes proper maintenance practices.
	For different ECMs, this may need to be adjusted for reliability, run-hours and cycling rates. For example, lighting is often expressed in 'life hours', and so the lifespan is directly related to usage rates.

Factor	Consideration
Installation and commissioning	The installation and commissioning of equipment can have a significant bearing on savings and lifespan. Incorrect installation can cause premature wear and tear and early failure, significantly degrading energy savings. Similarly, it is important that commissioning is carried out correctly to ensure equipment is functioning as intended and that this is revisited periodically.
Maintenance and part replacement practices	Ongoing maintenance has been proven to sustain energy savings through simple techniques such as lubrication and re-alignment, belt tightening, reviewing control settings, etc. In addition, it is important that part replacement is considered (e.g. to ensure that efficient lamps aren't replaced with less efficient ones when they fail, adversely affecting the energy savings being achieved).
Inherent decay in performance due to the specific technology and wear and tear	The efficiency gains for equipment may reduce over time due to wear and tear. It is arguable that the savings reductions for efficient equipment would match, or even be less severe than those of "business as usual", however it is a major consideration. The European Commission noted that "it has been shown that larger clean water pumps can lose, on average, around 5% of their new efficiency in the first five years of operation."
	In some cases, this may not have an effect on energy savings (e.g. lighting efficiency degradation affects lighting levels, not energy use), whilst others will result in high energy usage, and lower savings (e.g. reduced chiller efficiency will result in higher usage to meet conditions).
Operation and control strategies	For selected ECMs, operation and control will have a high influence on savings persistence. Choices of automated or manual controls, sensors and feedback, and associated training and awareness are important considerations. For example, the savings persistence of implementing zoning controls for lighting will be higher for automated movement-based sensor control, than for simple manual switch controls.
Obsolescence	Technology may reach an early end of life due to obsolescence. This is of particular relevance to IT technology, and will accordingly reduce the achievable lifetime savings.
Renovations or occupancy changes, and removal rates	The effective life of an ECM can be drastically affected by external changes made to the environment through refurbishments and occupancy changes. Vacating tenants may result in a refurbishment (e.g. changes to lighting system luminaires or controls), or may simply mean that an ECM becomes obsolete entirely.
	For example, "almost 50% of buildings had undergone renovation or remodelling since participating in a commercial incentives program in the previous two years" [12].
Changes to operating patterns or ambient conditions (e.g. time schedules, operating loads, areas served)	This is an area that has an impact that will be very project specific. When evaluating ECMs, the effects of changing time schedules, operating loads, or areas served may not be discernible.
Rebound effects and changing energy prices	An ECM may experience rebound, for example staff may change comfort conditions due to increased affordability from ECM, resulting in reduced savings. Conversely, increases in energy prices may result in further scrutiny of energy usage, and may result in increased overall savings due to increased take up of an initiative, or more rigorous monitoring and control.

6.2

6.2.3 Verifying persistence using ongoing or periodic M&V

The most robust way to confirm that savings from an ECM are persisting is to consider repeating the M&V exercise on a periodic or ongoing basis. With proper planning and set up (e.g. establishing permanent metering), ongoing M&V can be a straightforward exercise embedded into business processes. For example a production manager may be asked to report monthly on the performance of a particular production line. With changing production levels a key performance indicator may be developed which is simply a reflection of the baseline energy model. Adjustments to baseline energy use can be regularly calculated according to changes in production levels and compared with the current period's actual use.

Periodic M&V can also be conducted where ongoing M&V is too complicated, expensive or simply not necessary. It may be conducted annually or every few years, depending on the ECM and the need to confirm that savings persist.

As with ongoing M&V, this task may be combined with performance testing related to equipment condition and maintenance practices.

Considerations for ongoing M&V:
- Plan for long-term M&V and adopt a method and boundary that is unlikely to change
- Install permanent metering or base your M&V design on existing metering. Extra upfront cost may be required however this may result in very low ongoing M&V costs.
- Aim to embed M&V reporting into other regular reporting tasks so that it becomes standard business practice. M&V reports may be used for performance reporting as well as confirming persistence.

Appendix A: M&V examples

M&V Options

The following examples illustrate a typical application of each of the four IPMVP Options that are introduced in Section 4.1.1.

Option A – Key parameter measurement

A mid-size shopping centre contains a multi-level underground car park, fitted with T12 fluorescent fixtures with iron core ballasts. An ECM is proposed to retrofit the existing fittings with LED tubes, as these do not require ballasts or starters, enabling the existing fittings and wiring to remain in place. This provides a cost effective retrofit with very limited disruption to the car park operations during installation.

Electricity for the lighting is fed from various circuits located within floor level distribution boards. The lower floors operate between 5am and 11pm on weekdays, whilst the upper floors operate continuously.

The centre operator is seeking verification of savings, with minimal M&V cost. An Option A approach has been selected.

M&V design

The energy savings from the lighting retrofit are dependent on:
1. Power draw of the lighting fixtures
2. The operating hours of the lighting circuits

Option A involves the measurement of the *key* parameter and, given the nature of the ECM, the change in fixture efficiency has been selected for measurement. Thus the power draw of the old and retrofitted fixtures will be measured, whilst operating hours will be estimated.

The car park is not air conditioned and so there are no interactive effects. It is expected that lighting levels will remain largely unchanged or will improve and will not influence M&V design.

M&V process

Prior to the retrofit, the instantaneous power draw on each lighting circuit was measured using a true rms power meter. Following the retrofit, the exercise was repeated. Readings were collected over a 3 day period by the lighting contractor as each circuit was retrofitted and tested. The same power meter was used on all circuits.

Results

The post-retrofit kilowatt load was measured as before using a true rms power meter. Savings were determined by calculating the change in measured power draw, multiplied by the estimated operating hours for each circuit.

Savings (kWh) = (kW$_{before}$ – kW$_{post\text{-}retrofit}$) x Operating Hours

The calculated savings were 43,500 kWh per annum.

The standard error of each circuit was determined, using the precision of the power meter (±0.2% of measured reading as per instrument specification) and an uncertainty estimate of ±50 hours for annual operating hours. The standard errors for before and after measurements and

operating hours for each circuit were determined, and then aggregated as described in Appendix G. The overall relative error was found to be ±6.7%.

The outcome is stated with 95% confidence that the energy savings are 43,500 kWh ±6.7% for the estimated number of operating hours.

Option B – Full Parameter Measurement

A courthouse is provided with air conditioning from reverse cycle air conditioning units which provide both heating and cooling, each serving a dedicated area. The units are connected to a central condenser water loop, which provides heat rejection or added heat as required. The condenser water pump operates whenever any air conditioning unit is running and provides constant flow through all units.

An ECM is proposed that involves:
- fitting isolating valves to the condenser water supply to each air conditioning unit, which will be linked to the 'cooling call' and 'heating call' signals and will shut off water flow to the unit when only ventilation is required or the unit is off; and
- installing a Variable Speed Drive (VSD) on the condenser water pump motor and controlling its operation based on changes in water flow pressure, which will vary with the operation of the isolating values at each air conditioning unit.

Energy savings are expected from reduced energy use from the condenser water pump.

M&V design

The air conditioning units are controlled by time clocks and staff have the capability to request additional air conditioning using after-hours run-on timers.

Due to uncertainties with both occupancy and demand, an Option B approach will be used. Within the M&V design, it is assumed that the VSD will be commissioned to provide the air conditioning units with the correct amount of condenser water in order for internal comfort to be maintained.

The savings in pump energy use within the measurement period will depend on:
1. Pump energy use – before and after
2. Operating times of air conditioners and their need for condenser water.

Within the measurement period, the energy saved is calculated by subtracting the measured actual consumption from the baseline energy use, which has been adjusted for the post-retrofit operating hours of the pump.

The baseline will be captured using short-term logging as the power draw is expected to be static, when one or more air conditioning units are operating in cooling mode. The steady-state power draw will be determined from the logging data.

Post-retrofit, we are interested in:
- pump energy use
- concurrent air conditioning unit operating times.

Due to the change in control strategy, there may be times when one or more air conditioners are operating in ventilation mode only, and the condenser water pump may be off. The pump's 'call to run' control signal is already set up to control the pump when an air conditioner is operating. This signal will be used to determine the concurrent operating hours of the air conditioners.

The pump's post-retrofit energy use will be logged as before over a period of six weeks. The pump's 'call to run' control signal will also be logged.

Estimating the annual savings from those calculated from the measurement period will be dependent on changes in the demand for condenser water, which is based on:

1. Building occupancy and operating times for the air conditioning
2. The time of year that the M&V exercise was conducted
3. Changes in internal heating and/or cooling demand throughout the year.

From the extended period of logging, it was determined that the results were a fair representation of the building occupancy and operating times for the air conditioning.

Annual weather data will be used to estimate annual heating and cooling load profiles, which will be correlated against the M&V measurement period.

Results

The pump's baseline energy use was logged for a week to confirm the expected steady-state baseline usage. It was noted that the usage was unchanged when one or more air conditioning units were operating.

Following the retrofit, the logger was re-installed to measure the condenser pump's energy use for six weeks. Air conditioning operating hours were determined from the logged results of the pump control signal.

The adjusted baseline was calculated by pro-rating the pump's average hourly baseline energy use by the operating hours of the air conditioners observed within the post-retrofit period.

Savings were calculated by subtracting the measured post-retrofit energy use from the adjusted baseline. Uncertainty was calculated by determining the standard error for measurements for operating hours and energy use, prior to calculating the overall relative error and confidence.

Extrapolating savings

Analysis was conducted to estimate the full year savings. Daily data from the post-retrofit period was used to create a model of pump energy use as a function of ambient temperature by converting to heating and cooling degree days. The model was applied to 12 months of daily weather data to estimate the daily pumping usage, factoring in public holidays.

The average daily operating hours from the measurement period were used to calculate the baseline annual usage of the pumps, once again allowing for public holidays.

The annual savings were calculated by subtracting the estimated post-retrofit usage determined from the model and annual weather data, from estimated baseline usage.

Option C – Whole Facility

A large retailer is implementing a range of ECMs at several of its supermarkets. The projects range in nature from lighting upgrades, installation of air curtains, refrigeration plant upgrades and 'night blinds' for open refrigeration cabinets. Multiple ECMs are being installed at each site and forecast average savings are predicted to be around 15% per site.

Factors affecting M&V design

The stores share similar fit-out characteristics, however operating hours vary and the stores are spread across several geographical regions.

The retailer is seeking ongoing confirmation that savings are being achieved in conjunction with improved monitoring of store performance.

ECMs will be implemented at various times across the sites; however the retailer is interested in cumulative savings for the sites from the date of commissioning.

M&V design

The nature of the ECMs was reviewed in conjunction with the retailer's need for ongoing M&V. It was decided that an Option C approach would be used, as this calculates actual savings at the site level, using long term data.

The approach was to conduct multi-variable regression analysis to develop a baseline model for each site using historical energy data, combined with data from independent variables identified by the retailer as potentially affecting site energy use. The resulting baseline model is an equation that describes energy use as a function of each variable.

The modelling was successful for around 95% of the sites, with coefficients of determination (R^2) values of 0.8 or higher. The standard errors and 't-statistics' for each regression coefficient was analysed to determine the overall relative error.

The remaining sites were reviewed with the aim of determining why usage was not related to independent variables.

Calculating savings

In order to facilitate ongoing M&V an online performance reporting web-portal, linked to a data repository was developed. The database incorporated data for monthly energy use at each site and data for each independent variable. Processes were developed to capture future data from various internal sources on a monthly basis.

The model for each site was programmed into the database. Reports were developed that used the model equation and applied the most recent data for each independent variable to calculate an adjusted baseline. The actual monthly usage was then subtracted from the adjusted baseline to determine savings.

Option D – Calibrated Simulation

A new hospital is constructed under a Public-Private Partnership agreement in which the government health service and the services contractor have entered into a performance contract based, amongst other things, on the energy use of the building.

Due to the variable local weather conditions, both parties are seeking a verifiable approach for evaluating the contractor's management of the facility, which is linked to a risk-reward payment.

As this is a new building, no performance data was available. An Option D M&V approach has been agreed.

Factors affecting M&V design

The new building sits within a broader precinct which is metered under a single utility meter. A new sub-meter will monitor energy use within the new building.

As this is a new building, no performance data was available. An Option D M&V approach has been agreed.

Appendix A

Although there are no ECMs being implemented, the outcomes from the model become a performance benchmark, and a formal M&V approach is used in this manner to verify performance against a baseline calibrated for the actual conditions.

M&V process

Using a building modelling program, the entire building was modelled. Inputs included:
- building layout and fabric
- positioning and orientation on site
- inventory of all equipment to be installed including HVAC, lighting and connected loads
- forecast control strategies and operational schedules for equipment based on occupancy and demand
- forecast patient activity
- hourly data for ambient temperature for a typical year.

The building simulation software manipulates the ambient temperature data against the proposed interior temperature set points to develop figures for the expected daily heating and cooling requirements.

Energy use is then simulated for all static loads (e.g. light and power) as well as variable loads such as heating and cooling demand.

The hospital was modelled, producing monthly energy use and demand figures based on weather data. Outputs were sanity-checked against data from existing hospitals

It was agreed that the outputs from the model (with an agreed tolerance) would become the basis for measuring performance, following an initial commissioning and fine-tuning period. The contractor would be rewarded for exceeding performance (lower usage without compromising conditions) and would be penalised for not meeting the performance figures (higher usage).

Calculating savings

The Option D approach requires the re-calibration of the model so baseline performance can be simulated using current conditions.

Once the hospital had been completed and opened, monthly usage data was collected from the building's sub-meter.

The building simulation was updated to incorporate the 'as built' nature of the hospital, including the actual equipment installed and actual operating schedules and control strategies (as dictated by the health agency).

For the next 12 months following the commissioning period, the hospital simulation was recalibrated on the quarterly basis using the observed weather data and occupancy levels.

The actual energy use was then subtracted from the simulated energy use to determine the performance of the contractor.

Savings additionality example

The following example relates to managing the issue of additionality where multiple ECMs with overlapping boundaries are being implemented. The example demonstrates the methods described within Section 4.1.6.

An office tenancy is undergoing a lighting upgrade. Two ECMs have been implemented:
- ECM #1: Existing luminaires have been retrofitted with higher efficiency luminaires
- ECM #2: Occupancy based controls have been installed.

The chart below illustrates the Baseline (red) and Post-Retrofit (blue) load profiles for the retrofit.
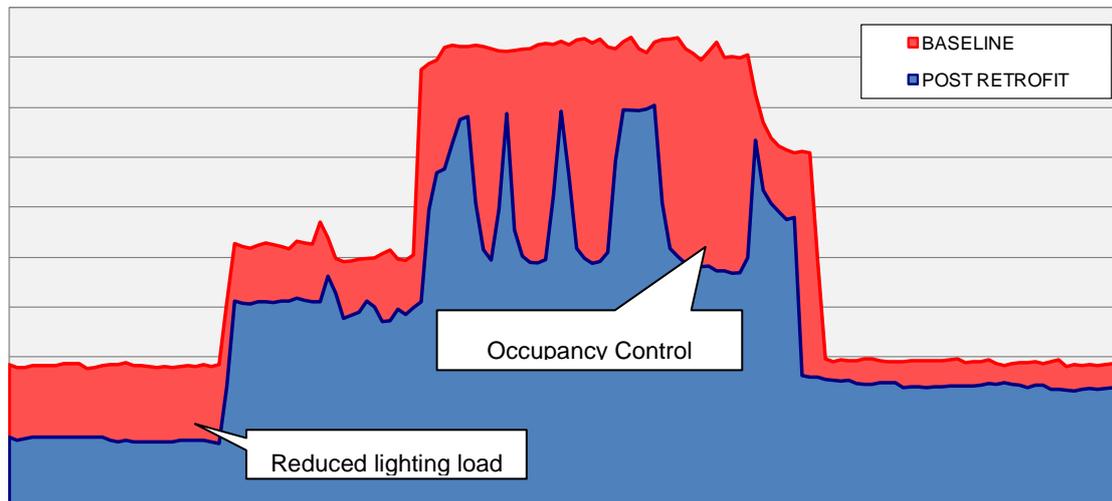
Each project delivers energy savings, however the savings cannot simply be added together because the control based savings (reduction in operating hours) impacts the savings from the reduced connected load and vice versa.

In this situation, the Black Box or Ordered Summation of Remainders approaches can be used to aggregate the two ECMs.

Using the Ordered Summation of Remainders approach

The projects are ordered as follows:
1. ECM #1 = High efficiency luminaires
2. ECM #2 = occupancy controls

Steps to calculate are:
1. The savings for ECM #1 are measured using Option A (measure change in connected load, and assume the same operating hours)
2. The savings for ECM #2 are measured using Option A (measure change in hours). ECM #1 is assumed to be implemented, and hence the post retrofit connected load is used as the baseline for calculating savings for ECM #2.
3. Aggregated savings are calculated by adding the 'full' savings for ECM #1 with the reduced savings for ECM #2.

Using the Black Box approach

M&V Option B is chosen as both the changes in operating hours and the connected load affect the savings. The savings are calculated as the combined difference in operating hours and reduced load, as depicted by the red shaded area in the example load profile.

Using this approach, the savings are stated for the combined ECM. Savings cannot be stated separately for each ECM.

M&V design examples

The following examples highlight how the M&V Option, measurement boundary and key parameters are interrelated to each other and how they can be combined into an overall M&V design which also takes into account interactive effects, operating cycles and additionality issues.

These concepts are described in Section 4.1. The intention here is to highlight various M&V design options for the same system based on the nature of the ECM.

Consider the system diagram below which describes a typical air conditioning plant. The system comprises a central plant room in which chillers produce chilled water and pumps distribute the chilled water to air handlers located throughout the building via a central chilled water loop. A condenser water loop is also located in the plant room, which serves the chillers to remove heat via condenser water pumps to roof mounted cooling towers.

Figure 18: M&V design example: HVAC system diagram
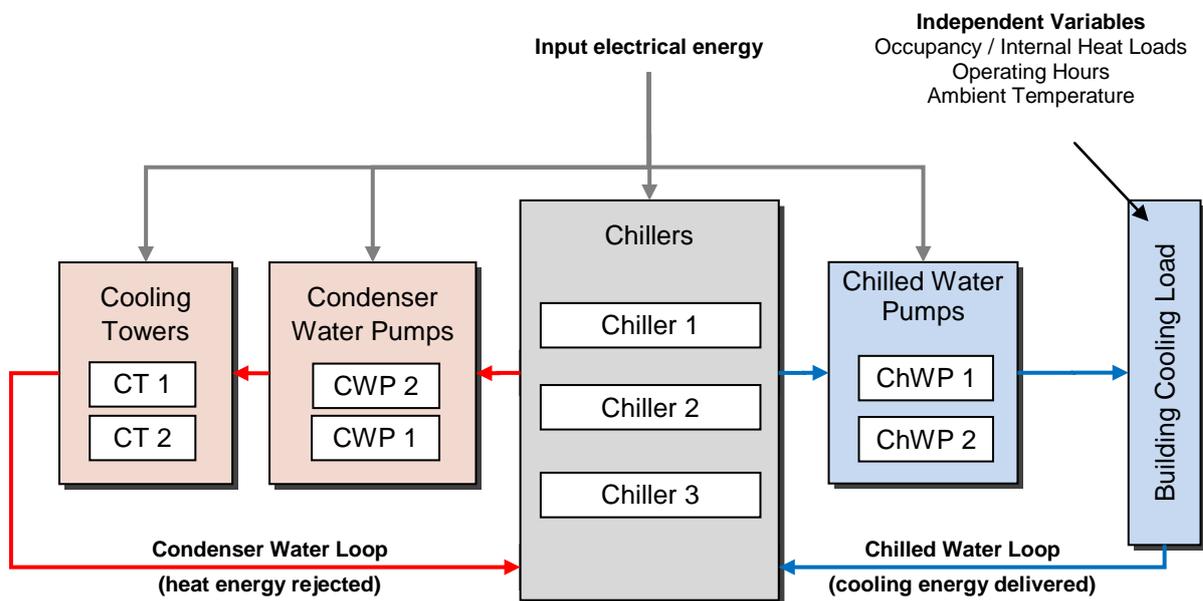
Now consider the following ECMs and the available choices for M&V Option, measurement boundary and key parameters:

1. Chiller 2 is replaced
2. Variable speed drives are fitted to condenser and chilled water pumps
3. Adjustments are made to temperature set points within conditioned spaces
4. All of the above

## ECM #1 – Chiller 2 is replaced with a more efficient model

This ECM involves replacing a chiller with a more efficient model, and as a result, we expect to see reduced energy consumption for the same delivery of chilled water. The amount of savings is dependent on:

1. The difference in efficiency between the old and the new models at different loads
2. The cooling load within the conditioned space, and the subsequent need for chilled water
3. The operating hours and loading of the retrofitted chiller within the staging sequence based on overall building requirements.

With this ECM, we have a number of measurement boundary choices, as shown in the diagrams below – in each case the chosen boundary is highlighted in Green.

Table 21: M&V design example: ECM#1 design options

Boundary Option #1
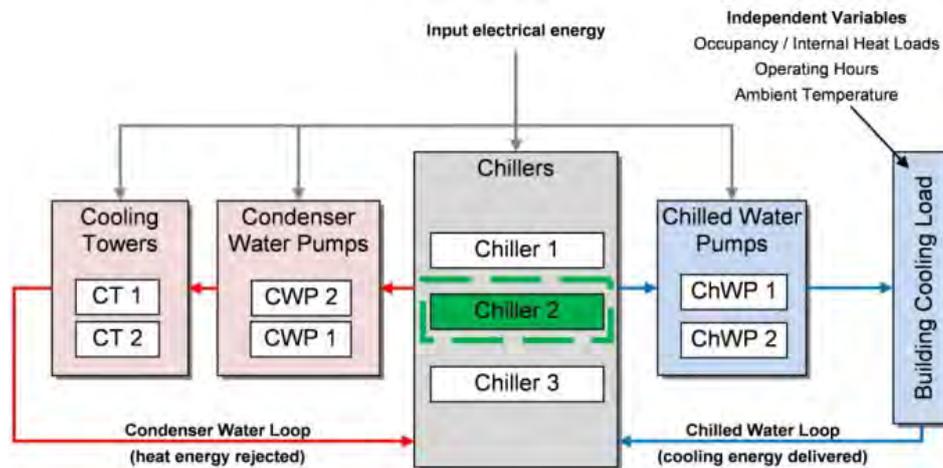
This is the smallest boundary available. The chiller is considered in isolation and the independent variables that will dictate the improved performance are:

- Chilled water energy (flow and temperature differential) – difficult to measure in a common loop unless the chiller is operating alone.
- Operating hours

Energy savings are determined by multiplying the change in performance by an estimated load condition.

Effects on chiller staging may be considered an interactive effect since replacing Chiller 2 may increase or decrease the operating hours of the other chillers.

The operating cycle may be 1 day to 4 weeks, depending if a sufficient range of chiller operation can be achieved.

M&V Option A – Chiller efficiency is the key parameter. Conduct load tests of both chillers to develop performance curves. Estimate cooling demand and operating hours, factoring in chiller staging.

M&V Option B – Input energy and chilled water energy must be measured for Chiller 2 only (i.e. when operating alone). Need to estimate operating hours, factoring in chiller staging.

Boundary Option #2
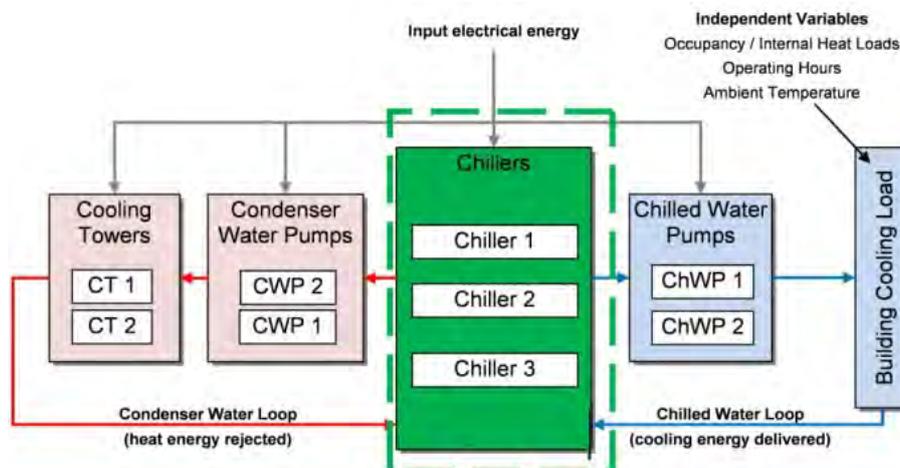
In this scenario, the chillers are considered as a set. This option makes it easier to relate input energy to the chilled water energy requirements, and chiller staging and associated interactive effects is not an issue as the combined effect is evaluated.

More measurement equipment/cost may be required to measure input energy from 3 chillers rather than 1.

The operating cycle may be 2-4 weeks, depending if a sufficient range of chiller operation can be achieved.

M&V Option A – Chiller set efficiency is key parameter. Conduct a load test on chiller set, incorporating existing chiller staging sequence. Estimate total chilled water load. Estimate operating hours factoring in chiller staging, assuming that performance of remaining chillers is unchanged.

M&V Option B – Measure combined input energy from the 3 chillers (or measure separately and combine), as well as total chilled water energy. Develop baseline performance curve and adjust using post-retrofit chilled water energy.

Boundary Option #3
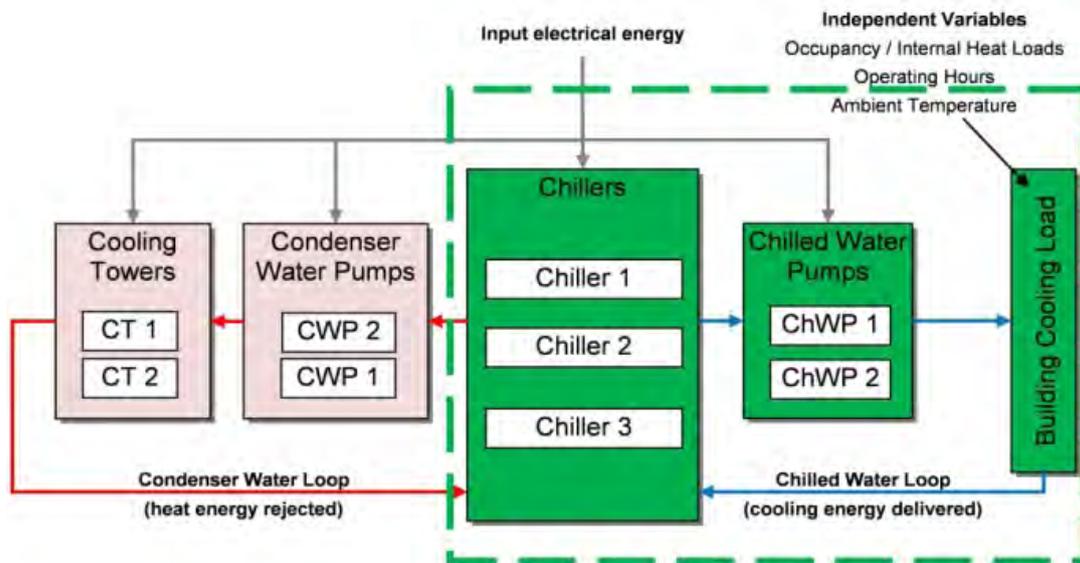
This boundary is similar to #2, where we are considering the total cooling needs of the building. This may be chosen where existing metering is in place.

The chilled water pumps must now be considered. This may be trivial if they are constant flow, however additional analysis may be required if they operate on variable flow or are staged to operate simultaneously based on demand.

M&V Options A and B – as per #2, however the input energy includes the pumps. Ambient air temperature may be considered as the independent variable, rather than chilled water energy, depending on its correlation. Using chilled water energy rather than ambient temperature has the advantage of factoring in cooling requirements for various areas of the building based on occupancy (e.g. 24 hour data centre).

The operating cycle needs to cover all climatic seasons if ambient air is used as the independent variable, hence a full operating cycle will be 12 months.

Alternatively, the operating cycle may be reduced 2-4 weeks if total chilled water energy (estimated) is used, depending if a sufficient range of chiller operation can be achieved during the measurement period.

Appendix A
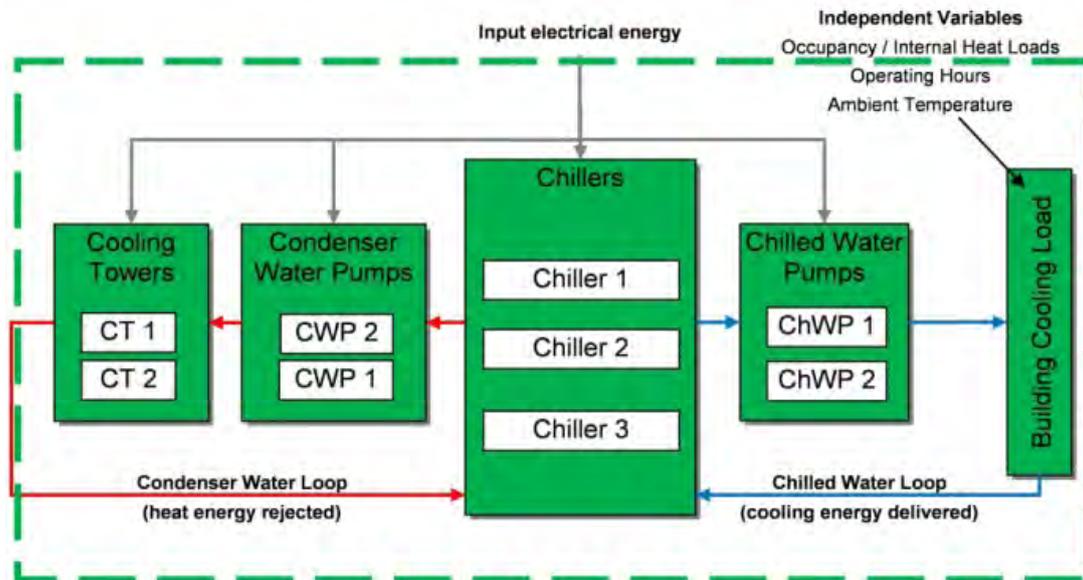
This is the largest boundary possible within the immediate vicinity of the chiller, and now includes the condenser water system. As before the choice may be due to the presence of existing metering.

In reality, the energy usage and savings from the chiller retrofit is dependent on the amount of cooling required (ambient temperature or chilled water energy), and therefore the condenser water system is not required within the boundary. Rather, the operation of the condenser pumps and fans is dependent on the heat rejection needs of the chiller. If condenser system savings are expected, then it should be included in the boundary.

M&V Options A and B – as per #3, however input energy now includes chillers, pumps and cooling towers.

M&V Option C – Assuming ECM savings are >10% of total site usage, the boundary can be extended to cover entire site. Use 12 months or more of historical data to develop a model of site energy use based on ambient temperature and other independent variables (e.g. occupancy). Measure post-retrofit use over an extended period. Create an adjusted baseline using post-retrofit data for independent variables and then subtract actual energy use.

## ECM #2 – Install variable speed drives on condenser and chilled water pumps

This ECM involves reducing the water flow to the building and cooling towers based on the demand for cooling and heat rejection. Variable speed drives are fitted to each motor, and the pump speeds are controlled by temperature or pressure. As a result, the water volumes will change, however the overall energy transfer should remain the same. We expect to see reduced pumping energy. The amount of savings is dependent on:

1. The amount of 'turn down' that can be achieved, which is based on the cooling and heat rejection requirements.
2. The operating hours of each pump

With this ECM, we have a number of measurement boundary choices, as shown in the diagrams below.

Table 22: M&V design example: ECM#2 design options

Boundary Option #1
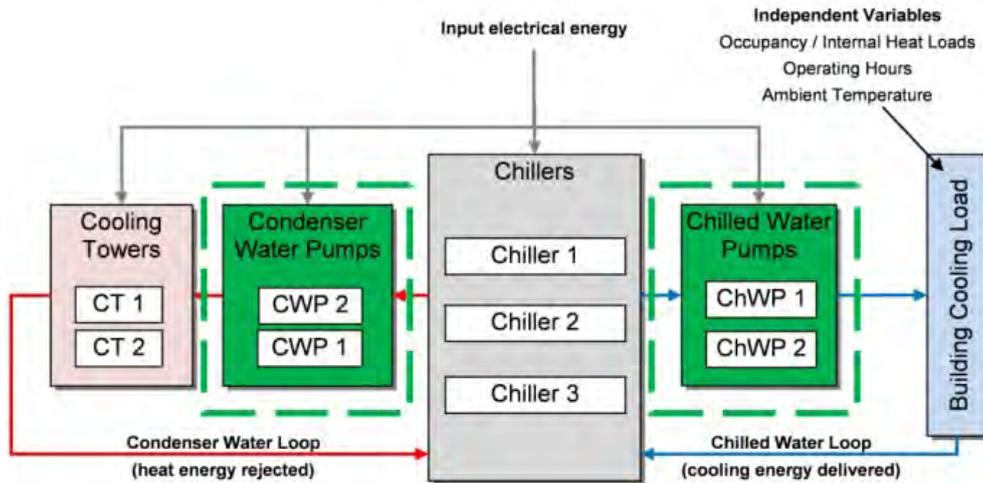
The two water loops are considered separately using mutually exclusive measurement boundaries.

This approach has the advantage of avoiding any complexity associated with the chillers, such as different efficiencies and staging strategy.

Since this ECM will vary the chilled and condenser water flows through the chiller, cooling towers and at the heat loads, this may cause interactive effects with these other associated systems outside the measurement boundary which may be ignored or estimated depending on the size of the effect.

An operating cycle of up to 2 weeks could be selected for this ECM.

M&V Option A – Load test pump efficiency for each pump, by measuring the input energy for different pump speeds. Factor in duty cycle to determine the overall efficiency improvement. Estimate the chilled water and condenser water flow.

M&V Option B – Measure input energy and water flow to develop a baseline energy model. Use post-retrofit water flow to adjust the baseline to calculate savings.

An On/off test may be effective here, enabled by switching the VSD on and off. This involves measuring the energy use for a week without the ECM, followed by a week with the ECM working, then repeat.

Boundary Option #2
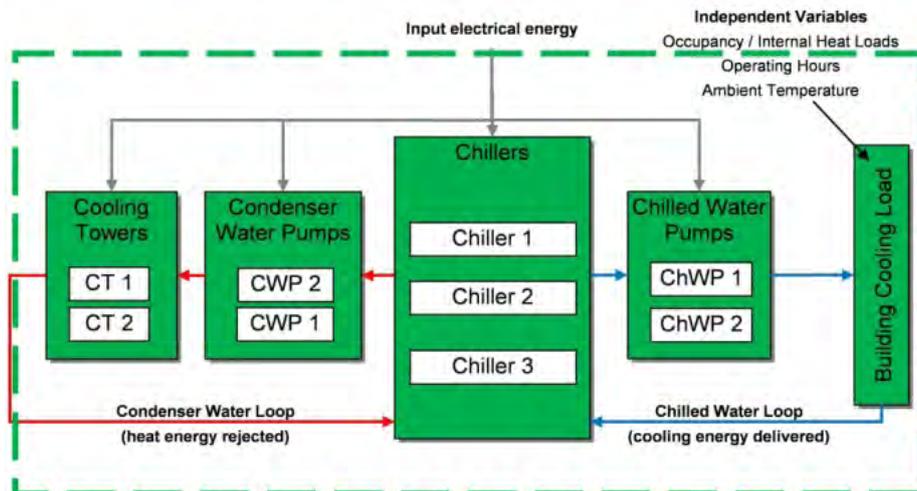
The combined pumping savings are now considered within the one boundary, which now includes the chillers and cooling towers.

The feasibility of using this boundary will depend on:

- Size of the pump savings in regard to overall system
- Ability to determine an energy use model

The condenser water flow will be considered to be dependent on the chilled water flow or ambient temperature, and so the model can be developed based on the one independent variable.

M&V Option B – measure combined input energy for the system, as well as total chilled water energy or ambient temperature. Develop a baseline energy model for overall system performance. Use post-retrofit water flow to adjust the baseline to calculate savings.

The operating cycle needs to cover all climatic seasons if ambient air is used as the independent variable, hence a full operating cycle will be 12 months.

Alternatively, the operating cycle may be reduced 2-4 weeks if total chilled water energy (estimated) is used, depending if a sufficient range of chiller operation can be achieved during the measurement period.

ECM #3 – Adjust temperature set points

This ECM involves widening the 'deadband' within which neither heating nor cooling is required. This overcomes heat-cool conflicts where the two systems work against each other. Internal temperatures are monitored using wall mounted thermostats located throughout the building. We expect to see reduced heating and cooling usage, with minimal effect on comfort conditions. The amount of savings is dependent on:

1. Input energy use for the heating and cooling systems.
2. New heating and cooling requirements within the conditioned space

This ECM will affect energy use across the cooling system, based on reduced demand; however the change in demand is not an independent variable, as it forms the basis for the ECM. In this case, we either:

- establish the relationship between cooling demand and ambient temperature, or
- avoid using cooling demand as a parameter and focus on the relationship between input energy and ambient temperature, whilst monitoring internal comfort conditions confirm they are acceptable.

Sample measurement boundary options and M&V approaches for this ECM are described below.

Table 23: M&V design example: ECM#3 design options
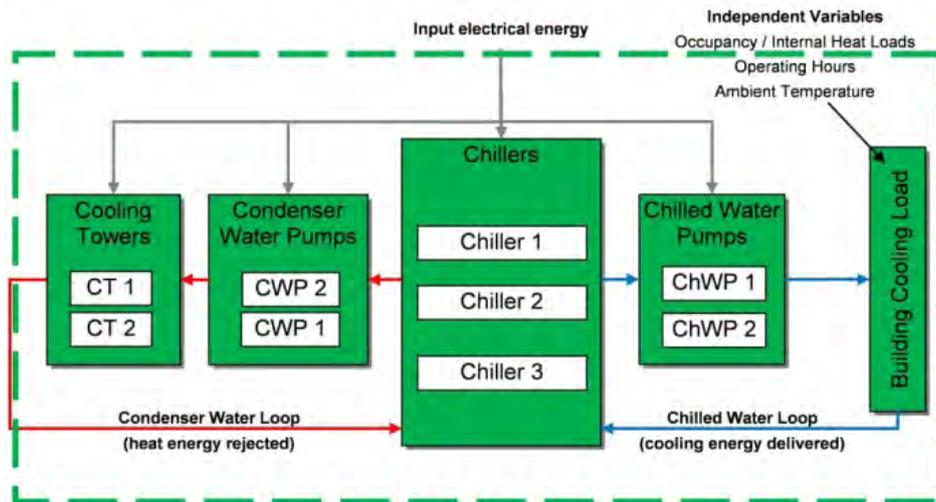
Boundary Option #1
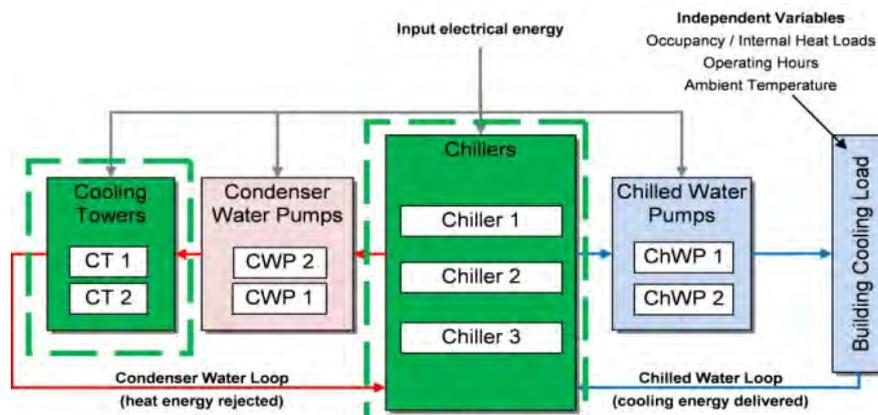
Temperature setpoint changes will affect the amount of cooling required for a given ambient temperature, including the associated heat rejection via the cooling towers. Water pumping will remain unchanged. Heating energy use changes will be an interactive effect and may be considered as a separate M&V project or the measurement boundary may be expanded to include the heating system.

M&V Option A – Change in cooling demand for given ambient temperature is the key parameter. Conduct a load test on chiller set, incorporating chiller staging sequence or use manufacturer performance curves to establish relationship between input energy and chilled water output. Measure chilled water energy over an extended period and model the relationship between chilled water demand and ambient temperature.

Measure post-retrofit chilled water demand, and use data to adjust baseline chilled water demand using post-retrofit ambient temperature and subtract post-retrofit chilled water demand. Finally, use the chiller performance curve to calculate savings.

M&V Option B – Measure input energy to chillers and cooling towers and develop a baseline energy model against ambient air temperature. Use post-retrofit temperature data to adjust the baseline to calculate savings.

Boundary Option #2

In this scenario the measurement boundary consists of the entire cooling system.

This may be considered due to metering arrangements.

M&V Options A and B will be analysed as per #1.

M&V Option C – To use M&V Option C, we need to consider the size of the estimated savings as a proportion of total site energy use.

If expected savings are >10% of total site use then the boundary can be extended to cover entire site.

Develop a model of site energy use based on ambient temperature and other independent variables. Measure post-retrofit use over an extended period. Adjust model input variables using post-retrofit data and then subtract actual energy use.

The heating system will also be included within this boundary, which may require separate analysis, and involve additional energy use data (e.g. natural gas data).

ECM #4 – Implement ECMs 1, 2 and 3

The combination of a chiller upgrade, variable speed drives for pumps and temperature set point changes will result in energy usage savings across the entire cooling system (heating as well!).

Determining the effects of a single ECM will not be easy as the interaction between ECMs is significant. For example, widening the deadband will result in lower chilled water demand, which will cause the pumps to slow down, as well as reducing the load on the chiller.

The combined savings from these ECMs is likely to be high, and an Option C approach is recommended. This will enable the heating system to be evaluated as well, so the total combined savings can be determined.

The M&V process may include:
1. Use of a facility boundary.
2. Developing a model of site energy use based on ambient temperature and other independent variables.
3. Measuring post-retrofit use over an extended period.
4. Adjusting model input variables using post-retrofit data and then subtracting actual energy use.

There is potential to evaluate each ECM separately, should they be implemented over an extended period of time however additionality issues will need to be considered. After an initial baseline is developed, the cumulative effects of each ECM could be evaluated; potentially incorporating an On/Off test for the variable speed drives as well.

More likely, a combined savings figure is all that is required, which will simplify data collection and analysis.

An Option B approach can also be considered with a measurement boundary consisting of the entire air conditioning plant. The approach will be similar to that described for Option C above. Consideration may be given to developing separate models relating:
1. input energy versus chilled water demand, and
2. chilled water demand versus ambient temperature

By preparing separate models, the end result may be more flexible with dealing with future non-routine adjustments (such as changes in occupancy).

Demand savings example using regression analysis

The example below illustrates the calculation of demand savings from chiller performance curves.

Example

The charts below illustrate the performance curves of a new chiller (grey) which is replacing an older chiller (orange).
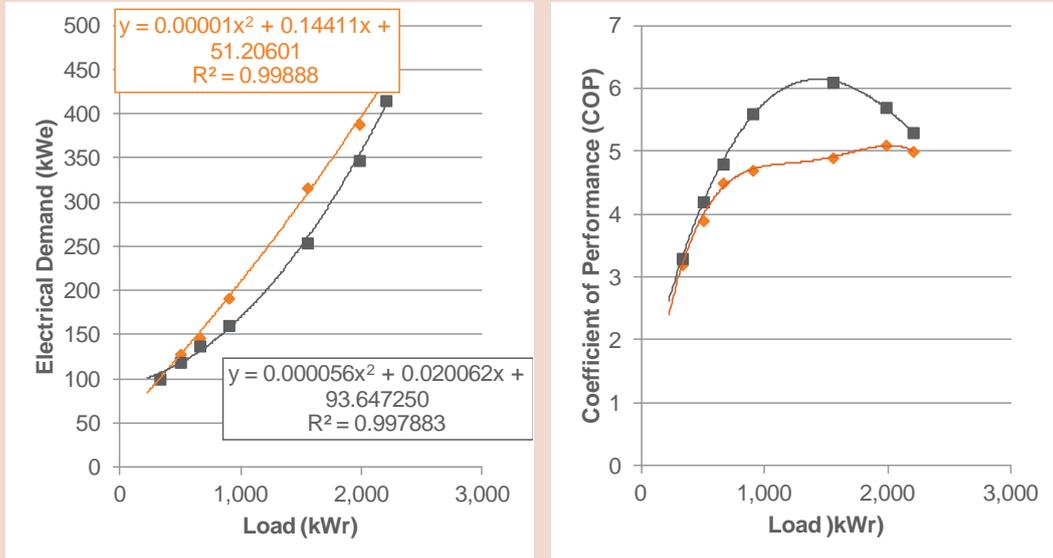
The electrical demand can be estimated for each chiller using the equations shown based on the corresponding cooling load.

Using 1,800 kWr as an example the demands for two chillers are:

Old chiller demand (kW) $= 0.00001 \times load^2 + 0.14411 \times load + 51.20601$
                             $= 343$ kW

New chiller demand (kW) $= 0.000056 \times load^2 + 0.020062 \times load + 93.647250$
                             $= 311$ kW

And the demand saving is: $= 343 - 311$
                             $= 32$ kW

By applying this process to a chilled water load profile, we can estimate the electrical profile, and compare them to determine the demand savings for a given load, time of day, or season.

It is important to note that in this case the savings will vary depending on the load of the chiller (i.e. the savings at low loads are different to those at peak COP or even full load. This variation will occur due to changing ambient conditions (day/night, summer/winter, etc) as well as control strategies, particularly if multi-chiller staging occurs

Calculating cost avoidance examples

The examples below illustrate the process for determining cost avoidance using the three approaches (average cost, marginal cost and tariff structure) as described in Section 5.5.4.

## Example 1: Average and marginal cost avoidance calculations

Suppose that a police station has seen the monthly energy use and cost listed below:

Month	Monthly Use (kWh)	Monthly Cost ($)
July	43,330	$8,680
August	43,060	$8,218
September	41,540	$8,505
October	51,220	$9,142
November	61,510	$11,403
December	62,670	$11,942
January	65,830	$12,649
February	75,070	$13,433
March	72,040	$12,992
April	47,150	$8,988
May	46,690	$8,708
June	45,700	$8,995
12 months	655,810	$123,655

The average price across the 12 month period is:

Average price   = $123,655 / 655,810

                 = $0.1886/kWh

                 = 18.86 cents/kWh

The marginal price is determined using regression analysis:
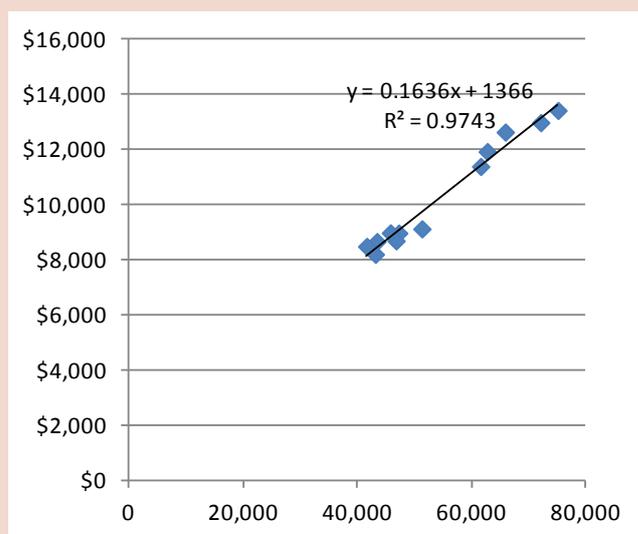
From the chart above, the marginal price is shown by the slope of the line:

Marginal price   = $0.1636/kWh

## Example 2: Savings calculations based on energy tariff structure

A major water utility uses a pump to maintain the water level within a reservoir based on sensors for low water (pump start) and high water (pump stop). The pump operates at a fixed speed and is required to move the required amount of water based on the water level in the reservoir.

An ECM is proposed to fit the pump with a variable speed drive and operate the pump at a lower speed. This will result in the pump operating longer hours, but use less energy overall.

Pump costs are billed using the energy tariff schedule below. We wish to accurately forecast the change in cost by fitting the VSD.

Energy Category	Energy Rates
Retail Items	
Peak (kWh) (2pm to 8pm weekdays)	$0.065
Shoulder (kWh) (7am to 2pm and 8pm to 10pm weekdays)	$0.065
Off-Peak (kWh) (all other times)	$0.031
Network Items	
Network Access Charge (day)	$7.26550
Demand Charge Peak Period (kVA/month)	$5.20200
Network Peak Energy Charge (kWh)	$0.0186300
Network Shoulder Energy Charge (kWh)	$0.0186300
Network Off-Peak Energy Charge (kWh)	$0.0152400
Other Items	
Mandatory Renewable Energy Target Certificates (kWh)	$0.0007
NSW Energy Savings Scheme Certificates (kWh)	$0.003
Meter Provision (meters x days)	$2.48

The before and after load profile for the pump is shown below (for one day), adjusted for the same water volume. The Peak, Shoulder and Off Peak billing periods from the energy tariff are also shown below.
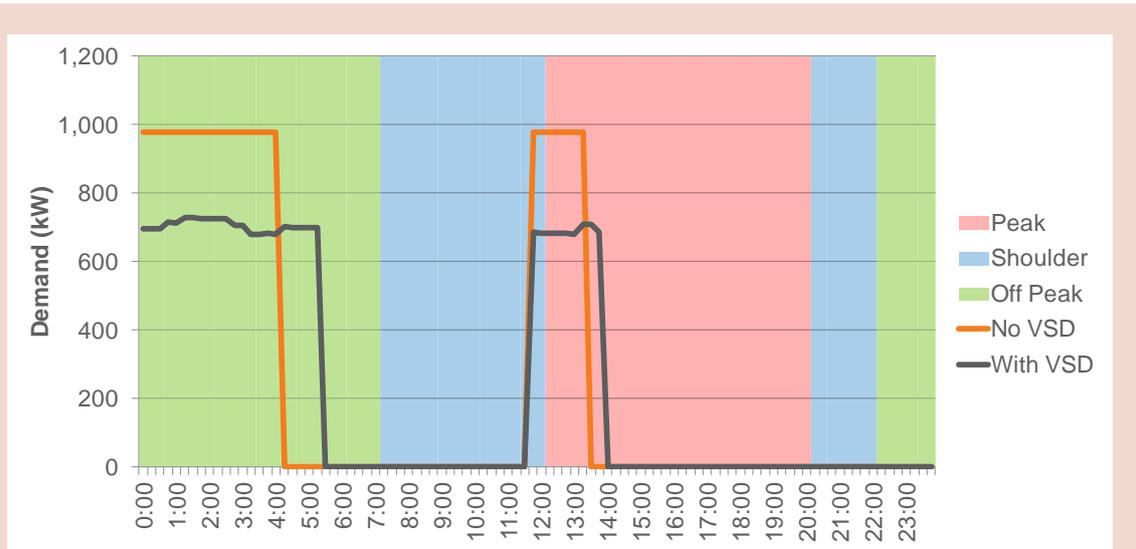
We can see that energy use occurs across all three time periods. Demand charges occur for the peak period only. The data is input into a spreadsheet, and the 'time of use' (e.g. Peak, Shoulder, Off Peak) is allocated against each time period.

By summing the energy used within each time period, the energy savings are:

Energy Use (kWh)	Peak	Shoulder	Off Peak	Total
No VSD (baseline)	1,221	489	10,015	11,725
With VSD (post-retrofit)	1,209	342	9,310	10,861
Savings (kWh)	12	147	705	864

Demand savings are determined by reviewing the *minimum* change that occurs in demand during the Peak Period, as this is the only time period that has a demand cost element associated with it.

The demand saving is found by:

Demand saving (kW)   = MAX(baseline Peak demand) – MAX(post-retrofit Peak demand)

=977 – 709

= 268 kW

So now the tariff schedule is applied to the savings quantities:

Energy Category	Energy Rates	Quantity	Cost avoidance $
Retail Items			
Peak (kWh) (2pm to 8pm weekdays)	$0.065	12	$0.78
Shoulder (kWh) (7am to 2pm and 8pm to 10pm weekdays)	$0.065	147	$9.56
Off-Peak (kWh) (all other times)	$0.031	705	$21.86
Network Items			
Network Access Charge (day)	$7.26550	no change	$0.00
Demand Charge Peak Period (kVA/month)	$5.20200	268	$1,394.14
Network Peak Energy Charge (kWh)	$0.0186300	12	$0.22
Network Shoulder Energy Charge (kWh)	$0.0186300	147	$2.74
Network Off-Peak Energy Charge (kWh)	$0.0152400	705	$10.74
Other Items			
Mandatory Renewable Energy Target Certificates (kWh)	$0.0007	864	$0.60
NSW Energy Savings Scheme Certificates (kWh)	$0.003	864	$2.59
Meter Provision (meters x days)	$2.48	no change	$0.00
Total Savings			$1,443.23

Note that demand savings need to be assessed over a full month, rather than the single day shown here. The savings above are valid if the pump is operating one day per month.

Appendix A

Appendix B: ECM and M&V lifecycle

The table below illustrates the task and timing considerations for conducting M&V within an overall end-to-end process for identifying, evaluating and implementing an ECM.

Table 24: ECM and M&V lifecycle

Milestone & Guide to Timing	Site Review (i.e. Energy Audit)	Decision Making	ECM Implementation	M&V Exercise
4 to 8 weeks	Project inception and planning			
	Collect and analyse site data			
	Conduct site visit to review energy use/data logging/identify opportunities			
	Develop site energy model (e.g. energy mass balance or similar)			
	Analyse opportunities to determine scope, savings, cost, payback			
	Report findings			
ECM Identified				
As required		Business evaluation of audit findings and decision making		
ECM implementation approved				
less than 1 week				Initial decision to conduct M&V
M&V to proceed				
As required			Project inception and planning	
			Facility/Energy Characteristics	
1 to 4 weeks				Determine basic M&V requirements
				Prepare M&V Plan
1 week to 12 months prior to ECM implementation			Request and Evaluate Proposals	Collect baseline data and develop energy model
			Contracting	
			Design	
M&V Baseline collected and analysed				
As required			Implement ECM	
			Conduct acceptance testing & commissioning	
ECM Implemented				
1 week to 12 months as per M&V Plan			Performance Period	Collect post-retrofit data
				Analyse data and calculate savings
1 to 4 weeks	Follow up if audit sponsored by government energy efficiency program	Report M&V outcome to decision makers		Report M&V results
			Project Closeout	Project Closeout
ECM Savings Measured and Verified				
As required				Conduct ongoing M&V as required
ECM Persistence verified				

Appendix C: Data measurement and collection principles

It is important that appropriate care is taken for conducting measurements as in most cases there is limited opportunity for capturing data, particularly within the baseline period.

Data collection from measurement equipment

Successful data collection involves:

1. Selecting the right equipment for the job which is:
   a. safe to use
   b. reliable and in good working order
   c. calibrated
   d. able to withstand the ambient conditions at the location where it will be placed (heat/water proof)
   e. able to achieve the desired measurement frequency and accuracy
   f. sufficiently powered or has enough battery life to record data for the required period.

2. Positioning the equipment correctly:
   a. refer to the manufacturer's instructions and specifications when placing and testing equipment set up.
   b. for distributed systems, consider issues such as changes/losses in temperatures or pressure.

3. Use the right people:
   a. qualified tradespeople may be required.
   b. equipment suppliers or consultants may be best suited for placing equipment

> **Tip**
>
> - test the equipment works (preferably before going to site)
> - test that data can be downloaded successfully
> - check that memory is available and delete any old data
> - secure equipment in place so that it won't be disturbed or accidentally removed
> - label the equipment with a sign including its purpose and emergency contact details
> - accurately record the key details of the installed equipment, including:
>   - date and time installed
>   - location (description and/or diagram)
>   - configuration details (e.g. CT settings, frequency, etc)

Additional tips for electrical measurements

- Ensure that only qualified electricians conduct measurements that involve access to switchboards. This generally applies for temporary measurements involving a clip-on ammeter, voltmeter or data loggers, etc.
- Make sure that the correct circuits are being measured. Ensure this by:
  - reviewing single line diagrams
  - reviewing distribution board circuit schedules
  - visual inspection

- When installing data loggers:
  - carry out instantaneous current readings to establish a reference point and to help set the range of the data logger current transformers
  - consider the full range of consumption values that are likely to be observed and set the range of the data logger to capture the range of interest
  - for highly variable loads, consider installing two data loggers set with different resolution scales – one to capture high energy use and the other to capture lower usage
  - once all loggers are in place, re-check them to confirm that the current transformer clamps are fully closed, and that the 'CT' ratio has not been bumped
  - if the option exists, connect the loggers to a PC and check that measurements are being taken in situ.
- for balanced loads, measurements need only be taken on one phase
- for unbalanced loads, measure each phase individually
- Note that although voltage will typically be assumed constant, the exact value can be collected, as it could range anywhere from 215 to 253 volts.

On-Off tests

Due to their nature, some ECMs involve a permanent change to the energy system in which it is implemented. Others can be switched on and off. The ability to control the operation of an ECM provides us with the ability to collect data and minimise the effects of independent variables, which simplifies our M&V project.

This approach is known as an On-Off Test, which involves defining a continuous measurement period for both the baseline and post-retrofit components. Data is collected for a period with the ECM switched off, and a similar period with the ECM switched on. This is then repeated.

Example: Solar hot water

A solar hot water collector is added to an existing gas hot water system. An isolation valve is fitted to isolate the flow of water to and from the roof. Due to the difficulties with measuring hot water demand, an On-Off test was conducted. Natural gas usage was measured on a daily basis using the main incoming natural gas meter for a period of 6 weeks with the isolation valve opened and closed at weekly intervals. Overall site usage patterns were tracked to ensure consistency.

Sampling

Sampling involves conducting measurements on a subset of a population to estimate the characteristics of the entire population. In a M&V context, this can be either:

1. periodic measurements of the same equipment to represent continuous measurement (e.g. multiple readings of the same circuit in different conditions)
2. sampling of a subset of devices, systems or components within a larger population

In either case, the aim is to develop a trend or energy model from the collected data.

A typical sampling process involves:

1. defining a population – this is easy for the first situation above. For the latter, initial analysis should be conducted to demonstrate that the 'units' indeed represent a population. If this cannot be achieved, then the results from the sampling exercise cannot be applied.

2. defining a sample size – this involves the selection of the appropriate number of data points required to suitably describe the population in terms of coverage and accuracy. The size of the population is dependent on the variability of the data that will be collected as more data must be collected for highly variable data (refer to Appendix G on how to calculate the required sample size for the desired precision and confidence level).

3. defining the sampling approach – this is the approach for collecting data as defined in your M&V plan.

4. collecting and analysing sample data.

> **Tip**
>
> - Be greedy when sampling: collect more than the minimum amount of data
> - It may be worthwhile to strata a population into sub-groups where there are known differences so that each group has less variability.
> - Aim to collect samples that cover the entire range of the population to eliminate selection bias
> - Use random selection to choose data points to be sampled
> - For consistency, use the same equipment and measurement techniques
> - Once initial samples are collected, re-confirm that the sample size is sufficient and conduct additional sampling if needed.

Reviewing data integrity

It is highly recommended that data is reviewed to ensure completeness and integrity prior to being used for developing energy models or calculating savings. It is good practice to document within your M&V plan, your data quality control procedures and review techniques.

Another good reason to document the approach is in preparation for audit and verification. Auditors pay close attention to underlying data processing quality controls as well as the calculations and final outcome.

The process and skills required will vary depending on the nature, source and format of the data, the instrumentation being used, as well as the nature of the ECM itself. Specialist skills may be required to properly review data (e.g. chemical engineer, database analyst, site staff vs. corporate staff).

Ideally the process controls exist within your organisation and you can simply leverage them by accessing data from quality-assured sources.

For example, using utility billing data or interval data supplied by a meter data agent can be considered accurate, however a sanity check is still recommended to ensure completeness.

Where direct measurement is being conducted a number of checks are recommended.

- Following data entry, ensure that you confirm data entry against recorded source data (e.g. compare spreadsheet against written readings)
- Where data is obtained from measuring equipment (downloaded or extracted), check that:
  - dates and times are correct
  - measurement frequency is as expected
  - data is complete, and check the interval is consistent by sorting by date and time.

Appendix C

- where readings are zero or appear saturated, the data points should be queried. Measurement equipment usually has a defined range (sometimes adjustable). It is important to identify where measured values have deviated. Depending on the severity and frequency, re-measurement may be required.
- instrumentation constants are applied correctly (e.g. k-factors for meters, meter scaling values for CTs and multimeter range selections)
- calculated data has integrity against other known data (e.g. engineering calculations, historical data or spot measurements)

Tips

Where data is extracted from databases, there are a number of steps that are recommended.
- Ensure that reference data is extracted (such as record identifiers) so that:
  - data can be traced back to source tables
  - references can be confirmed
  - various datasets can be compared to other references or data sources (e.g. download NMI and account number as well as usage data)
  - appropriate labels can be used in calculations and savings statements.
- Check that the period covered is correct.
- Check that data is complete. Look for missing records or records with zeros. If unique row identifiers are available they can be sorted to find gaps.
- Include units of measure in the output.
- Where a query is used to aggregate data, check that the correct aggregation function is being used (i.e. average, sum, cost, max, min, etc)
- Where a query involves multiple table joins, check that data hasn't been duplicated due to an incorrect table join. For example, a query that is created within a database containing account and bill data may result in duplicate rows or double counting if the NMI is used for joining (a non-unique data item), rather than the account identifier (unique data item).
- Keep a copy of the equation or routine used to extract the data for future use and audit.
- Check that internal calculations and pre-calculated formulas are appropriate and applied correctly.
- Ensure that processes and quality control procedures relating to the input and control of data within the database, are adequate and being used.

Major issues in data quality and completeness will usually require re-measurement, or for data to be obtained from alternate sources (e.g. utility data from supplier rather than internal accounts payable).

Minor issues in data quality can be addressed in the following ways (the priority is take actions that result in real data being used).

1. Minor adjustments to the measurement period (move forward or back one day to ensure a complete day of data is used). Ensure that the period is still representative, and that all other data sources are adjusted accordingly.
2. Fill in minor data gaps with estimates by referencing data from another source (e.g. a missing utility bill may be 'gap filled' using interval meter data, or by using meter readings found on adjacent bills)
3. Fill in minor data gaps using best-estimates derived from techniques such as interpolation. The predictability of the data is an important consideration.
4. Leave out the measurement from the analysis (e.g. where multiple samples are being taken, we can ignore those where it is obvious a measurement error has occurred, assuming the remaining sample size is still representative).

Appendix D: Calculating energy use and demand

Calculating energy use

Depending on the approach, energy use may be established in the following ways.

1. Explicitly known from ongoing measurement during the measurement period.
2. Calculated from instantaneous, periodic or continuous measurement of power draw or energy volume.
3. Estimated (where not the key parameter) using equipment specifications or manufacturer's data.

Calculating electricity use

Situation 1 above is the preferred option as it will not introduce errors due to assumptions. In situations 2 and 3 above, the following equations may assist with calculating energy use.

Relationship between voltage, current, power and energy

Power is a combination of voltage and current, which are related as follows:

power (kW)   = voltage (volts) x current (amps) x power factor

Energy is a combination of power draw over time, as follows:

energy (kWh)   = power (kW) x time (hours)

It is important to note that voltage, current and power factor all vary continuously, and it is highly recommended that instruments that measure power (kW) or electricity use (kWh) are used in preference to separately measuring voltage, current and power factor and combining within the equations above.

Where an estimate must be used, select a value or range of values that will result in a conservative savings estimate.

For single phase circuits:

power (kW) = line voltage (volts) x line current (amps) x power factor

Where:

line voltage (volts) is the average (root mean square or rms) voltage measured between an active terminal and neutral

line current (amps) is the average (root mean square or rms) current flowing through the circuit wire

power factor is a dimensionless number between 0 and 1 and is as the ratio of the real power (measured in either watts or kW) flowing to the load over the apparent power (measured in either volt-amps or kVA) in the circuit. In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred.

For three phase circuits:

Power is either evaluated by summing each phase as follows:

Power (kW)$_{tot}$ = (line voltage (volts)$_{ab}$ x line current (amps)$_a$ x power factor)

+ (line voltage (volts)$_{bc}$ x line current (amps)$_b$ x power factor)

+ (line voltage (volts)$_{ca}$ x line current (amps)$_c$ x power factor)

Where **a**, **b**, and **c** refer to the three phases on the circuit or equipment being measured, and

line voltage (volts) is the average (root mean square or rms) voltage measured between the active terminals of two different phases of the same circuit

Alternatively for balanced loads, the following equation can be used, where one phase of the circuit is measured:

Power (kW)$_{tot}$ = √3 x line to neutral voltage (volts) x line current (amps) x power factor

Where:

line to neutral voltage is the average (root mean square or rms) voltage measured between the active and neutral terminals of one phase.

In Australia, line to neutral voltage is stipulated to range between 216 volts and 253 volts, with an average of 242 volts. Where voltage is not measured, most calculations would assume a voltage of 240 volts.

In three phase circuits, Line-to-line voltage = √3 x line-to-neutral voltage. Thus using 240 volts line-to-neutral), the line-to-line voltage is 416 volts. Where voltage is not measured, most calculations assume a line-to-line voltage of 415 volts.

Note that it is important that the average voltage and current (root mean squared or rms) is measured, rather than peak voltage or current. This will almost always be the case, however check instrumentation to confirm.

Power Factor

Power factor is important to consider as utility companies supply customers with apparent power (volts x amps) and bills are calculated using real power (kilowatts).

Power factor is a measure of how efficiently a facility uses electricity. Power factor is the ratio of your demand for 'real' electric power (kW), divided by demand for 'apparent' power, (kVA). Power factor is represented by a figure between 0 and 1, with 1 being ideal.

Real power represents the actual power required to operate equipment within a site. The apparent power includes additional amounts required to deliver the real power, as a consequence of the electrical characteristics of energy using equipment, including magnetisation of motors.

Power factor relates real demand and apparent demand according to the following vector relationship:

$$Power\ factor = \frac{Real\ Power\ (kW)}{Apparent\ Power\ (kVA)} = Cos\ \theta$$
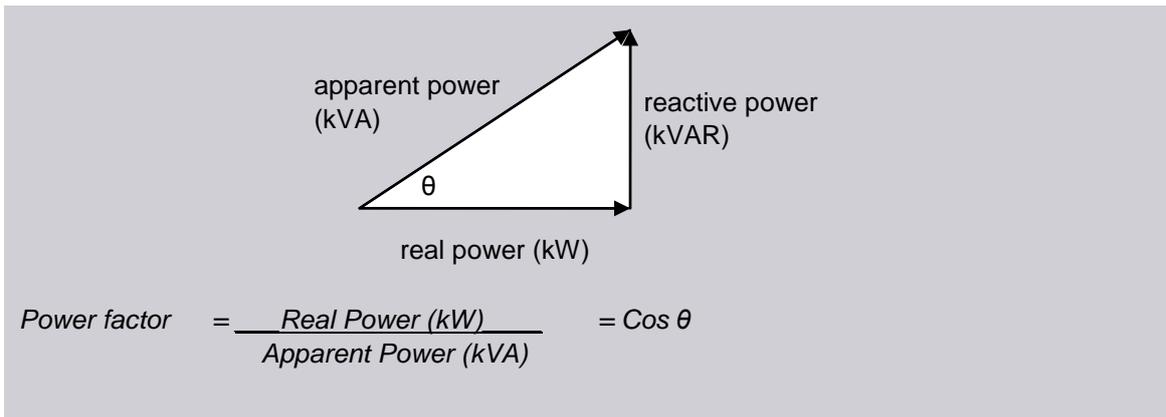
Calculating energy use for solid, liquid and gaseous fuels

Unlike electricity, solid, liquid and gaseous fuels have a physical presence and can be expressed in volumetric terms as well as energy terms. For example natural gas is delivered as a gas within a pipeline, and is typically expressed in volume (i.e. cubic metres) as well as energy (megajoules or gigajoules).

The relationship between volumes or weights and energy is dependent on the energy content of the particular fuel. Different fuels contain varying amounts of energy per standard unit. From a M&V perspective these fuels are usually measured in relation to their volume or weight which is then converted to energy.

Most fuels are derived from nature and the energy content per kilogram, litre, or cubic metre for a given fuel can vary due to various factors, including:
- temperature
- pressure
- purity and moisture content
- chemical composition
- blends

Calculating energy use from these fuels is usually achieved by either:
- Determining the energy content of the fuel through measurement. This usually involves taking samples and conducting laboratory tests
- Estimating the energy content of the fuel using publicly available data.

In most cases, publicly available energy content factors are used. Two recommended sources for factors are listed below:
- **National Greenhouse Accounts Factors** [10] – provides methods and factors to assist businesses calculate energy use and greenhouse gas emissions.
- **National Greenhouse and Energy Reporting (Measurement) Determination 2008** [9] – provides methods and criteria for calculating greenhouse gas emissions and energy data under the National Greenhouse and Energy Reporting Act 2007 (NGER Act).

Calculating energy use indirectly from manufacturer specifications

Where an Option A approach is adopted, the situation may arise where energy use is not the key parameter and hence is estimated rather than measured. For example within a lighting control project where the change in operating hours is key, the power draw of the lighting system may be estimated.

In this case, engineering calculations should be used to estimate the energy use, which will be a combination of equipment ratings (power draw) x measured operating hours.

Calculating demand

Demand is simply the instantaneous power draw at any given time, which can be:

1. explicitly known from ongoing measurement during the measurement period using an rms power meter
2. calculated from instantaneous, periodic or continuous measurement of power draw
3. estimated (where not the key parameter) using equipment specifications or manufacturer's data

In all cases demand will be calculated from energy use, be explicitly known, or described via a demand model. The more important challenge is estimating demand savings, which is discussed in 5.5.3.

Appendix E: Regression based energy models

Regression analysis for weather correction

In sites where air conditioning and refrigeration is used, energy use can often be modelled against ambient air temperature. Within these systems a constant temperature is desired to maintain a comfortable space, yet the ambient outside temperature fluctuates during the course of a day, and throughout the year. Energy use of the system will usually vary in direct proportion to the differential between the desired internal temperature and the ambient external conditions. The effect applies to heating and cooling systems.

The chart below displays an example relationship between daily energy use and ambient maximum and minimum temperatures. Note that the energy use includes weekdays when energy use exceeds 1,000 units per day, and weekends where use is below 500 units per day.

Figure 19: Relationship between energy use, weekday/weekend, and daily min/max ambient temperatures
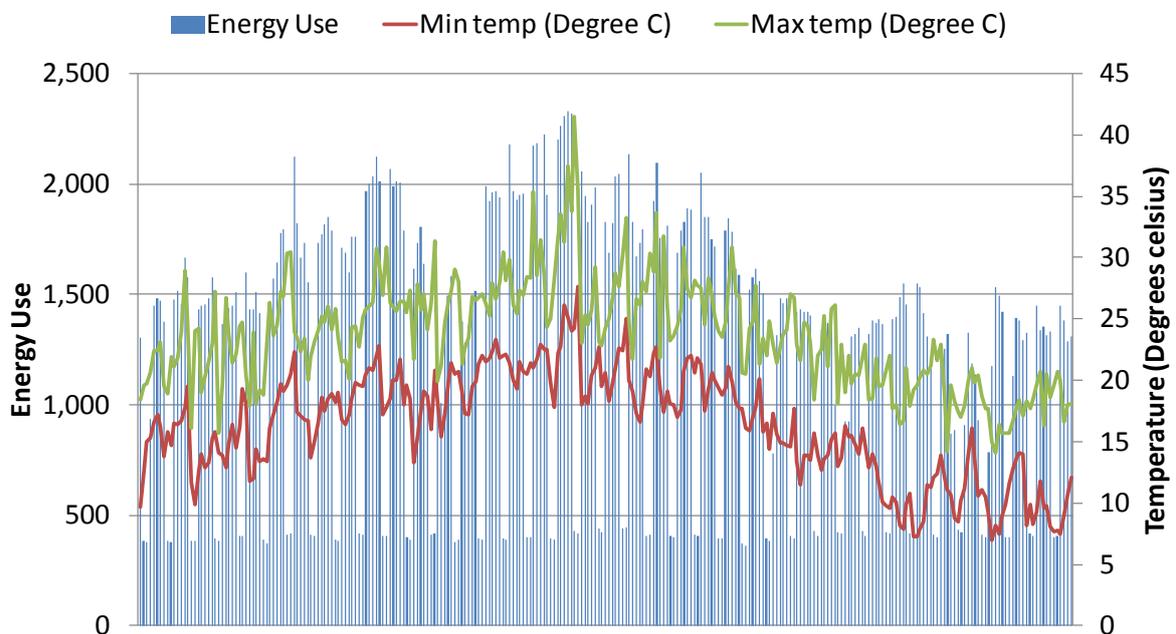
An energy use model can be developed to describe this relationship. This involves:
1. Determining an average temperature
2. Selecting a base temperature, known as a balance point
3. Calculating the difference between the daily average and the balance point to determine the heating or cooling requirement. This figure is known as a 'degree day'.
4. Summing the degree days over the intended period to align with business cycles

The use of degree days is a powerful tool to assist with establishing energy model based on weather correction.

A **degree day** is a measure of heating or cooling requirement. A degree day is equal to a difference of 1 degree between the outdoor daily average temperature and a base temperature (balance point). Degree-days are an indicator of how far the average temperature departs from a human comfort level called the base.

- A higher number of cooling degree days (CDDs) will create a demand for cooling.
- A higher number of heating degree days (HDDs) will create a demand for heating.

Degree days can be added over time to evaluate the cumulative effects over months or a year.

Rather than deal directly with temperatures, the differential between ambient and base conditions is evaluated. A base temperature for the internal space is nominated, which is known as the balance point. Separate balance points may be defined for heating and cooling. The chart below demonstrates this concept using a common balance point for heating and cooling.

Figure 20: Daily CDDs and HDDs for a common cooling and heating balance point
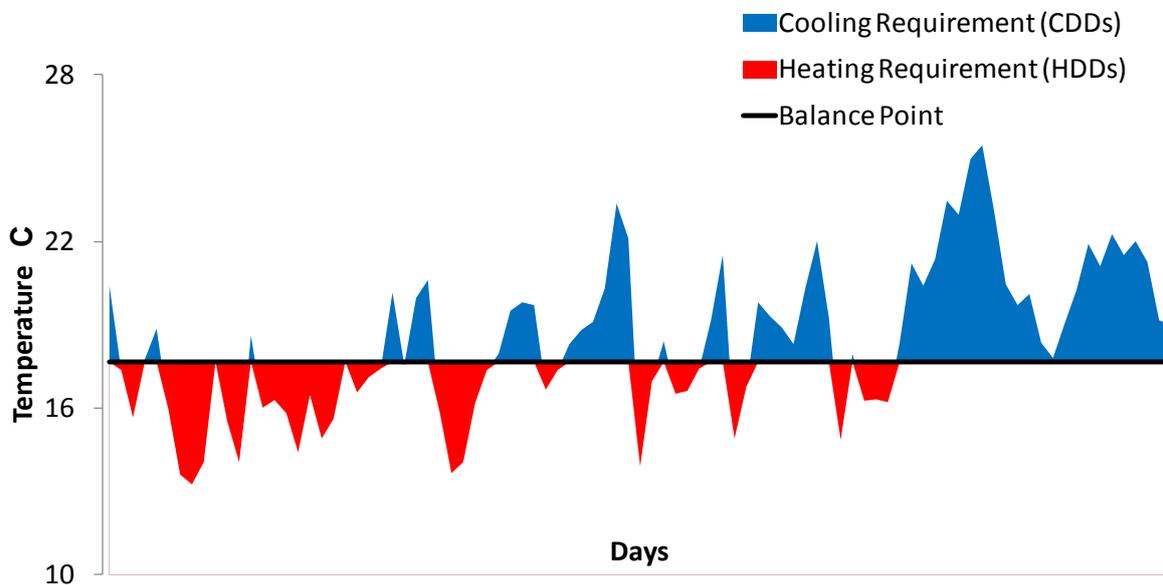
Degree days imply the amount of work that needs to be done to achieve the base conditions given the changing ambient ones. One key advantage of degree days is that, unlike temperatures, the figures can be aggregated into weeks, months and years, which allows comparison with periodic energy use data, or for normalisation.

While degree days can be calculated in a variety ways and over various time intervals, a common method for M&V projects is to calculate degree days as follows:

$Average\ daily\ temperature =\ ([Maximum\ Daily\ Temp] + [Minimum\ Daily\ Temp])/2$

Then cooling degree days (CDDs) is calculated as follows:

$CDDs = Daily\ average\ temperature - Cooling\ balance\ point$

CDDs > 0 where: daily average temperature > cooling balance point

CDDs = 0 where: daily average <= cooling balance point

This is due to the inherent nature of the system, where cooling is only required where the external temperature exceeds the target value – otherwise the cooling system will not operate.

Appendix E

Heating degree days (HDDs) is calculated as follows:

$HDDs = Heating\ balance\ point - Daily\ average\ temperature$

HDDs > 0 where: heating balance point > daily average temperature

HDDs = 0 where: heating balance point <= daily average temperature

As with cooling, if the daily average is above the balance point, then heating should not be required.

Example

The following example illustrates the concept:

Day	Daily Minimum Temp (°C)	Daily Maximum Temp (°C)	Max Average Temp (°C)	CDDs (balance point = 15 °C)	HDDs (balance point = 18 °C)
1	14.6	22.4	18.5	3.5	0
2	13.9	19.5	16.7	1.7	1.3
3	11.7	20.1	15.9	0.9	2.1
4	12.2	17.6	14.9	0	3.1
5	9.2	15.0	12.1	0	5.9
6	7.5	14.3	10.9	0	7.1
7	5.0	9.8	7.4	0	10.6
7 day total	-	-	-	6.1	30.1
Combined CDD + HDD 7 day total				36.2	

In the table above, Day 2 is calculated as follows:

Average daily temp   = (13.9 + 19.5) / 2 = 16.7

CDDs   = average daily temp – CDD balance point

     = 16.7 – 15.0 = 1.7

HDDs   = HDD balance point – average daily temp

     = 18.0 – 16.7 = 1.3.

After evaluating daily HDDs and CDDs we can sum the figures over time to obtain weekly, monthly or annual totals, which equate to the cumulative heating and cooling requirements.

The scenario below illustrates weekly energy use for a major air conditioning system, as well as the weekly sum for CDDs which is aggregated from daily calculations.

Scenario

A large CDB office has a dedicated sub-meter measuring energy use of its air conditioning plant, including chillers, chilled water and condenser water pumps, and cooling towers. The plant operates all year round to remove heat loads within the building, however the weekly energy use fluctuates significantly throughout the year.

Figure 21 below illustrates the weekly energy use of the building's air conditioning system as well as cooling degree days at the optimum balance point.

**Figure 21:** Weekly cooling degree days (CDDs) vs. weekly energy use (kWh)
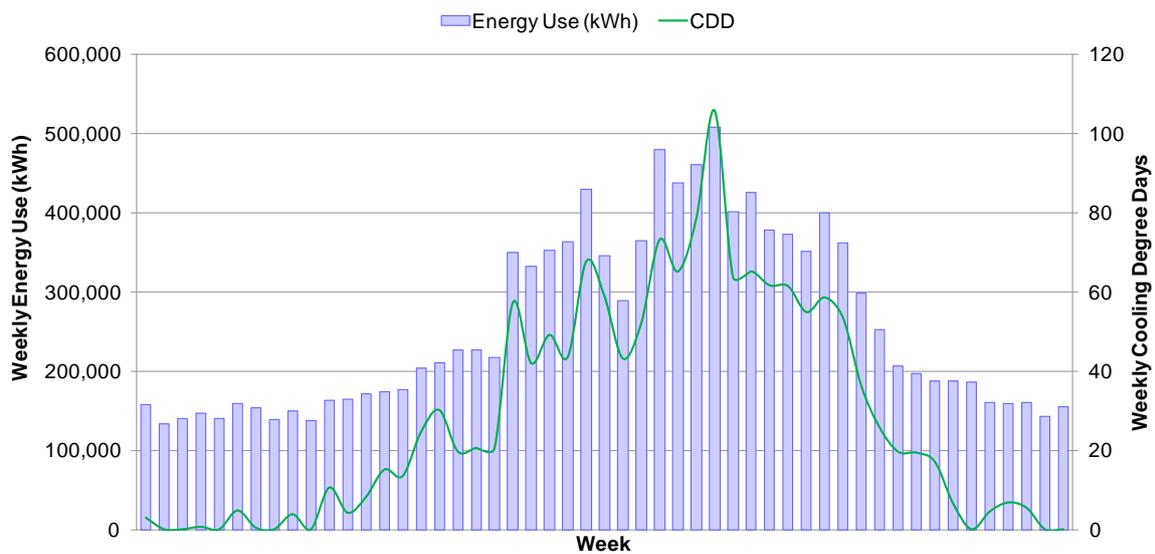
It should be noted that not all usage can be attributed to ambient temperature. For example, a typical air conditioning system may operate year round to remove heat from people and appliances.

More generally, energy usage patterns will be attributed to a combination of static factors and variables. In Figure 21 we can see that weekly usage is always above 130,000 kWh, even at times of low CDD values.

As a result, the bars in the chart above can be divided into fixed and variable components. It is the variable part that we wish to understand and evaluate in the context of the independent variables.

Finally we can analyse the relationship using an XY scatter chart from which we can observe the direct relationship between CDDs and energy use. This is illustrated in the chart below:

Figure 22: XY scatter chart: weekly CDDs vs. weekly electricity use
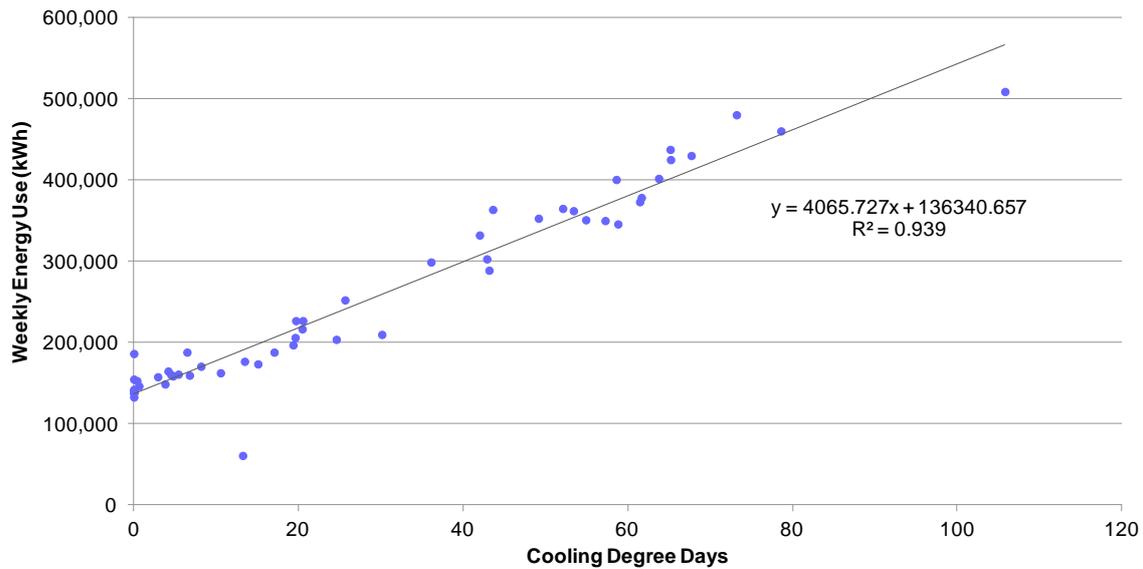
The arrangement of the 'dots' shows a clear trend. A trend line is added to the chart to establish the trend, which is essentially a linear regression. The resulting equation becomes the energy model that describes energy use as a function of CDDs.

The energy model for this building is:

$$Energy\ use\ (kWh) =\ 136{,}340.657\ kWh + 4{,}065.727 \times (CDDs)$$

Where:

Cooling degree days are based on a balance point of 14.13°C.

As mentioned, the equation reveals that weekly energy usage will be approximately 136,000 kWh when value for CDD is zero. Usage will increase by approximately 4,066 kWh per week for each additional CDD.

The energy model can now be applied to estimate energy use across alternate time periods where ambient temperature is gathered CDDs are calculated.

Validating the model

Using the validation tests defined earlier, we can confirm the validity of the model. Following a visual inspection, we can look at the regression analysis output generated by the modelling software (Microsoft Excel in this case).

From the statistical validation tests shown in we can be satisfied that our model is appropriate.

Appendix E

Figure 23: Excel single variable regression analysis output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.969232628
R Square	0.939411887
Adjusted R Square	0.938223884
Standard Error	28339.58869
Observations	53

✓ $R^2 > 0.75$

✓ base load and coefficient are positive (i.e. >0)

ANOVA

	df	SS	MS	F
Regression	1	6.35076E+11	6.35076E+11	790.7492658
Residual	51	40959746637	803132287	
Total	52	6.76036E+11		

	Coefficients	Standard Error	t Stat	P-value
Intercept	136340.6569	5710.101051	23.87710055	2.40457E-29
X Variable 1	4065.727308	144.5835381	28.12026433	1.02318E-32

Other calculated values

Mean (average) value from dataset	253,814
Sum of residuals sum(actual value - modelled value)	3.62343E-09

✓ t-stat for coefficient > 2

CV(RMSE)
= standard error / mean

0.111654903

✓ CV(RMSE) < 0.25

Mean Bias Error (MBE)
= sum(residuals) / sample size

0.000000006837%

✓ MBE < 0.005%

Evaluating the uncertainty of the regression model

The uncertainty inherent in the regression model should be determined and evaluated against any internal or external minimum thresholds for precision and confidence (refer to Appendix G for more information on uncertainty, statistical methods and equations)

Using the regression model standard error ($SE_{\hat{Y}}$) of $\pm$ 28,339.59 kWh from the results in Figure 23 above, the absolute precision can be calculated for a range of confidence levels using t-statistic values (t) from Table 27 in Appendix G (the t-statistic for ∞ data points will be used since there are 50 data points and the table only provides t-statistics for up to 30 data points).

Absolute precision (P_a) is calculated as:

$$P_a = t \times SE_{\hat{Y}}$$

Relative precision (P_r) is calculated as:

$$P_r = \frac{P_a}{estimate}$$

where the $estimate$ is the predicted value from the regression model after the independent variables have been substituted into the regression model.

The table below presents the regression model precision for a range of confidence values. The relative precision has been calculated by using the average energy consumption (253,814 kWh) from above as the $estimate$.

Appendix E

Table 25: Regression model precision for a range of confidence levels

Confidence level	50%	80%	90%	95%
t-statistic for ∞ data points	0.67	1.28	1.64	1.96
Absolute precision	$\pm\ 18987.5\ kWh$	$\pm\ 36{,}274.7\ kWh$	$\pm\ 46{,}476.9\ kWh$	$\pm\ 55{,}545.6\ kWh$
Relative precision	$\pm\ 7.5\ \%$	$\pm\ 14.3\ \%$	$\pm\ 18.3\ \%$	$\pm\ 21.9\ \%$

The desired confidence level and associated regression model precision in the table above should be evaluated against any internal/external requirements for uncertainty associated with the final savings estimate. If the level of uncertainty in the regression model is unacceptable, then adjust the regression model with consideration to the key tips for conducting regression analysis outlined in section 5.2.2.

Tuning for HDD and CDD balance points

The choice of balance points is a critical component for preparing a model that correlates. In the example above, the balance points have been tuned through several iterations of the model in order to maximise the 'fit' of the trend line.

Use of incorrect balance points will cause the incorrect number of degree days to be calculated *for the specific application,* and will cause problems with obtaining the best fit, or may result in poor correlation.

It is more important to tune the model to achieve the highest correlation by altering the balance points, rather than relying on 'industry standard' values for balance points.

The examples below use the same dataset as above with different choices for balance points.

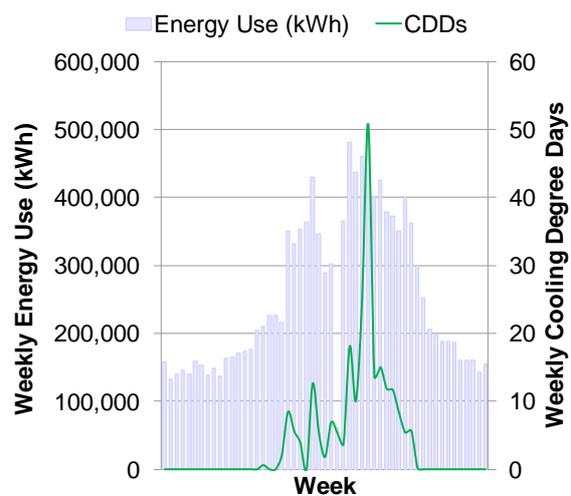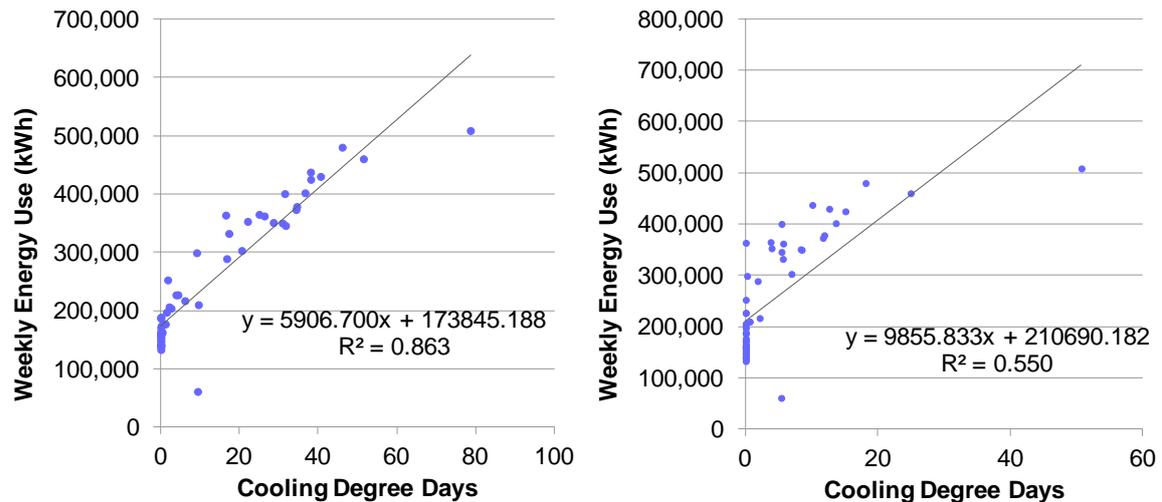**Figure 24:** Effects of different balance points on identical data sets

Example 1
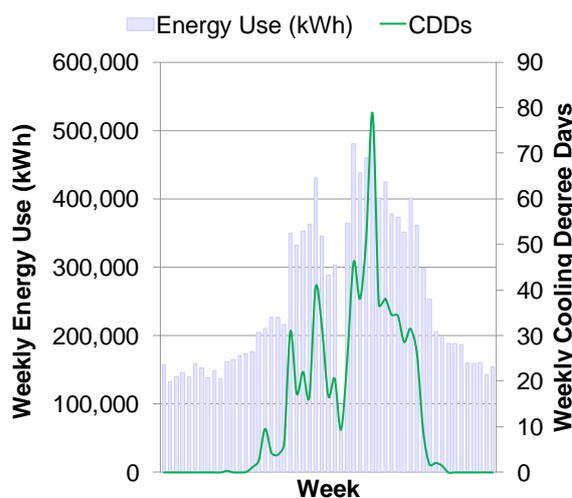
where:
CDD balance point = 18°C

Example 2

Where:
CDD balance point = 22°C

Appendix E

It can be seen that by changing the balance point, we markedly alter the days in which 'cooling is required' and hence the degree days that are considered (shown in the green lines).As the balance point shifts farther from the optimal value, the relationship between energy use and CDDs degrades.

Comparing the charts in Figure 24 with those in Figure 22 and Figure 23, we observe the following:

CDD Balance Point	R^2 Value
14.2°C (optimal value derived from tuning)	0.939
18°C	0.863
22°C	0.550

The final choices for balance points will vary from site to site. For example a swimming pool may require a balance point around 25°C, whereas a commercial building may typically correlate with balance points between 15°C and 20°C.

Further information on weather correction and use of degree days can be found at

http://www.degreedays.net/regression-analysis.

Weather data can be obtained from: www.bom.gov.au.

Alternatively, degree day information can be downloaded for selected balance points directly from sources such as: www.degreedays.net.

Assessing HDD and CDD using multi-variable regression

In the scenario below we analyse another commercial building in which energy usage varies due to both heating and cooling demands. As there are multiple dependent variables, we make use of multi-variable regression analysis.

We seek to define energy use as a function of each variable as follows:

$Energy\ use = a + b_1 CDD + b_2 HDD$

where:

a =base load usage not affected by temperature

b_1 = coefficient associated with CDDs

b_2 = coefficient associated with HDDs

Additional variables can be added if required. These variables may represent activity indicators (e.g. occupancy, customers/staff, production levels, etc) or other identified parameters.

Scenario

A public library is metered from a single revenue meter which captures energy usage for general light and power and HVAC. The HVAC system consists of reverse cycle air conditioning units which are fed with condenser water from a central loop. The library is situated in a moderate climate in which there are demands for heating and cooling at varying times throughout the year.

Figure 25 below illustrates the library's weekly electricity consumption together with the corresponding CDDs and HDDs.

Figure 25: Weekly HDDs and CDDS versus weekly energy use (kWh)
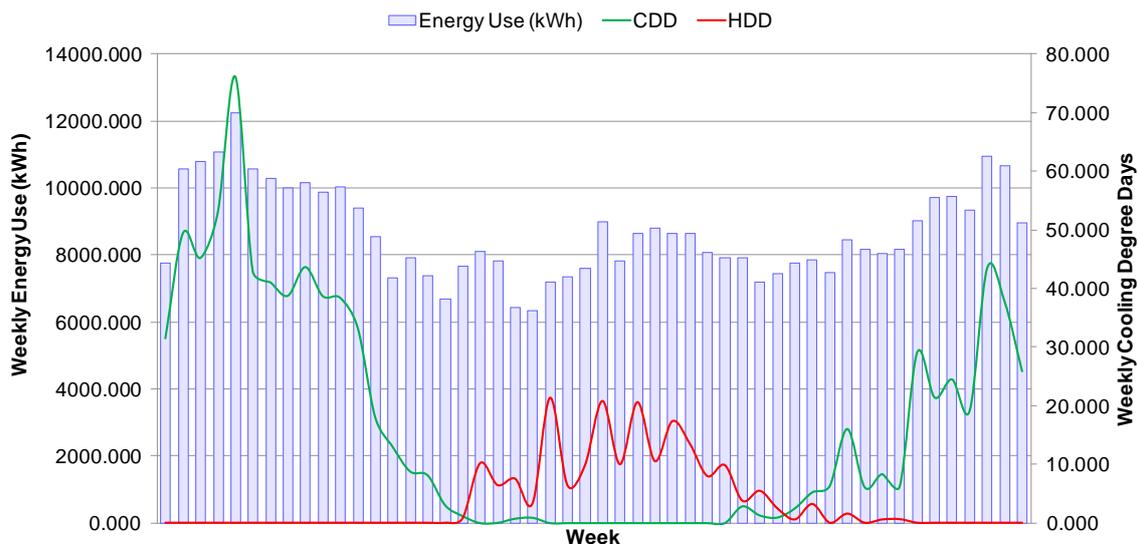
The regression analysis is conducted in a similar fashion to the previous scenario however we now use HDDs and CDDs as separate input variables.

The 'Regression' analysis tool within the Microsoft Excel 'Analysis Tool Pack' is used. This yields the following equation:

$Energy\ use\ (kWh) = 7{,}219 + 71.93 \times CDD + 60.73 \times HDD$

With:

$CDD\ Balance\ Point = 17.65\text{℃}$

$HDD\ Balance\ Point = 15.46\text{℃}$

As before, we can confirm the validity of the model. In addition to the existing tests, the Adjusted R^2 becomes an important metric as it provides an indication of the correctness of fit as we add more independent variables.

Figure 26: Excel multi variable regression analysis output

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.905846977
R Square	0.820558745
Adjusted R Square	0.812922947
Standard Error	583.8652453
Observations	50

ANOVA

	df	SS	MS	F
Regression	2	73267350.54	36633675.27	107.46208
Residual	47	16022235.36	340898.6247	
Total	49	89289585.91		

	Coefficients	Standard Error	t Stat	P-value
Intercept	7219.028093	157.291123	45.89596638	1.08108E-40
X Variable 1	71.93208926	5.188542329	13.86364121	3.1793E-18
X Variable 2 CDD	60.72522754	16.36633665	3.710373852	0.000546721

Other calculated values

Mean (average) value from dataset   8668.90152

Sum of residuals sum(actual value - modelled value)   7.82165E-11

CV(RMSE)
= standard error / mean   0.067351699

Mean Bias Error (MBE)
= sum(residuals) / sample size   0.000000000156%

Checkmark annotations:
- ✓ $R^2 > 0.75$
- ✓ Adj. $R^2 > 0.75$
- ✓ base load and coefficients are positive (i.e. >0)
- ✓ t-stats for each coefficient > 2
- ✓ CV(RMSE) < 0.25
- ✓ MBE < 0.005%

From the above tests, we can be satisfied that our model is appropriate and as before, the inherent uncertainty should be calculated and evaluated against any internal or external minimum thresholds for precision and confidence. This time however, the standard error will be $\pm$ 583.865 kWh.

Adjusting a model for post-retrofit conditions

After all the effort to that went into developing and tuning the baseline model, adjusting it for post-retrofit conditions is straightforward. We simply need to apply the regression equation and input the desired variables.

The model can be adjusted to meet actual conditions within a desired period in order to calculate 'actual savings'. Alternatively the model can be adjusted using a 'standard' set of conditions in order to calculate 'normalised' savings.

Example

Consider the monthly energy use model below, in which energy use is dependent on both HDDs and CDDs:

$$Energy\ use\ (kWh) = 7{,}219 + 71.93 \times CDD + 60.73 \times HDD$$

The table below summaries the monthly energy use as calculated using the model, based on the HDDs and CDDs shown:

Month	Calculated HDDs	Calculated CDDs	Modelled Energy Use (kWh) (=adjusted baseline)
July	50	1	10,327
August	24	8	9,252
September	3	43	10,494
October	5	37	10,184
November	0	142	17,433
December	0	145	17,649
January	0	201	21,677
February	0	186	20,598
March	0	151	18,080
April	0	82	13,117
May	7	11	8,435
June	50	0	10,256
Adjusted Baseline (12 months)	**139**	**1,007**	**167,503**

In the table above, the values for each month represent the adjusted baseline for that month.

Appendix F: Electricity billing information

Electricity bills can be particularly complex, often involving combinations of the following:

- energy volume based charges
- demand charges
- fixed and non-energy related charges

Small electricity users

Electricity bills for small users can be simple, often involving 'bundled' charges that incorporate many of the items below.

Your energy retailer is the best place to start if you want to find out more about your energy bill. Check their website for helpful information about understanding their bills including examples and tariffs for smaller accounts.

Large electricity users

Electricity bills for large users are usually quite detailed, often containing line items that relate to:

- energy commodity charges
- network charges
- metering charges
- regulated and environmental charges.

The retailer from which you receive your bill charges you for the commodity expenses only, and passes through costs associated with network, metering and other charges so they appear on a single bill.

Ask your procurement team for details of energy contract schedules to determine the commodity charges, rules and key dates.

However if we want to find out more information regarding network charges the Local Network Service Provider (LNSP) is the best source.

To find out more about your network fees and the rules to which they apply, you need to determine:

1. The network within which your site is located
2. The specific tariff, within the range of tariff options that is being used for billing.

Use the first four digits of your NMI (National Meter Identifier – which is located on your bill) to find out your LNSP, by referencing the following NMI Allocation List maintained by the Australian Energy Market Operator (AEMO) below:

http://nullnullnull.aemo.com.au/electricityops/0610-0015.pdf

Once you know your network supplier, you can obtain a Network Price List, which is available via the Internet. Alternatively contact them and ask for a copy.

Often, tariffs incorporate charges based on maximum demand, or the maximum observed within a set time period (e.g. Maximum Demand within 'Peak' Periods). In other cases, a 12 month rolling 'Capacity' charge is used, which applies a demand-based price to the highest value observed in the preceding year. Still others apply seasonal based pricing (e.g. summer

demand) pricing based on minimum or maximum demand values (cap and collar, MDQ, excess or additional demand).

Using an energy tariff schedule it is possible to specifically calculate demand cost avoidance. This is of interest for demand-focussed ECMs including power factor correction and load shifting, although it can be applied to all ECMs.

The table below lists the common tariff line types and things to consider when calculating M&V cost avoidance.

Table 26: Common energy tariff line types and considerations

Item	Description	Considerations	Example
Energy volume charges			
Time of use energy use	Energy is separately priced based on the time of day that usage occurs. Typically these time brackets are referred to as Peak, Shoulder and Off Peak periods. The specific periods will be defined by the supplier. Separate line items may be billed for commodity and network components. Time of use periods may be different!!	We need to understand when savings occur so the correct tariff item can be applied.	Peak Energy Shoulder Energy Off Peak Energy Network Peak Network Shoulder Network Off Peak
Block based energy use	Energy is separately priced in blocks of usage within a given time period. Blocks may be referred to as "First", "Next", or "Balance". Separate line items may be billed for commodity and network components.	We need to understand the blocks and the time periods that apply to the blocks. Savings will be realised in the last block first!	First, Next, Balance Block 1, 2, 3
Non-time of use	Energy is simply billed based on the metered amount. Non-TOU is often used as the basis for calculating regulatory and market based fees. In this case costs to be recovered are billed to consumers based on their overall usage and so a single rate is applied to total energy use, irrespective of time or volume brackets	Simplest rate structure which provides a simple way to calculate cost avoidance	All Energy General supply Environmental charges, including: ▪ RECs ▪ GECs ▪ NGACs ▪ Energy Savings Scheme Market charges, including: ▪ AEMO Pool Fees ▪ AEMO Ancillary Fees

Green energy	A premium that is applied for voluntary purchase of electricity from renewable sources.	Be careful how this is represented on invoices. On some bills, the usage is duplicated from other line items, with only the green premium applied. On other bills, the usage is separated into green and 'black' components. The rates for green items include the green premium as well as the underlying 'black' component.	e.g. GreenPower

Demand charges

Demand	Fees are charged for maximum demand that occurs within site across a month. Demand is usually recorded as 30 minute averages from interval data collected from the meter. There are a myriad of ways in which demand may be charged, which is at the discretion of the Local Network Service Provider (LNSP). Charges are kVA or kW based Pricing may be seasonal (e.g. summer, winter, mid-season) Pricing may apply to demand measured during particular time periods (e.g. Peak Demand) Alternatively demand may be priced in steps Minimum thresholds may apply (i.e. min 120kW is billed if measured demand is lower)	It is important to understand the following and relate these to the ECM: ▪ The structure of demand components (time of use, stepped) ▪ The time periods covered by demand charges (e.g. 12pm-8pm weekdays only) ▪ How demand charges change throughout the year due to seasonal rates (summer, winter, midseason) ▪ kW or kVA based ▪ minimum thresholds which would be billed	Basic: Maximum monthly demand Time of Use: Peak Demand Shoulder Demand Off Peak Demand Stepped: Demand Step 1 Demand Step 2 Seasonal: Summer Demand Thresholds: Contract Demand Excess Demand Additional Demand
Capacity	Capacity is a form of demand charge, whereby the maximum demand observed over a defined time period (usually 12 months) is used as the basis for billing. This charge is designed to focus consumers on managing their overall annual peak demand. When a new maximum demand is recorded, the consumer is charged this figure for the next 12 months or until a higher figure is recorded.	Demand considerations above apply Eventually savings in demand will result in a reduction in capacity charges however this may take up to 12 months.	Capacity Charge Rolling Demand Charge

Fixed or non-energy related charges			
Metering and data forwarding charges	Fees associated with provision of a meter and ongoing reading and data management. Fees are typically fixed per meter.	Will likely remain constant within M&V calculations, unless changes to metering are made (e.g. PV projects)	Meter Charge Meter Provision Meter and Data Forwarding MDA Charges
Supply fees and standing charges	Administration fees associated with providing network supply.	Will likely remain constant within M&V calculations	Network Standing Charge Daily Access Charge Network Fixed Fee
Other fees	Miscellaneous fees for other services rendered	Will likely remain constant within M&V calculations	Equipment rental

Appendix F

Appendix G: Uncertainty

The Appendix contains a summarised version of the approach used to determine uncertainty described within IPMVP volume 1, 2012, Appendix B [1].

Determining the required precision and confidence levels

The precision and confidence levels required for evaluating uncertainty in the calculated energy savings is arbitrary and is dependent on internal and/or external factors.

For example, management may require a minimum level of confidence and precision in the energy savings calculated before funding can be approved for ECM implementation. Likewise, a government energy saving grants scheme may require minimum confidence and precision to be eligible to apply for a grant to support the ECM project.

As a rule of thumb, the maximum possible confidence level should be used when expressing uncertainty provided the precision is within an acceptable range.

Below are examples of poor uncertainty:

**Poor precision:** Achieved savings are 100,000kWh ±100% with 90% confidence

Low confidence: Achieved savings are 100,000kWh ±7% with 10% confidence

Balancing precision and confidence

A balance needs to be made between confidence and precision because if you improve the confidence level, you will reduce the precision and vice versa. The balance in uncertainty will be based on the specifications of the M&V exercise, may be internally or externally imposed or it may be a fixed requirement.

The figures below present two scenarios of uncertainty based on the same data set, which each have the same observed savings of 10,000. These scenarios are described below.

1. **Relatively high confidence but relatively low precision:** The savings are expressed as: savings 10,000 ± 1,600 with 90% confidence. Or in other words, we can be 90% confident that the savings will range from 8,400 to 11,600.
2. **Relatively high precision but relatively low confidence:** The savings are expressed as: savings 10,000 ± 300 with 10% confidence. Or in other words, we can be 10% confident that the savings will range from 9,700 to 10,300.

Figure 27: relatively high confidence but relatively low precision
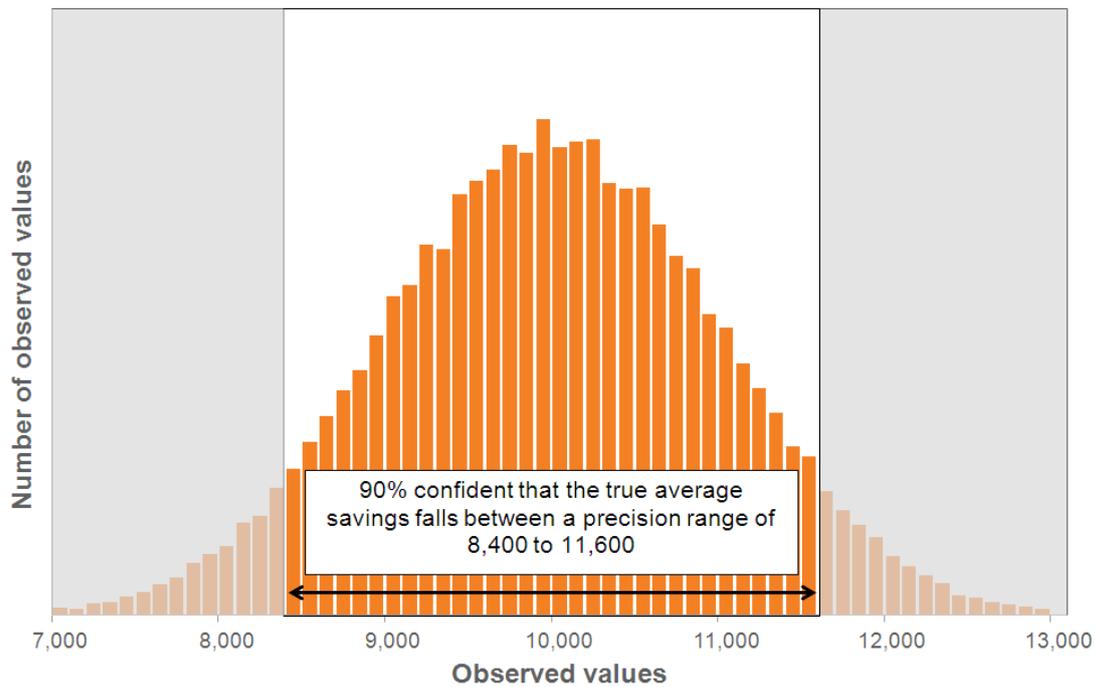
Figure 28: relatively high precision but relatively low confidence
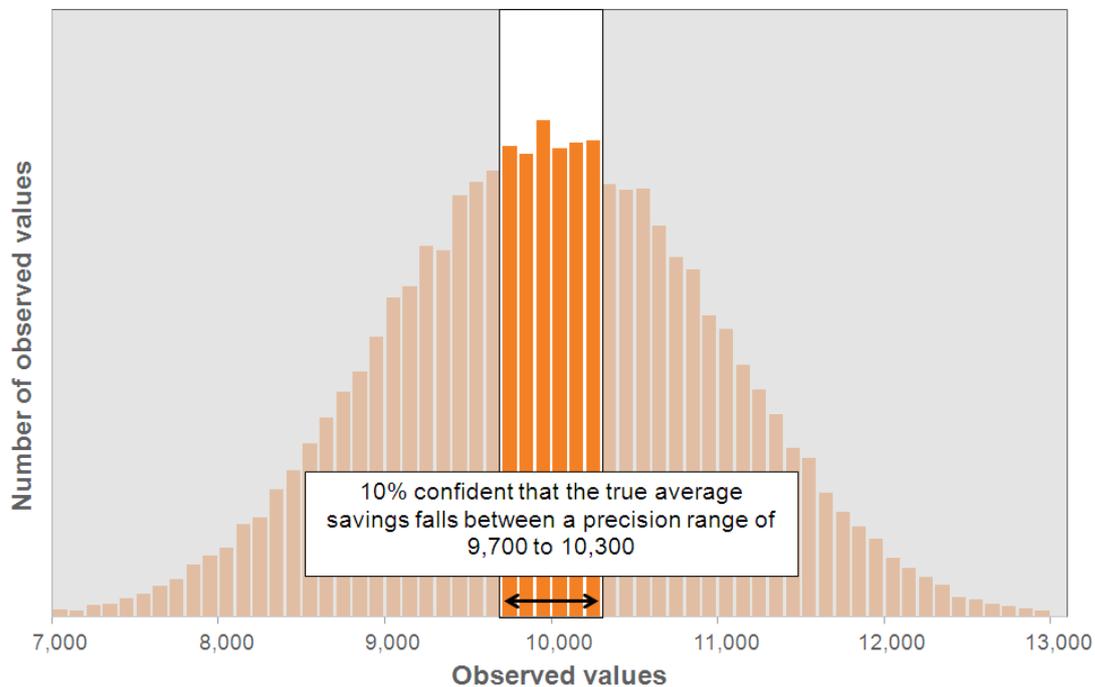
The uncertainty associated with the observed savings is therefore meaningless unless both the precision and confidence levels are stated.

Acceptable uncertainty

Savings are deemed to be statistically valid if they are large relative to the statistical variations. Specifically, the savings need to be larger than twice the standard error (see in definitions below) of the baseline value. If the variance of the baseline energy model is excessive, the

unexplained random behaviour in energy use within the measurement boundary will be high and the calculated savings will be unreliable. Where uncertainty is unacceptable, consider taking the following actions.

- Use more precise measurement equipment
- Look for more independent variables that have an influence on energy consumption
- Increase the measurement sample size
- Review the measurement boundary to minimise unknowns
- Use an alternative M&V option that is less affected by unknown variables

Statistical definitions and terms

The following statistical definitions and terms apply to a standard normally distributed data set.

Sample Mean ($\overline{Y}$): is the mathematical average of a set of (n) data points (Y_i) as follows:

$$\overline{Y} = \frac{\sum Y_i}{n}$$

Sample Variance (S^2): measures the extent to which observed values differ from each other. A larger variability indicates greater uncertainty in the mean. The variance is calculated as follows:

$$S^2 = \frac{\sum(Y_i - \overline{Y})^2}{n - 1}$$

Sample Standard Deviation (s): is the square root of the sample variance as per the following. The units for sample standard deviation are the same as the units for the data.

$$s = \sqrt{S^2}$$

Coefficient of Variation (cv): is standard deviation of the readings divided by the mean.

$$\frac{s}{\overline{Y}}$$

Sample Standard Error (SE): is the standard deviation divided by $\sqrt{n}$. It is used to combine components of uncertainty from measurements and observations which is then used to calculate the overall uncertainty in the savings calculation. The sample standard error is calculated as follows:

$$SE = \frac{s}{\sqrt{n}}$$

Sample Standard Deviation of the Total (S_{tot}): is used to define the precision about a sample *total*, rather than a *mean*. It is defined as the sample standard deviation times the square root of the sample size $\sqrt{n}$.

$$S_{tot} = s \times \sqrt{n}$$

t-statistic (t): is used to calculate the precision (see below) for a specified level of confidence by using t-statistic lookup tables as per the table below. The t-statistic is also used to test the statistical significance of independent variables that form part a regression model in estimating the dependent variable (discussed later).

Confidence: refers to the probability that the quoted range contains the estimated parameter.

Absolute Precision (P_a): is the measure of the absolute range within which the true value is expected to occur for a specified level of confidence.

$P_a = t \; x \; SE$

Relative Precision (P_r): is the measure of the relative range within which the true value is expected to occur for a specific level of confidence. The relative precision is presented as a percentage (%) and is calculated as follows:

$P_r = \dfrac{P_a}{estimate}$

Where "estimate" is any empirically derived value for a parameter of interest (e.g. total consumption, average power draw etc).

Range: in general, the true value of any statistical estimate expected, with a given confidence level, to fall within the range by:

$$range = estimate \; \pm \; precision$$

Table 27: t-statistic table[6]

Degrees of Freedom DF	Confidence level				Degrees of Freedom DF	Confidence level			
	50%	80%	90%	95%		50%	80%	90%	95%
1	1.00	3.08	6.31	12.71	16	0.69	1.34	1.75	2.12
2	0.82	1.89	2.92	4.30	17	0.69	1.33	1.74	2.11
3	0.76	1.64	2.35	3.18	18	0.69	1.33	1.73	2.10
4	0.74	1.53	2.13	2.78	19	0.69	1.33	1.73	2.09
5	0.73	1.48	2.02	2.57	21	0.69	1.32	1.72	2.08
6	0.72	1.44	1.94	2.45	23	0.69	1.32	1.71	2/07
7	0.71	1.41	1.89	2.36	25	0.68	1.32	1.71	2.06
8	0.71	1.40	1.86	2.31	27	0.68	1.31	1.70	2.05
9	0.70	1.38	1.83	2.26	31	0.68	1.31	1.70	2.04
10	0.70	1.37	1.81	2.23	35	0.68	1.31	1.69	2.03
11	0.70	1.36	1.80	2.20	41	0.68	1.30	1.68	2.02
12	0.70	1.36	1.78	2.18	49	0.68	1.30	1.68	2.01
13	0.69	1.35	1.77	2.16	60	0.68	1.30	1.67	2.00
14	0.69	1.35	1.76	2.14	120	0.68	1.29	1.66	1.98
15	0.69	1.34	1.75	2.13	∞	0.67	1.28	1.64	1.96

---

[6] Source: IPMVP volume 1, 2012, Table B.1

Appendix G

Where degrees of freedom (DF) is calculated as follows:

$DF = n - 1$ for a sample distribution

$DF = n - p - 1$ for a regression model

Where:

$n = sample\ size$

$p = number\ of\ regression\ model\ variables$

Uncertainty with regression analysis modelling

When a model is used to predict an energy value (Y) for given independent variables, the accuracy of the prediction is measured by the standard error of the estimate ($SE_{\hat{Y}}$). This accuracy measure is provided by all standard regression packages and spreadsheets. The standard error of the estimate is given by:

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

where p is the number of independent variables in the regression model. The standard error of the estimate is often referred to as the root-mean squared error (*RMSE*).

Once the value(s) of the independent variable(s) are entered into the regression model to estimate an energy value ($\hat{Y}$), an approximation of the range of possible values for $\hat{Y}$ can be calculated by:

$\hat{Y} \pm t \times SE_{\hat{Y}}$

where:

$\hat{Y}$ is the predicted value of the energy (Y) from the regression model

t is the t-statistic obtained from above.

$SE_{\hat{Y}}$ is the standard error of the estimate (prediction)

An acceptable range of the possible values of $\hat{Y}$ will be dependent on the M&V project requirements for precision and confidence.

Sampling uncertainty and required sample size

Sampling creates errors because not all units under study are measured. The simplest sampling situation is to randomly select n units to measure from a total population of N units. For example, taking light fitting sample measurements of power draw savings for a lighting upgrade project. The sample set would be a randomly selected subset of homogeneous light fittings that are part of a larger population. This saves both time and cost associated with the M&V project as not all light fittings have to be measured. However increasing the sample size will reduce the uncertainty of the calculations and therefore the sampling method used will be a balance between M&V costs and reducing uncertainty.

The following sections provide the steps required to set the sample size:

Select a homogeneous population

The expected measurement values should be the same for the entire population. If there are two different types of units in the population, they should be grouped and sampled separately.

Determine the desired precision and confidence levels

Higher precision and confidence levels will require larger sample sizes which will need to be balanced with the M&V budget. As a rule of thumb, improving precision from $\pm 20\%$ to $\pm 10\%$ will increase the sample size by 4 times, while improving it to $\pm 2\%$ will increase the sample size by 100 times.

How the desired precision and confidence level are to be applied should also be determined at this point. For example, do the desired precision and confidence levels apply at the measurement level or will the desired level apply at the final energy savings result. This choice on how and where the uncertainty is applied will provide different results on the required sample size and final uncertainty statement in the energy savings result.

For example, suppose the average load is around 500 kW and the anticipated savings are around 100 kW. A $\pm 10\%$ precision at 90% confidence can be applied two ways:
- If applied to the load measurements, absolute precision will be 50 kW (10% of 500kW) at 90% confidence.
- If applied to the final energy savings result, absolute precision in the measured savings load will be 10 kW (10% of 100 kW) at the same 90% confidence level. However since two separate sets of sample measurements need to be conducted at the pre and post retrofit period, the uncertainty of each sample set needs to be combined which will require actual load measurement absolute precision of 7 kW (refer to combining units of uncertainty below).

Therefore, applying the precision and confidence levels to the final savings result will require much higher precision in the individual load measurements.

Calculate the initial sample size

Based on the information above, an initial estimate of the overall sample size can be determined using the following equation:

$$n_0 = \frac{z^2 \times cv^2}{P_r^2}$$

where:

n_o is the initial estimate of the required sample size, before sampling begins.

cv is the coefficient of variance. Until the actual coefficient of variance can be estimated from actual samples, 0.5 may be used as an initial estimate of cv. In some cases it may be desirable to initially conduct a small sample of measurements for the sole purpose of estimating a cv value to assist with planning the sampling program. Also values from previous M&V work may be used as appropriate initial estimates of cv.

P_r is the desired level of relative precision.

z is the standard normal distribution value from with an infinite (∞) number of readings and for the desired confidence level (0.67 for 50%, 1.28 for 80%, 1.64 for 90%, 1.96 for 95% confidence).

Adjust initial sample size estimate for small populations

The necessary sample size can be reduced if the entire population sampled is no more than 20 times the size of the sample. This adjustment reduces the sample size (n) as follows:

$$n = \frac{n_0 N}{n_0 + N}$$

where N is the total size of the population.

Finalise sample size

Because the initial sample size (n_o) is determined using an assumed cv, it is critical to remember that the actual cv of the population being sampled may be different. Therefore a different actual sample size may be needed to meet the desired precision. As sampling continues, the cv of the measurements should be recalculated along with the actual required sample size. This recalculation may allow early curtailment of the sampling process. It may also lead to a requirement to conduct more sampling than originally planned. The maintain M&V costs within budget, it may be appropriate to establish a maximum sample size. If this maximum is actually reached after the above recalculations, the final savings result should note the actual precision achieved by the sampling.

Uncertainty with metering and measurement equipment

Utility metering

Since utility meters define the amounts payed, its reported values may be treated 100% accurate ($SE = 0$), regardless of meter error.

Non utility metering and measurement equipment

Energy quantities and independent variables are often measured as part of a M&V program using metering and measurement equipment. No measurement equipment is 100% accurate or precise. The precision of meter and measurement equipment is published by the manufacturer from laboratory tests. Proper sizing of metering and measurement equipment is important to ensure the range of possible quantities to be measured fall within the acceptable limits of the equipment being used.

The readings of meter and measurement equipment will 'drift' over time due to wear and tear. It is important to maintain the accuracy and precision of meters in the field through routine maintenance and calibration against known standards.

In addition, other possibly unknown effects can reduce meter system precision:
- Poor placement of the meter so it does not get a representative 'view' of the quantity it is supposed to measure.
- Data acquisition errors which randomly or systematically omit measurement data.

As a result of such unquantifiable measurement errors, it is important to realise that manufacturer quoted precision probably overstates the precision of the actual readings in the field however there is no way to quantify these other effects.

Standard error calculation

When a single measurement is used in a savings calculation, rather than the mean of several measurements, the standard error of the measured value is:

$$SE = \frac{measurement\ equipment\ relative\ precision\ \times measure\ value}{t}$$

Where t is the t-statistic from [Table 27](#) based on the large number of laboratory sampling done by the manufacturer, considered to be infinite (∞), when developing its relative precision statement for the measurement equipment.

Manufacturer precision statements should be in accordance with the relevant industry standard for their product. Care should be taken to determine the confidence level used in quoting a meter's precision. Unless stated otherwise, the confidence is likely to be 95% when determine the t-statistic.

Combining components of uncertainty

Both the measurement and energy calculations can introduce uncertainty in reported savings. The uncertainties in the individual components can be combined to enable overall statements of savings' uncertainty. This combination can be performed by expressing the uncertainty of each component in terms of its standard error. Once the standard error of the savings is determined, it is possible to make appropriate concluding statements about the relative amount of uncertainty inherent in the savings which will include an overall savings precision and confidence level.

The components must be independent to use the following methods for combining uncertainties. Independence means that whatever random errors affect one of the components are unrelated to the errors affecting the other components.

If the reported savings is the sum or difference of several independently determined components (C_i), then the standard error of the reported savings can be estimated by:

$$SE(savings) = \sqrt{SE(C_1)^2 + SE(C_2)^2 + \ldots + SE(C_n)^2}$$

For example, if savings are calculated as the difference between the Adjusted Baseline and Actual Post Retrofit energy usage, the standard error of the difference (savings) is calculated as:

$$SE(savings) = \sqrt{SE(adjusted\ baseline\ energy)^2 + SE(actual\ post\ retrofit\ energy)^2}$$

If the reported savings estimate is a product of several independently determined components (C_i), then the relative standard error of the savings is given approximately by:

$$SE(savings) \approx savings \times \sqrt{\left(\frac{SE(C_1)}{C_1}\right)^2 + \left(\frac{SE(C_2)}{C_2}\right)^2 + \ldots + \left(\frac{SE(C_n)}{C_n}\right)^2}$$

A good example of this situation is determining lighting savings through load reduction:

$$savings = \Delta Watts \times hours$$

The lighting example above, if both power draw (Watts) and operating hours are parameters to be measured, then both parameters will have their own standard error. Therefore the standard error of the calculated savings for the lighting example is thus:

$$SE(savings) \approx savings \times \sqrt{\left(\frac{SE(\Delta Watts)}{\Delta Watts}\right)^2 + \left(\frac{SE(hours)}{hours}\right)^2}$$

Appendix G

Since $\Delta Watts$ is itself the difference between the pre and post retrofit wattage measurements of the lighting load example above, the pre and post wattage measurement samples will have their own standard error which will need to be combined using the sum/difference standard error equation above. The combined pre and post wattage measurement uncertainties will provide the standard error $SE(\Delta Watts)$.

When a number of savings results are totalled and they all have the same standard error, the total reported savings will have a standard error calculated using:

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

Where N is the number of savings results with the same standard error that are added together (e.g. N will be 12 when calculating the standard error for an entire year of identical monthly savings).

References

[1]   Efficiency Valuation Organization, "International Performance Measurement and Verification Protocol," Efficiency Valuation Organization, 2012.

[2]   Energy & Environmental Education Resources, Inc, [Online]. Available: www.energymanagement.org.

[3]   Energy Decisions, "Australian Best Practice Guide for Measurement and Verification," Energy Efficiency Council, 2004.

[4]   Lawrence Berkeley National Laboratory, "M&V Plan," [Online]. Available: mnv.lbl.gov/keyMnVDocs/mnvplan.

[5]   Office of Energy Efficiency and Renewable Energy, US Department of Energy, "Federal Energy Management Program," [Online]. Available: www1.eere.energy.gov.au.

[6]   F. Anscombe, "Graphs in Statistical Analysis," *The American Statistician,* vol. 27, no. 1, pp. 17-21, 1973.

[7]   Entergy Arkansas, Inc, "Measurement and Verification Guidelines," [Online]. Available: http://www.entergy-arkansas.com/content/energy_efficiency/docs/MV_Guidelines.doc.

[8]   World Resources Institute and World Business Council for Sustainable Development, "Greenhouse Gas Protocol," [Online]. Available: www.ghgprotocol.org.

[9]   Clean Energy Regulator, "National Greenhouse and Energy Reporting," [Online]. Available: www.cleanenergyregulator.gov.au.

[10] Department of Climate Change and Energy Efficiency, "National Greenhouse Accounts Factors," [Online]. Available: www.climatechange.gov.au.

[11] Department of Resources, Energy and Tourism, "Energy Efficiency Opportunities Program," [Online]. Available: www.ret.gov.au/energy/efficiency/Pages/EnergyEfficiency.aspx.

[12] E. L. Vine, Persistence of Energy Savings: What Do We Know and How Can It be Ensured?, Elsevier, 1992.