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Measurement and Verification Operational Guide

Whole Building Applications

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1 Your guide to successful M&V projects

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

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

But what is M&V exactly?

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

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

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

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

1.1 Using the M&V Operational Guide

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

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

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

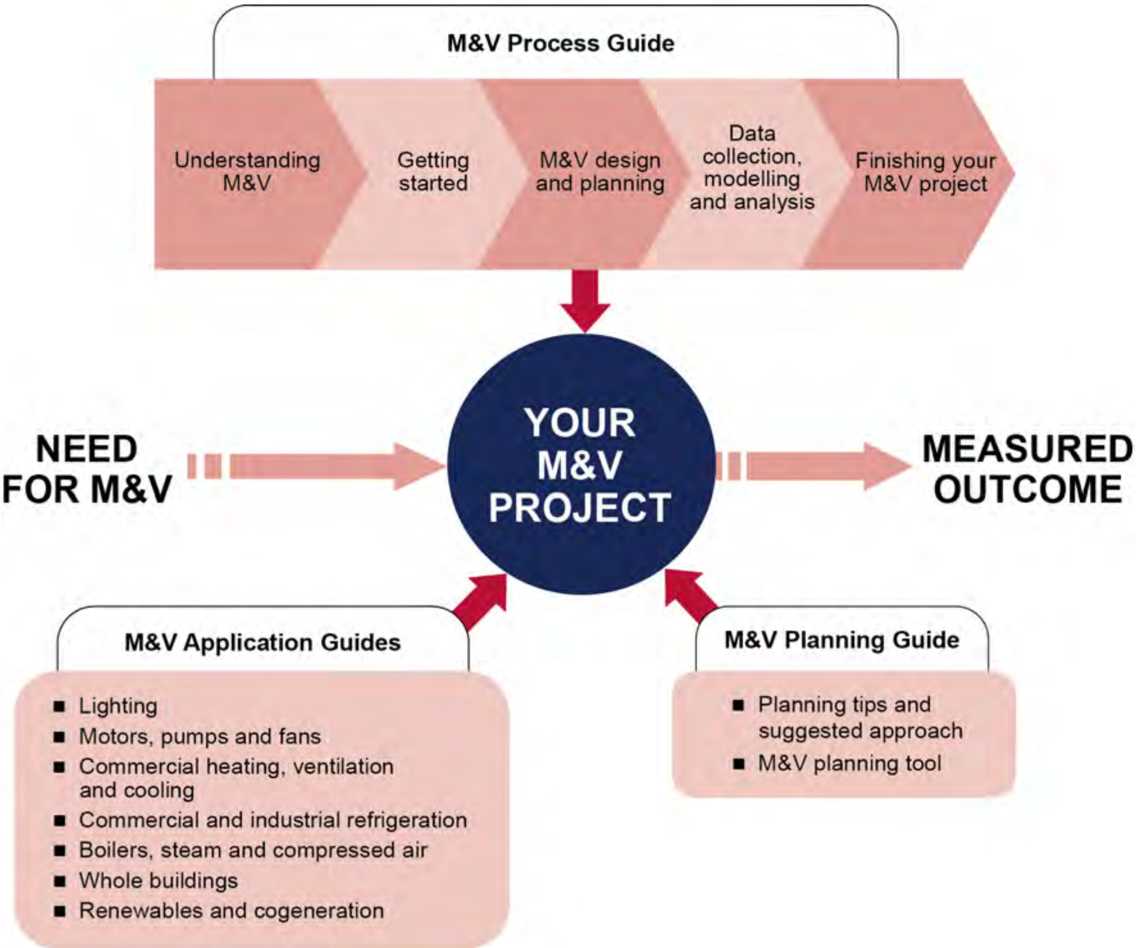
Applications Guides: Seven separate application-specific guides provide new and experienced M&V practitioners with advice, considerations and examples for technologies found in typical commercial and industrial sites. The *Applications Guides* should be used in conjunction with the *Planning Guide* to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

[1] Source: www.energymanagementworld.org

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 Whole Building Applications (this guide)

The *Whole Building Applications Guide* provides specific guidance for conducting M&V for large and/or multiple projects throughout a site. It is designed to be used in conjunction with the *Process Guide*, providing tips, suggestions and examples specific to conducting evaluation using a facility boundary.

The *Whole Building Applications Guide* is presented as follows:

▪ Understanding M&V concepts	Section 2 presents a high level diagram of the best practise M&V process.
▪ Getting started	Section 3 provides a discussion on key things that need to be considered when getting your M&V project started.
▪ M&V design and planning	Section 4 provides guidance on how to design and plan your whole building M&V project and key considerations, potential issues and suggested approaches.
▪ Data collection, modelling and analysis	Section 5 provides guidance on data collection, modelling and analysis for your whole building M&V project.
▪ Finish	Section 6 provides a discussion on reporting M&V outcomes, ongoing M&V and ensuring savings persist over time.
▪ References to examples of M&V projects	Section 7 provides a reference list of example projects located within the IPMVP and throughout this guide.
▪ Example whole building scenario A	Appendix A illustrates the M&V process using a worked example of a food processing plant project
▪ Example whole building scenario B	Appendix B illustrates the M&V process using a worked example of a commercial building project

2 Understanding M&V concepts

2.1 Introducing key M&V terms

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

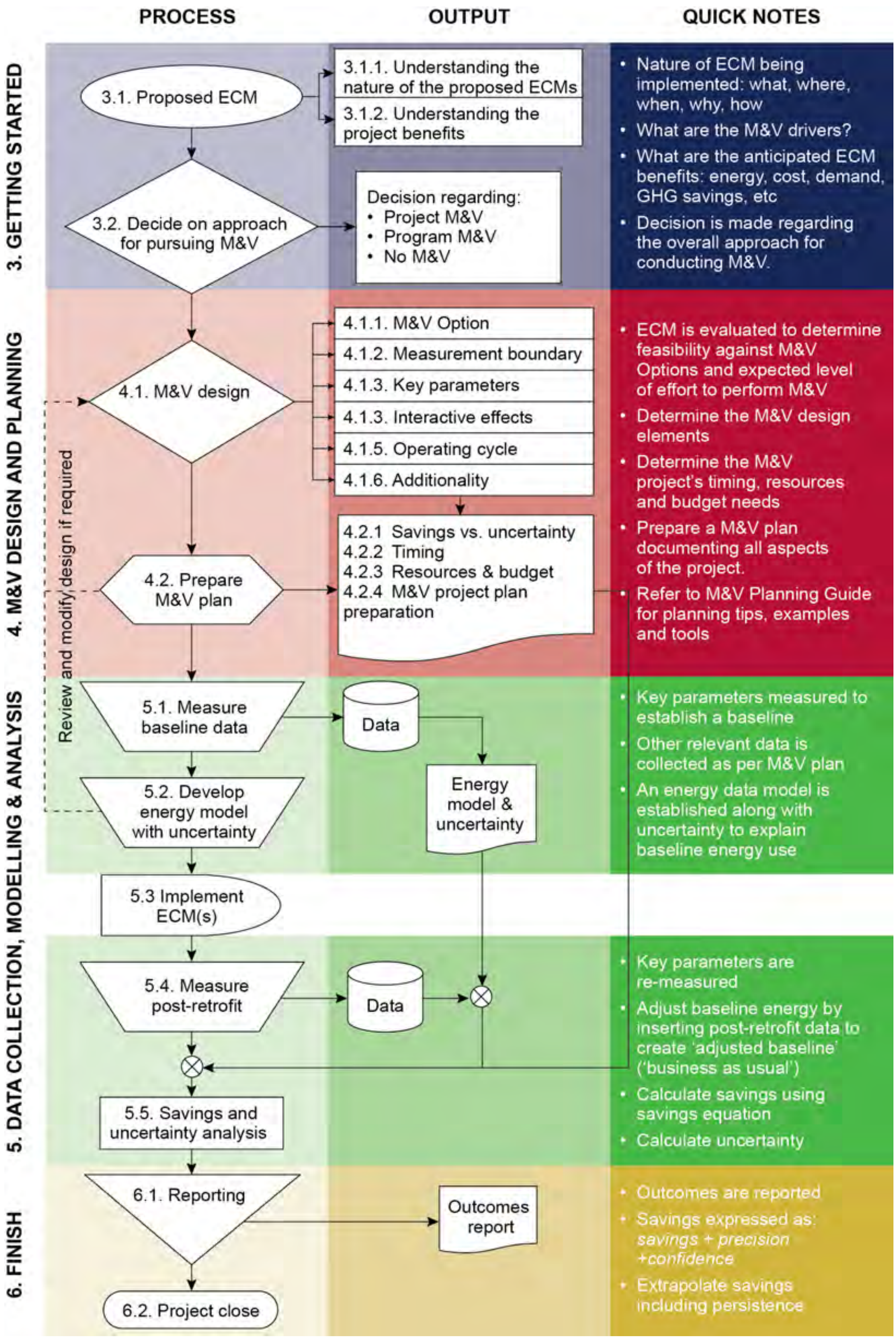
Table 1: Key M&V terms

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

2.2 Best practise M&V process

The following figure presents the best practise M&V process which is how the rest of the *Whole Building Applications Guide* is structured. Refer to the *Process Guide* for detailed guidance on the M&V processes.

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



3 Getting started

3.1 Proposed whole building ECM(s)

3.1.1 Whole building projects

In previous sections we have discussed M&V for various applications with most guidance relating to Option A and B boundaries. Within this section we focus on a facility/sub-facility level boundaries using Options C or D.

Whole building analysis is often preferred for the following reasons:

- Often utilises existing metering, energy invoices and other business data
- Can determine actual savings in relation to cost and usage from energy bills
- Enables multiple ECMs to be evaluated within a single M&V exercise which:
  - Reduces M&V costs
  - Avoids additionality issues
  - Encompasses all interactive effects
- Useful where the baseline period would otherwise be too short as existing data covering a longer period can be used
- Ongoing M&V can be performed
- Can usually be conducted as a desktop exercise.

Whole building M&V has its drawbacks, which include:

- Savings must be greater than 10% of usage at the project boundary (i.e. site) to be claimable
- Effects of individual ECMs cannot be separately evaluated
- Baseline period is 12 months or more, and post-retrofit period is typically 6 months or more
- Relies on our ability to create an energy model for the facility, which may be difficult for complex sites or those that cannot be explained in relation to independent variables.

3.1.2 Key points to note

When considering an M&V, it is important to understand the nature of the site and proposed EMC(s) (what, where, when, why, how much) and the project benefits (e.g. energy, demand, greenhouse gas and cost savings).

Option C

Key points to note when getting started using Option C are:

- The proposed ECMs should be reviewed to ensure that combined savings is estimated to exceed 10% of the site's total energy use.
  - Where multiple fuels are involved this should extend to each fuel individually. The advantage of analysing fuels individually is that different models can be created, using only those independent variables and static factors that apply.
  - Alternatively, analysis may be conducted on total energy, which is a combination of all fuels.
- In addition to energy use, the identification of the right key parameters is important. Prior to modelling, all potential parameters should be identified. Data availability and quality should be assessed.
- Where data deficiencies exist for important variables, additional effort may be required to collect better data. This may require searching for alternate data sources, identifying a proxy, or choosing a measurement period for which suitable data is available. An Option D approach could also be considered.

- The nature of the ECMs to be implemented is only somewhat important. It is a good idea to understand the type of ECM and the areas it may affect, however with a facility level boundary it will not alter the data that is collected. Consideration should be made if the ECM involves changes to independent variables to ensure that the developed model will provide a realistic adjusted baseline once the project is implemented.
- Measurement periods are typically 12 months or more for baseline data and 6 months or more for post-retrofit data.
- Ongoing M&V may be considered, assuming that ongoing data for energy use, independent variables and static factors can be collected and that the baseline energy model is still valid.
- Using an ongoing approach, the effects of a staged implementation program can be progressively reported.
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.
- Savings accuracy is dependent on the accuracy input data and the accuracy of the developed model.

Option D

Key points to note when getting started using Option D are:

- Computer simulation software is used to predict the facility energy use. This is applicable for new buildings and for retrofits where baseline data cannot be obtained.
- Energy use is predicted by inputting all key characteristics of the building, including:
  - Physical properties of building materials (walls, floors, roof, windows, partitions, doors, insulation)
  - Site specific information, including location, reflectivity of external surfaces, wind conditions, shading from external objects
  - Infiltration rates (how well the building is sealed)
  - Internal loads, including occupancy density, metabolic rate (activity levels and clothing)
  - Occupancy patterns (occupation levels at various times)
  - Equipment details (energy using equipment including size, power draw, equipment usage patterns and control strategies, heat output)
  - Lighting details (types, numbers, locations of lights and/or lighting density, heat output, operating schedules)
  - Air conditioning / refrigeration equipment (type and operation, electrical loads, coefficients of performance, operating schedules and control strategies)
  - Data for independent variables and process loads (e.g. weather/temperature, wind, rainfall, process equipment and corresponding heat loads, raw material inputs, and production outputs)
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.
- Accuracy is determined from the uncertainties associated with data collection, combined with the calibration error between the developed model and the actual energy use data.
- When the building is modelled, various scenarios are considered, known as ‘Off-Axis’ or ‘what if’ scenarios. Examples include:
  - Part of building switches from 9am-5pm operation to 24/7.
  - Variable air volume dampers get stuck open
  - Tri-generation system has to be shut down.
- Accurate computer modelling and calibration against actual usage are key challenges. Simulation results must match for both usage and demand from monthly data.
- Modelling incorporates 12 months of data, usually in hourly or half-hourly increments.
- Ongoing M&V may be considered, assuming that ongoing data for energy use, independent variables and static factors can be collected and that the baseline energy model is still valid.

3.2 Decide approach for pursuing M&V

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

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

4 M&V design and planning

4.1 M&V design

4.1.1 M&V Option

Option C is the most common form of facility based analysis, which involves the development of an energy model from historical meter/billing data combined with data for independent variables across the site.

Option D is used where there is no baseline data. The site is modelled in detail, usually via specialised energy modelling software. The model is built from the 'bottom up', including a full asset list and equipment ratings, operating schedules, control strategies, and data for site-based independent variables.

Both options involve a long-term approach for conducting M&V.

4.1.2 Measurement boundary

Either facility level boundary using Option C or Option D. Option D may also be used in conjunction with an ECM boundary. The energy system's usage must be separated from the rest of the facility using a permanent meter

4.1.3 Key parameters

For whole building M&V we need to consider the key parameters shown in the diagram and table below.

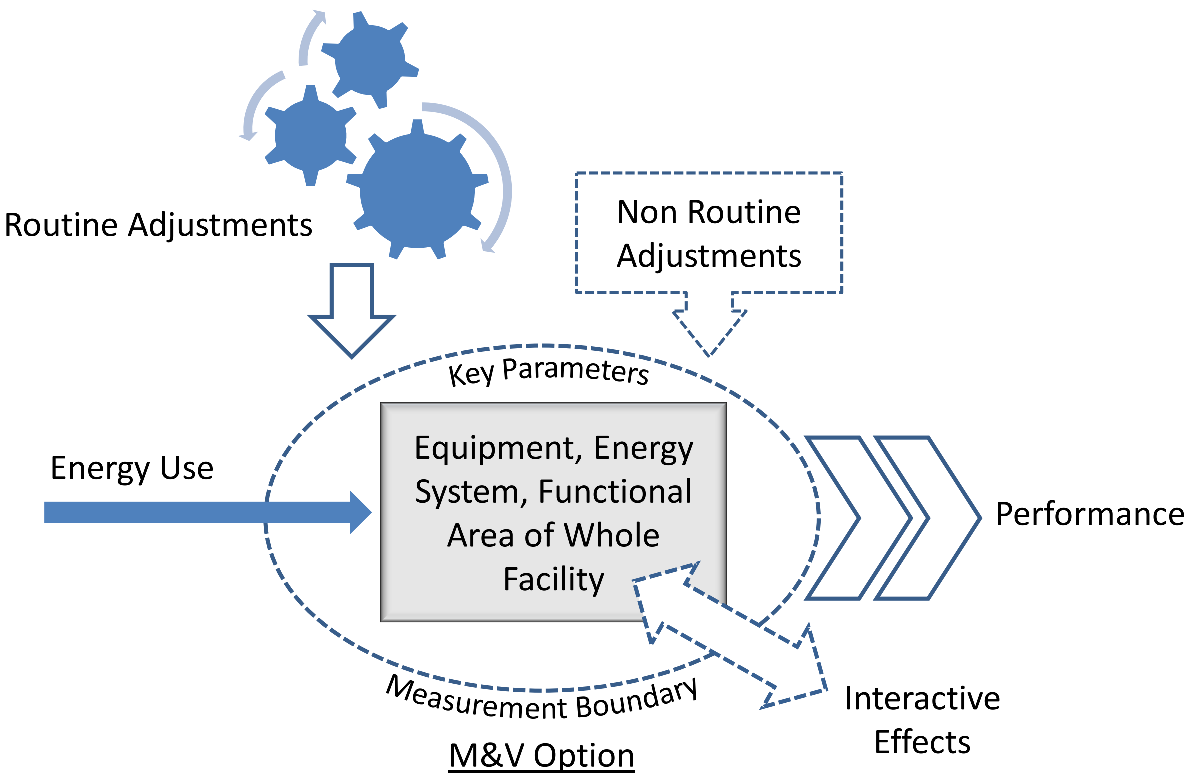


Table 2: key parameters to be considered when conducting M&V for whole building projects

Parameter	Description
Energy use	Energy use is typically obtained from the site's incoming revenue meter or from energy invoices. Measurement periods may be short, such as 15/30 minute interval data for electricity or natural gas, through to monthly or quarterly invoices. Where billing periods are long, meters can be read periodically (e.g. weekly, monthly) to segment billing periods into shorter time intervals. Bulk fuels (e.g. diesel, petrol, LPG, coal, etc) are often stockpiled on site, which may lead to differences between the fuel's purchase and subsequent use. It is important that data is captured for the time period (quantities and dates/times) when the fuel is used. This may require downstream metering (e.g. fuel pump readings taken when vehicles are filled, rather than relying on bulk fuel purchases which may be periodic or sporadic). Internal sub-metering can be used to describe a portion of a facility (e.g. buildings within a larger campus) or major energy systems.
Routine adjustments and performance outputs via independent variables	The identification of independent variables that affect a site is an important step for assessing sites using Options C or D. It is important to consider variables that may influence use across the measurement boundary, and these may include variables that are within the site's control as well as those that occur naturally. Examples of independent variables include: ▪ Weather – including ambient temperature, humidity, rainfall, wind speed/direction ▪ Operating hours – daily/weekly/seasonal operating schedules ▪ Occupancy – staff, students, patients, shoppers, tenants, visitors, etc ▪ System loads/ activity levels – heating/cooling requirements, temperature set points, work required from equipment, etc ▪ Input raw materials – temperatures, purity, density, moisture content, etc ▪ Production types and amounts – product quantities, volumes, weight, etc Where a site engages in multiple activities, data for each may be required in order to effectively model site energy use. With all independent variables it is important that the range of possible values is known.
Non-routine adjustments via static factors	Given the long-term approach taken when using Option C and D, the effects of non-routine adjustments may become significant and require once off or permanent adjustments. The identification and collection of data relating to static factors may assist with identifying or adjusting outlying data points, or with making a permanent step change in modelling forecast figures. Typical static factors include material and permanent changes to independent variables listed above, as well as: ▪ Change in product mix (e.g. plant stops making product A and start making product B) ▪ Equipment retrofits (either directly related to energy or not) ▪ Production schedule/shift changes ▪ Building changes (renovation, extension, facade changes, etc) ▪ Extreme and infrequent weather events (flood, fire, cyclone, etc) ▪ Effects of ECMs

4.1.4 Interactive effects

Since total facility energy consumption is captured within the measurement boundary, interactive effects between energy systems will be accounted for.

4.1.5 Operating cycle

When using Option C or D, the baseline period is 12 months or more, and post-retrofit period is typically 6 months or more

4.1.6 Additionality

Since total facility energy consumption is captured within the measurement boundary, additionality will not be an issue for the M&V project.

4.2 Prepare M&V plan

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

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

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

Table 3: Considerations, issues and suggested approach for whole building projects

Consideration	Issue	Suggested Approach
Modelling software and modelling/simulation skills	Insufficient skill or familiarity with complex modelling tools	Seek formal training on use of specific software packages. The software vendor is a useful place to start enquiries. OR Engage a suitably qualified professional to conduct the analysis
Difficult sites to model	Certain site types	Consider variations to linear regression, including: ▪ Multivariable regression ▪ Non-linear curves ▪ Stepped regression ▪ Separate regression for each fuel type Consider alternatives to regression including bottom up energy use models using Option D.
Validating regression models	Understanding the process for validating regression models	Refer to the *Process Guide* for further information.

5 Data collection, modelling and analysis

5.1 Measure baseline data

5.1.1 Measurement data sources, measurement tools and techniques

The following provides general guidance on measurement and data collection:

- Conduct baseline measurement in line with the prepared M&V plan prior to implementing the project.
- Ensure appropriate records are kept including the placement of measuring equipment and take lots of photographs.
- Collect any associated data required for calculating baseline energy use or adjustments for independent variables.
- Measurement should consider period demand and, where applicable, measurement should be made during any and all relevant demand periods.

5.1.2 Conducting measurements

Option C

The following provides guidance on the approach and placement for conducting measurements specific to Option C:

- Energy use measurements will be conducted using permanent metering.
- Data for independent variables should also be collected using ongoing, robust and quality assured processes.
- Data may be collected electronically from control systems (e.g. BMS, SCADA systems), or be the result from manual counts or surveys.
- Meter calibration should be considered periodically.

Option D

Under Option D, measurements are taken only within the post-retrofit period.

5.2 Develop energy model and uncertainty

This is the most critical step when using Option C or D, as we aim to develop an energy model that explains the baseline energy use as accurately as possible. Spreadsheets may be adequate for simple models however specialised regression analysis software may be required for models that involve multiple independent variables and the adjustment of weather data against target temperature 'balance points'.

Where possible it is a good idea to develop the energy model prior to implementing the ECM in case problems arise, that may require a delay or change or M&V Option from C to either A, B or D.

When using Option D, data for relevant inputs described in 3.1.2 are input into the building simulation program. The software produces a simulated energy output at either daily or hourly frequency. Separate models will need to be developed; one with the ECMs and one without.

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

5.3 Implement ECM(s)

Implement the ECM. Under Option C, this may have already occurred, which shouldn't be an issue if a successful energy model has been determined. Ensure that appropriate commissioning has been conducted to confirm that the ECMs are operating as expected.

Under Option D, the new building is constructed or the ECM is implemented.

5.4 Measure post retrofit data

Option C

Conduct post-retrofit measurement in line with the prepared M&V plan using the same techniques as for the baseline (section 5.1).

Collect any associated data required for calculating post-retrofit energy use or adjustments based on independent variables (e.g. monthly heating and/or cooling degree days). Confirm data integrity and completeness.

Option D

Post-retrofit data for energy use, independent variables and static factors is collected, allowing a suitable time to commission the building or 'bed in' a new ECM.

- Measurements are taken only within the post-retrofit period.
- Energy use measurements will be conducted using permanent metering.
- Data for independent variables should also be collected using ongoing, robust and quality assured processes.
- Data may be collected electronically from control systems (e.g. BMS, SCADA systems), or be the result from manual counts or surveys. Meter calibration should be considered periodically.

5.5 Savings analysis and uncertainty

5.5.1 Savings equations

Option C

The energy model previously developed is now used to forecast across the post-retrofit the business as usual consumption which would have occurred without the ECM. This is achieved by applying the various data inputs specified by the model for independent variables and static factors.

Savings are then calculated by subtracting the business as usual forecast from the actual savings from the metered energy use. From an uncertainty point of view, billed energy data is considered 100% accurate. Other uncertainties will be dependent on the modelling uncertainty, plus those from data collection.

The general equation for energy savings is:

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

Option D

Calibrate the building simulation against post-retrofit energy use and conditions to calculate savings:

- Both developed simulation models (simulation models with and without ECMs) are re-calibrated using data from the post-retrofit period for all key independent variables. The installed equipment and controls, internal heat loads and other characteristics are confirmed and adjusted.
- Changes are applied to both models as required, based on the concept of calibrating the model that contains the ECMs (i.e. 'as built' model) so that it accurately reflects the metered energy use from the measurement boundary.
- It should confirm that it appropriately describes both the energy use and demand profile from monthly data. 12 months of post-retrofit data is used to calibrate the model.
- Actual weather data is also used.
- Once off or short term measurement of individual equipment may assist with appropriately calibrating the model for complex systems.
- The calibration error is determined at a monthly level using the 'as-built' model and the actual energy data. Calibration errors are applied to the baseline model in order to incorporate uncertainty within savings.
- Savings are calculated in one of two ways:
  - Actual savings = Actual energy use – calibrated baseline model, OR
  - Normalised savings = calibrated as-built model – calibrated baseline model
- Actual savings are determined for the post-retrofit period, by applying the appropriate data to the baseline model.
- Normalised savings can be determined using any set of data for independent variables (e.g. 10 year average weather patterns), once the models are calibrated. The data is applied to both models.

5.5.2 Extrapolation

Extrapolate the calculated savings for the measured period as required.

5.5.3 Uncertainty

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

6 Finish

6.1 Reporting

Prepare an outcomes report summarising the M&V exercise. Ensure any extrapolated savings are referred to as estimates, as the ‘actual’ savings only apply to the measurement period. Energy uncertainty is expressed with the overall precision and confidence level.

6.2 Project close and savings persistence

Under Option C, ongoing M&V can be conducted regularly as required by collecting independent variables and inserting them into the energy model. Typically under Option D, the first year of data forms the baseline of an ongoing Option C M&V approach.

7 M&V Examples

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

7.1 Examples from the IPMVP

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

Table 4: Example M&V projects from the IPMVP

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

7.2 Examples from this guide

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

Table 5: Example M&V projects from the M&V Operational Guide

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

Appendix A: Example scenario A – food processing plant

The scenario below provides details of how **Option C** is used to measure and verify the savings from multiple ECMs across a manufacturing plant.

A food processing plant in a regional town prepares and packages a range of tinned and snap frozen vegetable products grown in the local area. The plant operates year-round, however activity in a given month is seasonal based on the produce and consumer spending patterns.

The plant consists of several production lines, some of which serve multiple products throughout the year. Broad beans, which are the plant's most popular product is highly seasonal and is only produced for 5 months of the year.

The basic process involves food preparation (skinning, dehusking, etc), cooking, and either snap freezing and packaging, or canning. A centralised set of boilers provide hot water and steam for cooking and sterilisation, whilst a set of air compressors provide compressed air for operating much of the machinery.

The site is a significant energy user and receives monthly invoices for electricity and natural gas. At present there is no sub-metering of energy use across the site.

Following an energy audit, the Site Manager has gained approval to proceed with implementing several ECMs across the site. At first the low cost measures are to be implemented and once savings can be verified, capital will be available for more significant upgrades.

The identified ECMs are mostly small to medium and include:

1. Adding a heat exchanger to capture waste heat from the air compressor system to pre-heat boiler feedwater.
2. Reducing compressed air and steam delivery pressures
3. Introducing occupancy based lighting controls for seldom used areas

When combined together, the Site Manager estimates that the above ECMs will reduce site energy use by around 15%. Each ECM relates to a different energy system, and there is the potential to assess each individually.

Monthly energy use is highly variable, which the Site Manager believes is due to changes in product output, however she cannot be sure. The Site Manager is only interested in determining combined savings, and does not have the funds available to invest in temporary metering.

More importantly, the Site Manager seeks to develop an approach for conducting M&V that will apply into the future as more ECMs are implemented.

For these reasons, an Option C approach is to be used to verify savings. Management are interested in savings to a confidence of 90%.

Getting started

Budget

The potential savings (15% of site usage) from these projects are significant, however the site is has complex, interlinked manufacturing processes. Due to the difficulty of defining appropriate project measurement boundaries, combined with the fact that the Site Manager does not have funds for temporary metering, an Option C approach has been adopted which simply involves desktop analysis using existing data. It is anticipated that the analysis can be conducted and savings calculated within 12 hours. A nominal budget of $2,500 of time has been set aside.

Measurement boundary

The measurement boundary is the combination of electrical and natural gas supplies that supply the facility. Both fuels will be affected by the proposed ECMs. Although the Site Manager is only interested in overall savings, separate analysis will be conducted for electricity and natural gas in order to calculate cost savings.

Identification of key parameters

After working at the site for a number of years in various roles, the Site Manager has developed her opinion regarding the variables that may affect energy use. She hasn't conducted detailed analysis before to determine these, and so she plans on collecting data for the following variables and attempting various models to find the best combinations of data. The variables to be investigated include:

Variable	Data source
Metered electricity and natural gas use	Monthly electricity invoices
Ambient air temperature (heating and cooling degree days)	Daily figures for maximum and minimum air temperatures from the Bureau of Meteorology
Production figures for various product lines, divided into: ▪ Canned Mixed Vegetables ▪ Broad beans ▪ Peas ▪ Other production (combined)	Monthly site reports which include data compiled from shift-based production outputs

The plant operates continuously, and so operating hours will not be considered. However some products are highly seasonal, which will be reflected in the monthly production volumes.

Timing

Baseline data is available for the last 3 years. The ECMs are due to be implemented during September 2010, and so the period just prior has been chosen. The baseline period will consist of the 12 months between September 2009 and August 2010.

Interactive effects

There are no interactive effects due to the choice of a facility based measurement boundary.

Summary of M&V plan

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

Item	Plan
Project Summary	Implementation of the following ECMs on central service equipment: ▪ waste heat capture from the air compressor system to pre-heat boiler feedwater ▪ pressure reduction strategy for compressed air and steam systems ▪ occupancy based control of lighting in seldom used areas
Required Outcome	To confirm savings in excess of 15% with a 90% confidence level in order to convince management to invest in more capital intensive energy efficiency projects.
Budget	$2,500 (1 day of desktop analysis)
M&V Option	C – Whole Facility
Measurement Boundary	Total incoming electrical and natural gas supplies being fed to the BeanCo Central West Processing Plant, located in 23 Rabie Road, Parkes, NSW.
Key Measurement Parameters	Data for the following key parameters will be collected and modelled in order to determine the most relevant factors affecting energy use: ▪ Metered electricity and natural gas use ▪ Ambient temperature (in the form of heating/cooling degree days) ▪ Monthly production figures for processed goods – Canned mixed vegetables – Broad beans – Peas – Other food products
Other Parameters to consider	None identified
Potential interactive effects	None identified
Approach for conducting measurement and collecting data	Energy use data will be collected directly from energy invoices. Ambient temperature data will be sourced for the nearest weather station from the Bureau of Meteorology. Production data will be obtained from monthly reports, which are compiled from daily shift data.
Measurement equipment required	Existing revenue meter and energy invoice data
Measurement period	12 month base year period, 1 month project implementation, and 6+ month post-retrofit measurement.

Item	Plan
Approach for calculating results	Separate energy models for electricity and natural gas will be developed using regression analysis to explain baseline energy use in regard to relevant independent variables. As the relationship between independent variables and energy use is unknown and potentially complex, several energy models will be tested to identify the variable (or combination of variables) that best describe energy use for each fuel type. A preferred energy model will be selected for each fuel type, based on highest R^2 value, satisfying regression validity tests and having the smallest standard error. Once the ECM has been implemented, post-retrofit data for these variables will be entered into the fuel specific models in order to forecast the adjusted baseline or business-as-usual energy use. Savings are calculated by taking the difference in the adjusted baseline and actual energy use data on a monthly basis. Cost savings are calculated by applying the following energy rates: ▪ Natural gas - $7.30 / GJ ▪ Electricity - $0.18 / kWh

Baseline model development

The decision was made to conduct the modelling using Microsoft Excel. As it is not clear which variables will best explain monthly energy use, several scenarios will be modelled and compared.

A spreadsheet was developed that contained the following elements:

- Monthly baseline historical data for the key energy use parameters in independent variables
- Daily weather maximum and minimum temperatures for the local weather station
- HDDs and CDDs that have been derived from ambient temperature data, as described within Section 6.5.2 within the *Process Guide*.

The baseline site data is summarised below:

Month	Energy use		Production Data (tonnes)				Total Production (tonnes)
	Electricity (kWh)	Natural Gas (GJ)	Canned Mixed Vegetables	Broad beans	Peas	Other Production	
B1	537,825	3,661	187	0	246	227	660
B2	496,767	2,487	166	0	122	185	473
B3	696,798	3,967	340	0	170	181	691
B4	498,189	2,510	227	0	280	103	610
B5	653,955	2,948	0	256	212	422	890
B6	1,069,023	4,119	0	433	473	553	1,459
B7	712,298	3,270	0	211	231	382	824
B8	898,471	4,376	34	360	661	937	1,992

Month	Energy use			Production Data (tonnes)			Total Production (tonnes)
	Electricity (kWh)	Natural Gas (GJ)	Canned Mixed Vegetables	Broad beans	Peas	Other Production	
B9	882,253	5,523	34	280	25	685	1,024
B10	466,539	3,563	14	0	211	342	567
B11	451,487	4,072	18	0	326	296	640
B12	488,450	2,985	20	0	299	242	561

In addition to the data above, weather data was collected from the Bureau of Meteorology for the nearest weather station. From the average daily temperatures, values for Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) were computed.

Initial values for HDD and CDD balance points were chosen, and were added into the analysis spreadsheet as reference values in linked cells. The balance points were adjusted as part of tuning various energy models so that the R^2 value was maximised for each energy model.

The LINEST() function is used to conduct multivariable linear regression on a dataset to produce a function describing *y* in terms of $x_{1 \text{ to } n}$ in the form:

$$y = b + m_1x_1 + m_2x_2 + ... + m_nx_n$$

where:

y = energy use

b = baseload energy use (without influence of any variables) – also known as y-intercept

$x_{1 \text{ to } n}$ *= data for independent variables 1 to n*

$m_{1 \text{ to } n}$ *= coefficients determined by the function that correspond to each x variable*

It accepts an array of *y*-values (i.e. energy use) and corresponding arrays of *x*-values (data for independent variables) and produces various outputs as shown below:

- Coefficients and standard errors for the baseload energy use (*b*) and each independent variable ($m_{1 \text{ to } n}$)
- Coefficient of determination (R^2), and Adjusted R^2 which describe the 'appropriateness of fit' for the regression model
- Standard error for *y*

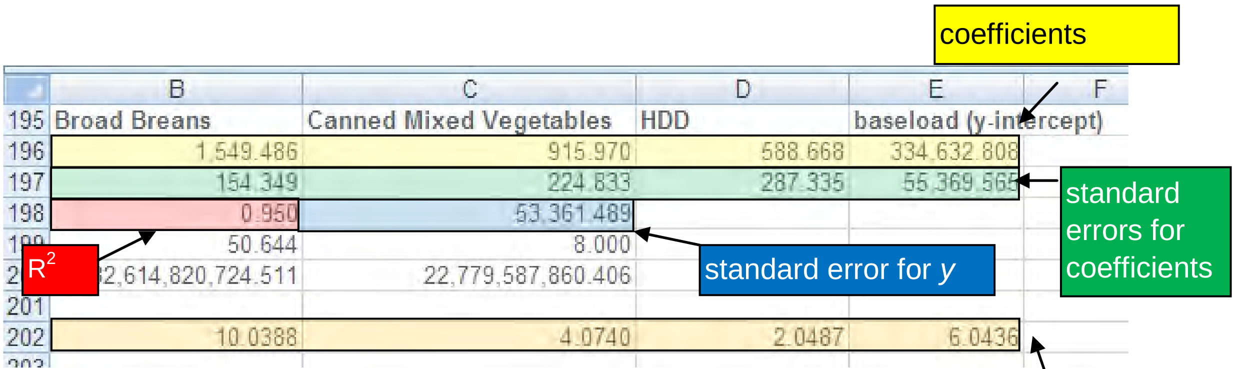
Developing the energy model for electricity

Seven different regression models were calculated, each incorporating a different combination of parameters as shown in the table below.

Scenario	Electricity (kWh)	Production(tonnes)				Total Production (tonnes)	Ambient temperature	
		Canned Mixed Vegetables	Broad Beans	Peas	Other		HDDs	CDDs
1	Yes	-	-	-	-	Yes	-	-
2	Yes	-	-	-	-	Yes	Yes	-
3	Yes	-	-	-	-	Yes	-	Yes
4	Yes	Yes	Yes	-	-	-	Yes	Yes
5	Yes	Yes	Yes	-	-	-	-	-
6	Yes	Yes	Yes	-	-	-	Yes	-
7	Yes	Yes	Yes	Yes	-	-	Yes	-

The combinations above were selected as the analysis proceeded. As each model was developed, the t-stats for each coefficient were examined to see which variables were providing a strong correlation. Any coefficient with a t-stat value less than 2 was further examined in subsequent models. In addition, changes in R^2 provided a guide as to how each model reacted to inclusion of new variables, based on a base model involving total production.

Refer to Help within Microsoft Excel for assistance with using the LINEST() function. An example of the output using the input data above for Scenario 6 is shown below:



The output above equates to the following:

Energy use = 334,632.808

+ 588.668 x (HDD)

+ 915.970 x (Canned Mixed Vegetables (tonnes))

+ 1,549.486 x (Broad Beans (tonnes))

The R^2 value is 0.950 and the standard error is 55,369.565

Each model was generated in turn using the LINEST() function.

Validating the regression outputs

As described in Section 6.5.1, each model must be validated to confirm that it can be used. This involves equating some additional attributes and confirming their validity. The attributes to be reviewed are:

Attribute	**Description and Validity Test**
R^2	Must be 0.75 or higher. Output from LINEST() function
Adjusted R^2	To be evaluated when multiple independent variables are used. Values should be 0.75 or higher. Calculated as follows: $Adjusted\ R^2 = 1 - (1 - R^2) \times \frac{(n-1)}{(n-k-1)}$ Where: *R^2 = the value calculated from LINEST()* *n = number of data points in sample size* *k = number of coefficients within the regression model*
t-statistic for each coefficient	Determine the validity of each *x* coefficient. Values must be greater than 2. Calculated as follows: Each 't-stat' is calculated as follows: $t_{Xn} = \frac{coefficient_{Xn}}{standard\ error_{Xn}}$
Absolute mean bias (MBE)	Determines the overall bias in the regression estimate. MBE values should be < 0.005%. Calculated as follows: $MBE = \frac{\sum(modelled_n - actual_n)}{n}$ Where: *n = the number of samples* *$modelled_n$ = predicted value for sample item n* *$actual_n$ = actual value for sample item n*
Monthly Mean Error CV(RMSE)	Related to the standard error of the model. CV(RMSE) values should be < 0.25. Calculated as follows: $CV(RMSE) = \frac{standard\ error\ for\ y}{average(actual\ values)}$

In our example above:

$$Adjusted\ R^2 = 1 - (1 - 0.950) \times \frac{(12-1)}{(12-3-1)} = 0.931$$

For our three coefficients in the example above:

$$t_{canned\ mixed\ vegetables} = \frac{915.970}{224.833} = 4.07$$

$$t_{broad\ beans} = \frac{1{,}549.486}{154.349} = 10.04$$

$$t_{HDDs} = \frac{588.668}{287.335} = 2.05$$

MBE is calculated by first determining the modelled energy values by using the data for independent variables. Modelled values are then subtracted from actual values to calculate the difference for each measurement. These residuals are summed and divided by the number of data points to determine the MBE, as follows:

Month	Actual energy	Example Scenario 6 modelled energy	Residual (modelled – actual)
B1	537,825	553,614	15,789
B2	496,767	505,050	8,283
B3	696,798	650,419	-46,379
B4	498,189	544,030	45,841
B5	653,955	731,301	77,346
B6	1,069,023	1,005,560	-63,463
B7	712,298	661,574	-50,724
B8	898,471	942,046	43,575
B9	882,253	891,876	9,623
B10	466,539	452,269	-14,270
B11	451,487	478,067	26,580
B12	488,450	436,249	-52,201
Sum			-5.82 x 10^{-10}
Average	**654,337.92**		

And, MBE is calculated as follows:

$$MBE = \frac{-5.82 \times 10^{-10}}{12} = -4.85 \times 10^{-11}$$

CV(RMSE) is calculated for the example above as follows:

$$CV(RMSE) = \frac{53{,}361.49}{654{,}337.92} = 0.0816$$

Validity tests for each of the seven models were conducted. The results are shown in the table below. Conditional formatting is used to highlight test results. Each value is coloured green if it passes the validity test and red if it fails.

Validity Test	Energy Model						
	1	2	3	4	5	6	7
	1 variable	2 variables	2 variables	4 variables	2 variables	3 variables	4 variables
Test	Total Production	Total Production + HDDs	Total Production & CDD	HDD, CDD, Canned Mixed Vegetables & Broad Beans	Canned Mixed Vegetables & Broad Beans	HDDs + Canned Mixed Veg + Broad Beans	Peas, Broad Beans, Canned Mixed Vegetables & HDDs
R2 > 0.75	0.688	0.734	0.793	0.953	0.924	0.950	0.950
Adj R2 > 0.75		0.675	0.747	0.927	0.907	0.931	0.922
Y intercept > 0	325474.19	443493.41	363063.05	528.96	0.00	334632.81	338729.75
coeff a > 0	379.79	-266.32	31315.17	855.41	430333.78	588.67	584.52
coeff b > 0		352.73	310.68	1556.79	607.43	915.97	912.68
coeff c > 0					1335.47	1549.49	1554.24
coeff d > 0							-15.22
Y intercept > 2	4.17	3.65	5.25	5.42	12.43	6.04	5.06
coeff a > 2	4.70	-1.25	2.14	-0.73	3.13	2.05	1.89
coeff b > 2		4.32	4.06	1.27	10.10	4.07	3.78
coeff c > 2				3.36		10.04	9.21
coeff d > 2				9.66			-0.13
residual (calculated value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
standard error (from LINEST())	119121.31	115960.44	102290.29	55146.57	62120.86	53361.49	56977.13
CV(RMSE)	0.1820	0.1772	0.1563	0.0843	0.0949	0.0816	0.0871
Mean Bias Error (MBE)	4.85064E-12	0	-3.3954E-11	-2.91038E-11	-7.27596E-11	-4.85064E-11	-1.16415E-10

Scenarios 5 and 6 pass all the validity tests. Scenario 6 was selected from the table above as the preferred scenario as it had the highest R^2 and Adjusted R^2 values and the lowest standard error.

Summarising the electricity model

The output from the LINEST() function for Scenario 6 is shown below.

	B	C	D	E	F
195	Broad Beans	Canned Mixed Vegetables	HDD	baseload (y-intercept)	
196	1,549.486	915.970	588.668	334,632.808	
197	154.349	224.833	287.335	55,369.565	
198	0.950	53,361.489			
199	50.644	8.000			
200	432,614,820,724.511	22,779,587,860.406			
201					
202	10.0388	4.0740	2.0487	6.0436	
203					

From the above the energy model describes monthly energy use as:

$$\begin{aligned} Electricity\ use(kWh) \\ &= 334{,}633 + (588.67\ \times HDDs) + \ (915.97\ \times Canned\ Mixed\ Vegetables) \\ &+ (1{,}549.49\ \times Broad\ Beans) \end{aligned}$$

And the standard error is ± 53,361.49 kWh

Calculating electricity savings

The ECM was implemented in September 2010. Following a number of months, the savings were calculated for the ECM by forecasting the adjusted baseline by applying post-retrofit data to the baseline energy model. This is shown in the table below.

Period	Month	Actual electricity use (kWh)	Independent Variables: HDD Balance Point = 13°C	Independent Variables: Canned Mixed Vegetables (tonnes)	Independent Variables: Broad Beans (tonnes)	Energy Model Output: Adjusted Baseline (kWh)	Savings (kWh)
Baseline Period	B1	537,825	87.1	187	0	556,726	
	B2	496,767	33.4	166	0	506,331	
	B3	696,798	8.6	340	0	651,117	
	B4	498,189	2.7	227	0	544,146	
	B5	653,955	0.0	0	256	731,301	
	B6	1,069,023	0.0	0	433	1,005,560	
	B7	712,298	0.0	0	211	661,574	
	B8	898,471	34.5	34	360	943,908	
	B9	882,253	162.8	34	280	895,485	
	B10	466,539	184.0	14	0	455,761	
	B11	451,487	221.8	18	0	481,675	
	B12	488,450	147.6	20	0	439,857	
						Average = 654,337.92	
	Implement ECM						
Post-retrofit Period	P1	448,370	2.7	230	0	546,984	98,614
	P2	562,401	0.0	0	263	741,466	179,065
	P3	930,050	0.0	0	454	1,037,543	107,493
	P4	641,068	0.0	0	218	672,750	31,682
	P5	781,670	34.5	35	375	967,801	186,131
	P6	776,383	162.8	34	283	899,616	123,233
	P7	419,885	184.0	14	0	455,772	35,887
	P8	392,794	221.8	19	0	482,479	89,685
	P9	429,836	147.6	21	0	440,391	10,555
	P10	426,011	96.4	194	0	569,499	143,488
	P11	375,953	52.4	170	0	521,134	145,181
	P12	564,406	0.2	361	0	665,335	100,929
	Total Latest 12 months	**6,748,827**	**903**	**1,078**	**1,592**	**8,000,770**	**1,251,943**

From the table above, we can see that the savings achieved during the post-retrofit period is 1,251,943 kWh. This represents a 15.6% saving against the 'business as usual' adjusted baseline.

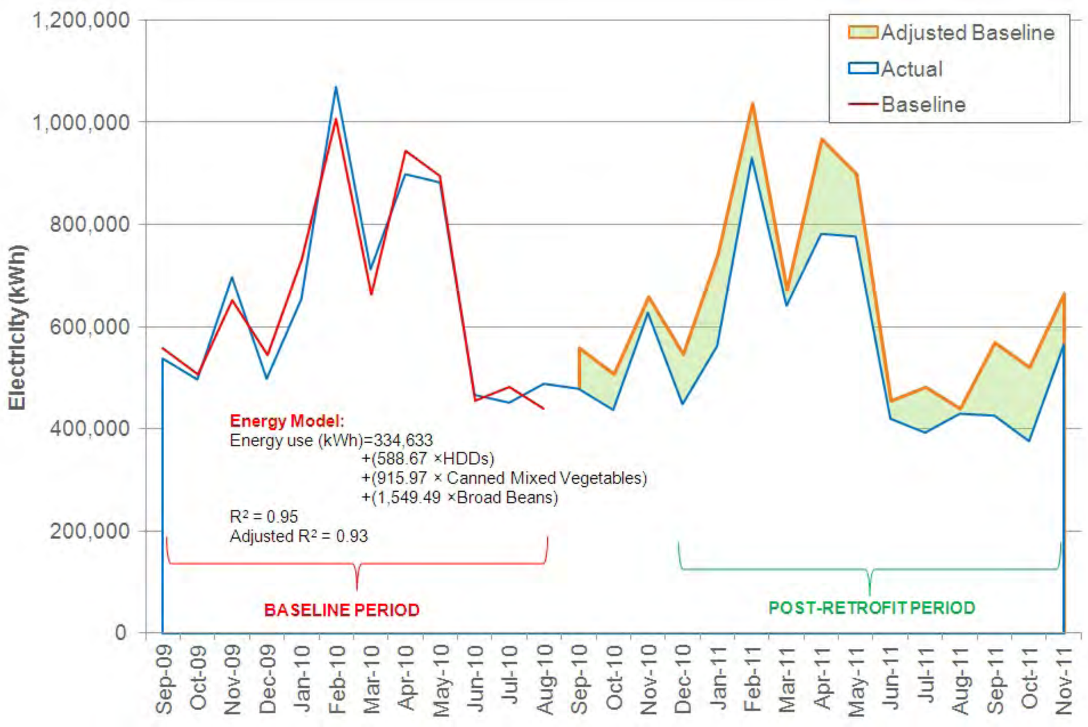
Cost savings are calculated by applying the agreed cost rate to the electricity savings figure as follows:

$$Cost\ savings\ (\$) = energy\ savings\ (kWh) \times energycost\ rate\ (\frac{\$}{kWh})$$

$$Cost\ savings\ (\$) = 1{,}251{,}943 kWh \times \frac{\$0.18}{kWh}$$

$$Cost\ savings\ (\$) = \$225{,}349.74$$

The actual energy use is plotted against the baseline and adjusted baseline. The energy savings are shown in green.



Uncertainty analysis

As shown earlier, the standard error (SE) of the baseline energy model is:

$$standard\ error(SE) = 53{,}361.49\ kWh$$

Using the standard error we can calculate the absolute precision (AP) by applying the t-statistic for our chosen sample size (where DF = 12 data points – 3 variables -1 = 8) and required confidence (90%). Refer to Table 27 within Appendix G of the *Process Guide* for the list of t-statistics.

Absolute precision is calculated as follows:

$$Absolute\ precision\ (AP) = t \times SE$$

$$Absolute\ precision\ (AP) = 1.86\ \times 53{,}361.49 = 99{,}252.37\ kWh$$

And the relative precision (RP) is calculated by dividing the absolute precision by the average predicted energy use as follows:

$$relative\ precision\ (RP) = \frac{AP}{average\ monthly\ modelled\ usage}$$

$$relative\ precision\ (RP) = \frac{99{,}252.37}{654{,}337.92} = \pm 15.2\%$$

The uncertainty of the savings is calculated as follows:

$$SE(monthly\ savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(post\ retrofit)^2}$$

$$= \sqrt{53{,}361.49^2 + 0^2} = 53{,}361.49\ kWh$$

Note that the post retrofit standard error is zero since we are using billing data as our source which is deemed to be 100% accurate.

Assuming that the standard error of each month's savings will be the same, the standard error for the annual savings is:

$$SE(annual\ savings) = \sqrt{12 \times 53{,}361.49^2} = 184{,}849.62\ kWh$$

Using a t-statistic of 1.80 (12 measurement points with 90% confidence, DF = 11), the range of possible annual savings will be:

$$Range\ of\ Savings\ (kWh) = 1{,}251{,}943 \pm 1.80 \times 184{,}849.62 kWh$$

$$= 1{,}251{,}943 \pm 332{,}729\ kWh$$

The relative precision of the annual savings reported is thus ±26.6% (184,850 / 1,251,943)

Developing the energy model for natural gas

A similar process was applied to the natural gas. As before seven different regression models were calculated, each incorporating a different combination of parameters as shown in the table below.

Scenario	Natural Gas (GJ)	Production (tonnes)				Total Production (tonnes)	Ambient temperature	
		Canned Mixed Vegetables	Broad Beans	Peas	Other		HDDs	CDDs
1	Yes	-	-	-	-	Yes	-	-
2	Yes	-	-	-	-	Yes	Yes	-
3	Yes	Yes	Yes	-	-	-	-	-
4	Yes	Yes	-	-	-	-	Yes	-
5	Yes	Yes	-	-	Yes	-	Yes	-
6	Yes	Yes	Yes	-	-	-	Yes	-
7	Yes	Yes	Yes	Yes	-	-	Yes	-

Again as before, validity tests for each of the seven models were conducted. The results are shown in the table below. Conditional formatting is used to highlight test results. Each value is coloured green if it passes the validity test and red if it fails.

Validity Test	Energy Model						
	1	2	3	4	5	6	7
	1 variable	2 variables	2 variables	2 variables	3 variables	3 variables	4 variables
Test	Total Production	Total Production + HDDs	Canned Mixed Vegetables + Broad Beans	HDD + Canned Mixed Vegetables	Canned Mixed Vegetables+ other production + HDD	HDDs + Canned Mixed Veg + Broad Beans	Peas, Broad Beans, Canned Mixed Vegetables & HDDs
R2 > 0.75	0.27	0.57	0.24	0.16	0.74	0.92	0.85
Adj R2 > 0.75		0.48	0.07	-0.03	0.64	0.89	0.77
Y intercept > 0	2740.85	2011.06	3242.28	3320.41	1595.29	1161.28	1277.61
coeff a > 0	1.02	5.25	0.45	1.97	6.23	12.38	5.37
coeff b > 0		1.33	2.66	-1.10	3.79	7.11	4.59
coeff c > 0					3.43	7.30	6.79
coeff d > 0							-0.96
Y intercept > 2	5.40	4.00	6.95	6.40	3.14	3.92	2.53
coeff a > 2	1.94	2.51	0.17	1.10	2.72	8.32	5.33
coeff b > 2		3.01	1.49	-0.46	2.09	5.92	3.02
coeff c > 2					4.28	8.84	5.74
coeff d > 2							-1.13
residual (calculated value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
standard error (from LINEST())	775.03	627.03	837.89	879.05	518.76	286.00	415.45
CV(RMSE)	0.2139	0.1731	0.2312	0.2426	0.1432	0.0789	0.1147
Mean Bias Error (MBE)	3.79E-14	-1.51582E-13	-3.41E-13	0	1.13687E-13	-2.27374E-13	7.57912E-14

From the above we can see that only one of the models developed passes all the validity tests. This is Scenario 6. Note that Scenario 7 has a high R^2 value of 0.85 and Adjusted R^2 is also satisfactory. However the coefficient for 'coefficient d' is less than zero and its t-stat is less than 2.

Summarising the natural gas model

The output from the LINEST() function for Scenario 6 is shown below.

	B	C	D	E
195	Broad Breans	Canned Mixed Vegetables	HDD	Y intercept
196	7.297	7.106	12.376	1,161.279
197	0.825	1.200	1.487	296.519
198	0.921	286.000		
199	31.013	8.000		
200	7,610,180.691	654,366.226		
201				
202	8.8437	5.9219	8.3215	3.9164

From the above the energy model describes monthly energy use as:

$$\begin{aligned} Natural\ gas\ use (GJ) &= 1{,}161.3 + (12.376\ \times HDDs) + \ (7.106\ \times Canned\ Mixed\ Vegetables) \\ &+ (7.297\ \times Broad\ Beans) \end{aligned}$$

And the standard error is ± 286 GJ

Calculating natural gas savings

The ECM was implemented in September 2010. Following a number of months, the savings were calculated for the ECM by forecasting the adjusted baseline by applying post-retrofit data to the baseline energy model. This is shown in the table below.

			Independent Variables			Energy Model Output	
	Month	Actual natural gas use (GJ)	HDD Balance Point = 13.2°C	Canned Mixed Vegetables (tonnes)	Broad Beans (tonnes)	Adjusted Baseline (GJ)	Savings (GJ)
Baseline Period	B1	3,661	87.1	187	0	3,564	
	B2	2,487	33.4	166	0	2,754	
	B3	3,967	8.6	340	0	3,684	
	B4	2,510	2.7	227	0	2,808	
	B5	2,948	0.0	0	256	3,029	
	B6	4,119	0.0	0	433	4,321	
	B7	3,270	0.0	0	211	2,701	
	B8	4,376	34.5	34	360	4,457	
	B9	5,523	162.8	34	280	5,461	
	B10	3,563	184.0	14	0	3,538	
	B11	4,072	221.8	18	0	4,034	
	B12	2,985	147.6	0	0	2,988	
						Average = 3,612	
	Implement ECM						
Post-retrofit Period	P1	2,385	2.7	230	0	2,830	445
	P2	2,801	0.0	0	263	3,077	276
	P3	3,736	0.0	0	454	4,471	735
	P4	2,786	0.0	0	218	2,754	-32
	P5	3,926	34.5	35	375	4,572	646
	P6	3,977	162.8	34	283	5,481	1,504
	P7	2,779	184.0	14	0	3,538	759
	P8	2,973	221.8	19	0	4,040	1,067
	P9	2,358	147.6	0	0	2,988	630
	P10	2,487	96.4	194	0	3,736	1,249
	P11	1,843	52.4	170	0	3,017	1,174
	P12	2,676	0.2	361	0	3,729	1,053
	Total Latest 12 months	**34,727**	**903**	**1,057**	**1,592**	**44,233**	**9,506**

From the table above, we can see that the savings achieved during the post-retrofit period is 9,506 GJ. This represents a 21.5% saving against the 'business as usual' adjusted baseline.

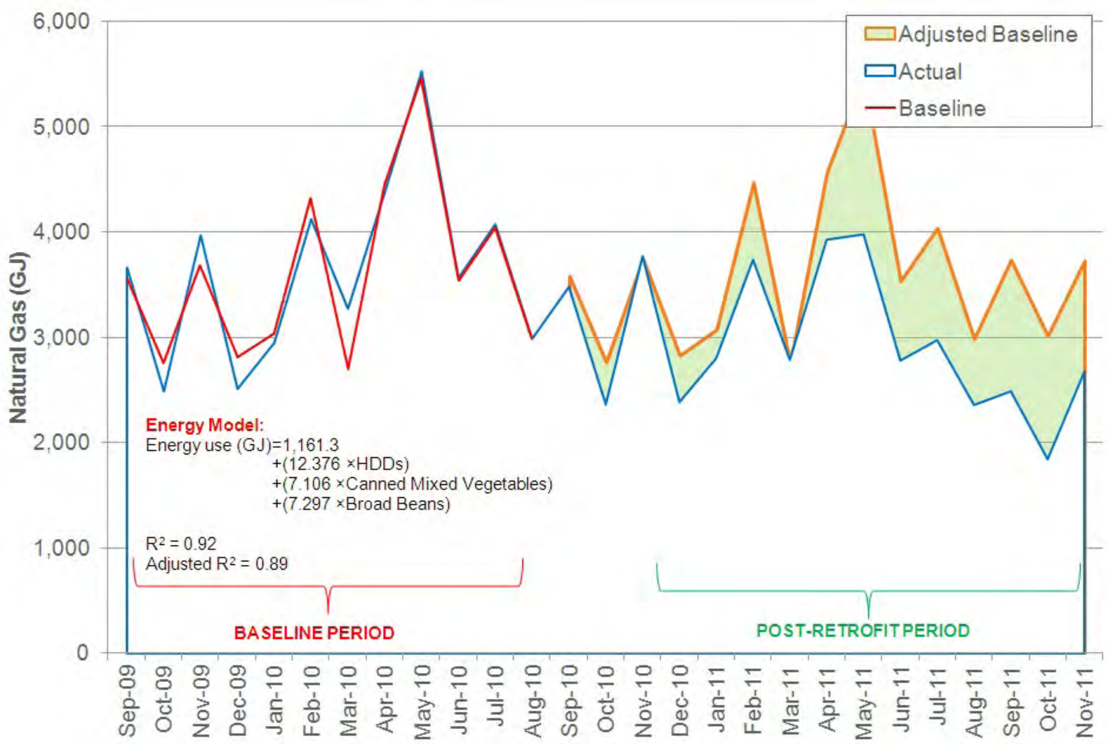
Cost savings are calculated by applying the agreed cost rate to the electricity savings figure as follows:

$$Cost\ savings\ (\$) = energy\ savings\ (GJ) \times energy\ cost\ rate\ (\frac{\$}{GJ})$$

$$Cost\ savings\ (\$) = 19{,}506\ GJ \times \frac{\$7.30}{GJ}$$

$$Cost\ savings\ (\$) = \$69{,}393.80$$

The actual energy use is plotted against the baseline and adjusted baseline. The energy savings are shown in green.



Uncertainty analysis

A similar process to that described earlier for the preferred electricity model was conducted to determine the uncertainty associated with the natural gas energy model and calculated savings. This analysis resulted in the following outputs:

$$standard\ error (SE) = 286\ GJ$$

$$Absolute\ precision\ (AP) = 1.86\ \times 286 = 532\ GJ$$

$$Relative\ precision\ (RP) = \frac{532}{3{,}612} = \pm 14.7\%$$

The uncertainty of the savings is calculated as follows:

$$SE(monthly\ savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(post\ retrofit)^2}$$

$$= \sqrt{286^2 + 0^2} = 286\ GJ$$

Note that the post retrofit standard error is zero since we are using billing data as our source which is deemed to be 100% accurate.

$$SE(annual\ savings) = \sqrt{12 \times 286^2} = 991\ GJ$$

$$Range\ of\ Savings\ (kWh) = 9{,}506 \pm 1.80 \times 991\ GJ$$

$$= 9{,}506 \pm 1{,}783\ GJ$$

The relative precision of the annual savings reported is thus ±18.8% (1,783 / 9,506)

Calculating combined energy savings and uncertainty

The combined energy savings is determined as follows:

$$Total\ Energy\ Savings\ (GJ) = electricity\ savings\ (GJ) + natural\ gas\ savings(GJ)$$

$$= (electricity\ savings\ kWh \times 0.0036 \frac{GJ}{kWh}) + natural\ gas\ savings(GJ)$$

$$= (1{,}251{,}943\ kWh \times 0.0036 \frac{GJ}{kWh}) + 9{,}506(GJ)$$

$$= 14{,}013(GJ)$$

The forecasted total site energy usage is:

$$Total\ forecast\ energy\ use(GJ) = electricity\ (GJ) + natural\ gas\ (GJ)$$

$$= (electricity\ kWh \times 0.0036 \frac{GJ}{kWh}) + natural\ gas\ (GJ)$$

$$= (8{,}000{,}770\ kWh \times 0.0036 \frac{GJ}{kWh}) + 44{,}233(GJ)$$

$$= 73{,}036(GJ)$$

Thus, the combined energy savings represent a 19.2% overall reduction against forecast site usage of 73,036 GJ

$$Total\ Cost\ Savings\ (\$) = electricity\ savings\ (\$) + natural\ gas\ savings(\$)$$

$$= \$225{,}350 + \$69{,}394$$

$$= \$294{,}744$$

The combined standard error of the total savings is:

$$SE(total\ savings)(GJ) = \sqrt{SE(electicity)^2 + SE(natural\ gas)^2}$$

$$= \sqrt{SE(184850\ kWh \times \frac{0.0036GJ}{kWh})^2 + SE(990.73\ GJ)^2}$$

$$= \pm 1{,}193.5(GJ)$$

And finally, the absolute and relative precision of the combined savings is:

$$Absolute\ precision\ (AP) = t \times SE$$

$$Absolute\ precision\ (AP) = 1.80\ \times 1{,}193.5 = 2{,}148\ GJ$$

$$Relative\ precision\ (RP) = \frac{2148}{14{,}013} = \pm 15.3\%$$

Reporting results

The savings results can be described as follows:

Electricity

Annual electricity savings are calculated to be 1,251,943 kWh ± 26.6% or 332,729 kWh with a 90% confidence factor. This represents an estimated cost saving of $225,350. Savings fall within the range of 919,214 kWh to 1,584,672 kWh.

Overall these savings represent between 11% and 20% of the forecast site electricity consumption of 8,000,770 kWh.

Natural gas

Annual natural gas savings are calculated to be 9,506 GJ ± 18.8% or 1,783 GJ with a 90% confidence factor. This represents an estimated cost saving of $69,394. Savings fall within the range of 7,723 GJ to 11,289 GJ.

Overall these savings represent between 17.5% and 25.5% of the forecast site natural gas consumption of 44,233 GJ.

Total energy

Annual energy savings are calculated to be 14,013 GJ ± 15.3% or 2,148 GJ with a 90% confidence factor. This represents an estimated cost saving of $294,744. Savings fall within the range of 11,865 GJ to 16,161 GJ.

Overall these savings represent between 16% and 22% of the forecast site natural gas consumption of 73,036 GJ.

Appendix B: Example scenario B – commercial building

The scenario below provides details of how **Option C** is used to measure and verify the savings from multiple ECMs across a commercial building.

A commercial office building situated within the Sydney CBD provides 26 floors of office accommodation with a 3 level basement car park. The building dates from the 1980s and was purchased by its new owners in 2008.

When acquired, the property's air conditioning plant and equipment was in fair condition although some major equipment was original and was nearing its practical end-of-life. An energy audit determined that the building would benefit from upgrading several components of its air conditioning system, as well as implementing key control changes to improve performance.

The audit recommendations included:

- New main chiller and cooling tower
- Recommissioning of economy cycle
- Fitting new motors with variable speed drives to main air handling units

The new owner had limited capital to invest and was anxious to confirm that each ECM will deliver its predicted savings, and so a staged implementation plan incorporating formal measurement and verification was devised. Formal measurement and verification using an Option C approach was chosen for the following reasons:

- Provide a method that can be used for multiple ECMs to be implemented over a 24 month period
- Support claims for Energy Savings Certificates under the NSW Energy Savings Scheme
- Minimise M&V costs by evaluating all ECMs within a single exercise and use existing data
- Potential to use existing data for verifying potential future lighting upgrades

Management are interested in savings to a confidence of 95%.

Getting started

Budget

An Option C approach has been adopted as this simply involves desktop analysis using existing data. It is anticipated that the analysis can be conducted and savings calculated within 8 hours. A nominal budget of $1,000 of time has been set aside.

Measurement boundary

The measurement boundary is the combination of electrical and natural gas supplies that supply the facility. Both fuels will be affected by the proposed ECMs.

Identification of key parameters

The building operates on an extended but regular time schedule and staff numbers and movements also follow regular patterns. Following some initial data analysis conducted as part of the energy audit, the key parameters affecting electricity and natural gas usage was changes in ambient temperature.

The variables to be investigated are:

Variable	Data source
Metered electricity and natural gas use	Monthly electricity invoices
Ambient air temperature (heating and cooling degree days)	Daily figures for maximum and minimum air temperatures from the Bureau of Meteorology

Should these parameters fail to provide a suitable energy model, then additional parameters will be investigated.

Timing

Baseline data was obtained from the previous owner and further baseline data was collected during late 2008/09 whilst preparations were made to implement the ECMs. The ECMs were implemented over 12 months commencing August 2009, and so the period just prior was chosen for the baseline. The baseline period consists of the 12 months between July 2008 and June 2009.

Interactive effects

There are no interactive effects due to the choice of a facility based measurement boundary.

Summary of M&V plan

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

Item	Plan
Project Summary	Implementation of the following ECMs on the base building air conditioning system: ▪ new main chiller and cooling tower ▪ recommissioning of economy cycle ▪ fitting new motors with variable speed drives to main air handling units
Required Outcome	To confirm savings with a 95% confidence level in order to support application for Energy Savings Certificates under the NSW Energy Savings Scheme.
Budget	$1,000 (1 day of desktop analysis)
M&V Option	C – Whole Facility The ESS application will be made using the Normalised Baseline method
Measurement Boundary	Total incoming electrical and natural gas supplies being fed to 1540 Kent St, NSW.
Key Measurement Parameters	Data for the following key parameters will be collected and modelled in order to determine the most relevant factors affecting energy use: Metered electricity and natural gas use Ambient temperature (in the form of heating/cooling degree days)
Other Parameters to consider	Building occupancy – building occupancy has not changed during the last 3 years however major changes in the future may require additional modelling.
Potential interactive effects	None identified

Item	Plan
Approach for conducting measurement and collecting data	Energy use data will be collected directly from energy invoices. Ambient temperature data will be sourced for the nearest weather station from the Bureau of Meteorology.
Measurement equipment required	Existing revenue meter and energy invoice data
Measurement period	12 month base year period, 1 month project implementation, and 12 month post-retrofit measurement.
Approach for calculating results	An energy model will be developed using regression analysis to explain baseline energy use in regard to relevant independent variables. Once the ECM has been implemented, post-retrofit data for these variables will be entered into the model in order to forecast the adjusted baseline or business-as-usual energy use. Savings are calculated by taking the difference in the adjusted baseline and actual energy use data on a monthly basis.

Baseline model development

Microsoft Excel was chosen as the modelling tool. Two energy models will be developed as follows:

1. Electricity only model to be used to support ESS Application
4. Total energy model to be used for internal reporting

A spreadsheet was developed that contained the following elements:

- Monthly baseline historical data for the key energy use parameters in independent variables
- Daily weather maximum and minimum temperatures for the local weather station
- HDDs and CDDs that have been derived from ambient temperature data, as described within Section 6.5.2 within the *Process Guide*.

The baseline data is summarised below:

Month	Energy use			Electricity Only Ambient temperature		Total Energy Ambient temperature	
	Electricity (kWh)	Natural gas (MJ)	Total energy (MJ)	HDDs Balance point = n/a	CDDs Balance point =18°C	HDDs Balance point =18.45°C	CDDs Balance point =13.6°C
B1	404,023	652,740	2,107,223	0	0	177	9
B2	378,914	638,848	2,002,938	0	0	177	7
B3	415,370	373,414	1,868,746	0	36	81	101
B4	468,311	37,021	1,722,941	0	56	36	166
B5	459,173	46,618	1,699,641	0	68	5	197
B6	520,358	0	1,873,289	0	124	1	260
B7	564,346	410	2,032,056	0	178	0	314
B8	510,519	2,461	1,840,329	0	132	0	255
B9	540,463	0	1,945,667	0	129	0	265
B10	419,802	46,910	1,558,197	0	50	15	169
B11	375,856	266,736	1,619,818	0	2	58	93
B12	339,846	419,441	1,642,887	0	0	132	26
12 months	**5,396,981**	**2,484,599**	**21,913,731**	**0**	**774**	**681**	**1,865**

Each model was generated using the LINEST() function.

The LINEST() function is used to conduct multivariable linear regression on a dataset to produce a function describing *y* in terms of $x_{1 \text{ to n}}$ in the form:

$$y = b + m_1x_1 + m_2x_2 + ...+ m_nx_n$$

where:

y = energy use

b = baseload energy use (without influence of any variables) – also known as y-intercept

$x_{1 \text{ to } n}$ *= data for independent variables 1 to n*

$m_{1 \text{ to } n}$ *= coefficients determined by the function that correspond to each x variable*

It accepts an array of *y*-values (i.e. energy use) and corresponding arrays of *x*-values (data for independent variables) and produces various outputs as shown below:

- Coefficients and standard errors for the baseload energy use (*b*) and each independent variable ($m_{1 \text{ to } n}$)
- Coefficient of determination (R^2), and Adjusted R^2 which describe the 'appropriateness of fit' for the regression model
- Standard error for *y*

Each model was tuned by using the "Solver" function that is available within the Analysis Tool pack within Microsoft Excel. Refer to Help within Microsoft Excel for further information for the LINEST() function and the "Solver" routine.

Preparing the weather data

Weather data was downloaded from the Bureau of Meteorology website and imported into Excel. This is shown in columns C to K in the screenshot below.

The average daily temperature was calculated by averaging the daily maximum and minimum temperatures (Column L).

HDDs and CDDs were then calculated by determining the difference between the average daily temperature and the balance point (linked from another worksheet called "Energy Model").

commercial building.xlsx - Microsoft Excel

	Data from Bureau of Meterology									HDD/CDD Calculations				
2	Product code	Bureau of Meteorology station number	Year	Month	Day	Minimum temperature (Degree C)	Maximum temperature (Degree C)	Days of accumulation of maximum temperature	Quality	Average Temperature (Degree C)	Electricity HDD	Electricity CDD	Total Energy HDD	Total Energy CDD
552	IDCJAC0011	66062	2008	1	1	19.4	25.8	1	Y	22.6	0	4.6	0	9
553	IDCJAC0011	66062	2008	1	2	19.3	26.4	1	Y	22.85	0	4.85	0	9.25
554	IDCJAC0011	66062	2008	1	3	20.9	27	1	Y	23.95	0	5.95	0	10.35
555	IDCJAC0011	66062	2008	1	4	21.7	25.6	1	Y	23.65	0	5.65	0	10.05
556	IDCJAC0011	66062	2008	1	5	21.4	25	1	Y	23.2	0	5.2	0	9.6
557	IDCJAC0011	66062	2008	1	6	20.5	28.9	1	Y	24.7	0	6.7	0	11.1
558	IDCJAC0011	66062	2008	1	7	21.9	26.9	1	Y	24.4	0	6.4	0	10.8
559	IDCJAC0011	66062	2008	1	8	21.4	24.4	1	Y	22.9	0	4.9	0	9.3
560	IDCJAC0011	66062	2008	1	9	21.7	27.6	1	Y	24.65	0	6.65	0	11.05
561	IDCJAC0011	66062	2008	1	10	22.6	26.4	1	Y	24.5	0	6.5	0	10.9
562	IDCJAC0011	66062	2008	1	11	20.6	27.1	1	Y	23.85	0	5.85	0	10.25
563	IDCJAC0011	66062	2008	1	12	21.2	26.7	1	Y	23.95	0	5.95	0	10.35
564	IDCJAC0011	66062	2008	1	13	21.9	30.6	1	Y	26.25	0	8.25	0	12.65
565	IDCJAC0011	66062	2008	1	14	19.2	22.5	1	Y	20.85	0	2.85	0	7.25
566	IDCJAC0011	66062	2008	1	15	19.5	25	1	Y	22.25	0	4.25	0	8.65
567	IDCJAC0011	66062	2008	1	16	20.9	29.5	1	Y	25.2	0	7.2	0	11.6
568	IDCJAC0011	66062	2008	1	17	20.3	22.9	1	Y	21.6	0	3.6	0	8
569	IDCJAC0011	66062	2008	1	18	19.7	22.8	1	Y	21.25	0	3.25	0	7.65
570	IDCJAC0011	66062	2008	1	19	19.6	23	1	Y	21.3	0	3.3	0	7.7
571	IDCJAC0011	66062	2008	1	20	20.7	27.6	1	Y	24.15	0	6.15	0	10.55
572	IDCJAC0011	66062	2008	1	21	20	23	1	Y	21.5	0	3.5	0	7.9
573	IDCJAC0011	66062	2008	1	22	16.1	24.7	1	Y	20.4	0	2.4	0	6.8
574	IDCJAC0011	66062	2008	1	23	17.3	24.1	1	Y	20.7	0	2.7	0	7.1
575	IDCJAC0011	66062	2008	1	24	15.9	25.4	1	Y	20.65	0	2.65	0	7.05
576	IDCJAC0011	66062	2008	1	25	18.9	25.1	1	Y	22	0	4	0	8.4
577	IDCJAC0011	66062	2008	1	26	18.8	25.8	1	Y	22.3	0	4.3	0	8.7
578	IDCJAC0011	66062	2008	1	27	18.8	26.6	1	Y	22.7	0	4.7	0	9.1
579	IDCJAC0011	66062	2008	1	28	21.2	27.3	1	Y	24.25	0	6.25	0	10.65

Cost Model | Energy Model & Savings | Weather | Building Data | Legals

Separate calculations were performed for each model so that the most appropriate balance points can be determined independently.

Developing the energy model using LINEST()

The screenshot below presents the worksheet used to develop the energy model. Separate models were developed for Electricity based on CDDs and Total Energy based on both HDDs and CDDs.

The key elements of the worksheet are:

- Baseline Data – derived from monthly energy invoices (Columns A to E)
- Balance points for calculating degree days (Rows 2 to 4) – these are values that are initially entered and then adjusted (which in turn alters the number of HDDs and CDDs within each model) in order to maximise the correlation between ambient temperature and electricity/total energy use.
- 2 energy models using the LINEST() function.

1540 Kent Street, Sydney								
					Balance Points			
					Electricity		Total Energy	
				Balance Points	0	18	18.45	13.6
Actual Data					Weather - HDDs & CDDs			
					Electricity		Total Energy	
Month	Total Energy MJ	Electricity kWh	Electricity MJ	Natural Gas MJ	HDD	CDD	HDD	CDD
1/07/2008	2,107,223	404,023	1,454,483	652,740	0	0	177	9
1/08/2008	2,002,938	378,914	1,364,090	638,848	0	0	177	7
1/09/2008	1,868,746	415,370	1,495,332	373,414	0	36	81	101
1/10/2008	1,722,941	468,311	1,685,920	37,021	0	56	36	166
1/11/2008	1,699,641	459,173	1,653,023	46,618	0	68	5	197
1/12/2008	1,873,289	520,358	1,873,289	0	0	124	1	260
1/01/2009	2,032,056	564,346	2,031,646	410	0	178	0	314
1/02/2009	1,840,329	510,519	1,837,868	2,461	0	132	0	255
1/03/2009	1,945,667	540,463	1,945,667	0	0	129	0	265
1/04/2009	1,558,197	419,802	1,511,287	46,910	0	50	15	169
1/05/2009	1,619,818	375,856	1,353,082	266,736	0	2	58	93
1/06/2009	1,642,887	339,846	1,223,446	419,441	0	0	132	26
Sum	**21,913,731**	**5,396,981**	**19,429,132**	**2,484,599**	**0**	**774**	**681**	**1,865**
Average	**1,826,144**	**449,748**	**1,619,094**	**207,050**				

The key outputs of this function are highlighted below. In addition, the adjusted R^2 value and the t-stats for each coefficient were calculated in order help validate each model.

Model 1: Electricty vs CDDs (for ESS Application)		
t-stats	11.78809948	45.27479276
	CDDs	Y intercept
	1119.962892	377529.4762
	95.00792677	8338.624059
R^2	0.932867564	19595.7751
	138.9592894	10
	53359589195	3839944016

coefficients

standard errors for coefficients

standard error for *y*

R^2

Model 2: Total Energy vs HDDs & CDDs (for internal performance reporting)			
Adj R^2	0.810877095		
t-stats	6.638427801	7.0042272	5.903920669
	CDDs	HDDs	Y intercept
	3935.877171	6442.948983	848776.0556
	592.8929694	919.8657895	143764.8138
R^2	0.845263077	77104.77839	
	24.58161752	9	
	2.92283E+11	53506321650	

coefficients

standard errors for coefficients

standard error for *y*

R^2

The output above equates to the following:

Model 1:

$$Electricity\ Use\ (kWh) = 377{,}529.48 + 1119.96 \times CDDs$$

With a CDD balance point = 18 degrees Celsius

The R^2 value is 0.933 and the standard error is 19,595.78.

Model 2:

$$Total\ Energy\ Use\ (MJ) = 848{,}776.06 + 3{,}935.88 \times CDDs + \ 6442.95 \times HDDs$$

With :

CDD balance point = 13.6 degrees Celsius

HDD balance point = 18.45 degrees Celsius

The R^2 value is 0.845 whilst the Adjusted R^2 is 0.811 and the standard error is 77,104.77.

Validating the regression outputs

As described in Section 6.5.1, each model must be validated to confirm that it can be used. This involves equating some additional attributes and confirming their validity. The attributes to be reviewed are:

Attribute	Description and Validity Test
R^2	Must be 0.75 or higher. Output from LINEST() function
Adjusted R^2	To be evaluated when multiple independent variables are used. Values should be 0.75 or higher. Calculated as follows: $Adjusted\ R^2 = 1 - (1 - R^2) \times \frac{(n-1)}{(n-k-1)}$ Where: *R^2 = the value calculated from LINEST()* *n = number of data points in sample size* *k = number of coefficients within the regression model*
t-statistic for each coefficient	Determine the validity of each *x* coefficient. Values must be greater than 2. Calculated as follows: Each 't-stat' is calculated as follows: $t_{Xn} = \frac{coefficient_{Xn}}{standard\ error_{Xn}}$

Attribute	Description and Validity Test
Absolute mean bias (MBE)	Determines the overall bias in the regression estimate. MBE values should be < 0.005%. Calculated as follows: $MBE = \frac{\sum(modelled_n - actual_n)}{n}$ Where: n = the number of samples $modelled_n$ = predicted value for sample item n $actual_n$ = actual value for sample item n
Monthly Mean Error CV(RMSE)	Related to the standard error of the model. CV(RMSE) values should be < 0.25. Calculated as follows: $CV(RMSE) = \frac{standard\ error\ for\ y}{average(actual\ values)}$

Validating Model 1

We calculate the following:

T-Stats:

$$t_{CDDs} = \frac{1119.962892}{95.00792677} = 11.79$$

MBE:

MBE is calculated by first determining the modelled energy values by using the data for independent variables. Modelled values are then subtracted from actual values to calculate the difference for each measurement. These residuals are summed and divided by the number of data points to determine the MBE, as follows:

Month	Actual electricity (kWh)	Modelled electricity (kWh)	Residual (modelled – actual) (kWh)
B1	404,023	377,529	-26,494
B2	378,914	377,529	-1,385
B3	415,370	417,512	2,142
B4	468,311	440,695	-27,616
B5	459,173	454,023	-5,150
B6	520,358	516,069	-4,289
B7	564,346	576,435	12,089
B8	510,519	525,197	14,678
B9	540,463	521,837	-18,626
B10	419,802	433,360	13,558
B11	375,856	379,265	3,409
B12	339,846	377,529	37,683
Sum	**5,396,981**	**5,396,981**	**1.70×10^{-10}**
Average	**449,748**		

From the above MBE is calculated as follows:

$$MBE = \frac{1.7 \times 10^{-10}}{12} = 1.46 \times 10^{-11}$$

CV(RMSE):

CV(RMSE) is calculated for the example above as follows:

$$CV(RMSE) = \frac{19595.78}{449748} = 0.0436$$

Validating Model 2

We calculate the following:

T-Stats:

$$t_{CDDs} = \frac{3935.877}{592.893} = 6.64$$

$$t_{HDDs} = \frac{6442.949}{919.866} = 7.00$$

MBE:

MBE is calculated by first determining the modelled energy values by using the data for independent variables. Modelled values are then subtracted from actual values to calculate the difference for each measurement. These residuals are summed and divided by the number of data points to determine the MBE, as follows:

Month	Actual energy (electricity + natural gas) (MJ)	Modelled energy (MJ)	Residual (modelled – actual) (MJ)
B1	2,107,223	2,023,330	-83,893
B2	2,002,938	2,019,199	16,260
B3	1,868,746	1,768,321	-100,425
B4	1,722,941	1,733,434	10,493
B5	1,699,641	1,658,112	-41,529
B6	1,873,289	1,876,686	3,397
B7	2,032,056	2,084,641	52,586
B8	1,840,329	1,852,944	12,614
B9	1,945,667	1,892,767	-52,899
B10	1,558,197	1,612,283	54,086
B11	1,619,818	1,591,563	-28,254
B12	1,642,887	1,800,450	157,563
Sum	21,913,731	21,913,731	2.56×10^{-09}
Average	**1,826,144**		

From the above MBE is calculated as follows:

$$MBE = \frac{2.56 \times 10^{-9}}{12} = 2.13 \times 10^{-10}$$

CV(RMSE):

CV(RMSE) is calculated for the example above as follows:

$$CV(RMSE) = \frac{77104.78}{1826144} = 0.0422$$

Validation summary

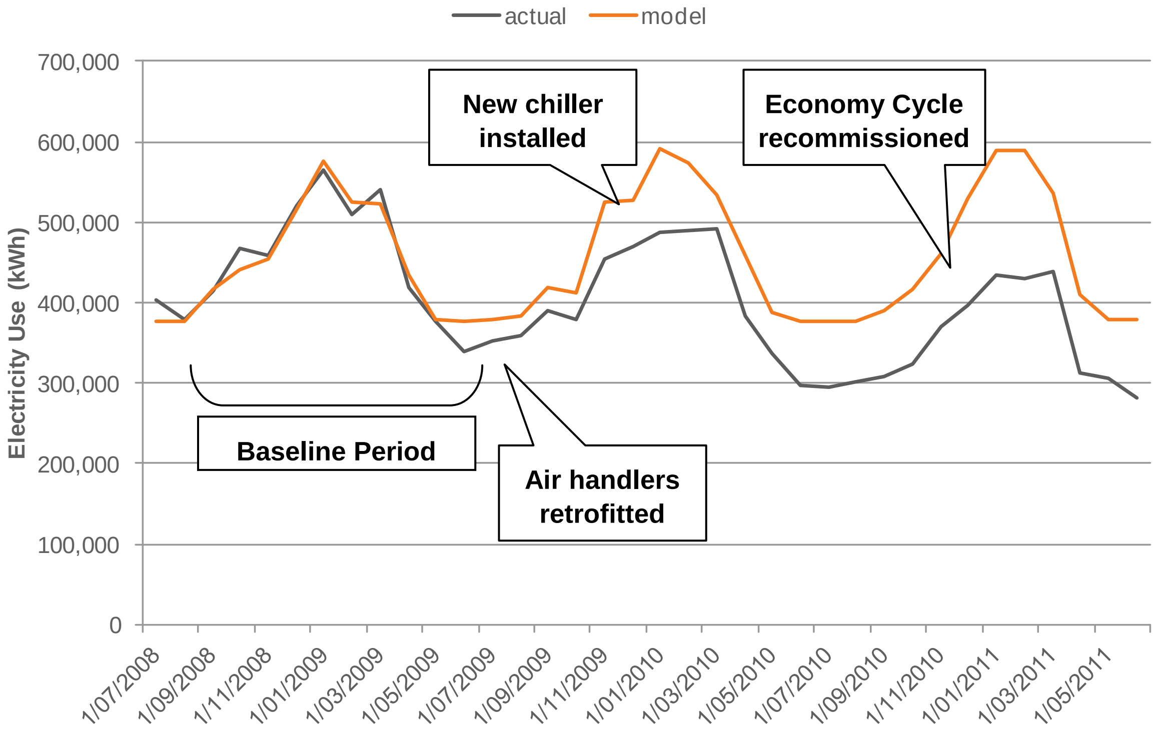
The metrics for each model are shown below. Each value is coloured green if it passes the validity test and red if it fails.

Validity metric	Model 1	Model 2
R^2	0.93	0.85
Adjusted R^2		0.81
t-stat: Y intercept	377529.48	848776.06
t-stat: CDDs	11.79	7.00
t-stat: HDDs		6.64
residual	0.00	0.00
standard error	19595.78	77104.78
CV(RMSE)	0.0436	0.0422
Mean Bias Error (MBE)	1.45519E-11	2.13428E-10

Both models pass all the validity tests and can now be used to calculate savings.

Calculating electricity savings from Model 1

The chart below illustrates the monthly electricity use for the property, in which the baseline period (used for developing the energy model) and key implementation dates have been highlighted.



The trendline shown in Orange forecasts the monthly energy consumption for 'business as usual' based on the energy model that has been developed. Savings can now be calculated simply by subtracting the actual electricity use (shown in black) from the forecast.

This data is listed in the table below.

Month	Actual Electricity Use (kWh)	CDDs	Adjusted Baseline (kWh)	Savings (kWh)
P1	295,194	0	377,529	82,335
P2	302,304	0	377,529	75,225
P3	309,246	11	389,345	80,099
P4	323,011	35	416,280	93,269
P5	369,061	75	460,967	91,906
P6	396,045	135	529,228	133,183
P7	434,738	190	590,266	155,528
P8	430,390	190	590,210	159,820
P9	438,535	142	536,788	98,253
P10	312,149	29	410,288	98,139
P11	305,246	1	378,929	73,683
P12	282,111	1	378,145	96,034
Total 12 months	**4,198,030**	**808**	**5,435,508**	**1,237,478**

Uncertainty analysis for Model 1

As shown earlier, the standard error (SE) of the baseline energy model is:

$$standard\ error(SE) = 19595.78\ kWh$$

Using the standard error we can calculate the absolute precision (AP) by applying the t-statistic for our chosen sample size (DF = 12 data points – 1 variable – 1 = 10) and required confidence (95%).

$$Absolute\ precision\ (AP) = t \times SE$$

$$Absolute\ precision\ (AP) = 2.23\ \times 19595.78 = 43{,}699\ kWh$$

And the relative precision (RP) is calculated by dividing the absolute precision by the average predicted energy use as follows:

$$relative\ precision\ (RP) = \frac{AP}{average\ monthly\ modelled\ usage}$$

$$relative\ precision\ (RP) = \frac{43699}{449748} = \pm 9.7\%$$

The uncertainty of the savings is calculated as follows:

$$SE(monthly\ savings) = \sqrt{SE(adjusted\ baseline)^2 +\ SE(post\ retrofit)^2}$$

$$= \sqrt{19595.78^2 +\ 0^2} = 19595.78\ kWh$$

Assuming that the standard error of each month’s savings will be the same, the standard error for the annual savings is:

$$SE(annual\ savings) = \sqrt{12\ \times\ 19595.78^2} = 67881.76\ kWh$$

Using a t-statistic of 2.20 (12 measurement points with 95% confidence), the range of possible annual savings will be:

$$Range\ of\ Savings\ (kWh)\ = 1237478 \pm 2.20 \times 67881.76\ kWh$$

$$= 1{,}237{,}478 \pm 149{,}340\ kWh$$

The relative precision of the annual savings reported is thus ±12.1% (149,340 / 1,237,478)

Reporting results from Model 1

The savings results can be described by the following:

The annual savings are calculated to be 1,237,478 kWh ± 12.1% or 149,340 kWh with a 95% confidence factor.

Savings fall within the range of 1,088,138 kWh to 1,386,818 kWh.

Using this result, the property owner is able to suitably demonstrate a robust M&V methodology within its ESS Application to support its Energy Savings Certificates claim.

Reporting results from Model 2

Using similar techniques, the total energy savings determined by Model 2 are found as follows:

Month	Actual Electricity Use (MJ)	HDDs	CDDs	Adjusted Baseline (MJ)	Savings (MJ)
P1	1,833,621	165	12	1,956,838	123,217
P2	1,684,046	142	23	1,854,236	170,190
P3	1,307,465	63	91	1,610,976	303,512
P4	1,202,624	28	150	1,615,659	413,036
P5	1,333,753	12	198	1,701,905	368,153
P6	1,425,762	1	271	1,923,864	498,102
P7	1,565,057	0	326	2,133,250	568,193
P8	1,549,404	0	313	2,081,099	531,695
P9	1,579,171	0	279	1,946,278	367,107
P10	1,123,800	13	154	1,535,922	412,122
P11	1,283,828	105	51	1,722,919	439,092
P12	1,244,207	129	28	1,788,582	544,375
Total 12 months	**17,132,737**	**656**	**1,895**	**21,871,529**	**4,738,792**

The savings results can be described by the following:

The annual savings are calculated to be 4,738,792 MJ ± 12.4% or 587,617 MJ with a 95% confidence factor.

Savings fall within the range of 4,151,175 MJ to 5,326,409 MJ.

More simply, the annual savings are calculated to be 4,739 GJ ± 12%.