Office of Environment & Heritage

Measurement and Verification Operational Guide

Renewable and Cogeneration Applications

Published by:
Office of Environment and Heritage NSW
59 Goulburn Street, Sydney NSW 2000
PO Box A290, Sydney South NSW 1232
Phone: (02) 9995 5000 (switchboard)
Phone: 131 555 (environment information and publications requests)
Phone: 1300 361 967 (national parks, climate change and energy efficiency information, and publications requests)
Fax: (02) 9995 5999
TTY: (02) 9211 4723
Email: info@environment.nsw.gov.au
Website: www.environment.nsw.gov.au

Report pollution and environmental incidents
Environment Line: 131 555 (NSW only) or info@environment.nsw.gov.au
See also www.environment.nsw.gov.au

ISBN 978 1 74293 958 2
OEH 2012/0992
December 2012

Printed on environmentally sustainable paper

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) across a typical M&V process. Practical tips, tools and scenario examples are provided to assist with decision making, planning, measuring, analysing and reporting outcomes.

But what is M&V exactly?

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

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

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

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

1.1 Using the M&V Operational Guide

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

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

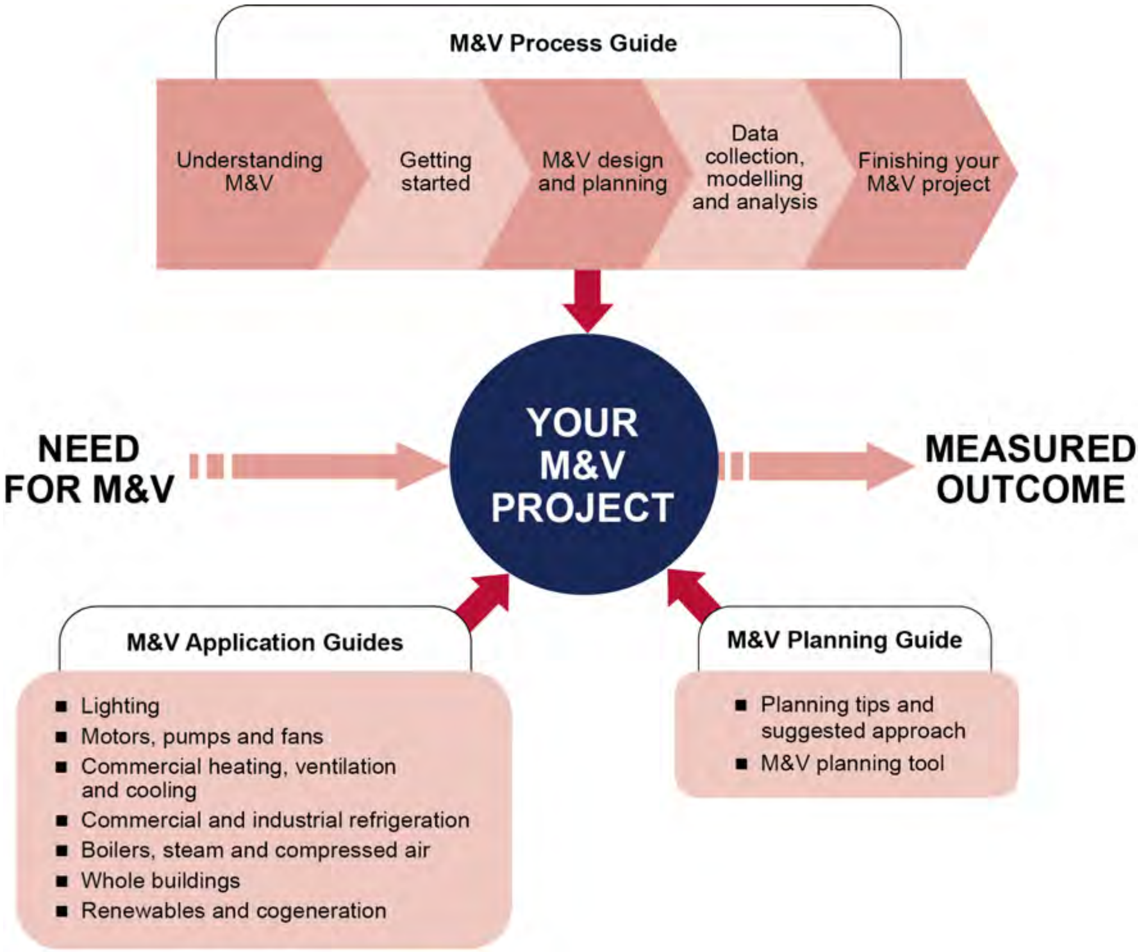
Planning Guide: The *Planning Guide* is designed to assist both new and experienced practitioners to develop a robust M&V Plan for your energy savings project, using a step-by-step process for designing a M&V project. A Microsoft Excel tool is also available to assist practitioners to capture the key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

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

[1] Source: www.energymanagementworld.org

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

Figure 1: M&V Operational Guide structure



1.2 The Renewables and Cogeneration Applications Guide (this guide)

The *Renewable and Cogeneration Applications Guide* provides specific guidance for conducting M&V for projects that involve fuel switching to renewables as well as cogeneration and trigeneration systems (R&C projects). It is designed to be used in conjunction with the *Process Guide*, providing tips, suggestions and examples specific to R&C projects.

The *Renewable and Cogeneration 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 R&C 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 R&C 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 cogeneration scenario A	Appendix A illustrates the M&V process using a worked example of a cogeneration project to verify system performance
▪ Example cogeneration scenario B	Appendix B illustrates the M&V process using a worked example of a cogeneration project to verify annual savings
▪ Example renewable energy scenario	Appendix C illustrates the M&V process using a worked example of a solar water heater 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.

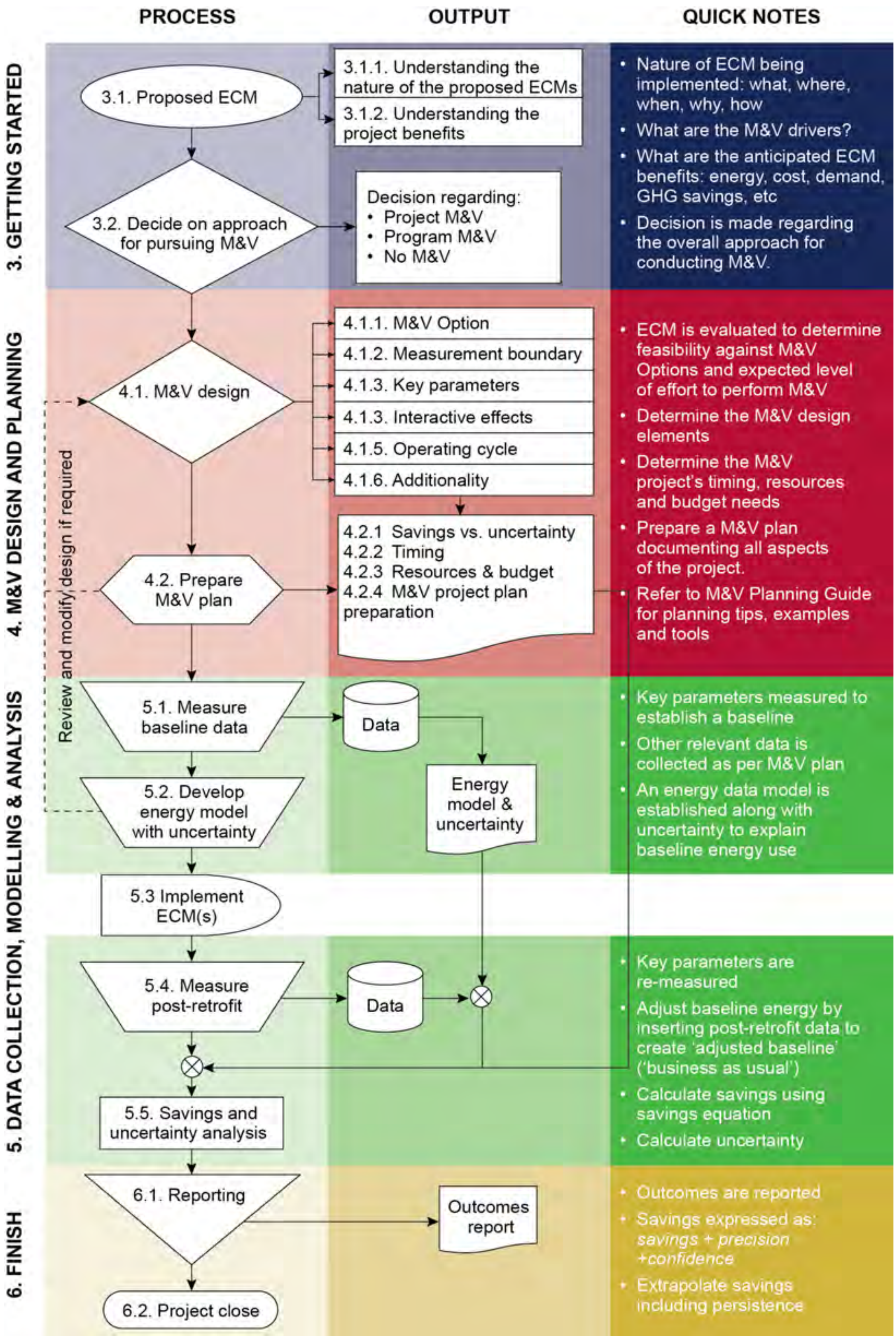
Table 1: Key M&V terms

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 *Renewable and Cogeneration 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 Renewable and Cogeneration ECM(s)

3.1.1 Renewable energy technologies

Renewable energy technologies make use of energy sources that are regenerated in nature and therefore sustainable in supply. From an M&V perspective, these technologies are different from most in that all renewable energy technologies supply energy rather than reduce the energy consumed.

Renewable energy projects aim to offset fossil fuel use through the implementation of renewable energy technologies. Technologies covered in this guide include:

- Wind
- Solar Hot Water (SHW)
- Photovoltaic (PV)

Verifying projects through M&V will usually involve utilising Option A or B for most scenarios, with medium-term measurements. Option C is available for large-scale projects and Option D for projects with no data available for post-implementation comparison.

3.1.2 Cogeneration

Cogeneration or Combined Heat and Power (CHP) refers to fuel driven engines that operate to transform the input fuel into two separate forms of energy – electricity and heat. A cogeneration unit is installed on site to generate electricity in preference to drawing power from the grid. Waste heat that is traditionally exhausted to the atmosphere is captured and converted into hot water or steam for use in heating applications such as hot water, space heating or as an input to manufacturing processes.

Cogeneration projects can be categorised as fuel switching projects, whereby a fuel (typically electricity) that is sourced directly from the grid is substituted for electricity generated on site. The key drivers for cogeneration projects are usually to derive cost or greenhouse gas savings, or make use of available fuel sources that would otherwise be wasted.

M&V for renewable and cogeneration projects will typically be focused on quantifying and verifying one or more of the following:

1. Amount of renewable energy collected/generated
2. Changes in Billed Energy use
3. Changes in Billed Electricity use only
4. System performance of installed technology (efficiency, utilisation)
5. Reduced electrical demand
6. Cost savings (based on changes in Billed Energy)
7. Greenhouse gas savings (based on changes in Billed Energy)

The purpose and desired outcomes of the M&V project will have a major impact on the choice of measurement boundary and key parameters to be measured. It is important to understand the energy flows for the baseline and post-retrofit systems including dependent systems.

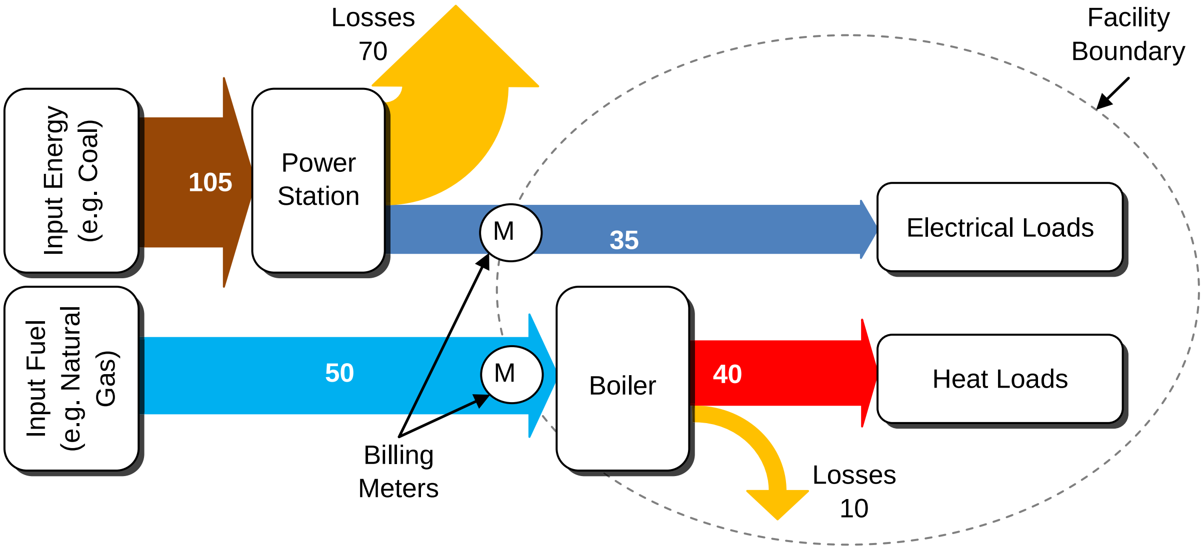
3.2 Energy flows for renewable and cogeneration projects

The Sankey diagrams below illustrate the energy flows for a facility with electrical and heat loads under three scenarios.

In each scenario the building requires 35 units of electricity and 40 units of heat in the form of hot water to supply the internal loads.

3.2.1 Scenario 1: Grid purchased electricity with natural gas boiler

In this scenario the facility consumes electricity and natural gas from the grid to supply the required electrical and heat loads.



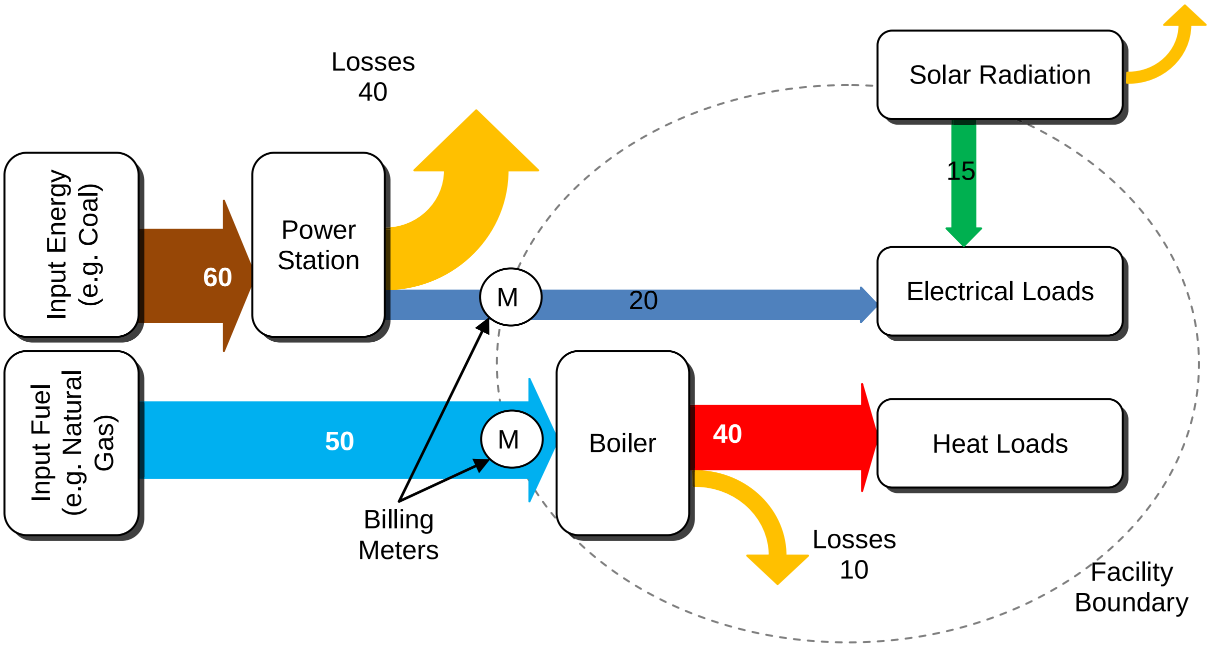
In the diagram above the site purchases 35 units of electricity and 50 units of natural gas. A boiler is used to convert natural gas into hot water, and results in 10 units of losses.

Upstream of the electricity billing meter there are additional losses in electricity generation, transportation and distribution (Note that network losses also exist for natural gas. These have been omitted as they are the same in both diagrams).

3.2.2 Scenario 2: Grid purchased electricity with solar PV

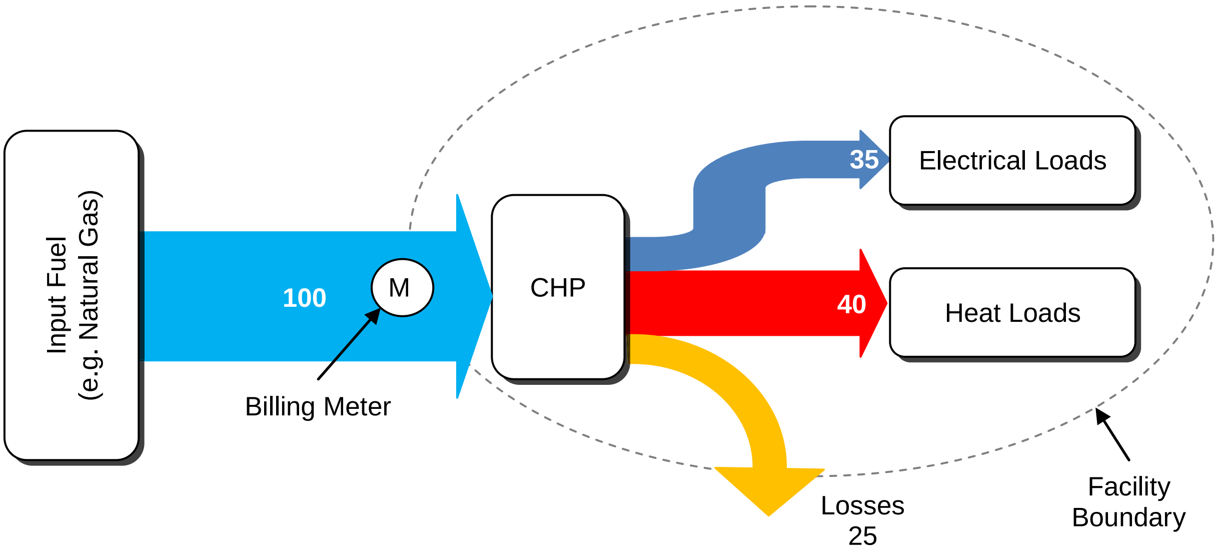
In scenario 2, the same facility uses photovoltaic cells to supply the part of its electrical loads.

In the diagram below, the site collected 15 units of electricity via roof mounted photovoltaic cells. This reduces the amount of electricity that is purchased from the grid by 15 units, which in turn reduces the input energy at the power station by 45 units due to reduced losses.



3.2.3 Scenario 3: Cogeneration unit

Within scenario 3, the same facility uses a cogeneration plant to supply the equivalent loads.



In this diagram the site purchases 100 units of natural gas, which the cogeneration unit converts into electricity and hot water through waste heat recovery. The system results in 25 units of losses.

The three scenarios are summarised as follows:

Scenario	Useful Energy	Purchased Energy	Total Energy (fossil fuels) consumed to deliver Useful Energy
1. Grid purchased electricity with natural gas boiler	75	85	165
2. Grid purchased electricity with natural gas boiler + solar PV	75	70	110
3. Cogeneration unit	75	100	100

On initial inspection the site cogeneration unit in Scenario 3 requires the purchase of 15 additional units of Purchased Energy to deliver the same Useful Energy to the connected loads in Scenario 1.

Although this appears unfavourable, the Total Energy required is significantly lower due to the higher generation efficiency of the cogeneration unit over a traditional power station. The additional Total Energy required results in higher electricity prices as the consumer ultimately pays for losses incurred for electricity generation, transmission and distribution.

Cogeneration units are also typically much lower in greenhouse gas emissions intensity compared to large scale coal fired power stations.

The inclusion of a renewable energy source directly reduces the need for Purchased Energy.

3.2.4 What does this all mean for M&V?

In all three scenarios the site energy use has not changed unless other systems have been altered during the retrofit - however the supplied energy mix has. In their basic sense, these projects are simply fuel switching projects, which do not save energy when viewed from a facility boundary perspective via Purchased Energy figures.

In contrast renewable and cogeneration projects may result in lower (or possibly eliminated) electricity bills. This has an effect on energy costs and greenhouse gas emissions, both of which may be project drivers.

3.2.5 Key points to consider

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

- All options are available and are suited to differing M&V outcomes and budgets.
- From project goals and objectives, determine the type of output required. Option A is generally performance based, whereby the compliance of a project is compared with clearly stated supplier performance claims.
- If the motives of a project are based on claims to save electrical demand (kW), energy metering can be used (Option B). A baseline for a whole facility or facilities with multiple renewable energy projects can be developed (Option C) and through modelling (Option D).
- Options A or B treat the project in isolation thus avoiding the need to deal with the effects of other systems.
- Identify independent variables that may affect before and after comparison including, for example: load, solar radiation, wind speed and ambient temperature.
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.

- The length of measurement is determined by the chosen option, and the desired level of accuracy.

3.2.6 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 A can be used to determine the efficiency of the installed system or technology (e.g. cogeneration plant efficiency) via a load test, or can be used to estimate changes in consumption patterns based on measured operating hours and manufacturers equipment specifications.

Option B can be applied to the renewable energy or cogeneration system, or the downstream energy system to determine changes in consumption patterns. This option is useful at complex sites where billing data analysis is too complex.

Option C is a common method for evaluating projects such as cogeneration plants due to their typical size and impact on the site's incoming energy supplies. Option C often provides a simple and cost effective approach for M&V that ensures that all internal losses and energy transformations are accounted for, and provides the best outcome for determining actual savings that will be seen on energy bills.

Option D can be applied for new buildings or where a model has previously been developed as part of the initial project design for a retrofit to an existing building.

4.1.2 Measurement boundary

The measurement boundary can be an ECM boundary or a facility boundary. The choice of measurement boundary should be decided based on the M&V project aims and desired outcomes listed above.

Decisions made regarding the installation of permanent metering may influence the choice of measurement boundary. If no additional sub metering is being installed, then a facility boundary may be the preferred option.

An ECM related boundary may suite where renewable energy system components can be separately metered or where a small part of a larger site is affected. It is important that an ECM boundary also includes any system that will be altered in conjunction with the renewable energy technology. This is primarily the heat-related systems (e.g. cogeneration, trigeneration and solar hot water) and will extend to the loads as well as the baseline heat sources (e.g. boiler replaced by cogeneration waste heat).

In situations where the intent is to verify the efficiency of the renewable energy or cogeneration system an ECM related boundary may be defined around the unit and associated equipment. This type of project will typically involve an Option D approach whereby the actual performance is compared to a computer simulation or manufacturer's performance specification.

For the remaining drivers the requirement to understand the difference between the baseline and post-retrofit systems requires a measurement boundary that suitably captures the changes in energy use across the retrofitted system itself as well as the any dependent systems which are supplied with either electricity or heat.

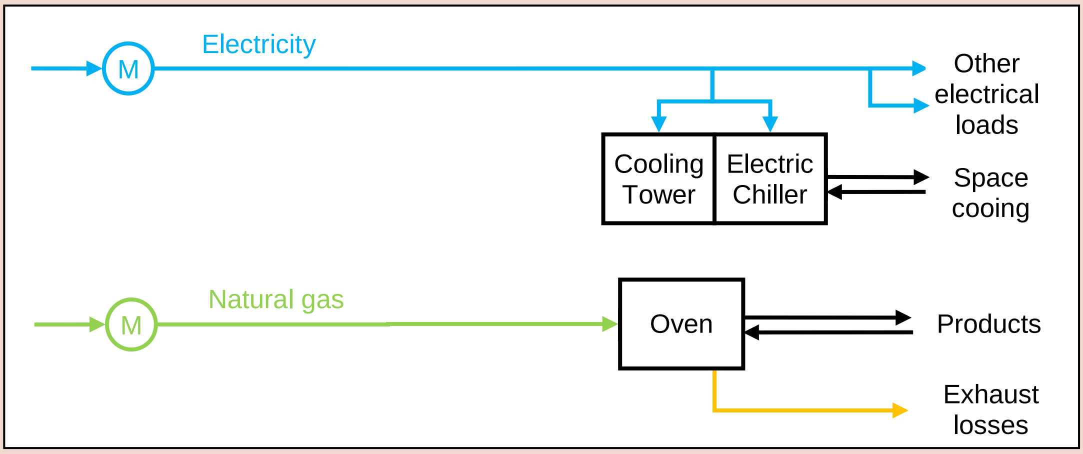
For cogeneration systems harnessing the heat output from the unit can result in the retrofit of downstream process-related equipment (such as heat exchanges or absorption chillers), which could significantly change the efficiency of those systems.

When planning an M&V exercise it is important that the system is analysed and the potential metering points are identified for each system. With such significant changes in interrelated systems as shown above, it is important that careful attention is paid to the boundary to ensure that a like-for-like comparison can be made.

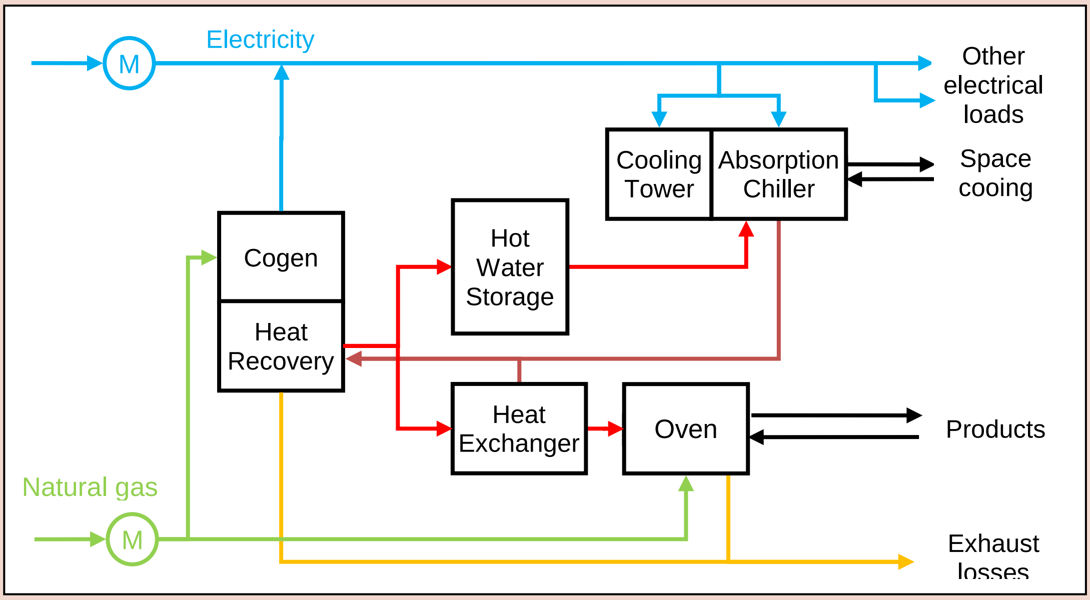
Example Cogeneration

The two diagrams below illustrate a change in equipment associated with the installation of a cogeneration unit within a mixed use facility. The first diagram shows the baseline system which consists of:

- an air conditioning system incorporating a reciprocating chiller
- a gas fired curing oven



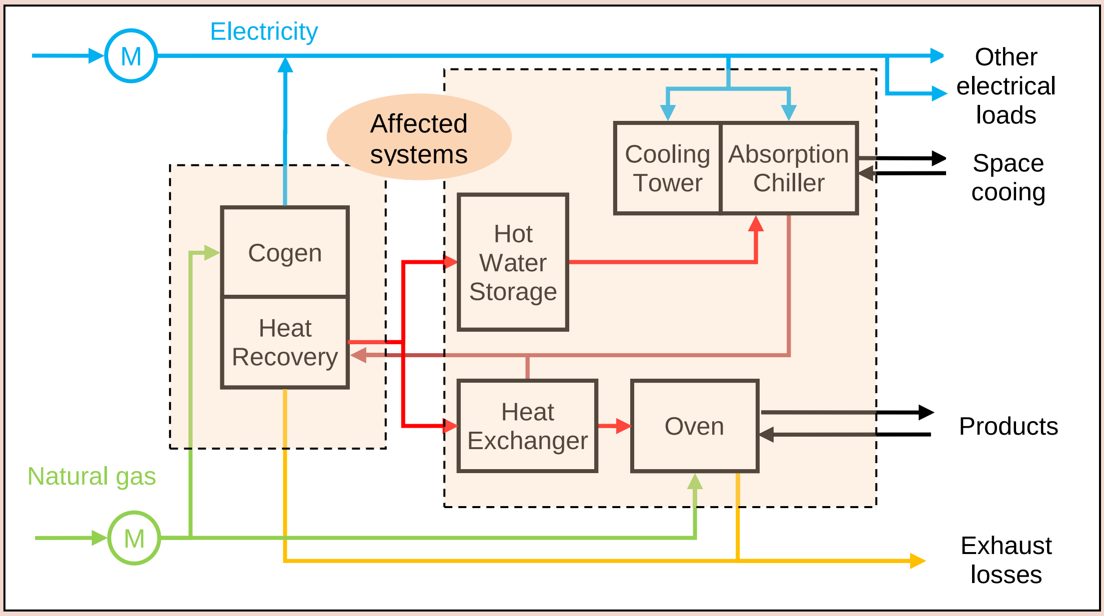
Suppose a cogeneration plant is installed at this facility. The recovered heat will be used to provide pre-heating for the curing oven as well as providing cooling to the administration area via the replacement of the reciprocating chiller with an absorption chiller. The resulting system diagram now looks like:



The retrofit has resulted in new equipment being installed each of which may affect individual systems in differing ways. The anticipated system changes include:

1. The installation of the cogeneration unit should see a rise in natural gas usage and a drop in electricity consumed from the grid.
2. Overall energy use will increase, however overall cost and total greenhouse gas emissions should reduce.
3. The use of a heat exchanger to pre-heat the air intake on the oven should reduce its natural gas usage. There may also be effects on curing times within the manufacturing process.
4. The electric chiller has been replaced with an absorption chiller, which will result in a change in system performance. The coefficient of performance for the chiller plant will drop significantly. Overall electricity use will drop noticeably.
5. The inclusion of a hot water storage tank will enable the absorption chiller to operate when the cogeneration unit is not functioning.

The affected systems are highlighted in the diagram below. As can be seen, our M&V project focuses on developing baseline models for the affected systems based on independent variables such as space cooling and heating needs, and production levels. This may be supplemented with M&V of the cogeneration plant to confirm efficiency.



4.1.3 Key parameters

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

Table 2: Key parameters to be considered when conducting M&V for R&C projects

Parameter	Description
Baseline and post-retrofit energy use, including: ▪ input energy for each affected system and each source fuel ▪ electricity generation ▪ electricity exported off site	This comprises the metered energy use for the measurement boundary, including: ▪ Baseline: – metered electricity for the affected systems/facility – metered source fuel (where already used) that will serve as the input to the cogeneration system (e.g. natural gas). ▪ Post-retrofit – metered electricity for the affected systems/facility – metered source fuel for the energy collection system or cogeneration unit – metered electricity generated by the cogeneration unit – metered electricity that is exported off site (e.g. sold back to the grid) Ideally, information would be captured in appropriate intervals by permanent metering. This will facilitate detailed analysis of changes in electrical demand. Energy use is typically obtained from the site's incoming revenue meter, internal sub-meters or from energy invoices. Ideally measurement periods are short, such as 15/30 minute interval data for electricity. Where billing periods are long, meters can be read periodically (e.g. daily, weekly, monthly) to segment billing periods into shorter time intervals. Bulk fuels (e.g. diesel, petrol, LPG, etc) may be 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).
Renewable energy source	This is the resource that is harnessed to produce useful energy. Examples include wind speed and direction, and solar radiation.
Operating hours	This is simply the amount of time the installed system operates. This will be dictated by the external factors (such as daylight or wind speed), the internal control strategy of the plant and its overall system design. Where a cogeneration unit is sized to handle baseload electricity use or connected to the grid for exporting electricity then it may operate continuously. If the primary aim is for heat recovery then the unit may operate only when heat is required (i.e. seasonal or process related).
Heat recovery (flow + temp)	This is the thermal energy that is recovered from a solar hot water installation or cogeneration unit and is typically measured using thermal meters, which measure temperature and flow. Careful attention should be paid to the location of metering. When metering is positioned adjacent to the output of the installed unit the recovered heat energy may serve to verify the unit's system performance. This ignores downstream losses. Alternatively metering can be positioned at the point of use to measure and verify the actual amount of useful heat recovered. This approach factors in all system losses.

Parameter	Description
Routine adjustments and performance outputs via independent variables	The identification of independent variables that affect a site is an important step for developing baseline energy models. 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	Should a long-term or ongoing approach be taken for assessing cogeneration projects 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
Operating efficiency (system performance or capacity to perform)	This is the ratio between the amount of raw input energy required to operate the cogeneration plant and the useful output energy delivered by that process. This is determined by collecting data for input fuel use and output useful energy, or from model manufacturer performance curves.

4.1.4 Interactive effects

The interactive effects, if any, will be dependent on the type of R&C project implemented, measurement boundary and M&V Option used. Refer to the *Process Guide* for more guidance on interactive effects.

4.1.5 Operating cycle

The length of measurement is determined by the chosen Option, and the desired level of accuracy. The table below outlines the suggested measurement timeframes for baseline and post-retrofit periods.

Table 3: Suggested measurement timeframes for baseline and post retrofit periods

Option	Type of Measurement	
	Once off measurement	**Metered energy use**
A	Typically between one day, one week and one month, taking into consideration seasonality.	
B		At least one site operation 'cycle'. For example, 12 months baseline data is required where seasonality is a factor. Typically require 12 months of post-retrofit data
C		At least one site operation 'cycle', that includes changes in other energy systems. For example, 12 months baseline data is required where seasonality is a factor. Typically require 12 months of post-retrofit data
D		For the baseline typically one site operation 'cycle' is modelled and it should include other energy systems. Post-retrofit measurements are used to re-calibrate the baseline model. Typically 12 months data is required where seasonality is a factor.

4.1.6 Additionality

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

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

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

4.2 Prepare M&V plan

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

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

The basic M&V planning concepts and process can be applied to renewable and cogeneration projects. Special consideration should be made to the following:

- These projects typically focus on fuel switching rather than energy saving, however accompanying retrofits to other systems/equipment may result in changes in usage patterns and plant efficiency.
- Changes are usually significant and affect multiple systems

- Measurement boundaries, key parameters and metering points may change during the retrofit, and must be carefully considered to ensure a like-for-like comparison.
- Implementation costs are usually material and so permanent metering is recommended

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

Table 4: Considerations, issues and suggested approach for R&C projects

Consideration	Issue	Suggested Approach
Changing environmental conditions	Outside of project developer's control	Take historical environmental conditions (e.g. solar radiation or wind data) into considering when forming an M&V plan for renewable energy projects. Depending on the M&V outcome, is may be preferred to calculate normalised savings based on standard environmental conditions, rather than actual savings. Incorporate seasonality into M&V plans and savings calculations.
Quality of energy – electricity versus heat	Simple measurement of thermal output energy is not a true reflection of the maximum useful work possible through use of that energy.	In situations where the useful heat output of a cogeneration system must be evaluated as an input to another measurement boundary, we need to consider the exergy of the heat output.
Exported electricity to grid	The project produces electricity that is exported back to the grid. The tariff structures for revenue gained are usually linked to wholesale prices rather than retail and network rates. Administration fees are often deducted. Network transmission and distribution losses (TOUS and DUOS) may not apply.	Metering will be installed to record the quantity of electricity exported back to the grid for billing purposes. Check for separate or two channelled meters. Look for exports on electricity invoices. Ensure that electricity sold back to the grid is deducted from site energy use when developing energy models and evaluating savings. Confirm the appropriate tariff structure and rates, and ensure that the correct rates are applied to electricity sold back to the grid so that financial savings are not overstated.
Auxiliary equipment	The installation of renewable equipment or cogeneration may require auxiliary equipment such as pumps and fans that need to be considered in the measurement boundary.	Ensure auxiliary equipment is accounted for in measurements, computer simulations and within energy models.
Accounting for dependent systems	Usable energy is dependent on both the available source, but also the dependent systems that will utilise the generated energy. *For example – the maximum amount of energy obtainable from a solar hot water system is the amount that can be used.*	As with any M&V project, consider the variables that affect energy use. For renewable and cogeneration projects this is often carried out by evaluating other systems.

5 Data collection, modelling and analysis

5.1 Measure baseline data

5.1.1 Baseline definition and development

If performance claims for a renewable energy or cogeneration technology are based on energy delivery, rather than savings, then there is no requirement for development of a baseline. Energy produced by the chosen technology can be directly measured and compared to the supplier's performance claims. In terms of M&V, direct metering of delivered energy is often the recommended approach as it is accurate and cost effective.

If performance claims are based on energy savings, then the savings are determined indirectly. In this way, the difference between the baseline energy and the metered energy is calculated.

Following are four methods which may be used for developing an energy baseline for a renewable energy or cogeneration project, to be used as input to an M&V exercise. These methods are applicable when only the utility energy is measured and renewable energy is measured indirectly[2].

Table 5: Methods for developing an energy baseline for a renewable energy or cogeneration project

Comparison Method	Process
Control Group	Compare metered energy of loads with renewable energy systems to similar loads (control group) without renewable energy systems. The baseline is established as the average energy use of the control group. The control group must consist of a sufficient number of units in order to make a significant comparison. This method is effective for systems assessing larger populations such as rollout of solar hot water systems.
Before-and-after	Measured energy usage before the project is installed is compared against measured usage after the system is installed. The energy use before the project is installed is established as the energy baseline. Data collection must be over a timeframe long enough to eliminate seasonal variation. This method is similar to a standard M&V approach for an energy savings project, and is well suited to all types of renewable energy and cogeneration projects.
On-and-off	The renewable energy project is switched in and out of the energy system in a pre-planned sequence. Measured energy use with and without the renewable energy project is compared. The period in the "on" state must be large enough to capture average renewable energy production, especially in intermittent resources such as wind and solar. This method is appropriate for projects that can be switched on and off. Examples include photovoltaic, solar hot water with mains booster, and cogeneration projects.
Calculated Reference	To determine baseline energy: ▪ Use engineering calculations and/or modelling calibrated to actual reference energy usage patterns. ▪ Subtract metered energy use. This method may apply for large projects where detailed analysis has been conducted as part of developing the business case. Indeed the M&V outcome may be to validate the engineering analysis.

[2] *Reference: Christensen, C., and Burch, J. 1993. Monitoring Strategies for Utility Solar Water Heating Projects, National Renewable Energy Laboratory, Golden, Colorado.*

5.1.2 Measurement data sources, measurement tools and techniques

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

Table 6: Potential M&V data sources

Data Type	Source	Comments
Heat energy	Thermal metering	Temporary or permanent metering to measure thermal delivery in terms of temperature change and water/steam flow.
	Temperature sensor	Can be used for Solar Hot Water. Temperature of solar heated preheat tank, for example.
	Manufacturers' product specifications	Can be used when delivered energy is estimated (as it is not being measured).
Energy usage and energy delivered	Utility bills	Typical frequency of one to three months. Are considered 100% accurate, when not estimated by the supplier.
	Revenue meter – interval data	Typically 30 minute data intervals, which can be used to accurately calculate savings across a day, week or longer. Can also be used to estimate operating hours based on profile changes. Data provided by a Meter Data Agent is used for billing and is considered 100% accurate.
Power draw	Permanent sub-meter – interval data	Similar characteristics to the revenue meter above. Data quality will be high, but may not be revenue quality. Data should be reviewed for meter 'drop outs'.
	Temporary energy logger	Similar to a sub-meter, an energy data logger is connected to a circuit and acts as a temporary meter. Data quality depends on the quality, range and an accuracy of the logger and associated CTs. Some units experience difficulties capturing large changes in loads. Be careful to size the CTs for the load to be measured. A tong reading will assist with sizing, however all operating loads should be considered.
	Manual meter readings (e.g. hourly/daily)	Periodic manual readings of a revenue/sub-meter. Take care to read the meter in the correct way and apply any meter multiplier 'k factor' to the values if stated on the meter. Contact the electricity supplier if unsure how to read the meter.
	Instantaneous measurement using current and voltage meter	Use calibrated equipment and measure current, voltage and power factor in order to evaluate energy and demand savings.
	Manufacturers' product specifications	Can be used when power draw is estimated (as it is not being measured).

Environmental Data	Sunrise/sunset times from Bureau of Meteorology	Historical weather data including sunrise and sunset times are available from the Bureau of Meteorology, and may be used to estimate operating hours for solar hot water and photovoltaic installations.
	Wind data from Bureau of Meteorology	Historical wind data is available from the Bureau of Meteorology, and may be used to estimate operating hours for wind turbine installations.
	Various renewable energy resources data	Interactive data such as, for example, Sustainability Victoria's resource section: (http://www.sustainability.vic.gov.au/www/html/2109-renewable-energy-resources.asp).

5.1.3 Conducting measurements

The following provides 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. Take lots of pictures.
- 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.

5.2 Develop energy model and uncertainty

Conduct analysis of baseline data to develop an appropriate energy model that explains energy consumption patterns based on the identified independent variables.

Separate models will be required if multiple fuels and/or boundaries have been selected.

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

5.3 Implement ECM(s)

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

5.4 Measure post retrofit data

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

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

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

5.5 Savings analysis and uncertainty

- Analyse data and calculate savings according to the prepared M&V plan, making adjustments for independent variables.
- Estimate the savings uncertainty, based on the measurement approach, placement, impact of variables, length of measurement and equipment used.
- Extrapolate the calculated savings for the measured period as required.

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

Once the M&V project has finished, ongoing M&V may be conducted as required to savings persistence and/or continual energy generation.

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 7: 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 8: 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 – cogeneration performance

Evaluating cogeneration system for performance guarantee

The scenario below provides details of how **Option D** is used to measure and verify the performance of a cogeneration system against manufacturer's performance claims.

A school located in Queanbeyan has been approached by a supplier of cogeneration systems with the offer to install a cogeneration system. The manufacturer has carried out preliminary design and analysis to determine the system sizing and has stated a minimum guarantee for the efficiency of the cogeneration system.

Operating patterns within the school change throughout the year due to many factors including school terms, seasonal weather conditions and operation of the school's 50 metre swimming pool.

As a result, the heat output from the cogeneration unit may not always be required, and therefore the school may only operate the system at times when the heat will be useful.

To support their proposal, the manufacturer has agreed to measurement and verification of the installed system to confirm that the stated efficiency can be achieved. The guarantee only applies to the initial heat recovered – not against the useful energy obtained from that heat as this is dependent on the school's load requirements which are outside the control of the manufacturer.

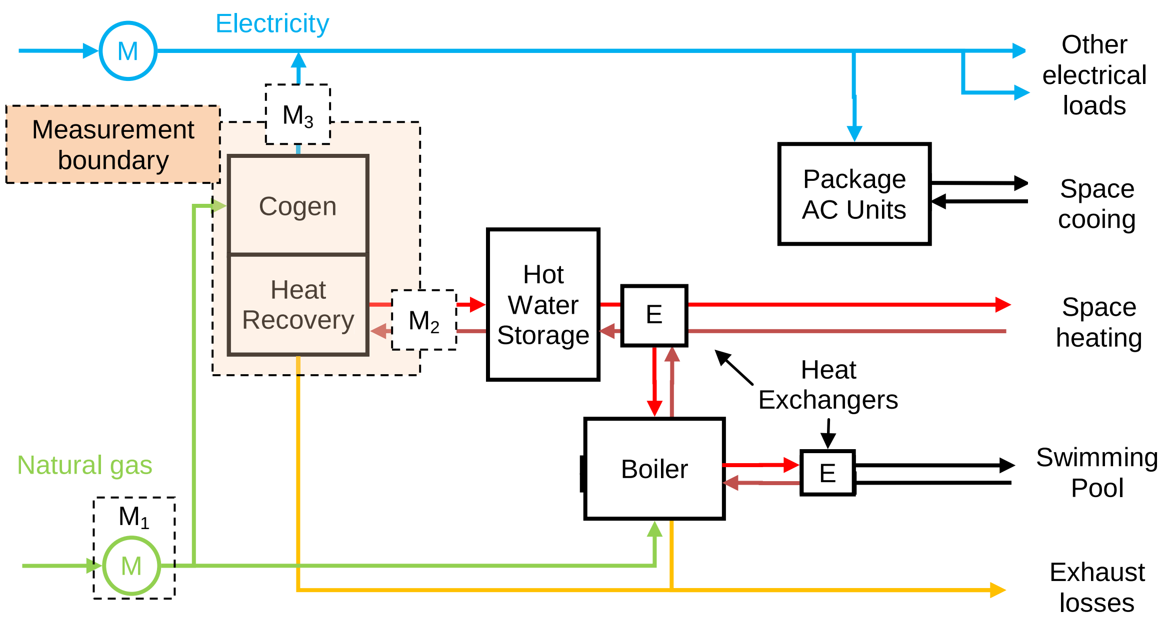
The school decided to install a hot water storage tank as part of the installation to assist with demand shifting. The natural gas supply to the school also requires upgrade and a new interval meter will be installed.

Getting started

System diagram

The existing system consisted of a natural gas fired boiler that provides hot water for space heating for classrooms and administration buildings, as well as for the swimming pool.

The retrofit comprised a package natural gas fired cogeneration unit and a hot water storage tank. The hot water pipes for the space heating were redirected to the hot water tank with the boiler becoming a boost. The retrofitted system is described in the diagram below:



Measurement boundary

The measurement boundary is the cogeneration unit itself, as shown in the diagram above.

Key parameters and energy model

The desired outcome is to develop a system performance curve for the cogeneration system's range of operation. This model will relate the consumption of natural gas usage to the amount of electricity generated and the amount of heat recovered.

These three parameters are to be measured as part of a load test. The metering locations are marked on the diagram above. These are:

M_1 – measurement point for incoming natural gas – gas usage will be tracked using the newly installed interval data meter via the energy retailer. Values will be recorded in cubic metres and the energy content of the natural gas will be obtained from the latest utility invoice.

M_2 – measurement point for heat output – a temporary thermal meter will be placed across the supply and return water pipes to measure the flow and temperature differential in order to calculate the energy transferred to the hot water storage tank.

M_3 – measurement point for electricity generation – a permanent interval data meter will be installed to record the amount of electricity generated by the system.

Timing and approach for conducting measurement

A load test will be conducted over an 8 hour period, with data captured at 15 minute intervals. The cogeneration unit will be cycled through from low load to full load.

Interactive effects

Natural gas use by the boiler.

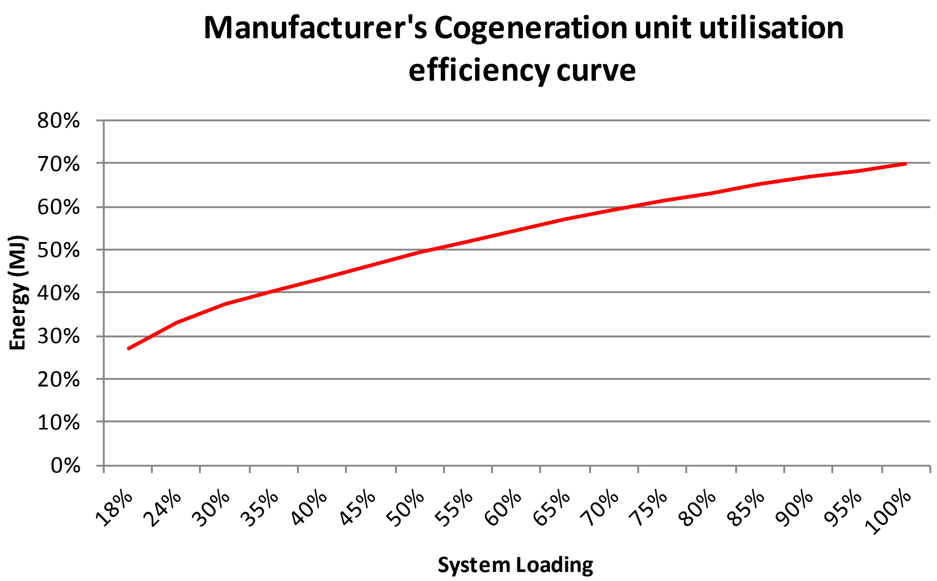
Summary of M&V plan

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

Item	Plan
Project Summary	Verification of actual performance of a newly installed cogeneration system against manufacturer's guaranteed performance.
Required Outcome	To verify that the actual energy efficiency of the cogeneration unit is equal to or greater than the guaranteed performance by the manufacturer.
Budget	$5,000 for temporary metering, analysis and reporting
M&V Option	Option D – Actual vs. computer simulation
Measurement Boundary	As per the system diagram.
Key Measurement Parameters	Input natural gas Output hot water Output electricity generation
Other Parameters to consider	None
Potential interactive effects	Natural gas use by the boiler. The boiler will be isolated prior to the test being conducted as they share a common meter.
Approach for conducting measurement and collecting data	Data will be collected continuously over an 8 hour period and will be summarised into 15 minute intervals.
Measurement equipment required	Temporary thermal metering will be installed to capture data for heat output A permanent electricity meter will be installed to capture data for the electricity generated by the cogeneration unit. The new natural gas billing meter will be used capture data for input fuel to the cogeneration unit.
Measurement period	8 hours
Approach for calculating results	The results will be determined by developing an energy model to evaluate input natural gas versus the electricity generated and the recovered heat. The performance curve calculated within the energy model will be compared against the manufacturer's performance curve to confirm that actual performance meets or exceeds the stated claims.

Baseline model

The baseline model consists of the manufacturer's performance curve.

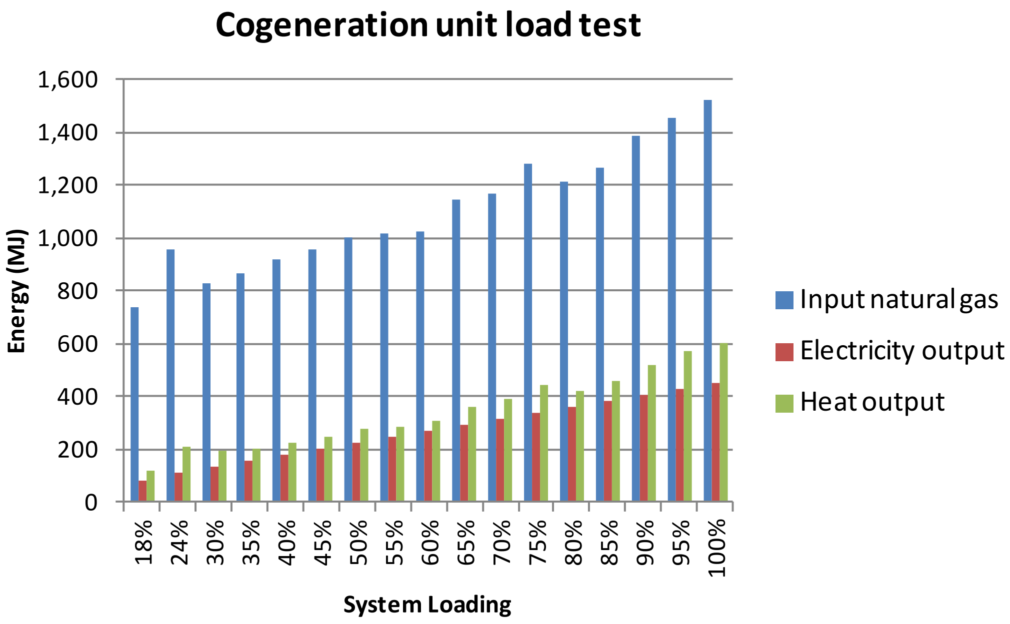


Performance model

The load test was conducted and yielded the following results:

	Measurements				Efficiency			
% Loading	Input gas (m^3)	Input gas (MJ) @ energy content = 36 MJ/m^3	Electricity generation (MJ)	Heat Recovered (MJ)	Combined Output (MJ)	Efficiency of electrical output (η_{elec})	Efficiency of heat output (η_{heat})	Combined Efficiency (η_{cogen})
18%	20.46	737	83	124	207	11%	17%	28%
24%	26.61	958	109	205	314	11%	21%	33%
30%	23.00	828	135	193	328	16%	23%	40%
35%	23.96	863	155	205	360	18%	24%	42%
40%	25.43	915	178	227	405	19%	25%	44%
45%	26.61	958	200	254	454	21%	27%	47%
50%	27.71	998	223	289	513	22%	29%	51%
55%	28.21	1016	245	290	535	24%	29%	53%
60%	28.43	1095	271	320	591	26%	31%	57%
65%	31.79	1144	294	339	633	26%	30%	55%
70%	32.50	1173	316	396	712	26%	33%	60%
75%	34.05	1255	337	432	769	26%	34%	60%
80%	37.10	1273	361	468	829	27%	35%	62%
85%	35.05	1308	383	494	877	28%	36%	64%
90%	36.80	1320	404	492	895	31%	37%	68%
95%	40.26	1449	429	534	964	31%	39%	70%
100%	42.33	1524	449	555	1003	30%	37%	68%

The chart below plots the results for the input and outputs measured during the load test.



The efficiency of the cogeneration unit as a function of the electricity generated, η_{elec} is described as:

$$\eta_{elec} = \frac{Electrical\ Output\ (MJ)}{Energy\ Input\ (MJ)}$$

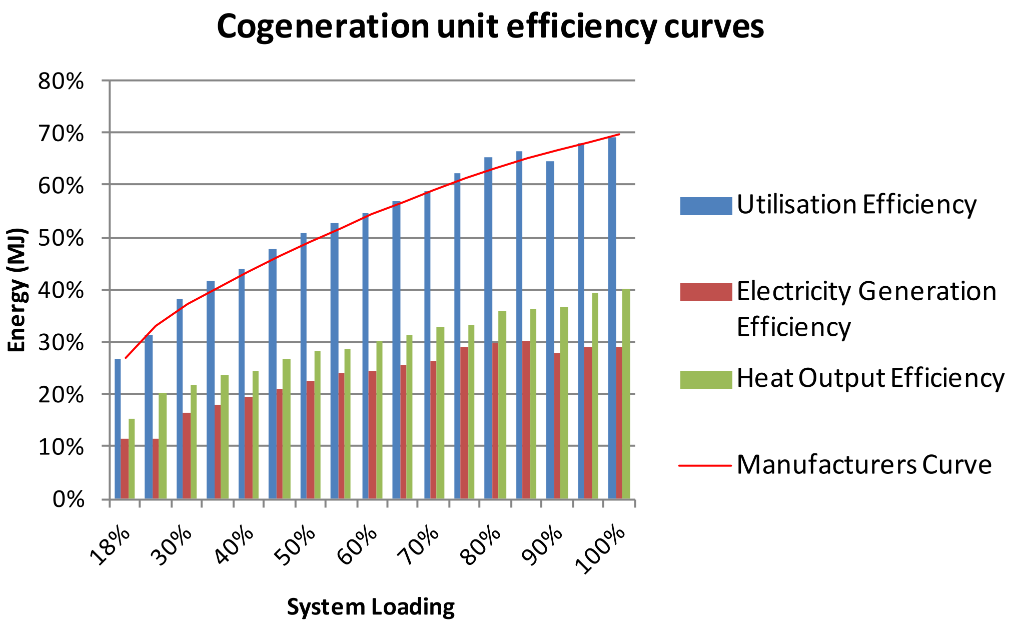
The efficiency of the cogeneration unit as a function of heat generated, η_{heat} is described as:

$$\eta_{heat} = \frac{Heat\ Output\ (MJ)}{Energy\ Input\ (MJ)}$$

And the combined efficiency (also known as utilisation efficiency) of the cogeneration unit as a function of both outputs, η_{cogen} is:

$$\eta_{cogen} = \frac{Electrical\ Output\ (MJ) + Heat\ Output\ (MJ)}{Energy\ Input\ (MJ)}$$

Values were calculated at each point in the load test. The chart below summarises the efficiency curves for η_{elec}, $\eta_{heat,\ and}$ η_{cogen} for each point on the load test.



The performance curve provided by the manufacturer is also plotted. It can be seen that on visual inspection, the cogeneration unit is performing as promised.

Appendix B: Example scenario B – cogeneration savings

Evaluating cogeneration system annual savings

The scenario below provides details of how **Option C** is used to measure and verify the performance of a cogeneration system against an energy baseline.

A hospital located in NSW's central west provides a regional centre and surrounding rural community with premium health care. The building was constructed about 10 years ago.

The site has been experiencing some electricity supply reliability issues in recent times and has decided to install a backup generator set to operate essential loads in case of mains supply interruption.

Following discussions with various suppliers, a cogeneration system was chosen as it meets several needs, including:

- Provide maximum benefit in terms of greenhouse gas emission reductions due to the heat recovery, which will be used for space heating and domestic hot water.
- Partly offset impending electricity price increases by switching part of its load to natural gas.
- Enables the hospital to access the department's capital works funding to subsidise the installation.
- Enables the hospital to update its natural gas contract with more competitive rates due to the increased load.

The strategy is to install a cogeneration unit that will offset the majority of the building's domestic hot water and space heating needs. The current boiler will be retained as a booster in winter times.

The cogeneration unit will be run around 90% of the time at a minimum of 75% loading. This will supply base load electricity for the site – there is no anticipated export of electricity to the grid. It is anticipated that some energy savings will result from avoiding excess natural gas consumption due to boiler turndown.

The unit was installed and commissioned during 2010.

The hospital engaged an M&V specialist to review the situation. An Option C approach was chosen for conducting M&V for the following reasons:

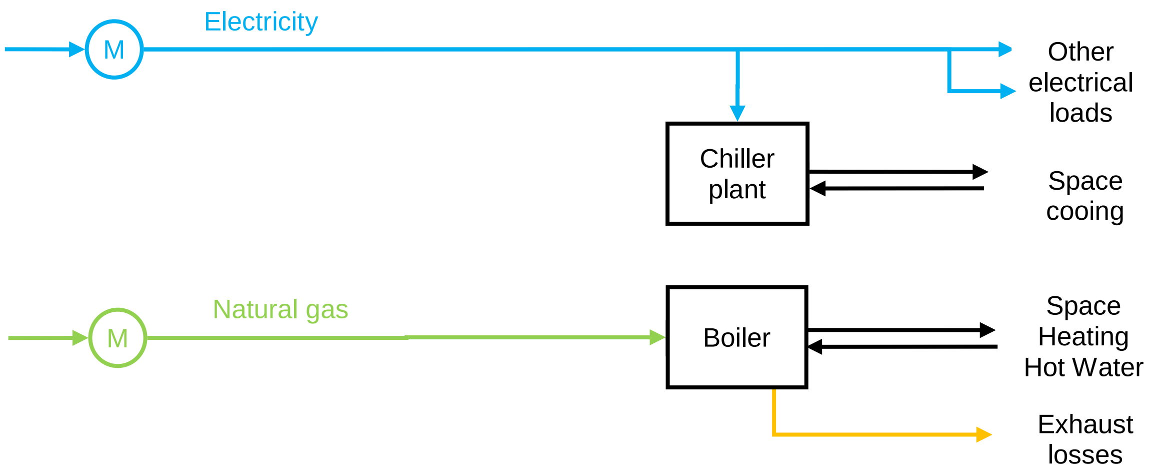
- Reduce M&V costs by relying on existing meters/sub meters.
- The project had already been installed, and so there was no opportunity to collect new baseline data

The heat output from the cogeneration unit is used by the domestic hot water and HVAC systems. A facility level boundary was found to be the simplest method for capturing all the key systems and energy transformations.

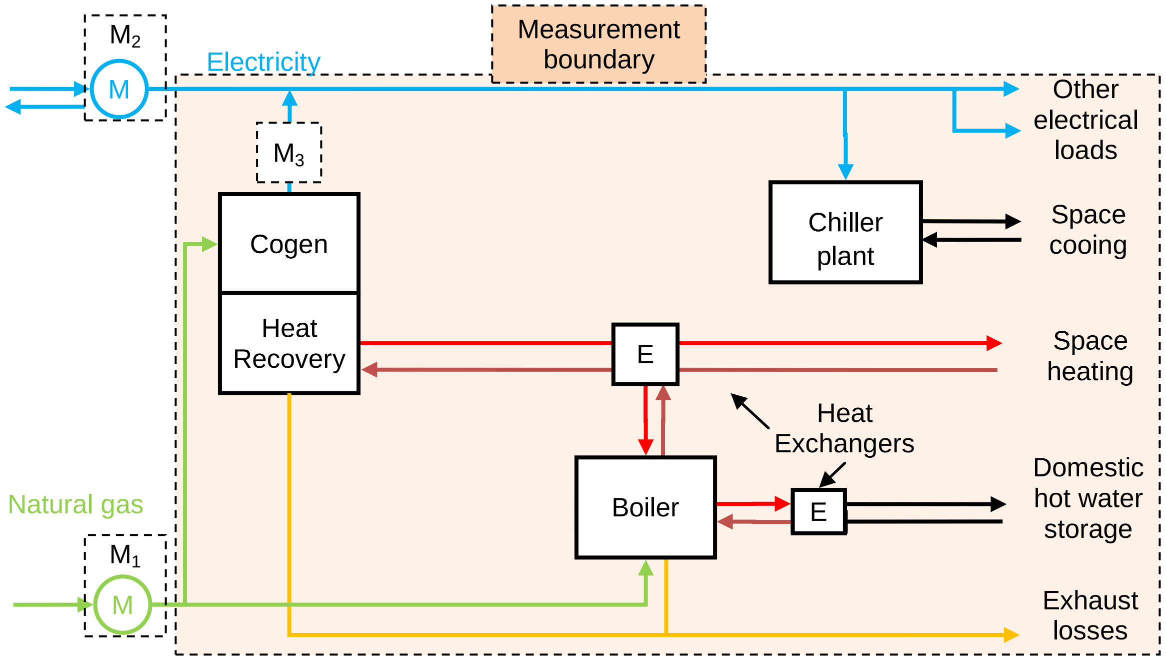
Getting started

System diagram

Two system diagrams are presented below. The first describes the situation prior to the cogeneration unit being installed.



The second diagram incorporates the changes that took place when the cogeneration unit was installed.



Measurement boundary

The measurement boundary consists of the entire hospital, as shown in the diagram above.

Key parameters and energy model

The key outcome is to provide some analysis backed by statistical confidence to quantify the change in hospital performance in regard to energy use by fuel type, demand, cost and greenhouse gas emissions.

The overall plan is to use an IPMVP Option C approach to verify the last 12 months of operation at the site (January to December 2011) against a set of baseline for the corresponding months in 2009.

An energy model will be developed for key billing elements for electricity and natural gas that will attempt to describe energy use or demand against independent variables that will be discussed with the hospital.

The model will then be updated with current data to forecast what the use and demand would have been had the cogeneration unit not been installed.

The key steps are:

1. Conduct discussions with staff regarding the cogeneration system and general site operational issues.
2. Identify the key internal and external variables that will affect the baseline energy consumption patterns.
3. Obtain detailed historical billing data for electricity and natural gas the 2009 baseline period and 2011 performance period. Collect data for independent variables. Obtain energy cost rates (available from latest invoice) and greenhouse gas emission factors.
4. Enter the data and analyse to develop an energy model for time of use consumption, time of use demand, and natural gas use.
5. Calculate the uncertainty (precision and confidence) for each model.
6. Apply the model to data for independent variables form 2011 to adjust the baseline.
7. Subtract the actual figures for corresponding periods to determine energy and demand savings.
8. Energy and demand savings will be calculated. The site's current electricity and natural gas cost rate structures will be applied to the data. For natural gas, the project has foreshadowed a new supply contract with lower rates. The new rates shown on the bills will be evaluated against the old rates, as this was one of the benefits of the project. Greenhouse gas emissions will be calculated from published emission factors covering Scopes 1, 2 and 3.

Timing and approach for conducting measurement

The timing for this project is one week and the analysis can commence immediately since the baseline period is retrospective and historical billing meters will be used for data.

Interactive effects

There are no interactive effects to consider.

Baseline model

Following discussions with hospital staff it emerged that ambient temperature would be the key independent variable. Staff mentioned that patient numbers fluctuate but not to a great extent (±5%). Although different activities occur on specific days during the week, the hospital's operating and energy consumption patterns when viewed from a weekly or monthly basis is mostly uniform. To complicate matters, data for other variables would be difficult to obtain.

It was decided to take a first pass at the analysis focusing on temperature, and investigate further if a suitably accurate result could not be obtained. The number of weekdays and weekends within each month will also be analysed.

Approach

From the baseline model we wish to determine energy and demand savings in sufficient detail so that cost savings can be calculated using the hospital's electricity and natural gas tariff structures, which are shown below:

Electricity	Rate ($/unit)
Peak (kWh)	0.06160
Shoulder (kWh)	0.06160
Off-Peak (kWh)	0.02760
REC (kWh)	0.00080
GAB (kWh)	0.00310
Network Access Charge (day)	7.51620
Demand Charge Peak Period (kVA/month)	5.38150
Demand Charge Shoulder Period (kVA/month)	5.38150
Demand Charge Off-Peak Period (kVA/month)	1.52900
Transport Peak Energy Charge (kWh)	0.01930
Transport Shoulder Energy Charge (kWh)	0.01930
Transport Off-Peak Energy Charge (kWh)	0.01580
Total Electricity ($)	
Natural Gas	Rate ($/unit)
Gas (MJ)	0.01450
Cogeneration Gas	0.01450

In order to apply the cost structure above we are required to develop an energy model that can predict the following parameters:

- Peak, Shoulder and Off Peak consumption
- Peak, Shoulder and Off Peak demand
- Natural gas consumption

Linear regression was used to create a separate model for each tariff item – a total of seven regression models.

It was decided to develop multiple models so that we could accurately predict each parameter based on its own fluctuations due to the independent variables. The relationship between Peak energy use and CDDs/HDDs is different to the one for Off Peak as Peak usage occurs morning and afternoon, whilst Off Peak usage occurs overnight and weekends.

More importantly, the relationship between Peak Demand is different to that of Peak usage even though they share the same time period. In the case of Peak Demand the model we develop aims to identify the highest value that would occur in a given month, rather than a summation of daily figures spanning a month.

For this reason the daily figures for HDDs and CDDs were analysed in two ways as follows:

- For Peak, Shoulder and Off Peak consumption – HDDs and CDDs were calculated for each day and summated into calendar months. The monthly totals for degree days were regressed against the monthly totals for the consumption period (e.g. Peak).
- For Peak, Shoulder and Off Peak demand – the maximum monthly figures captured from the energy bills and interval data correspond to an occurrence on a particular day within the month. Thus our analysis only includes the HDDs and CDDs for the days during the year in which the 12 figures for maximum demand occur – note these days differ within each usage period.

By taking separate approaches for demand versus usage to create models for each time period we can develop the most accurate model that applies to each billing line item component and minimise uncertainty.

Analysis

The baseline model and analysis was conducted using Microsoft Excel.

The historical billing data and meter interval data was entered in sufficient detail. Daily weather data was imported and equations were developed to calculate heating and cooling degree days by referencing a target temperature or balance point.

The LINEST() function within Excel was used for statistical analysis and describing each energy model.

The “Solver” function within Excel was used in several iterations for each model as decisions were made regarding the impact of either CDDs or HDDs, or both, and the balance points. This function was used to maximise the R^2 value for each equation.

Charts were created to assist with refining and validating each model. Visual analysis was valuable for identifying data outliers which may be creating uncertainty.

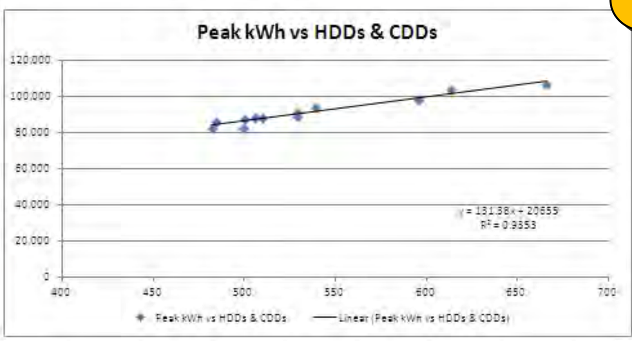
Example energy model – Peak kWh

The screenshots below show the energy model for the Peak energy consumption parameter. The model consists of the following sections:

1. Baseline actual data, HDD and CDD totals and modelled output
2. Regression model
3. Model validation and uncertainty
4. Chart of model

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
81	Model Outputs - Peak kWh	Jan	Feb	Mar	[illegible]	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average / Totals
82	Baseline actual data	106,335	97,721	93,756	[illegible]	82,548	86,209	90,973	82,010	87,284	87,779	88,826	104,070	91,316
83	Model Output	108,128	98,872	91,495	[illegible]	86,229	84,293	90,199	83,990	86,350	87,647	90,179	101,269	91,316
84	Model Residual	1,792	1,152	-2,261	-1,142	3,681	-1,916	-775	1,980	-933	-132	1,354	-2,801	0
85	HDDs	92	74	203	252	368	418	503	411	346	310	189	133	3,298
86	CDDs	403	366	236	178	92	47	19	50	108	140	239	338	2,216
87	combined degree days	666	595	539	506	499	484	529	482	500	510	529	614	
88														
89														

	A	B	C	D
	Peak kWh	CDDs	HDDs	y intercept
	balance point	20	6	n/a
	coefficient	187.14	131	20,655
	standard error of coefficient	26.37	25	11,694
94	R^2 / standard error of y	0.935	2,193	
95				
96				
97	Statistical validity	CDDs	HDDs	
98	adjusted R^2	0.921		
	t-stats	7.10	5.26	
	CV(RMSE)	0.0240		
	Mean Bias Error (MBE)	-2.425E-12		
	Uncertainty Analysis	Uncertainty Analysis		
103	confidence	95%		
104	t-stat	2.20		
105	Absolute Precision (AP)	4,824		
106	Average Monthly Modelled Energy Use	91,316		
107	Relative Precision (RP)	5.3%		



The resulting model equation parameters can be seen in Section 2 of the above worksheet and the final model is defined as:

$$Peak\ Usage\ (kWh) = 187.14\ \times\ \mathrm{CDD} + 131.38\ \times\ \mathrm{HDD} + 20655.22$$

Baseline data and modelled output

Section 1 contains the baseline actual data and monthly summaries for the HDDs and CDDs for the Peak kWh line item.

	A	B	C	D	E	F	G
81	Model Outputs - Peak kWh	Jan	Feb	Mar	Apr	May	Ju
82	Baseline actual data	106,335	97,721	93,756	88,276	82,548	86,2
83	Model Output	108,128	98,872	91,495	87,135	86,229	84,2
84	Model Residual	1,792	1,152	-2,261	-1,142	3,681	-1,91
85	HDDs	92	74	203	252	368	41
86	CDDs	403	366	236	178	92	47

HDDs and CDDs are calculated from the daily weather data and summated for each month to align with the billing data. A balance point is defined for each, which can be found in cells B91 and C91 (see next section).

The model output is calculated by inputting the monthly values for HDDs and CDDs into the model equation. The residual is calculated by subtracting the actual value from the modelled value.

LINEST() regression function

Within Section 2, the LINEST() function is used to calculate the multi-variable linear regression model. The model below is based on both HDDs and CDDs.

B92 fx {=LINEST($B$33:$M$33,B85:M86,TRUE,TRUE)}

	A	B	C	D	E
90	Peak kWh	CDDs	HDDs	y intercept	
91	balance point	20	6	n/a	
92	coefficient	187.14	131.38	20,655.22	
93	standard error of coefficient	26.37	24.96	11,693.62	
94	R^2 / standard error of y	0.935	2,192.56		
95					
96					
97	Statistical validity	CDDs	HDDs		
98	adjusted R^2	0.921			
99	t-stats	7.10	5.26		
100	CV(RMSE)	0.0240			
101	Mean Bias Error (MBE)	-2.43E-12			
102	Uncertainty Analysis	Uncertainty Analysis			
103	confidence	95%			
104	t-value (DF = 12 - 2 -1 =9)	2.26			
105	Absolute Precision (AP)	4,955			
106	Average Monthly Modelled Energy Use	91,316			
107	Relative Precision (RP)	5.4%			

The formula bar shows the LINEST() formula found in cell B92. This function outputs the figures shown in cells B92 to D94. Data labels have been added for clarity.

Cells B91 and C91 contain the CDD and HDD balance points. By varying these, the number of HDDs and CDDs will change, which then affects the modelled output.

The “Solver” pop up window is shown below which shows the configuration used to maximise the R^2 value (found in cell B94) which is achieved by manipulating cells B91 and C91. Upper and lower limits of 0-20 Degrees Celsius have been included.

Model validation and uncertainty analysis

Section 3 contains the validation and uncertainty analysis conducted for the model. The results for each test are colour coded by setting the “conditional formatting” to show either green or red text depending on whether the value passes or fails the relevant test.

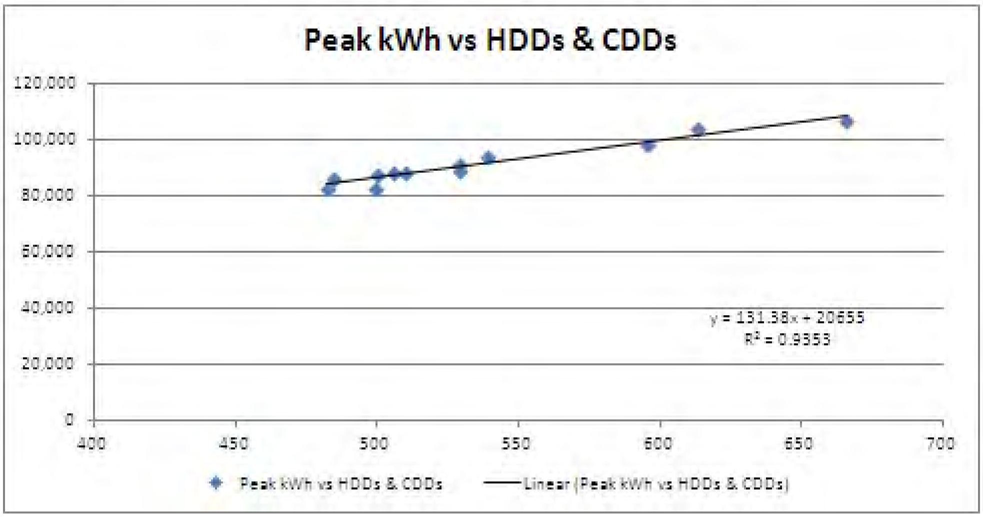
	A	B	C	D
97	Statistical validity	CDDs	HDDs	
98	adjusted R^2	0.921		
99	t-stats	7.10	5.26	
100	CV(RMSE)	0.0240		
101	Mean Bias Error (MBE)	-2.43E-12		
102	Uncertainty Analysis	Uncertainty Analysis		
103	confidence	95%		
104	t-value (DF = 12 - 2 -1 =9)	2.26		
105	Absolute Precision (AP)	4,955		
106	Average Monthly Modelled Energy Use	91,316		
107	Relative Precision (RP)	5.4%		

The precision for the model is then calculated. A 95% confidence level was chosen, which requires a t-stat of 2.2 to be used for calculating Absolute Precision (AP = t x standard error).

The Relative Precision was calculated by dividing the Absolute Precision by the average monthly value as calculated by the model.

X-Y scatter chart

An X-Y scatter chart was developed to assist with assessing the “appropriateness of fit” for the model. The chart was used for sanity checking as the model was altered iteratively.



X-Y scatter charts are only capable of relating the output parameter (Y axis - Peak kWh in this case) against a single input parameter (X axis). Therefore it was necessary to create a single parameter that combined the effects of HDDs and CDDs.

Demand values and degree days

As mentioned a different approach was used for relating demand with degree days. For each month, the date on which the maximum demand occurred was determined from the meter interval data.

The corresponding ambient temperature data for that day was then used as the independent variable for calculating HDDs and CDDs. All remaining data for the month was ignored.

This was repeated for each time of use period as the dates of occurrences for the maximums occur on different days.

Baseline model outputs

The table below summarises the seven models that were developed.

Line Item	Independent Variables (with temperature balance points)	Model	Relative Precision at 95% confidence
Peak Usage (kWh)	HDDs (@ 20.0°C) CDDs (@ 6.0°C)	*Peak*=187.14 × CDD+131.38 × HDD+20655.22	±5.4%
Shoulder Usage (kWh)	HDDs (@ 20.0°C) CDDs (@ 4.7°C)	*Shoulder*=285.06 × CDD+178.17 × HDD+60163.55	±7.5%
Off Peak Usage (kWh)	CDDs (@ 7.7°C) No of weekend days in month	*Off Peak*=140.98 × CDD+12497.13 × WEdays+106028.23	±3.8%
Peak Demand (kW)	Max Day CDDs (@ 11.1°C)	*Peak Demand*=39.84 × MaxDayCDD+830.35	±9.8%
Shoulder Demand (kW)	Max Day CDDs (@ 8.1°C)	*Shoulder Demand*=35.09 × MaxDayCDD+876.01	±8.3%

Line Item	Independent Variables (with temperature balance points)	Model	Relative Precision at 95% confidence
Of Peak Demand (kW)	Max Day CDDs (@ 7.6°C)	$Off\ Peak\ Demand$=36.73 × MaxDayCDD+682.22	±10.7%
Natural Gas Usage (GJ)	HDDs (@ 3.7°C)	$Gas\ Use$=16.84 × HDD+788.1	±14.6%

Calculating savings

Developing the Adjusted Baseline

The next step was to use the energy models to predict the values for each line item for the 2011 performance period. The daily weather data for the year was manipulated in a similar manner to that of the baseline year. HDDs and CDDs were calculated separately for each model using the previously determined balance points.

For Maximum Demand, the highest daily value for CDDs occurring within each month was used. Data was filtered to weekdays for Peak and Shoulder time of use periods.

The model equation for each model was then used to forecast the monthly values. The results from the electricity model are shown below.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Peak	107,166	97,692	94,733	84,273	82,815	80,6[illegible]	92,652	92,464	1,067,937
Shoulder	203,027	186,890	181,681	162,291	153,634	148,5[illegible]	178,225	177,331	2,018,645
Off Peak	286,926	252,832	241,708	232,791	221,526	206,5[illegible]	240,757	248,468	2,832,393
Total monthly Usage (kWh)	597,119	537,413	518,122	479,355	457,976	435,7[illegible]	511,634	518,262	5,918,974
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Peak	1,384	1,424	1,173	1,053	830	830	1,223	1,069	1,424
Shoulder	1,469	1,504	1,283	1,178	981	916	1,327	1,192	1,504
Off Peak	1,321	1,358	1,127	1,016	811	743	1,173	1,097	1,358
Maximum monthly demand (I	1,469	1,504	1,283	1,178	981	916	1,327	1,192	1,504

The value for January 2011 was calculated by applying the energy model formula using values of HDD = 18.35 and CDD = 449.40 as follows:

$$\text{Peak Usage} = 187.14 \times \text{CDD} + 131.38 \times \text{HDD} + 20655.22$$

$$= 187.14 \times 449.40 + 131.38 \times 18.35 + 20655.22$$

$$= 107{,}166\ \text{kWh}$$

Determining savings

Savings were calculated by subtracting the values within the adjusted baseline for each line item with their corresponding actual value that was derived from the invoice data. Using the Peak Usage line item as an example, the following equation was applied:

$$\text{Peak Usage Savings} = \text{Peak}_{\text{adj.baseline}} - \text{Peak}_{\text{actual}}$$

The actual value for January 2011 was 89,970 kWh. Therefore the Peak Usage Savings is:

$$\text{Peak Usage Savings} = 107166 - 89970$$

$$= 107166 - 89970 = 17196\ \text{kWh}$$

Savings were determined for natural gas and electricity for each line item for each of the 12 months. The resulting savings are shown in the table below:

Total Energy Savings (GJ)	Jan	Feb	Mar	A	Dec	Total	% Change
Electricity (from grid)	25	62	-29	-2	-141	-394	-1.8%
Natural Gas	-110	-22	-127	-1	-109	-4,583	-46.7%
Energy Savings	**-85**	**40**	**-156**	**-2**	**-250**	**-4,977**	**-16.0%**

Positive figures represent savings whilst negatives represent an increase in usage. We can see that usage increased for both electricity and natural gas. This is expected from implementing a cogeneration (fuel switching project) in the absence of implementing any savings measures.

Overall the hospital has seen a 16% increase in energy use.

Calculating cost and greenhouse savings

Apart from resolving electricity supply issues, the purpose of installing the cogeneration unit was to derive cost and greenhouse savings.

Cost savings are calculated by applying the electricity and natural gas tariff rates for each line item to the calculated energy and demand savings.

The table below lists the electricity and natural gas tariff items and the annualised energy and demand savings.

Electricity	Rate ($/unit)	Energy/demand	Cost saving ($)	% saving
Peak (kWh)	0.06160	164,588	$10,139	
Shoulder (kWh)	0.06160	199,361	$12,281	
Off-Peak (kWh)	0.02760	634,653	$17,516	
REC (kWh)	0.00080	998,602	$799	
GAB (kWh)	0.00310	998,602	$3,096	
Network Access Charge (day)	7.51620	0	$0	
Demand Charge Peak Period (kVA/month)	5.38150	1,238	$6,799	
Demand Charge Shoulder Period (kVA/month)	5.38150	896	$4,923	
Demand Charge Off-Peak Period (kVA/month)	1.52900	1,594	$2,486	
Transport Peak Energy Charge (kWh)	0.01930	164,588	$3,177	
Transport Shoulder Energy Charge (kWh)	0.01930	199,361	$3,848	
Transport Off-Peak Energy Charge (kWh)	0.01580	634,653	$10,028	
Total Electricity ($)			**$75,090**	**13.3%**
Natural Gas				
Gas (MJ)	0.01450	9,811,722	$142,270	
Cogeneration Gas	0.01200	-14,394,974	-$172,740	
			-$30,470	**-21.4%**
Total				
Total			**$44,620**	**6.3%**

Note:

1. A power factor of 0.98 was used for the demand line items. This was derived from the actual invoices.
2. The change in natural gas price is factored in.

In summary, the hospital has seen a 6.3% reduction in energy costs, which comprises a 13.3% reduction in electricity and a 21.4% increase in natural gas costs.

Greenhouse savings were calculated by multiplying the annual energy savings by default greenhouse gas coefficients. The total energy figures for each fuel are used.

GHG Emission Savings (Scope 1 :	Greenhouse coefficien	Forecast	Actual	Savings	% savings
Electricity (from grid) / kg CO2 / kV	1.070	6,333	5,265	1,069	16.9%
Natural Gas (kg CO2 / GJ)	66.330	651	955	-304	-46.7%
Total GHG Emission Savings		**6,984**	**6,220**	**764**	**10.9%**

The hospital's Scope 1,2 and 3 Greenhouse Gas Emissions have reduced by 10.9%.

Calculating uncertainty

Whilst developing each model the relative precision for a monthly figure was calculated. The uncertainty of the savings is calculated for each line item as follows:

Whilst developing each model the relative precision for a monthly figure was calculated. The uncertainty of the savings is calculated for each line item as follows:

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

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

$$SE(annual\ savings) = \sqrt{12 \times SE(monthly\ savings)^2}$$

Using a t-statistic of 2.20 (12 measurement points = 11 degrees of freedom, with 95% confidence), the range of possible annual savings (absolute precision) will be:

$$Absolute\ precision \quad = t \times SE\ (annual\ savings)$$

And the relative precision is:

$$Relative\ precision \quad = \frac{Absolute\ precision}{Annual\ savings}$$

These calculations are summarised for energy savings in the table below:

Category	Savings (GJ)	Standard Error Monthly	Standard Error Annual	Absolute Precision @ 95% confidence	Relative Precision
Electricity Peak	593	8	27	60	10%
Electricity Shoulder	718	20	71	156	22%
Electricity Off Peak	2,285	14	49	108	5%
Natural Gas	-4,583	60	209	459	-10%
Energy Savings Uncertainty	**-988**	**66**	**227**	**500**	**-51%**

The savings are within ±500 GJ however due to their small nature the relative precision is large.

Cost uncertainty is calculated in the table below. Uncertainty is calculated for each cost item, followed by the aggregated uncertainty which is the square root of the sum of squares for each item.

Electricity	Cost saving ($)	SE Monthly Cost	Standard Error Annual	Absolute Precision @ 95%	Relative Precision
Peak (kWh)	$10,139	$135	$468	$1,029	10.2%
Shoulder (kWh)	$12,281	$349	$1,210	$2,662	21.7%
Off-Peak (kWh)	$17,516	$109	$378	$832	4.7%
REC (kWh)	$799	$6	$20	$44	5.5%
GAB (kWh)	$3,096	$22	$78	$171	5.5%
Network Access Charge (day)	$0	$0	$0	$0	0.0%
Demand Charge Peak Period (kVA/month)	$6,799	$246	$854	$1,878	27.6%
Demand Charge Shoulder Period (kVA/mon	$4,923	$209	$724	$1,593	32.4%
Demand Charge Off-Peak Period (kVA/mon	$2,486	$77	$265	$583	23.5%
Transport Peak Energy Charge (kWh)	$3,177	$42	$147	$322	10.2%
Transport Shoulder Energy Charge (kWh)	$3,848	$109	$379	$834	21.7%
Transport Off-Peak Energy Charge (kWh)	$10,028	$62	$216	$476	4.7%
Total Electricity ($)	**$75,090**		**$1,835**	**$4,038**	**5.4%**
Natural Gas					
Gas (MJ)	$142,270	$874	$3,026	$6,658	4.7%
Cogeneration Gas	-$172,740	$723	$2,505	$5,510	-3.2%
Total Natural Gas	**-$30,470**		**$3,928**	**$8,642**	**-28.4%**
Total					
Total	**$44,620**		**$4,336**	**$9,539**	**21.4%**

Note that since the tariff rates are stipulated from energy invoices, they are deemed to be 100% accurate.

The uncertainty for greenhouse gas emissions is calculated using similar techniques. The results are shown in the table below.

GHG Emission Uncertainty (Scope 1 2 3)	Savings	SE Monthly GHG	Standard Error Annual	Absolute Precision @ 95% confidence	Relative Precision
Electricity (from grid) / kg CO2 / kWh	1,069	7.76	26.88	59.14	5.5%
Natural Gas (kg CO2 / GJ)	-304	4.00	13.84	30.46	-10.0%
Total GHG Emission Uncertainty	**764**	**8.73**	**30.24**	**66.52**	**8.7%**

Note that since the greenhouse gas coefficients are drawn from default factors they are deemed to be 100% accurate.

Reporting results

The savings results can be described by the following:

The hospital has seen a 4,977 GJ or 16% increase in annual energy use which comprises a 394 GJ (1.8%) increase in electricity and 4,583 GJ (46.7%) increase in natural gas. The aggregated uncertainty is ±500 GJ with a 95% confidence factor.

Overall energy spend has reduced by $44,620 or 6.3%, which comprises a $75,090 reduction in electricity cost and $30,470 increase in natural gas expenditure. The aggregated uncertainty is ± $9,539 with a 95% confidence factor.

Scope 1, 2 and 3 greenhouse gas emissions savings are 764 t. CO_2-e or 10.9%. The aggregated uncertainty is ±67 t. CO_2-e with a 95% confidence factor.

Appendix C: Example scenario C – renewable energy

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

This example is based on Example 2, from the IPMVP Volume 3 – Renewable Energy[3]

A small housing area, where there is no air-conditioning installed, has houses both with and without solar water heating installed. The solar hot water systems are each $6m^2$. The purpose of the M&V project is to determine the energy savings associated with the solar water heaters.

Getting started

Key Parameter(s)

Given that the project aim is to determine savings rather than energy delivery performance, the M&V method involves indirect measurement of energy. Therefore, the key parameter is metered energy use.

Measurement Boundary

The measurement boundary was chosen as a sample of 50 houses in the housing area; 25 with solar hot water (SHW) and 25 without.

Approach for Conducting Measurement

The chosen approach for indirect end-use measurement was a monitoring system such as a temporary electrical data logger at each of the 50 residences. The data logger was attached to the electric water heaters already in place.

Timing

Power consumption was recorded at 15 minute intervals. The monitoring period was from June 11 to July 25, in order to sufficiently cover a wide range of conditions such as sunny, cloudy, warm and cold.

Developing a baseline for comparison

Because performance claims for this scenario are based on energy savings, then the savings are determined indirectly. In this way, the difference between the baseline energy and the metered energy is calculated.

Using the control group method, a comparison of metered energy of loads with SHW is made to similar loads (control group) without SHW. The baseline is established as the energy use of the control group.

[3] Reference: *IPMVP Concepts and Practices for Determining Energy Savings in Renewable Energy Technologies Applications. Volume 3. 2003.*

Summary of M&V Plan

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

Item	Plan
Project Summary	A small housing area, where there is no air-conditioning installed, has both houses with and without solar hot water (SHW) installed. The solar hot water systems are each 6m^2. There is one utility meter for the entire settlement.
Required Outcome	Determine savings associated with the installed SHW systems.
M&V Option	B – Retrofit isolation. Indirect measurement through energy metering
Measurement Boundary	Sample of 50 houses: 25 with SHW, 25 without SHW
Key Measurement Parameters	Metered energy consumption
Approach for conducting measurement and collecting data	Data loggers installed on current electric water heaters at all residences.
Measurement equipment required	Temporary electrical data loggers capable of 15 minute interval readings.
Measurement period	June 11 to July 25
Approach for calculating results	Subtract power consumption of houses with SHW from determined baseline (houses without SHW).

Conducting measurements and calculating savings

As previously mentioned, the chosen approach for indirect end-use measurement was a monitoring system such as a temporary electrical data logger at each of the 50 residences. The data logger was attached to the electric water heaters already in place. Power consumption was recorded at 15 minute intervals for the period June 11 to July 25.

Calculating energy savings

After completion of the monitoring period, the readings were as follows:

House Type	Average Energy Used For Water Heating
Without SHW installation	11.1 kWh/day
With SHW installation	2.5 kWh/day

This equates to savings of 8.6kWh/day.

Calculating demand savings

The entire housing area (facility) is connected to one utility meter, including more houses than the 50 houses selected to sample for the project. As no air conditioning is installed within the community, it is assumed that the electricity peak is coincident with the water heating peak.

House Type	Aggregate Peak Water Heating Demand
Without SHW installation	38kW
With SHW installation	12.2kW

This equates to an average demand saving of 1.0 kW per residence.

Reporting results

Estimated savings are reported as:

Component	Baseline (houses without SHW)	Post Retrofit (houses with SHW)	Savings
Energy	4052 kWh (per year)	913 kWh (per year)	3139kWh (per year)
Demand	38 kW	12.2 kW	1kW (per residence)