Measurement and Verification Operational Guide

Motor, Pump and Fan Applications

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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
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1 Your guide to successful M&V projects

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

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

But what is M&V exactly?

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

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

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

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

1.1 Using the M&V Operational Guide

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

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

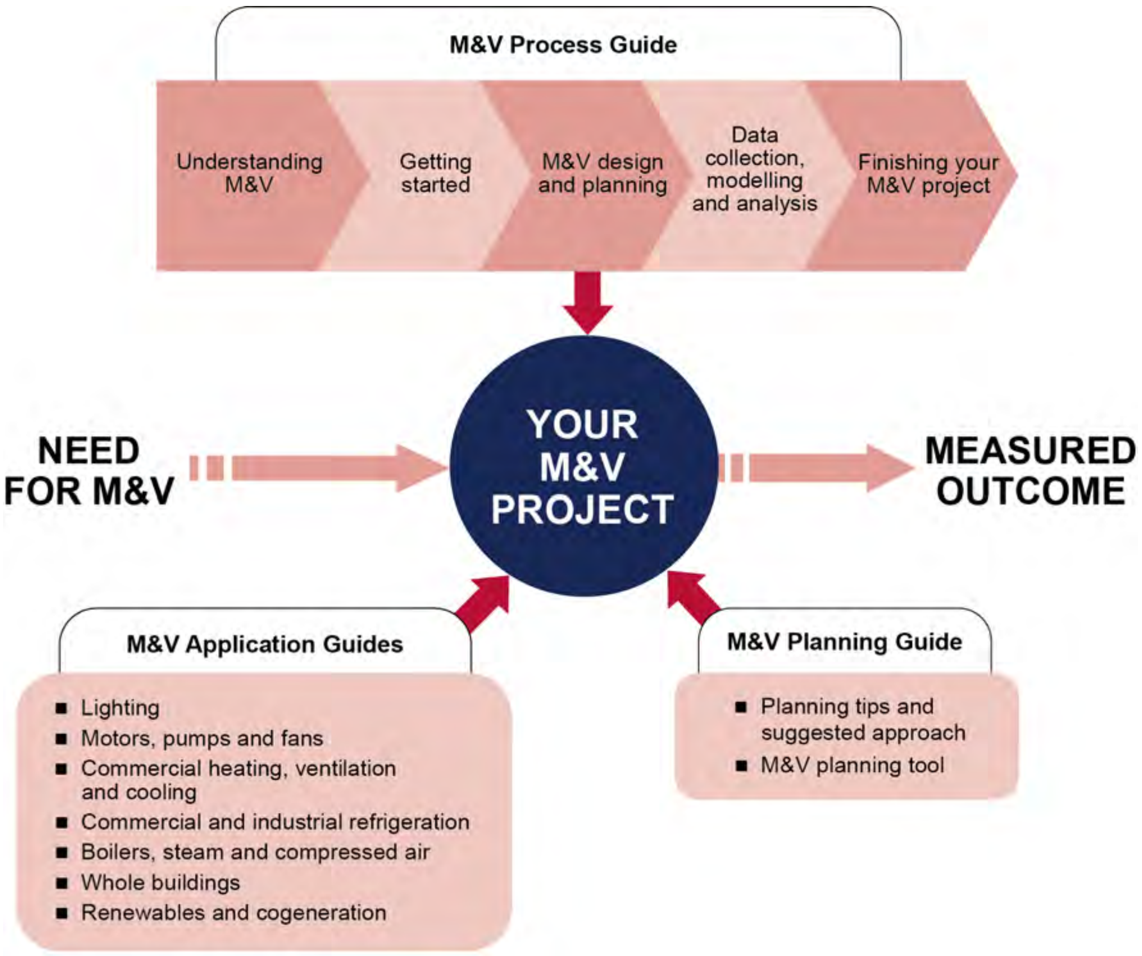
Planning Guide: The *Planning Guide* is designed to assist both new and experienced practitioners to develop a robust M&V Plan for your energy savings project, using a step-by-step process for designing a M&V project. A Microsoft Excel tool is also available to assist practitioners to capture the key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

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

[1] Source: www.energymanagementworld.org

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

Figure 1: M&V Operational Guide structure



1.2 The Motors, Pumps and Fans Applications Guide (this guide)

The *Motors, Pumps and Fans Applications Guide* provides specific guidance for conducting M&V for common projects that involve electric motors, pumps or fans. It is designed to be used in conjunction with the *Process Guide*, providing tips, suggestions and examples specific to motor related projects.

The *Motors, Pumps and Fans 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 motor, pump or fan 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 motor, pump or fan 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 motor and pump scenario	Appendix A illustrates the M&V process using a worked example of a project
▪ Example motor, VSD and fan scenario	Appendix B illustrates the M&V process using a worked example of a 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.

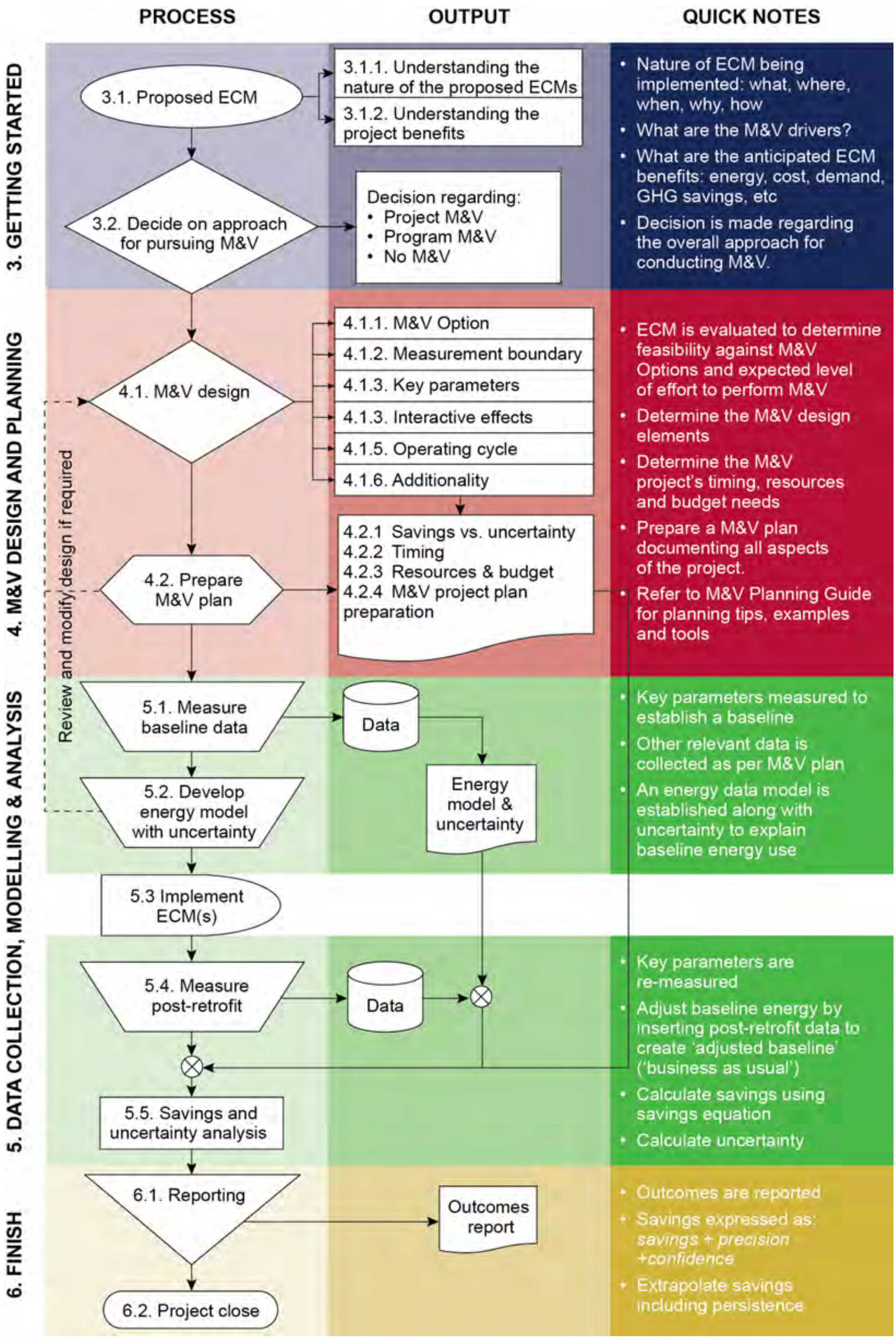
Table 1: Key M&V terms

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 *Pump, Motor and Fan 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 motor, pump and fan ECM(s)

3.1.1 Pump, motor and fan projects

Pumps and fans are driven by electric motors. Electric motors are also used to drive a broad range of machinery from compressors and machine tools right up to large conveyor belts or blowers. Power is delivered to electric motors which operate through the interaction of magnetic fields and current-carrying conductors to generate force.

A fundamental component of improving motor, pump or fan efficiency is to reduce the power delivered to motor as a function of the useful work output. This is achieved by increasing the efficiency of the motor, the efficiency of the transmission mechanism and by matching the load to the demand as accurately as possible.

Motor, pump and fan Energy Conservation Measures (ECMs) aim to reduce motor demand and/or energy use through:

1. reducing power draw by:
    a. improving motor efficiency
    b. improving efficiency of power delivered between the motor and working fluid, such as improving the efficiency of belts or couplings
    c. installing variable speed drives to motors
    d. properly matching the pump or fan system to demand
    e. eliminating voltage imbalance
    f. reducing friction by removing throttling of pumps and damping of fans
2. introducing or adjusting controls to limit operating times of motors, pumps and fans
3. combinations of 1 and 2 above

3.1.2 Key points to note

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

- All options are available, however typically, motor, pump or fan projects use M&V Option A or B, which treat the project in isolation, thus avoiding the need to deal with the effects of other systems - except where the performance affects another part of the system e.g. HVAC condenser fans and chillers.
- Identify independent variables that may affect before and after comparison include changing operating hours/patterns, seasonality, human behaviour.
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.
- The length of measurement is determined by the chosen option, and the desired level of accuracy.

Section 4.2 provides detailed information on other M&V considerations for motor, pump and fan projects.

3.2 Decide approach for pursuing M&V

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

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

4 M&V design and planning

4.1 M&V design

4.1.1 M&V Option

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

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

Typical projects	M&V Option	Key parameters		
		To measure	To estimate or stipulate	To consider
Changes in efficiency (input power draw versus work output requirement): ▪ Replace existing motor with a high efficiency Electronically Commutated (EC) or High Efficiency Motor (HEM). ▪ Motor, pump or fan major refurbishment. ▪ Replacing inlet vanes on fans with VSD for better control ▪ Matching motor, pump or fan system to actual demand: ▪ Installation of variable speed drive (by removing bypass value and installing associated isolation valving and controls). ▪ Impeller trimming for oversized pumps so they operate at highest efficiency and use less absorbed power. ▪ Replacing pump, drive or fan to properly match system demand and/or with higher efficiency. ▪ Reducing pipe / duct pressure losses: ▪ Unthrottle valves and change pump or impeller. ▪ Increasing pipe/duct diameters to reduce resistance where appropriate. ▪ Replace fan belt with high efficiency synchronous belt. ▪ Voltage optimisation / eliminating voltage imbalance.	OPTION A	Change in power draw	Work output requirement (e.g. production within in a process environment, or weather related for HVAC or refrigeration) Operating hours Interactive effects	Rebalancing to meet system demand Future plant capacity requirements Occupant comfort Interactive effects

Typical projects	M&V Option	Key parameters		
		To measure	To estimate or stipulate	To consider
Changes in controls: ▪ Reduction in plant and equipment operating times. ▪ Occupant push-button activation and timer control (e.g. for supplementary condenser water in meeting rooms). ▪ Installation of sensors to control fan or pump operation (e.g. to control contaminates such as carbon dioxide or carbon monoxide in car parks). ▪ Changes to set points for existing sensors such as indoor dry bulb temperature.	**OPTION A**	Operating hours	Changes in power draw Interactive effects	Occupant comfort Interactive effects Effects on existing motor VSDs
Combination of operational control and motor, pump or fan efficiency initiatives above and additional initiatives listed below: ▪ Installation of additional low-load / multiple pumps to reduce power draw during low demand periods and reduced operating hours for larger pumps.	**OPTION A**	Measure the parameter with the biggest impact or uncertainty on the accuracy of the outcome. **If both are unknown or uncertain, then Option A cannot be used.**	Estimate or stipulate the remaining key parameters, including: ▪ Changes in power draw ▪ Operating hours ▪ Interactive effects	Rebalancing to meet system demand Occupant comfort Interactive effects Effects on existing motor VSDs Choice of measurement boundary
All motor, pump or fan projects	**OPTION B**	Changes in power draw and work output requirement based on independent variables (e.g. operating hours, sensor based control)	Interactive effects	Rebalancing to meet system demand Future plant capacity requirements Occupant comfort Interactive effects
All motor, pump or fan projects	**OPTION C**	Whole facility energy consumption and Independent variables	Interactive effects	Estimated savings are “large” (>10% of baseline energy) Rebalancing to meet system demand Future plant capacity requirements Occupant comfort

Typical projects	M&V Option	Key parameters		
		To measure	To estimate or stipulate	To consider
Projects with no metered baseline	OPTION D	Actual energy consumption and Independent variables	Simulation input and modelling	Model calibration Modelling difficulty for certain building types/ECM's

4.1.2 Measurement boundary

Using M&V Option A or B, this is the part(s) of the motor, pump or fan system affected by the project. Similarly, for ease, the measurement boundary can be:

- divided into sections (sub-projects), or
- expanded to include foreign loads (e.g. connected power) if power draw, usage patterns and independent variables can be ascertained.

Using M&V Option C this is the whole facility, or a large segment covered by a utility meter or sub-meter. Using this Option may result in reduced data collection cost, however the boundary covered by the meter usually includes additional loads, which may introduce undue data analysis complexity. In addition, the predicted savings from the motor, pump or fan project should be 10% or more of the total meter usage, in order to use Option C.

Option D may be considered in the following situations:

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

Suggested ECM related measurement boundaries (for Options A/B):

- Motor only
- Motor and pump/fan only
- Motor pump fan + system

Option C is usually not a viable approach unless the site usage is very simple (e.g. pumping station) or the site undergoes significant retrofit to systems (switch CAV to VAV or flour mill motor upgrade) where contribution is significant.

4.1.3 Key parameters

The table below lists the key parameters to be considered when conducting M&V for a motor, pump or fan efficiency project.

Table 3: Key parameters to be considered when conducting M&V for motor, pump and fan projects

Parameter	Description
Power draw and energy use	For motor, pump or fan efficiency retrofit projects, the change in power draw or energy use to the motor relative to its work output is the key parameter to measure. For simplified M&V within motor, pump or fan control projects, it may be assumed that the work output requirement, or duty of the fan or pump system remains unchanged (constant). For more complex systems (e.g. where a VSD is already installed), instantaneous power draw will not be sufficient to determine the change in energy use and as such the power draw must be measured over a suitable baseline period (i.e. energy use). It is important to note that the name plate rating of a motor lists the power output, not the electrical input. To determine the electrical input (at full load) the efficiency of the motor must be considered. The loading of the motor must also be considered. Power draw is usually expressed in kilowatts (kW) for motors however small motors under 1 kW may be expressed in watts (W). Energy use is usually expressed in kilowatt-hours (kWh).
Operating hours	This is simply the amount of time the motor, pump or fan system operates. Control of operating hours is achieved using the following methods: ▪ manual control by staff (e.g. kitchen exhaust fan) ▪ automated controls such as time clocks to switch motors on and off at pre-determined times ▪ feedback sensors that monitor variables related to demand for work output (e.g. CO sensor may control when a car park exhaust fan turns on and off). ▪ combinations of above (e.g. time clock + feedback sensor). The operating hours are dictated by the installed controls and subsequent operating patterns of the motor, pump or fan system which may be influenced by: ▪ motor, pump or fan system type and application – HVAC, industrial processes, tools and machinery, utilities (e.g. water pumping) ▪ occupancy times – business hours, 24/7 operation, seasonality, public holidays ▪ operating times of site plant and equipment ▪ type, placement and use of controls ▪ weather effects – typically for HVAC systems that use pumps and fans ▪ staff culture or behaviour affecting manual controls. For motor, pump or fan control projects, the change in operating hours are a key parameter to measure. For simplified M&V within motor, pump or fan efficiency retrofit projects, operating hours may be assumed constant, depending on their variability and associated uncertainty.

4.1.4 Interactive effects

If the motor, pump or fan system is part of a larger process (e.g. heated water pumped through a boiler), then there may be interactive effects which should be considered and assessed. Efficiency retrofit projects on motors, pumps and fans that are part of a larger system may have an interactive effect on the other equipment due to:

- changes in flow rates and/or pressures
- changes in motor operating hours

If the change to the other equipment is minor, then its effects can be ignored. If the change is material, then the measurement boundary should be extended to include the other equipment.

In cases where the interactive effects are complex and overall savings are significant, it may be more practical and cost effective to use Option C and measure the whole facility energy use.

4.1.5 Operating cycle

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

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

Option	Measured parameter		
	Power draw	**Metered energy use**	**Independent variable linked to work output requirement (e.g. operating hours, CO sensor)**
A (power draw is key)	Short/instantaneous power draw during relevant time periods.	Not required unless load varies, then between one week and one month or periodic. Repeat periodically if seasonality is an issue (e.g. weather related, production levels)	
A (operating hours is key)			Typically between one week and one month or periodic. Repeat periodically if seasonality is an issue (e.g. weather related, production levels)
B	short/instantaneous power draw during relevant time periods	Not necessary for constant electrical loads For varying loads measure usage for one week to one month or periodic. Repeat periodically if seasonality is an issue (e.g. weather related, production levels)	Typically between one week and one month or periodic. Repeat periodically if seasonality is an issue (e.g. weather related, production levels)
C		At least one site operation 'cycle', that includes changes in other energy systems. For example 12 months baseline data is required where seasonality is a factor. Typically require at least three months of post-retrofit data.	At least one site operation 'cycle', that includes changes in other energy systems. For example 12 months baseline data is required where seasonality is a factor. Typically require three months of post-retrofit data.

Option	Measured parameter		
	Power draw	**Metered energy use**	**Independent variable linked to work output requirement (e.g. operating hours, CO sensor)**
D	For the baseline typically one site operation 'cycle' is modelled.	For the baseline typically one site operation 'cycle' is modelled.	For the baseline typically one site operation 'cycle' is modelled. This is validated with at least one 'cycle' of post-retrofit measurement. Within a motor, pump or fan project ,a 'cycle' may represent a day, week or longer, depending on operating variables (e.g. weekdays vs. weekends and seasonality such as climate)

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 table below outlines issues commonly found when conducting M&V on motor, pump or fan projects and provides suggested approaches for addressing them in you M&V plan and when executing the M&V project.

Table 5: Considerations, issues and suggested approach for pump, motor and fan projects

Consideration	Issue	Suggested Approach
Installing ECMs on motors with existing variable speed drives	Due to the variable nature of VSD's, ECMs that have an effect on existing VSD operation can introduce complexities and uncertainties in calculating the reduction in load and/or operating hours.	Understand the required work output for the motor. Measure or collate data for current VSD operational trends based on the influencing variables controlling the VSD frequency (e.g. pressure, CO_2). Determine if the required useful work output for the motor will change. If not, then either an Option A or B approach can be adopted (e.g.: changing the belt type for a belt-driven supply air fan fitted with a VSD – the air flow requirements remain the same). If the required useful work output will change materially, then an Option A approach should not be considered. Adopt an Option B approach to measure both the input energy use and the required work output. Be careful when using data from the VSD (such as frequency as a proxy for work requirements as this relationship may change as a result of implementing the ECM. We need to base our energy model on data from the independent variable itself
Maintaining comfort conditions	ECMs for a motor, pump or fan system that are part of a large HVAC system may result in changes in comfort conditions.	Ensure the HVAC system can meet the demand, particularly during maximum demand periods. This may require reviewing design documentation and specifications and recalculating heat loads to ensure sufficient HVAC capacity and associated flow rate and pressure is available. Comfort conditions should be monitored to confirm that they have been maintained or improved.
System demand	Any retrofit project to a motor, pump or fan must ensure the system demand can be satisfied.	As with occupant comfort, this may require reviewing existing design documentation and specifications. Consideration to future system demand changes and capacity requirements (e.g. plant expansion) should also be considered.
Power factor	Potential changes in power factor, which might affect demand and thus cost savings.	Technology retrofits may affect the power factor within the M&V boundary. The proposed approach is: 1. estimate the power factor before and after the retrofit by conducting measurements or reviewing equipment specifications. If the change is minor, then its affects can be ignored. If the change is material, then: 2. Determine if the change in power factor is likely to affect overall site maximum demand (if this is an energy cost item). *Does the motor, pump or fan system operate at peak demand times?* *Will an existing power factor correction unit negate this issue?* 3. If maximum demand is affected, then apply the appropriate demand cost rates to calculate the financial impact.
Persistence and	The savings calculated from	When extrapolating the savings verified during the

extrapolation	short-term measurements are often extrapolated to 'estimate' annual project savings. It is important to incorporate additional factors, which may include: reliance on human behaviour seasonal effects (weather, holidays, etc) varying work output requirements (e.g. production levels, throughput) calibration changes and failures likelihood of future changes within the measurement boundary.	post-retrofit period to estimate annual savings, it is important to identify influencing factors and assess their impact. If minor, they can be ignored. If material, the M&V plan should document how they are to be addressed. Examples include: a. repeating M&V at various times throughout the year b. collecting appropriate data (such as site closure dates and public holidays) and adjusting accordingly c. combining short-term measurement of power draw with more periodic measurement of control (e.g. human behaviour) d. occasional spot measurements to verify assumptions e. collecting data relating to work output requirements and applying to a developed energy model
Entire pump, fan system replacement	A pump or fan and its associated motor are replaced with newer technology	This is a typical ECM and should not pose any major issues. Confirm that the new system meets the required performance levels. The required work output should remain unchanged we can focus on the change in input energy by developing and comparing appropriate energy models.
Changes to load requirements due to pipe/duct network modifications	The area/system supplied by the pump or fan is altered so that the work output requirements have changed	This may be an ongoing change (e.g. installing isolation valves) or a static change (e.g. changes to ductwork layout), and should be considered on its merits. The change may not be due to an ECM (e.g. renovation or extension), but may affect savings on an existing one. This poses issues for Option A M&V where the work output requirement was estimated. Essentially the work output requirement has changed and needs to be incorporated into analysis.

5 Data collection, modelling and analysis

5.1 Measure baseline data

5.1.1 Determine existing motor, pump and fan inventory

If not already done, catalogue the baseline motor, pump and fan inventory, including:

- Motor, pump and fan application, types and model numbers.
- kW or W rating of motors, speed
- Type of motor starter (e.g. Direct-On-Line (DOL) or Variable Speed Drive (VSD)).
- Type of connection between motor and equipment, (e.g. belt driven, direct driven, gearbox etc).
- Controls such as sensors or time clocks.
- Plant operation times.
- Control set points such as temperature or pressure.
- The inventory may be best represented in a spreadsheet which enables application of results of measurements and “what-if” demand calculations.

5.1.2 Measurement data sources, measurement tools and techniques

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 and take lots of photographs.
- Collect any associated data required for calculating baseline energy use or adjustments for independent variables.

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
Power draw	Instantaneous measurement using current and voltage meter	Appropriate for Option A where hours are estimated. Use calibrated equipment and measure current, voltage and power factor in order to evaluate energy and demand savings. Appropriate for Option B where motor power draw will be constant.
	Manufacturers’ product specifications	Can be used when power draw is estimated (as it is not being measured) when Option A is used.
Energy usage	Utility bills	Typical frequency of one to three months. Can be used for Option C, and are considered 100% accurate, when not estimated by the supplier.
	Revenue meter – interval data	Typically 30 minute data intervals, which can be used to accurately calculate savings across a day, week or longer. Can also be used to estimate operating hours based on profile changes. Data provided by a Meter Data Agent is used for billing and is considered 100% accurate.

Data Type	Source	Comments
Energy usage	Permanent sub-meter or BMS trend log – 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.
Work output requirements (i.e. independent variables such as operating hours, temperature, pressure, liquid flow, CO/CO_2 sensors)	Security system records (access swipe cards)	Time stamped records may be available from security systems, which may assist with tracking occupancy and operating patterns.
	Existing metering or temporary data logging	Electrical load profiles can be used to interrogate when electrical motors turn on and off. Temporary temperature or vibration data loggers could also be fitted to a motor's casing which could be a cost effective method for ascertaining operating hours.
	Plant and equipment control schedules/settings (e.g. time clocks, building management systems, run on time settings, VSDs)	Fixed or logic based control parameters that are in place for the motor, pump or fan system. The control system can usually be interrogated to extract the controlling variable however this may require timed observations (see below).
	Production schedules	Production schedules can be used to interrogate when a particular system was operating
	Timed observations	Manual readings taken periodically to approximate the work output for an area or control patterns for a motor, pump or fan system. This is time intensive, but may be achieved using a data log sheet filled in by various staff as they come and go.
	Facility management records including BMS or SCADA system trend logs	Trend logs may be configured within control systems to record relevant work output variables. These will usually be automated sensors which provide feedback to the motor via the control system. Operating schedules can also be obtained.
	Business hours of operation schedules	Published business schedules, such as stated hours of operation including public holidays or non-occupancy periods.

5.1.3 Conducting measurements

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

Table 7: Methods for conducting electrical measurements

Technique	Placement	Guidance
Direct measurement of whole measurement boundary	Energy meter or data logger that covers all energy use within the measurement boundary	This provides highly accurate project measurements. Should a meter or logger be placed where it covers several motor systems with different operating patterns, then an instantaneous ‘load test’ could be conducted where each motor system is operated separately to determine the power draw (providing the motor loads are stable), from which the relevant operating hours could be applied.
Various direct measurements at selected motors	Energy meter or data logger connected to relevant motor circuits	This approach may be necessary for large, complex or distributed projects. Logging selected switches/circuits enables different motors to be segregated and savings can be calculated separately and in aggregate. Consistent results may be extrapolated across the project. For example, various metering points may be required to measure the effects of an ECM that will affect a distributed conveyor system.
Direct measurement using a sample based approach using selected motors	Temporary data logger (for energy use) or instantaneous power meter (for power draw) measures selected motors	Measuring instantaneous power load for motors before and after retrofit may be very cost effective if motor loads are stable. It is important that the number of motors involved (before and after) is known to correctly calculate savings. This may be supplemented with measurements elsewhere within the project to ensure all system losses are captured. This is not suitable for motors with variable speed drives or variable system loads.

Measurements for output parameters can be conducted as per the following table.

Table 8: Methods for conducting measurements of output parameters

Technique	Placement	Guidance
Direct measurement by appropriate measurement device (e.g. motor vibration meter and button temperature logger).	The placement is dependent on the type of measurement device used. Refer to product instructions.	It is important to ensure the measurement device collects data as accurately as possible. As such, the position and configuration of the measurement device should be carefully considered to avoid failures or registration of false readings.
Indirect measurement using energy load profile data	Data is derived from electrical measurement	Applicable for determining operating hours. Depending on the meter placement and level of data resolution, motor operation can be clearly visible on load profiles. The observed on/off times can be used to create an operation schedule. Please note: ▪ Typical revenue meter data summates in 30 minute intervals, and rapid or complex switching may not be accurately observed. ▪ Temporary data loggers can often record data in shorter time intervals. ▪ Interval data may include a variety of loads and deciphering the correct operating patterns with certainty may not be possible.

5.2 Develop energy model and uncertainty

Typically for motor, pump or fan projects, an energy model will be established for the associated motor that will take on the following form:

$$Energy\ consumption\ (kWh) = \sum_{t=1}^{n} motor\ power\ draw(kW_t)x\ \Delta t$$

Where

kW_t is the average motor power draw at time interval Δt.

Motor power draw will fluctuate as the loading on a motor changes. Where motor power draw is constant, the equation above can be simplified to:

$$Energy\ consumption\ (kWh) = motor\ power\ draw\ (kW) \times time\ (hours)$$

Note that the energy consumption calculated above is derived from measurements of motor power draw which is dependent on the loading of the motor. Where the motor loading is likely to change, power draw should be measured over an extended period and the first equation above should be applied.

The term 'load factor' is used to describe the extent to which a motor is loaded. It is determined as follows:

$$Load\ factor = \frac{average\ load\ (kW)}{motor\ rating\ (kW)}$$

Where the motor power draw cannot be measured, load factor should be used in conjunction with the information from the motor name plate to determine motor rating (electrical input) and estimate motor power draw:

$$motor\ power\ draw\ (kW) = \ motor\ rating\ (kW_e) \times load\ factor$$

Where:

$$motor\ rating\ (kW_e) = \frac{motor\ name\ plate\ (kW_{NP})}{motor\ efficiency}$$

The motor demand model will take on the following form:

$$Electrical\ demand\ (kW) = \frac{power\ draw\ (watts)}{1000}$$

For single phase motors, the power draw is:

$$motor\ power\ draw\ (kW) = \frac{voltage\ (V) \times current(I) \times power\ factor}{1000}$$

For three phase motors (balanced load), the power draw is:

$$motor\ power\ draw\ (kW) = \ \sqrt{3}\ \times (voltage_{LN}(V) \times current(I) \times power\ factor \times \frac{1}{1000}$$

Where:

$voltage_{LN}\ (V)$ is the voltage as measured between the line and neutral

$current(I)$ is the current measured through one of the phases

More complex energy models may be developed using regression and analysis for motor, pump and fan projects, typically if the load (wattage) and operating hours are variable and suitable independent variable(s) can be identified e.g. chilled water load, weather, etc.

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.

Motor electrical load will vary dependent on the motor's load, and cannot simply be read from the motor name plate. As an alternative to direct measurement of motor power draw, motor electrical load can be calculated from name plate and other details as follows:

1. Measure motor shaft speed (RPMs) using a tachometer or similar (*'measured RPM'*)
2. Obtain the following data from the motor name plate or from the manufacturer:
   - Motor shaft output power (kW_{NP})
   - Full load shaft speed ('full load speed RPM') (RPM)
   - Motor efficiency (fraction or %)
   - Number of pole pairs for the motor

3. Determine 'no load' motor speed:

$$No\ Load\ speed(RPM) = \frac{50\frac{cycles}{second} \times 60\frac{seconds}{minute}}{number\ of\ pole\ pairs}$$

Note: The electricity supply frequency in Australia is 50 cycles per second or 50 Hz. For example a 2-pole pair motor has a No Load Speed of 1,500 RPM.

4. Calculate full load slip (design slip):

$$Design\ Slip\ (full\ load\ slip) = \ no\ load\ speedRPM - full\ load\ speed\ RPM$$

5. Calculate actual slip:

$$Actual\ Slip\ \ = \ no\ load\ speedRPM - measured\ RPM$$

6. Calculate load factor which is a measure of how loaded the motor is:

$$laod\ factor = \frac{Actual\ Slip}{Design\ Slip}$$

7. Finally, calculate the motor input power draw using:

$$motor\ wattage\ (kW_e) = \frac{kW_{NP} \times\ load\ factor}{motor\ efficiency}$$

Note that care should be taken with the approach above for old or rewound motors as details from the name plate may not be available or may no longer be accurate.

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

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

5.5.1 Savings equations

The general equation for energy savings is:

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

In the case of motor, pump or fan projects, energy savings can be calculated as:

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

Where:

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

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

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

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

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

The installation of new pumps, motors and fans generally results in an overall demand reduction. The general equation for calculating demand savings is:

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

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

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

$$= ([kW\ savings]\ x\ [monthly\ demand\ cost\ rate]\ x\ 12)$$

$$+ ([kWh\ savings]\ x\ [energy\ cost\ rate])$$

5.5.2 Extrapolation

If a sample-based approach is used (selected motors and/or sites), then extrapolate across the project's measurement boundary or across the population.

Extrapolate the calculated savings for the measured period as required.

5.5.3 Uncertainty

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

6 Finish

6.1 Reporting

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

6.2 Project close and savings persistence

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

- An inspection of the area to ensure equipment remains consistent with that specified in the installation.
- Review of pump/fan fluid flow and head characteristics.
- Review of valve/damper positions.
- Review of wire to air/water efficiency (i.e. motor input vs. power imparted to the fluid).

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 9: 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 10: 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

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

A beer brewery company wants to reduce its energy use. The brewery contains a glycol beer cooling system which comprises a duty and standby pump each directly coupled to a 112 kW electric motor. The cooling system demands a constant flow rate of 5,455 litres per minute. The duty and standby pumps are rotated on a weekly basis with the cooling system operating 24 hours with an average shutdown time of 2 weeks per year.

A recent energy audit was conducted on the pumping system with the following findings:

- The gate valve on both pump discharge was substantially closed.
- Recent pressure measurements show the pumps produce 90 meters of head.
- It was calculated 70 percent of the 90m head produced by the pumps was being consumed by the substantially closed gate valve on each pump discharge.
- The original design specification states the system requires 30m of head and 5,455 litres per minute to operate at peak system pressure (maximum required flow).
- The pumps have an impeller diameter of 432 mm.

The energy auditor advised the duty and standby pump and motor had been oversized in the original design and recommended to properly match the pumping system to the system demand by implementing the following:

- Trim the pump impeller diameters to 300 mm.
- Replace the two 112kW motors with new high efficiency 56kW motors.
- Fully open the gate valves on the pump discharge.

The energy auditor guarantees the pumping load will reduce by 30%.

Getting started

Budget

The required output from the M&V exercise is to confirm the level of savings being achieved from the pump efficiency project are greater than 30%. An external consultant will be engaged to conduct the M&V project and a budget of $2,000 is allocated. This represents less than 3% of the estimated savings from the project. With such a small budget available, M&V Option A has been chosen.

Key parameter(s)

The project involves retrofits to the supply pumps that aim to improve their efficiency. Power draw has been determined to be the key measurement parameter. The work output is the amount of fluid pumped, which is a function of flow rate and operating hours. Neither of these parameters is predicted to materially change, and so they will be stipulated.

Measurement boundary

The measurement boundary is chosen to be the two pumps and associated motors that supply the glycol beer cooling system.

Approach for conducting measurement

As the operation of the pumping system remains constant, instantaneous readings of input motor power will be taken at the switchboard the day before the efficiency retrofit project.

The same measurements will be repeated two weeks after the efficiency retrofit to allow an even rotation of duty/standby pumps and some time for "bedding in".

Measurement is to be conducted by a qualified electrician and the estimated time for conducting measurements is 60 mins each time.

Pump and motor inventory

The existing and pump and motor system inventory is shown below:

Pump Specifications		**Motor Specifications**	
Pump type	Single Stage Centrifugal	**Motor Type**	AC Induction 3 phase 4 pole
Motor Make/Model	[*Make & Model Number*]	**Motor Make/Model**	[*Make & Model Number*]
Pump Flow Rate (max)	6,160 L/min	**Power Supply**	415 Volts 50Hz
Pump Head	90m measured (100m max)	**Rated Motor Power**	112 kW
Pump Impeller Diameter	432 mm	**Rated Motor Efficiency**	87%
Operating Pressure (max)	1,600 kPa	**Motor Speed**	1,300 rpm
Discharge Valve Type	Gate valve (X% closed) 63m calculated pressure drop	**Drive Type**	Direct-On-Line (DOL)
Application	Glycol/chilled water beer cooling system, constant flow rate through chiller of 5,455 L/min		
Control Type	Manual on/off		
Operating Times	24/7 (typical shutdown duration of 2 weeks per annum)		
Comments	Duty/standby pump and motor arrangement rotated on a weekly basis		

Operating hours

The cooling system runs continuously and is controlled by the plant operator to rotate the duty and standby pumps on a weekly basis for maintenance. The operating hours are not affected, so the baseline and post-retrofit period are stipulated. In order to confirm this, annual operational records have been reviewed and anecdotal evidence from the brewery management staff indicates the plant is typically shutdown for 2 weeks during the holiday break.

The operating hours for the cooling pump and motor system are:

Operating hours = 24 hours/day x (365 days – 14 days)/annum = 8,424 hours per annum

Interactive effects with refrigeration system

The application of the pump and motor efficiency retrofit project may affect the operation of the chiller which cools the chilled water and glycol fluid. This is because the flow rate through the chiller may be altered slightly from the efficiency retrofit and the opening of the gate valves.

It is likely such interactive effects will negligibly benefit/burden these systems and thus may be ignored for the purpose of the motor and pump efficiency M&V.

Summary of M&V plan

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

Item	Plan
Project summary	Retrofit to two 112 kW pumps which circulate glycol within the industrial refrigeration plant. The pumps are oversized for the application and the circuit is throttled via a gate valve as a consequence. The retrofit actions involve: ▪ Trimming the pump impeller diameters from 432 to 300 mm. ▪ Replacing the two 112kW motors with new high efficiency 56kW motors. ▪ Fully opening the gate valves on the pump discharge
Required outcome	To confirm that savings of 30% or more are being achieved from the pump and motor efficiency project.
Budget	$2,000
M&V Option	Option A – Project Isolation Key Parameter Measurement
Measurement boundary	Two 112 kW glycol pumps and associated motors. The pumps cycle between duty/standby,
Key measurement Parameters	Power draw
Other parameters to consider	operating hours
Potential interactive effects	Potential for minor flow rate changes, which may affect chiller operation
Approach for conducting measurement and collecting data	Power draw: Instantaneous power readings are to be measured of the each pump prior to and post-retrofit. Operating hours: to be estimated following a review of historical operation schedules
Measurement equipment required	A true rms power meter will be used to measure the voltage and current and determine the real power draw of each pump.
Measurement period	Instantaneous measurement conducted prior to retrofit, and repeated once the ECM has been installed.
Approach for calculating results	Savings are to be estimated by multiplying the estimated operating hours by the change in average power draw from the two pumps. Cost savings will be calculated using an average rate of $0.153/kWh. Uncertainty will be calculated using statistical methods by determining the overall standard error, absolute precision and relative precision to 90% confidence level.

Conducting measurements

The baseline and post-retrofit power draws were determined by measuring real power by connecting the line current (via a current transformer) and voltage using a digital true rms power meter. Each measurement was held for approximately 15 seconds to ensure that a steady-state reading was obtained.

To establish the baseline, the input motor power to the duty pump (which was currently in operation) measured a constant 110.2 kW. The duty pump was then shutdown and the standby pump was started. Once a steady state was reached by the standby pump, the input motor power was measured at a constant 109.8 kW.

The process was repeated for the post-retrofit period. For the duty and standby pump stated above, the input motor power measured a constant 54.5 kW and 53.2 kW respectively.

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

Calculating savings

Since the duty and standby pumps are evenly rotated on a weekly basis, the average of the pre and post retrofit readings can be used to calculate the reduction in power draw:

Average pre-retrofit load = (110.2 + 109.8) / 2 = 110.0 kW

Baseline energy use = 110.0 kW x 8,424 hours per annum

= 926,640 kWh pa

Baseline energy cost = kWh_{base} x average cost rate

= 926,640 kWh x $0.153

= $141,776

Post-retrofit:

Average post-retrofit load = (54.5 + 53.2) / 2 = 53.85 kW

Post-retrofit energy use = 53.9 kW x 8,424 hours per annum

= 453,632 kWh pa

Post-retrofit energy cost = $kWh_{post\text{-}retrofit}$ x average cost rate

= 453,632 kWh x $0.153

= $69,406

Thus, savings are:

Demand saving = 110.0 – 53.85 = 56.15 kW

Energy saving = 926,640 kWh - 453,632 kWh = 473,008 kWh

Cost saving = $141,776 - $69,406 = $72,370

% saving = 473,008 / 926,640 = 51%

Estimating uncertainty

Option A provides the simplest and most inexpensive method of M&V; however this may result in higher levels of uncertainty. The level of accuracy is determined by the accuracy of the equipment inventory, the estimation of the operating hours and the capability of the metering equipment.

The manufacturer's specification for the power meter was consulted and it was found the measurement relative precision is ±1.0% of the reading. This is assumed to be with a confidence level of 95%. It is noted the power reading was taken within the acceptable limit ranges for temperature, frequency, current and voltage.

Further analysis was also carried out to quantify the uncertainty of the stipulated operating hours. The Site Manager advised that plant operation has been consistent without any major changes in the past 5 years. A statistical analysis of operational records over the past 5 years show mean annual operating hours of 8,424 hours per annum with an absolute precision of ±72 hours at a 95% confidence level. This can be calculated to a relative precision of ±0.9% (rounded up). Management also advised they don't foresee any major operational changes over the next few years.

A summary of values used in calculating the uncertainty is presented in the table below.

	Measured power draw (kW load)	**Stipulated operating hours**
relative precision	±1.0%	±0.9%
measured value(s)	Pre retrofit 1 (A): 110.2 kW Pre retrofit 2 (B): 109.8 kW Post retrofit 1 (C): 54.5 kW Post retrofit 2 (D): 53.2 kW	8,424 hours per annum
samples	∞	5
confidence factor	95%	95%
t-value (t)	1.96	2.78

Note: For power draw it is assumed that the accuracy of the power meter has been extensively tested by the manufacturer across a large sample set – hence the number of samples has been chosen as infinity.

The t-values have been obtained from Table 27 within Appendix G of the *Process Guide* by referencing the column representing 95% confidence, and using look up values for degrees of freedom as follows:

- Operating hours - DF_{hours} = 5 -1 = 4
- Power draw – $DF_{power\ draw}$ = ∞

Uncertainty is estimated as follows:

1. Calculate the standard error for each input
2. Calculate the standard errors for change in power draw and operating hours
3. Calculate the standard error for energy savings
4. Calculate the absolute precision of the energy savings (based on confidence)
5. Calculate the relative precision of the energy savings

The standard error (SE) of measured loads and stipulated hours is calculated using the equation below:

$$\text{SE} = \frac{relative\ precision\ \times\ measured\ value}{t}$$

Using the values from the previous table, $SE\ (A\ kW)$ is calculated as follows:

$$SE\ (\text{A kW}) = \frac{0.01\ \times\ 110.2}{1.96}$$

$$= 0.562$$

Repeating the process for other measurements, the results are:

$$SE\ (B\ kW) = 0.560$$

$$SE\ (C\ kW) = 0.278$$

$$SE\ (D\ kW) = 0.271$$

$$SE\ (hours) = 27.272$$

The reduction in kW load is calculated from the difference between the average pre and post retrofit measured kW load. Therefore, the standard error for the change in kW load is calculated as per the following:

$$\text{SE}(\Delta\text{kW}) = \sqrt{SE\ (A\ kW)^2 +\ SE\ (B\ kW)^2 +\ SE\ (C\ kW)^2 +\ SE\ (D\ kW)^2}$$

$$\text{SE}(\Delta\text{kW}) = \sqrt{0.562^2 +\ 0.560^2 +\ 0.278^2 +\ 0.271^2}$$

$$SE\ (\Delta kW) = 0.883\ \text{kW}$$

The standard error of the energy savings is calculated:

$$SE\ (kWh\ savings) =\ savings(kWh)\ \times\ \sqrt{\left(\frac{SE(\Delta kW)}{\Delta kW}\right)^2 + \left(\frac{SE(hours)}{hours}\right)^2}$$

$$SE\ (kWh\ savings) =\ 473{,}008\ \times\ \sqrt{\left(\frac{0.883}{56.15}\right)^2 + \left(\frac{27.272}{8424}\right)^2}$$

$$SE\ (kWh\ savings) = 7{,}594\ \text{kWh}$$

Absolute precision (AP) can be calculated using the t-value for more than 30 readings. The t-value can be found within Table 27 of Appendix G within the *Process Guide*.

$$AP = t\ \times SE$$

Relative precision (RP) is then calculated to be:

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

In the table below, absolute and relative precision are calculated at various levels of confidence by applying the appropriate t-value:

Confidence Level	**50%**	**80%**	**90%**	**95%**
t-value	0.67	1.28	1.64	1.96
Absolute Precision (AP)	= 7,594 x 0.67 = 5,088 kWh	= 7,594 x 1.28 = 9,720 kWh	= 7,594 x 1.64 = 12,455 kWh	= 7,594 x 1.96 = 14,884 kWh
Relative Precision (RP)	= 5,088 / 473,000 = 1.1%	= 9,720 / 473,000 = 2.1%	= 12,455 / 473,000 = 2.6%	= 14,884 / 473,000 = 3.1%

Reporting results

Finally, the energy savings can be expressed as:

It is 90% probable that the energy savings will equal 473,008 kWh per annum ± 2.6%. In other words, it is 90% probable that the annual energy savings will range between 460,545 and 485,455 kWh per annum.

The figures are more appropriately quoted as 473,000 kWh per annum ± 2.6% with 90% confidence.

Appendix B: Example scenario B

The scenario below provides details of how **Option B** is used to measure and verify the savings from a car park exhaust VSD project.

The body corporate of a large residential apartment complex wants to reduce energy consumption and associated costs. The apartment complex has a large underground car which contains a 24 kW exhaust fan to remove carbon monoxide (CO) and other exhaust particulates. The car park exhaust fan currently operates 24 hours, 7 days per week irrespective of vehicle traffic. Vehicles enter and exit the car park through a boom gate which requires swipe card access where a date/time stamp is recorded on the Building Management System (BMS) for security purposes.

A recent energy audit suggested installing a Variable Speed Drive (VSD) on the car park fan and a number of CO sensors throughout the car park to control fan speed proportional to minimum and maximum CO predefined set points. The sensor with the maximum CO reading will drive the fan operation. The fan will not operate if all the CO readings are below the minimum set point and will ramp up to maximum speed if any of the sensors exceed the maximum CO set point.

The body corporate is able to apply for a government grant to support project funding it can be demonstrated the energy savings have been calculated with a precision of +/- 20% at 80% confidence using the M&V principles of IPMVP.

Getting started

Budget

The VSD retrofit project is expected to save approximately $15,000 per annum. Since it is important to get the M&V right to apply for the government grant, an initial M&V budget of 10% of estimated savings ($1.500) will be allocated.

Key parameter(s)

Daily energy consumption will be the key parameter to measure. Since the fan currently operates 24 hours, 7 days per week irrespective of vehicle traffic there will be no independent variables during the baseline measurement period.

During the post retrofit project, the daily energy consumption of the fan will be dependent on the daily number of vehicles entering and exiting the car park which will be a key parameter to measure.

Measurement boundary

The measurement boundary will encompass the car park exhaust fan and motor. No other equipment will be within this boundary.

M&V Option

M&V Option B has been selected since both the car park exhaust fan load and operating hours will be affected by the VSD retrofit project.

Approach for conducting measurement

Fan energy consumption will be measured by installing a temporary electrical data logger at the mechanical switchboard circuit that powers the fan motor. The data logger will remain during the baseline and post retrofit periods.

Once the post retrofit period concludes, the BMS system will be interrogated to extract vehicle entry and exit date/time stamp data. The data will be manipulated to count the number of vehicle entries and exists for each day during the 2 week post retrofit period.

An energy model will be developed for the post retrofit fan operation which relates daily fan energy consumption to daily vehicle entry/exit numbers. The energy model will then be used to extrapolate expected energy savings across an entire year using the previous year's vehicle exist and entry time stamp data which is assumed representative.

Interactive effects

No significant interactive effects are anticipated.

Performance

The performance of the car park exhaust system will not be affected as the minimum and maximum CO set points have been selected to meet applicable standards and codes.

Summary of M&V plan

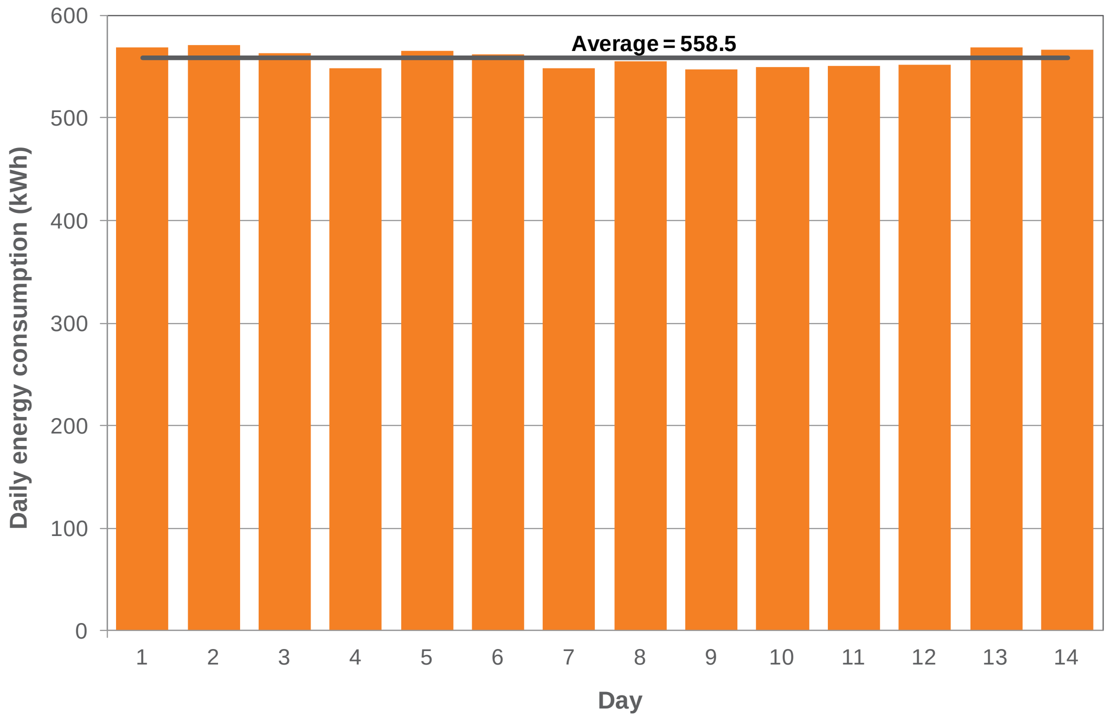
The key elements of the project's M&V plan in summary are:

Item	Plan
Project summary	VSD retrofit project to car park exhaust fan using CO control. Energy savings are expected due to the reduced fan load and operating hours. A VSD will need to be installed to the fan motor located in a basement plant room. CO sensors will be installed and wired throughout the car park and connected to the BMS which controls the fan.
Required outcome	Demonstrate energy savings have been calculated with a precision of +/-20% at 80% confidence using the M&V principles of IPMVP.
Budget	The actual budget ($1,960) is slightly higher than the initial budget of $1,500 however it is within an acceptable limit. **Total budget: $1,960** Data logger hire: $1,000 (5 weeks @ $200 per week) Data logger setup/installation/removal: $360 (4 hours @ $90/hour) M&V data collation/analysis/report: $1,200 (8 hours @ $150/hour)
M&V Option	Option B – Full Parameter Measurement
Measurement boundary	Car park exhaust air fan and motor
Key measurement Parameters	Daily energy consumption and daily number of vehicles entering/existing the car park

Item	Plan
Other parameters to consider	Performance - car park CO levels remain below the maximum threshold as per the relevant standards and codes.
Potential interactive effects	There may be additional electricity consumed through the communications and control network between CO sensors, BMS and car park fan VSD. This has been assumed insignificant.
Approach for conducting measurement and collecting data	Place temporary electrical data logger at the mechanical switchboard circuit that powers the fan motor. The data logger will remain during the baseline and post retrofit periods. BMS system will be interrogated after the post-retrofit period to extract vehicle entry and exit date/time stamp data.
Measurement equipment required	Electrical data logger
Measurement period	The VSD retrofit project will be implemented during the Christmas holiday period. Baseline measurements will occur 2 week prior and post-retrofit measurements will occur 2 weeks after the VSD retrofit.
Approach for calculating results	An energy model will be developed for the post retrofit fan operation which relates daily fan energy consumption to daily vehicle entry/exit numbers. The energy model will then be used to extrapolate expected energy savings across an entire year using the previous year's vehicle exist and entry date/time stamp data which is assumed representative.

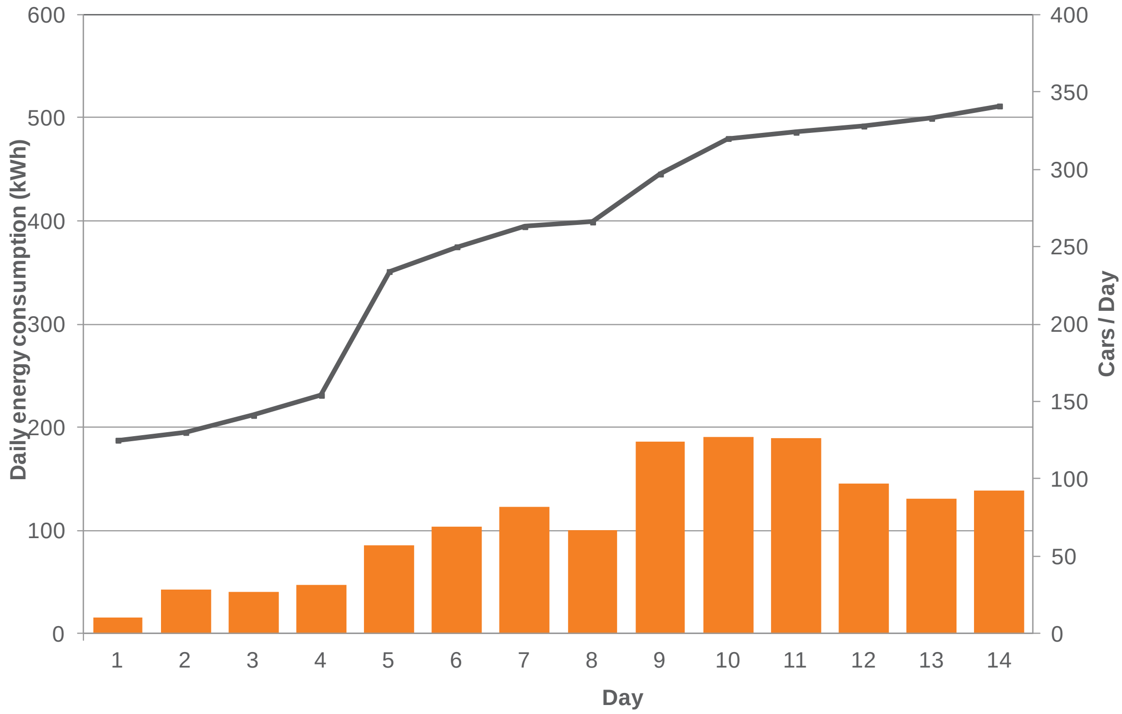
Conducting measurements

The chart below shows the daily measurements of the car park exhaust air fan energy consumption over the 2 week baseline measurement period. Daily energy consumption remains relatively constant between 500 and 600 kWh per day.



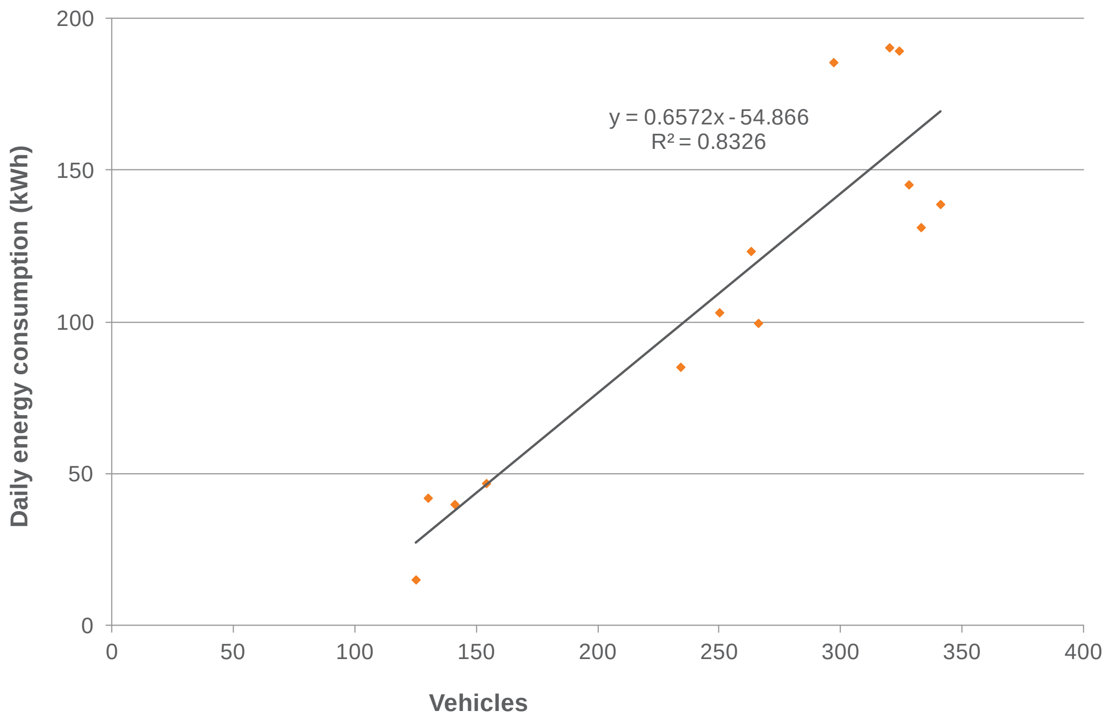
The total consumption measured across the 14-day baseline period is 7,820 kWh.

The consumption for the post-retrofit period is shown in the chart below. The chart also includes data for the number of cars per day that frequent the car park.



The total consumption measured across the 14-day post-retrofit period was 1,536 kWh.

The chart below shows the regression analysis results of the daily measurements of the car park exhaust fan energy consumption over the 2 week post-retrofit measurement period correlated with the daily vehicle entry/exit numbers.



Developing an energy model

The energy model for the baseline period is simple; the daily car park exhaust fan energy consumption is simply the average hourly consumption across all intervals (558.5 kWh/day), as seen in the previous baseline chart.

Developing an energy model for the post retrofit period is more complex and a relationship between the daily number of vehicle entry/exit and daily car park exhaust fan energy consumption needs to be established.

From the chart above, the energy model for the post retrofit data will be:

$$daily\ energy\ consumption\ (kWh) = 0 \qquad (x \leq 83)$$

$$daily\ energy\ consumption\ (kWh) = 0.6572x - 54.87 \qquad (x > 83)$$

where x is the daily number of vehicle entries and exits.

Only the coefficient of determination will be used to test the statistical validity of the regression model. Since R^2 is greater than 0.75, it is assumed the model is statistically valid for the purpose of this example.

Calculating savings

During the baseline, the total energy consumption is 7,820 kWh. During the post-retrofit period, the energy consumption was 1,536 kWh.

As we have like-for-like time periods and no other basis for adjustment, we can calculate savings as follows:

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

$$= \ 7{,}820 - 1{,}536$$

$$= \ 6{,}284\ kWh$$

However, we wish to extrapolate these savings across an entire year using the previous year's vehicle entry and exit date/time stamp data. To do this, the previous year's daily vehicle entry and exit numbers will be applied to the post retrofit model to calculate the predicted energy consumption which will then be subtracted from the baseline model (average daily energy consumption of 558.5 kWh).

This is achieved through the following equation:

$$Annual\ energy\ savings\ (kWh) = \sum_{i=1}^{n} 558.5 - E_i$$

Where

E_i is the daily energy consumption that is calculated from the post-retrofit energy model, namely:

$$daily\ energy\ consumption\ (kWh) = \ 0 \qquad (x \leq 83)$$

$$daily\ energy\ consumption\ (kWh) = \ 0.6572x - 54.87 \qquad (x > 83)$$

And:

x = number of vehicles

The table below illustrates the results of this calculation across a typical week:

Day	Cars	Baseline (kWh)	Post-retrofit (kWh)	Savings (kWh)
1	348	558.5	173.8	384.7
2	360	558.5	181.7	376.8
3	296	558.5	139.7	418.9
4	254	558.5	112.1	446.5
5	243	558.5	104.8	453.7
6	115	558.5	20.7	537.8
7	146	558.5	41.1	517.5

Using day 4 as an example:

$$psot\ retrofit\ usage\ _{Day\ 4}(kWh) = \ 0.657\ \times 254 - 54.87$$

$$= \ 112.1\ kWh$$

Daily values for 'business as usual' forecast or 'adjusted baseline' as well as post-retrofit usage and daily energy savings are calculated across an entire year.

The extrapolated savings are calculated to be 157,935 kWh.

Estimating uncertainty

Actual post-retrofit period savings uncertainty

The standard error of the baseline model SE_b (standard error associated with the average daily energy consumption calculation) is calculated as follows:

$$SE_b = \frac{s}{\sqrt{n}} = \frac{8.712}{\sqrt{14}} = 2.3285 = SE_{pr}$$

Where s is the standard deviation and n is the number of data points (14 days) of the measured baseline data. This also equals the daily standard error of the actual post retrofit energy savings.

The loggers used to measure the baseline and post-retrofit data have a relative precision of ±1.0%. It is assumed that the accuracy of the power meter has been extensively tested by the manufacturer across a large sample set, assumed to be infinite. It is also assumed that the precision is provided at 95% confidence, which is the most conservative figure.

The t-value has been obtained from Table 27 within Appendix G of the *Process Guide* by referencing the column representing 95% confidence, and using look up value for degrees of freedom, $DF_{power\ draw} = \infty$.

The loggers take readings every minute, and so the average value recorded across the 14 days is:

$$\text{average reading} = \frac{7{,}820}{14 \times 24 \times 60}$$

$$\text{average reading} = 0.38788$$

The standard error (SE) of a reading is calculated using the equation below:

$$\text{SE} = \frac{relative\ precision\ \times\ measured\ value}{t}$$

$$= \frac{0.01\ \times\ 0.38788}{1.96}$$

$$= 00.00198$$

The standard error (SE_b) of the 14 day baseline period is:

$$SE_b\ (kWh) = \sqrt{14 \times 24 \times 60 \times\ SE_{reading}{}^2}$$

$$= \sqrt{14 \times 24 \times 60 \times\ 0.00198^2}$$

$$= 0.281\ kWh$$

Applying the process above to the post-retrofit period, the standard error (SE_{pr}) for the 14 day post retrofit period is:

$$SE_{pr}\ (kWh) = 0.055\ kWh$$

The standard error for the 14 day savings calculation is calculated as:

$$SE_{14\ day\ savings}\ (kWh) = \sqrt{{SE_b}^2 + {SE_{pr}}^2}$$

$$= \sqrt{0.281^2 + 0.055^2}$$

$$= 0.286\ kWh$$

The absolute precision (AP) for a given confidence level (80% in this case) can then be calculated for the actual savings achieved during the post retrofit period by the following:

$$AP = t \times SE_{14\ day\ savings}$$

Where t is obtained from the t-statistic table for 80% confidence and 14 data points (or 13 degrees of freedom) which equals 1.35 (Refer to Table 27 within Appendix G of the *Process Guide*). Thus the absolute precision for savings over the two week period:

$$AP = 1.35 \times 0.286$$

$$= 0.387 = \pm 1\ kWh$$

The relative precision (RP) is calculated by dividing the absolute precision by the savings estimate:

$RP = \frac{1}{6{,}284} = \pm\ 0.02\%$ -> negligible

Given the extremely small value above, metering uncertainty will be ignored.

Extrapolated savings uncertainty

The extrapolated savings calculation makes use of energy models for estimating the baseline consumption, as well as forecasting the post-retrofit consumption based on vehicle traffic. Therefore the savings uncertainty will incorporate modelling errors from both models.

The standard error of the baseline model SE_b (standard error associated with the average daily energy consumption calculation) has been calculated as follows:

$$SE_b = \frac{s}{\sqrt{n}} = \frac{8.7124}{\sqrt{14}} = 2.3285$$

Where s is the standard deviation and n is the number of data points (14 days) of the measured baseline data.

The standard error of the post-retrofit regression model $SE_{\hat{Y}}$ is calculated as follows.

$$SE_{\hat{Y}} = \sqrt{\frac{\sum(\hat{Y}_i - Y_i)^2}{n-p-1}} = \sqrt{\frac{7{,}436.67}{14-1-1}} = 24.894 \qquad (x \geq 83)$$

where $\hat{Y}_i$ is the model-predicted post-retrofit energy consumption for day i, Y_i is the actual post-retrofit energy consumption for day i, n is the number of data points (14 days) and $p = 1$ is the number of independent variables in the regression model.

The table below illustrates the process:

Day	Actual (kWh)	Modelled (kWh)	$(\widehat{Y}_i - Y_i)^2$
1	15.17	27.28	146.68
2	42.07	30.57	132.39
3	39.98	37.79	4.76
4	46.90	46.34	0.31
5	85.19	98.91	188.35
6	103.14	109.43	39.57
7	123.33	117.97	28.73
8	99.64	119.94	412.15
9	185.53	140.31	2044.62
10	190.40	155.43	1223.31
11	189.32	158.06	977.37
12	145.26	160.69	238.04
13	131.19	163.97	1074.81
14	138.80	169.23	925.59
Total	**1535.91**	**1535.91**	**7436.67**

Since the predicted daily energy consumption is subtracted from the average daily baseline consumption using the previous year's vehicle entry and exit data, the daily baseline and post retrofit components of uncertainty must be combined by using the following equation:

$$SE(daily\ savings) = \sqrt{{SE_b}^2 + {SE_{\hat{Y}}}^2}$$

Therefore:

$$SE(daily\ savings) = \sqrt{2.3285^2 + 24.894^2} = 25.003$$

The standard error above applies to the daily savings calculations and must be combined using the following equation to cover an entire year ($n =$ 365 days) using the previous year's vehicle entry and exit data for the x variable.

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

$$Total\ SE(savings) = \sqrt{365} \times 25.003 = 477.68$$

Using the t-statistic of 1.35 (14 data points at 80% confidence), the absolute precision is ±645 kWh and the relative precision is ±0.41%.

Reporting results

During the 2 week post retrofit period, savings were measured to be 6,824 kWh ± 0.02% at 80% confidence level. Extrapolating the savings over an entire year using the previous year's vehicle entry/exit data, savings have been estimated at 157,935 kWh ± 0.41% at 80% confidence level