Office of Environment & Heritage

# Measurement and Verification Operational Guide

## Commercial and Industrial Refrigeration Applications

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# 1 Your guide to successful M&V projects

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

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

But what is M&V exactly?

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

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

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

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

## 1.1 Using the M&V Operational Guide

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

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

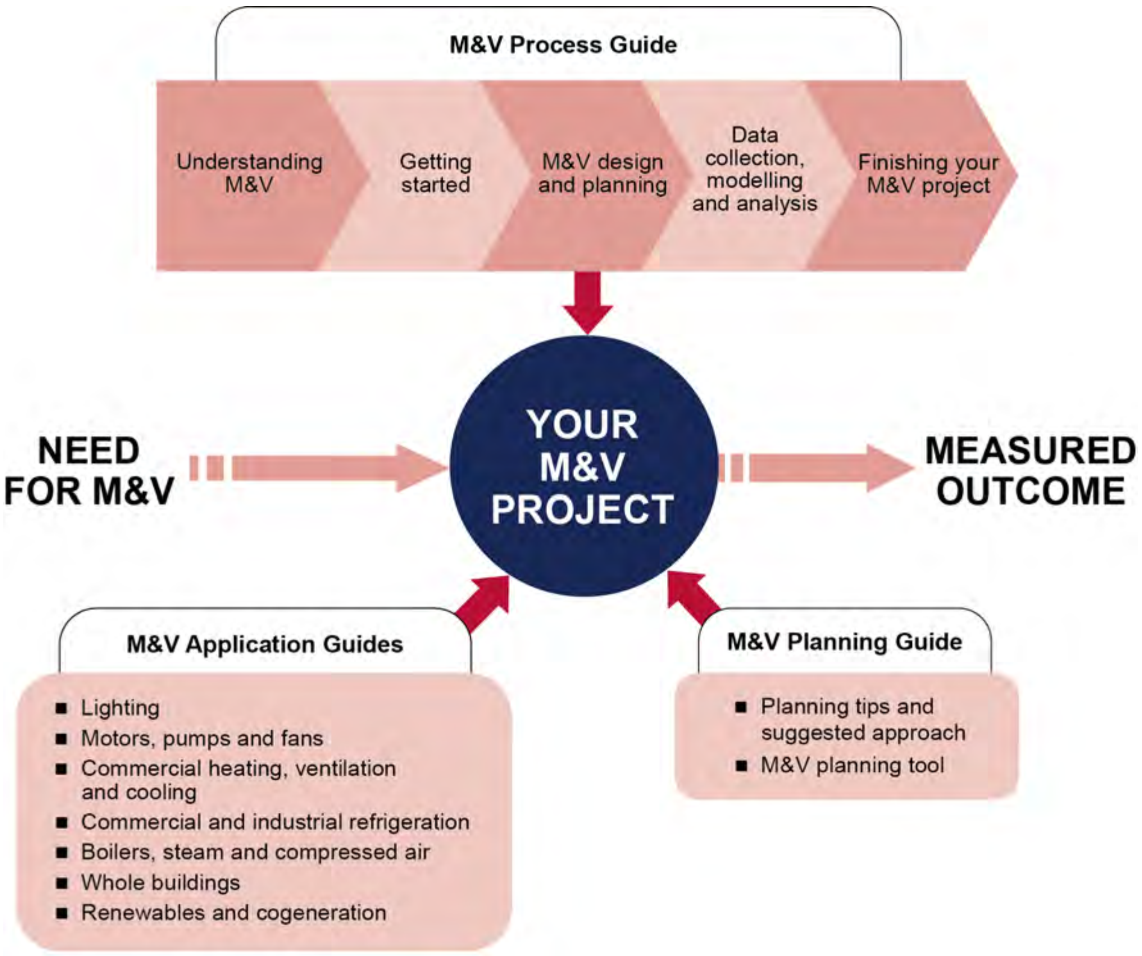
**Planning Guide:** The *Planning Guide* is designed to assist both new and experienced practitioners to develop a robust M&V Plan for your energy savings project, using a step-by-step process for designing a M&V project. A Microsoft Excel tool is also available to assist practitioners to capture the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

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

[1] Source: www.energymanagementworld.org

- 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 Commercial and Industrial Refrigeration Applications Guide (this guide)

The *Commercial and Industrial Refrigeration Applications Guide* provides specific guidance for conducting M&V for commercial and industrial refrigeration projects. It is designed to be used in conjunction with the *Process Guide*, providing tips, suggestions and examples specific to these types of projects.

The *Commercial and Industrial Refrigeration 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 refrigeration 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 refrigeration 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 refrigeration scenario | Appendix A 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.

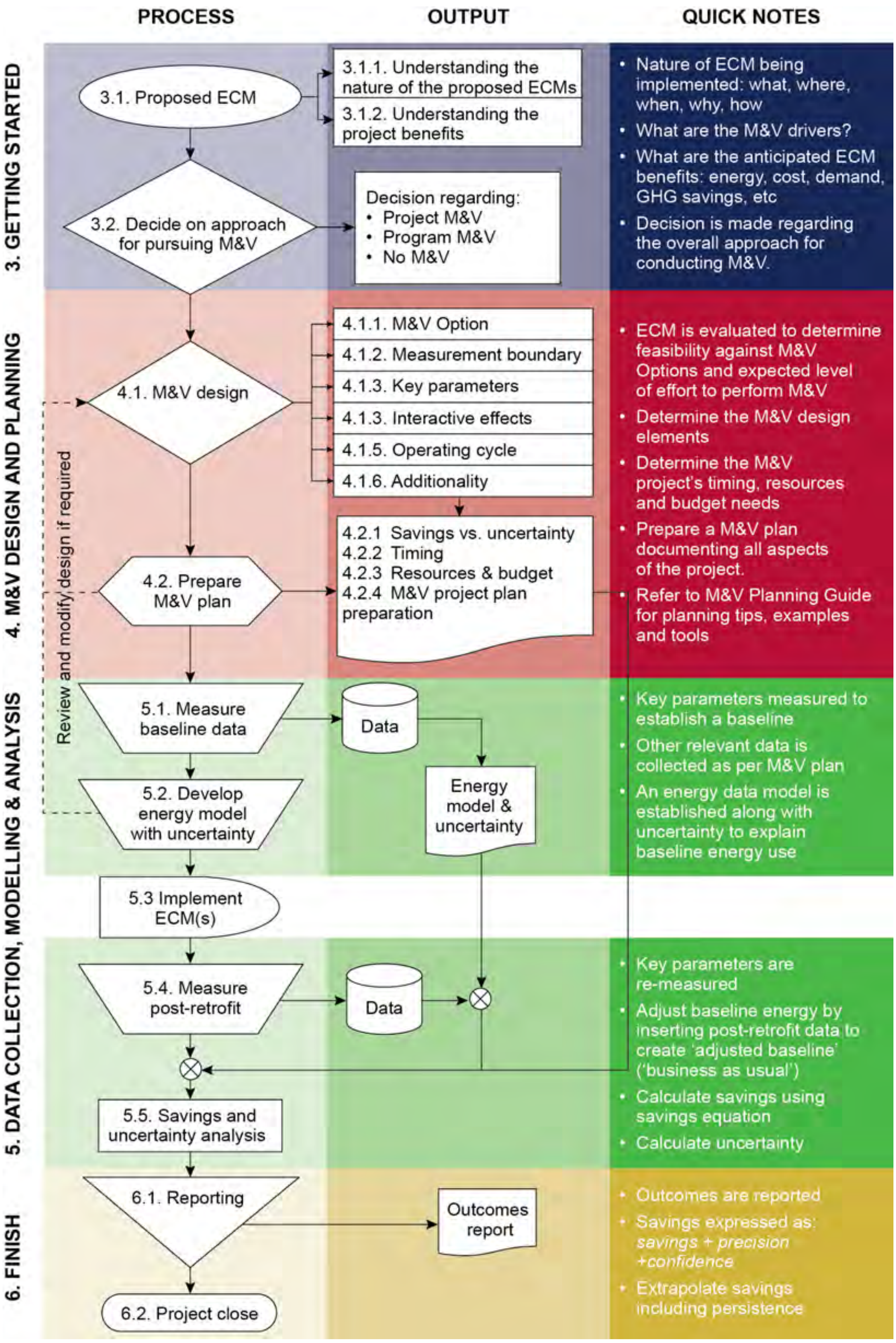
**Table 1:** Key M&V terms

| 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.<br>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 *Commercial and Industrial Refrigeration 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 refrigeration ECM(s)

### 3.1.1 Refrigeration projects

Refrigeration systems consume large amounts of electricity and thereby contribute greatly to the running cost of business with considerable cooling requirements. Reducing energy consumption from industrial refrigeration is done through[2]:

1. **Reducing heat gains**
   a. Allowing ambient cooling of product before refrigeration
   b. Increasing insulation on pipe work and cooled space
   c. Reduce solar gain
   d. Locating cooling equipment as far away as possible from heat sources
   e. Minimising air infiltration into a cooled space
   f. Install more efficient internal fan motors and pumps
   g. Minimise opening of refrigeration doors
   h. Minimise the amount of time a person spends inside a cooled space
2. **Reducing pump energy of coolant distribution system**
   a. Ensure the most appropriate secondary fluid is used to minimise the amount of fluid pumping required
   b. Installing large diameter pipes to minimise pumping pressure
   c. Installing high efficiency motors
   d. Correctly match the equipment against the system load by installing variable or adjustable speed drives on pump motors, installing multiple pumps, unthrottling valves and minimising bypass.
3. **Optimising compressor efficiency, part load performance and heat rejection**
   a. Installing variable speed drives to condenser fans and interlocking fan speed control to minimise compressor head pressure and optimise energy savings.
   b. Install common compressor suction and discharge piping across condensers to minimise the head pressure of the compressor.
   c. Minimise part-load operation by splitting the load up between smaller compressors or installing variable speed drives on compatible compressors.
   d. Install energy efficiency compressors such as oil-free, magnetic bearing and variable speed compressors.
   e. Installing automatic controls for sequencing compressors so they run at optimum efficiency and be switched off when not required.
   f. Raising the suction pressure.
   g. Reducing temperature lift between the evaporating and condensing temperatures.
   h. Reduce suction line pressure drop.
   i. Install floating head pressure control.
   j. Installing heat recovery systems for activities such as domestic hot water, boiler feed water pre-heating etc.

### 3.1.2 Key points to note

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

[2] Source: Sustainability Victoria, Energy Efficiency Best Practise Guide to Industrial Refrigeration

- All options are available.
- Option A may be preferred in situations where
  - the thermal load demands on the system are consistent or an annual load curve can be easily derived or estimated
  - ECMs apply to a single piece of equipment within the system (e.g. condenser fans, pumps)
- Option B will usually be preferred to Option A where:
  - A more accurate result is desired
  - Thermal load demands fluctuate or the effects of ambient temperature are material
  - The boundary encompasses the entire refrigeration plant
  - Existing electrical and/or thermal metering is in place
- Option C may be preferred where:
  - The refrigeration system is the major energy user at the site.
  - Savings from the ECM are > 10% of total site (or approximately 20-30% of the refrigeration system)
  - Actual savings is desired
  - Long-term M&V is desired
- Option D may be preferred where:
  - Detailed specifications can be obtained for equipment
  - Systems are difficult to access
  - Costs of metering baseline usage is prohibitive
  - Various what if scenarios are involved
- Identify independent variables that may affect before and after comparison including changing operating hours/patterns, seasonality, human behaviour.
- Determine the desired level of uncertainty (precision + confidence).
- Determine the required and desirable M&V outcomes.
- The length of measurement is determined by chosen option, and the desired level of accuracy.

Section 4.2 provides detailed information on other M&V considerations for refrigeration 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

<table>
<tr><th rowspan="2">Typical projects</th><th rowspan="2">M&V Option</th><th colspan="3">Key parameters</th></tr>
<tr><th>To measure</th><th>To estimate or stipulate</th><th>To consider</th></tr>
<tr><td>Reducing heat gains<ul><li>Allowing ambient cooling of product before refrigeration</li><li>Increasing insulation on pipe work and cooled space</li><li>Reduce solar gain</li><li>Locating cooling equipment as far away as possible from heat sources</li><li>Minimising air infiltration into a cooled space</li><li>Install more efficient internal fan motors and pumps</li><li>Minimise opening of refrigeration doors</li><li>Minimise the amount of time a person spends inside a cooled space</li></ul></td><td rowspan="2">OPTION A</td><td>Thermal load has changed.<br>Need to measure change in thermal load in relation to underlying "productivity" parameter (e.g. thermal load per tonnes of throughput)</td><td>Operating hours<br>Annual Thermal load profile<br>Plant coefficient of performance<br>Energy savings are indirectly calculating using a stipulated COP combined with measurement of changing thermal load against production output.</td><td>Interactive effects</td></tr>
<tr><td>Reducing pump energy of coolant distribution system<ul><li>Ensure the most appropriate secondary fluid is used to minimise the amount of fluid pumping required</li><li>Installing large diameter pipes to minimise pumping pressure</li><li>Installing high efficiency motors</li><li>Correctly match the equipment against the system load by installing variable or adjustable speed drives on pump motors, installing multiple pumps, unthrottling valves and minimising bypass.</li></ul></td><td>Metered energy use<br>Changes in power draw (i.e. load test)</td><td>Thermal load</td><td>Interactive effects</td></tr>
</table>

| Typical projects | M&V Option | Key parameters | | |
|---|---|---|---|---|
| | | To measure | To estimate or stipulate | To consider |
| **Optimising compressor efficiency, part load performance and heat rejection**<br>▪ Installing variable speed drives to condenser fans and interlocking fan speed control to minimise compressor head pressure and optimise energy savings.<br>▪ Install common compressor suction and discharge piping across condensers to minimise the head pressure of the compressor.<br>▪ Minimise part-load operation by splitting the load up between smaller compressors or installing variable speed drives on compatible compressors.<br>▪ Install energy efficiency compressors such as oil-free, magnetic bearing and variable speed compressors.<br>▪ Installing automatic controls for sequencing compressors so they run at optimum efficiency and be switched off when not required.<br>▪ Raising the suction pressure.<br>▪ Reducing temperature lift between the evaporating and condensing temperatures.<br>▪ Reduce suction line pressure drop.<br>▪ Install floating head pressure control.<br>▪ Installing heat recovery systems for activities such as domestic hot water, boiler feed water pre-heating etc. | **OPTION A** | Metered energy use<br>Changes in power draw (i.e. load test)<br>Heat recovered and used outside the measurement boundary. | Thermal load | Interactive effects |
| Any the above projects where efficiency is changing together with highly variable thermal loads | | If both are unknown or uncertain, then Option A cannot be used.<br>Look at Option B or C | | |

| Typical projects | M&V Option | Key parameters | | |
|---|---|---|---|---|
| | | **To measure** | **To estimate or stipulate** | **To consider** |
| All industrial refrigeration projects | OPTION B | Metered energy use at ECM boundary<br>Thermal load<br>Ambient temperature<br>Heat recovered and used outside the measurement boundary. | Non-routine adjustments | Interactive effects |
| | OPTION C | Metered energy use at facility boundary<br>Heat recovered and transferred off site. | Non-routine adjustments | All independent variables within the measurement boundary, including those from other energy systems |
| Projects with no metered baseline | OPTION D | Post-retrofit energy use<br>(In this case baseline parameters cannot be measured, and so both must be post-retrofit and used to recalibrate the developed baseline model | Non-routine adjustments | All independent variables within the measurement boundary, including those from other energy systems |

### 4.1.2 Measurement boundary

For M&V Option A, B or D, this is the part(s) of the industrial refrigeration system affected by the project. This is either:

- a piece of equipment (e.g. single condenser or compressor)
- groups of equipment (e.g. all compressors)
- the entire refrigeration plant

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

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

### 4.1.3 Key parameters

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

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

| Parameter | Description |
|---|---|
| Power draw | Using power draw as the key parameter is typically only used when replacing industrial refrigeration equipment that has a static load when operating such as pump or fan motors.<br>For industrial refrigeration efficiency retrofit projects, the change in the power draw may be a key parameter to measure depending on the variability of the operating hours and associated uncertainty. For simplified M&V within industrial refrigeration control projects that result in reduced plant run-times, power draw may be assumed constant, but once again this will depend on the variability of the power draw and associated uncertainty.<br>The power draw is usually expressed in kilowatts (kW) for industrial refrigeration projects. |
| Operating hours | This is the amount of time during which the industrial refrigeration system operates. This may be a key parameter for systems that don't operate continuously. For those that do, the thermal load is more important (see below).<br>Operating hours may be manually controlled by staff or through the use of automated controls and timers. Operating hours are dictated by the installed controls and subsequent operating patterns of the industrial refrigeration, which are influenced by one or more of the following:<br>▪ Site occupancy times – business hours, 24/7 operation, seasonality, public holidays.<br>▪ Production cycles<br>▪ Type, placement and use of controls and automatic timers.<br>▪ Shutdowns and scheduled maintenance periods<br>▪ Weather seasonality.<br>For industrial refrigeration control projects which reduce plant run-times, the change in operating hours may be a suitable key parameter to measure depending on the variability of the power draw and associated uncertainty.<br>For simplified M&V within industrial refrigeration retrofit projects which result in a reduction of a static load, operating hours may be assumed constant, but once again this will depend on the variability of the operating hours and associated uncertainty. |
| Operating efficiency or Coefficient of Performance (COP) | This is the ratio between the amount of raw input energy required into a particular process and the useful output energy delivered by that process. Operating efficiency may be a useful key parameter to measure if the industrial refrigeration load is variable during the measurement period however it will require having in place thermal energy metering.<br>For industrial refrigeration systems, the operating efficiency may be defined as:<br>*The ratio between the thermal cooling energy delivered to the refrigerated space and the raw input energy consumption into the refrigeration process.*<br>For simplified industrial refrigeration projects which improve operational efficiency, the input and output energy of the industrial refrigeration equipment or system are the key parameters to measure. The efficiency is calculated by dividing the measured output energy by the input energy. This calculation is performed during pre and post retrofit periods so the improvement in efficiency can be determined.<br>For simplified M&V within industrial refrigeration efficiency improvement projects, a base year can be selected to determine the annual input energy consumption of |

| | |
|---|---|
| | the industrial refrigeration system. This consumption can be assumed constant and multiplied by the efficiency improvement to calculate annual energy savings. The suitability of assuming constant annual input energy consumption will be determined by its variability and associated uncertainty. |
| Thermal load requirements | The thermal load refers to the demand for cooling by the system that the refrigeration serves. Refrigeration systems serve a range of applications, each with their own thermal load profile. Examples include:<br>▪ Cold storage and commercial refrigeration – low, medium, high temperature storage for perishable items. Product volumes and temperatures are important, as well as insulation losses.<br>▪ Food manufacturing – freezing/cooling food products and storage. Start and target temperatures, product types and volumes are important.<br>▪ Manufacturing production processes – process chilled water is used for process cooling or to help maintain temperature set points through heat rejection. Production may continuous, batched , shift based or seasonal, and the demand for process cooling fluctuate throughout the production process (e.g. process cooling within plastics manufacturing) |
| Ambient temperature | Refrigeration system operation is typically weather dependent, with changing levels of demand throughout the course of a year. |

### 4.1.4 Interactive effects

The *interactive effects* will be dependent on the type of refrigeration ECM 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 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** | **Thermal load** |
| A (power draw is key) | Short/instantaneous power draw during relevant time periods<br>Changes in power draw (i.e. load test) | Dependent on refrigeration end use, based on the cyclical nature of the thermal load. Measure for one operating cycle, typically between two weeks to three months. | |
| A (thermal load is key) | | | Typically between two weeks and three months or periodic.<br>Repeat periodically if seasonality is an issue (e.g. school terms) |

| Option | Measured parameter | | |
|---|---|---|---|
| | Power draw | Metered energy use | Thermal load |
| B | | Typically between two weeks and three months | Dependent on refrigeration end use, based on the cyclical nature of the thermal load. Measure for one operating cycle, typically between two weeks to three months.<br>Repeat periodically if seasonality is an issue (e.g. school terms) |
| C | | At least one site operation 'cycle', that includes changes in other energy systems. For example, 12 months baseline data is required where seasonality is a factor.<br>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.<br>Typically require three months of post-retrofit data |
| D | | For the baseline typically one site operation 'cycle' is modelled.<br>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.<br>Typically require at least three months of post-retrofit data | For the baseline typically one site operation 'cycle' is modelled. Within a lighting project, a 'cycle' is typically two weeks or more.<br>Post-retrofit measurements are used to re-calibrate the baseline model, and so both *operating hours* and *power draw* must be measured. |

### 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 refrigeration 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 refrigeration projects

| Consideration | Issue | Suggested Approach |
|---|---|---|
| Understanding end use | Refrigeration is used for cooling and/or freezing products. Perishable items may also undergo storage.<br>Refrigeration is used for cold storage.<br>Refrigeration is used within a manufacturing process. | Understanding the nature of the thermal load requirements of the refrigeration system assists with decision making regarding M&V Option, and measurement or estimation of key parameters.<br>Ideally data tracking the thermal load is available. In its absence, review the overall site profile and correlate against key site activities and production outputs that require use of the refrigeration system. |
| Changes in ambient temperature combined with changing productivity | Refrigeration loads vary with changes in ambient temperature as well as productivity. | This is a highly likely scenario. Multivariable regression analysis should be used to develop an energy model to explain input energy against each input parameter. |
| Power factor | Potential changes in power factor, which might affect demand and thus cost savings.<br>*For example: motors used for mechanical compressors in chillers will operate at different power factors depending on type, size, speed and % load.* | Technology retrofits may affect the power factor within the M&V boundary, which may impact demand savings. The proposed approach is:<br>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:<br>2. Determine if the change in power factor is likely to affect overall site maximum demand (if this is an energy cost item).<br>*Does the industrial refrigeration system operate at peak demand times?*<br>*Will an existing power factor correction unit negate this issue?*<br>3. If maximum demand is affected, then apply the appropriate demand cost rates to calculate the financial impact. |

| Consideration | Issue | Suggested Approach |
|---|---|---|
| Persistence and extrapolation | The savings calculated from short-term measurements often extrapolated to 'estimate' annual project savings. It is important to incorporate additional factors, which may include:<br>reliance on human behaviour<br>seasonal effects (climate, holidays, etc)<br>calibration changes and failures<br>likelihood of future changes within measurement boundary. | When extrapolating the savings verified during the post-retrofit period to estimate annual savings, it is important to identify influencing factors and assess their impact.<br>If minor, they can be ignored.<br>If material, the M&V plan should document how they are to be addressed. Examples include:<br>a. repeating M&V at various times throughout the year<br>b. collecting appropriate data (such as site closure dates and public holidays) and adjusting accordingly<br>c. combining short-term measurement of load with more periodic measurement of control (e.g. human behaviour)<br>d. occasional spot measurements to verify assumptions. |

# 5 Data collection, modelling and analysis

## 5.1 Measure baseline data

### 5.1.1 Determine existing refrigeration inventory

If not already done, catalogue the baseline industrial refrigeration inventory, including:

- Plant and equipment types and quantities
- kW and efficiency ratings (e.g. COP)
- Operation times
- Controls, such as sensors (e.g. control of condenser fan speed for head pressure control, compressor staging and variable evaporator fan speeds) and their set points and control algorithms
- Brief description of plant layout and system redundancy

The inventory may be best represented in a spreadsheet. A system diagram may assist with documenting the measurement boundary and for selecting the appropriate placement for measurement equipment.

### 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.
- Measurement should consider period demand and, where applicable, measurement should be made during any and all relevant demand periods.

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 a true rms power meter or concurrent measurements for current and voltage and power factor. | Appropriate for Option A where hours are estimated. Use calibrated equipment and measure real power in order to evaluate energy and demand savings. |
| | Manufacturers' product specifications | Can be used when power draw is estimated (as it is not being measured). |
| Energy usage | Utility bills | Typical frequency of one to three months. Can be used for Option C, and are considered 100% accurate, when not estimated by the supplier. |

| Data Type | Source | Comments |
|---|---|---|
| Energy usage | Revenue meter – interval data | Typically 30 minute data intervals, which can be used to accurately calculate savings across a day, week or longer.<br>Can also be used to estimate operating hours based on profile changes. Data provided by a Meter Data Agent is used for billing and is considered 100% accurate. |
| | Permanent sub-meter – interval data | Similar characteristics to the revenue meter above. Data quality will be high, but may not be revenue quality. Data should be reviewed for 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. |
| Thermal load | Permanent thermal metering | Thermal metering measures liquid flow as well as the difference between supply and return temperatures to determine thermal energy transfer.<br>Existing thermal metering may be interrogated via analogue or pulse outputs. Meters may have on-board memory to store historical data. |
| | Temporary thermal metering | Similar to above, except that temporary metering is installed. |
| | Equipment thermal metering | Some types of equipment may have thermal energy monitoring capabilities built in. A potential difficultly may be in accessing the data. |
| | Proxy based on ambient temperature | In situations where product flow into and out of the cooled space is fairly constant, ambient air temperature may be the only variable to consider. In this case access to weather data may be appropriate. |
| | Site/plant control systems | BMS/SCADA or plant control systems should typically be controlling compressor operation based on existing flow meters, thermocouples and/or thermal meters.<br>Obtaining data from a control system may be simpler than trying to access the meter directly. Functionality may also exist to set up trend logs or access volumes of historical data. |

### 5.1.3 Conducting measurements

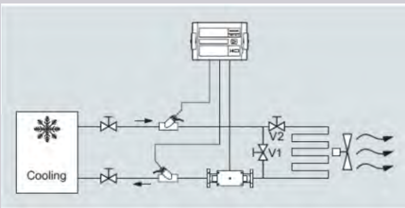
Electrical measurements can be conducted in a variety of ways as per the table below.

**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.<br>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 plant equipment | Energy meter or data logger connected to relevant equipment loads | 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 (e.g. remotely located pumps). |

Thermal measurements can be conducted in a variety of ways, including:

**Table 8:** Methods for conducting measurements of thermal loads

| Technique | Placement | Guidance |
| --- | --- | --- |
| Direct measurement by thermal meter<br>Meter encompasses a flow meter and supply and return temperature sensors | Place either side of refrigeration plant. Refer to product instructions.<br>Requires a straight section of pipe work.<br><br>*Source: Siemens FUE950 product brochure* | Energy is determined by calculating the change in water temperature between supply and return, multiplied by the water flow.<br>Typically thermal meters are permanently installed and linked to refrigeration plant or Building Management System controls<br>Meters can usually be interrogated directly. Some may have on board memory to store data. Alternatively a temporary data register can be attached to gather analogue or pulse outputs. |
| Clamp-on ultrasonic flow meter<br>Supplemented by temporary measurement for supply/return temps logger | As above where practical | A temporary alternative to installing a thermal meter. Ultrasonic meters operate by measuring the velocity of a liquid using ultrasound.<br>These meters can potentially be difficult position and calibrate.<br>They are suited to clear fluids. |

## 5.2 Develop energy model and uncertainty

For refrigeration projects, an energy model can be established using regression analysis which relates energy consumption to the number of cooling degree days (CDDs). Other independent variables may be included in the regression analysis as appropriate (e.g. volumes of product produced).

As an example, the refrigeration regression model may take on the following form:

$$Energy\ consumption(kWh) = \ a + b_1 CDD + \ b_2 V$$

where:

$a$ is the baseline refrigeration system which is not dependent on the independent variable(s) (e.g. base load fan consumption)

$b_1$ is the coefficient of the CDD independent variable

$b_2$ is the coefficient of the independent variable associated with the volume of product produced ($V$).

Simple energy models may be developed if the refrigeration load is static (e.g. constant flow pumps). For example:

$$Energy\ consumption(kWh) = \frac{refrigeration\ equipment\ wattage\ \times operating\ hours}{1000}$$

Some refrigeration M&V projects may require measuring the operational efficiency of the refrigeration system or piece of equipment (e.g. compressor replacement projects). The operational efficiency $\eta$ of a refrigeration system or equipment is equal to:

$$\eta = E_{out} / E_{in}$$

where:

$E_{out}$ = *the useful output refrigeration energy usually expressed as kWh or MJ*

$E_{in}$ = *raw input energy into the refrigeration system (usually electricity, gas or oil)*

The useful output refrigeration energy $E_{out}$ will typically be a fluid flow such as chilled water, coolant, refrigerant or air and can be calculated by the following equation:

$$E_{out}(MJ) = \int_0^t V\rho C_p \Delta T \ dt$$

where:

$V$ = *volumetric flow rate of the fluid usually expressed in litres per second L/s*

$\rho$ = *density of the fluid usually expressed as $m^3$/kg*

$c_p$ = *specific heat capacity of the fluid usually expressed as kJ/kgK*

$\Delta T$ = *temperature differential of the flow and return fluid usually expressed as ºC or K*

$dt$ = *time incremental of the calculation – summing the energy of each time incremental from 0 to t equals the total fluid flow energy during the measurement period.*

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

The general equation for energy savings is:

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

or

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

As system load demands vary due to product throughput and ambient temperature, an energy model will usually be required in which the input energy is modelled against the load conditions.

The model developed within the baseline period is then populated with post-retrofit data for the key independent variables, to calculate the 'adjusted baseline' energy use which can then be compared against the actual post-retrofit data.

### 5.5.1 Extrapolation

If a sample-based approach is used (selected refrigeration systems 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.

### 5.5.2 Uncertainty

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

# 6 Finish

## 6.1 Reporting

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

## 6.2 Project close and savings persistence

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

- An inspection of the area to ensure equipment remains consistent with that specified in the installation
- Review of cooling conditions and control set points.
- Wear and tear of refrigeration equipment and reduction in operational efficiency.

With Option C, ongoing verification can easily be achieved by simply applying the baseline energy model to ongoing invoice data and independent variables.

# 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 B** is used to measure and verify the savings from an industrial refrigeration efficiency project.

A food production company utilises an industrial scale refrigeration system to store their frozen product line. The refrigeration control system is almost fully automatic and used conventional step logic. Analysis of trend data identified more compressors were running when required, there were many unnecessary start/stop operations and some compressors were running only part loaded. This meant below optimum energy efficiency, increased running hours and more start/stop operations.

Facility management decided to implement a programmable logic controller system that would regulate the loading and unloading of the compressors. The controller would also manage the start and stop function and provide optimal control of condensing temperatures depending on ambient temperature.

The manufacturer of the new controller has advised the food production company they will save at least $20,000 each year on refrigeration electricity costs for a pilot site based on an average electricity costs of 10 cents per kWh. The food production company seeks to perform measurement and verification on the pilot site before rolling the ECM out to other sites. Implementation costs have been quoted at $80,000 resulting in a maximum payback of 4 years.

An existing sub meter is installed on the feeder which supplies electricity to the refrigeration system which can be used for the M&V project.

## Getting started

### Budget

A budget of $2,000 (10% of $20,000) has been allocated for completing the M&V. This includes the cost to calibrate and validate the existing electrical sub meter.

### Key parameter(s)

Since both the reduction in the power draw and changes in the start/stop operation of the compressors are unknown, M&V Option B has been selected for this project. Therefore the power draw and operating hours are both key parameters to measure.

### Measurement boundary

The measurement boundary is the input electricity supply into the industrial refrigeration system which powers the compressors, evaporator/condenser fans and all other auxiliary components and controls.

### Approach for conducting measurement

The existing electrical sub meter on the power supply was calibrated and validated for the M&V project. It was also confirmed the meter and current transformer sizes have been correctly sized for the load.

The sub meter records 30 minute readings of average kW load which is converted to kWh. The kWh reading therefore is an equivalent reading of both power draw and operating hours key parameters.

Analysis of historical sub meter data shows that daily kWh energy consumption of the industrial refrigeration system remains reasonably constant throughout the year and no significant seasonality or operational cycles could be identified. It was therefore decided to measure the changes in pre and post retrofit daily kWh energy consumption to calculate the savings.

### Timing

Since energy consumption is not dependent on seasonal or cyclical factors, the M&V can take place during any time of the year. A period of 4 weeks (28 days) for both pre and post retrofit periods was decided to be sufficient time to take into account the variation in daily energy consumption and build a valid statistical model. The installing contractor will require 2 days to install the new control followed by 5 days of commissioning, testing and fine tuning for optimal energy efficiency.

### Industrial refrigeration inventory

A basic inventory of the refrigeration system is provided below.

| $kW_e$ per compressor | 64 kW |
|---|---|
| No. Compressors | 5 |
| Total $kW_e$ | 320 kW |
| Control type | Conventional set logic |
| Freezer temperature | -12 ºC |
| Past 12 months electricity consumption | 1,404,765 kWh |
| Average operating load | 160.4 kW |
| Past 12 months electricity costs | $140,476 |

### Interactive effects

No significant interactive effects were identified and have assumed to be nil for the purpose of this case study.

## Summary of M&V plan

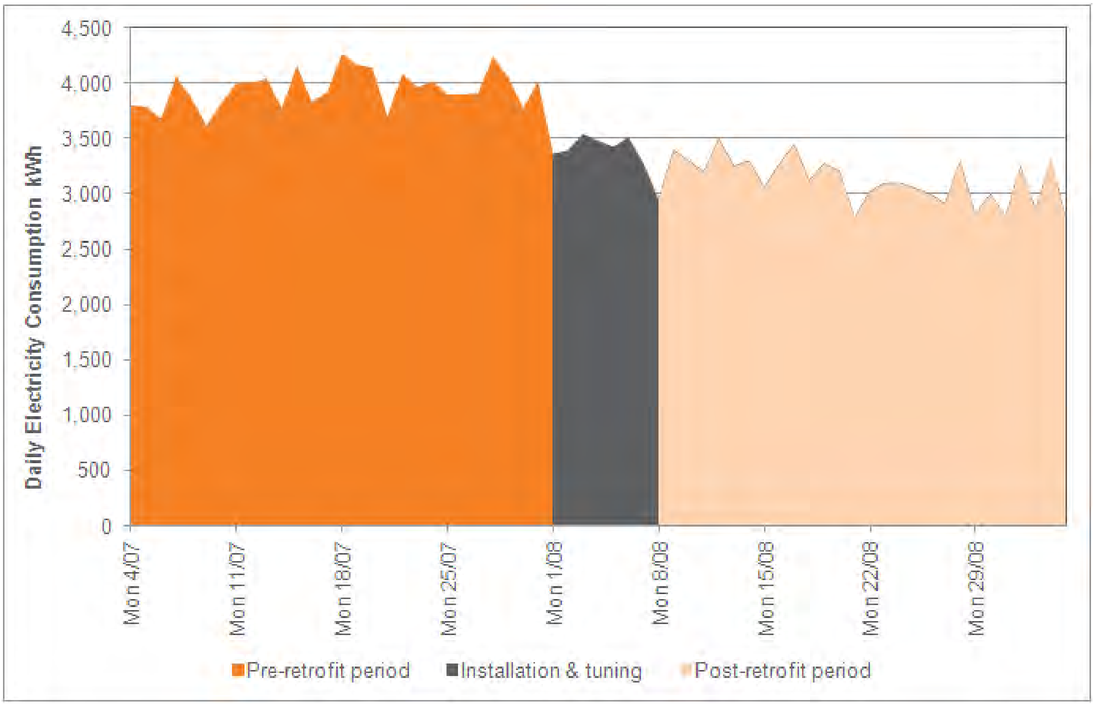
The key elements of the project's M&V plan in summary are:

| Item | Plan |
|---|---|
| Project summary | Install new programmable logic controller system to the industrial refrigeration system |
| Required outcome | The facility managers of the food production company must verify the return on investment will achieve a maximum payback of 5 years with a 90% probably before management will sign off implementing the control to the remaining sites. |

| Item | Plan |
|---|---|
| Budget | $2,000 (10% of expected savings $20,000) |
| M&V Option | Option B –retrofit isolation full parameter measurement |
| Measurement boundary | Incoming electricity supply to the industrial refrigeration system. |
| Key measurement parameters | Power draw and operating hours as represented by kWh readings of the sub meter. |
| Other parameters to consider | Ambient air temperature |
| Potential interactive effects | n/a |
| Approach for conducting measurement and collecting data | Extracting 30-minute average kW readings from the existing sub meter and converting to daily kWh energy consumption at the end of the measurement period. |
| Measurement equipment required | Existing electrical sub meter (calibrated and validated) |
| Measurement period | Pre retrofit period: 4 weeks (28 days)<br>Implementation & tuning: 1 week<br>Post retrofit period: 4 weeks (28 days) |
| Approach for calculating results | ▪ Calculate the average daily kWh consumption for pre and post retrofit periods.<br>▪ Calculate the kWh consumption difference between pre and post retrofit periods (daily kWh savings).<br>▪ Extrapolate daily savings for entire year.<br>▪ Conduct an uncertainty analysis. |

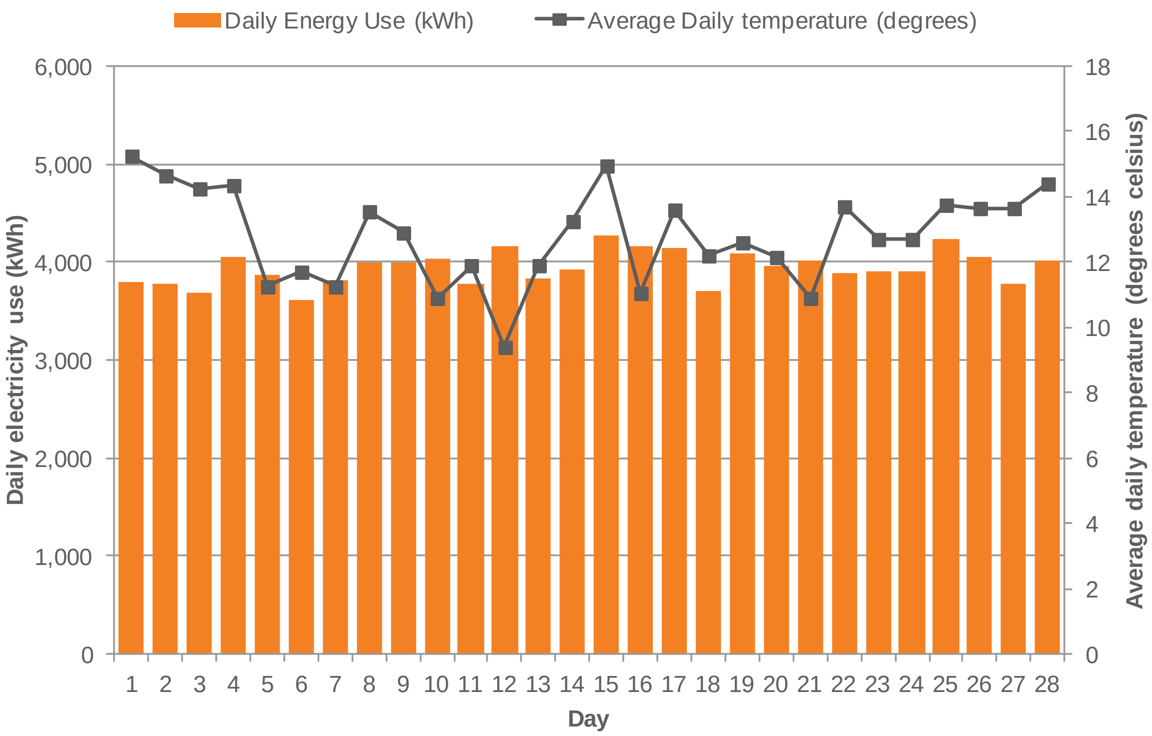
## Conducting measurements

The chart below shows the daily kWh measurements that were taken during the different M&V periods.

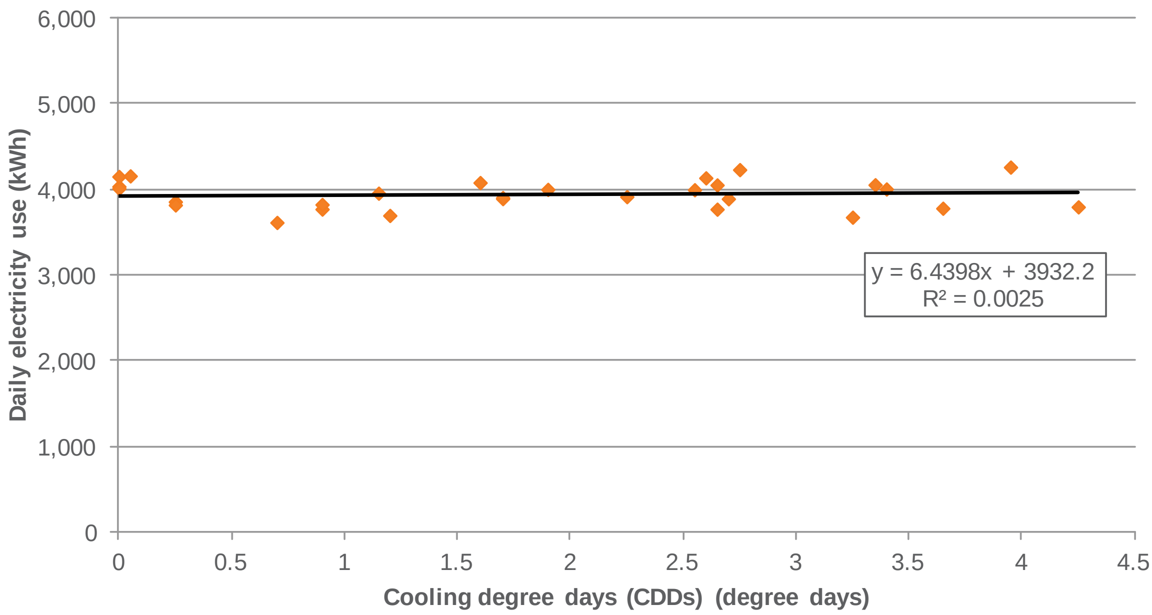



## Developing an energy model

The baseline period was reviewed to explore its relationship with temperature. The chart below illustrates the daily baseline energy use together with the average daily ambient temperature.




Further, the relationship was tested using an XY-scatter plot, as shown below:




Cooling degree days (CDDs) were calculated from the average daily temperatures using the following formula:

$$if\ \text{Average daily temperature}(°\text{C}) > \ Balance\ Point\ (°\text{C})\ \text{then}$$

$$CDDs = \ \text{Average daily temperature}(°\text{C}) - \ \text{Balance Point}\ (°\text{C})$$

$$else$$

$$CDDs = \ 0$$

It can be seen that the daily electricity use is consistent (i.e. flat), independent of the number of CDDs. Finally the $R^2$ value = 0.0025 from the trend line shows there is no correlation.

From this we can determine that daily energy use is consistent and can develop an energy model based on the samples taken without taking into consideration any further adjustments.

The baseline data is presented in the table below:

| Date | kWh | Date | kWh |
|---|---|---|---|
| Mon 4/07/2011 | 3,800 | Mon 18/07/2011 | 4,264 |
| Tue 5/07/2011 | 3,784 | Tue 19/07/2011 | 4,162 |
| Wed 6/07/2011 | 3,680 | Wed 20/07/2011 | 4,139 |
| Thu 7/07/2011 | 4,058 | Thu 21/07/2011 | 3,700 |
| Fri 8/07/2011 | 3,861 | Fri 22/07/2011 | 4,084 |
| Sat 9/07/2011 | 3,618 | Sat 23/07/2011 | 3,960 |
| Sun 10/07/2011 | 3,822 | Sun 24/07/2011 | 4,016 |
| Mon 11/07/2011 | 4,000 | Mon 25/07/2011 | 3,895 |
| Tue 12/07/2011 | 4,004 | Tue 26/07/2011 | 3,896 |

| Date | kWh | Date | kWh |
|---|---|---|---|
| Wed 13/07/2011 | 4,038 | Wed 27/07/2011 | 3,908 |
| Thu 14/07/2011 | 3,774 | Thu 28/07/2011 | 4,235 |
| Fri 15/07/2011 | 4,155 | Fri 29/07/2011 | 4,056 |
| Sat 16/07/2011 | 3,828 | Sat 30/07/2011 | 3,773 |
| Sun 17/07/2011 | 3,919 | Sun 31/07/2011 | 4,009 |
| Samples | 28 | | |
| Total baseline consumption(kWh) | 110,437 | | |
| Average daily use (kWh) | 3,944 | | |
| Standard deviation – calculated using Microsoft Excel *STDEV()* function across the 28 readings | 169 | | |

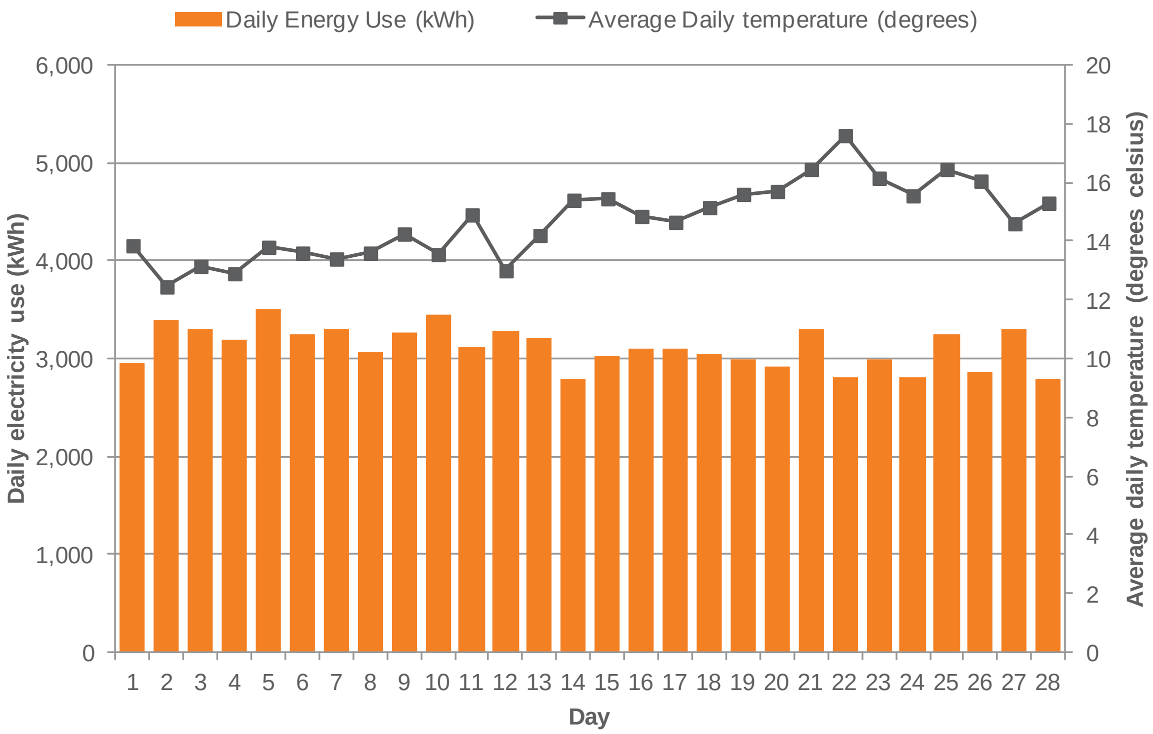
The baseline total energy consumption is 110,437 kWh. The baseline energy model is simply the average of the daily consumption figures, namely 3,944 kWh.

## Post retrofit readings

The table below summarises the post-retrofit readings taken:

| Date | kWh | Date | kWh |
|---|---|---|---|
| Mon 8/08/2011 | 2,948 | Mon 22/08/2011 | 3,020 |
| Tue 9/08/2011 | 3,396 | Tue 23/08/2011 | 3,100 |
| Wed 10/08/2011 | 3,300 | Wed 24/08/2011 | 3,103 |
| Thu 11/08/2011 | 3,200 | Thu 25/08/2011 | 3,052 |
| Fri 12/08/2011 | 3,500 | Fri 26/08/2011 | 3,000 |
| Sat 13/08/2011 | 3,250 | Sat 27/08/2011 | 2,914 |
| Sun 14/08/2011 | 3,302 | Sun 28/08/2011 | 3,300 |
| Mon 15/08/2011 | 3,061 | Mon 29/08/2011 | 2,816 |
| Tue 16/08/2011 | 3,268 | Tue 30/08/2011 | 3,000 |
| Wed 17/08/2011 | 3,449 | Wed 31/08/2011 | 2,800 |
| Thu 18/08/2011 | 3,122 | Thu 1/09/2011 | 3,250 |
| Fri 19/08/2011 | 3,278 | Fri 2/09/2011 | 2,859 |
| Sat 20/08/2011 | 3,206 | Sat 3/09/2011 | 3,300 |
| Sun 21/08/2011 | 2,789 | Sun 4/09/2011 | 2,795 |
| Samples | 28 | | |
| Total post-retrofit consumption(kWh) | 87,378 | | |
| Average daily use (kWh) | 3,121 | | |
| Standard deviation – calculated using Microsoft Excel *STDEV()* function across the 28 readings | 206 | | |

As before, the daily energy use was plotted against average daily temperature to investigate if the relationship against ambient temperature had changed.




It can be seen that the daily energy consumption remains largely constant even with increases in average daily temperature.

The post-retrofit total energy consumption is 87,378 kWh. The post-retrofit energy model is simply the average of the daily consumption figures, namely 3,121 kWh.

## Calculating savings

The actual electricity savings observed during the performance period is calculated as follows:

$$Actual\ savings\ (kWh) = baseline\ energy\ use\ (kWh) - \ Post\ retrofit\ energy\ use(kWh)$$

$$= 110{,}437 - \ 87{,}378$$

$$= 23{,}059 kWh$$

$$Actual\ cost\ savings\ (\$) = Actual\ savings\ (kWh) \times electricity\ cost\ rate \left(\frac{\$}{kWh}\right)$$

$$= 23{,}059\ kWh \times \frac{\$0.1}{kWh}$$

$$= \$2{,}3{,}06$$

## Using the models to extrapolate savings

The average daily kWh energy consumption for the pre and post retrofit periods and resulting energy savings calculation and extrapolation is shown below:

Average daily kWh consumption pre-retrofit = 3,944 kWh

Average daily kWh consumption post-retrofit = 3,121 kWh

$$Daily\ energy\ savings\ (kWh)$$
$$= Baseline\ modelled\ energy\ (kWh) - post\ retrofit\ modelled\ energy\ (kWh)$$
$$= 3{,}944 - 3{,}121$$
$$= 824\ kWh$$

Annual energy savings are extrapolated from the daily savings:

$$Annual\ energy\ savings\ \left(\frac{kWh}{year}\right) = Daily\ energy\ savings\ (kWh)\ \times \frac{365\ days}{year}$$
$$= 824\ kWh \times 365$$
$$= 300{,}588\ kWh$$

Annual Cost Savings are calculated by applying the agreed energy cost rate to the annual savings:

$$Annual\ cost\ savings\ (\$) = Annual\ savings\ (kWh) \times electricity\ cost\ rate\ \left(\frac{\$}{kWh}\right)$$
$$= 300{,}588\ kWh \times \frac{\$0.10}{kWh}$$
$$= \$30{,}059$$

The simple payback for the project can now be determined using the initial project cost:

$$Simple\ payback(years) = \frac{Project\ implementation\ cost(\$)}{Annual\ cost\ savings\ \left(\frac{\$}{year}\right)}$$
$$= \frac{\$80{,}000}{\$30{,}059}$$
$$= 2.7\ years$$

## Uncertainty analysis

Since multiple measurements are taken of daily kWh energy consumption, the random errors introduced by inaccuracies of the sub meter have been ignored since it can be assumed the random errors cancel each other out.

The standard error must be calculated for the average daily kWh energy consumption for both the pre and post retrofit measurement periods. The standard errors are then combined and then extrapolated for an entire year and multiplied by a t-statistic of 1.70 (28 days of measurement points with 90% confidence/probability level) to obtain the absolute error margin in the savings calculations.

$$Number\ of\ samples\ (n) = 28$$

$$Degrees\ of\ freedom\ (DF) = 28 - 1 = 27$$

$$\text{Desired level of confidence} = 90\%$$

The t-statistic is obtained from Table 27 within Appendix G of the *Process Guide*.

$$t - statistic(t) = 1.70$$

Pre-retrofit

$$Standard\ deviation\ (s) = 169 \quad - determined\ via\ STDEV()function\ withn\ Microsoft\ Excel$$

$$Standard\ error\ \left(SE_{pre}\right) = \frac{\mathrm{s}}{\sqrt{\mathrm{n}}} = \frac{169}{\sqrt{28}} = 31.89$$

Post-retrofit

$$Standard\ deviation\ (s) = 206 \quad - determined\ via\ STDEV()function\ withn\ Microsoft\ Excel$$

$$Standard\ error\ \left(SE_{pr}\right) = \frac{\mathrm{s}}{\sqrt{\mathrm{n}}} = \frac{206}{\sqrt{28}} = 39.02$$

Daily kWh energy savings

$$Standard\ error\ \left(SE_{daily\ savings}\right) = \sqrt{\mathrm{SE}_{\mathrm{pre}}^2 + \mathrm{SE}_{\mathrm{post}}^2}$$

$$= \sqrt{31.89^2 + 39.02^2} = 50.40$$

Annual kWh energy savings

$$Standard\ error\ (SE) = \sqrt{365 \text{ x } \mathrm{SE}_{\text{daily savings}}^2}$$

$$Standard\ error\ (SE) = \sqrt{365 \text{ x } 50.40^2} = 962.80$$

The absolute precision can now be calculated. Since t derives from the model of the baseline, it remains at the 1.70 value used above. Therefore the absolute precision for annual savings is

$$Absolute\ precision\ (AP) = \mathrm{t\ x\ SE}$$

$$= 1.70 \text{ x } 962.80$$

$$= \pm 1{,}637 \text{ kWh}$$

## Reporting results

The energy savings are reported as follows:

The electricity savings calculated during the measurement period have been extrapolated over an entire year to equal 300,588 kWh ±1,637 kWh with a 90% probability.

It should be noted here that this is a highly accurate range with readings taken in the winter months of July and August. It is recommended that further measurement is conducted during mid-season and summer months to confirm these findings.