Using Submeters for Measurement and Verification of Energy Retrofit Projects

By

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Summary: Many energy saving retrofit projects (including federal ESPC contracts) rely on stipulated savings with little or no verification procedures, primarily due to the mistaken belief that proper monitoring is simply an added expense that adds no value. In reality, appropriate monitoring hardware and software not only provides proof of the actual savings realized by implementing Energy Conservation Measures (ECM's) but also provides a valuable tool for maximizing the return on investment over the life of the equipment.
The key to a successful Measurement and Verification (M&V) program is that the right equipment is selected for monitoring a particular ECM so that the information gathered is both appropriate and timely. Use of submeters (i.e., meters installed "behind" the primary meter for a facility) can be a very effective tool for maximizing Return On Investment (ROI) for both the building owner and the performance contractor (ESCO).

Submetering and the IPMVP: The International Performance Measurement and Verification Protocol (IPMVP) defines four methods for measuring and verifiying performance of ECM's. While a discussion of the methods is beyond the scope of this paper, the key focus of the IPMVP is to use methods appropriate to the ECM and the use of submeters is most appropriate as a part of Method C (Retrofit Isolation) as the meters and sensors can be used to:

- Provide specific energy savings results that are verified in isolation from other performance factors (e.g., population changes); and
- Provide data that can be used by the building owner and contractor to fine tune the performance of the installed systems to maximize the ROI over the life of the equipment installed

This paper provides an overview of:

1. How to select the right equipment for submetering;
2. Examples of information that can be gathered by submeters;
3. A road map for estimating the costs of installing submetering

The primary focus of this paper is on the hardware and systems required to gather the raw data from the building and the options available to the ESCO for getting the information into a useful format.

Hardware overview: Meters and sensors are installed in a facility to monitor the energy savings from energy retrofit projects on systems such as lighting and HVAC (Heating, Ventilating and Air Conditioning). The sensors are connected to a Data Acquisition Server (DAS) or Building Control System (BCS) and the run times or energy consumption are measured and compared to energy usage prior to the installation. One of the key elements in the system design is gathering interval information that can be used to match system performance to other operating parameters such as outside air temperature, building occupancy, etc.

Software overview: Raw interval data gathered by the hardware is used to compare baseline energy data with actual energy consumption post retrofit. Depending on the application, this information may be "normalized" using weather data or occupancy changes where appropriate.

Background: Facility managers in commercial and retail buildings are tasked with operating the buildings as efficiently as possible in order to maintain (or improve) the operating margins and profits for the owners. In many industries (e.g., retail) margins tend to be small and savings in energy use translate into significant bottom line impacts, but energy savings have to be realized with little or no impact on temperatures, lighting levels, etc. There is no shortage of potentially energy reducing technologies such as higher efficiency lights, variable speed motors, high efficiency compressors, etc., but it is very challenging for facility managers in a dynamic environment to accurately determine the benefits of these technologies once they are installed..

Consider the following example: a retail store facility manager attends a trade show and learns about a new, low cost technology for lighting in areas such as storage and warehouse space. Savings of 30% and more are projected and it looks like a logical program for all the manager's 100 stores, but he wisely decides to do a pilot program in one store to evaluate the results. He hires a lighting contractor who does the retrofit and after a commissioning session and a training program for local staff, he waits for the next month's lower electric bill. When the bill arrives, he finds that the bill is actually higher than the previous month and the prior year. Certain that the contractor made a mistake, he calls the lighting contractor who goes to the job site and assures that after significant review and testing , the system is working as specified and should be producing savings.

What went wrong? The facility manager calls the local store manager to find out if there were any changes to operations or other factors that might have influenced energy usage. He finds out the following from the local store manager:

- It "…seemed a lot hotter this year than last year"
- Sales were up 3% from last year and the receiving area was "busier than usual"
- "Our 'Midnight Madness' sales promotion on a couple of weekends added a fair number of hours to our normal operation."

- And when he reviews the bills more carefully he notes that last year's electric rate was 10% lower than this year's and that in fact the energy use had actually decreased, however the bill this year was actually higher because of the higher electric rate

To make a long story short, it's virtually impossible for the facility manager to determine whether the lighting retrofit fell short, met or exceeded the energy savings expectations. It's budget time, and the facility manager needs to decide whether to plug in a capital item to do all 100 stores, but he has no way of knowing whether the test site was a success or not. A clearly defined measurement and verification (M&V) program that provides definitive proof of the savings from this retrofit would have prevented this dilemma. This application note provides some guidelines for getting a solid M&V program for energy retrofits.

How does it work: The owner and the energy management contractor must agree in advance about the desire to measure and verify the energy savings because it is important in many cases to establish a "benchmark" for performance before changes are made. The M&V system may have to be in place and operational for anything from several days to several months in advance, depending on the types of loads and their variability, to establish a sound baseline for comparison. The key to the ultimate success or failure of the M&V program is the ability to isolate the specific systems being modified (e.g., lighting) from the rest of the energy consuming equipment in the building. The steps required in a typical M&V program are:

1. *Pre-retrofit* – Before any systems changes are made, sensors and an acquisition server are installed to determine how much energy is being used by the system to be modified. The amount of time required to establish a baseline will depend on a number of factors, such as seasonal changes, operational complexity, etc. If the building has been part of an accountability metering program, this baseline data may already be available. The purpose of this baselining exercise is to verify the expected savings and to adjust the payback estimates to reflect the actual usage. Part of the baselining is not only establishing the energy use benchmark but also the operation "benchmarks" so that you can normalize post-installation results if there are operational changes that occur.
2. *During installation* – If possible, the sensors and data acquisition server (DAS) installed during the baseline period should remain in place during and after the installation to provide consistency in measurement. The information from the DAS can be valuable in commissioning the new system as this data provides 24 hour, 7 day a week measurement to ensure that systems are operating to the proper setpoint and times. Many commissioning and acceptance programs focus on a "snapshot" view of system performance that may or may not be reflective of the longer term operation. Reports at this period are invaluable for fine-tuning system operation for the maximum return on investment for the contractor and owner.
3. *Post retrofit* – Many energy retrofits perform well initially, but the ROI is never realized because system efficiency degrades over time due to calibration drift,

manual overrides, etc. Post-retrofit M&V will not only serve as a warning system for loss of efficiency, but can also provide valuable insight to the total cost of installing and maintaining energy efficiency. For example, assume that a package unit retrofit costs $10,000 and saves $1,000 per month, providing a payback period of 10 months. If post-retrofit monitoring shows that the new system requires quarterly calibration visits (at $250 per quarter) to maintain efficiency, the actual payback period is 11 months, or 10% longer. If this particular retrofit is being used as a model project for multiple locations, determining the total cost of the project is crucial prior to a wider rollout.

There is no discussion on data integrity and reliability. A complete M&V plan includes all the necessary data checks (range, relational, and redundancy) plus the methods to be used to analyze and present the results. These need to be developed beforehand so that the proper level of submetering can be specified.

Benefits: The facility manager evaluating the success of a particular project can move forward with a much greater degree of certainty about the energy and dollars saved from the project if he or she is looking at actual data from the data acquisition system rather than projections and calculations. In addition, the manager actually improves the likelihood of a successful project if the proper tools are in place for M&V as real time feedback becomes available to the manager and the contractor.

Drawbacks: Adding real M&V to an energy retrofit project adds costs in the form of hardware and software and the manpower needed to review the reports and track the project's success. Establishment of a baseline for measurement can delay the implementation of the project for a few weeks, stretching the payback time.

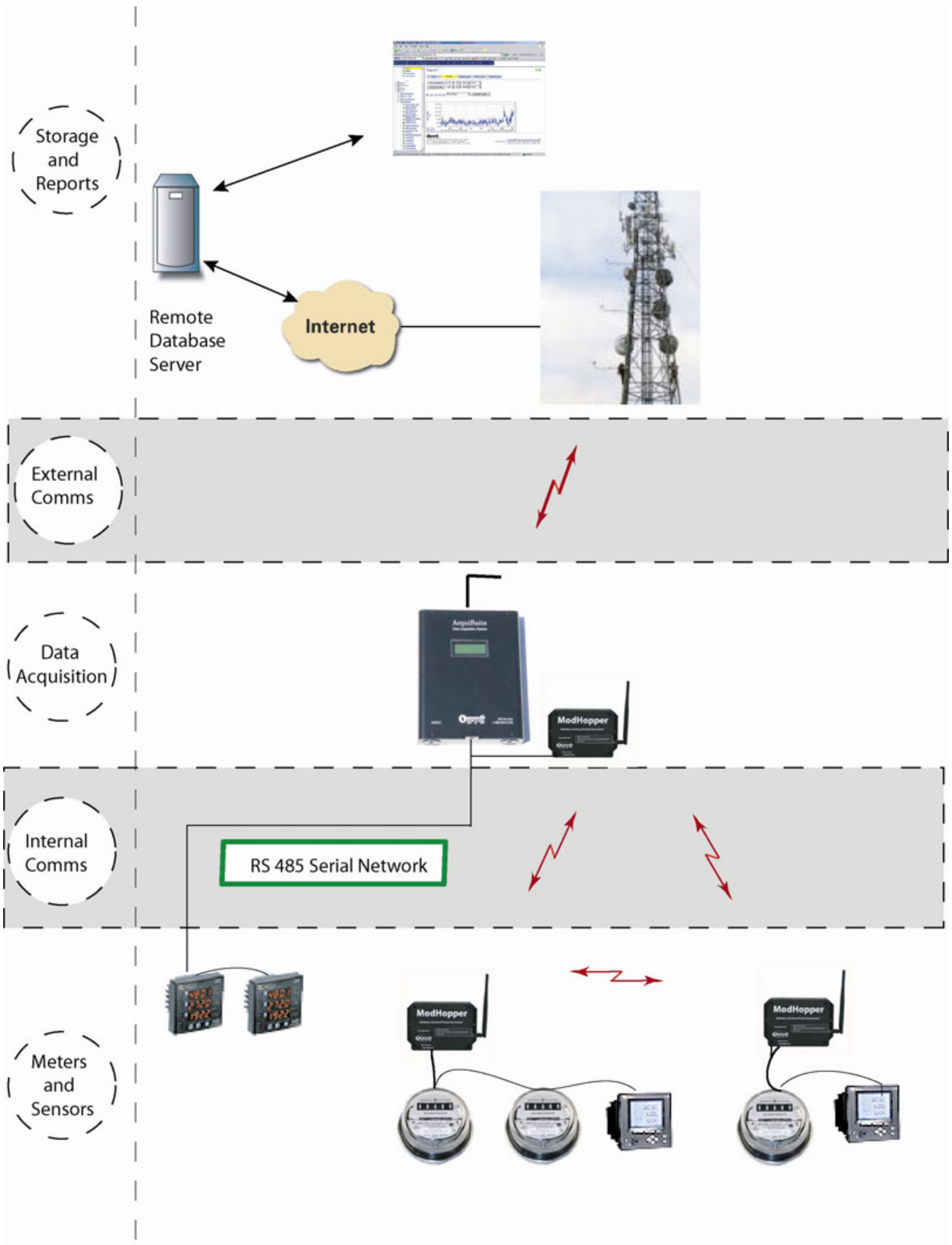
System overview: Although the specific sensors and metering equipment required will vary depending on the nature of the ECM, in general there are five key components for getting raw data and converting it into useful information:

1. Meters and sensors – the first element in getting data is to install appropriate hardware to measure the key parameters. This would include electrical submeters, flow meters, temp sensors, etc.
2. Internal communications – installing the meters is one step in getting information, but in most cases the raw data must be collected on a regular basis, which requires some means of internal communications. In general, this will either be a hard wired system or some form of wireless communications.
3. Data acquisition – raw data from the meters and sensors is only useful for M&V if the energy consumption can be tied to other parameters by establishing not only how much was used, but when. The data acquisition hardware and software provides two functions: 1) gathering and time stamping the raw data, and 2) communicating the interval data to a server for storage and reporting.
4. External communications – once the interval data is gathered by the DAS, there must be some form of communications to either a local or remote server. The most common forms of communications are LAN, phone line or cellular

communications. There are also opportunities for wireless communications such as Wi-Fi.

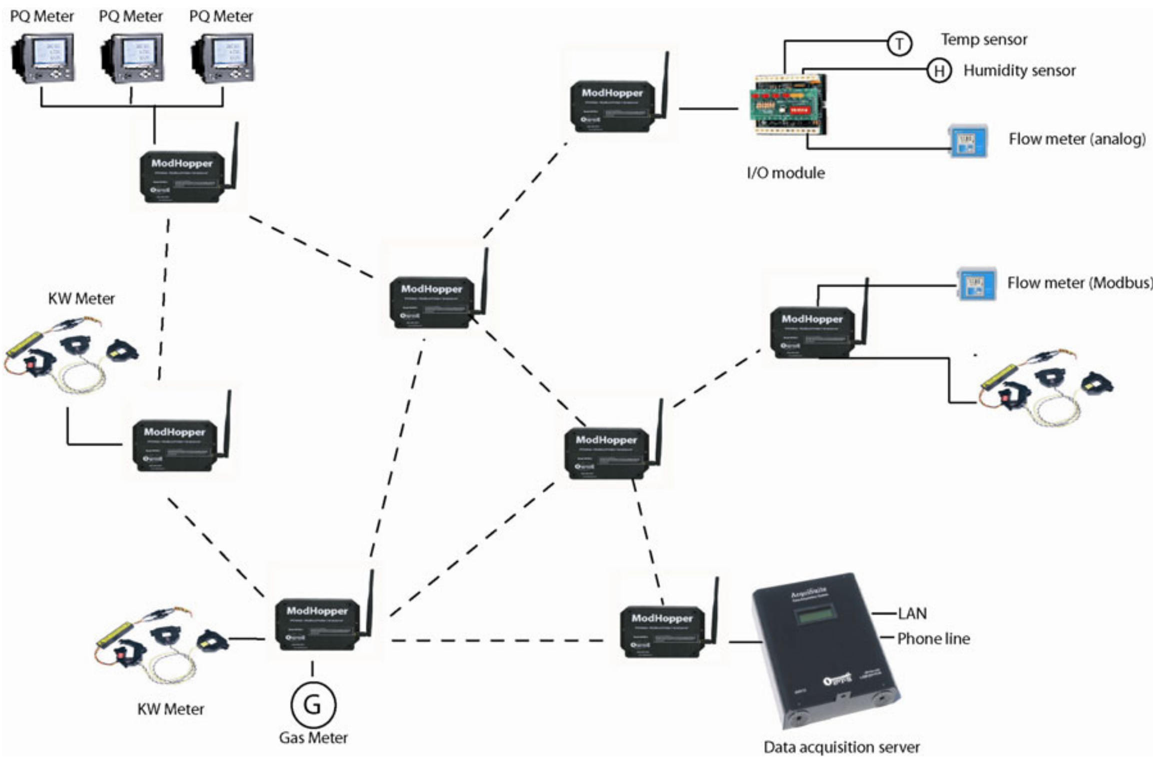
5. Storage and reporting – to make the information really useful for both the facility owner and the ESCO, the data must be converted into meaningful reports that provide a timely evaluation of the performance of the ECM's.

The following illustration provides a graphical overview of these elements:



Level 1 - Meters and sensors: While a detailed description of the meters and sensors available in the market today is beyond the scope of this paper, it is important to note that many manufacturers are producing sensors that are designed specifically for retrofit applications (e.g., split core electrical meters that can be installed without rewiring or ultrasonic flow meters that do not require pipe cutting). In addition, many suppliers are providing wireless sensors that save the cost of expensive labor to run wires.

Level 2 – Internal communications: Obviously, in most applications, the meters and sensors will be installed in multiple locations throughout the facility and getting the information back to the DAS represents a very significant investment. Probably the biggest advance in the area of internal communications is the proliferation of wireless mesh radio networks that provide a viable alternative to hard-wiring in many applications. An example of an RS-485 mesh network is show below:



In this example, the data from a variety of meters and sensors is being communicated using wireless transceivers in a mesh topology. This wireless communications network has the advantage of being self-healing, which means that the installation does not require a host PC or software. The network establishes and maintains wireless transmission of data from remote meters and sensors to a centralized collection point. This network may be within a single building or may be used to send data from building to building and can be mixed with hard-wired sensors where appropriate.

Level 3 – Data acquisition: There are several options for taking the raw data from the meters and sensors, time stamping it and communicating the interval information to a database server for reporting storage. Among the most common options:

- New or existing building automation systems – using the BAS for data acquisition has several advantages, most notably that the communications infrastructure already exists and the data can be shared with other BAS functions. The biggest drawbacks to using the BAS are that these systems are typically not designed for data acquisition on a continuous basis and reporting options may be limited.
- Supervisory Control And Data Acquisition (SCADA) systems – these systems are designed primarily for monitoring and control of electrical distribution systems. Like the BAS, they may provide a low cost (at least for electrical data) as most of the points are already monitored. The limitations of the SCADA systems are that they usually don't have good capabilities beyond electrical monitoring and the reporting functions may make it difficult to extract the most important information.
- Data Acquisition Servers (DAS) – the DAS is a relatively new development that uses hardware and software specifically designed for data acquisition and communications with little or no control functionality. These systems are typically designed for Web communications inherently and provide a means for sending data from the DAS to other building hardware and software such as the BAS. The biggest advantages are low cost and flexibility, while the major drawback is the need for installing a parallel communications infrastructure, either wired or wireless. An example of a DAS is shown below:

Level 4 – External communications: Once the interval information is gathered by the DAS, it must be sent to a database server for storage and reporting. Generally, the DAS is designed to provide this information using web-based protocols and architecture. Options will vary depending on the application, but will generally include HTTP, FTP, XML, etc. Options for the communications infrastructure include:

- LAN
- WAN
- POTS line (dial-up)
- Cellular (GSM) networks
- Wi-Fi

Level 5 – Storage and reporting: The interval data must ultimately be available to the user(s) via standard reports that address the performance of the ECM(s) in a timely manner. The most common ways to do that are to either employ web-based tools that access information from a database using standard browsers or to provide reports using proprietary systems. Most common today are web based servers that are either local or remote to the facility.

Installation requirements: The specific hardware required for M&V will, obviously, be dependent on the systems being retrofitted and the expected outcome. Consider the following examples for general guidelines:

1. Chiller retrofits – chiller retrofits generally are designed to improve the efficiency of the chiller system in producing cooling (typically measured in kW/ton). The benefits and savings from most chiller retrofits can be determined using the following:

    - Data acquisition server (DAS) – gathers the data on user-specified intervals and stores it until it is sent to the remote server
    - Electrical sub-meter – provides data on the power (kW) consumed by the chiller system to produce cooling (tons)
    - Chilled water supply and return temperature sensors – used to measure the temperature differential between supply and return temps (ΔT)
    - Flowmeter – used to determine how many gallons of chilled water move through the chiller; when combined with ΔT, the amount of cooling produced (in tons) can be calculated
    - Software to calculate chiller efficiency (in kW/ton) to provide comparison to before and after retrofit and to fine tune performance

2. Variable Frequency Drives (VFDs) – great savings can be realized from converting constant volume fans and pumps to variable speed as the load on the fan or pump can be reduced during non-peak load periods, but if the system is not properly sized and calibrated, the savings can be lost. There are several options for monitoring the performance of VFD's:

    - DAS – gathers the data on user-specified intervals and stores it until it is sent to the remote server
    - [Option 1] Electrical sub-meter – provides data on the power (kW) consumed by the motor; most accurate and most expensive

- [Option 2] Analog current sensor – connected to one leg of the motor electrical supply, the current sensor measures amps which can be used as a measure of the load on the motor (note: the sensor should be located upstream of the VFD to capture the losses introduced by the VFD itself).

- [Option 3] Analog output from the drive – many VFD's provide an analog output signal proportional to the load. For example, a 4 to 20 mA output signal would read 12 mA at 50% of full load. This is usually the least expensive option if the analog signal is available from the drive. It is still important to take sample measurements of power consumption at a variety of load levels to develop and implement a model for performance..

3. Lighting retrofits – most simple lighting retrofits (e.g., ballast and tube replacements) are the easiest to measure since the amount of energy saved (in watts) per fixture is nearly constant and the only variable that needs to be monitored is the run time once the power draw is established. It is also important to monitor light levels to verify that savings are not coming at the expense of necessary light levels in the space. Typical requirements are:

    - DAS – measures the total runtime on user-specified intervals and stores it until it is sent to the remote server
    - On/off current sensor – this sensor is similar to the analog current sensor described above, but the current sensor simply uses current flow to determine whether the lights are on and the DAS calculates the run time to verify that the hours of operation are the same as the baseline period
    - [Optional] Analog current sensor – the analog sensor can be used to measure the actual current draw and verify not only that the hours of operation are consistent, but that the equipment is functioning properly
    - [Optional] Ambient light sensor – If there is concern that the retrofit will have a negative effect on light levels; one or more ambient light sensors can be installed to verify that the lighting levels are acceptable (or do a series of one-time measurements to establish whether there is an effect).

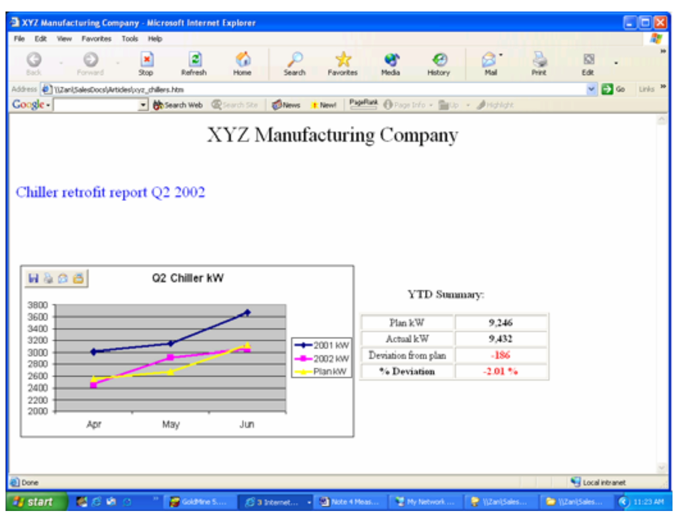
Reports: The reports for M&V can be relatively simple (baseline energy use vs. actual) or can involve a great deal of post-processing. For example, analysis of a chiller retrofit would likely have to include some "normalization" of energy use to include temperature differences from the baseline period to the M&V period to account for higher temperatures or internal loads that might impact the load on the chiller.
One of the most important elements to remember in designing M&V for chillers is to look beyond just the chiller itself to the building side and to the condensing loop to capture the total power usage for all the parts of the system.
For example, a complete chiller plant retrofit will often include VFD's to replace constant volume fans and pumps for the chilled water side and the cooling tower plant in addition to new chillers. In this environment, measuring just the load and efficiency on the chillers may not accurately reflect the total power used to provide cooling to the building. Raising the chilled water discharge temperature might improve the chiller efficiency, but

might require the chiller water pumps to operate at higher levels to compensate for the higher temperature. In addition, it is very important to monitor the loads on just the chiller(s) to be able to evaluate the most efficient long-term operation (e.g., partial loads on several chillers vs. heavy loading on a single chiller).
To effectively model the overall chiller plant savings, the following steps are recommended:

1. Monitor total chiller plant operation at various load levels before the retrofit (including chilled water and condenser side loads);
2. At a minimum, install the following sensors:
   - kW meters for the chiller(s)
   - Entering and leaving chilled water temps
   - Flow on the building side
   - kW meters for the chilled water loop
   - kW meters for the condenser loop

Using the data gathered pre and post retrofit in both long term and short term measurements provides the necessary data for analysis under both static and variable loads. Analysis of performance may be as simple as the example provided below or may involve more complex review such as regression analysis depending on the variability of the loads within the building and the operation of the plant itself.

A simple example showing plan vs. actual savings for a chiller retrofit might look like the following: need to get a better graphic. Might be O.K. but its too small to really see what's going on.



Analysis/Actions: A targeted M&V program can greatly accelerate an energy program because the facility manager (and contractor) can:

- React more quickly to correct problems that are identified in the M&V audit. Many retrofits are installed or operated incorrectly and the problems are not identified until weeks or months later when the utility bills are analyzed. In many cases, it is difficult if not impossible to determine the root cause of poor performance months later.

- Quickly determine the success (or lack thereof) of a particular energy retrofit and make better decisions about wider implementations to more locations
- Provide measurable proof for owners and executives of the impact of energy retrofits on the bottom line, greatly improving the chances of getting additional program support

Costs: As with all the application notes in this series, it is very difficult to estimate costs due to a variety of factors (wiring distances, communications issues, scheduled shutdowns, etc.), but some general guidelines for costs (hardware and installation) are:

- Data acquisition server - $1,200 to $1,800
- Electrical sub-meter (3 phase) - $600 to $1,000
- Current sensor (digital or analog) - $100 to $200
- Data storage and reports - $20 per month per DAS

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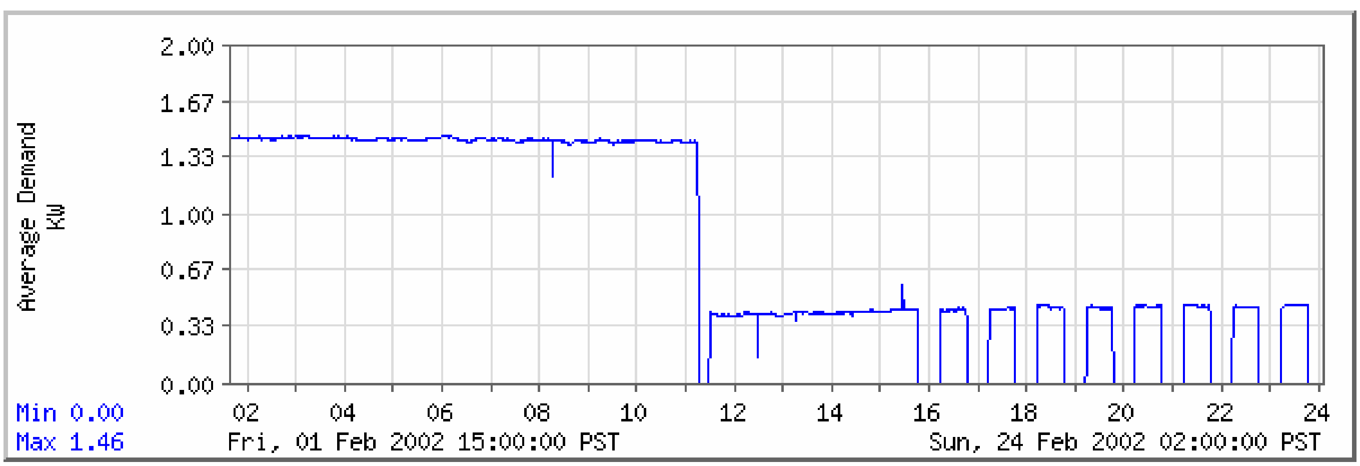
Example: Lighting retrofit

Background: A retail chain in the northeast was considering a lighting retrofit for all of its stores, but wanted to do a test project using extensive M&V to evaluate the ROI. They decided to install electrical meters to establish a baseline of energy usage on the particular circuits and gather the data with a DAS. The M&V system was installed for approximately two weeks in advance of the retrofit and was then monitored after the installation. The data gathered from the retrofit is shown below:



The graph above shows the kW consumption on one of several identical circuits. The data was gathered using an electrical meter installed in an electrical panel serving the lighting system. This particular example not only demonstrates the use of submeters for M&V, but also shows the use of submeters for monitoring ongoing operations of building systems.

The left part of the graph shows the kW load for approximately 11 days, with a steady load of roughly 1.4 kW. In the center of the chart is a brief period of zero consumption during the evening of the 11th when the system was de-energized for the installation of the new lighting tubes and ballasts. When the power is restored, the chart shows us that the new load (post-retrofit) was slightly over .33 kW, a reduction of more than 1 kW for this particular circuit. Based on the operating hours of the store, it is clear that this kind of data provides timely and accurate feedback on the ROI to be expected from implementing this same retrofit on other circuits.

One interesting side note to this particular chart is that while it clearly shows the payback to be realized from the retrofit, it also provided an unexpected benefit. While the client and contractor were reviewing the excellent results from the lighting change, they also noticed that the lights were on 24 hours a day in a retail store. It was discovered that a contactor had burned out on the lighting control system, and once it was replaced, the pattern shown on the right side of the chart was observed, with the lights shutting off at night and on during the day.

While other M&V applications may involve more detailed analysis, the important point of this example is that it shows how much information can be gained from simply observing interval data from the monitored systems and using that data to calculate savings and verify system performance.

Notes/miscellaneous: Historically, energy contractors and building owners have been reluctant to add equipment for measurement and verification, choosing instead to rely on calculations (aka, stipulated savings), snapshot studies and utility bill analysis to verify savings from energy retrofits. This view has resulted in many projects that may not have any return being accepted as successful and has also almost certainly caused projects with good returns to be deemed as failures because extraneous factors masked real savings. The simple fact is that a good M&V program, using well-designed and cost-effective technologies, pays for itself both in the near term and over the long haul as managers is assured that the retrofits they invest in continue to provide the expected returns for many years to come.