Will Interval Data + Advanced M&V Analytics + Free Software = Change?

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ABSTRACT

Advancements in building metering and analytic technologies have reduced the cost and improved the quality of conducting measurement and verification (M&V) of energy savings from building energy efficiency projects. These advancements can have a positive impact on program administration costs and investor confidence in savings investments. New analytic methods based on more time granular (e.g. 15-minute, hourly, or daily, not monthly) can accurately predict what baseline use would have been in buildings after installation of energy efficiency measures: savings are the difference between predictions and actual energy use. Quantifying savings with this approach has several advantages over standard engineering calculations: uncertainty in savings estimates can be quantified, the method is based on industry standards, and the analysis is based on only a few data sources. However, the energy modeling and accompanying uncertainty analysis critical to rigorous M&V remains largely an academic exercise or available only from highly skilled service providers.

This paper presents free M&V software that uses 15-minute, hourly, or daily measurements of energy use (rather than monthly utility bills) to establish energy use baseline models, quantify savings, and track energy performance with accuracy and transparency. It reduces data preparation barriers, incorporates advanced modeling algorithms that greatly improves prediction accuracy, and calculates savings uncertainty. Case studies of its application in whole building and retrofit isolation approaches in commercial and residential building projects are presented. Discussions are promoted about its use as a quality assurance or savings settlement tool, impact on program administration costs, and effect on investor confidence.

Introduction

Nationally, the delivery of energy efficiency is supported through state policies, legislation, codes and standards, and public programs, including utility ratepayer funded programs. In the private sector, energy efficiency is often delivered through energy savings performance contracts. In most cases, decision-makers must weigh a project’s costs and benefits before investing. While financial decision makers are well equipped to assess an investment’s risks and uncertainties, it has been challenging and costly for the industry to demonstrate the returns of energy efficiency projects and programs. A result is that investment capital for energy efficiency remains largely in markets where loans are secured by the equity of the owner’s property and not on the efficiency project’s potential returns (Investor Confidence Project 2014).

Many efficiency programs that target the large potential savings in existing buildings require that the benefits and costs of each energy efficiency measure be quantified prior to implementation so that its financial merits may be assessed, and potential incentives determined. This emphasis on individual measures presents many administrative and technical problems. It can mean costly data collection to characterize building subsystem, their operations, and energy performance. It can require time-consuming and detailed measure-by-measure estimates of savings, often including the lowest-cost measures, such as control system set point adjustments. As there are no industry standard methods for calculating savings for individual measures, much less for multiple measures, savings submittal packages tend to be highly customized, and require technical reviewers with specialized skills. The general individual measure savings calculation practice does not include considerations of risk factors, such as uncertainties in savings and costs. The calculations must often consider additional baselines to account for savings above applicable equipment energy performance standards, for which regulatory agencies allow payment of incentives.

Using these measure-based calculation approaches, several steps are taken to assure savings are realized. Technical review of facility audits and prior-to-installation savings estimations are performed by program administrators. Upon implementation, a large amount of data may be required to verify assumptions about post-implementation operations and performance, with savings calculations corrected to account for actual performance. However much this time consuming and costly process is streamlined, it is still too arduous a process to repeat throughout each measure's expected useful life, hence performance breakdowns can go undetected. Lack of savings persistence is a large factor behind the low realization rates for California's early retro-commissioning programs (SBW 2010).

Verifying savings at the building level quantifies the net energy savings for all installed measures, and addresses many of these cost, accuracy, and administrative issues. Standardized approaches to measurement and verification (M&V), applied using advanced modeling methods and hourly or daily energy use measurements, have been in existence for many years. The Efficiency Valuation Organization (EVO) maintains the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2012), which describes best practices in retrofit isolation and whole building approaches for savings verification. The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) provides Guideline 14 (ASHRAE 2002), which describes technical detail, data requirements, and compliance pathways for verifying savings. Regulatory agencies reference IPMVP for evaluating public-goods funded programs, and while it provides guidance to help stakeholders manage a project's real risks, its methods have yet to become widespread practice.

Advancements in building metering and analytic software are lowering the cost and improving the quality of M&V for energy efficiency projects. Advanced metering systems are producing energy use data in short measurement intervals, from sub hourly to daily (PG&E 2014). Energy modeling methods have been developed to leverage this data for quantifying demand-response savings (Matthieu, et.al., 2011). An M&V software tool ("M&V Tool") funded by the California Energy Commission (CEC) was developed to leverage the increasingly available short time interval energy data, streamline the analysis process, and improve accuracy of the regression-based M&V analysis for quantifying savings. This software, available at www.utonline.org, is expected to facilitate more rigorous and accurate applications of IPMVP and ASHRAE Guideline 14 M&V methods, while reducing data preparation and analysis time. Additional goals include promoting standardization and transparency across projects, and ultimately raising confidence in savings results. This M&V Tool will be described and its applications demonstrated with a few case studies. A discussion of similar software, applications, and potential impacts on program and project designs is provided.

Brief Background

While the energy efficiency industry as a whole was still relying on engineering calculations to provide estimates of savings in customized and capital-expense projects, a unique program provided the opportunity to apply regression based M&V analysis to account for actual savings of all installed measures. The Monitoring-Based Commissioning (MBCx) Program available to California's Universities and State Universities in partnership with its Investor Owned Utilities (UC/CSU/IOU Partnership 2005) provided whole-building energy meters to individual campus buildings prior to starting the MBCx projects. Under this program, engineering calculations were used to determine cost effectiveness of more expensive measures, but the low cost measures could be installed directly without energy savings estimates. The net project savings of all installed measures was quantified from analysis of metered energy use. The M&V analysis method was used in several MBCx projects at the University of California at Berkeley and Davis campuses.

At the time, the approach required inverse regression model algorithms to develop statistical relationships between the dependent energy use variables and independent ambient temperature variables. This process was cumbersome and arduous. However, the process of creating baseline and post installation models based on actual energy use provided confidence in the actual savings realized by the project.

The program procedures were eventually adapted to require three months of baseline energy data and three months of post-installation energy data in the M&V analysis. Projects conducted with such M&V in the MBCx program were shown to provide a rigorous check on the estimated savings for the installed measures at the whole building level (Jump et.al., 2007). MBCx projects sampled in evaluation impact studies have consistently returned high realization rates.

MBCx projects conducted over the next six years saw refinements in the process that reduced the time required to complete the M&V analysis from weeks to days. Such refinements included use of available tools, such as the Inverse Model Toolkit (IMT) (ASHRAE 2002). However, the need for a simple, standardized tool was readily apparent.

M&V Tool Description

The M&V Tool was developed to achieve four main goals: (1) enable users to develop accurate regression-based energy models from short-time interval measurements of energy use that is increasingly available from time-of-use and smart meters, as well as from sub metered data from building subsystems, (2) enable the estimation of baseline model and savings uncertainty, (3) reduce the overall time to conduct the M&V analysis, and (4) provide the analysis capability in a widely known and free software package, enabling easy transfer of analysis files among interested parties to facilitate project reviews and promote standardization and transparency. Developmental and testing versions of the Tool have been available since Winter 2013, and the publically available beta release of the Tool became available in April 2014. It has been used in over 30 building efficiency projects by a small but growing number of users.

The first goal to provide the ability to create a statistical energy model based on interval load data was achieved by automating and expanding the model of Mathieu et al. (2011). The model was designed to apply to commercial buildings or to other buildings in which most of the load at a given time is a combination of scheduled loads (controlled by a timer), routinely occurring loads that recur for long periods, and loads that are predictable from outdoor air temperature as described below. Buildings for which there is substantial load variability that is not scheduled, routine, or predictable from temperature, such as single-family homes that are unoccupied during some evenings and occupied during others, will be fit less well by the model.

Many commercial buildings have an *occupied* mode in which the indoor air temperature is maintained at a comfortable level and an *unoccupied* mode during which the indoor air temperature is either uncontrolled or is maintained only within a broad band. In a typical commercial building, the dependence of load on temperature is a nonlinear function of temperature, and depends on which mode the building is in. In occupied mode, it is common for building load to be positively correlated with outdoor air temperature at high temperatures (when using energy for cooling), negatively correlated at low temperatures (when using energy for heating), and relatively uncorrelated at moderate temperatures (when not using energy for cooling or heating). In unoccupied modes in warmer climates such as in California, load typically has little correlation with outdoor air temperature.

In either mode, there is a recurring time-dependent pattern in addition to the temperature dependence. For example, many office buildings show a pattern of generally increasing electricity consumption starting at 7 a.m., reaching a plateau from the late morning through mid-afternoon, with a dip at lunchtime, and decreasing consumption starting at 5 p.m. Electricity consumption is often lower on Mondays and Fridays than during the rest of the week and much lower on weekends than on weekdays. For many commercial buildings, the load variability is primarily driven by weather, hour of week, or day of week.

The model that is implemented in the M&V Tool allows different temperature dependence in occupied and unoccupied modes and also accounts for a recurring weekly pattern. The details of both the weekly pattern and the temperature dependence are estimated from historical data. The Tool will model temperature dependence for each hour of the week, so if Friday afternoon has lower loads than other weekday afternoons, the statistical model is able to recognize that pattern.

The second goal was achieved by implementing the procedure described in Walter et al. (2014), which estimated baseline model uncertainty and thus energy savings uncertainty. The uncertainty algorithm is based on a cross-validation methodology that entails partitioning the data into subsets, fitting the model to one subset, and then validating the model with another subset. The data set (e.g., one year of data) was separated into many shorter time intervals (e.g., one month). The model was fit for one interval and used to predict the next interval; the difference between the prediction and the actual load was computed for each time interval; then repeated for each interval in the data set. The result provides a statistical distribution of prediction errors, which was then summarized to quantify the uncertainty in the predictions. Walter et al. (2014) shows that cross-validation is an effective method for computing uncertainty and demonstrates the method by predicting energy use and uncertainty in 17 real commercial buildings.

The third and fourth goals were achieved by adding this M&V analysis capability to an appropriate computational platform. The M&V Tool was developed as an analysis module in Pacific Gas & Electric's version 3 of its Universal Translator software (UT3). Processing speed in UT3 is much faster than previous versions. UT3 provides a platform for uploading the data and conducting data quality checks. UT3 has wizards that recognize data from different sources and file formats, such as popular data logging devices and building energy management system trend files; users need only drag files across the screen to upload the data. Attributes of the data files can then be assigned, such as naming the files, adding a description and specifying time interval re-sampling rate (i.e. creating hourly or daily time intervals from the raw data). The user interface facilitates merging of data sets, filtering, applying functions, and charting. Each of these functions is useful in preparing for M&V analysis. All tool charts, data, and model outputs are exportable, for use in other software, spreadsheets, or reports. UT3 allows users to develop analysis modules, providing developer a toolkit to assist in the process.[1] Through its Public Interest Energy Research (PIER) Program, the CEC funded development of the M&V analysis module that has been released with UT3.

The M&V Tool was designed to be integrated with the development and implementation of energy efficiency measures. The data required is building energy use and weather. The Tool currently accepts separate energy and weather data files; however future versions may have capability to assist the user in collecting the weather data. Weather data is readily available from many web-based sources. Prior to measure installation, baseline data is collected, prepared, and a baseline model is developed and assessed. The statistics R^2 and CV(RMSE) [2] are calculated and checked to assure good model 'fit' to the independent variables. The Tool also calculates the uncertainty of the baseline model to allow users to compare it with the expected savings. If the uncertainty is too large or the model fit is poor, users can refine the baseline model, collect more data, or decide on an alternate M&V approach. The Tool allows users to repeat baseline development until a satisfactory model is established.

Figure 1 shows the UT3 user interface with the M&V analysis module open. The module uses the M&V terminology of the IPMVP, and users complete the savings analysis by completing the actions under each tab, called Baseline, Post-Installation, Avoided Energy Use, and Normalized Energy Savings. Actions under Baseline and Post-Installation tabs are similar – the dependent and independent variables and the baseline and post-installation periods are defined. Filters may be used to define analysis bins of similar building operations, or capture anomalous energy behavior for additional analysis. The Model Builder tab shown in Figure 1 allows users to define the type of regression for the selected analysis bin. Selections may include a time and temperature model; a time-only or a temperature-only model, or a simple average. For temperature dependent models, the user may also select the number of line segments used, and how the line segments are defined. Selecting the compute button develops the regression model for the defined analysis bin. The R^2 and CV(RMSE) values are displayed, and various charts are provided to help the user understand how well the model fits the data.

Following a project's installation and enough time to collect post-installation data, the Tool allows users to again upload, merge, re-sample, check data quality, and proceed with the M&V analysis to calculate savings and uncertainty. Savings may be calculated for post-installation conditions, called Avoided Energy Use, or Normalized Savings may be calculated if a year of typical meteorological (TMY) weather data is available. All of the raw and processed data and analysis work performed is stored in a project file. In addition, all raw and processed data and analysis results are available for export to other software. With the appropriate energy and independent data files available, the time to develop a baseline energy model and conduct a complete savings analysis is less than an hour.

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[1] Descriptions of the available functions and features of the UT3 are available on the utonline.org website.
[2] R^2 is the coefficient of determination, and CV(RMSE) is the coefficient of variation of the root-mean squared error. Generally R^2 values of 0.80 or higher indicate good regression models. Values of CV should be low, typically less than 10%, however there is no industry standard rule, as higher values may be acceptable if the expected savings are also high.

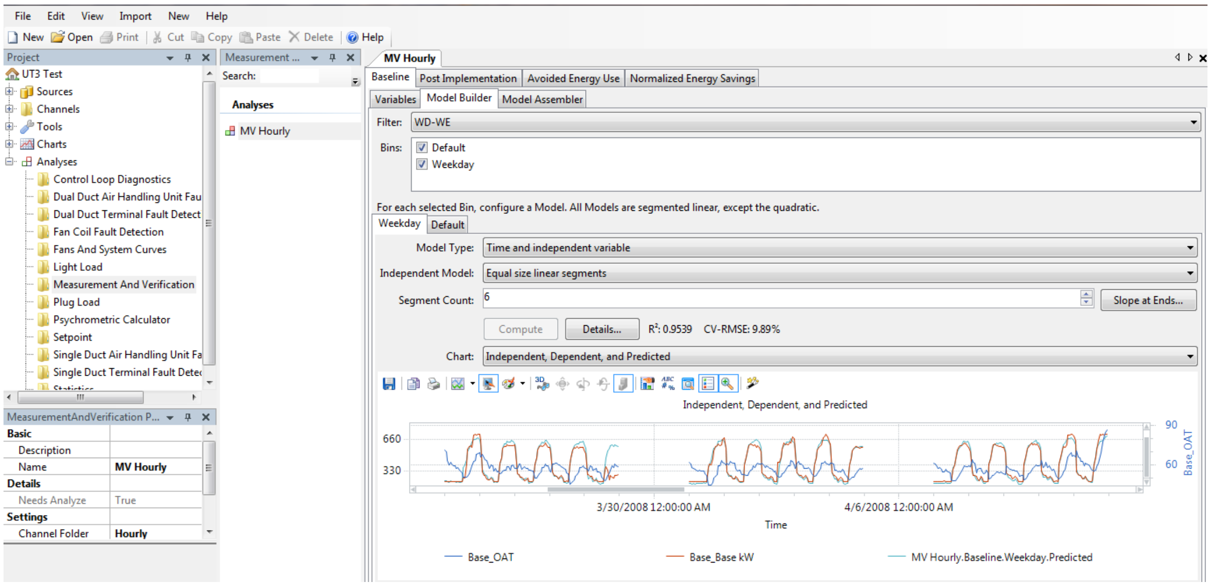

Figure 1. UT3 with M&V analysis module.

UT3 and its analysis modules are freely available on PG&E's utonline.org website. Test files and a tutorial document are provided to familiarize users with the Tool. Service providers working with owners to improve their building's energy efficiency, can develop and assess baseline models and calculate savings, and pass this analysis on to technical reviewers, who also have access to the Tool, making the process transparent. The M&V analysis may be applied with whole-building energy data, or with building sub meter or sub system usage data. As service providers, technical reviewers, and program impact evaluators gain experience using the Tool, feedback from these stakeholders can formalize the M&V procedure into a standard process.

Case Studies

Case Study #1: Savings Settlement for a Retro-Commissioning Project

An early version of the M&V Tool was used in 2012 on an MBCx project at the Valley Life Science Building at the University of California, Berkeley. This building is 420,000 ft^2 and was constructed in 1930. The building houses a natural history museum as well as several extensive archives of biological materials. The building also has a library, classrooms, lecture halls, offices and many lab areas. A thorough audit was conducted, resulting in the identification of 66 operational improvements across the mechanical systems. Most of the savings for this project came from the four large supply and exhaust fans that served the labs, and operated continuously 24 hours per day, 7 days per week. Based on trends and measurements, it was determined the airflow far exceeded the requirements of the space, causing energy waste. A test and balance contractor was procured to determine the actual flow required at the zone, enabling the fan speeds to be reduced, saving fan, chilled water, and heating energy.

The final saving settlement for this project was entirely based on baseline and post-installation energy measurement, adhering to IPMVP Option C: Whole Building. The M&V Tool was used to create the baseline and post-installation models that were submitted, along with the Tool to the program's technical reviewer. After a short half hour training session by phone, the reviewer was able to use the tool to see all components of the models, its fit statistics, and was able to try other models. In the MBCx installation review document, the reviewer reported: “MBCx project savings were calculated using Universal Translator 3 with a new M&V package which makes evaluation of data and extension on an annual basis simpler.” The baseline and post-installation energy use as a function of outside air temperature can be seen the scatter chart in Figure 2. This MBCx project resulted in verified savings of 1,900,000 kWh and 46,000 therms.

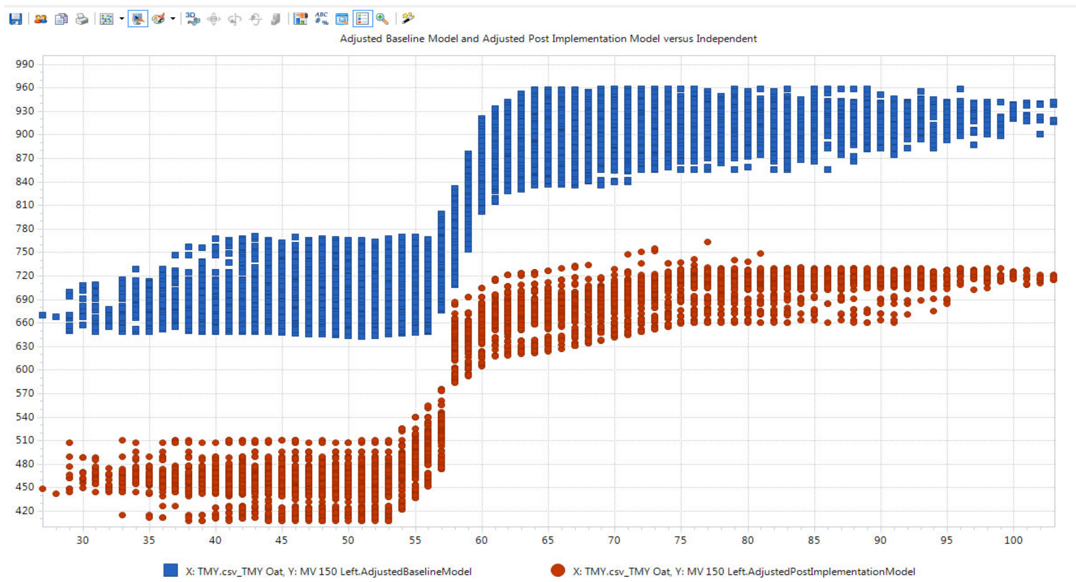

Figure 2. Scatter chart showing baseline (blue) and post-installation energy use (red), adjusted to typical meteorological year conditions.

Case Study #2: Application in 10 Southern California Residences

A project using the M&V Tool was completed for ten single-family residences in Southern California Edison’s service territory. The purpose of the project was to determine whether robust baseline models and whole-building savings analysis could be developed for less-predictable single family residences using advanced metering data and ambient temperatures from local weather stations. The efficiency upgrades in the homes included sealing against air infiltration around doors and windows, sealing air leaks in the home’s forced-air system ductwork, and adding insulation in the attics, walls and floors to well above code requirements. We were blind to the size, layout and construction of the houses, and to the actual number and type of measures installed. Energy savings estimates were not provided for this exercise, as the project administrator desired to obtain independent results.

The buildings were selected based on availability of data prior to installation of the upgrades. Buildings with twelve months of baseline and post-installation period data were preferred, however as little as 7 months of data was available for one house. The data were prepared by adding up energy use to daily intervals, and averaging ambient temperatures over each day. To develop baseline models, we applied the same modeling method to each house: a temperature-only model with 10 linear segments, and requiring an equal number of data points per linear segment. Results of the analysis for each house are shown in Table 1.

Table 1. Summary of M&V results from 10 Southern California residences

Site	Baseline Period (Mos.)	Post Period (Mos.)*	Incl. Warm Season? (May -Oct.)	Baseline Energy Estimate (kWh)	Baseline Model Statistics		Post-Install Model Statistics		Savings	
					R^2	CV-RSME	R^2	CV-RSME	kWh	%
1	11	13	through 8/21	9,086	0.77	23.2%	0.74	26.9%	50	1%
2	11	11	Y	4,999	0.79	19.2%	0.68	16.8%	95	2%
3	8	15	through 6/8	20,188**	0.25	22.9%	0.18	44.4%	8,875	44%
4	12	12	Y	3,303	0.50	25.7%	0.20	22.9%	384	12%
5	9	13	through 8/23	11,777**	0.51	22.5%	0.70	17.2%	740	6%
6	17	13	Y	7,122	0.62	27.9%	0.53	33.0%	1,039	15%
7	7	24	Y	10,817**	0.63	24.1%	0.68	22.3%	-1,481	-14%
8	11	12	Y	5,978	0.66	32.9%	0.70	28.7%	1,508	25%
9	11	12	Y	9,558	0.60	26.0%	0.57	23.5%	2,281	24%
10	11	13	through 8/1	3,736	0.45	38.5%	0.48	35.4%	-895	-24%

*Normalized savings for each site was based on period from 9/12/12 through 9/11/13

**Estimated based on fewer days of baseline kWh data

The results show poorly fitting models for all houses, as judged by low values of R^2 and high values of the coefficient of variation CV(RMSE). We did not attempt to develop the best model in each case; instead we consistently applied the same model for each house. This provided the opportunity to compare the model performance on the building population, identify general issues, and determine how the analysis may be improved. Several observations were made.

1. Two houses (7 and 10) resulted in negative savings. These houses had less energy data in the high-temperature summer months when savings were expected.
2. House 3 showed an unrealistically high estimate of savings, 44%. In this case, the baseline period duration was also short, and had less summertime energy data when savings are expected. This model had poor model fit as indicated by the low R^2 and high CV(RMSE) in the post-installation period.
3. A few sites exhibited energy use patterns in the baseline or post-installation period that were unexplained by temperature or day of week (see Sites 4, and 10).
4. Values of savings achieved for the remaining sites were reasonable for the measures installed. Most savings were expected in summer, as the measures served to reduce AC loads.
5. In general, the model goodness-of-fit statistic R^2 was moderately good in most cases, while the CV was poor. It was noted that the models could be improved on a case-by-case basis. The buildings generally exhibited distinct weekday versus weekend and holiday operation patterns. Including a day-of-week parameter in the model and filters for holidays would help develop more accurate baseline models.
6. Residential data is ‘noisy’ and is generally less predictable than in regularly-scheduled commercial data. A screening criterion may be applied to remove less predictable houses

from the sample, thereby improving overall predictive ability. This may be useful in targeting houses for this approach.

7. Costs to implement this savings methodology were minimal – approximately 6 hours for the 10 houses using this manual process. Costs may be further reduced with automation of the analysis. This study demonstrated that defensible results may be achieved with the smart meter data and applied analysis.

The Tool helps users to lower savings uncertainty by removing periods of anomalous energy use, selecting better model types (e.g. day of week and temperature), and generating better models (e.g. lower CV). Savings uncertainty is dependent on these factors, as well as on the amount of baseline and post-installation period data, and higher expected total savings (ASHRAE Guideline 14). A future study that determined the improvement in savings estimates resulting from better baseline models, and compared these savings predictions with the programs engineering calculations would be insightful. This work shows only that whole building M&V has promise in the residential sectors, using models developed for large commercial buildings.

Case Study #3: Savings Settlement in a Whole-Building Pay-for-Performance Program

The M&V Tool is monitoring and tracking energy use and savings under Seattle City Light's whole-building pay-for-performance program. The subject building is 34 stories high with 582,000 total square feet, of which approximately 30% was occupied (rented), although occupancy did rise to approximately 50% over the summer of 2013. Both heating and cooling systems are electric.

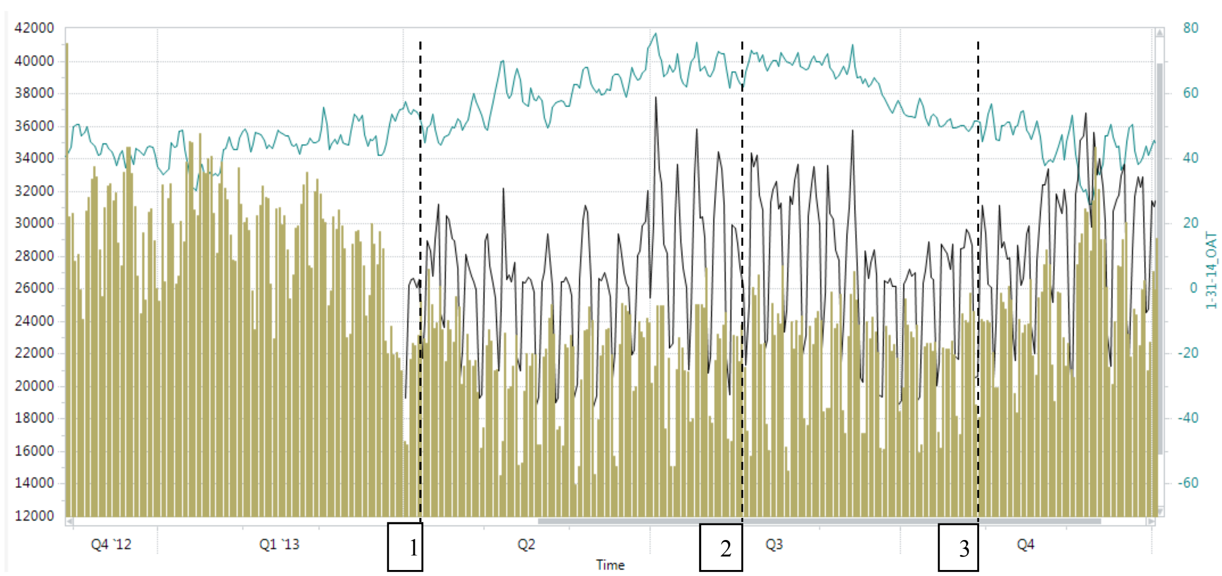

Figure 3. Energy savings in a large commercial building in downtown Seattle. Savings is shown by the gap between the predicted baseline (dark line) and measured post-installation use (beige bars). Ambient temperature is shown by the green line at the top. Energy conservation measures were implemented at the times shown on the chart: (1) installation of isolation dampers for unoccupied zones, (2) 1 of 2 550-ton chillers replaced + conversion to variable-primary loop, (3) VFDs installed on 2 large (100 hp supply, 60 hp return) fan systems.

A time-and-temperature baseline model was developed for each of two electric energy meters for the year starting March 1, 2012. Beginning March 1, 2013 the first of three large energy conservation measures was installed as shown in Figure 3. Figure 3 shows the Tool's prediction of the baseline relative to the metered energy use for the combined meters. There is a dramatic decrease in use relative to the predicted baseline after installation of the first measure. In total, for the post-installation period since April 1, 2013, savings amounts to 16% of baseline period annual energy use. This percentage would be higher if the Tool could account for changes in occupancy. Interestingly, the Tool's estimate of savings uncertainty (at least 13%, with 68% confidence) closely matched a separate calculation of savings uncertainty using the fractional savings methodology (ASHRAE 2002).

Discussion

In the preceding case studies, the M&V Tool showed how current practices may be enhanced. Several benefits were demonstrated through applying the M&V Tool with data from time-of-use and smart meters. These benefits included: (1) Flexibility in application: the M&V Tool was applied successfully in a large university building, a large commercial office building, and showed potential in single family residences. (2) Use as quality assurance to support traditional savings calculations, or as the savings settlement methodology in a pay-for-performance program. (3) Providing transparency and standardization that facilitates technical review – data files are transferrable, and may be viewed by anyone who has the free software. (4) Low learning curve, technical reviewers and other stakeholders may be brought up to speed quickly.

The M&V Tool does have limitations: The preceding case studies showed that its regression modeling algorithm is appropriate for regularly scheduled and temperature sensitive buildings. Many buildings do not exhibit such regular behavior. For such buildings, the M&V Tool's regression algorithm will generate large CV(RMSE) and low R^2 values, and high baseline model uncertainties. Acceptable values of these metrics may be established as a means of screening out buildings where the M&V Tool cannot produce acceptable models.

The initial release of the M&V Tool has many useful features and capabilities. There are several ways in which it may be improved. Addition of another independent parameter to the regression algorithm may help make the tool more useful. As was indicated in the Seattle City Light case study, there is currently no means by which the Tool can include both building occupancy and temperature effects, as it allows only one independent variable. Also, granular occupancy data rarely exists. Future versions of the tool will allow additional independent variables, enabling user to use less granular (e.g. monthly) occupancy data. The impact of humidity may be important in some climates. These capabilities should be developed and tested. Another improvement would be to test the uncertainty algorithms with more buildings and in more climate zones and with additional fuels.

What Does Change Look Like?

The M&V Tool is one of several tools that have similar savings analysis methods. For example, in the public domain, ASHRAE provides source and executable code for its Inverse Modeling Toolkit (ASHRAE 2002). The IMT provides linear change-point modeling capability that relates ambient temperature to energy use, but does not estimate savings uncertainty. The spreadsheet-based Energy Charting and Metrics (ECAM) Tool (Koran 2014) also implements ASHRAE's change-point modeling capability as well as the fractional savings method to estimate savings uncertainty. In the last few years, many Energy Management and Information

Systems (EMIS) vendors have appeared, each with some capability to remotely assess building operations data, recommend improvements, establish an energy baseline model, and quantify savings over time (Kramer et.al. 2013). While their software is proprietary, their baselines and savings may be evaluated in order that stakeholders have confidence in their results. Several utilities are conducting pilot and demonstration programs using these EMIS products (Erickson 2012).

Clearly, improved metering and analysis technologies are penetrating the energy efficiency industry, and change from status quo is likely. The methods and tools promote standardization of the energy settlement process, enabling all involved parties, from service providers, technical reviewers, and impact evaluators to understand the data requirements, measurement duration, analysis methods, metrics and criteria of application. This should serve to reduce administration costs and increase confidence in savings at both the project and program levels. Such change is likely to include a streamlining of the saving settlement process, more standardization, and faster program throughput – leading to capture of more savings. More emphasis on whole-building pay-for-performance and on savings persistence is a likely result, with efficiency, behavioral, and demand response programs better integrated.

Service providers may be relieved of the arduous and costly process of data collection and analysis for individual measures, freeing them to identify more savings opportunities in buildings. Previously hard-to-reach market sectors may become more cost-effective to serve. For example, a contractor-driven direct-install program may address a small building sector, while savings are determined from analysis of the building's smart meter data. Such programs allow more market actors into the industry, unlocking the savings potential in these hard-to-reach sectors.

Expanding financing of energy efficiency from government and public goods-funded sectors to the private sector can increase the amount of economic activity in this area. Through rigorous, standard, and transparent applications of M&V, financing experts will gain the information they need to better assess individual project risks and returns. This can stimulate more confidence in energy efficiency, which in turn initiates more projects, involves more market actors, and ultimately scales up energy conservation. The new metering technologies and M&V tools can foster this positive change in the market.

Conclusion

The M&V Tool has been shown to address several technical, cost, and administrative issues in energy efficiency projects and programs. In its short history, it has been applied to diverse project types in different market sectors. Several improvements have been identified, such as automatic collection of weather data, adding more independent variables to the model algorithms, and testing it in different climates and buildings. Funding opportunities to support further testing and development are sought, and are anticipated as its use and applications increase.

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