Advances in Measurement and Verification that are Good for All Industry Stakeholders

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ABSTRACT

There has been a long-standing need to streamline the measurement and verification (M&V) process for estimating savings in commercial buildings. Savings estimates have traditionally been based on pre-project engineering calculations, and not "true" M&V that relies and pre- and post-project measurements of energy use. Because of the challenges in modeling the actual energy use, there has been a general perception M&V is not possible within reasonable budgets.

Recently, new public domain software tools for M&V have been developed. This means that improved estimates of site-specific energy savings can be made. This capability is made even more valuable by the installation of "smart" meters, which has increased the availability of energy use data by orders of magnitude in comparison to monthly billing data. These new M&V tools can use either smart meter data or equipment/subsystem data, and can estimate not only savings but also the uncertainty in those savings estimates.

An easy-to-use, free software tool that has been used by utilities and national laboratories is presented in this paper. This tool can use sub-hourly, hourly, or daily interval data to establish energy use models. For completeness, the tool can also use monthly billing data. The tool facilitates the definition of daytypes or occupancy periods, and provides a number of model types that are based on ASHRAE research.

This paper provides examples of its use in several projects, discusses how such tools can be used to streamline projects and programs, and provide confidence in project results for utilities, regulators, and investors.

Introduction

Measurement and Verification (M&V) is defined by the International Performance Measurement and Verification Protocol (IPMVP) as "the process of using measurement to reliably determine actual savings created within an individual facility by an energy management program." Historically, savings were estimated before a project using engineering calculations or simulation. In some cases, these estimates were "trued-up" after project implementation, using knowledge of variances from the pre-implementation project design, and in some cases measurements. However, only very rarely were actual pre- and post-project measurements of energy use the basis for final savings estimates.

The significant barriers to measurement-based M&V included the absence of pre-project measurements, the time and cost of measurement, and perhaps most significantly, the lack of easy and affordable tools that related energy use to its drivers, such as schedules, production, and weather. The increasing prevalence of interval meter data, and now free tools, removes the most significant barriers to M&V.

Key Requirements and Desired Characteristics for M&V

Site-specific M&V requires data for energy use and the energy use drivers (independent variables), such as ambient temperature and daytype, e.g. weekday/weekend. These data are needed for both the baseline and post periods. To facilitate the M&V, software is needed to relate energy use data to all of the independent variables, estimate savings, estimate the uncertainty in the savings, and adjust or project the savings estimate to a typical year. Other desired characteristics for M&V software include informative data visualizations and tabular output, ease and flexibility in the definition of the baseline and post periods, the ability to handle data of various types and intervals, and transparency in the overall process.

M&V software should be flexible in the definition of baseline and post periods because it can be advantageous to be able to define a baseline (and/or post) period that includes multiple non-contiguous time periods. The definition of baseline and post periods is mostly commonly on a calendar basis: a specified time period before a project is the baseline, and a specified time period after the project is the post. However, some retrofits allow electronic disabling or emulation of baseline conditions. Similarly, controls changes can be alternated between efficient and baseline modes. There is an intersection between M&V and optimization where M&V processes can be used to determine the most efficient setpoints, resets or modes of operation.

M&V software also should have the ability to handle data of various types and intervals. Monthly billing data is most universally available, so the software should support its use. But daily, hourly, or shorter interval data is increasingly available. These data represent an increase in information by orders of magnitude per year over monthly data, and hence can permit more robust, higher-resolution models. Therefore, these higher-frequency data should also be supported. (IPMVP and other sources recommend that higher-frequency data be aggregated to the daily level for M&V, but higher-frequency data can be useful for performance tracking and diagnostics, and occasionally for M&V.) Finally, the types of models available should allow the software to be used with data from different levels in the building hierarchy: whole-building, system, or individual pieces of equipment.

The software should also expose its models and calculations so that they are understood and can be properly applied. The introductory letter to the IPMVP 2012 Volume I says that, "Basically, the knowledge that energy savings can be <u>transparently</u> reported is vital to the acceptance of energy efficiency proposals" and that "Clear definition of terms, and heavy emphasis on consistent and <u>transparent</u> methods are the core precepts of the IPMVP." (Emphases added.) There are multiple other references to transparency in the IPMVP.

Software Tool Introduction

ECAM+, which stands for Energy Charting and Metrics <u>plus</u> Building Re-tuning and Measurement and Verification, had M&V capabilities added in 2012 and 2013. It is a Microsoft Excel Add-in, compatible with Excel 2007, 2010, and 2013 for Windows; 32-bit and 64-bit versions. Most features also work in Excel 2003. It is not yet available for Macintosh.

Much of the core code in ECAM+ was originally developed for personal use. Formal development of ECAM+ was possible because of the support of the following organizations:

- The Northwest Energy Efficiency Alliance
- Bonneville Power Administration,
- Pacific Northwest National Laboratory

- New Buildings Institute
- The California Energy Commission, Public Interest Energy Research (through the California Commissioning Collaborative)

ECAM+ has many data analysis features in addition to M&V. It is widely used in the United States, and there are a number of international users. An introductory webinar presented in early 2013 had nearly 700 registrants from over 30 countries.

ECAM+ M&V Features

ECAM+ is intended to meet the requirements and have the desired characteristics listed above. It is also intended to facilitate M&V that is adherent to IPMVP.

The most common application for ECAM+ models is to characterize energy use as a function of ambient (outdoor) air temperature. However, models using other variables can also be created. ECAM+ provides a variety of statistical regression models. While some projects have a linear energy response to temperature, many of them have “change points”, where the response changes its slope, e.g., when changing from the heating season to the cooling season. ECAM+ can model up to a 6-parameter model, with two change points and three slopes.

The linear and change-point linear models, and associated uncertainty, are based on classical statistics and ASHRAE approaches. The ASHRAE approaches were developed and documented through research project 1050-RP, *Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models*, and also documented in ASHRAE Guideline 14, *Measurement of Energy and Demand Savings*

General features of ECAM+ M&V include:

- Monthly, daily, or hourly models with scatter charts to visualize models
- Load profile by weekday to support easy ad-hoc definition of daytypes
- ‘Hourtypes’ based on input schedule
- Combination of hourtype or daytype models into a model for all hours or days
- Model statistics, uncertainty estimation, and charts for analysis of residuals
- Annual extrapolation or normalization using TMY3 weather data

ECAM+ M&V Inputs and Outputs

Some of the menu items associated with M&V in ECAM+ are described in this section. Figure 1 displays a portion of the ECAM+ menu in excel.

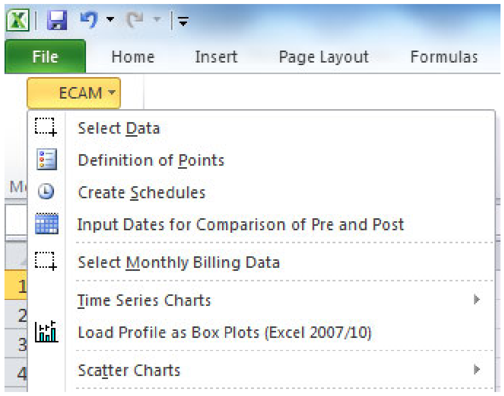

Figure 1. ECAM+ menu.

Inputs

"Fractional Savings Uncertainty" (FSU) is described in Annex B of ASHRAE Guideline 14. Its purpose is to help evaluate whether a baseline model will be adequate for use in estimating savings. The uncertainty must be low relative to the expected savings. ECAM+ provides users with instructions on the required inputs so that ECAM+ can estimate the FSU.

The menu item to Create Load Profile by Day of Week and Evaluate Daytypes is used for many M&V projects since modeling is often done by daytypes. Unless the default daytypes (Weekday, Saturday, Sunday, and Holiday) are appropriate, custom daytypes should be created. The user selects the point, and ECAM+ creates the chart of the dependent variable. Figure 2 shows a typical example, with average electrical power vs. hour of the day, for each daytype.

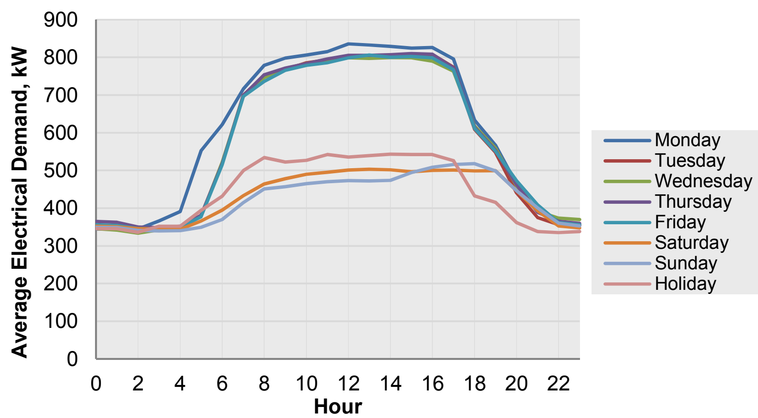

Figure 2. Load profile by day of week.

This chart can help users identify how to group days of the week into custom daytypes. For example, this chart shows that Mondays are different than the other weekdays, and Tuesday through Friday can be grouped as a common daytype.

If the M&V is using monthly billing data, then no daytypes are able to be defined or used.

If the user is not using data from all the available timestamps in a baseline model, then the model time periods should be defined. For continguous time periods, the menu item to "Input

Dates for Comparison of Pre and Post" can be used. For non-contiguous time periods, the user can edit the column defining whether an individual timestamp is "Before," "After," or "During" a project, using those keywords. Since ECAM+ is a spreadsheet Add-In, this is done very easily using a formula.

After these initial inputs are made, models can be created. After selecting the menu item to "Create Models," a UserForm allows selection of Daytypes, Occupancy, or Hourly models. The Daytypes models use data that is averaged to the daily level, occupancy models use data that is averaged to the various occupancy periods, and hourly models use data averaged to the hourly level. After making a selection, the user gets to "Choose a Model Type." Figure 3 shows the top portion of the UserForm. The user clicks one of the thumbnail charts to select that type of model.

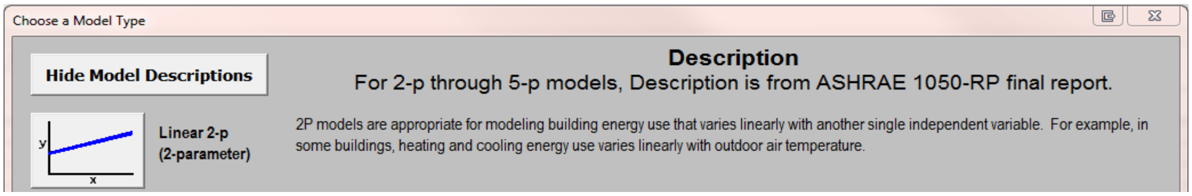

Figure 3. Top portion of model selection userform with model descriptions shown.

Outputs

Figure 4 is a chart of a 6-parameter change point model (2 change points and 3 slopes) based on hourly data, and Table 1 shows the model description. More statistics are included, but are not shown. Figure 5 shows a time history of energy use and savings based on monthly data.

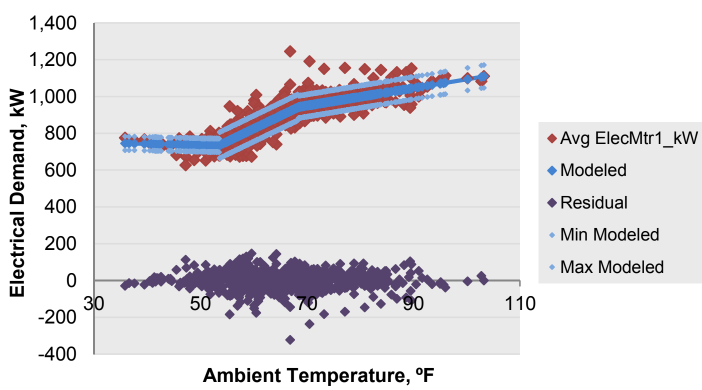

Figure 4. Six-parameter change point model and residuals.

Table 1. Spreadsheet description for a six-parameter change point model

Model Type	6P-Model Summary	Left Model	Middle Model	Right Model
Change Point Values	All Data	53.55		68.50
RMSE	48.40			
R^2	0.799	0.008	0.506	0.323
CV(RMSE) or Standard Error %	5.5%			
Fractional Savings Uncertainty	0.41			
Savings Range from FSU	5.0% ± 2.0%			
Net Determination Bias	0.000%			
Intercept at X=0		767.4547373	-15.34306105	616.2606954
Slope		-0.631852567	13.98498292	4.76448095
Standard Error, % of Avg.	6.3%	3.8%	6.4%	4.7%

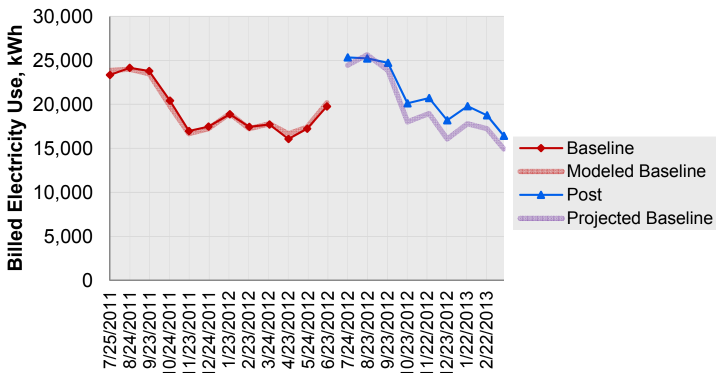

Figure 5. History of energy use and savings for a model based on monthly data.

ECAM+ also provides charts for analysis of residuals. Of these, the most informative for energy analysis is the time-series chart. It shows whether the energy use is increasing or decreasing over time, after accounting for the independent variables such as weather. Obviously, we generally assume that energy use is constant during a baseline period; the time-series of residuals shown in Figure 6 allows us to evaluate that assumption.

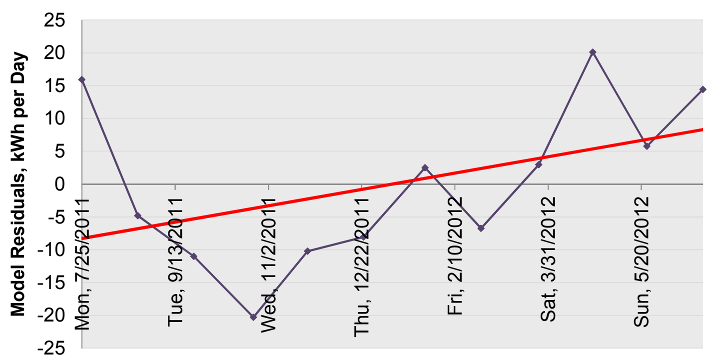

Figure 6. Chart of residuals vs. time for a model based on monthly billing data.

Based on the way the residual is defined—the actual use subtracted from the modeled use—a positive number indicates savings and a negative number indicates increased use. Therefore, in the graph above, energy use is generally decreasing during the baseline period.

Streamlining Projects and Providing Confidence in Project Results

In the last couple of years utilities, researchers, evaluators and regulators have vocalized their interest and use in ECAM+ for many different reasons, but primarily due to the features of ECAM+ that provide confidence in its results. These features include transparency with open-source code and visible formulas, quick visualization tools to support forensic analyses, and statistics. The Bonneville Power Administration's (BPA) need for these features in a cost-effective and repeatable analysis tool led to the choice of ECAM+.

Since 2012, the BPA has developed and used a streamlined approach to M&V for K-12 school projects in the State of Washington. The need for this was due to a surge of custom projects (non-prescriptive measures) driven by the State's Office of Superintendent of Public

Instruction (OSPI) Energy Grants Program. Since 2009, the WA OSPI has received approximately $134 million in state funds for energy savings projects. The projects were primarily developed and implemented by a number of Energy Service Companies (ESCOs). In order to handle the surge of projects in a short amount of time, BPA's streamlined programmatic approach was structured to ensure that projects were evaluated in a consistent, reliable, transparent and repeatable way by various reviewing engineers, serving utilities, school districts and ESCOs.

The majority of school projects approved by BPA had highly interactive energy efficiency measures (EEMs), i.e. HVAC system and control improvements, shell measures, lighting, etc. Due to the high interactivity between EEMs, BPA chose to use a whole building M&V approach, using monthly data, which was guided by IPMVP Option C and BPA's Energy Modeling M&V Protocol.

BPA's use of ECAM+ to verify building performance was not limited to the post-retrofit M&V period. BPA's approach starts with an investigation of the facility baseline performance prior to project approval. This is done using ECAM+ monthly baseline visualization and normalization features. These features allow BPA to 1) quickly assess the ESCO savings estimates and assumptions, 2) provide feedback on under/over-estimation of savings, 3) estimate the length of time needed for the post-retrofit M&V performance period, and 4) enabled all stakeholders to understand what the reference point (aka. facility normalized baseline) is for assessing post-retrofit performance and incentive payment before the project was implemented.

In general, the tools that ECAM+ provides have enabled BPA to engage in assessing building performance throughout the life-cycle of the project and has provided all stakeholders the confidence that has been needed to ensure the energy savings are reliable and transparent.

Following the success of the streamlined school program, BPA has approached similar custom commercial projects in the same manner. Furthermore, BPA's confidence in ECAM+ has led its customer utilities to request training on the use of ECAM+ for use in their programs and evaluations. Much of the interest is particularly focused around ECAM+'s ability to perform monthly analysis. This user friendly feature in ECAM+ is enabling utilities that historically had a difficult time performing whole building M&V or technology/program evaluations to now assess savings or program results in a quick, cost effective way.

Visualization Applications

While not necessarily a part of the M&V process, data visualization can be of great use not only to analysts, but to non-technical people who may be involved with energy efficiency projects, such as facility staff and decision makers. For the non-technical audience, graphs and plots help make sense of the welter of numbers and statistics that may be used by enthusiastic technical staff. For the technical users, visualization can identify problems to make sure that statistical tools are applied to meaningful projects.

ECAM+ has several built-in graphs that can help identify these problems. While there are other tools that will produce graphs, the ease with which these graphs can be generated from energy data make them extremely convenient and easy to apply to all energy analyses.

When energy use is largely dependent on temperature, one of the most basic ways to look at the data is to plot temperature and energy use on the same time scale. This simple plot can reveal interesting insights about changes in building operation, which are especially useful in the common case in which there is a long lag between a project's scoping study and implementation.

Figure 7 demonstrates this case. In late 2011, a proposed controls project got funding to reduce energy use at a high school in central Washington. As part of the streamlined schools methodology, monthly average temperature vs. billed electricity, including the time period since the project was proposed, was plotted. As shown in Figure 7, the chart revealed that energy use had already dropped sharply, then began to fluctuate erratically. Further investigation found that a controls strategy had already been implemented by building operations staff in 2011, but controls failures in 2012 led to the erratic use. The 2009-2010 baseline proposed by the contractor was rejected.

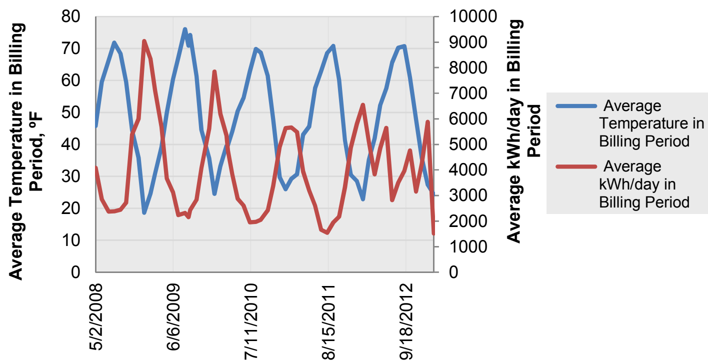

Figure 7. Data used to evaluate a 2009-2010 baseline for a proposed project.

Subtle reductions in energy use may not always be visible in the time-series plot. Another useful visualization feature in ECAM+ is a plot of energy use vs. temperature showing times before and after the project, as shown in Figure 8. This can show which temperature ranges show the greatest energy benefit, communicate to stakeholders the benefits of the implemented project, and help focus areas for future efficiency projects.

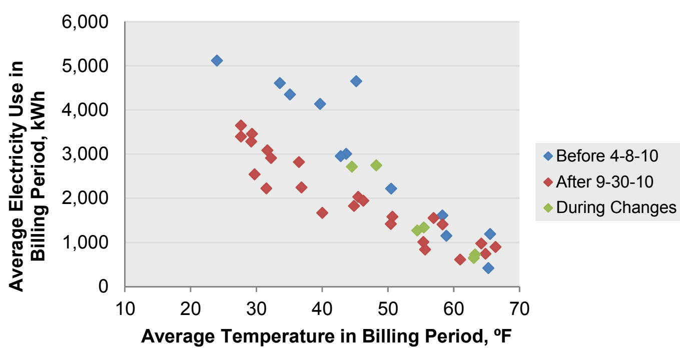

Figure 8. Energy use was reduced in the winter after installation of a controls project at a high school in NE Washington. Winter energy use reductions were greater than those in summer.

Another use of this type of graph is examining the usefulness of available data. Figure 9 illustrates the perils of not accounting for seasonal variation during data collection. Baseline data on this chiller in Idaho was taken in summer, but post-project data collection was taken in winter. Neither data collection regime represents equipment behavior over the full temperature range!

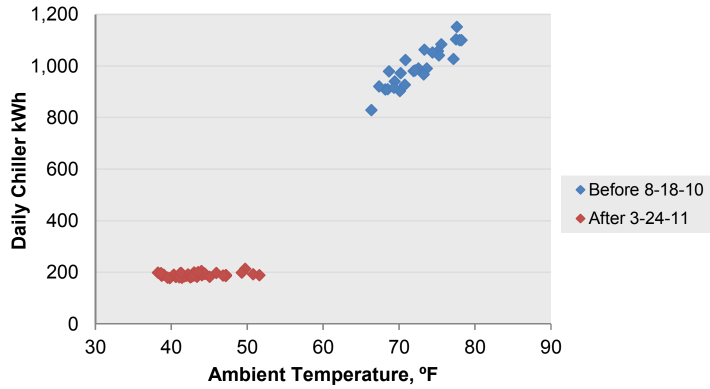

Figure 9. Data collection timing is important. Baseline chiller data was taken during summer (blue points at top), while post-project data was collected in the winter (red points at bottom).

M&V Applications

The following case studies highlight a few of the capabilities and features of ECAM+ which include daily change point modeling, day-typing, savings normalization, monthly modeling and avoided savings estimation.

Project 1: Central Plant

At a central plant, the chilled water supply temperature was increased to evaluate the potential savings while verifying that all loads were still satisfied. This project demonstrates the potential interactivity between optimization and M&V processes. ECAM+ was used to evaluate the savings for changing the chilled water supply temperature.

In this case, baseline was not a specific time period, but all the days with the lower chilled water temperature, and the post had a higher water temperature. The water temperatures tried were 40, 42, and 44 ºF, and the plant changed temperatures multiple times during the five-month monitoring period. For an initial analysis, the data was just divided into two groups. Baseline was defined as water temperatures less than 41.5 ºF, and the post was temperatures greater than or equal to 41.5 ºF. This resulted in 54 "baseline" days and 117 "post" days.

Figure 10 shows the baseline model. A 6-parameter model provided a great fit.

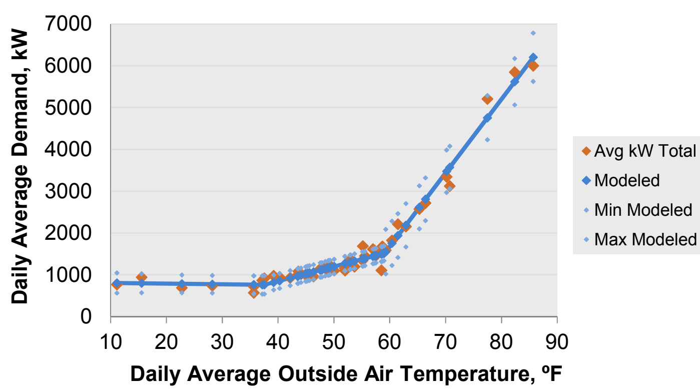

Figure 10. Baseline fit for chilled water plant demand with chilled water temperatures <41.5 ºF.

Not surprisingly, there was not a great difference between baseline and post. However, the results were informative. Figure 11 shows a comparison of baseline and post models.

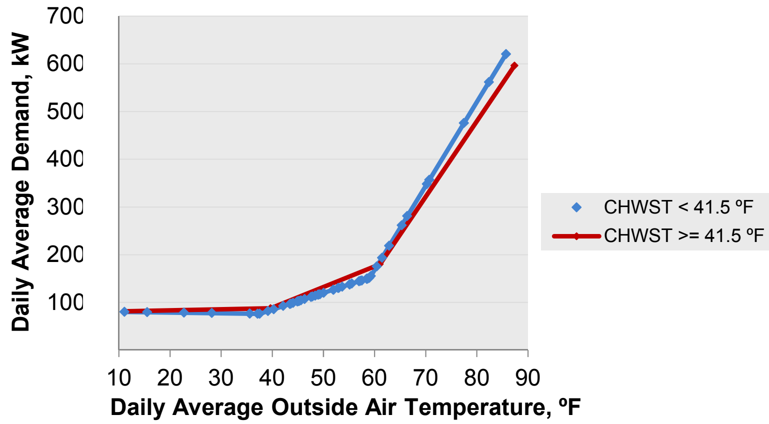

Figure 11. Effect of chilled water supply temperature on plant demand.

Reducing the supply temperature clearly saved energy at high temperatures and plant loads, but increased energy at moderate and low loads, within the resolution of the models. This information and further monitoring will be used to continue to optimize the plant.

Project 2: Engine Generator Block Heater

This M&V process assessed the performance of a forced circulation Engine Generator Block Heater for BPA's emerging technology program. The baseline for this project was a thermo-syphon (natural circulation) heater and the post condition was a forced circulation heater. The M&V consisted of a traditional pre/post M&V (following IPMVP Option A) using change of state CT loggers (run-time) and true RMS power measurements (kW). The M&V testing period started on 4/17/12 and lasted thru 11/7/12, with a retrofit period of 9/11/12 & 9/12/12. Throughout the testing period the generator cycled on a weekly basis (every Monday) for operational testing, as shown in Figure 12. These cycling periods needed to be separated and analyzed separate from the rest of the dataset. ECAM+'s daytyping feature was used to analyze Mondays separately from other days.

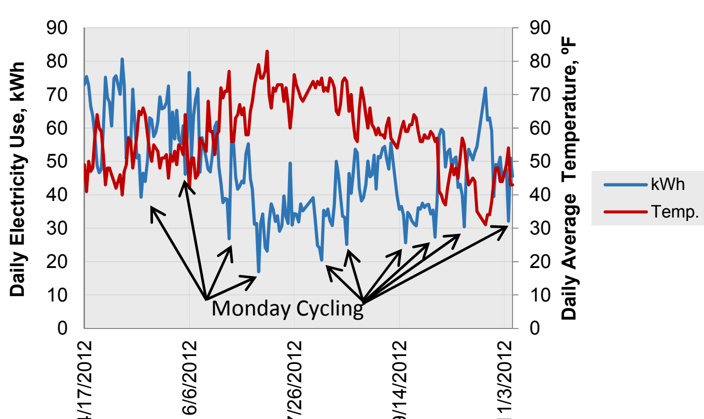

Figure 12. Time series of engine block heater cycling.

Figure 13 shows the baseline and post period energy use in a scatter chart.

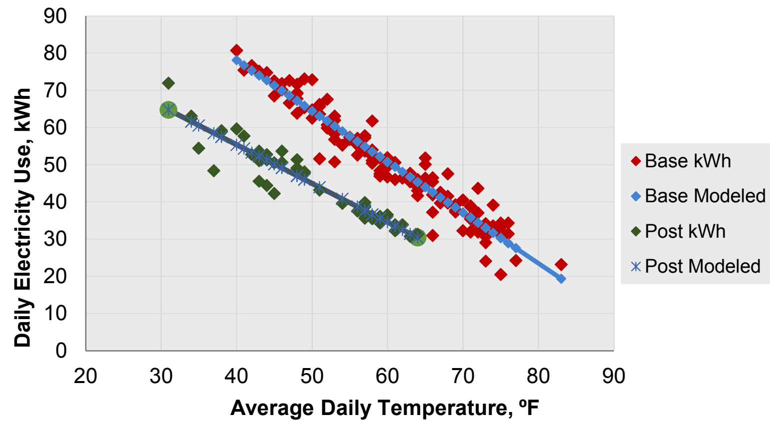

Figure 13. Scatter chart show pre- and post-energy use for the engine block heater.

ECAM+ has a weather normalization feature that allows TMY data to be used for IPMVP "Normalized Savings" estimates. ECAM+ applies the TMY data to the daytype models to estimate baseline and post energy use for a typical year, and savings for a typical year. Figure 14 shows the time series plot of energy use and savings for a typical year.

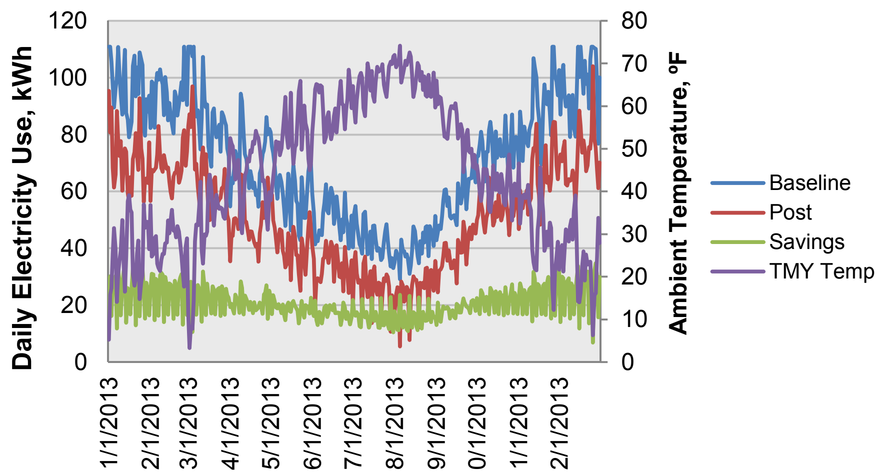

Figure 14-Normalized time series of electricity use and savings.

Project 3: Comprehensive Retrofit of Office Building

Although interval data is desirable when modeling projects, sometimes the only energy data available is billing data. As temperature data supplied by the National Weather Service is freely available, it is possible to evaluate energy savings using this tool with these limited inputs. The project shown in Figure 15, involves both monthly data and change point models. It involved complex, interactive measures, including chiller upgrades, heat recovery, fan replacement and VFD installation, along with some controls upgrades in an office building on the Olympic Peninsula.

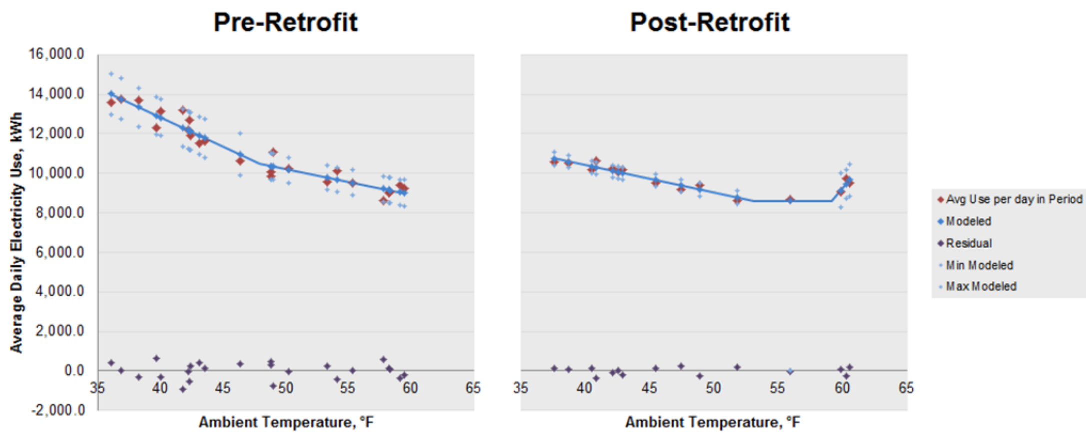

Figure 15. Change point models for building behavior before energy upgrades (left) and after (right). Notice the increased energy use in the cooling season after cooling capacity was added.

Table 2 shows the estimated avoided savings over a 15-month period after the retrofit.

Table 2. Savings for retrofit of office building

kWh	
3,996,882	Projected Baseline Energy
3,504,055	Measured Energy
492,828	Energy Savings
90,282	Projected Baseline ±Uncertainty @ 80% Confidence Level
492,828 ±90,282	Energy Savings and Uncertainty @ 80% Confidence Level
2.3%	Projected Baseline ±Uncertainty @ 80% Confidence Level
12.3% ±2.3%	Energy Savings and Uncertainty @ 80% Confidence Level

Conclusion

As discussed in this paper, ECAM+ is a free, easy to use software tool that incorporates many features and capabilities that enable it to be a transparent, reliable, consistent and cost effective M&V tool which has led to an increase in use by various stakeholders in recent years and will continue to provide a high level of confidence to projects and programs for utilities, regulators and investors for years to come.

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