How Much is Enough? Lessons Learned on Performance Periods for Monthly Whole Building Regression Modeling

Eva Urbatsch, Aerotek
Erik Boyer, Bonneville Power Administration

ABSTRACT

Whole Building data analysis with temperature regression data modeling (similar to International Performance Measurement and Verification Protocol (IPMVP) Option C) is Bonneville Power Administration's (BPA) energy efficiency engineers' preferred method for determining energy savings in commercial projects with interactive effects. These are projects that include complex systems that have interaction with other systems, such as air handlers with fans, hot and chilled water valves, economizers, mixed air dampers, and controls for space temperature and outside air temperatures. Each of these systems can each significantly impact savings, and if just one system is off, it can affect the others. Trend logging of one system will not provide sufficient information to model the entire building and simultaneous trend logging of each system is often cost prohibitive.

While sufficient baseline data is generally available, the desire for prompt incentive payment (or other factors that drive short measurement and verification (M&V) turnaround) limits data collections after project installation. In trying to establish a reasonable balance between cost effectiveness, customer needs, information availability, and data accuracy, BPA's commercial measurement and verification team has developed preliminary "commandments" to guide M&V implementation using monthly billing data. These rules attempt to balance all factors and still ensure validity of savings.

This paper describes these guidelines and two different approaches for M&V performance periods shorter than one year using monthly data. These approaches are applied to three different buildings, and the results are compared to results for the same buildings with a longer, IPMVP-compliant monitoring period.

Introduction

The Bonneville Power Administration (BPA), like many utilities, is focusing efforts on energy efficiency as the lowest cost resource for meeting load growth. As such, BPA provides incentives for projects that have verifiable energy savings. The International Performance Measurement and Verification Protocol (IPMVP) (Energy Valuation Organization, 2012), provides rigorous guidelines to address measurement and verification (M&V) standards, but these guidelines are often impractical for real-world application. Contract officials overseeing projects may not be familiar with energy savings M&V protocols, and contracts seldom sufficiently address M&V. Performance verification is often done by someone not involved in project installation, who must determine what happened from reports and bills. Most of these reviews are done by technical staff who are familiar with energy efficiency implementation, but are not statisticians.

While the Northwest has an active regional peer group (the Regional Technical Forum) that has approved unit energy savings for certain specific measures (e.g., kWh/unit, kWh/ton, kWh/hp, etc.), determining energy savings from other types of projects require M&V in accordance with BPA's M&V Protocols (BPA 2012a). For large, complex projects, whole building methodology is the method of choice.

M&V seeks to generate reliable numbers, but this requires data. For most commercial facilities, outdoor temperature is the major driver of variation in energy use. Simple regression, with temperature as the independent variable and energy use as the dependent variable, is the preferred method for determined energy savings in commercial projects with large interactive effects. In many cases, energy use is determined from bills, and actual temperature is taken from freely available weather data measured at a nearby airport.[1]. The benefits of using billed data include reasonable certainty about the measurement of the energy from the utility meter (100% accurate, per IPMVP 4.8.5., p. 27) and the fact that interactive effects are accounted for. Additionally it incorporates actual building operation, which may diverge significantly from the optimal operation projected by theoretical modeling/simulation. The ease of availability of these data points for a wide range of project locations means they are a low-cost method of M&V on most efficiency projects.

While much research has been done on shortening data collection for interval data using hourly or daily data (e.g., ASHRAE (formerly American Society of Heating, Refrigerating and Air Conditioning Engineers) Research Paper RP-1404 (Abushakra 2012)), this is still not available at most sites, particularly when M&V is required post hoc. This paper discusses approaches for shortening the M&V period to less than a year, incorporating lessons learned by the commercial engineering team performing verification of a large number of energy-savings projects compliant with BPA's Energy Modeling Protocol (BPA 2012b).

These analyses were conducted using a free Microsoft Excel add-in tool called Energy Charting and Metrics Plus (ECAM+). This tool uses iterative processes to develop regression-based energy use models quickly and easily. It is available from http://www.northwrite.com/ECAM+.asp (registration required). Resources on its use can be found at Pacific Northwest National Laboratory's website at http://buildingretuning.pnnl.gov/ecam.stm .

The ECAM+ software uses classical statistics and ASHRAE approaches to develop change-point models for energy behavior. Rather than one straight line to describe all the data, these models use piece-wise approaches to fit data in several lines, with a "change point" where the lines meet. The modeler chooses the number of parameters to describe the model shape, with increasing number of parameters describing increasingly complicated model shapes. A 2 parameter model is appropriate where building energy use varies linearly with outdoor temperature; a 3 parameter model has one range where energy use is constant and one where it varies linearly with temperature; and so on through a 5 parameter model, which has three ranges, including a range with constant energy use sandwiched between two ranges where building energy use varies linearly (Kissock 2002). ECAM+ can fit models up to 6 parameters, although due to data constraints, 5 parameters is usually the maximum model complexity for monthly models.

---

[1] While occupancy could in theory increase due to increased building comfort after energy efficiency retrofits, raising energy use, the authors are unaware of any evidence this commonly occurs.

Table 1. Summary of building baseline model types and typical applications

Model type	Equation form[2]	Typical condition
2 parameter	$E = \beta_1 + \beta_2 T$	Building has linear response to temperature
3 parameter heating	$E = [\beta_1 + \beta_2 (T - \beta_3)]^- [\beta_0 + 0 (T - \beta_3)]^+$	No cooling
3 parameter cooling	$E = [\beta_0 + 0 (T - \beta_3)]^- [\beta_1 + \beta_2 (T - \beta_3)]^+$	High heating loads or gas heat + space cooling
4 parameter	$E = [\beta_0 + \beta_2 (T - \beta_4)]^- [\beta_1 + \beta_3 (T - \beta_4)]^+$	Various, as in electric central heating with resistance space heat
5 parameter	$E = [\beta_0 + \beta_2 (T - \beta_5)]^- + \beta_4 + [\beta_1 + \beta_3 (T - \beta_5)]^+$	Electric heating and cooling

Where: E = Energy (kWh), T = Outdoor air temperature (°F), and β_X = Regression coefficient. Superscripts indicate that parenthetic term is set to zero when $T-\beta_x$ term is negative or positive, respectively.

Energy Modeling Rules of Thumb

The guidelines presented in this paper have been developed to help standardize energy modeling across engineering review teams. Most engineers have a basic statistical understanding, but are not statisticians, and without any guidance, team members tend to develop idiosyncratic review methodologies. Using consistent guidelines help make analysis less subject to chance and more reproducible. Modeling, however, is more of an art than a science. For each rule, there are exceptions and caveats; they are not absolute.

The baseline period is the energy use before project implementation. For most projects, a period of at least a year is used. The post period (or performance period) is the amount of time after the project has been installed and commissioned during which energy use is collected to determine how much energy use has been reduced.

Baselines Should Be in 12 Month Increments

The baseline period is the energy use before project implementation. Most commercial buildings operate on a fairly consistent schedule, year over year. Even buildings with distinctive seasonal occupancy modes, such as schools, have a reasonably consistent operating schedule from school year to school year. Weather, while also variable, also has general consistency year over year. In order to avoid over-representing various combinations of occupancy and temperature, use a 12, 24, or 36 month baseline. Baselines are discussed further, below. (This guideline is also spelled out in IPMVP Option C, 4.8.4 p. 27.)

Number of Model Parameters Should Not Decrease

Buildings exist where electricity use correlates linearly to ambient temperature. However, in many buildings, there are distinctive electric profiles depending on season. For example, electric use may have a flat profile (constant) in the winter, and increase with temperature in the summer as cooling loads increase. (This would be a 3 parameter cooling model.)

[2] These forms are slightly different from those presented in Guideline 14, but more fully describe the models.

Installation of an energy efficiency project will often change the response of the building to temperature. This change could be a simple shift in change point, as when better controls help a building respond more exactly to temperature changes, or could modify the model type by increasing the number of parameters required to describe the data. A common example of this latter project in the Northwest would be installation of a ductless heat pump system to replace electric resistance heating. Not only does efficiency increase, but cooling is now available when it previously was not. This will change the model type from a 3 parameter heating model to a 5 parameter model (with two change points), for the heating, base load, and cooling load.

While model complexity may increase, it is extremely rare to find a case where model complexity decreases. If the modeler finds that the post period data is best described by fewer parameters than described the baseline period, the energy efficiency measures should be carefully reviewed to ensure that they provide an adequate explanation for this behavior.

Models Should Strive to Obtain the Full Range of Each Independent Variable

This is perhaps the most fundamental concept of a model, but one that seems to be widely ignored in the energy efficiency community. A model can only confidently represent data that it contains. In other words, it is only reliable over the range of data (in this case ambient temperatures) used to construct it. While some extrapolation is not unreasonable, too often a two-week measurement is said to represent annual building operation. Even intuitively, this often does not make sense for energy efficiency projects. HVAC systems run differently in the summer than in the winter (most buildings in the Pacific Northwest do not use cooling in the winter) so to determine a reasonable annual post-retrofit behavior, summer and winter data is required to capture several modes of operation.

The modeler would generally prefer more data. However, “more data” may still fail to provide the information necessary for modeling, if the data points all represent a small subset of the independent variable, i.e., are all taken at similar temperatures. This is also why having daily energy data available may not shorten the M&V period very much; ambient temperatures are not randomly generated. Even in climates with large seasonal variation, the daily average ambient temperature changes only gradually. And on the rare occasions where an unusual, enormous swing in external temperature occurs, the performance of a building and its occupants may differ from, and so not be generalizable to, more typical, gradual shifts in temperature.

Ideally, baseline and post data sets would cover every possible condition (including the hottest and coldest temperatures), so energy use could be fully determined with no extrapolation uncertainty. However, extreme events are unlikely to occur during the monitoring period (for the very reason that they are extreme). The generally accepted procedure is to ask for a specified number of months of billing data after installation of an energy efficiency project. However, depending on when in the year these months fall, this can provide too little data.

Much of the Pacific Northwest has a cool, rainy climate for 8-9 months of the year, with a brief summer. This means that if the project is completed at the wrong time, it can be 9 months without a cooling event happening. This is particularly frustrating if the energy efficiency project is expected to have its greatest savings during summer weather, as would be typical of improvements to the chiller system. For this reason, finding a generally applicable, statistically valid rule for M&V performance periods shorter than a year is a challenging endeavor.

How Much Is Enough?

Approaches to M&V Performance Period Determination

In many cases, particularly in public buildings, owners are quite interested in the incentive payment they expect to receive, sometimes more than they are interested in the long-term energy efficiency gains from the project. For this reason it is desirable to know in advance how long the M&V period will last. Stipulating a length of time is a simple way to determine the M&V period, but when trying to find a period shorter than a year, criteria beyond a hard number may be more effective. Two approaches to determine how to collect data for less than a year were tested and compared to either a one or two year performance period on three sites, with various Northwestern climates zones.

The M&V performance period approaches selected time ranges based on historical average monthly temperature (typical meteorological year (TMY) data or Western Regional Climate Center (WRCC) data sets were used for these temperatures). The temperature ranges used for comparison were: 1) including the months with the historical hottest and coldest temperatures, and 2) choosing months that covered half the expected range of temperatures around the baseline modeled change point. (For buildings that had 2 parameter baseline models, the range was chosen based on the middle 50% of the average monthly temperatures). Figure 1 illustrates this methodology graphically.

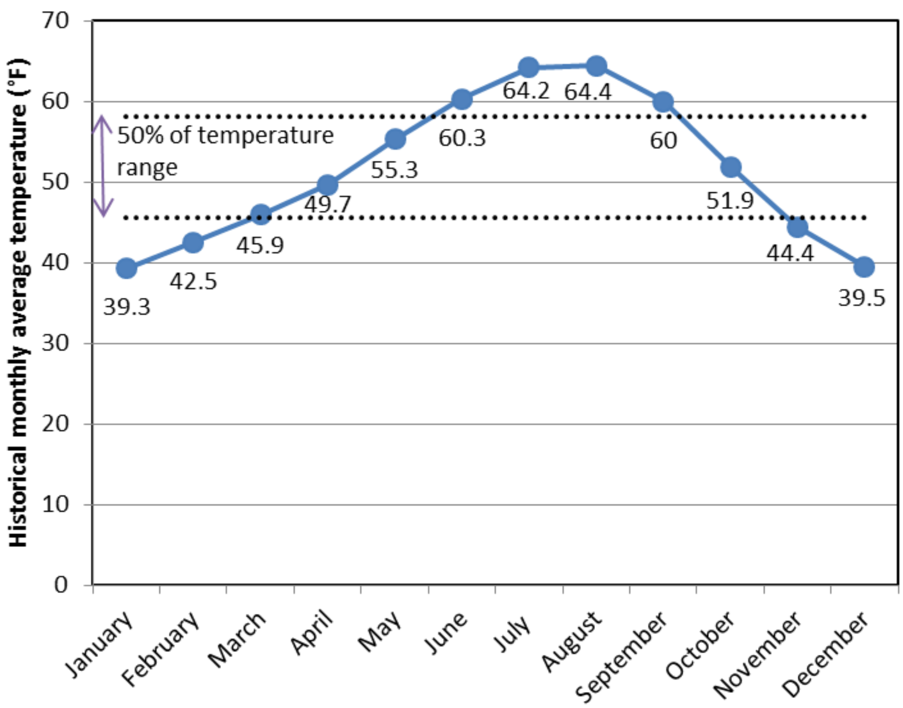

Figure 1. The half range approach for a 2 parameter model, illustrated for Southwest Elementary.

For these approaches the months were chosen based on historical average temperatures, not temperature during the M&V performance period. This meant that if August was historically the hottest month, the performance period included August, even if that year's August was unseasonably cool. This attempts to define the M&V performance period before project installation begins. The “rules of thumb” above, were combined with these approaches when choosing post-implementation periods.

All buildings used for this analysis were public buildings in the state of Washington. The projects used saved more than 10% of building energy, consonant with IPMVP’s Option C whole-building guidelines. (EVO 2012, p. 25) Pre- and post-project energy use was normalized to historical monthly average temperatures.

These approaches were applied to several buildings to determine the most promising methodology for shortening the M&V period using monthly data.

Building Descriptions

Building 1: County Building on Olympic Peninsula

This building is located in a marine climate zone, with moderate temperatures year round. The month with the hottest average monthly temperature is August (60.2°F), and the month with the coldest average temperature is December (39.4°F, although the January average is 39.5°F). All energy to this building is supplied via electricity. This project included:

- Replaced 30 year old 100 ton chiller (chilled water system for 2 air handlers and a small AC unit
- Replaced rotary wheel heat exchanger with a fixed plate and frame heat exchanger
- Replaced existing single large supply and exhaust fan and motor with an array of smaller fans and efficient motors that operate on a variable frequency drive
- Added heat exchanger bypass
- Added temperature sensors in return air, exhaust air, and supply air

The equation describing the 4 parameter baseline model is:

$$E = [24{,}784 - 127(T - 47.9)]^{-} [486{,}890 - 299(T - 47.9)]^{+}$$

Building 2: Southwest Elementary School

This building is an elementary school in southwest Washington, north of Portland. This building has gas heat. This project included:

- Controls system upgrade
- Variable frequency drive (VFD) on main air handler

The equation describing the 2 parameter baseline model is: $E = 2{,}593 - 24.4T$

Building 3: Northeast High School

This project is a high school and gym in northeastern Washington, near Idaho. All energy to this building is supplied via electricity. This project included:

- Upgrading T12 lighting
- Adding a preheat coil (to preheat outside air)

- Fan motor VFD
- Pneumatic to DDC conversion and controls system upgrade

The equation describing the 2 parameter baseline model is: E = 8,111 - 114.4T

Details about the projects are summarized in Table 1, below.

Table 1. Summary of building baseline models

Building	Baseline model type	Model change point (°F)	Normalized baseline energy (kWh per year)
County Building on Olympic Peninsula	4p	47.9	3,963,296
Southwest Elementary School	2p	N/A	486,890
Northeast High School	2p	N/A	1,071,827

Modeling Approaches

One of the limitations that quickly becomes apparent when modeling with monthly data is the fact that with one point per month, it takes a long time to get enough degrees of freedom for meaningful analysis. Any two points will form a line, but a straight line (2 parameter model) may not be representative of the data. Also, with change point models, more than a few points are required even if the points do not deviate from a perfect line. In ECAM+, for example, for a 2 parameter model, a minimum of 3 points are required, and 6 points are required for a 4 parameter model.

Post period modeling was done for 1-2 years of post-data, to get an IPMVP-adherent model to compare the other approaches to. After this, the “worst case” data period (the shortest number of months that would fulfill the requirements) was determined, with the goal of making this period as short as possible. If necessary, this period was expanded to ensure that there were at least enough points to create the baseline change point model. Models were considered unacceptable if their uncertainty band at the 80% confidence level exceeded the predicted savings, i.e., where the model did not conclusively show savings. Model types were chosen by experienced modelers to best fit the data. The model type was chosen primarily by minimizing percentage root mean square deviation (CV (RMSE)).

A summary of average monthly temperatures for these three sites used for determining post periods is shown in Table 2, below.

Table 2. Historical average monthly temperatures at modeled buildings

	County Building on Olympic Peninsula (°F)	Southwest Elementary School (°F)	Northeast High School (°F)
January	39.5	39.3 C	24.8 C
February	39.7	42.5	29.4
March	42.6	45.9	36.9
April	48.2	49.7	45.2
May	50.0	55.3	53.3
June	56.0	60.3	59.5
July	59.0	64.2	65.8 H
August	60.2 H	64.4 H	64.3
September	56.2	60.0	56.0
October	48.8	51.9	45.2
November	44.0	44.4	34.0
December	39.4 C	39.5	27.2

The historical hottest months are denoted with an "H", coldest with a "C". *Source*: TMY3 data, WRCC data

Building 1: County Building on Olympic Peninsula

The worst case period for the hottest/coldest approach was August-December (5 months), but since the baseline model was 4 parameter, 6 months of data (points) were required. Data from August– January (6 months) was used.

For the half-range approach, the worst case is September through December. Extending this period to 6 points for a 4 parameter model was substantially similar to the hottest/coldest approach, so February-July was chosen instead as a more interesting option.

The results, summarized in Table 3, do not show a statistically significant difference between an IPMVP-adherent project and either alternative

Table 3. County building modeled results

	Post model type	Model description	Modeled post energy (kWh)	Energy savings (kWh)	Energy savings and uncertainty @ 80% confidence level
IPMVP	5p	$E = [16{,}395 + 757(T - 16395.2)]^{-} + 8{,}588 + [-36{,}136 - 148(T + 59.1)]^{+}$	3,470,816	492,480	12.4% ± 2.8%
hottest/ coldest	4p	$E = [-148 - (T - 16395.2)]^{-} [757 - (T -36136.0)]^{+}$	3,558,568	404,728	10.2% ± 2.4%
half-range	4p	$E = [-78 - (T - 13358.0)]^{-} [-12 - (T + 10087.5)]^{+}$	3,516,079	447,218	11.3% ± 3.3%

The modeled baseline was 3,963,296kWh.

Building 2: Southwest Elementary School

The worst case period for the hottest/coldest approach was August–January (6 months), although since the average monthly temperatures December was within 0.2 °F of January temperature, August–December (5 months) was used. This did not meet the 50% uncertainty threshold, thus the model was considered unacceptable and the performance period was expanded.

Because the available performance period data ended in December, continuous August-January data was unavailable. (Continuous data was used to more closely simulate how this model would be applied in practice.) Instead, the performance period of January through July was chosen, to expand the performance period to 6 months. (The July average monthly temperature was again within 0.2 °F of that of August, the hottest month, so this was the shortest period considered acceptable.) This data set appeared to form a 3 parameter cooling model. Uncertainty was within acceptable limits for this model.

For the half-range approach, the worst case is September through November (3 months). This was modeled, although the uncertainty in the savings exceeded the modeled savings number, which was unacceptable. Months were successively added to either end of the September-November time period model until the savings uncertainty was less than the savings number, which coincided with the August-December period of the hottest/coldest model. Since that time period had already been examined, no further months were added.

The comparison of these three approaches, in Table 4, at this facility shows the perils of a shorter time period. While the uncertainty results for the expanded hottest/coldest model are quite satisfactory, it turns out that the month of July was an outlier, with unusually low monthly usage as compared to temperature. While this is quite clear when 12 months of data are examined, this fact would not be obvious to the modeler with only that shortened performance period, and since this model meets the other criteria (uncertainty), there would be no signs that this model is not representative.

Table 4. Southwest Elementary modeled results

	Post model type	Model description	Modeled post energy (kWh)	Energy savings (kWh)	Energy savings and uncertainty @ 80% confidence level
IPMVP	2p	$E = 1{,}410 - 5.8T$	405,687	81,204	16.7% ±5.6%
hottest/coldest Aug-Dec (*unacceptable model*)	2p	$E = 936 + 4.4T$	423,366	63,525	13.0% ±9.4%
expanded hottest/coldest Jan-July	3p cooling	$E = [1{,}155 + 0\,(T - 53.1)]^{-}$ $[3{,}627 - 47(T - 53.1)]^{+}$	366,288	97,648	24.8% ±2.8%
half-range (*unacceptable model*)	2p	$E = 65 + 21.1T$	420,703	66,188	13.6% ±14.1%

The modeled baseline was 486,890 kWh.

Building 3: Northeast High School

At this site, the worst case scenario for the hottest/coldest performance period was 6 month, so the periods were of equal length. Both periods were modeled to see difference between the first half period (January-July) and the second half period (July-January). The shortest "half-range" period was September-November.

The results, summarized in Table 5, show no significant difference in the approaches from the IPMVP-adherent approach, although the uncertainty on some of the approaches was quite high. Interestingly, the uncertainty on the second half hottest/coldest model is lower than any of the others, even though this model is of the "incorrect" form. This illustrates the peril of using model statistics with no reference to whether the data set is representative! The estimated savings are higher on all of the non IPMVP approaches because the low change point (47.3°F) was not captured in most data sets.

Table 5. Northeast High School modeled post period results

	Post model type	Model description	Modeled post energy (kWh)	Energy savings (kWh)	Energy savings and uncertainty @ 80% confidence level
IPMVP	4p**	$E = [5{,}086 - 40(T - 47.3)]^{-}$ $[3{,}146 - 81(T - 47.3)]^{+}$	601,081	470,746	43.9% ± 5.7%
hottest/coldest first half	4p	$E = [6{,}582 - 71(T - 39.9)]^{-}$ $[4{,}595 - 121(T - 39.9)]^{+}$	575,602	496,225	46.3% ±12.9%
hottest/coldest second half	2p	$E = 4{,}384 - 61.6T$	583,591	488,237	45.6% ± 8.5%
half-range	2p	$E = 3{,}656 - 46.2T$	571,411	500,416	46.7% ±13.4%

** The baseline model used 2 parameters, so post periods were not required to meet the six point minimum. The modeled baseline was 1,071,827 kWh.

Discussion and Conclusions

The modeled results were compared to the IPMVP-adherent models to evaluate how the shorter post periods compared. The hottest/coldest criteria, combined with the modeling rules of thumb, mostly seemed to generate results with uncertainty within acceptable tolerances (although uncertainty was always lowest for the IPMVP model). The results for savings and uncertainty at 80% confidence for all models for each building is shown graphically in Figure 2.

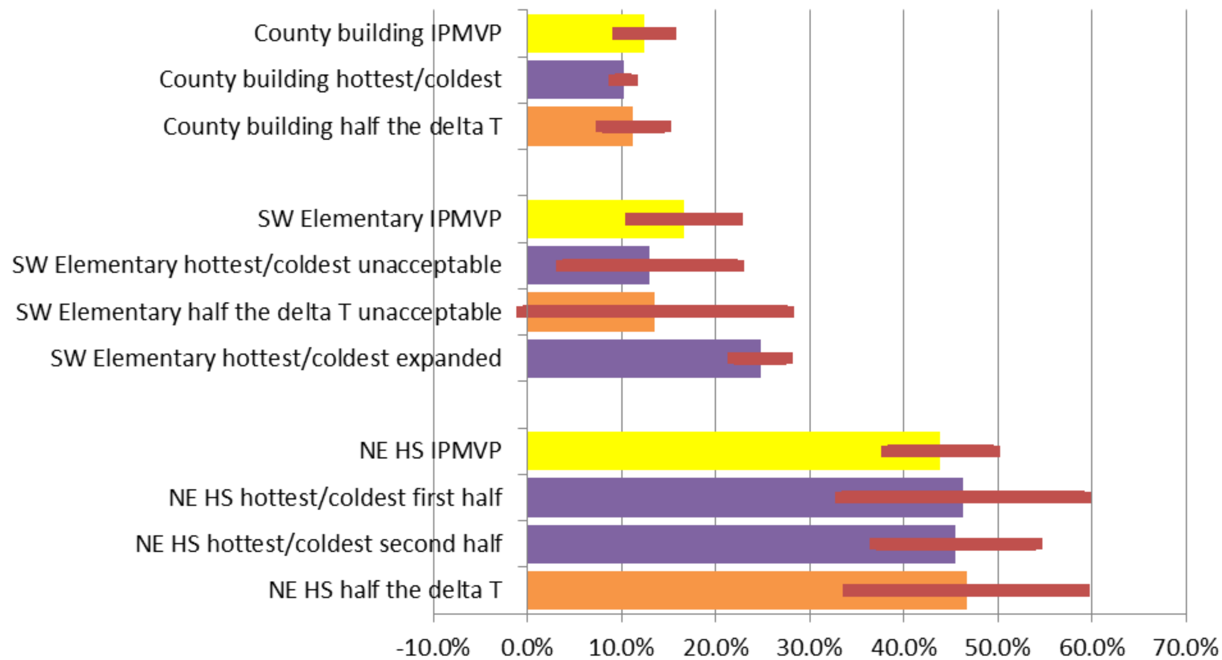

Figure 2. A graph illustrating all modeled approaches compared to the IPMVP results. Uncertainty for each model is shown as a red bar.

Due to the small number of points used for these models, one outlier data point can disproportionately affect the modeling, as occurred in the Southwest Elementary example. This confirms that shortening the performance period on monthly data sets to less than a year will not always give desired results, and with a small number of points in any section of a change point models, it will not be obvious whether the model actually represents the data.

While a year of post data, as described by IPMVP, is still the most reliable methodology for monthly whole building modeling, it may be possible to use a shorter verification period and still get acceptable results if a full range of temperatures can be captured in a shorter time period. Model validity appears to be best when at least as many points as are required to reproduce the baseline change point model are included, and the historical hottest and coldest months are included in the performance period. Knowing this ahead of time, project installation could be timed to take advantage of a shorter M&V period, for example by completing commissioning in May to capture summer or in November to capture winter usage.

These guidelines provide a transparent methodology to use easily accessible data to define M&V requirements ahead of project performance period. Having these guidelines in place can help ensure that various stakeholders involved with installing, operating, and verifying energy efficiency projects are all fully aware of how verification will be done, and ideally can adjust their implementation schedule to help shorten the performance period.

Further research should be conducted to determine if there are specific conditions or circumstances which control whether an IPMVP-adherent performance period should be required. These guidelines should be tested in other climate zones, to ensure that they are widely applicable.

References

Abushakra, B., Reddu, A., and Singh, V. 2012. *Measurement, Modeling, Analysis and Reporting Protocols for Short-term M&V of Whole Building Energy Performance Report.* ASHRAE RP-1404.

Bonneville Power Administration (BPA). 2012a. *Measurement &Verification (M&V) Protocol Selection Guide and Example M&V Plan.*

Bonneville Power Administration (BPA). 2012b. *Verification by Energy Modeling Protocol, Version 1.0.*

Efficiency Valuation Organization (EVO). 2012. *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings Volume 1*. EVO 10000 – 1:2012.

Kissock, J., Haberl, Jeff, and Claridge, David. 2002. *Development of a Toolkit for Calculating Linear, Change-point Linear and Multiple-Linear Inverse Building Energy Analysis Models.* ASHRAE RP-1050.