# Overcoming Barriers to Whole Building M&V in Commercial Buildings

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**ABSTRACT**

As energy efficiency programs evolve, utilities are pursuing more complex and highly interactive measure packages, which may include hard-to-quantify savings from operational improvements, enabling technologies such as monitoring systems, and/or building occupant behavior changes. These innovative approaches require a way to quantify energy savings that minimizes cost and effort. Conducting whole building savings analysis is one approach that meets the evolving requirements of these new energy efficiency programs. Applied correctly, whole building analysis reduces measurement and verification (M&V) costs, while still complying with rigorous M&V requirements.

Multiple case studies on large commercial and grocery energy efficiency projects were conducted to define requirements for estimating annual energy savings using whole building data. Included in the analysis is an examination of the timing and amount of data required, the percent savings range that can be accurately verified, and the impact of reduced monitoring length on estimated savings. These studies help inform scalable program designs.

This paper also discusses the need for an approved programmatic framework for whole building M&V to gain significant traction for verifying savings in commercial buildings. At a minimum, the framework should include pre-screening criteria for method selection, setting the bar for uncertainty metrics, and methods for claiming savings.

## Introduction

One standardized approach to whole building measurement and verification (M&V) is described by both ASHRAE Guideline 14 and IPMVP Option C (AHSRAE 2002, IPMVP 2010). Generally, this approach uses sophisticated regression analysis to identify and quantify changes to the building's energy use using data from the main energy meters[1]. This approach has not been widely used in utility programs due to the level of specialized expertise required for the analysis, the length of monitoring time required to obtain sufficient data to characterize building energy use, and the lack of evidence demonstrating the accuracy of energy savings estimates using less than one year of monitored data.

The current guidelines discuss recommended monitoring length and minimum level of savings, typically one year to claim annual energy savings and 10% of whole building consumption, respectively, to achieve acceptable results (ASHRAE 2002, IPMVP 2010). These constraints pose significant barriers that have prevented wide scale adoption of whole building M&V in utility programs. However, these guidelines are based on the historical approach of using monthly utility data. The increasing availability of interval data presents an opportunity for energy efficiency programs to utilize whole building approaches with reduced monitoring timeframes and lower percent energy savings.

[1] Other analytical approaches include, but are not limited to: Change point, nearest neighbor, or dynamic bins.

Furthermore, as the energy efficiency industry continues to evolve, there will be fewer "low hanging fruit" opportunities. Utilities are looking for approaches that achieve deeper energy savings, increasing the need to quantify energy savings from more complex and interactive measures. New programs may include hard-to-quantify savings from enabling technologies such as monitoring systems or building occupant behavior changes. These innovative programs are not well suited for a traditional measure-by-measure savings approach. Whole building M&V accounts for interactions between systems and multiple energy conservation measures (ECM), and captures hard to measure savings from operations and maintenance (O&M), training, enabling tools, and behavior change.

Lastly, there is a growing requirement for empirical evidence that proves energy savings are real (RTF 2011). Providing empirical evidence using traditional measure-level approaches is costly and often not scalable. Maintaining cost effectiveness targets with innovative programs that achieve deeper energy savings is challenging, especially when empirical evidence of energy savings is required. Whole building M&V uses measured data to quantify savings, reduces calculation and verification costs compared to traditional measure-level approaches, and is a more scalable option since the analytical approach doesn't depend on building or system type.

Whole building M&V addresses many of the evolving needs in the industry and is beginning to attract more attention for use in utility programs. However, there is a need to develop the historical whole building M&V methodologies to leverage new tools, data availability, and resources to meet present requirements. This paper identifies barriers to the wide-spread adoption of whole building M&V, presents original research performed by PECI to address several of the key barriers, and discusses the need for a program design framework to achieve broader acceptance of whole building M&V.

## Core Issues for Whole Building M&V

While several whole building pilot programs are currently underway, an evaluation of this approach has not yet been conducted in the commercial sector[2]. Using a whole building approach to M&V can be complicated, especially in the absence of applicable standards or guidelines. For whole building M&V to be widely adopted, research and guidelines that address outstanding technical, programmatic design and regulatory policy issues are needed. The core issues and key questions to consider are:

- Building and toolset qualification – What is the screening process and criteria to identify, select, and enroll buildings that are well suited for whole building M&V? What qualifications do software platforms (such as Energy Information Systems) have to meet?
- Data collection requirements – How should the baseline be documented? What normalization factors need to be considered? How should changes in building operations be addressed? How closely should energy efficiency measure implementation be tracked?
- Evaluation, Measurement, and Verification (EM&V) – What percentage of whole building savings is needed for accurate verification? What level of uncertainty is acceptable? What length of monitoring is required, pre- and post-ECM?

[2] Examples of pilot programs are available in the Consortium for Energy Efficiency's website: http://www.cee1.org/files/WBCEI&EMISProgSumm.pdf

- Calculating and reporting energy savings – Can whole building programs claim savings at a project/site level or do they have to be attributable at a measure level? Can operational and behavioral savings be claimed?
- Program duration and effective useful life – How can long-term continuous improvement be encouraged with funding cycle requirements? What is the effective useful life of whole building approaches?

The original research presented in the next section focuses on the M&V issues and seeks to address three of the key technical questions[3] regarding the use of whole building M&V with interval meter data, specifically:

- How much savings is needed? – Energy use in buildings has a degree of randomness that can vary greatly over the year. To accurately verify energy savings, the savings must be significantly greater than this degree of uncertainty (CCC 2012). Some research implies that savings of at least 5% of overall building consumption can be detected when using interval data (Katipamula 1994). However, a better understanding of what percent savings is required for accurate verification is needed.
- How good do the results need to be? – There are many statistical metrics that can be used to evaluate the quality and "goodness of fit" of whole building M&V regressions. For regressions created from monthly utility data, IPMVP states that measured savings should be at least double the standard error of the baseline regression, and ASHRAE states the baseline model shall have a maximum CV(RMSE) of 20%. Guidance on which metrics are acceptable for interval data models is needed.
- How long should the monitoring period be? – Previous guidelines and existing research generally stipulate that 12 months of baseline and 12 months of post-implementation data are needed (ASHRAE 2002, IPMVP 2010). The greater resolution provided by interval meters shortens the required monitoring periods, as greater ranges of operating conditions are recorded in less time. Guidance on the length of the data collection period needed to establish the post-implementation period (assuming pre-implementation interval data is available) is needed.

## Methodology and Results

PECI conducted research on several existing projects to investigate the questions presented in the previous section. In total, eight case studies were developed using whole building M&V to determine electric savings. Five of these case studies are grocery stores and three are large office buildings. All the buildings are located in California, split between coastal and inland climates. The complete case studies are available upon request.

Initially, the variables with the largest impact on energy use were identified for each building type. The whole building energy savings were then calculated for each project using one full year of baseline and post-installation monitored data. These full-year energy savings were used as a basis of comparison to evaluate the questions presented in the previous section.

Project data such as location, installed measures, and the original project's deemed savings are shown in Table 1 and Table 2.

[3] ASHRAE Research Project 1404 is also investigating similar questions, but results are not yet available.

**Table 1. Grocery Stores: Original Project Data**

| Grocery Store | Chain 1 | | | Chain 2 | |
|---|---|---|---|---|---|
| | Store 1 | Store 2 | Store 3 | Store 4 | Store 5 |
| Location | Los Banos | Fresno | San Francisco | San Mateo | San Francisco |
| Implementation date | June 2009 | March 2009 | October 2008 | March 2009 | January 2010 |
| Deemed Savings (kWh) | 357,750 | 113,893 | 199,686 | 38,000 | 30,400 |
| % whole building savings | 17.8% | 4.5% | 9.4% | 1.9% | 1.25% |
| Anti Sweat Heater Controls | X | X | X | X | X |
| Floating Head Pressure Controls | X | | X | | |
| Multiplex Compressor | | | X | | |
| Auto-Closers for Glass Reach-in Doors | X | | X | | |
| Gaskets for Reach-in Glass Doors | X | | X | | |
| Strip Curtains | | | X | | |
| Photocell Lighting Control | X | X | | | |
| Time-Clock Lighting Control | X | X | | | |

**Table 2. Large Offices: Original Project Data**

| Large Office | Building 1 | Building 2 | Building 3 |
|---|---|---|---|
| Location | Los Angeles | Santa Ana | San Diego |
| Size ($ft^2$) | 162,634 | 338,070 | 173,570 |
| Implementation date | 6/1/2008-5/31/2009 | 3/1/2008-5/31/2008 | 7/1/2009-6/30/2010 |
| Custom Savings (kWh) | 113,125 | 903,683 | 113,157 |
| % whole building savings | 3.2% | 16% | 11% |
| Reset CHW temperature | X | | |
| Implement optimized start | X | | |
| Optimize boiler lockout and reset schedule | X | | |
| After hours fan operation | | X | |
| Constant duct static pressure set point | | X | |
| Economizers not functioning properly | | | X |
| Add VFDs to chilled water pumps | | | X |

**Which variables should be included in the models?** When conducting regression analysis, the variables that influence energy use the most need to be identified. These variables might include factors such as ambient temperature, building schedule, or throughput metrics such as the amount of sales or number of units produced, and is dependent on the building type or use.

Analysis of the grocery stores considered occupancy, dry bulb temperature, wet bulb temperature, and relative humidity using both hourly and daily data. Occupancy patterns had negligible impacts on the grocery energy use. Dry bulb temperature was the most influential variable and the statistics for the regression created using dry bulb temperature are shown in Table 3. Including variables in addition to dry bulb had negligible improvements on the uncertainty metrics.

Analysis of the large offices also included occupancy, dry bulb temperature, wet bulb temperature and relative humidity. Day of week (Monday, Tuesday, etc.) and weekday/weekend were analyzed for daily models; and time-of-day and schedule (occupied/unoccupied) were analyzed for hourly models to account for occupancy impacts. Separate regressions for each variable and multivariate regressions for each combination of variables were created.

When using interval meter data rolled up into daily data, the weekday/weekend variable was most influential followed by dry bulb temperature[4]. The regression developed with weekday/weekend and dry bulb temperature was chosen for the remainder of the analysis since the inclusion of additional variables made negligible improvements (<0.5% of Standard Error) to the uncertainty metrics. The statistics for the office multivariate regression using weekday/weekend and dry bulb temperature are shown in Table 3.

Energy savings estimates in these case studies used the avoided energy use method (IPMVP 2010). A baseline regression using a full year of monitored data prior to implementation was created. Then the actual conditions recorded during the full year following implementation were used in the regression to create an adjusted baseline which projects the baseline operation into the post-installation monitoring period. The difference between the adjusted baseline and measured post-installation energy use is the avoided energy use. For the case studies presented in this paper, we define the savings calculated with one year of pre and one year of post implementation data as the "best practice" methodology and represent "accurate" savings. The avoided energy use estimates were used as a basis of comparison when analyzing accuracy throughout the analysis. The avoided energy use results are shown in Table 3.

**Table 3. Case Studies Summary: Uncertainty Metrics and Savings Results**

| | **Large Office** | | | **Grocery** | | | | |
|---|---|---|---|---|---|---|---|---|
| **Uncertainty Metric** | **Building 1** | **Building 2** | **Building 3** | **Store 1** | **Store 2** | **Store 3** | **Store 4** | **Store 5** |
| SE | 24,798 | 28,600 | 4,451 | 2,961 | 3,553 | 3592 | 4,222 | 3,992 |
| $R^2$ | 0.71 | 0.83 | 0.77 | 0.92 | 0.94 | 0.25 | 0.6 | 0.35 |
| CV(RMSE) | 13.4% | 9.8% | 8.3% | 2.8% | 2.7% | 3.1% | 3.9% | 3.15% |
| Avoided Energy Use (kWh)* | 296,952 | 700,202 | 210,289 | 285,630 | 94,597 | 106,747 | 101,908 | 166,374 |
| % whole building savings | 8.4% | 12.6% | 19.82% | 14.3% | 3.8% | 5.3% | 5.0% | 6.9% |

*Calculated with one year of pre and post data.

**What percent whole building savings can be validated?** As discussed in the core issues section, there is a lack of clarity around how much savings, as a percent of whole building energy use, are needed before they are detectable over the "noise" of the general energy data. Various ranges of estimated savings were chosen to investigate this question.

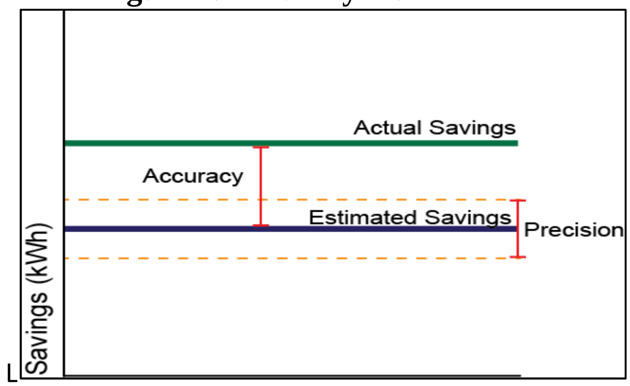
Confidence that the project has achieved savings (i.e. the savings are detectable) requires that the actual energy use in the post period be statistically different from the adjusted baseline. At a minimum, we recommend following guidance set forth in Appendix B of the IPMVP that states the estimated whole building savings should be at least twice the standard error (SE or RMSE) in the baseline model (IPMVP 2010). From Table 3, it can be seen that this condition is easily met for all the buildings. Thus, there is a statistical difference between the energy use and

[4] Hourly regressions were created in the case studies but not reported in this paper since IPMVP recommends rolling interval data into daily resolutions. In these case studies, occupied/unoccupied, dry bulb temperature, and weekday/weekend in descending order were the most influential variables for hourly data.

the energy savings and we have confidence that the savings are detectable and have been achieved.

These traditional uncertainty metrics are statements of precision and are used to evaluate the quality of the regressions. However, they are not the best indicators for the level of accuracy of the savings estimate (Reddy 2000). Thus, these metrics indicate whether savings are achieved, but not how close the estimated savings are to the "actual" savings. This difference between accuracy and precision is illustrated in Figure 1.

**Figure 1. Accuracy vs. Precision**

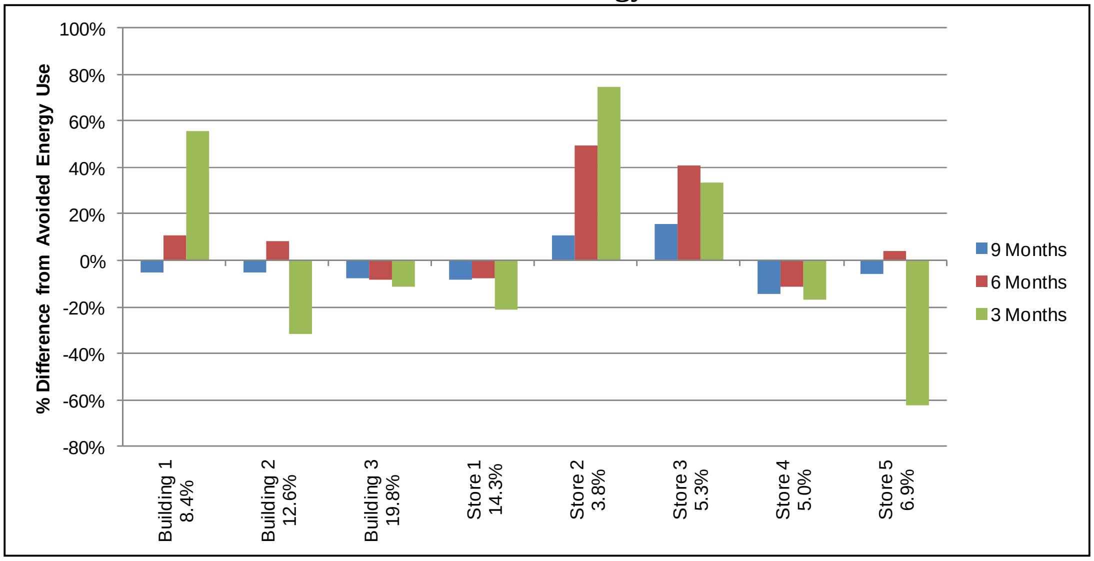



**What is the impact of shorter duration monitoring on the accuracy of savings?** For the case studies presented in this paper, we define the savings calculated with one year of pre and one year of post implementation data as the "best practice" methodology that represents "accurate" savings using whole building M&V. By defining an accuracy target, the impact that shorter duration monitoring has on the accuracy of savings can be evaluated.

Energy savings using less than one full year of post implementation monitoring were calculated for each site using a normalized energy use approach. The normalized savings approach involves the creation of baseline and post-installation energy regressions using monitored data from the respective time periods. Both regressions are then driven by a common data set, such as Typical Meteorological Year (TMY) temperature (Reddy 2000). Post installation monitoring periods of nine months, six months, and three months were used. The baseline monitoring period remained constant at one year of data based on the assumption that historical data is available at the start of the project. The results are compared to the avoided energy use (shown in Table 3) and the differences are shown in Figure 2. In general, as the duration of the monitoring period decreases the accuracy of the results decreases.

For these case studies we used the guidance specified by the Northwest Power and Conservation Council's Regional Technical Forum (RTF) that requires site specific savings estimates to be within ±20% of the best practice method (RTF 2011). Within these case studies, using 9 months of data produces the desired accuracy for both building types. In most cases (75%), six months of data also produces the desired accuracy. Three of the projects met the desired accuracy with three months of data; however, a definite conclusion about the suitability of shorter monitoring periods cannot be drawn with such a small sample set.

**Figure 2. Comparison of Normalized Savings Using Less than One Year of Data to Avoided Energy Use**




Seasonality has an impact when short monitoring periods are used; therefore, seasonal impacts on savings accuracy were evaluated using models created with three-month monitoring periods that spanned each of the four seasons. Additional models using six months of data were also created to determine whether capturing a swing season in the post-implementation period improved accuracy. The savings calculated using these regressions were again compared to the avoided energy use. The results of the seasonal analysis are shown in Figure 3. Seasons within ±20% of the stores' avoided savings are shaded green. When looking at the results from three months of monitoring, the swing seasons were the most accurate for the grocery stores. There does not appear to be a discernible trend for the most accurate seasons for large offices. Most of the results for six months of monitoring (i.e. including both a swing and a fringe season) produce accurate results. Across all the buildings, the six month periods of Spring-Summer and Summer-Fall produced the most accurate results.

Based on this limited number of case studies, rules of thumb are starting to emerge. Three months of post implementation monitoring seems to be enough for projects with large expected savings, or for climate zones with relatively small annual variation that realize full ranges of operation in less time than climates with large seasonal ranges. For projects with lower expected savings, six months of monitoring appears to be acceptable in most cases. Additional case studies are needed to fully understand if the trends observed in these case studies hold true in a broader data set. Analysis of this larger data set could establish more definitive rules of thumb for when and for how long monitoring is required.

**Figure 3. Seasonality Analysis Results**

| | Higher Savings | | Lower Savings | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Building 3 San Diego | Store 1 Los Banos | Building 2 Costa Mesa | Building 1 Los Angeles | Store 5 San Francisco | Store 3 San Francisco | Store 4 San Mateo | Store 2 Fresno |
| Summer | -12% | 2% | -43% | 35% | -57% | 57% | 6% | -50% |
| Winter | -2% | 6% | 13% | 38% | 86% | -46% | -42% | 149% |
| Fall | -1% | 4% | 27% | -15% | 19% | -3% | 23% | 36% |
| Spring | 23% | -16% | 22% | 43% | 6% | -31% | 17% | 116% |
| Spring-Summer | 4% | 1% | 0% | 18% | -15% | -1% | 10% | 34% |
| Summer-Fall | -9% | 4% | 8% | 10% | -21% | 19% | 15% | -4% |
| Fall-Winter | -1% | 5% | 5% | -23% | 21% | -6% | -6% | 23% |
| Winter-Spring | 15% | -16% | 19% | 42% | 31% | -30% | 1% | 91% |

Percent difference of seasonal savings from avoided savings. Green cells are ±20% from the avoided energy use.

## Lessons Learned from Research

The research presented in this paper addresses some of the barriers and issues surrounding whole building M&V. In these projects, whole building savings as low as 3.8% can be detected. Interdependency between the level of whole building savings and the required monitoring period needed for accurate results is demonstrated. In this limited sample, nine months of data seems to always suffice despite the level of savings. Three months of monitoring appears to suffice for projects with large savings whereas six months of monitoring might be appropriate for projects with lower savings. Wide spread adoption of the whole building approach for savings verification may require more evidence that demonstrates how long monitoring periods should be and when that data should be collected. However, these results demonstrate that implementing whole building M&V with less than 10% savings and less than one year of post monitoring data is possible.

Current analytical techniques require sophisticated users to conduct the regression analysis. While formalized whole building M&V approaches are described by long standing protocols (ASHRAE 2002, IPMVP 2010), there has been little "how-to" guidance to assist the industry in implementing the protocols. The California Commissioning Collaborative recently produced "Guidelines for Verifying Savings from Commissioning Existing Buildings" (CCC, 2012). In spite of this detailed guidance, a relatively high level of expertise and understanding of statistics and regression analysis is still required to effectively implement whole building M&V. This need for specialized expertise can be a limiting factor when developing a scalable programmatic approach. Identification of alternative approaches that simplify or automate the analysis will be required for wide scale use of whole building M&V in utility programs.

Furthermore, the level of understanding gained from limited data requires a building-by-building, "try it and see" approach to assess the applicability of whole building M&V. This increases both the risk and cost of using whole building M&V and is not scalable for a large utility program. A framework for determining the applicability of whole building M&V to a program portfolio is needed.

## Scaling Up Whole Building M&V

Scaling up whole building M&V to verify savings in commercial building programs requires advances in the following areas:

- Enabling tools that automate whole building M&V analysis and reduce the requirement for expert users are available, but need to be evaluated and approved for use in large utility programs;
- Pre-screening criteria for M&V method selection;
- Agreement on “what’s good enough” regarding uncertainty metric requirements
- Approval to claim savings at the project level rather than measure-by-measure

The following section discusses these issues in more detail.

### Use of Enabling Tools

Statistical software (such as SAS) and advanced Energy Information Systems (EIS) that help automate data collection and conduct whole building savings analysis are commercially available. These tools help lower implementation costs by significantly reducing analysis time and eliminating the need for an expert user to calculate savings. They also offer an opportunity to build more automated, cost-effective persistence strategies into programs, as the energy data required for a whole building M&V analysis is often the same data used as key performance indicators for building performance tracking and management[5].

While advanced EIS are starting to gain traction in several pilot programs, the rigor and accuracy of the software’s calculation methodologies have not yet been formally evaluated in a utility program. Specific software platform qualifications should be developed and formalized by utilities, regulators, and evaluators.

### Screening Criteria

Establishing a clearly defined pre-screening process and criteria to identify, select, and enroll buildings that are suited for whole building M&V will help ensure that it is applied at the right time for the right type of programs. High level pre-screening criteria can be established now based on building operating characteristics and energy use data availability. Buildings with relatively stable operations, such as ambient temperature driven grocery stores or large office buildings with relatively consistent operating schedules, are well suited for using whole building M&V. Ideal candidate buildings do not have major occupancy changes (tenants moving in/out) or energy efficiency or demand response projects implemented during the baseline period. If major changes have occurred, documentation of the change and its impact is required so adjustments can be made to the baseline. Preferred candidates already have historical interval data available (1 year preferred), otherwise program timeframes must include the additional time required to collect the baseline data before starting the project.

As more projects complete a whole building approach, it is likely that screening criteria can be defined simply through readily-available building and project characteristics, such as

[5] The CCC’s Building Performance Tracking Handbook (CCC, 2011) provides guidance on managing building performance and discusses available tools that help ensure the persistence of improvements.

building type and size, operational profile, efficiency project history, potential for improvements, expected monitoring length, program goals, measure types, and competing programs.

### Agreement on "What's Good Enough"

As discussed in the core issues section, there is no clarity around which statistical metrics and what levels are acceptable when higher resolution interval data is used. Overcoming this challenge needs policy development (and industry consensus) between utilities and regulators. Based on PECI's experience implementing this approach, evaluation guidelines, and discussions with evaluators, Table 4 presents a list of recommended metrics (described in standard statistics textbooks) and values for use in a programmatic framework for evaluating regressions.

**Table 4. Uncertainty Metrics**

| Metric | Specification |
|---|---|
| Standard Error (SE) | Estimated savings should be at least two times the SE of the baseline model |
| Confidence Interval (CI) | At least 80% confidence should be used |
| $R^2$, adjusted $R^2$ | Use the $R^2$ as an initial check of the model. Models should not be rejected or accepted solely on the basis of $R^2$. Should be reported. |
| CV(RMSE) | Use CV(RMSE) as an initial check of the model. Models should not be rejected or accepted solely on the basis of CV(RMSE). Should be reported. |

In conclusion, there is no single metric that tells the entire story. The standard error and confidence intervals are better suited to evaluate the accuracy of a regression, while the traditionally used $R^2$ and CV(RMSE) provide a simple check of validity.

### Ability to Claim Savings at Project or Site Level

Ideally, savings verified using whole building M&V can be claimed at a site level. However, in many geographical areas verified savings currently have to be directly attributed to measures for incentive payment and reporting purposes. Additionally, overlap with other programs may lead to double-counting savings unless the individual programs are well-coordinated. Methodologies to document and quantify actions taken outside of the program are required to adjust whole building M&V savings accordingly. The policy discussion between utilities and regulators should also seek to promote communication and planning with evaluators during the program design phase to reach agreement on the approach for claiming savings and accounting for concurrent programs.

## Conclusions

The research presented in this paper demonstrates that utilizing a whole building M&V approach with less than 10% savings and less than one year of post-implementation data is possible. For these case studies, using six or even three months of data is sufficient, depending on the level of savings. In spite of the remaining core issues, whole building M&V addresses many of the new M&V needs and is beginning to attract more attention for use in utility programs. Applied correctly, whole building M&V:

- Reduces calculation and verification costs compared to traditional measure level approaches
- Accounts for interactions between systems and multiple measures
- Captures hard to measure savings from operations and maintenance, training, enabling tools, and behavior change
- Simplifies implementation as multiple building types use similar approaches
- Can increase persistence of savings if implemented with an EIS
- Is a formal M&V approach that uses measured data to quantify savings

As whole building programs become more widely adopted, more data and additional guidance will be available to support the widespread adoption of whole building M&V. This requires:

- Additional research or pilots to define how to best implement the approach (or when not implement the approach) by building types, climate zones, and percent savings ranges
- More evidence that demonstrates how long monitoring periods should be and what seasons must be included
- Feedback from utilities, regulators, and evaluators to receive "buy-in" on the approach and level of rigor

The research and framework presented here demonstrates that, with proper planning and analysis, whole building M&V can gain significant traction for verifying savings in commercial buildings. Implementing a rigorous method for measuring energy savings at the whole building level will help operational improvement and behavioral programs more readily scale up to achieve significant energy savings in the commercial sector.

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