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Jessica Granderson, Samuel Fernandes

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The State of Advanced Measurement and Verification Technology and Industry Application

Jessica Granderson[1], Samuel Fernandes
Lawrence Berkeley National Laboratory
Berkeley, CA, United States

Abstract
With the expansion of advanced metering and increased use of energy analytics tools, the energy efficiency community has begun to explore the application of advanced measurement and verification (or "M&V 2.0") technologies. Current literature recognizes their promise, but does not offer in-depth assessment of technical underpinnings. This paper assesses the state of the technology and it's application. Sixteen commercially available technologies were characterized and combined with a national review of their use.

Keywords: Advanced M&V; M&V 2.0; baseline modeling; goodness of fit; utility efficiency programs; analytics technology.

1. Introduction
The past decade has seen an increase in the deployment of Advanced Metering Infrastructure (AMI), which has resulted in increasing availability and access to energy consumption data. As of 2015, there were more than 64 million smart meters deployed nationally (EIA 2017). The increased availability of data has resulted in rapid expansion of energy analytics offerings, including those that offer advanced, automated measurement and verification or "M&V 2.0."

The term *M&V 2.0* is increasingly understood to refer to the use of automated analytics in combination with higher granularity data to quantify project energy savings. Higher granularity may refer to increased sampling frequency, as in the transition from monthly data to 15-minute interval data, increased volume, or increased resolution in moving from whole-building to end-use level measurement. Many of the technologies that offer M&V 2.0 capability are not exclusively tools for energy savings estimation, but rather multi-featured tools that are used to support various types of data-driven approaches to operational efficiency in buildings. These *energy management and information systems* (an increasingly used term) may offer, for example, interval meter analysis and visualization, system-level fault detection and diagnostics, and benchmarking (Kramer 2013), and afford significant operational savings with short payback (Granderson 2016a). As the technologies have evolved over time, some have been designed and targeted for use by utility program administrators, and may support program tracking, customer screening, and targeting. At the same time, and while expanding the breadth of their offerings, many software providers have built up suites of offerings that may encompass different user types (utility program administrators versus energy managers) or cross-compatible modules with specific functionality (savings estimation versus fault detection).

[1] 1 Cyclotron Rd., Berkeley CA, 94720 United States; JGranderson@lbl.gov

Independent of the specific form in which it is delivered to the market in packaged tools, M&V 2.0 offers many potential benefits, particularly in the context of utility program delivery. First is the ability to access more timely and detailed feedback on achieved savings. The continuous and automated nature of M&V 2.0 means that rather than waiting until the end of a program or project, savings can be tracked as they accrue. This enables a practitioner to identify under-performing projects and provides an opportunity to make course corrections, potentially increasing savings realization rates. Second, the frequent use of interval data provides a means to maximize the value of AMI investment, while also offering the ability to location- and time-differentiate savings. This "time and location dependent valuation" is becoming increasingly important as policy makers begin to distinguish between the relative value of a kilowatt-hour saved at one time of day versus another, and in locations supplied with diverse generation mixes.

A third potential benefit of advanced M&V being discussed in the industry is the ability to reduce the labor time and cost associated with savings estimation while delivering results of equal or improved accuracy—particularly whole-building measurement and verification that relies upon existing conditions baselines. Opening the door to streamlined, accurate whole-building M&V is critical to realizing the next "wedge" of utility program savings, as traditional measures that are relatively simple to deem or calculate begin to saturate. Less common program designs that include a combination of operational, commissioning, and behavioral measures, or multiple retrofit measures, promise to deliver deeper savings, and are also best suited to meter-based savings estimation using existing conditions baselines—especially when combined with pay-for-performance incentive designs.

A growing body of work is recognizing the promise and industry relevance of these advanced techniques for energy savings estimation. For example, recent publications have articulated the potential advantages of advanced M&V and intersections with evaluation (DNV-GL 2015; Franconi 2017a), as well as the development of new data analysis and modeling techniques (Ahmad 2017; Araya 2017; Burkhart 2014; Heo 2012). Testing and validation of advanced M&V has been highlighted in case studies and technical articles (Franconi 2017b; Granderson 2014, 2015, 2016b; Kupser 2016). And finally, technology attributes have also been documented over a period of years (Crowe 2014; Kramer 2013; Kupser 2016; NEEP 2016). However, the literature does not offer an in-depth publicly accessible assessment of the technical underpinnings of today's advanced M&V technology or synthesis of the level of national uptake of these approaches within the utility program sector.

In response, this paper presents research designed to answer the following questions:

- What is the state of today's advanced M&V technology?
- How are these technologies distinguished; what are common and emerging capabilities?
- How has the technology evolved over the past 3–5 years?
- What is the state of application of advanced whole-building savings estimation at the regulatory, state, and utility levels?

2. Methodology

To evaluate the state of advanced M&V technology, a framework of features and characteristics was defined. This framework comprised the integration of several sources of information, including:

- Existing literature on high-level distinguishing characteristics and previous inventories and surveys (Crowe 2014; Franconi 2017a; Kramer 2013; Kupser 2016)
- Existing literature on attributes of analytics technologies for management of operational efficiency in commercial buildings
- The principles of M&V expressed in the International Performance Measurement and Verification Protocol and ASHRAE Guideline 14 (ASHRAE 2014; EVO 2012)
- Discussion with industry stakeholders to understand key attributes of highest interest

Based on these sources, a framework of 12characteristic elements was developed.

1. Primary market sector focus: commercial, small commercial, residential, and industrial.
2. Primary target user: building owners, operators, and managers; utility program administrators and energy efficiency service providers.
3. Principal technology design intent: interval meter analytics and visualization, system-level fault detection and diagnostics, direct optimized HVAC control, energy/load disaggregation, benchmarking and utility bill analysis, utility customer screening and engagement, utility program tracking, and measurement and verification.
4. M&V method: International Performance Measurement and Verification Protocol (IPMVP) option B, C, D, and other.
5. Mathematical approach: Linear, non-linear, machine learning, physics-based simulation, and other.
6. Input data frequency: monthly, interval, and both.
7. Statistical goodness of fit metrics: coefficient of determination (R^2), coefficient of variation of the root mean squared error CV(RMSE), normalized mean bias error (NMBE), and other.
8. Display of fitness metrics: output to the user through the user interface, or computed and accessible through the tool's "back end."
9. Support for non-routine adjustments: ways in which the tool accommodates documentation or quantification of non-routine changes in energy use.
10. Quantification of savings uncertainty: whether the tool estimates the uncertainty in savings that is due to model error.
11. User-adjustable parameters: independent variables used in the model, specific fitness metrics, baseline time period, type of model, and other.
12. Algorithm transparency: tool provider's willingness to document the M&V algorithm in further detail and make it available publicly.

Sixteen technologies were evaluated according to this framework. They were chosen based on: representation in the published literature (Crowe 2014; Kramer 2013; Kupser 2016) and market presence; the researchers' subject matter knowledge of current market offerings; web searches to identify offering not otherwise known to the researchers; discussion with utility and owner stakeholders to isolate offerings of high interest to target users; and vendor or developer willingness and ability to share information necessary for a complete characterization.

Although these offerings comprise a *representative* as opposed to *comprehensive* sample of current market offerings, they do comprise a large number of the technologies that offer M&V 2.0 capability. To characterize each technology, publicly available information was gathered from vendor product brochures and websites. Additional information was acquired through interviews and surveys with the vendors and developers of each tool. The information that was acquired was therefore based on self-reporting from the technology provider. It was not within the scope of this effort to independently verify reported functionality and characteristics of each technology that is included.

To assess industry exploration and application of advanced M&V, primary research was conducted, comprising a review of public documentation of cases studies and recent regulatory actions. This was complemented with documentation of discussions with utility industry practitioners and non-practitioner stakeholders.

3. State of Technology of M&V 2.0 Tools

Table 1 details sixteen commercially available M&V 2.0 tool offerings. As the market is constantly evolving, and technologies are continuously modified, these findings represent a snapshot in time. Moreover, it is important to note that the product offerings that comprise the focus of this review are those that provide M&V 2.0 capability; in many cases they are delivered as part of a suite of complementary software applications, or modules within the vendor's line of offerings.

Following Table 1, the findings for each product offering are synthesized to provide insights into the state of today's M&V 2.0 technology.

Table 1. Characteristics and capabilities of tools that offer M&V 2.0

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
Lucid, BuildingOS	Commercial	Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option C Whole Building	Machine learning (Ensemble approach combining nearest neighbors)	Interval	CV(RMSE), R^2, AIC, BIC, Adjusted R^2, t-values and confidence intervals	User	NA	NA	Independent variables, Baseline time period, Type of model	Yes
Gridium, Snapmeter	Commercial, Industrial	Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option C Whole Building	Non-linear model, advanced regression including a near term for drift	Interval	CV(RMSE), R^2, MAPE	Back end	No	Yes	Baseline time period	No, prefer to keep proprietary
Buildings Alive, Rapid Energy Feedback	Commercial	Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Machine learning (Support vector machine and Random forest)	Interval	CV(RMSE), R^2, Skewness, standard deviation	Back end	Yes	No	Baseline time period	No, prefer to keep proprietary
Cascade Energy, Sensei Energy Efficiency Software	Industrial	Utility program administrator, Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, Customer engagement	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear model	Monthly, Interval	CV(RMSE), R^2, NMBE, Standard Error, Auto-correlation coefficient	Back end	Yes	Yes	Independent variables, Choice of fitness metrics, Baseline time period, Type of model	No
Rodan Energy Solutions, Energent EMIS Solution	Commercial, Industrial	Building or portfolio owner/manager/ operator	Interval meter analytics and visualization	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear regression of multiple variables (9 independent variables)	Monthly, Interval	CV(RMSE), R^2, NMBE, F values	Back end	Yes	No	Independent variables, Baseline time period	Not yet considered

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
Bractlet, Advanced measurement and verification	Commercial	Building owner/manager/ operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option D Calibrated Simulation	Physics-based simulation with machine learning on submeter data to calibrate the model	Monthly, Interval	CV(RMSE), NMBE	User	Yes	Yes	Independent variables, Baseline time period, Choice of fitness metrics	Yes
EnergyCAP, EnergyCAP cost avoidance module	Commercial	Energy efficiency service provider, Building or portfolio owner/manager/ operator	Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building	Linear model with variable base degree days	Monthly	R^2	User	Yes	No	Baseline time period, Degree day balance point temperature	Yes
eSight Energy, Esight Platform	Commercial, Industrial	Utility program administrator, Energy Efficiency Service Provider, Building or portfolio owner/manager/ operator, Operations /Plant Manager/director /supervisor	Interval meter analytics and visualization, Measurement and verification, Program tracking	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear, Multi variable linear	Monthly, Interval	CV(RMSE), R^2, N and P values	User	Yes	No	Baseline time period, Independent variables	Yes
EnergySavvy, M&V 2.0 and program optimization	Small commercial, Residential	Utility program administrator	Customer screening and targeting, Measurement and verification, Program tracking	IPMVP Option C Whole Building	Linear and Machine learning (Random forest for bias correction)	Monthly, Interval	CV(RMSE), R^2	Back end	No	Yes	NA	Yes, available for the public

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
Ecova, Efficiency Track	Commercial, Small commercial	Utility program administrator, Building or portfolio owner/manager/ operator	Customer screening/ engagement, Measurement and verification	IPMVP Option C Whole Building	Linear and machine learning	Monthly, Interval	R^2, CV(RMSE), NMBE	Back end	No	No	Independent variables, Baseline time period, Choice of fitness metrics	No, prefer to keep proprietary
BuildingIQ, Automated Measurement & Verification	Commercial, Small commercial	Energy efficiency service providers, Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building	Linear and machine learning (Support vector machine), Advanced regression including a term for thermal mass	Interval	R^2, RMSE, NMBE, confidence intervals	User	Yes	No	Independent variables, Baseline time period, Type of model	No, prefer to keep proprietary
Open energy efficiency, OpenEEmeter	Small commercial, Residential	Utility program administrator, Energy efficiency service provider	Measurement and verification, Program tracking	IPMVP Option C Whole Building	Linear	Monthly, Interval	CV(RMSE), R^2	User	Yes	Yes	Choice of fitness metrics, Baseline time period, Type of model	Yes
PSD Consulting, Building Performance Compass	Commercial, Small commercial, Residential	Utility program administrator	Benchmarking and monthly utility bill analysis, Measurement and verification	IPMVP Option B Retrofit Isolation, IPMVP Option C Whole Building, IPMVP Option D Calibrated Simulation	Linear, (piecewise linear), Physics based simulation	Monthly, Interval	CV(RMSE), R^2	User	Yes	Yes	Independent variables, Baseline time period, Type of model	Yes
Universal translator 3	Commercial	Utility program administrator, Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Measurement and verification	IPMVP Option C	Linear	Interval	CV(RMSE), R^2	User	No	Yes	Type of model	Yes

Vendor, Tool	Sector	User	Intent	Method	Approach	Input Data	Metrics	Metrics Displayed	NR Adj	Uncert.	Adjustable Parameters	Transp.*
FirstFuel, First Engage/ First Advisor	Commercial, Small commercial	Utility program administrator	Interval meter analytics and visualization, Customer screening/ engagement, Energy disaggregation, Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building	Machine learning	Monthly, Interval	CV(RMSE), R^2, NMBE	User	Yes	Yes	NA	No, prefer to keep proprietary
Envizi, Program reporting, Measurement and verification	Commercial	Energy Efficiency Service Provider, Building or portfolio owner/manager/ operator	Interval meter analytics and visualization, System-level fault detection and diagnostics, Benchmarking and monthly utility bill analysis	IPMVP Option C Whole Building, IPMVP Option B Retrofit Isolation	Linear	Monthly, Interval	R^2, Adjusted R^2, Standard error, p-value, t and f statistic	User	No	No	Independent variables, Choice of fitness metrics, Baseline time period	Not yet considered

* Transparency indicates the tool provider's willingness to document the M&V algorithm in further detail and make it available publicly.
AIC = Akaike information criterion; BIC = Bayesian information criterion

3.1 Principal design intent, primary users, and target building sector

Technologies that offer M&V 2.0 capability offer multiple principal design intents, as well as diverse features and capabilities. Measurement and verification and interval meter analytics and visualization were the most frequently reported intended uses of the technologies. Less frequently noted were monthly utility bill analysis (often with benchmarking); system- and/or equipment-level fault detection and diagnostics (FDD); utility customer engagement, screening, and targeting; and utility program tracking.

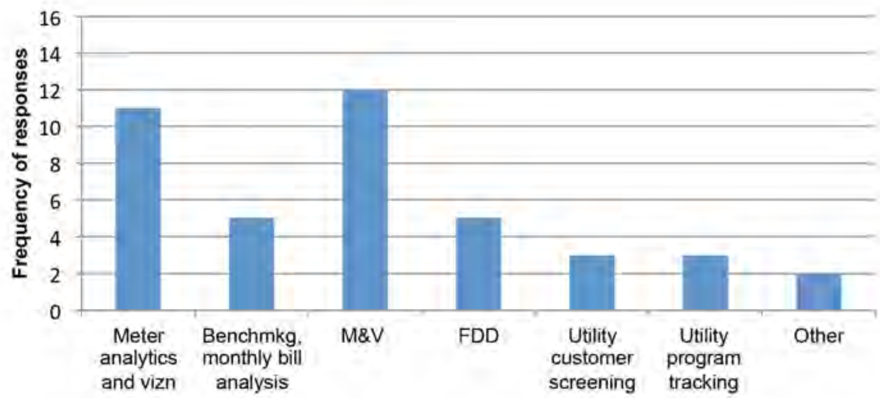

Figure 1. Principal design intent for surveyed technologies offering M&V 2.0 capability

The technologies' primary target users are reflective of their principal design intent. Eight of sixteen tools surveyed noted a single primary user type, while the remainder were found to target multiple users. Building owners, operators, and managers were the mostly commonly targeted, followed by program administrators. Efficiency service providers were the least commonly targeted; however, this is expected to change as analytics technologies expand to new user and delivery models.

As illustrated in Figure 2, tools that offer M&V 2.0 commonly serve multiple building sectors, with the commercial sector most prevalently targeted.

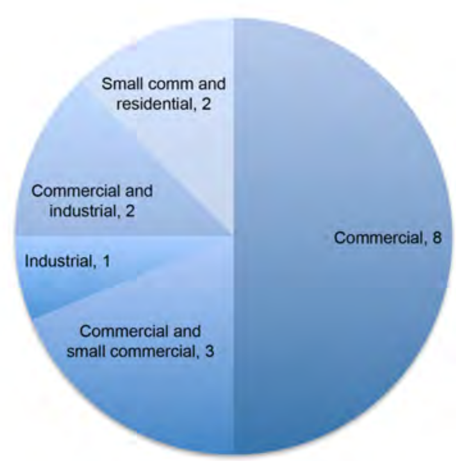

Figure 2. Target building sectors for surveyed technologies offering M&V 2.0 capability

3.2 M&V capabilities

All of the technologies surveyed provide M&V functionality aligned with the methods in the IPMVP, and some offer more than one of the IPMVP "Options." Fifteen of the technologies provide whole-building Option C analysis, consistent with the common primary design intent of providing interval meter analytics and visualization. Seven technologies provide Option B retrofit isolation analysis, and two provide Option D calibrated simulation modeling. One provides Option C, with two-stage billing analysis using a comparison group, as defined in the Uniform Methods Project (UMP) Chapter 8 (Agnew 2013). Moreover, the majority of tools (ten of sixteen) can conduct M&V using either monthly or interval data.

In terms of the mathematical method underlying the M&V algorithms, seven of the tools use linear and piecewise linear models, while three use machine learning and one uses a non-linear model type. Two use calibrated simulation modeling, and five of the technologies employ a hybrid combination of different modeling types.

The time period that defines the baseline period and the independent variables used in the baseline model are user-adjustable in the majority of cases. In six of the tools investigated, the underlying form of the model is adjustable; however, this is mostly true of tools provided by vendors that that offer strong analyst support in creating the models used in the automated savings estimates. This raises an important nuance regarding the extent of automation in today's technologies. Six of the vendors surveyed regularly involve a staff analyst to assess model fitness and suitability, either in partnership with the end user, or as a routine service performed through the "back end" of the tool. In one case, the staff analyst fits the model to the data outside of the analytics tool, and the fit model is then programmed into the tool for ongoing use and automated savings estimation.

Ten of 16 technologies provide some means of support to track the presence of non-routine events, to support adjustments to the automated savings estimates. While the methods used are diverse, they span text-based annotation, creation of virtual meters and re-baselining, direct input of quantitative adjustments, and version controlled simulation models representing different building and operational characteristics. In one case, non-routine events are not explicitly addressed at the building level, but rather accounted for through aggregation used in a two-stage analysis using comparison groups.

3.3 M&V transparency and use

One way that transparency in modeling and savings estimation is addressed is through the presentation of model fitness metrics and quantification of savings uncertainty due to model error. Fifteen of the technologies surveyed reported that they calculate model fitness metrics, with 10 displaying these directly to the end user, and 6 choosing to keep fitness metrics accessible through the "back end" for use by an analyst. R^2, CV(RMSE), and NMBE are heavily relied upon in standard industry M&V references such as the IPMVP and ASHRAE Guideline 14; their frequency in the tools surveyed is shown in Figure 3, as compared to other complementary fitness metrics.

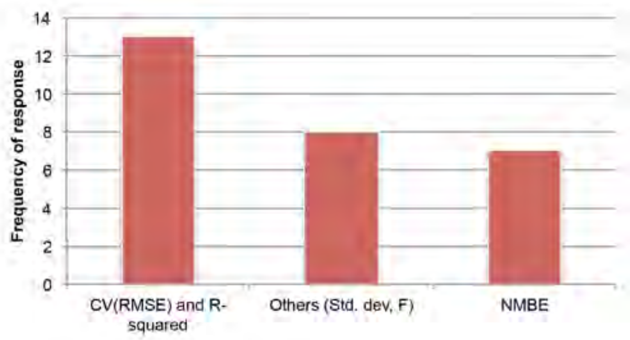

Fig 3. Output metrics from tools

While model fitness metrics are used to quantify model error, it is possible to estimate the uncertainty of the savings estimate that is *due* to model error. For example, the ASHRAE Guideline 14 formulation to estimate the uncertainty of the savings result is a function of CV (RMSE) or mean squared error (MSE), the magnitude of observed savings, the desired confidence level, and the number of data points in the baseline and performance periods. Half of the tools surveyed calculate savings uncertainty; those that do not offer uncertainty analysis as an out-of-the-box feature often report a willingness to do so upon customer request, noting that this is not yet a high-demand front-end capability.

In addition to model fitness and uncertainty of the savings result, transparency can be conferred through a willingness to disclose the mathematical form of the underlying model and savings estimation methodology (as noted in Section 2.1, this is distinguished from open code that can be fully inspected). Half of the tool providers surveyed have either published the form of their models, present it in reports, or plan to document their methods for the public in the near future. The remainder report that they either have not yet considered the degree of transparency that they are comfortable with or prefer to keep their methods proprietary.

Tools that offer M&V 2.0 capability can fall on a spectrum from proprietary to open documentation of methods to open code that can be fully inspected. The degree and precise form of transparency and standardization that the industry will ultimately require of M&V 2.0 tools is an open issue and an ongoing topic of discussion among stakeholder groups. Of the surveyed technologies, discussion with providers revealed that there is a roughly even split between those that are being used (in limited and early instances) as the basis of a savings claim, those that are being used in pilot assessments or for program support, and those that are not currently used in utility program delivery.

4. M&V 2.0 Tool Testing and Standardization

There is growing industry interest in technology performance testing procedures that can be used to verify that M&V 2.0 tools or methods are accurate and that their outputs are reliable. Accuracy and tool validity are common concerns across the wide diversity of M&V 2.0 stakeholders, which include: utility program administrators, implementers, evaluators, and regulators; energy services companies (ESCOs), facility owners, and grid planners. While these stakeholders have different requirements, the industry is consistently asking for increased rigor, transparency, and consistency in how savings are determined.

Researchers have developed, applied, and published a test procedure to determine the overall predictive accuracy of M&V 2.0 approaches for commercial buildings that are based on IPMVP Option C or Option B (Granderson 2014, 2015, 2016). This procedure is based on large test data sets of meter data and statistical cross-validation, and provides the ability to evaluate and compare and contrast both open and proprietary M&V 2.0 tools. There is not yet industry consensus as to whether performance-based testing alone will be sufficient to validate a given tool, or whether full transparency of algorithms and code will be required.

An active discussion in the M&V community related to tool testing is the role of standardization of process and methods. The term *standardization* can be understood in different ways. In the context of M&V 2.0, it may encompass formal standards and protocols that relate to technical methods of calculation, methods of testing and verification, or practitioner process for application. There may also be de-facto, informal standards that are adopted as typical best practice within the industry, thereby imparting uniformity in practice. Three examples of industry standardization efforts described in Franconi (2017a) include the Uniform Methods Project (U.S. DOE 2017), the CalTRACK initiative (CalTRACK 2017), and the Air Conditioning Contractors of America and Building Performance Institute's "Standard for Quantifying Energy Efficiency Savings in Residential Buildings."

Once the industry has standardized methods of determining savings and has tests to benchmark and quantify the accuracy and compliance of tools implementing those methods, practitioners will need guidance as to how M&V 2.0 tools can be integrated into their professional workflows. Given the need to ensure high accuracy in the savings result, practitioner workflows must be developed to address issues such as: how to determine which buildings or programs are well suited to M&V 2.0 tools, how to apply analytics to flag the potential need for non-routine adjustments, what data will support more consistency and rigor in quantifying adjustments, how and where to cost-effectively integrate additional data from a building automation system, and whether reporting savings uncertainty due to the error in the baseline model will serve as a useful quantitative indication of the quality of savings result.

5. Industry Exploration and Application of M&V 2.0

In recognition of its potential benefits, the industry has begun early explorations and trial or pilot applications; a cross section of some of these activities is presented in the following. While not an attempt to comprehensively overview the industry's work, this summary provides an illustrative characterization of the state of the industry today.

5.1 State and Regional Activities

The Northeast Energy Efficiency Partnerships' (NEEP's) Evaluation, Measurement, and Verification (EM&V) Forum has initiated a multi-year dialogue with its members on the opportunities and limitations of M&V 2.0 in the context of the Northeast regulatory and program delivery and evaluation context. In December 2015 they commissioned and published a white paper describing M&V 2.0, its relationship to current EM&V practice, and potential ways in which practice is or may evolve in the future (DNV-GL 2015). That work was followed by a December 2016 industry brief that provided an overview of selected M&V 2.0 vendors and associated case studies of technology testing an application (NEEP 2016). NEEP is currently working with the Connecticut Department of Energy and Environmental Protection (DEEP), Eversource, UI, and Lawrence Berkeley National Laboratory (LBNL) to pilot the use of commercial and residential M&V 2.0 tools to more comprehensively test the value proposition and determine which of the potential benefits prove out when field tested side by side with traditional approaches in live projects in the field.

In California, Senate Bill (SB) 350 and Assembly Bill (AB) 802 establish aggressive goals to increase building energy efficiency, and permit tracking and incentivizing savings through meter-based and pay-for-performance approaches. The California Public Utilities Commission's (CPUC's) Energy Division is working to provide guidance to investor-owned utilities developing M&V plans for programs that will use whole-building Option C savings estimation; this guidance may ultimately be incorporated into the California Evaluation Framework. Although not limited to or explicitly focused on M&V 2.0, the concepts surrounding rigor and accuracy that are entailed are also relevant to the application of M&V 2.0 tools. The CPUC is exploring a vision of embedded M&V, through which M&V can be built into program design, ultimately ensuring more continuity between the savings methods used in planning, implementation, and evaluation.

Bonneville Power Administration (BPA) is active in the delivery of whole-building programs, the use of whole-building measurement and verification, and exploration of the ways in which emerging software-based approaches could advance the efficacy of current approaches. The Industrial Strategic Energy Management (SEM) program has successfully been using whole-building M&V, and a Commercial SEM pilot will be launched in the later part of 2017. BPA has been including uncertainty analysis in meter-based savings estimation, and also investigating how to address non-routine adjustments and separate out the effects from concurrent program measures that may be implemented in a single facility. Through its Technology Innovation (TI) program, BPA is sponsoring ongoing work in M&V 2.0 tools and practitioner processes, with the expectation of including them in commercial SEM pilots and ensuring consistency in methods used by its customer utilities. The BPA TI work is also supporting a regional dialogue to determine acceptance criteria for more scaled adoption of meter-based savings estimation and automation.

The Virginia Division of Public Utility Regulation is investigating standardization of EM&V across the state, and the Virginia Energy Efficiency Council (VAEEC)—as well as the Virginia Department of Mines, Minerals and Energy—have encouraged the state to support piloting of EM&V 2.0 methods (which are founded upon M&V 2.0 software tools). In October 2016, the VAEEC hosted a statewide workshop on EM&V 2.0, and the State Corporation Commission has since determined that it will move forward with EM&V protocols; those protocols are expected to include procedures founded upon whole-building savings estimation, yet it remains to be seen the extent to which M&V 2.0 will explicitly be of focus.

In late 2016, the New York Public Service Commission published guidance encouraging program administrators and evaluators to use "Advanced M&V" (M&V 2.0) techniques when appropriate (NY State 2017). New York has defined continuous data analysis and ongoing feedback for process improvement as key criterion for advanced (automated) M&V, in their jurisdiction. In cases where the data have been verified to ensure independence reliability and lack of bias, the tools may be used for interim impact results. Following the issuance of this guidance, affected utilities are exploring how they might respond.

The Illinois Commerce Commission held a policy session in February 2017, "*Innovation and Emerging Technologies for the Evaluation, Measurement, and Verification of Energy Efficiency Programs*" [ICC 2017]. The session included regulators, staff, utilities, and other state efficiency stakeholders, and a discussion of current EM&V practice, benefits, drawbacks, and potential mechanisms for improvement that might be offered via 2.0 techniques. It is not yet clear what the next steps from this discussion will be, but there is clear interest in understanding the potential benefits and limitations of M&V 2.0 for Illinois.

The New Mexico Public Regulation Commission recently released a statewide request for proposals (RFP) that included an optional scope for M&V 2.0 (decision pending), and the State of Missouri is working on a report that describes how M&V 2.0 can support deemed savings updates for their statewide Technical Reference Manual (TRM) (Missouri Department of Economic Development 2017). Finally, the Maryland Commission (Maryland PSC 2016) has released an order that calls for use of "tracking actual energy savings…in real time…" for home performance programs.

5.2 Utility and Implementation Activities

For several years the Consortium for Energy Efficiency's (CEE's) Whole Building Committee has focused on supporting members to understand the opportunities for whole-building focused program delivery, including design considerations, whole-building-level M&V, and the role of M&V 2.0 in implementation and evaluation. The Savings Estimation Subcommittee developed a for-members internal resource to better help program administrators understand whole-building program design scenarios, as well as aspects of statistical metrics to evaluate whole-building baseline fitness and uncertainty. Over the coming quarters CEE is planning to work with their members to inventory their current whole-building activities and identify needs and knowledge gaps. Program design, portfolio diversification and expansion opportunities, and associated M&V requirements are expected to be key focus areas.

Pacific Gas and Electric (PG&E) is currently evaluating its Commercial Whole Building demonstration. The demonstration is designed to achieve 15 percent-plus energy savings in 12 commercial premises that have installed multiple energy efficiency measures and are now past a one-year performance period. Applying a preponderance of evidence approach, the evaluation will make recommendations for best practices for a scaled program. PG&E also plans to deliver a residential pay-for-performance program that has a stated goal of establishing a scalable model for a residential "whole house" program that incentivizes market actors. "Payable savings" will be determined using the savings estimation protocol based on daily meter consumption data that is currently being developed by the CalTRACK working group.

Seattle City Light is partnering with BPA and LBNL to pilot M&V 2.0 approaches in its commercial whole-building pay-for-performance projects, and potentially in future commercial Strategic Energy Management pilot sites. The pilot will focus on the development and application of: replicable approaches to screen buildings for M&V 2.0 suitability; automated calculation of savings and uncertainty due to model error at the site and portfolio level; automated flagging of the potential presence for non-routine events; and practitioner workflows to combine professional expertise with automated tools, to ensure a quality outcome. In this work, software tools for non-routine event identification, screening, and savings quantification will be provided to the industry in an open source format to facilitate their integration into commercial M&V 2.0 tool offerings.

Puget Sound Energy will be investigating the use of M&V 2.0 to support evaluation, in two activities slated for initiation in 2017. In the first, a sample of the largest projects in a commercial custom/retro-commissioning program will be selected for tracking as the projects unfold. The objective will be to proactively catch underperforming projects that, by virtue of their size, have the potential to significantly impact program realization rates. In the second, an RFP will be put out to bid to contract M&V 2.0 services to support contractor performance tracking for the delivery of commercial and residential rebate programs.

EnergySavvy is increasingly involved in efforts to implement M&V 2.0 in collaboration with the utility program sector. With Arizona Public Service, M&V 2.0 was implemented to conduct contractor quality assurance and track and manage contractor performance (EnergySavvy 2106a). In collaboration with PSEG Long Island, M&V 2.0 was demonstrated to correlate with traditional evaluation results within a 6 percent margin of error, confirming the ability to provide "early indicative insights into program performance" (EnergySavvy 2016b). DTE Energy is piloting M&V 2.0 with EnergySavvy as described in Kupser 2016. Additionally, a utility client is working with EnergySavvy on a team alongside a traditional EM&V firm, and the automated M&V 2.0 software is performing the billing analysis of record, while the traditional evaluation firm is performing any necessary supplemental work and reporting. The team expects to file an EM&V report in the second half of 2017.

Efficiency Vermont has been developing an M&V 2.0 platform for internal use, and is interested in the value of meter-based feedback as a way to improve customer experience and increase savings through customer feedback during program participation. They are piloting a small business program called Continuous Energy Improvement Lite that is focused on behavior and related changes that can be communicated via web portal and complemented by more intensive online learning delivered to a smaller group within the cohort. Leveraging M&V 2.0 application concepts being trialed in the industry, Efficiency Vermont conducted an initial screening of potential participants using a weather-normalized baseline model and analysis of baseload consumption using interval meter data. Anticipating the use of M&V 2.0 savings estimation, customers with facilities that exhibited poor model fit were screened out.

In a study that is expected be made public later in calendar year 2017, DNV-GL is conducting a pilot with a Northwest utility to develop a triage methodology for calculating savings from whole-premise consumption. The method establishes criteria for classifying premises as: (a) stable enough that no non-routine adjustment is needed; (b) requiring non-routine adjustments that can be determined from simple supplemental information; or (c) requiring customized analysis. The classification criteria will include consumption model statistical diagnostics, as well as information on changes at the premise, and the study will consider both baseline and performance period analyses.

Researchers at the University of Chicago Urban Center for Computation and Data have recently kicked off a study with a large utility and small-to-medium business (SMB) project implementer to assess the potential for increased data granularity to reduce M&V costs in SMB projects. The investigation explores the extent to which increased data granularity such as that used in M&V 2.0 can improve savings estimation in an SMB setting. The University of Chicago is also involved in a collaboration with BayREN, San Francisco Environment, National Renewable Energy Laboratory, and LBNL to link an Open Studio-based retrofit analysis application, the Standard Energy Efficiency Database (SEED), and the Open EE Meter, to provide an SMB open-source tool suite that establishes a complete feedback loop between benchmarking, simulation, investment, and M&V 2.0.

The IPMVP M&V 2.0 subcommittee plans two complete efforts in the short term: (1) post materials related to M&V 2.0 on the Efficiency Valuation Organization (EVO) website, and (2) post a two- to three-page M&V 2.0 overview document. It also aims to tackle key topics one by one and slowly assemble M&V 2.0 application guidelines (with a gross savings focus).

The Rocky Mountain Institute is moving forward with a New York City pilot project to compare three software-as-a-service tools tested in parallel in a large office building to identify energy efficiency opportunities, detect changes in operation, and perform ongoing commissioning and M&V 2.0. This work will highlight the multi-faceted capabilities of tools that offer both M&V 2.0 and continuous operational analytics.

6. Discussion and Conclusions

M&V 2.0 is fundamentally a data- and computing-enhanced approach to deliver meter-based savings estimation, using methods that align with the International Performance Measurement and Verification Protocol. It carries a multi-dimensional value proposition, with different prospective benefits for M&V stakeholders. Commercially available M&V 2.0 technology is diverse, with a number of offerings available for the commercial, industrial, and residential building sectors. The state of the technology assessment presented in this work reflects that diversity, and revealed several key findings.

The commercial building sector is still the most widely served, and is targeted in advanced M&V 2.0 tools more often than the residential and industrial sectors. When compared to prior published findings (Kramer 2013) several changes in technology capabilities can be identified. Many tools providers now identify M&V as a core element of their principal design intent, and there has been an increase in the number of offerings that accommodate both monthly and interval data. There also may be an increase in the number of solutions that offer isolation-based Option B savings analysis as well as whole-building level Option C analyses (however it may be that approaches other than whole-building were either not addressed in this prior work, or were intentionally not included). There is also indication that far more of today's technologies are offering estimates of savings uncertainty due to model error and that R^2 and CV(RMSE) are emerging as common metrics of model fitness. Although not explicitly covered in prior published work, discussion with the vendors suggested that developers are beginning to explore more advanced modeling techniques, including non-linear and machine learning approaches.

There is about a 50 percent overlap of the technologies surveyed in prior work with those surveyed in this work; some of this is attributable to the screening used in the prior study; however, there have been several new market entrants, as well as some notable market exits (excluding instances of known acquisitions).

It is worth noting several important ways in which the market has not changed. There remain a relatively small number of tools that offer savings estimation based on Option D calibrated simulation modeling. This is related to the fact that the majority of the technologies surveyed are used for meter data analysis and visualization for operational efficiency—it is still the case that data-driven techniques dominate the tools used for continuous operational analyses, while simulation-based methods are primarily used in design and retrofit analysis. Moreover, there is still a need for comprehensive solutions to identify, verify, and address non-routine adjustments. While the diversity of user support that tools offer may have grown, systematic approaches are still an outstanding technology need. Interestingly, although transparency is still a common part of industry dialogue, about half of vendors surveyed in prior work and today report a strong willingness to disclose model equations and specifications.

The level of current national activity in M&V 2.0 and associated whole-building, operational, behavioral, and maintenance programs indicates a high level of interest. However, it is important to recognize that the industry is still grappling with several issues related to M&V 2.0's usefulness and ultimate value. The authors have recently convened a national M&V 2.0 stakeholder group comprising a cross section of subject matter experts from the program administration, evaluation, implementation, and regulatory communities, as well as from the M&V 2.0 vendor community. The group was asked to identify the top three critical needs for industry with respect to M&V 2.0. Resonating with recent literature (Franconi 2017a), five topics were ranked most highly:

1. Pilots to demonstrate the practical viability of M&V 2.0
2. Standard requirements for accuracy and reporting of M&V 2.0 results
3. Methods to handle non-routine events and adjustments (critical to ensuring that meter-based savings are representative of savings due to implemented efficiency measures and not other unrelated changes in the building)
4. Standard M&V 2.0 software testing procedures
5. Expansion of the methods in today's tools to handle baselines other than existing conditions

Needs that were ranked less highly included:

- M&V 2.0 application guidance and reference materials
- Improvement of M&V 2.0 software tools
- Improved understanding of the intersection between M&V 2.0 from the implementation perspective and EM&V 2.0 from the evaluation perspective
- Application of M&V 2.0 to quantify peak demand reduction
- Concepts associated with uncertainty, confidence, and reliability of results

Accordingly, future work being undertaken by the authors and their partners includes pilots, articulation of accuracy and reporting requirements, and techniques to address non-routine events.

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