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The state of advanced measurement and verification technology and industry application

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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 its application. Sixteen commercially available technologies were characterized and combined with a national review of their use.

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-min interval data, increased volume, or increased resolution in moving from whole-building-level 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 et al., 2013), and afford significant operational savings with short payback (Granderson and Lin, 2016). 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).

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 underperforming 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 policymakers 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,

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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 et al., 2017), as well as the development of new data analysis and modeling techniques (Ahmad et al., 2017; Araya et al., 2017; Burkhart et al., 2014; Heo and Zavala, 2012). Testing and validation of advanced M & V has been highlighted in case studies and technical articles (Franconi and Jump, 2017; Granderson and Price, 2014; Granderson et al., 2015, 2016; Kupser et al., 2016). And finally, technology attributes have also been documented over a period of years (Crowe et al., 2014; Kramer et al., 2013; Kupser et al., 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 article 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 three to five 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 et al., 2014; Franconi et al., 2017; Kramer et al., 2013; Kupser et al., 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 et al., 2014; Kramer et al., 2013; Kupser et al., 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 16 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.

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 (Fig. 1).