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Lawrence Berkeley National Laboratory

Building analytics and monitoring-based commissioning: industry practice, costs, and savings

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Building Analytics and Monitoring-based Commissioning: Industry Practice, Costs, and Savings

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Abstract

As building energy and system-level monitoring becomes more common, facilities teams are faced with an overwhelming amount of data. This data does not typically lead to insights, corrective actions, and energy savings unless it is stored, organized, analyzed, and prioritized in automated ways. The Smart Energy Analytics Campaign is a public-private sector partnership program focused on supporting commercially available energy management and information systems (EMIS) technology use and monitoring-based commissioning (MBCx) practices. MBCx is an ongoing commissioning process with focus on analyzing large amounts of data on a continuous basis. EMIS tools are used in the MBCx process to organize, present, visualize, and analyze the data.

With Campaign data from over 400 million square feet (sq ft) of installed space, this paper presents the results achieved by owners that are implementing EMIS, along with associated technology costs. The study's EMIS users that reported savings achieved median cost savings of $0.19/sq ft and 7 percent annually, with savings shown to increase over time. For 35 portfolio owners, median base cost to install an EMIS was $0.03/sq ft, with an annual recurring software cost of $0.02/sq ft and estimated annual labor cost of $0.03/sq ft. Two types of EMIS systems – energy information systems and fault detection and diagnostic systems - are defined in the body of the paper. Of the two, we find that fault detection and diagnostic systems have both higher savings and higher costs. The paper offers a characterization of EMIS products, MBCx services, and trends in the industry.

1. Introduction and Background

The cornerstone of successful building data analytics is the ability to extract accurate and actionable insights from large amounts of data. Modern building automation systems (BAS) monitor hundreds of points per building, and an owner may have a portfolio generating many thousands of data points. The BAS can provide alarms for points out of range, but the analytical capabilities fall well short of helping achieve an optimized system. Further, common analysis tools for energy meter data tend to manage the monthly bills but do not support analysis of hourly interval data. Energy management and information systems (EMIS) are software that provide the needed analytical horsepower to building owners as they work to find meaning from data.

1.1 EMIS and Commissioning Defined

EMIS are the broad and rapidly evolving family of tools that monitor, analyze, and control building energy use and system performance. The data generated from EMIS tools enables building owners to operate their buildings more efficiently and with improved occupant comfort by providing visibility into and analysis of the energy consumed by lighting, space conditioning and ventilation, and other end uses. EMIS tools are used in the monitoring-based commissioning (MBCx) process to organize, present, visualize, and analyze the data.

While there is no universal consensus definition of EMIS, a broad categorization framework has been developed (Granderson et al. 2015) and has gained some traction in the industry. Figure 1 describes this framework that classifies EMIS into two technology categories: those with a primary focus on meter-level analytics and those with a primary focus on system-level analytics. An EMIS product may have attributes in multiple categories or just in one, as might be the case for a conventional building automation system (BAS).

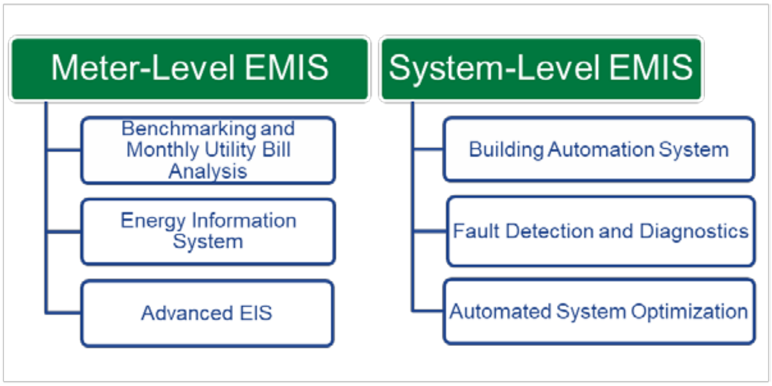

Figure 1: Energy Management and Information System (EMIS) Framework

While monthly bill management software and BAS are the most common types of EMIS, this work focuses on the more advanced EMIS including fault detection and diagnostic systems (FDD), energy information systems (EIS), and automated system optimization (ASO), technologies for which costs and benefits are less understood and where adoption is far lower. Buildings that do not have FDD, EIS, or ASO are not included in this research.

Descriptions of the EMIS technologies that are the focus of this work are as follows:

- **Energy information system (EIS) / Advanced EIS:** the software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data. EIS are a subset of EMIS that are focused on meter-level monitoring (hourly or more frequent, at a whole building or submeter level). These meter data are not yet commonly integrated with BAS. Advanced EIS automate the opportunity analysis and typically include predictive energy models that use interval meter data.
- **Fault detection and diagnostic (FDD) system:** software that automates the process of detecting faults and suboptimal performance of building systems and helps to diagnose their potential causes. FDD systems are a subset of EMIS that focus on system-level monitoring (using BAS data). An FDD system involves more nuanced analysis than BAS alarms. Alarms typically detect threshold-based deviations from an expected value based on real-time conditions. FDD incorporates more sophisticated logic that interrelates multiple data streams and performs rule-based or model-based diagnostics to isolate root causes. FDD tools are commonly implemented as a separate software application that integrates data from the BAS. FDD may provide a report of the duration and frequency of faults, cost and/or energy impacts, and relative priority levels. Katipamula and Brambley (2005) developed a classification scheme for FDD methods covering the range of techniques, including physical models, rule-based models, and artificial neural networks.
- **Automated system optimization (ASO):** software that continuously analyzes and modifies BAS control settings to optimize heating, ventilation, and air conditioning (HVAC) system energy usage while maintaining occupant comfort. These tools read data from the BAS and automatically send optimal setpoints back to the BAS to adjust the control parameters based on data such as submetered energy use and energy price signal. Supervisory control via two-way communication with the BAS distinguishes ASO solutions from FDD.

Previous research includes a complete description of EMIS components and details how organizations can plan and implement EMIS for successful use (Granderson et al. 2015). Complementing this work, various case studies document the benefits and lessons learned for specific EMIS installations; for example, Fernandes et al. (2018) and Henderson and Waltner (2013).

While EMIS are powerful tools, any tool needs a process that utilizes it to have impact. Commissioning is a process that “focuses on verifying and documenting that all of the commissioned systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner’s Project Requirements” (ASHRAE 2013), and this process can be augmented using EMIS. There are many types of commissioning, including:

retrocommissioning, a periodic process to improve how existing building and equipment systems function together (Stum and Bjornskov 2017); monitoring-based commissioning (MBCx), an ongoing commissioning process with focus on monitoring and analyzing large amounts of data on a continuous basis; and existing building commissioning (EBCx), an umbrella term that includes both MBCx and retrocommissioning (Building Commissioning Association 2018). EMIS are an integral part of streamlining MBCx analyses and automating the MBCx process.

1.2 EMIS Technology Benefits

EMIS are most often implemented as a part of an overall energy management approach that includes retrofits and commissioning. Thus, the benefits of using EMIS are difficult to isolate from other actions. In one EIS-focused study of 28 buildings and 9 portfolios across the U.S., energy savings ranged from -3 percent to 47 percent, with a median of 17 percent for individual buildings, and from 0 to 33 percent with a median of 8 percent for portfolios (Granderson and Lin 2016). Participants reported that this performance would not have been possible without the EIS. A wide range of costs were also found, with total costs of EIS software ranging over two to three orders of magnitude. Large cost ranges are driven in part by the size of the implementation (costs decreased significantly as the number of points exceeded 300), differences in pricing models, and lack of market maturity.

A recent study on FDD for commercial buildings provides a thorough characterization of functionality and application for 14 FDD technologies (Granderson et al. 2017), although the study scope did not include quantification of costs or benefits. Based on an analysis of the most common faults in building systems, studies estimate that the energy savings achievable from addressing these faults ranges from 5 to 30 percent whole building savings (Fernandez et. al 2017; Roth et. al 2005).

1.3 Smart Energy Analytics Campaign

In 2016 a research and industry partnership was formed to gather market information on building analytics use, practice, costs, and benefits. The *Smart Energy Analytics Campaign* (Smart Energy Analytics Campaign 2018) targets the use of a wide variety of commercially available EMIS technologies. This program offers expert technical support to commercial building owners in implementing analytics through EIS/advanced EIS, FDD, and/or ASO, and the program recognizes owners with exemplary deployments.

As a part of the program, participants are offered technical assistance and engagement with a peer network. Participants share data about their progress that is analyzed by the program annually to report the latest in EMIS savings, costs, and trends in implementation. This paper expands and builds upon previously published research based on an earlier version of the dataset (Kramer et al. 2018). Seventy-three commercial organizations across the United States contributed data to inform the research presented in this paper. These participants represent over 400 million square feet (sq ft) of gross floor area and 5,200 buildings, making this the most comprehensive dataset available on building analytics installation and use.

2. Methodology

The findings in this paper are based on data collected from owners with advanced EMIS, including EIS, FDD, and/or ASO. As stated previously, buildings solely with BAS or monthly utility bill analysis are not included in the analysis. Almost all buildings had a BAS in place, however BAS costs are not counted as a part of the EMIS installation. The study data originates from two main sources:

- **Survey data:** Updated annually, quantitative data includes floor area with EMIS, annual energy use, and EMIS costs. Participants report qualitative information such as the type of EMIS installed, how the EMIS has been used, and the most frequently implemented improvements in which the EMIS was utilized.
- **Ongoing interviews:** Participants are interviewed to better understand their current EMIS and MBCx implementation, then participate in activities such as individual and group technical support. The

information gained from these activities has been used to determine the barriers and enablers to successfully implementing EMIS.

Illustrated in Figure 2, participants in this research largely represent the office and higher education market sectors, with some participation also from healthcare and government laboratories. The most common portfolio size is between 1 million and 5 million sq ft.

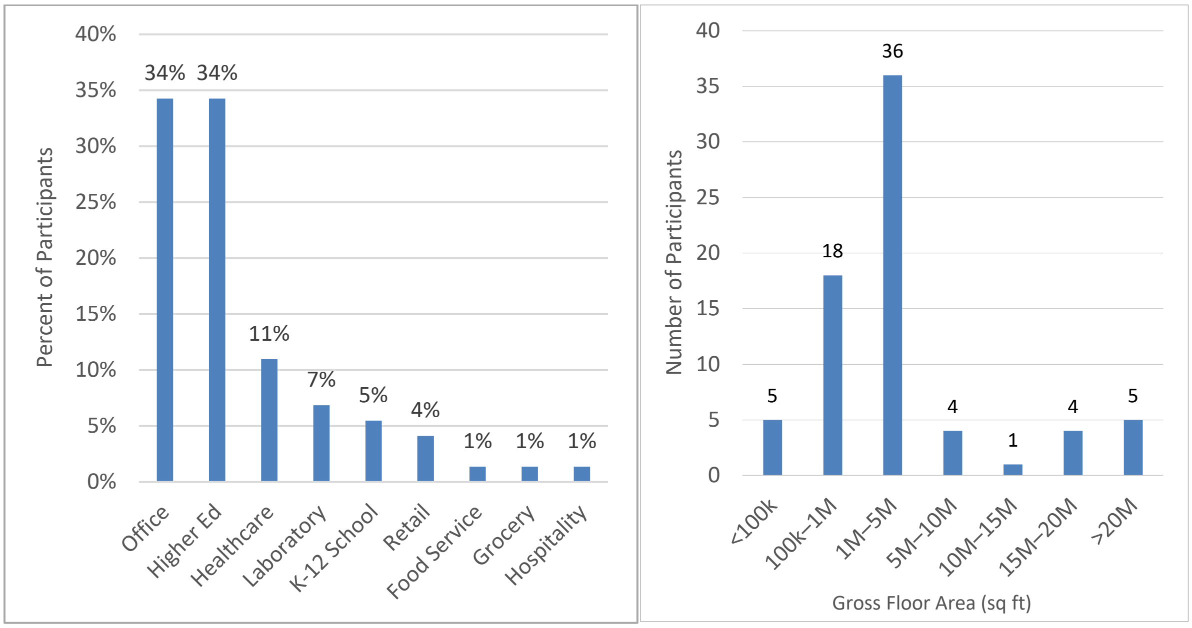

Figure 2: Composition of Participants: Primary Market Sector (left); Distribution of EMIS Installed by Participants (right) (n = 73)

To understand energy and cost savings benefits achieved by owners using EMIS technologies, participants are asked to provide annual energy consumption before and after EMIS implementation. These energy savings achievements are attributable to several energy efficiency activities including, but not limited to, use of the EMIS. Participants are asked to provide data only for buildings with active use of EMIS. Energy savings since EMIS installation were determined in four ways.

1. **Interval data analysis:** Pre-EMIS (baseline year) interval data were used to develop a model of building energy use. Energy use is projected using the baseline model and compared to actual energy use during the period after installing the EMIS. This method utilizes the International Performance Measurement and Verification Protocol (IPMVP) Option C methodology.
2. **Monthly bill analysis:** Pre-EMIS (baseline year) energy use was compared to the most recent full year of energy use. In some cases, participants normalized for weather using the ENERGY STAR Portfolio Manager.
3. **Engineering calculations:** This system analysis approach for estimating energy savings may use BAS trends or short-term measurements as baseline data. Spreadsheet calculations are based on engineering equations that often utilize temperature or load-based bin analysis.
4. **Building energy simulation:** Modeling whole facility energy use using simulation software such as eQUEST, EnergyPlus, Trane TRACE, or Carrier HAP.

Cost savings were calculated using the national average fuel prices to the commercial sector for electricity (US EIA 2018) and natural gas (US EIA 2019). Since whole building energy use was often provided by owners as a combined fuels aggregate, 65 percent of energy consumption was estimated as electric and 35 percent natural gas based on national average commercial building energy consumption breakdown (US EIA 2016).

Costs to implement an EMIS and perform MBCx were gathered from participants in the following categories:

- **Base cost:** Cost for EMIS software installation and configuration, including EMIS vendor and service provider costs. The base cost does not include additional costs such as the cost of energy metering hardware and communications, adding points to the BAS for EMIS monitoring purposes, retrocommissioning services, or retrofits.
- **Recurring EMIS cost:** Annual recurring costs were broken out into two categories: software cost and service provider cost. The annual software cost includes the annual cost for a software license or software-as-a-service fees. The ongoing MBCx service provider cost is the average annual cost to MBCx service providers or other consultants for support in analyzing and implementing EMIS findings.
- **In-house labor cost:** Labor costs were broken out into two categories: EMIS installation/configuration and ongoing EMIS use. Cost was determined using estimated hours for the team and $125/hour as an average labor rate. The EMIS installation and configuration cost is the approximate total labor hours spent by in-house staff to support installation and configuration of the EMIS. The ongoing EMIS use cost is the approximate time spent by in-house staff reviewing EMIS reports, identifying opportunities for improvement, and implementing measures. Reported in average hours spent per month.

Cost data were provided by participants in dollars for base cost and annual software cost, and then normalized by floor area.

3. Findings

Findings cover three areas: data and tools, the energy management process, and costs and benefits.

3.1 Data and Tools

As seen in Figure 3, 30 percent of participants are using a combination of EIS and FDD technologies; 29 percent are using EIS only, and 19 percent are using FDD only. ASO use is rare, with only 1 participant using it. Twenty percent of participants are in the procurement or installation process. Of those, there is an even split between FDD, EIS, and both EIS and FDD. More than half of FDD users also analyze whole building meter data, extending beyond system level fault diagnostics. Over 40 percent of participants have submeter data.

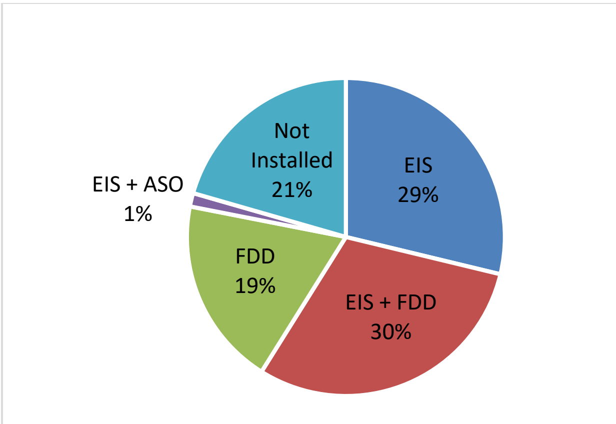

Figure 3: Type of EMIS Installed by Participants (n = 73)

Most participants needed less than six months to install and configure their EMIS. A few participants experienced significant challenges getting meters connected and properly communicating, with multiple years required to get all the issues resolved.

3.2 Energy Management Process

The use of data and software in combination with an overarching defined energy management process is critical in realizing the value of EMIS. Almost all participants have an energy management team mostly made up of facility engineers, technicians, and energy managers. The energy managers tend to lead the analysis process and are sometimes supported by a consultant or service contractor. Just over half of participants contracted with a service provider to support their MBCx process.

A portion of the participants implementing MBCx provided information on their scope of activities.

- **Common MBCx activities:** in-house review of EMIS analysis and reporting to identify issues, commissioning the EMIS to verify data accuracy and configuration, implementing a management process for correcting issues, and using the EMIS to document energy and/or cost savings.
- **Less common MBCx activities:** a program advocating that staff or occupants identify energy savings and an EMIS training program for in-house staff to maintain ongoing energy management processes.

An approximately even distribution of participants reviews their EMIS daily or weekly. FDD reports were reviewed most frequently at daily or weekly intervals, with some monthly analysis. EIS had an equal distribution of review across daily, weekly, monthly, and quarterly. While a daily or weekly review frequency is desirable to gain the greatest benefits from real-time analytics results, constraints on operations and maintenance (O&M) staff time may lead to monthly review, either in-house or through an MBCx service provider.

3.3 Costs and Benefits

This section reports on the results of data collection around motivation for EMIS, measures implemented using the EMIS, energy savings, and costs.

3.3.1 Benefits Motivating EMIS Implementation

Energy and cost savings are often a driving factor in the decision to implement an EMIS, as shown by the participant responses in Figure 4.

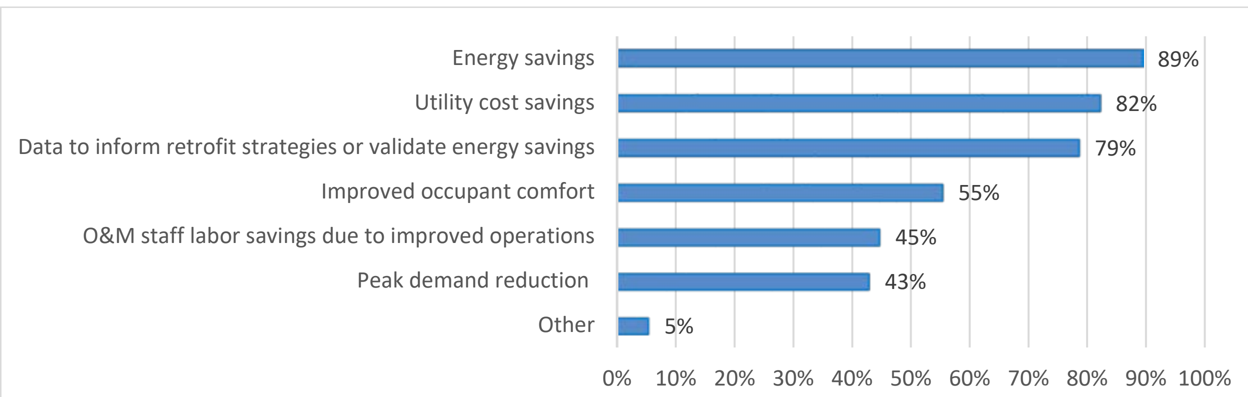

Figure 4: Frequency of Benefits of Implementing EMIS (Participants may select multiple benefits.)

Energy savings generally were validated by participants by exporting data and analyzing it outside the EMIS, with the EMIS supporting data acquisition and central storage. The wide range of benefits indicated points to multiple motivations to install an EMIS, and a value proposition from multiple perspectives: owners, energy/facility managers, and building operators.

3.3.2 Top Measures Implemented

Participants were asked to indicate up to 10 of the most frequently implemented measures identified with support from their EMIS from a list of 26 common operational improvements. The most common measures implemented are shown in Table 1; the top measures included improvements to HVAC scheduling, adjustment of HVAC setpoints, reduction of simultaneous heating and cooling, and improvements to airside economizer operation.

Table 1: Measures Implemented with EMIS Support (Respondents may indicate multiple measures; n = 56)

Category	Specific Measure	Percent of Participants Implementing the Measure
Scheduling Equipment Loads	Improve scheduling for HVAC & Refrigeration	71
	Improve scheduling for lighting	23
	Improve scheduling for plug loads	4
Economizer/Outside Air Loads	Improve economizer operation/use	46
	Reduce overventilation	45
Control Problems	Reduce simultaneous heating and cooling	48
	Tune control loops to avoid hunting	38
	Optimize equipment staging	38
	Zone rebalancing	14
Controls: Setpoint Changes	Adjustment of heating/cooling and occupied/unoccupied space temperature setpoints	59
	Reduction of terminal unit minimum airflow setpoint	36
	Duct static pressure setpoint change	27
	Hydronic differential pressure setpoint change	11
	Preheat temperature setpoint change	9
Controls: Reset Schedule Addition or Modification	Supply air temperature reset	41
	Duct static pressure reset	32
	Chilled water supply temperature reset	23
	Hot water supply temperature reset or hot water plant lockout	20
	Condenser water supply temperature reset	11
Equipment Improvements / Load Reduction	Add or optimize variable frequency drives (VFDs)	27
	Pump discharge throttled or overpumping and low delta	16
Occupant Behavior Modification	Routinely share energy information with occupants through EMIS	25
	Hold an energy savings challenge using EMIS data	20
Retrofits	Lighting upgrade or improve lighting controls	32
	High efficiency HVAC equipment: airside	20
	High efficiency HVAC equipment: waterside	16

These measures were implemented consistently across the major market sectors represented in the dataset (higher education, office, and laboratory). The higher education sector focused more than other sectors on occupant behavior through sharing energy information with staff and students, as well as by holding energy challenges on campus.

3.3.3 Energy Savings

Twenty-seven participants submitted energy data for all or a subset of their buildings (in total, 687 buildings with 94 million sq ft). The number of buildings reported by each participant ranged from 1 to 335. Two participants reported savings results determined from interval data analysis tools. Two participants estimated savings using engineering calculations. The energy savings from the other 23 participants were calculated by this paper's authors using monthly bill analysis.

Figure 5 shows the energy and cost savings results for each participant since the installation of their EMIS. The participant energy savings ranged from -6 to 28 percent, and the median was 7 percent. The median cost savings was $0.19/sq ft. In total, these 27 participants are saving 790 billion Btu/year and $18 million/year, comparing the most recent year for which data are available to the baseline year before the EMIS installation. These energy savings achievements are attributable to several energy efficiency activities including, but not limited to, use of the EMIS. Section 3.3.2 reports the top energy saving measures implemented in which the participants utilized the EMIS; measures beyond these improvements may also have been implemented.

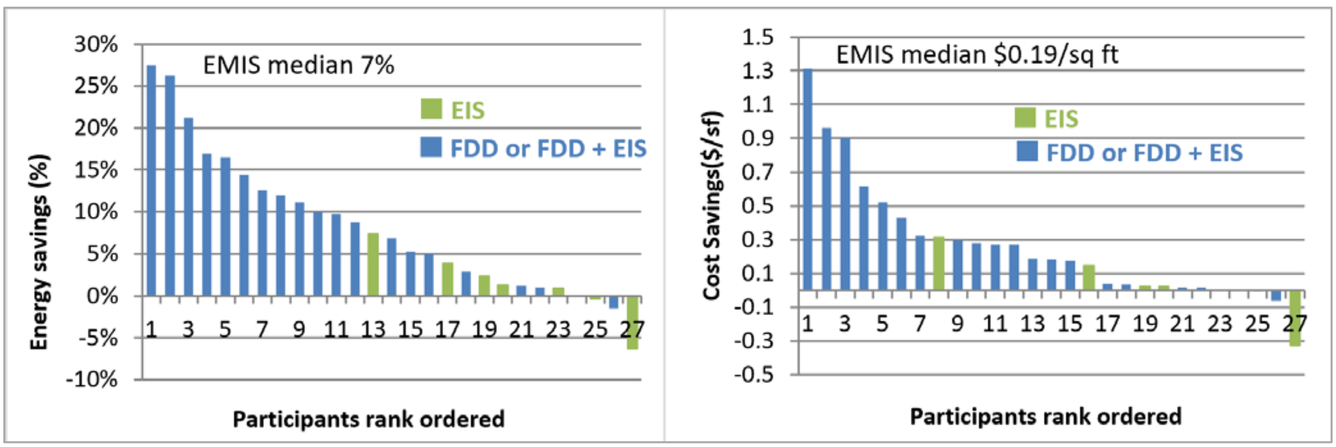

Figure 5: Participant Energy Savings (left) and Cost Savings (right) for Participants since EMIS Installation (n = 27)

In addition to annual savings, the savings for each year of EMIS implementation can be plotted, as in Figure 6. Here, each line represents a building, and the y-axis represents percent savings relative to the year before the EMIS installation; the "baseline year." The x-axis represents savings relative to the baseline year, for each year that the EMIS was in place. The red line indicates the median for the group of participants. Four participants had installed the EMIS for four years, 6 had installed it for three years, 10 had installed it for two years, and 17 had installed it for one year. This plot shows that for the four participants that had EMIS installed for four years, savings increased each year. Across all participants, the median savings since EMIS installation was 7 percent, or $0.19/sq ft.

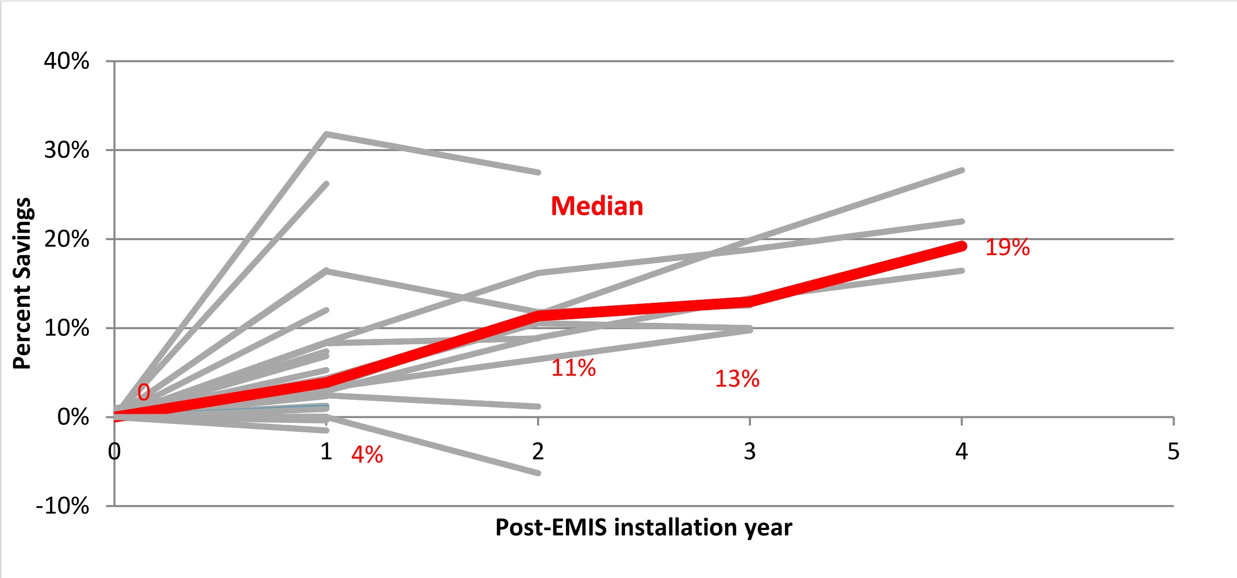

Figure 6: Percent Change in Participant Energy Use, Relative to the Year before EMIS Installation (Gray lines indicate savings for each of 27 participants; bold line is median savings for all participants)

Table 2 shows a breakout of savings by EMIS type, since the EMIS was installed (e.g., FDD had been installed for longer than EIS for 11 participants). In some cases, either the pre-EMIS baseline data was not available (so the earliest year of available data was used for the baseline), or the most recent year of energy data was not yet reported.

Table 2: Summary of Energy Savings for Participants with EMIS

EMIS Type	Median Energy Savings since EMIS Installation (%)	Range of Energy Savings (%)	Number of Years Energy Data Available since EMIS Installation
EIS (n = 7)	1	-6 to 7	1 year (n = 7)
EIS+FDD and FDD (n = 20)	10	-2 to 26	1 year (n = 9); 2–4 years (n = 11)
All EMIS (n = 27)	7	-6 to 26	1 year (n = 16); 2–4 years (n = 11)

3.3.4 Costs

The median costs from 35 participants with EIS, FDD, or both EIS and FDD are shown for each participant in Figures 7, 8, and 9, and summarized in Table 3. These costs do not include the cost of the BAS itself or the energy meters. A full description of costs included is in the methodology section. Most participants have large portfolios; therefore, the normalized costs reflect these economies of scale, with lower costs per square foot than would typically be found for smaller-scale implementations.

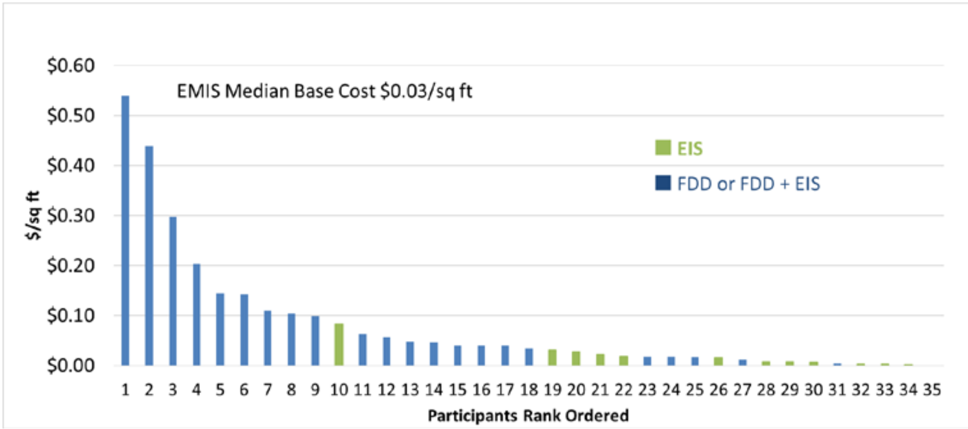

Figure 7: Base Cost by EMIS Type (n = 35)

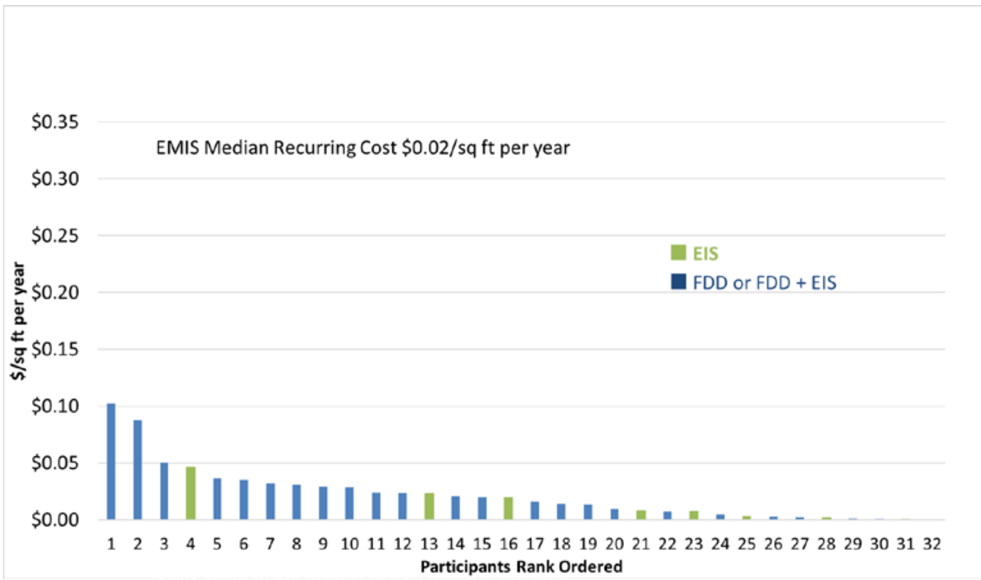

Figure 8: Recurring Software Cost by EMIS Type (n = 32)

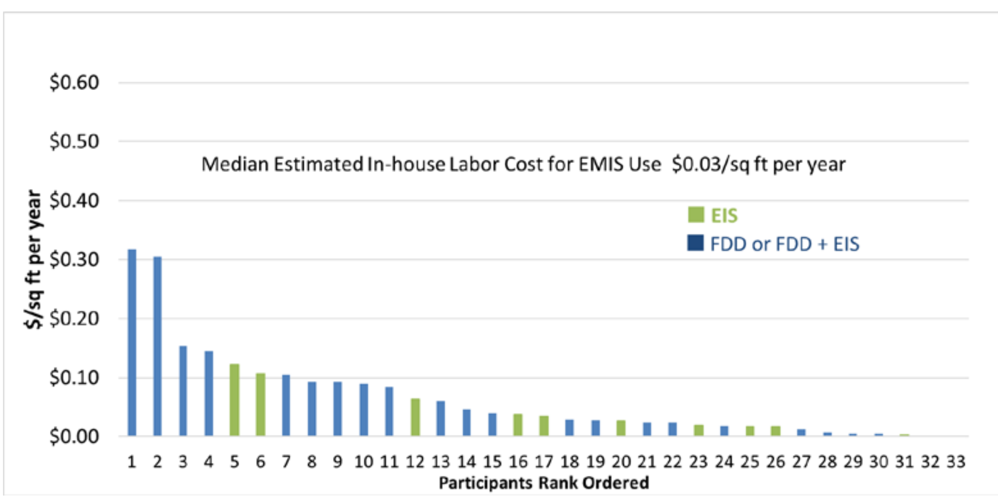

Figure 9: Estimated In-house Labor Cost by EMIS Type (n = 33)

Table 3: EMIS Cost Summary

Median Costs	Base Software and Install Cost($/sq ft)	Annual Software and MBCx cost ($/sq ft-year)	Estimated Annual In-house Labor Cost ($/sq ft-year)
EIS (n = 12)	0.01	0.01	0.03
EIS+FDD and FDD (n = 23)	0.05	0.02	0.05
All EMIS (n = 35)	0.03	0.02	0.03

4. Discussion

This section discusses the cost and benefit findings of the research and presents trends in EMIS product and services delivery. Using data gathered through Campaign interactions, enablers and barriers to implementation and industry needs are also summarized.

4.1 Costs and Benefits

Energy Savings

While a portion of the energy savings documented for participants may be due to changes in their buildings not related to the use of EMIS, almost all participants report a decrease in whole building energy use during the time EMIS has been implemented. FDD users achieved 10 percent median savings which is significantly higher than the 1 percent median savings for EIS users. The savings achieved by FDD users was within the expected range based on past research; however, the savings achieved by EIS users was lower than expected. With seven EIS users reporting first-year post-EMIS energy use, the median from EIS is only a preliminary finding, and is likely to increase as organizations report their energy data over a longer implementation period. A prior study (Granderson and Lin 2016) found 8 percent median savings for nine portfolios that implemented EIS, with seven of these EIS portfolios implementing EIS for at least three years (and five for 5 to 10 years).

Another study of MBCx projects in California found that energy cost savings were $0.25/sq ft-year, for a median simple payback time of 2.5 years (Mills and Mathew 2009). To date, our study has found that EIS are generally not being used to their full potential. Either participants are not reviewing the data frequently, or their EIS are not yet set up to meet their needs. Over time the EIS median savings from participants may increase as these participants engage more deeply with the analysis.

The Campaign reported 19 percent median savings after the fourth year of EMIS implementation, which points to the value of EMIS in supporting increased savings over time. Through continued participant engagement, the change in energy use relative to a pre-EMIS baseline will be tracked for another year, and these findings will be updated in subsequent publications. Over these longer time periods of EMIS implementation, it is likely that retrofits account for some of the energy savings in addition to the operational savings. EMIS are rarely if ever implemented as the sole efficiency strategy, making it difficult to definitively decouple the effect of the EMIS from other activities. To do so, a more resource intensive comparison group study design would be required.

Other Benefits

Although non-energy benefits are not the primary motivator for implementing EMIS, operational benefits play a key role in garnering O&M staff support for EMIS use. Analytics can identify issues before they grow into occupant complaints or equipment failures. For example, operators generally do not have time to perform preventative maintenance on all terminal units; operations are checked when there are comfort complaints. Using FDD, building operators can evaluate terminal unit performance cost-effectively and proactively at a broad scale in a fraction of the time it would take to check all the boxes. Cycling equipment is another common operational issue identified through EMIS; eliminating cycling improves equipment life.

Costs

With 23 owners reporting FDD (or EIS + FDD) costs, and 12 owners reporting EIS costs, we have been able to break out EIS and FDD costs from the overall EMIS cost, and provide an overview of base, recurring, and in-house labor costs. The cost data are still a relatively small dataset for drawing robust conclusions, therefore additional cost data will be added in the next reporting year.

- ***Base cost:*** Among reporting participants, the base cost for installing and configuring FDD software is several times that of an EIS. Significantly more work is required to integrate BAS data into the FDD software than to integrate meter data into EIS software, both because there are more BAS data and a variety of points must be mapped for it to be used in the FDD software. Based on the reported data, the high end of the base cost occurred at sites where the FDD was installed at greater depth or on more complex systems. The low end of the base cost generally occurred when there were fewer points brought into the EMIS.

  Some of the largest installations had notably lower costs per square foot, which reflects the economies of scale achievable through broad EMIS implementation. For FDD implementations greater than 1 million sq ft in size, costs flattened to $0.02/sq ft to $0.06/sq ft. Large portfolios gain benefits in implementing EMIS across their portfolio, including the ability to use EIS to benchmark their buildings, manage energy use from a single location, and sometimes control building systems remotely through an operations center.

- ***Recurring cost:*** The data indicate that EIS recurring software fees are about equal to the median base cost (both are $0.01/sq ft), and that FDD recurring software costs ($0.02/sq ft) are about 45 percent of the FDD base cost. These recurring costs include two components: the annual licensing/software-as-a-service fee and ongoing MBCx service provider fees. For EIS, both the upfront and ongoing effort is lower than FDD, and this is reflected in the pricing. Typically, participants with only EIS do not utilize MBCx service providers, and about half of participants with FDD are contracting with MBCx service providers for additional support.

- ***In-house labor cost:*** The time it takes to utilize the EMIS by in-house staff is a significant portion of overall EMIS costs. While the labor cost is a different type of cost since it may be embedded in existing staff workload (and thus may not be an additional cost of implementing EMIS), estimates of labor cost from building staff were significantly higher than the recurring software and MBCx costs. The high end of the labor cost was reported from sites in their first year of FDD installation, during which time many faults are detected that may have existed for some time. Not surprisingly, the highest labor costs occurred at sites that implement MBCx in-house without service providers. Overall, both the extent of engagement with the EMIS and the varying level of contracted MBCx support affected the estimated in-house labor cost.

The EIS cost findings from this research are supported by past research. A previous study (Granderson and Lin 2016) reported median $0.01/sq ft base software cost and $0.01/sq ft annual recurring software cost; the results from this research are the same.

While there is not a previous study to compare the FDD cost results, FDD implementations have more data streams and complexity in implementing diagnostics; therefore, higher costs than those associated with EIS were expected. The median FDD base cost at $0.05/sq ft was five times higher than the EIS base cost, and the median FDD ongoing costs ($0.02/sq ft) were double that of EIS.

This research does not break out savings specifically attributed to the EMIS software; therefore, we do not compare costs and savings to calculate EMIS cost-effectiveness. However, given many owners' desire to invest in FDD and the cost savings and operational benefits described by those implementing FDD, the value proposition is strong. To date, 17 success stories[1] are available that summarize best practices and savings of leading owners in their use of EMIS technologies and implementation of MBCx processes.

[1] Success stories are short case studies on those participants that received recognition by the U.S. Department of Energy. The success stories are available for download at https://smart-energy-analytics.org/success-stories.

The need to use both building-level meter data as well as system-level operational data is clear. This study surfaced cases in which users who implement FDD without incorporation of building-level meter data do not have a line of sight into how much energy they are using or saving. Conversely those that implement only meter-level analytics tend to focus mainly on schedules, baseload, and peak demand, and may miss more nuanced operational opportunities identified through FDD. From a technology standpoint, this suggests that both EIS and FDD can work together to provide both a top-down and bottom-up analysis of a building's energy use and systems (though, while it is technically possible to integrate building-level meter analytics into some FDD offerings, this is generally not how today's tools are configured or implemented).

4.2 MBCx Process and Service Providers

A compelling evolution in the industry is the expansion of market delivery of FDD through MBCx service providers with the FDD tools used to provide added value to their customers. This contrasts with earlier models that relied on in-house direct organizational use, and from analysis-as-a-service provided by the FDD vendor. MBCx service providers tend to be commissioning firms expanding into MBCx, controls vendors with MBCx service offerings, or EMIS software vendors that also provide services. The expansion in service offerings has the potential to make EMIS use achievable for building owners that do not have large in-house facility teams. Some service providers are national organizations, but most are likely to serve regional markets, as they are the outgrowth of regional engineering firms.

FDD users were most active in implementing findings when they had support from MBCx service providers in analyzing and prioritizing faults, and a routine process was in place for following up on faults with operations teams. Once established across a portfolio, FDD fault alerts can number in the hundreds or even thousands; therefore, there is the need to filter and prioritize. While many FDD software platforms have built-in estimation of the energy cost waste of each fault to use as a means of prioritization, many participants valued the role of MBCx service providers in diagnosing the root cause of faults highlighting the most important measures for immediate action. In some cases, the owner seldom or never accesses their EMIS directly, using only the service provider's reports or online dashboard.

This expansion in services offers potential to increase access to the technology and its associated benefits for a new class of owners who otherwise may not be using it due to the lack of in-house staff time or expertise to implement an MBCx process.

5. Conclusions and Future Research

There is a growing national trend in the use of analytics in commercial buildings. EIS are becoming common for portfolio owners who want to track energy use centrally and prioritize energy efficiency efforts, and FDD is gaining traction as it helps facility teams track the performance of their mechanical systems. These research conclusions drew from a dataset of 73 organizations using EMIS in more than 400 million sq ft of commercial floor area and more than 5,200 buildings. This is the largest U.S. dataset on EMIS technology use, and it will grow over the next year as the partnership continues.

The study's EMIS users that reported savings (27 organizations, 687 buildings, and 94 million sq ft) achieved median cost savings of $0.19/sq ft and 7 percent annually, with savings shown to increase over time. While these savings are not attributable to specific measures, the EMIS users shared their top measures implemented, including improvements to HVAC scheduling, adjustment of setpoints, reducing simultaneous heating and cooling, and improving airside economizer operation. FDD users achieved 10 percent median savings compared to 1 percent median savings for EIS users. The savings achieved by EIS users was lower than in past research results although it is likely to increase as organizations report their energy use beyond their first year of EIS implementation. Energy savings for all EMIS implementations will be updated as the research continues another year.

For 35 participants (306 million sq ft and over 3,400 buildings), the median base cost to install an EMIS was $0.03/sq ft, with an annual recurring software cost of $0.02/sq ft and estimated annual labor cost of $0.03/sq ft. FDD implementations have more data streams and complexity than EIS; therefore, higher costs than those associated with

EIS were expected. The FDD base cost at $0.05/sq ft was five times higher than the EIS base cost, and the FDD ongoing costs ($0.02/sq ft) were double that of EIS.

Additional research in three critical areas is needed to advance the state of the art and promote implementation of EMIS tools and MBCx processes. First, there is the opportunity to advance the technology through further development focusing on automated fault correction techniques, predictive diagnostics, and methods for improving the accuracy of hourly meter data to measure real-time savings. Second, standardized protocols to assess the performance of EMIS through field studies will enable consistent quantification of technology benefits, and synthesis of findings across studies. Finally, there is an overarching need to provide technology users targeted resources to navigate issues related to data management, integration, cybersecurity, and interoperability.

The use of EMIS tools in MBCx processes has expanded significantly over the past 20 years, yet there is still the challenge of moving these processes beyond the early adopters. While EMIS technology advances will help reduce the time necessary to implement EMIS and the value gained from the analytics, the market also needs a growing infrastructure of service providers and a trained building operations workforce to make the promise of these technologies a reality. And moving into the future, these advancements will help transform the use of EMIS into a standard cost of operation for commercial buildings.

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