Title

Proving the Business Case for Building Analytics

Authors
Kramer, Hannah
Lin, Guanjing
Curtin, Claire
et al.

Publication Date
2020-10-01

DOI
10.20357/B7G022

doi:10.20357/B7G022

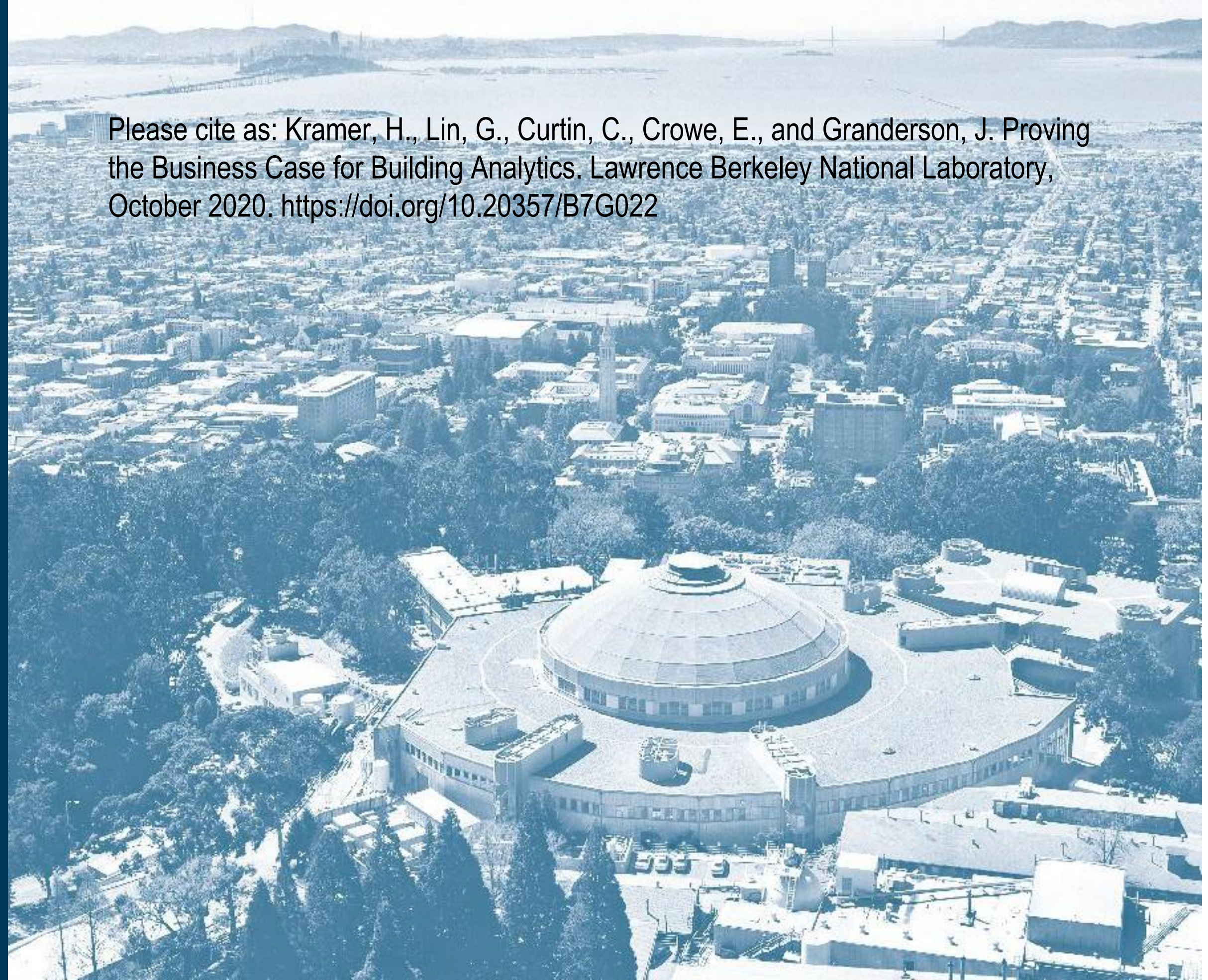
Lawrence Berkeley National Laboratory

Proving the Business Case for Building Analytics

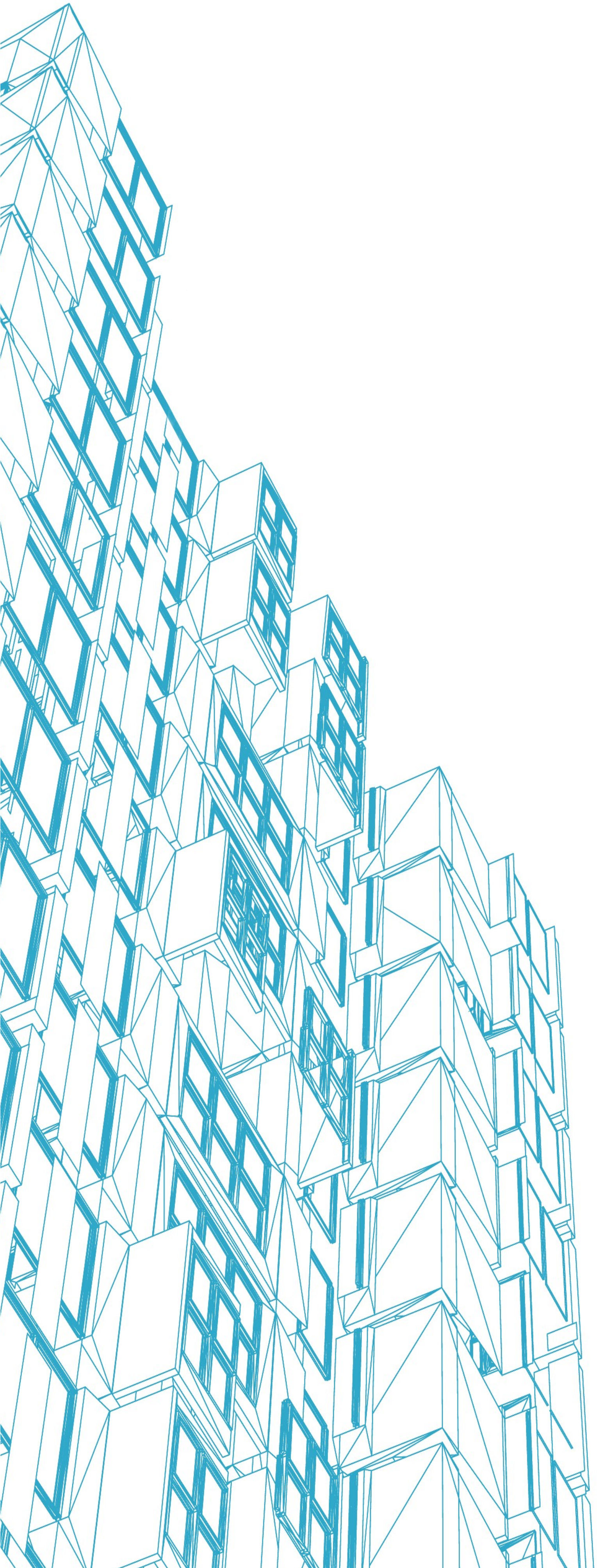
Hannah Kramer, Guanjing Lin, Claire Curtin, Eliot Crowe, and Jessica Granderson

Lawrence Berkeley National Laboratory, Berkeley

Energy Technologies Area
October, 2020



Please cite as: Kramer, H., Lin, G., Curtin, C., Crowe, E., and Granderson, J. Proving the Business Case for Building Analytics. Lawrence Berkeley National Laboratory, October 2020. https://doi.org/10.20357/B7G022



Proving the Business Case for Building Analytics

Results from scaled implementation of Energy Management and Information Systems, as documented by the Smart Energy Analytics Campaign

BUILDING TECHNOLOGY & URBAN SYSTEMS DIVISION

Lawrence Berkeley National Laboratory

PREPARED BY:

Hannah Kramer, Guanjing Lin, Claire Curtin,
Eliot Crowe, and Jessica Granderson

PREPARED FOR:

Amy Jiron and Cedar Blazek, U.S. Department of Energy

October 2020

BERKELEY LAB

Bringing Science Solutions to the World

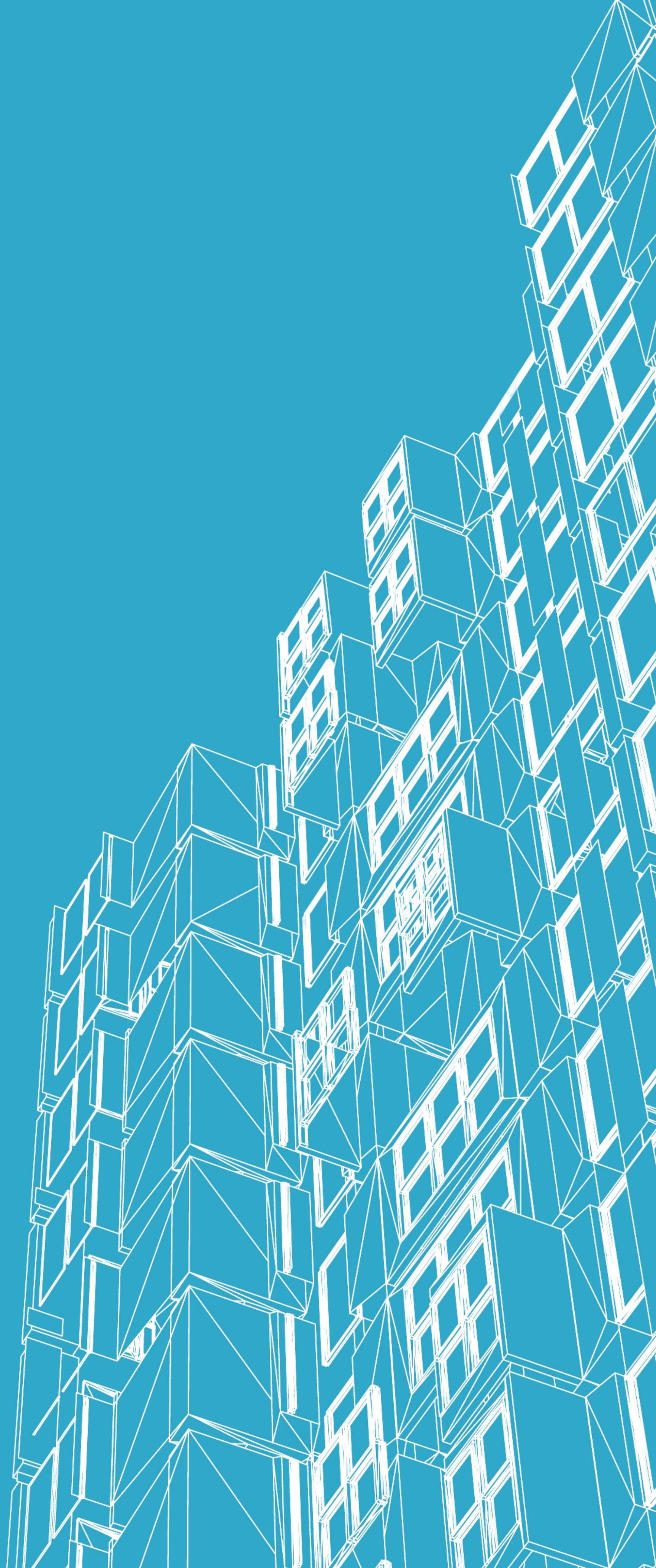
ACKNOWLEDGEMENTS

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Office, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors thank Nora Harris for data analysis support.

The authors wish to acknowledge the support of Amy Jiron and Cedar Blazek with the U.S. Department of Energy for their guidance and support of the Smart Energy Analytics Campaign, the research/industry partnership program that provided the means for data collection. We also recognize each of the owners who participated in the Smart Energy Analytics Campaign and provided data for this research.

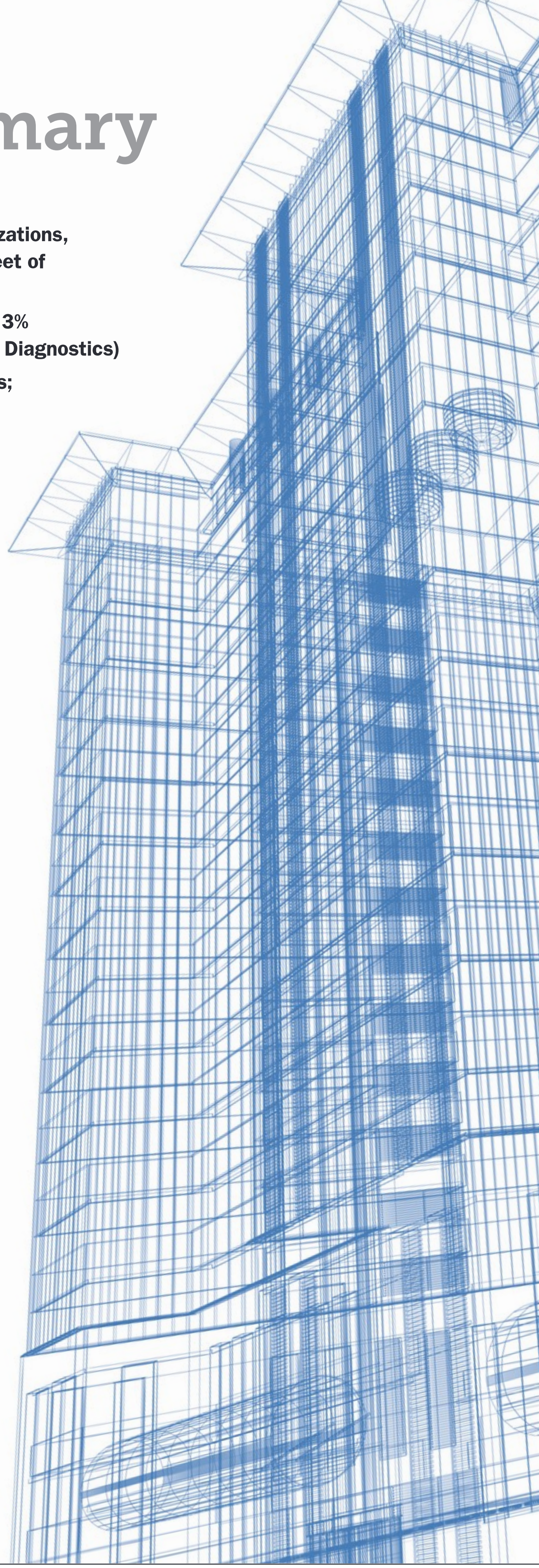
SUGGESTED CITATION

Please cite as: Kramer, H., Lin, G., Curtin, C., Crowe, E., and Granderson, J. *Proving the Business Case for Building Analytics.* Lawrence Berkeley National Laboratory, October 2020. https://doi.org/10.20357/B7G022



Contents

Executive Summary



HIGHLIGHTS:

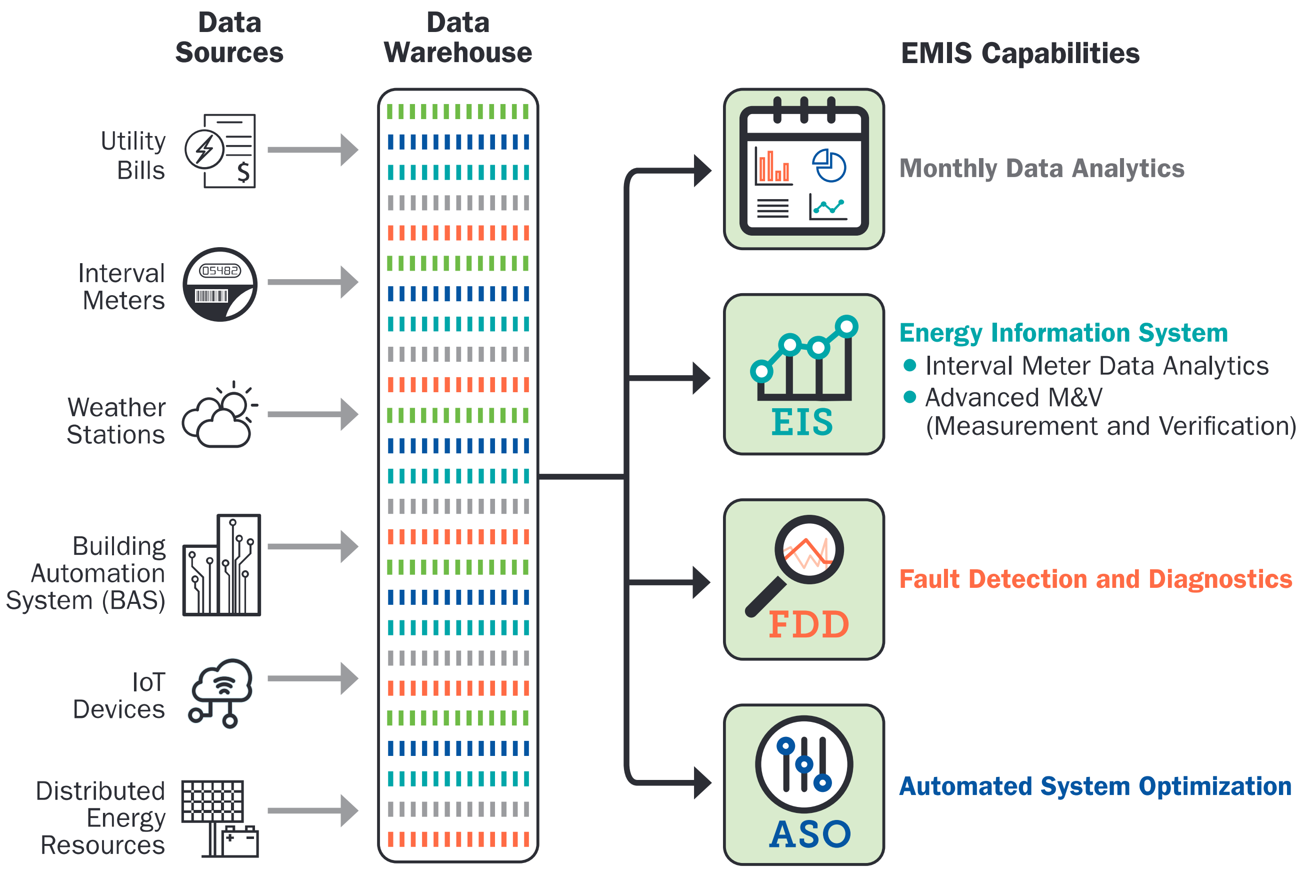
- **Smart Energy Analytics Campaign supported 104 organizations, with 6,500 buildings covering over half a billion square feet of combined floor area**
- **Campaign documented median annual energy savings of 3% (Energy Information Systems) and 9% (Fault Detection & Diagnostics)**
- **Produced the largest dataset on EMIS costs and benefits; showed a 2-year simple payback**

As building monitoring becomes more common, facilities teams are faced with an overwhelming amount of data. These data do not typically lead to insights or corrective actions unless they are stored, organized, analyzed, and prioritized in automated ways. Buildings are full of energy savings potential that can be uncovered with the right analysis. With analytic software applied to everyday building operations, owners are using data to their advantage and realizing cost savings through improved energy management.

The 2016–2020 Smart Energy Analytics Campaign (smart-energy-analytics.org) was a public–private sector partnership program to support commercially available Energy Management and Information Systems (EMIS) (Figure ES-1, next page) and monitoring-based commissioning (MBCx) practices for commercial buildings. MBCx is an ongoing commissioning process with emphasis on monitoring and 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. These tools have been available for decades, and their benefits have been documented through case studies and research on relatively small datasets. However, the past decade has seen significant growth in adoption of EMIS, spurred by a far greater range of EMIS offerings, improved ease of use and integration, a maturing market for third-party MBCx providers, and a broader recognition of the benefits EMIS can bring to energy management practices. The Smart Energy Analytics Campaign was conceived as an opportunity to assess the costs, benefits, and common practices of EMIS when installed at scale across a wide array of building types and sizes.

EMIS tools are used in the MBCx process to organize, present, visualize, and analyze the data

FIGURE ES-1: Data inputs and key capabilities of EMIS



Largest Dataset on EMIS Costs and Benefits

The Campaign coupled technical assistance with qualitative and quantitative data collection. Participating organizations were encouraged to share their progress and were eligible to receive national recognition. After four years in operation, Campaign participants included 104 commercial organizations across the United States, totaling 567 million square feet of gross floor area and more than 6,500 buildings, making this the most comprehensive dataset assembled on analytics installation and use. The dataset includes nine different market sectors (with office and higher education accounting for 80 percent of participants), and a wide range of building portfolio sizes. This report presents a characterization of EMIS costs and benefits, MBCx services, and trends in the industry based on data from these organizations.

By the second year of installation, Campaign participants with energy information systems (EIS)[1] achieved a median annual energy savings of 3 percent ($0.03/sq ft) and participants with fault detection and diagnostic tools (FDD)[2] achieved a median savings of 9 percent ($0.24/sq ft).[3] Applied across the organizations participating in the Smart Energy Analytics Campaign, savings are projected

[1] Energy information systems (EIS) are the software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data.

[2] Fault detection and diagnostic (FDD) tools are the software that automates the process of detecting faults and suboptimal performance of building systems and helps to diagnose their potential causes.

[3] Energy savings reported from sites with at least two years of EMIS implementation. The median savings are determined by comparing energy data from the second year after EMIS implementation with the baseline year before the EMIS was installed.

to be 4.1 trillion Btu and $95 million once EMIS use has been established at all of these organizations. Further, savings are expected to persist or increase in subsequent years as additional opportunities are uncovered (Figure ES-2 displays EIS and FDD savings, respectively).

These savings demonstrate the reduction in energy use achieved at buildings that are utilizing EMIS. However, the savings cannot be attributed solely to the operational improvements achieved with the support of the EMIS, since energy savings are determined at the whole building level, and other energy-impacting projects may be occurring simultaneously. The types of operational improvements executed with the help of EMIS were largely as expected and are common to traditional existing building commissioning (EBCx) practices; the top three improvement measures reported by Campaign participants were improved HVAC scheduling, space temperature adjustments, and correction of simultaneous heating and cooling. In contrast with EBCx, however, long-term EMIS users can look deeper with automated analytics over a wide range of equipment, enacting more sophisticated control routines and analyzing hundreds of heating, ventilation and air conditioning (HVAC) system components simultaneously in ways that are impossible with manual analysis. Organizations in the Campaign utilized a wide range of analytics and charting capabilities (see Figure ES-3 for examples, next page).

Savings are expected to persist or increase in subsequent years as additional opportunities are uncovered

FIGURE ES-2: Percent energy savings relative to the year before EMIS installation by organizations participating in the Smart Energy Analytics Campaign

(n = 22 in Year 1) **(n = 28 in Year 1)**

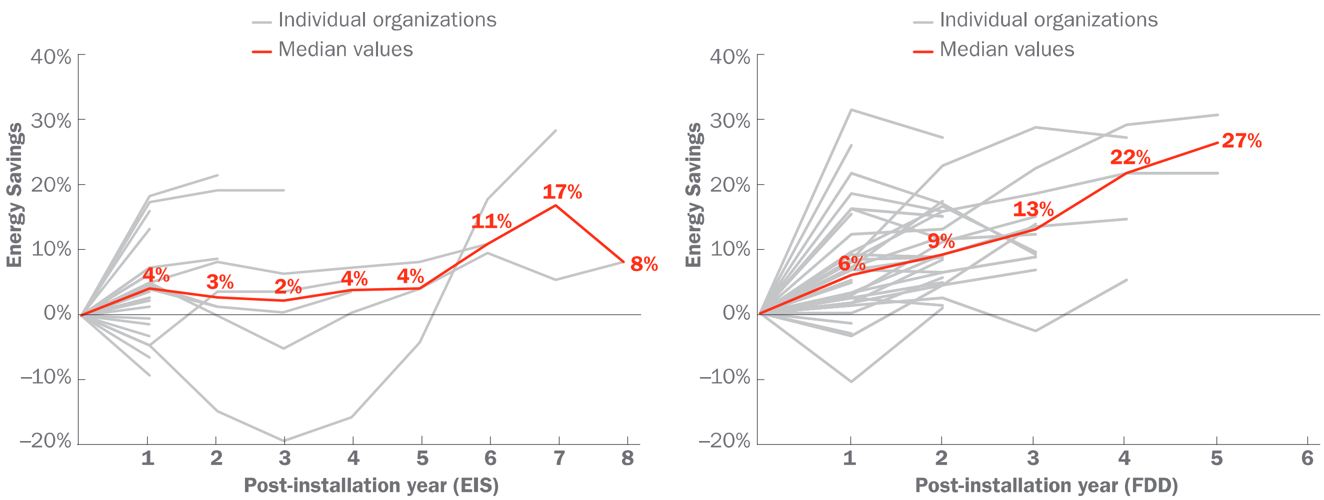
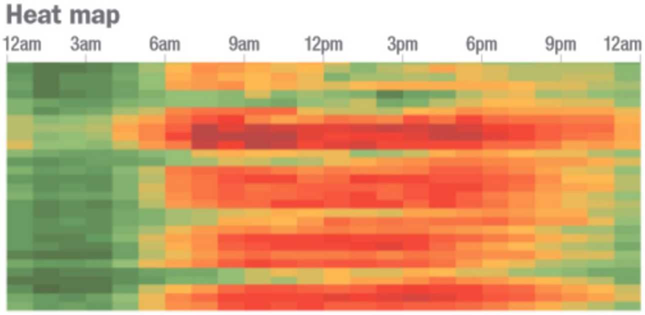
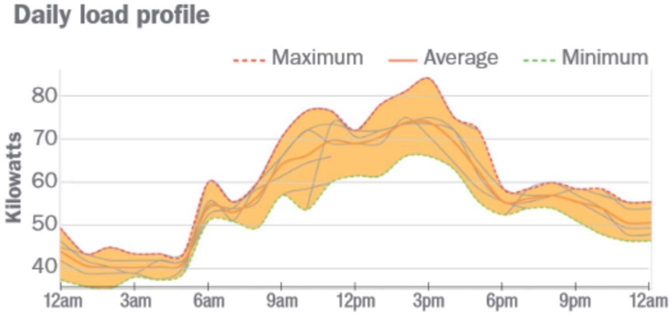


FIGURE ES-3: Examples of charting options available from EMIS



Source: Macalester College



Source: Carleton College

Two-Year Simple Payback

With cost reporting from 72 organizations, median costs and resource requirements were analyzed. Some EMIS vendors price by groups of points (e.g., cost per 10,000 points), while others price per building or based on total floor area.

- **EIS:** Software installation and configuration — $0.01/sq ft, annual recurring software cost — $0.01/sq ft, and an annual in-house labor of one hour per month per building.
- **FDD:** Software installation and configuration — $0.06/sq ft, annual recurring software cost — $0.02/sq ft, and an annual in-house labor of 8 hours per month per building.

Organizations with EIS or FDD installations had a median two-year simple payback period, making EMIS a highly competitive investment option when compared with other energy efficiency technologies.

Gathering cost and savings data was only one element of the Smart Energy Analytics Campaign. LBNL also gathered data on non-energy benefits such as improved occupant comfort or the ability to validate the performance of energy-saving retrofits.

The Campaign also recognized 24 organizations for their outstanding efforts with new EMIS installations, exemplary best practices, and innovative deployment of energy analytics, and cataloged an array of typical enablers and barriers to success. Once installed, EMIS becomes a tool to facilitate a shift in energy management practices from reactive to proactive.

Organizations with EIS or FDD installations had a median two-year simple payback period

Successful organizations — whether managing the analytics internally or through a third party — integrate EMIS review into their regular working practices to identify suboptimal performance before it shows up as comfort complaints or a spike in the energy bills.

Table ES-1 (next page) summarizes Campaign results to date using data collected from 104 participating organizations. The high level of participation in the Smart Energy Analytics Campaign points to a growing national trend in the use of analytics in commercial buildings. The Campaign supported an expansion in the use and acceptance of EMIS, helping organizations transition to building operations that are continuously informed by analytics.

TABLE ES-1: Summary of EMIS use by organizations in the Smart Energy Analytics Campaign

Summary Category	Energy Information Systems (EIS)	Fault Detection and Diagnostics (FDD)
Used by	Energy managers	Facility operations teams, energy managers, and service providers
Used for	**Portfolio management** – Portfolio key performance indicators (KPIs) / prioritize properties for improvements – Track energy use and identify opportunities – Communicate energy metrics with occupants – Measurement and verification (M&V)	**Detailed system analysis** – Reduce maintenance costs – Improve comfort with zone-level diagnostics – Find hidden energy waste and maintain savings
Typical installation	Whole building energy meters by fuel for large buildings in a portfolio, either with utility-provided interval data or an owner-installed meter. End-use submetering was less prevalent.	Installation focused on FDD for HVAC systems: central plants, air handling units (AHUs), and variable air volume (VAV) terminal boxes.
Common analytics	– Energy use intensity (kBtu/sq ft) – Heat map – Load profile, filtered by day type – Predictive models of energy use	– Chiller plant operations and setpoint optimization – Air handlers (simultaneous heating and cooling, economizers, leaky valves) – Terminal unit operation – Detection of sensor issues
Top measures implemented	– Improve HVAC scheduling – Reduce baseload and off-hours energy use – Reduce peak demand – Share energy information with occupants to encourage changes	– Improve HVAC scheduling – Improve economizer operation – Reduce overventilation – Reduce simultaneous heating and cooling – Adjust space temp setpoints – Reset supply air temp and duct static pressure – Tune control loops to avoid hunting
Energy savings	**Median energy savings after two years of EMIS installation** (whole building level, for all fuels): – EIS: 3% ($0.03/sq ft); range: -15% to 22% – FDD: 9% ($0.24/sq ft); range: 1% to 28%	
Cost	**Median base cost** (software + installation): EIS $0.01/sq ft; FDD $0.06/sq ft **Median annual recurring cost:** EIS $0.01/sq ft per year; FDD $0.02/sq ft per year **Median in-house labor:** EIS 1 hour/building per month; FDD 8 hours/building per month	
Cost-effectiveness	**Median simple payback period:** – EIS: 2 years (n = 7) – FDD: 2 years (n = 17)	

SECTION 1:

EMIS Evolution

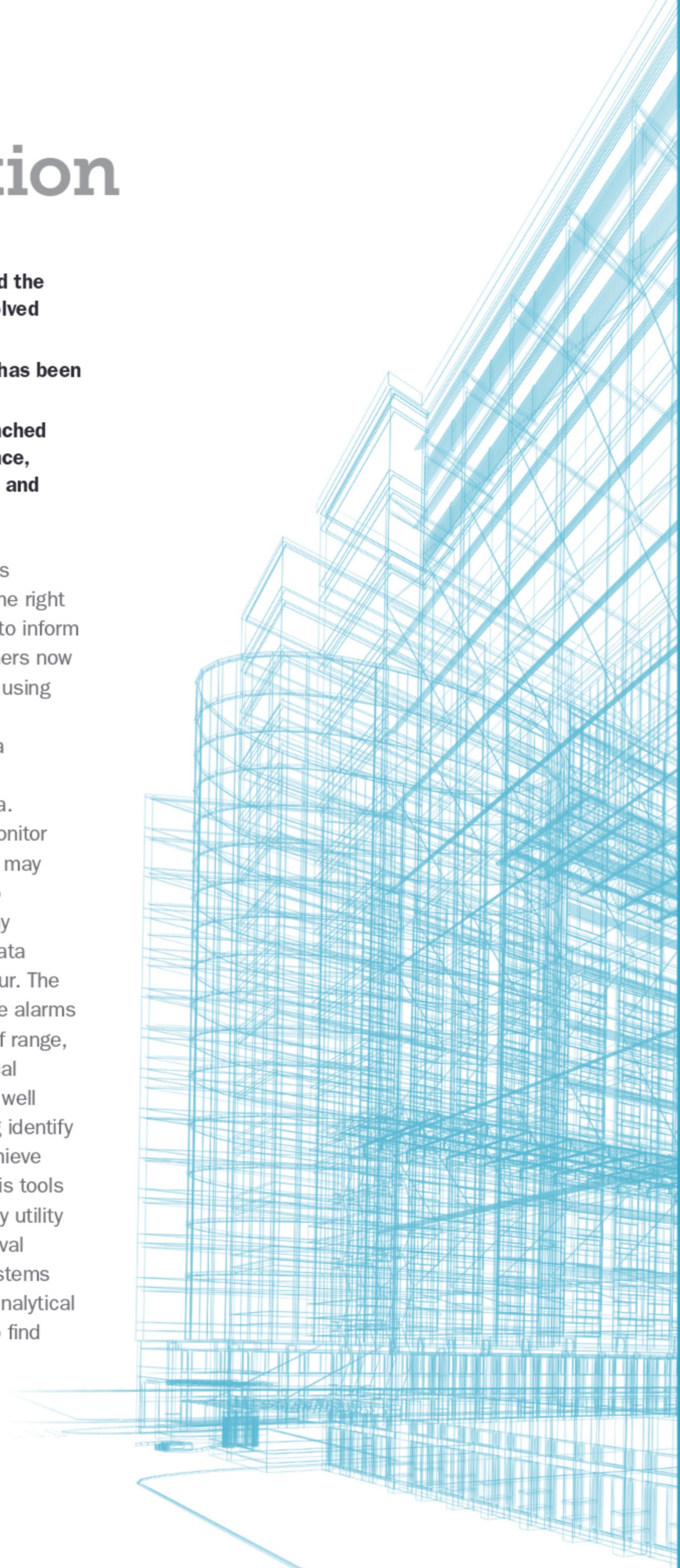
HIGHLIGHTS:

- **EMIS offer many analytical capabilities, and the quantity and quality of EMIS tools have evolved rapidly over the past decade**
- **Past research on EMIS costs and benefits has been limited to relatively small datasets**
- **The Smart Energy Analytics Campaign launched in 2016 to provide EMIS technical assistance, gather data on costs and benefits of EMIS, and recognize organizations**

Buildings are full of hidden energy savings potential that can be uncovered with the right analysis. With sophisticated software to inform and assist in building operations, building owners now are reducing energy and improving operations using building data analytics.

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 every hour. The BAS can provide alarms for points out of range, but the analytical capabilities fall well short of helping identify solutions to achieve an optimized system. Further, common analysis tools for energy meter data tend to focus on monthly utility bills but do not provide 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.

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 What are EMIS and MBCx?

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 enable 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, visualize, and analyze the data.

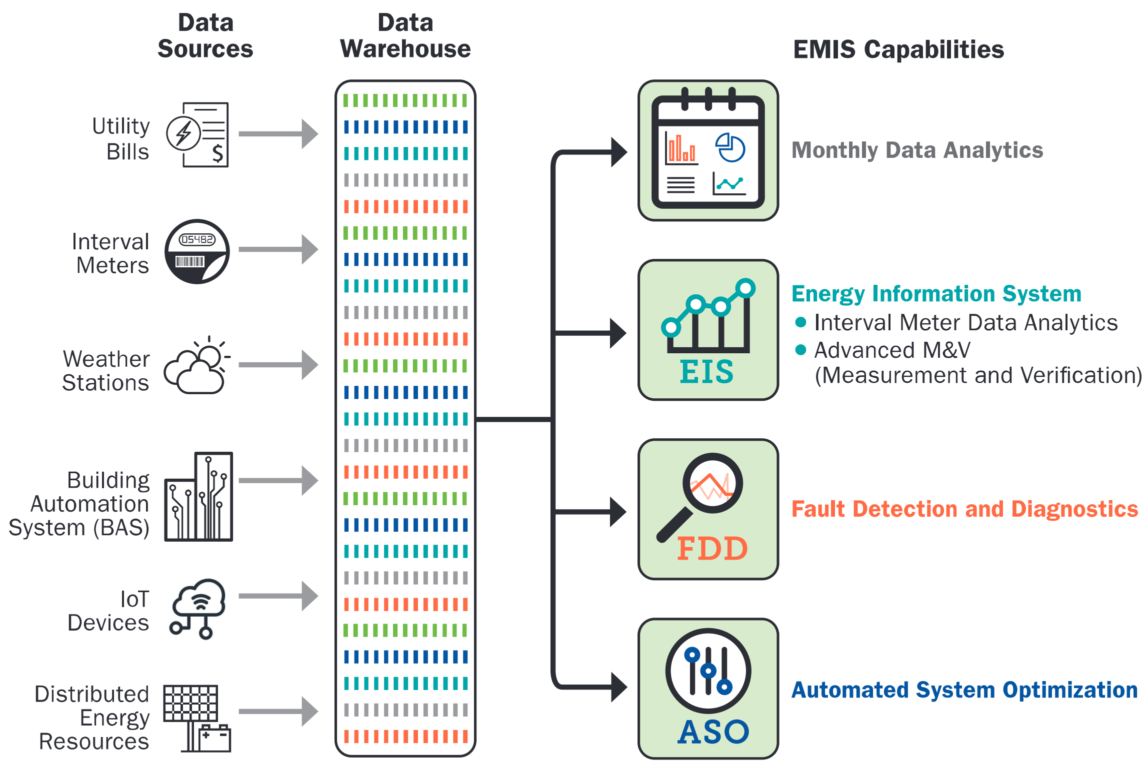
There is no consensus definition of EMIS, but a categorization framework has been developed (Granderson et al. 2015). Figure 1 describes this framework for classifying EMIS functionality. An EMIS product can have capabilities in multiple categories and accept a wide range of data inputs. The data warehouse may be hosted in the cloud or on-premise.

While monthly data analytics, which includes utility bill management software, is classified as the first tier of EMIS, this report focuses on the more advanced EMIS capabilities as the industry moves toward in-depth analytics.

BAS are used to control building heating, ventilation, and air-conditioning (HVAC) systems, and in some cases, building lighting and security systems. The BAS controls indoor temperature, humidity, ventilation, and lighting conditions. However, BAS often lack the ability to answer questions such as: How much energy is consumed at different times of the day? Does the economizer behave appropriately? What is the optimal air handling unit supply air temperature setpoint?

EMIS tools such as energy information systems (EIS), fault detection and diagnostics systems (FDD), and automated system optimization tools (ASO) supplement the BAS to facilitate analysis and management of building performance, including energy, comfort conditions, and ventilation. The following descriptions provide more in-depth information about the EMIS technologies that are the focus of this report.

FIGURE 1: Data inputs and key capabilities of EMIS



- **ENERGY INFORMATION SYSTEMS:** the software, data acquisition hardware, and communication systems used to store, analyze, and display energy meter data. EIS are a subset of EMIS that are focused on meter-level monitoring (hourly or more frequent, at whole building or submeter level). These meter data are not yet commonly integrated with BAS. Advanced EIS incorporate automated opportunity analysis that typically includes predictive energy models using interval meter data.
- **FAULT DETECTION AND DIAGNOSTIC SYSTEMS:** software that automates the process of detecting faults and suboptimal performance of building systems and helps to diagnose their potential causes. FDD are a subset of EMIS that focuses on system-level monitoring using BAS data. An FDD system is different than a BAS alarm. Alarms commonly detect sensor value deviation associated with a specific point based on real-time conditions. They do not typically allow for sophisticated logic that interrelates multiple data streams and performs rule-based or model-based diagnostics. FDD tools are most often applied as a separate software application that obtains data from the BAS and may provide a report of the duration and frequency of faults, cost and/or energy impacts, and relative priority levels.
- **AUTOMATED SYSTEM OPTIMIZATION:** software that continuously analyzes and modifies BAS control settings to optimize 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 control parameters based on data such as submetered energy use. Two-way communication with the BAS distinguishes ASO solutions from FDD.

EIS, FDD, and ASO systems can be implemented individually or in combination and are intended to support facility staff and management in meeting high levels of building comfort and performance. EMIS help prioritize efforts toward optimal system performance, as opposed to reactively fixing things only when they are broken. Further, providing a healthy building environment to occupants requires continuous monitoring of the systems that provide ventilation to occupant spaces, and this monitoring and analysis can be achieved through the use of EMIS. Previous research includes a complete description of the components of EMIS and details how organizations can plan and implement for successful EMIS use (Granderson et al. 2015).

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. MBCx is an ongoing commissioning process that monitors and analyzes large amounts of data on a continuous basis, and EMIS are an integral part of streamlining analysis and automating the MBCx process.

While EMIS are powerful tools, any tool needs a process that utilizes it to have impact

MBCx is a type of existing building commissioning (EBCx), which is defined as *"…a systematic process for investigating, analyzing, and optimizing the performance of building systems through the identification and implementation of low/no cost and capital-intensive Facility Improvement Measures and ensuring their continued performance"* (Building Commissioning Association 2018). Traditionally EBCx was implemented by commissioning providers manually analyzing a short-term data snapshot of building performance; the advent of EMIS has enabled these commissioning providers to provide automated analytics and "fixes" in real time. Energy savings from EBCx processes has been documented to be 3-12% from a database of almost 1300 projects (Crowe et al. 2020).

MBCx may be used during an EBCx process to streamline and automate data analysis during the investigation process and after EBCx to track whether energy savings persist and find additional opportunities over time. Figure 2 illustrates the three main elements of EMIS tools (data warehouse, data analytics, and monitoring), and shows how these tools are incorporated into the MBCx process.

While MBCx is a recommended best practice, many organizations have successfully implemented EMIS without a defined MBCx process. In the absence of formal MBCx, the EMIS may be integrated into daily building operations as a support tool, enabling data-driven decision making for facilities teams.

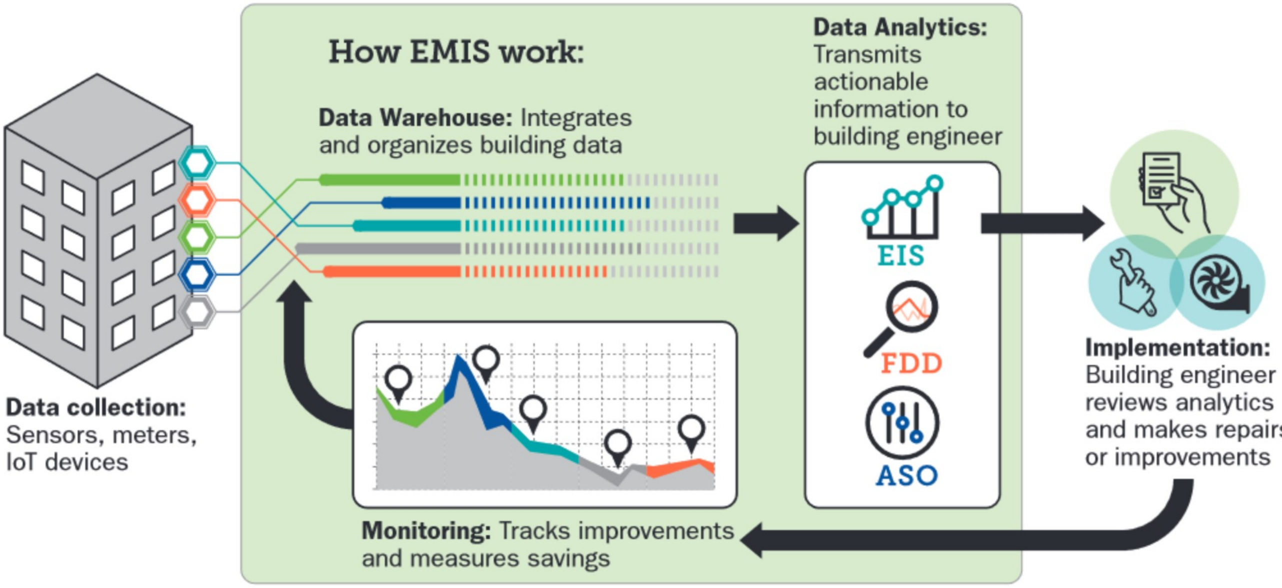
1.2 EMIS Technology Benefits

Energy and cost savings are often a driving factor in the decision to implement an EMIS. The number of commercially available EMIS has increased dramatically over the past decade, driven by the growing availability of higher-granularity energy (generally 15-minute to hourly) and BAS time-series data. Building staff can leverage these data to continuously monitor building performance and automate analysis through EMIS, leading to energy savings, peak demand reduction, and a reduction in service calls. Further, analytics can help owners move from the reactive to the proactive by detecting equipment cycling issues and avoiding unnecessary wear and tear that can reduce equipment life. To support owners in these aims, Lawrence Berkeley National Laboratory (LBNL) created a resource that summarizes how both EIS and FDD can be used to identify energy saving opportunities in commercial buildings (Lin et al. 2017). In addition to operational improvements, EMIS can be used to verify energy savings.

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 United States, energy savings ranged from -3 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). Study participants reported that performance improvements would not have been possible without the EIS.

Research results on the costs and benefits of commercialized FDD products are less available than those for EIS. A study on FDD for commercial buildings provided a thorough characterization of functionality and application for 14 FDD technologies (Granderson et al. 2017); however, the study scope did not include quantification of costs or benefits. Based on an analysis of the most common faults in building

FIGURE 2: **Monitoring-based commissioning process**



EMIS TOOLS: Energy information systems (**EIS**) help find energy waste using smart meter data. Fault detection and diagnostic tools (**FDD**) detect and prioritize HVAC system faults. Automated system optimization (**ASO**) includes control algorithms to minimize energy use across systems.

systems, studies estimate that the energy savings achievable from addressing these faults range from 5 to 30 percent whole building savings (Fernandez et al. 2017; Roth et al. 2005).

To allow for comparison of the savings analysis with past research, the existing studies that document savings or payback are shown in Table 1. While there are a few instances of payback calculated for projects, the research generally has not released software costs. The lack of savings and cost data available for EMIS points to the need for more cost-benefit research, and thus the focus of this research project.

1.3 Challenges in EMIS Use

With numerous vendors and feature packages available, it is difficult for owners to determine which type of EMIS will support their needs and meet thresholds for return on investment. Even if there is adequate energy metering in place, it is common to have problems integrating the data into the EMIS due to legacy data sources, varying communications protocols, and cybersecurity needs. It can be difficult to get disparate data collection systems into a single database to integrate with the EMIS.

TABLE 1: EMIS case studies that document energy savings results

Study	Type of EMIS	Number of Sites	Results
Building Energy Information Systems: Synthesis of Costs, Savings, and Best-practice Uses (Granderson and Lin 2016). Study performed in 2013	EIS	28 individual buildings and 9 portfolios	Median of 17% for individual buildings; median of 8% for portfolios
Monitoring-Based Commissioning: Tracking the Evolution and Adoption of a Paradigm-Shifting Approach to Retro-Commissioning (Meiman et al. 2012)	EIS	17 campuses (3.2 million sq ft)	8% energy savings; 4-year median simple payback
Monitoring Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects (Mills and Mathew 2009)	EIS	24 buildings	Energy cost savings were $0.25/sq ft per year, for a median simple payback time of 2.5 years
Corporate Delivery of a Global Smart Buildings Program (Fernandes et al. 2018)	FDD	116 buildings (6.7 million sq ft)	18.5% energy savings
Real-Time Energy Management: A Case Study of Three Large Commercial Buildings in Washington, D.C. (Henderson and Waltner 2013)	EIS and manual FDD	3 buildings (681,982 sq ft)	13% energy savings
M&V Report – Model-based Predictive HVAC Control Enhancement Software (SDG&E 2015)	ASO	1 building	6.5 year payback, 11% HVAC savings
Field evaluation of performance of HVAC optimization system in commercial buildings (Granderson et al. 2018)	ASO	5 buildings	0%–9% energy savings range

In addition to metering and data management hurdles, a common challenge is the lack of staff time to review the EMIS dashboards and reports, and to investigate and implement recommended findings. Staff may experience data overload if their EMIS is not configured properly, or if there is not enough automation of the analytics. With EIS, there may be difficulty in pinpointing opportunities in the data, and with FDD there are often challenges definitively isolating root causes. For example, the FDD software might detect a problem with the outside air economizer not bringing in enough air for free cooling and recommend that the damper actuator be checked, the temperature sensors calibrated, and the control sequence reviewed. As with all enabling tools, the EMIS itself does not directly produce savings, but requires action based upon the analytic results. In cases where owners are limited in staff to utilize the EMIS, there are a growing number of service providers equipped to help owners manage their analytics and implement findings.

1.4 Smart Energy Analytics Campaign

In response to these challenges in implementing and utilizing EMIS systems, a public-private partnership between the U.S. Department of Energy (DOE) and Lawrence Berkeley National Laboratory and industry was initiated in 2016, and this report is the fourth and final annual summary of findings. Concluding in 2020, the Smart Energy Analytics Campaign targeted the use of a wide variety of commercially available EMIS technologies and ongoing monitoring practices to support energy savings. This program provided expert technical assistance to commercial building owners in implementing indepth analytics, and the program recognized owners with exemplary deployments.

As a part of the Campaign, participants were offered engagement with a peer network. Participants shared data about their progress and the program team reported the latest aggregated results for EMIS savings, costs, and trends in implementation. This research report expands and builds upon previously published research based on an earlier version of the dataset (Kramer et al. 2019). By the end of the Campaign, there were 104 participating commercial organizations across the United States, totaling more than 567 million square feet of gross floor area and 6,500 buildings, making this the most comprehensive dataset assembled on analytics installation and use.

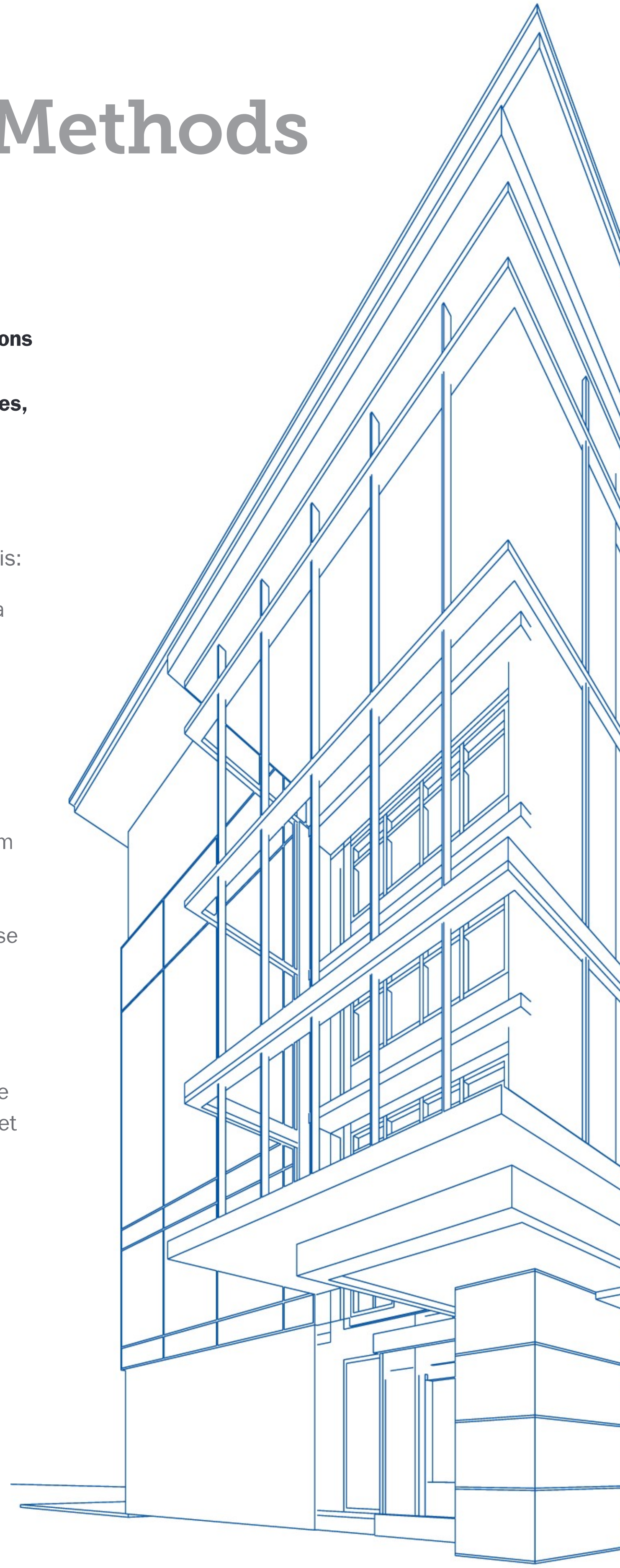
By the end of the Campaign, there were 104 participating commercial organizations across the United States, totaling more than 567 million square feet of gross floor area and 6,500 buildings, making this the most comprehensive dataset assembled on analytics installation and use

An EMIS Applications Showcase highlights exemplary EMIS new installation, best practices, and innovation examples from leading organizations recognized by the Campaign. More detail the achievements of the organizations recognized by the Campaign are documented in 24 success stories[4].

[4] Success stories are short case studies on those Campaign participants that received recognition by DOE. The success stories and EMIS Applications Showcase are available for download at https://betterbuildingssolutioncenter.energy.gov/smart-energy-analytics-campaign-toolkit

SECTION 2:

Data Analysis Methods



HIGHLIGHTS:

- **Findings in this report are drawn from the Smart Energy Analytics Campaign participants' data and supplementary research**
- **Reported savings are actual achieved energy reductions at Campaign participants' buildings**
- **Reported costs include base costs, recurring expenses, and in-house labor costs**

This section describes the sources of data upon which the research results are based, and the methods used to perform the cost-benefit analysis:

- **CAMPAIGN PARTICIPANT DATA:** Quantitative data were collected on annual energy use, floor area with EMIS, and EMIS costs. Organizations that were a part of the Campaign self-reported qualitative information such as the type of EMIS installed, how the EMIS has been used, and the most frequently implemented improvements in which they utilized the EMIS.
- **PRIOR EIS STUDY:** Energy savings and EIS costs from a prior study of nine portfolio owners (Granderson and Lin 2016) was combined with Campaign participant data. This integration of datasets was possible because the cost and savings methodologies were the same, with the exception that the prior study did not collect estimates of the time in-house staff spent using the EMIS. The cost and energy savings results were similar as well. By combining these data sources, more conclusive findings could be drawn because the dataset is larger. Throughout the Campaign results, the data from this study have been referred to as "2013 EIS study participants" since the study was completed in 2013, although the final journal paper was published in 2016.
- **CAMPAIGN PARTICIPANT AND INDUSTRY PARTNERS SURVEY:** An online survey was used to obtain additional information about enablers, barriers, and future technical needs associated with EMIS.
- **ONGOING INTERVIEWS:** Organizations were interviewed to better understand their current EMIS and MBCx implementation, then they participated in activities such as individual and group technical

support. The information gained from these activities has been used to categorize their EMIS implementations and determine the barriers and enablers to success.

Almost all organizations implemented or planned to implement EIS or FDD. While two organizations with ASO installed are in the study cohort, there are not enough data to report savings and costs for this technology.

2.1 Energy Savings

To understand energy and cost savings benefits achieved by owners using EMIS technologies, participants were 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. These organizations provided data only for buildings with active use of EMIS, and energy savings achieved since EMIS installation were determined in four ways.

- **INTERVAL DATA ANALYSIS:** Pre-EMIS (baseline year) interval data are used to develop a model of building energy use. Energy use is projected into the time period with EMIS in place using the baseline model. Predicted energy use is compared with actual energy use to determine savings. This method utilizes the International Performance Measurement and Verification Protocol (IPMVP) Option C methodology.
- **ANNUAL ENERGY USE ANALYSIS:** Pre-EMIS (baseline year) energy use is compared to each full year of energy use after EMIS implementation. Energy cost savings are calculated using national average energy prices. When the organization uses ENERGY STAR® Portfolio Manager for their buildings with EMIS, data are gathered through standard ENERGY STAR reports with weather-normalized energy usage. If organizations do not utilize ENERGY STAR Portfolio Manager, then the change in energy use has not been weather-normalized.
- **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 principles that often utilize temperature or load-based bin analysis.
- **BUILDING ENERGY SIMULATION:** Modeling whole facility energy use is a system analysis approach that employs energy simulation software such as eQUEST, EnergyPlus, Trane TRACE, or Carrier HAP.

2.2 Costs

Costs to implement an EMIS and perform MBCx were gathered from Campaign participants in the three categories shown below: base cost, recurring EMIS cost, and in-house labor cost. Cost data were provided by these organizations in dollars for the base cost and annual software cost and then normalized by floor area.

- **BASE COST:** costs for the EMIS software installation and configuration, including EMIS vendor and service provider costs. They do not include additional costs such as the cost of energy metering hardware and communications, adding points to the BAS for EMIS monitoring purposes, additional data servers, retrocommissioning, or retrofits.
- **RECURRING EMIS COST:** annual recurring costs are broken into two categories - annual software cost and ongoing MBCx service provider cost. These costs are incurred starting immediately after system implementation is complete.
  - ANNUAL SOFTWARE COST: the recurring annual cost for a software license, or software-as-a-service fees
  - ONGOING MBCX SERVICE PROVIDER COST: 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 are broken out into the categories of EMIS installation/configuration and ongoing EMIS use. In-house labor costs are reported in hours.
  - EMIS INSTALLATION AND CONFIGURATION: approximate total time spent by in-house staff to support installation and configuration of the EMIS
  - ONGOING EMIS USE: approximate time spent per month by in-house staff reviewing EMIS reports, identifying opportunities for improvement, and implementing measures (average hours per month)

2.3 Cost-effectiveness

Determining the cost-effectiveness of EMIS implementation is not straightforward since EMIS is an enabling tool; installation of the software does not directly create savings. Rather, savings are achieved by acting upon the information that the technology provides (i.e., the improvement opportunities that are identified). The only type of EMIS that achieves direct savings is ASO since the optimization is performed directly by the ASO software.

EMIS is an enabling tool; installation of the software does not directly create savings. Rather, savings are achieved by acting upon the information that the technology provides.

Attributing savings to an EMIS can be difficult since not all measures that an organization implements are due to use of the EMIS but may come from other things like capital upgrades or projects that would have happened without the EMIS. Even so, EMIS is often used to help identify the need for retrofits and measure the performance of those retrofits.

To develop estimates of EMIS cost-effectiveness, costs and savings were determined for all organizations in which the data are available, using the following methodology:

- **COSTS:** The median first-year cost includes base EMIS implementation cost, in-house labor cost to use the EMIS, EMIS recurring costs (licensing/software-as-a service fees), and an estimated cost to implement operational measures found using the EMIS. Second-year costs include an additional year of in-house labor cost and an additional year of EMIS licensing/software-as-a service fees. The Campaign did not collect data on hard costs for implementing measures (e.g., replacing a variable frequency drive), therefore these hard costs must be estimated. EBCx measures are consistent with the measures identified and implemented through use of EMIS software, so we used the median EBCx implementation cost as an estimate for EMIS measure implementation costs from a recent commissioning study (Crowe et al. 2020). In the commissioning study, typical EBCx measure implementation costs are reported as approximately one-third of the total EBCx cost. With a median EBCx cost reported in the commissioning study of $0.27/sq ft, we selected $0.11/sq ft as an implementation cost estimate for operational measures related to the use of EIS and $0.22/sq ft as a measure implementation cost estimate related to the use of FDD or correspond to the relative level of depth of measures.
- **SAVINGS:** The median savings were determined by comparing energy data from the first or second full year after EMIS implementation, depending on the amount of data available, with the baseline year before the EMIS was installed. For cases in which savings are negative, the simple payback period cannot be calculated, and these data were not used in the payback calculation.
- **COST-EFFECTIVENESS CALCULATION:** For each organization that reported costs and energy use, a simple payback period was calculated. For EIS, first year costs and savings were used since first-year savings data were more available than second-year savings. The first-year cost includes base EMIS software and installation cost, in-house labor cost, and an estimate of implementation costs for operational measures found using the EMIS. For FDD, second-year costs and savings were used, since second-year savings are an accurate representation as savings ramp up over the implementation period. Second-year costs include an additional year of recurring software cost. As a cross-check, we compared the Campaign cost-effectiveness results with other public source cost-effectiveness data documented in EMIS case studies.

SECTION 3:

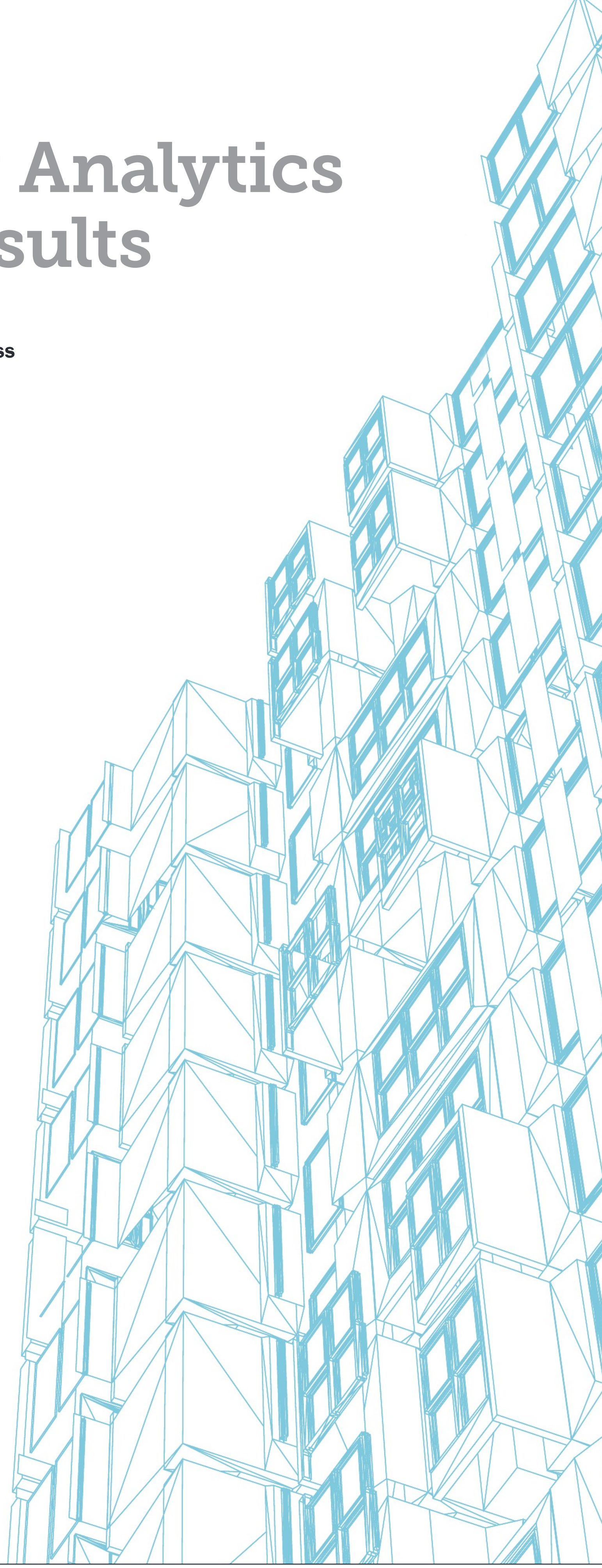
Smart Energy Analytics Campaign Results

HIGHLIGHTS:

- **Successful EMIS installations demonstrated across a large, diverse dataset comprising many market sectors and portfolio sizes**
- **Broad set of energy and non-energy benefits achieved using EMIS**
- **EMIS shown to have a 2-year simple payback with low upfront costs**
- **Key enablers and barriers to success documented**

In this section, we summarize information from 104 public and private sector organizations, representing a total gross floor area of 567 million sq ft and more than 6,500 buildings. Nineteen organizations (Campaign participants) had not yet implemented their EMIS and did not have data to report. Therefore, our analysis of the EMIS systems installed is based on 85 participating organizations representing more than 506 million square feet and 5,900 buildings. There were different reporting rates for different data requests, and the number of organizations (n) and square footage are reported for each finding. The findings provide an overview of the types of activities, analytic tools, and energy management processes that Campaign participants use. The section summarizes EMIS and MBCx benefits, costs, and cost-effectiveness results. Using data gathered through Campaign interactions, enablers and barriers to implementation are also summarized.

The findings provide an overview of the types of activities, analytic tools, and energy management processes that Campaign participants use



3.1 Characterization of Organizations in the Campaign

Campaign participants were mainly in the office and higher education market sectors, with healthcare and government laboratories also represented (Figure 3). The most common portfolio size was between 1 million and 5 million sq ft (Figure 4). The median building size with EIS installed was 91,000 sq ft, and with FDD installed was 155,000 sq ft. The median number of buildings per portfolio with EIS was 27 and with FDD was 8.

Almost all Campaign participants had access or were gaining access to whole building hourly data in addition to their monthly utility bill data, and almost 40 percent of organizations had submeter data for tenants or end uses. Those organizations who did not have access to whole building hourly data were FDD users who had not integrated meter data into their FDD software.

In addition to EIS and FDD software, the most common analysis tools used were the BAS for trend analysis, ENERGY STAR Portfolio Manager, spreadsheets, and utility-provided web portal to view energy use. Campaign interviews showed that where EIS and FDD have been implemented, operators benefitted from expanded analysis capabilities. About one-third of organizations are planning to install a new EMIS soon or installed a new EMIS during the Campaign, one-third used an existing EMIS, and one-third upgraded their EMIS to deploy in more buildings or add additional functionality. Of those planning to install, 32 percent planned to install an EIS, 42 percent planned to install FDD, and 26 percent planned to install both EIS and FDD technologies

Figure 5 shows the breakdown of EMIS type chosen by Campaign participants, with the largest portion (37%) implementing solely EIS to analyze hourly (or more frequent) interval data. With an additional 36% of participants installing a combined EIS and FDD software, 73% of organizations in the Campaign utilized EIS. Similarly, 25% of participants installed solely FDD, and with the combined EIS and FDD software implementation, 61% of organizations implemented FDD to identify HVAC operational faults. While almost all combined EIS and FDD installations occurred within the same software package, a few participants implemented separate EIS and FDD software.

FIGURE 3: Organizations participating in the Smart Energy Analytics Campaign by market sector

(n = 104)

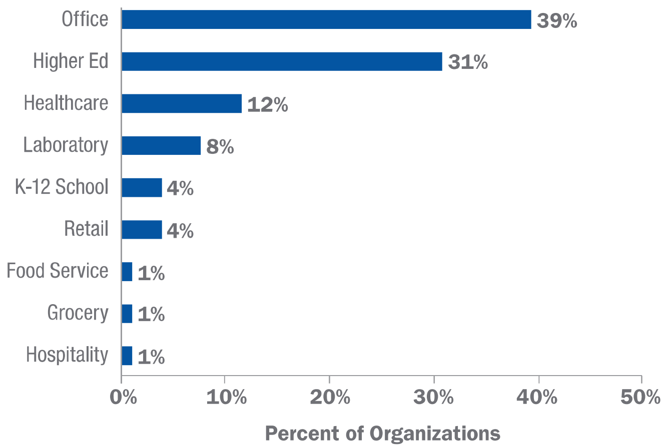


FIGURE 4: Distribution of gross floor area for organizations with planned or installed EMIS

(n = 104)

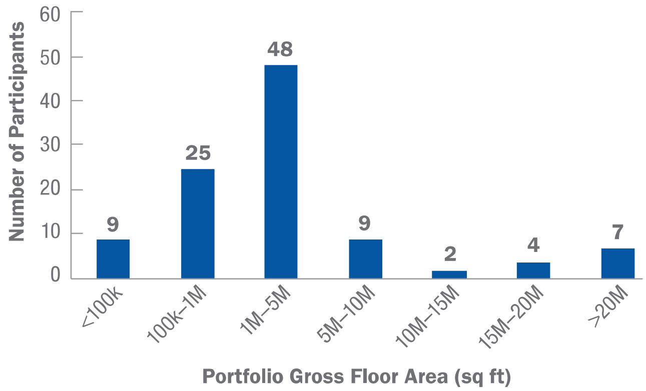
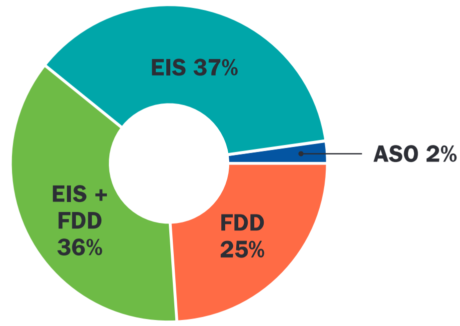


FIGURE 5: Type of EMIS installed by organizations in the Smart Energy Analytics Campaign

(n = 85)



ASO is not yet prevalent in the market generally, and was implemented by only two Campaign participants, and they also had EIS and/or FDD installed. We do not report costs or savings for ASO since there are only two data points.

EIS functionality was most utilized by energy managers. Organizations with both FDD and EIS tended to focus on the FDD functionality due to the detailed recommendations provided. The FDD implementations that integrated meter data analytics were categorized as EIS + FDD in Figure 5 (previous page). However, since the software applications were primarily FDD solutions, we have combined the FDD and EIS + FDD categories for the cost and savings analysis in the remainder of this report. Campaign participants implemented products from 40 different EMIS vendors, which points to the breadth of product type covered by this study.

Most organizations needed fewer than six months to install and configure their EMIS. A few organizations experienced significant challenges getting meters connected and communicating, with multiple years required to get all the issues resolved and the EMIS in use. For example, a large campus may be integrating meters and sub-meters for multiple fuels (electric, natural gas, chilled water, hot water, steam), with many different meter vendors and vintages across the campus.

Participants implemented products from 40 different EMIS software providers

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 organizations had an energy management team mostly made up of facility engineers or technicians and energy managers. The energy managers tended to lead the analysis process, sometimes supported by a consultant or service contractor. Just over half the organizations contracted with a service provider to support their use of EMIS, and more than half of the energy management teams used a formalized MBCx process that included continuous analysis (rather than periodic review).

The participating organizations that implemented MBCx provided information on their scope of activities:

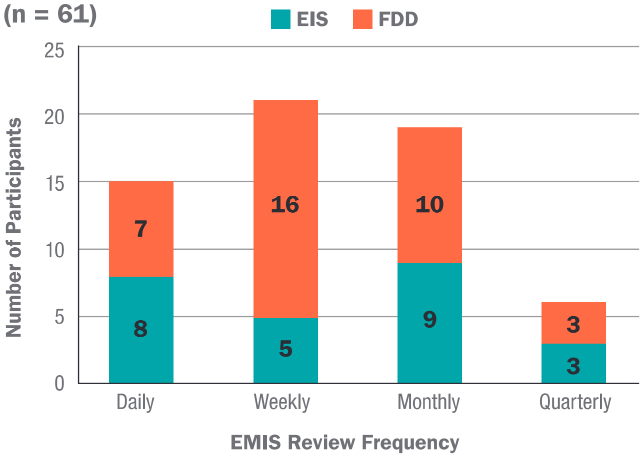
- **COMMON MBCX ACTIVITIES:** Commissioning the EMIS to verify data accuracy and configuration, in-house review of EMIS analysis and reporting to identify issues, implementing a management process for taking action to correct issues, and using the EMIS to document energy and/or cost savings
- **LESS COMMON MBCx ACTIVITIES:** Staff or occupant recognition for energy savings efforts, and an EMIS training program for in-house staff to maintain ongoing energy management processes

While the data inputs to EMIS are generally a combination of 15-minute and hourly data, EMIS outputs can be reviewed by staff as varying frequencies based on need. Figure 6 shows that FDD users most commonly review the outputs weekly, whereas EIS users most commonly review outputs monthly or daily. The EIS was often used both to conduct daily electric load analysis and to prepare for monthly energy team meetings and reports.

While a review frequency of daily or weekly is desirable to benefit from the real-time results of analytics, constraints on operations and maintenance (O&M) staff time may lead to monthly review, either in-house or through an MBCx service provider. Since notification of emergency-type faults are generally available through the BAS directly (e.g., a chiller is off-line), the issues found through an FDD may not be urgent from a safety and comfort perspective. The FDD software can assess the severity of the faults and determine how long they have occurred, so that responses can be prioritized for whatever frequency of action is desired.

FIGURE 6: Frequency of EMIS review by EMIS type

(n = 61)



3.2 EMIS Benefits

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

Benefits Motivating EMIS Implementation

Energy and cost savings are almost always a driving factor in the decision to implement an EMIS, as shown in Figure 7.

The wide range of benefits indicated by organizations provided motivations to install an EMIS and value from multiple perspectives: owners, energy/facility managers, and building operators. While energy cost savings was a common driver, it is noteworthy that 79 percent of organizations considered the EMIS a benefit for informing retrofits or validating project savings. Occupant comfort and improved operations were additional benefits considered important by more than half of participating organizations.

While energy cost savings was a common driver, 79 percent of organizations considered the EMIS a benefit for informing retrofits or validating project savings

Further, non-energy benefits played 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 typically assessed when there are comfort complaints. Using FDD, building operators can evaluate terminal unit performance 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.

Top Measures Implemented

Organizations participating in the Campaign were asked to indicate up to 10 of the most frequently implemented measures that they identified using their EMIS from a list of 26 common operational improvement opportunities. Figure 8 (next page) shows the frequency in which measures were selected.

The measures in Figure 8 are consistent with typical measures implemented during EBCx. The higher education and office sectors focused more than the other market sectors on occupant behavior through sharing energy information with staff and students. FDD supported identification of simultaneous heating and cooling, economizer operation, reset schedules, and control loop hunting, among other measures. Both EIS and FDD supported identification of improved schedules and setpoints. The ways in which EIS and FDD support the identification of these measures are summarized in Table 2 and Table 3 (page 21).

FIGURE 7: **Benefits of implementing EMIS**

(Percent of time benefit was chosen by participating organizations, may select multiple benefits)

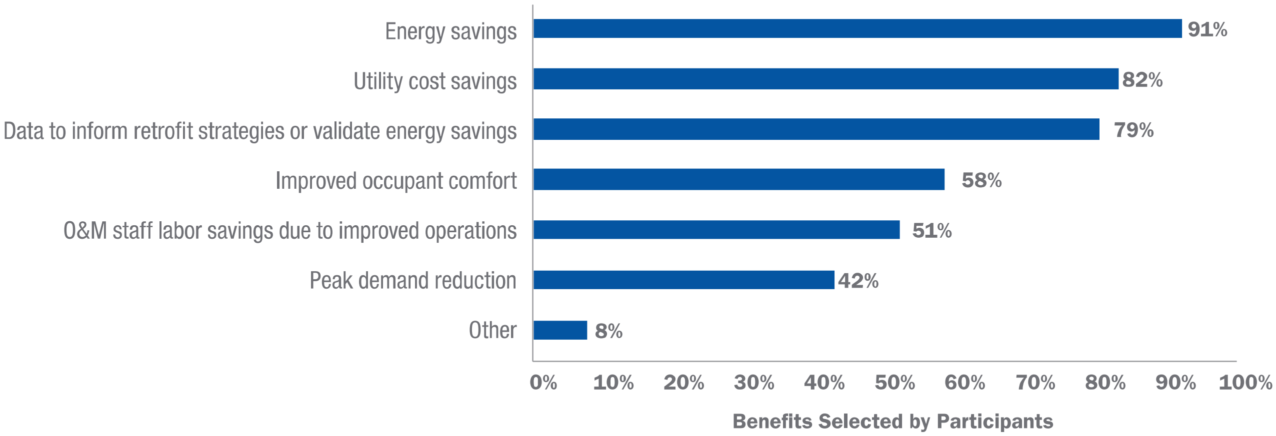


FIGURE 8: Measures implemented with EMIS support by organizations in the Smart Energy Analytics Campaign

(Respondents may indicate multiple measures; n = 78)

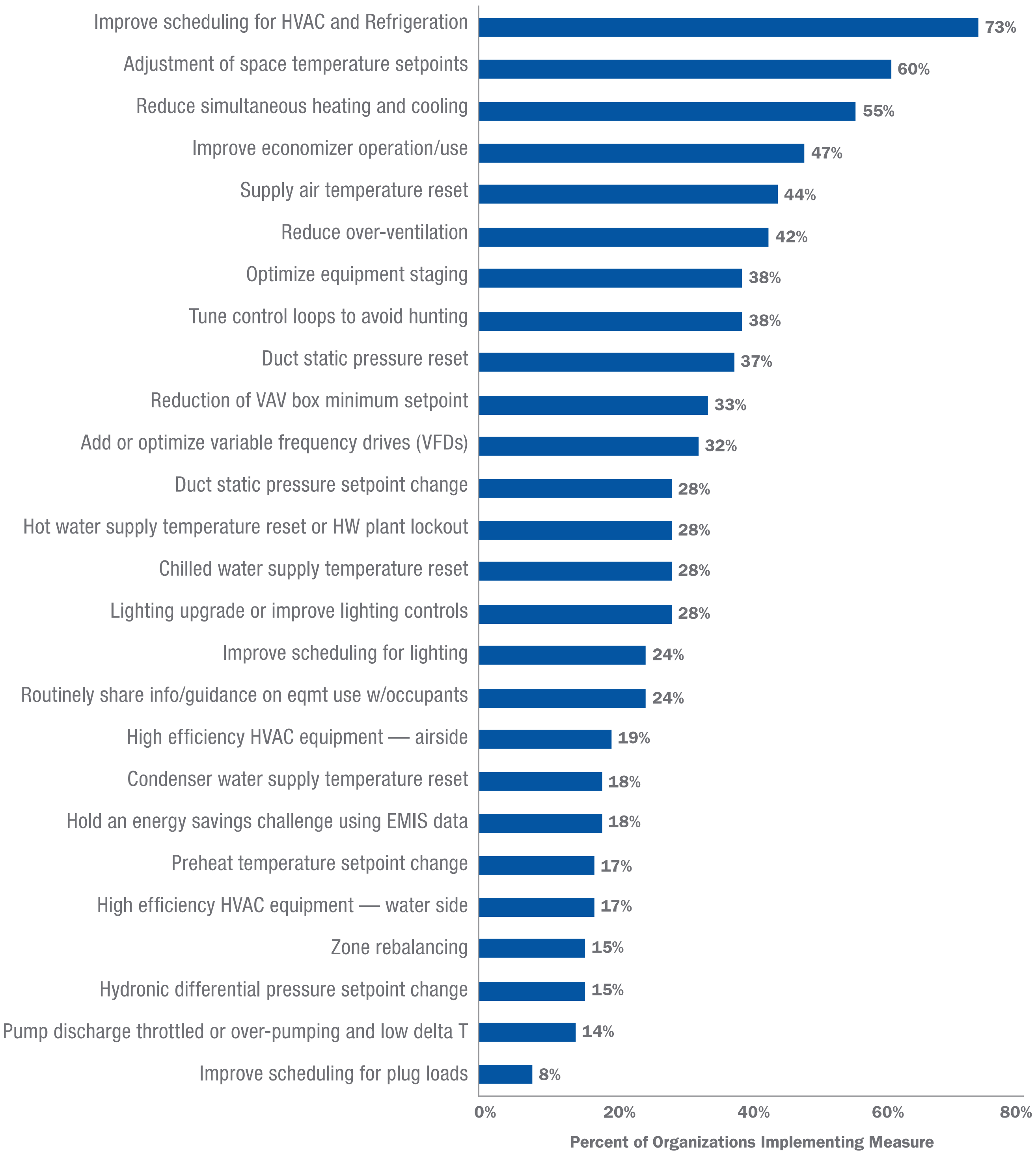


TABLE 2: Summary of commonly used metrics and analyses in EIS

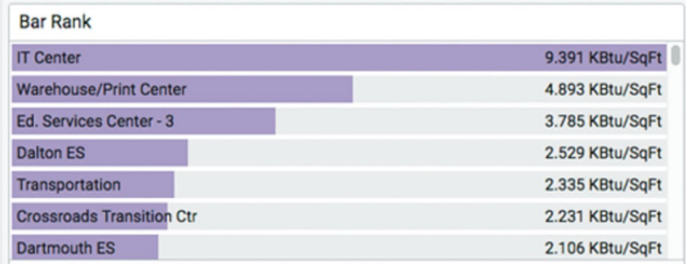
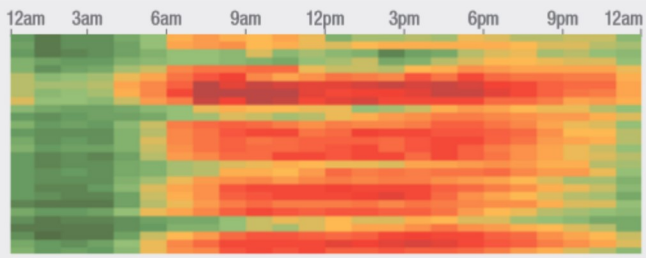
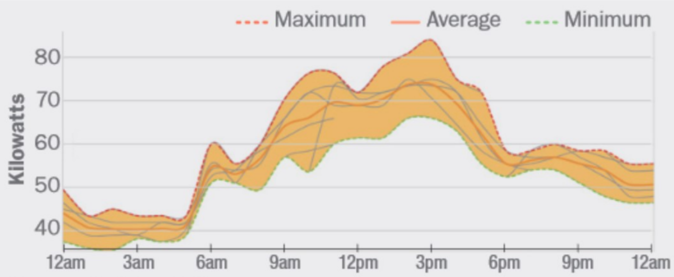
Common Metrics and Analyses	Used to Identify	Example
Energy use intensity (EUI), kBtu/sq ft	– High energy use relative to the portfolio	 *Source: Aurora Public Schools*
Heat maps	– Scheduling improvements – Baseline reduction opportunities	 *Source: Macalester College*
Load profiles	– Scheduling improvements – Baseline reduction opportunities – Peak demand reduction opportunities – Energy use by hour relative to modeled prediction	 *Source: Carleton College*

TABLE 3: Summary of common faults detected by FDD technology

System Components Analyzed	FDD Tool Analysis
Controllers (actuators/valves/ speed drives)	– Compare controller output setpoints to the actual condition to find failed devices. – Determine the stability of controllers.
Dampers (air handling units, terminal units)	– Identify if a damper is stuck open, closed, at a fixed position, or leaking. – Compare mixed air temp to return air temp with the outdoor air damper closed.
Cooling/heating valves and coils	– Identify if a valve is stuck or leaking. – Identify a fouled or blocked coil. – Detect when temp difference exists across a coil when valve is shut or when the system is not achieving a desired temp drop across a coil when valve is open.
Economizer operation/use	– Detect if the rooftop units (RTUs) or air handling units (AHUs) are not economizing when they should. – Detect if the RTU/AHU is economizing when it should not (i.e., calculate the relevant theoretical outdoor air ratio with outdoor air temp, return air temp, and mixed air temp). – Detect if the economizer lockout setpoint is too high or low.
Simultaneous heating and cooling	– Detect if unnecessary heating, economizer cooling, and/or mechanical cooling occur at the same time.

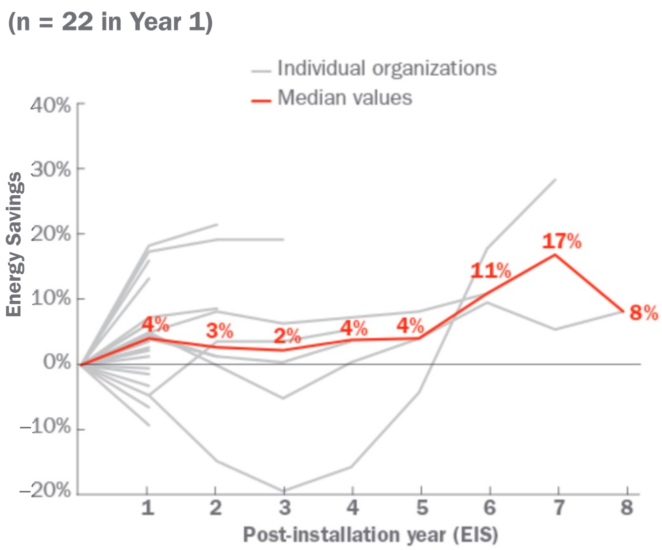
Energy Savings

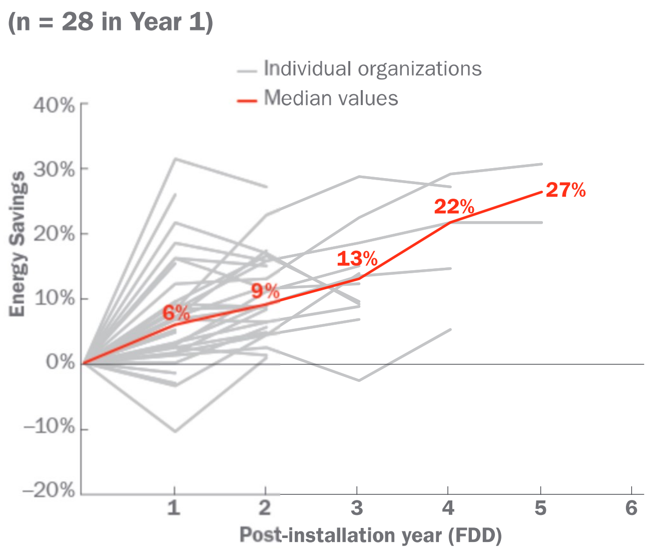
Four organizations reported savings results determined from interval data analysis tools. Two organizations estimated savings using engineering calculations. The energy savings from the other 44 participants were calculated by LBNL using annual energy use analysis.

With annual energy use data from 22 organizations[5] implementing EIS, and 28 organizations implementing FDD, the sub-cohorts were large enough to report energy savings for each EMIS type. The implementations with both EIS and FDD (17 organizations) were primarily FDD solutions that integrated some meter data analytics and were combined with the FDD-only implementations (11 organizations) within these results.

Figure 9 show the median savings across the buildings in each portfolio, for each year after implementation, or EIS and FDD implementations, respectively. In each plot, the gray line represents a single organization's portfolio of buildings, and the y-axis represents percent savings relative to the year before the EMIS installation, referred to as the "baseline year." The red line indicates the median savings across all organizations. The results indicate that savings generally increase over time for the organizations that had EMIS installed for multiple years. The decrease in savings for EIS in Year 3 is likely an artifact of the small number of organizations reporting at three years and beyond. Energy data were analyzed as provided by the owners without normalizing for other potential events such as changes in building equipment or occupancy levels.

FIGURE 9: Percent energy savings relative to the year before EMIS installation by organizations participating in the Smart Energy Analytics Campaign





[5] EIS energy use data were reported by 14 participants in the Campaign and 8 participants in the "2013 EIS study" (Granderson et al. 2016).

Tables 4 and 5 show median savings since the EMIS was installed, in percentage and dollars per square foot per year. In some cases, the EMIS had been installed for more years than the energy data were provided. For savings in Year 3 and beyond, the savings reported are not necessarily attributable to the EMIS, therefore these data are shown in darker gray.

Study participants with EMIS made improvements to their buildings, achieving a median second-year energy savings and ranges[6] as summarized below and shown by year in Table 4.

- **EIS:** 3 percent ($0.03/sq ft) savings range: –15% to 22%
- **FDD:** 9 percent ($0.24/sq ft) savings range: 1% to 28%

TABLE 4: Summary of cumulative energy savings for organizations with EIS

EIS	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Number of organizations	22	10	6	5	3	3	2	1
Floor area (millions of sq ft)	139	82	51	50	40	40	5	3
Number of buildings	2,109	1,333	1,234	1,216	1,139	1,139	62	54
Median savings (%)	4%	3%	2%	4%	4%	11%	17%	8%
Median savings ($/sq ft/yr)	$0.10	$0.03	$0.02	$0.05	$0.11	$0.41	$0.47	$0.23

TABLE 5: Summary of cumulative energy savings for organizations with FDD

FDD	Year 1	Year 2	Year 3	Year 4	Year 5
Number of organizations	28	18	10	5	2
Floor area (millions of sq ft)	101	90	50	37	3
Number of buildings	556	509	193	84	22
Median savings (%)	6%	9%	13%	22%	27%
Median savings ($/sq ft/yr)	$0.17	$0.24	$0.38	$0.37	$0.88

[6] Negative savings (an increase in energy use) occurred for two organizations with EIS in the second year after installation. Negative energy savings is likely attributable to changes in building use or additions to building floor area.

By the second year of installation, study participants with EIS achieved a median annual energy savings of 3 percent ($0.03/sq ft) and participants with FDD tools achieved a median savings of 9 percent ($0.24/sq ft). Applying these savings across the organizations participating in the Smart Energy Analytics Campaign, annual savings are projected to be 4.1 trillion Btu and $95 million once EMIS use is established for all organizations. Further, these savings are likely to increase in subsequent years as additional opportunities are uncovered.

Second-year savings are emphasized, since in many cases we found that the EMIS became better utilized over time, as users gained experience with the technology and established routine processes to act upon findings. Taking action also can require a certain amount of lead time purely for practical reasons. Second-year savings are therefore taken as a reliable representation of the benefits that EMIS provide. As previously described, these savings are not attributed exclusively to the use of EMIS. However, owners shared that it was essential to have the data and analysis readily available from their EMIS to enable savings from their overall energy management program. Figure 8 reported the top energy saving measures identified and implemented through use of the EMIS; additional measures may also have been implemented.

Ongoing EMIS use and operational integration supports persistence of savings and increases in savings over time

The results surfaced a three-fold increase in the median savings achieved by users of EMIS with FDD capabilities versus those with EIS capabilities. This result stems from the nature of the software; EIS provides big-picture trends in energy use while FDD pinpoints faults at the equipment level. Best practice implementation includes both EIS and FDD capabilities.

Ongoing EMIS use and operational integration supports persistence of savings and increases in savings over time. After the second year, other projects may be initiated, and portfolio or building-level savings may increase due to the EMIS or due to other efficiency projects. While we report 17 percent median savings at organizations with EIS after seven years and 27 percent median savings at organizations with FDD after five years, we do not have evidence to attribute these longer-term savings solely or even primarily to EMIS.

In addition to helping identify savings opportunities, EMIS gives owners the ability to monitor their energy savings progress over time, which is invaluable to all energy saving efforts. Further, almost 80 percent of organizations reported using their EMIS to inform retrofit strategies at their facilities, including identifying retrofits, sizing equipment, and verifying savings (Figure 7, page 19).

3.3 EMIS Costs

With cost data from 37 organizations[7] implementing EIS and 35 organizations implementing FDD (or a combination of EIS and FDD within a predominantly FDD-focused tool), the sub-cohorts were large enough to report energy savings separately for each EMIS type. These 72 organizations encompassed 471 million sq feet of gross floor area. The results for median base cost and recurring cost per square foot are presented in presented in Figures 10 (next page) and 11 (page 26) by EMIS type, with a separate bar for each organization. Most organizations participating in the Campaign have large portfolios; therefore, the costs normalized by floor area reflect these economies of scale, with lower cost per square foot than would be typically found for smaller scale implementations. As stated in the methodology, the base cost includes the software and installation costs, and the recurring cost includes the annual software fees and any MBCx service provider fees that were incurred. The range of costs observed in the Campaign data reflects the scope or depth of service provided with the EMIS installation, as well as the variability in industry pricing models.

Base cost

Among reporting organizations, the base cost per square foot for installing and configuring FDD software was five times that of EIS. There is significantly more work required to integrate the BAS data into FDD software than to integrate meter data into EIS software

[7] EIS cost data were reported by 20 participants in the Campaign and 17 participants (Granderson et al. 2016).

because there are more BAS data and a variety of points must be mapped for use in the FDD software. The high end of the base cost occurred at sites where the FDD was installed at greater depth or on more complex systems. Data integration across the BAS and many devices drove the higher base cost.

The low end of the base cost generally occurred when there were fewer points brought into the EMIS. Some FDD installations included all available BAS points and FDD rules, while others focused more narrowly on key systems. For example, the lowest base cost for FDD was for a large installed floor area that focused on FDD for their central plants and did not implement diagnostics at the zone level. In cases in which data was straightforward to access from the BAS, owners tended to bring all the BAS data into the FDD software even if the data were not initially being used in fault algorithms. For installations with more difficulty accessing and mapping the BAS data to the FDD software, fewer points were included to reduce installation costs.

Large portfolios gain benefits in implementing EMIS across the portfolio

In reviewing how the base cost of EMIS changes with the size of the portfolio implementation, a few trends emerged. For EIS installations, the base cost per square foot was largely stable across portfolio sizes up to 5 million sq ft, with costs between $0.01–$0.05/sq ft. The economies of scale for the base cost of FDD as the building portfolio size increases were more apparent. For FDD implementations in portfolios greater than 1 million sq ft in size, costs per square foot showed a downward trend from above $0.20/sq ft for portfolios under 1 million sq ft in size, reducing to $0.05–$0.10/sq ft for portfolios above 3 million sq ft. Many of the data infrastructure costs for any FDD project, regardless of portfolio size, are similar. FDD is generally applied to larger buildings because it has a higher base cost and is more time-consuming to implement than EIS.

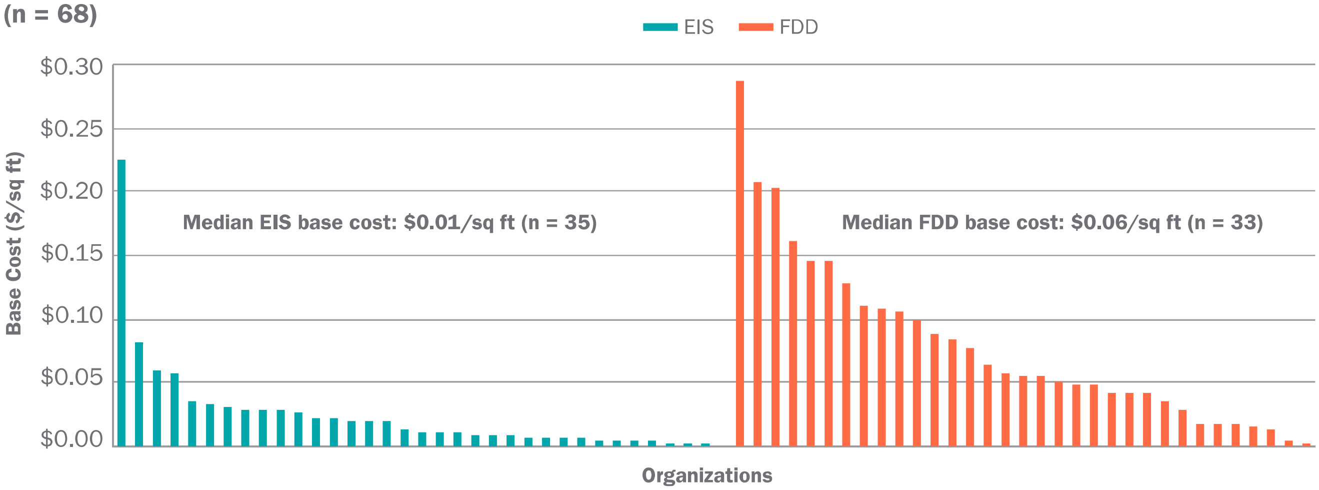
Large portfolios gain benefits in implementing EMIS across the portfolio, including the ability to use EIS to benchmark their buildings, manage energy use from a single location, and potentially control building systems remotely through an operations center. The type of FDD used by Campaign participants was focused on addressing issues in complex HVAC systems; other FDD products exist for packaged HVAC but were not used by Campaign participants. FDD software was more often implemented on the larger buildings in a portfolio due to the complexity of the systems and significant energy savings opportunities. EIS are implemented across a wide range of building sizes since whole building meter data is the minimum necessary input.

Recurring cost

Recurring costs for FDD were higher than for EIS. This cost difference was due to the complexity of tuning existing FDD rules to the organizations' HVAC systems and interpreting diagnostic results. As previously noted, the EMIS recurring costs include two components: the annual licensing/software-as-a-

FIGURE 10: Base cost by EMIS type

(n = 68)



service (SaaS) fee and ongoing MBCx service provider fees if they are part of the scope. Some vendors include MBCx services within their SaaS fees, so we have not reported the breakout between annual licensing cost and ongoing MBCx service provider fees.

For EIS, both the upfront and ongoing effort required are more modest than for FDD, and this is reflected in the pricing. For example, an FDD installation that includes ongoing turnkey measure implementation by the MBCx service provider resulted in the highest FDD recurring cost reported, at $0.16/sq ft, and the lowest recurring cost reported ($0.0002/sq ft) occurred at a large campus with an EIS connected to hundreds of building-level meters. Typically, organizations with EIS did not utilize MBCx service providers, and about half of the organizations with FDD contracted with MBCx service providers for additional support.

In addition to normalizing costs by floor area, costs were normalized by number of points (e.g., meters and sensor data from the BAS) and number of buildings. These metrics are shown in Table 6. The EIS cost per point (in this case, per meter) was $400, and the recurring cost was $150/meter. This cost does not include the cost of the meter itself, only the cost to integrate existing meters and configure the EIS software. There are, on average, four meters per

FIGURE 11: Recurring software and MBCx service cost by EMIS type

(n = 66)

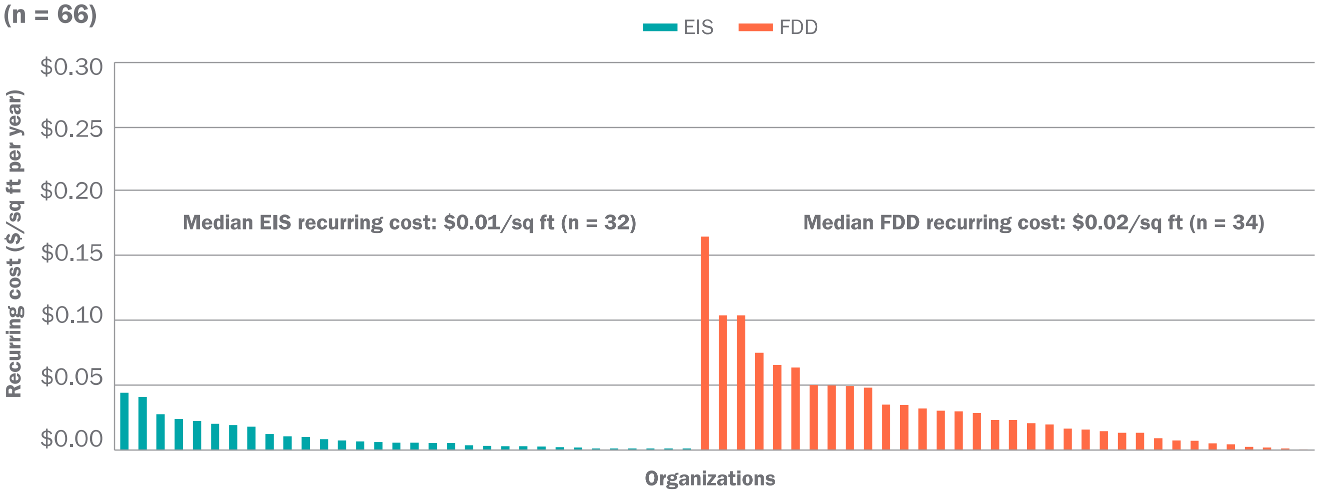


TABLE 6: EMIS cost summary

Costs by EMIS Type	Median Costs		
	Per point	Per building*	Per sq ft
EIS (n = 37)			
Base software and installation (one-time cost)	$400	$1,500	$0.01
Recurring costs ($ per year)	$150	$400	$0.01
FDD (n = 35)			
Base software and installation (one-time cost)	$9	$13,000	$0.06
Recurring costs ($ per year)	$4	$3,500	$0.02

*For each participant, a "per building" cost was established. This column represents the median of the participant "per building" costs. Since the median participant in the "per building" and "per sq ft" columns reference different building sizes, the "per building" and "per sq ft" costs do not have the same basis and therefore do not scale.

building connected to the EIS. Costs per point for FDD are low since more than 1,600 BAS points per building[8] are integrated. The median cost per building to implement FDD was shown to be more than eight times higher than that to implement EIS, however the median building size with FDD was larger (155,000 sq ft) than the median building size with EIS (90,000 sq ft).

When considering the price of EMIS software it is important to consider the full picture of base and recurring costs. For example, with the study cohort, there were instances where the base costs were low, but the recurring costs were much higher than average. There were also instances where the base cost was high but there was little to no recurring cost, since the software was hosted and managed in-house.

While we have calculated costs per point, per building, and per square foot, vendors price their systems in various ways. Some EMIS vendors price by groups of points (e.g., cost per 10,000 points), while others price per building or based on total floor area. When there are recurring software costs, these costs generally begin once the EMIS has been fully installed.

In-house labor cost

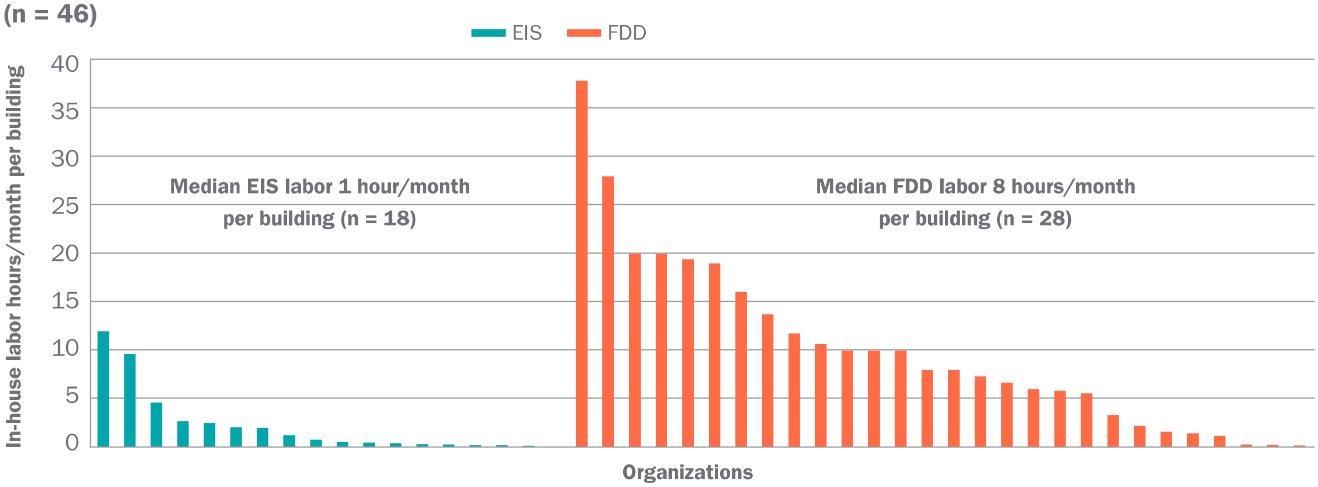
Last, we summarize the time it takes for in-house staff to use the EMIS to identify and follow up on issues. Figure 12 shows bars by organization. Each organization interacts with their EIS about one hour per month per building and interact with their FDD about eight hours per month per building. It is not surprising that owners spend more time using their FDD software than their EIS software, due to the detailed recommendations included with FDD implementation and the larger median building size for buildings with FDD in the dataset.

Overall, the total cost of use and ownership for EIS was lower than that for FDD. With easier installation, EIS is often the point of entry for an owner new to EMIS. FDD implementations have more data streams and complexity in implementing diagnostics, therefore higher costs than those associated with EIS can be expected.

The time it takes in-house staff to utilize the EMIS is a significant portion of overall EMIS costs. While the labor cost may be embedded in the existing staff workload (and thus may not require additional funding), estimates of the labor cost from building staff were significantly higher than the recurring costs for FDD. The high end of the labor cost was reported from sites in their first year of FDD installation, during which time many faults were detected that may have existed for some time. Not surprisingly, the highest labor costs occurred at sites that use in-house staff to manage the MBCx process rather than service providers since service provider costs are considered recurring costs in our cost categorization methodology.

FIGURE 12: Estimated in-house labor cost by EMIS type

(n = 46)



[8] The average number of BAS points per building integrated with the FDD software was calculated for each participant, and the median of those values is 1,655 points.

Some organizations' annual labor costs are quite low per square foot, either due to outsourcing to an MBCx service provider or a lack of engaged use with their EMIS. Levels of support from the integrators and vendors in installation and configuration varied widely, from mostly in-house EMIS installation by operations staff with a low level of vendor support to full-service installation with vendor support to analyze findings. Both the extent of engagement with the EMIS and the varying level of contracted MBCx support affected the estimated in-house labor cost.

Overall, the total cost of use and ownership for EIS was lower than that for FDD. With easier installation, EIS is often the point of entry for an owner new to EMIS. FDD implementations have more data streams and complexity in implementing diagnostics, therefore higher costs than those associated with EIS can be expected.

3.4 Cost-effectiveness

Using the cost-effectiveness methodology described in Section 2, we calculated cost-effectiveness for EIS and FDD by participant, then report the median, as shown in Figure 13. The median simple payback period for both EIS and FDD is two years with a total of 206 million sq ft of floor area analyzed.

While these cost-effectiveness estimates entail an inherent degree of uncertainty, they are based on more data than have previously been available from actual EMIS installations. Moreover, they are well within the two- to four-year payback requirements that drive most energy efficiency decision making.

Figure 13 shows mostly cost-effective EMIS implementations across the 24 organizations (21 portfolios, 2 high rise office buildings, and 1 manufacturing facility). Three organizations with EIS installed had negative energy savings, and therefore were not included in the analysis since the payback period calculation is not applicable in these cases.

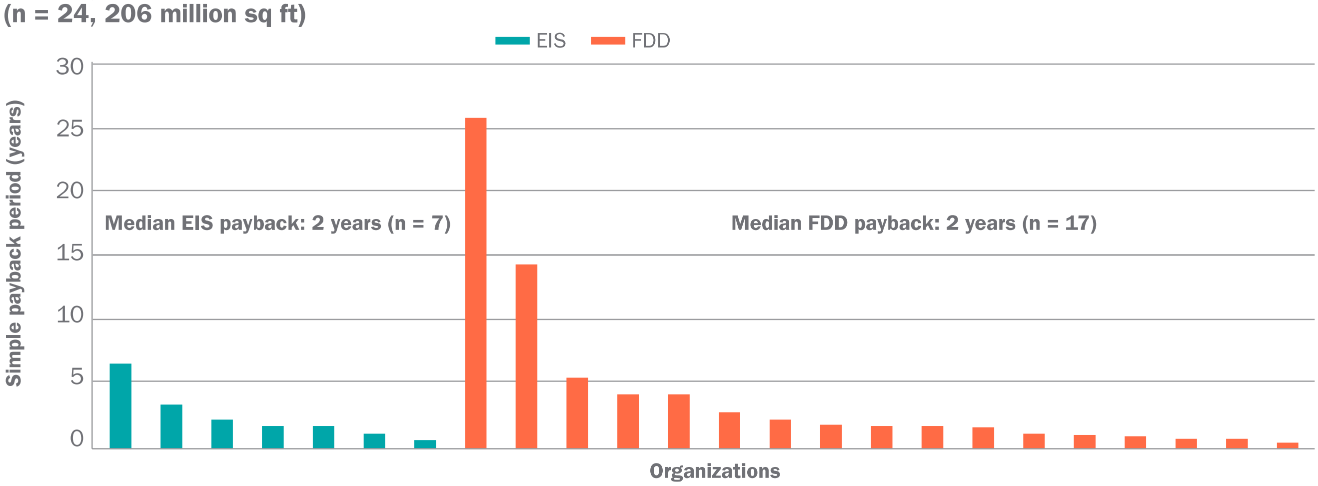
We compared these cost-effectiveness estimates with published EMIS cost-effectiveness results, and we found only one study that quantified cost-effectiveness. An MBCx program was implemented for the University of California and California State University systems which supported implementation of EIS and MBCx through incentives provided by California's investor-owned utilities. This MBCx program utilized an EIS coupled with EBCx and resulted in 11 percent site-level energy savings and a median simple payback time of 2.5 years for 24 buildings representing 3.2 million sq ft (Mills and Mathew 2009). The MBCx program result is comparable to the 2-year simple payback found through the Campaign dataset.

Results show a two-year simple payback for EIS and FDD

Organizations in the Campaign used their EMIS as part of an integrated energy management strategy, informing operational improvements, the need for retrofits, and retrofit sizing. Determining cost-effectiveness of an EMIS (a tool in the MBCx process) is akin to determining the cost-effectiveness of any business-specific software—the software is one of many tools needed to effectively perform the job.

FIGURE 13: Estimated simple payback period by EMIS type

(n = 24, 206 million sq ft)



However, cost effectiveness of EMIS can be estimated by comparing the energy savings they enable to the costs to procure and use them.

3.5 Enablers and Barriers to EMIS Implementation

Through the course of technical assistance and qualitative data collection from Campaign partners, we have evaluated and summarized enablers and barriers to successful EMIS software and MBCx process implementation. Two of the most significant barriers to successful EMIS software and MBCx process implementation include managing data quality and implementing changes based on the analytic findings.

- **DATA QUALITY AND DATA MANAGEMENT:** Accurately and efficiently gathering, communicating, and storing data from various systems and devices is a common challenge that can lead to long implementation time frames. One barrier to EMIS integration has been lack of consistency in data naming conventions. The data in each building are labeled with names that describe the data type, content, unit, location, and relationships to other equipment. Interpreting the names of data points into a unified format that is readable for FDD tools typically involves labor-intensive efforts. FDD software installation is streamlined when data points are named and tagged in a standardized way (potentially reducing installation time with automated data tagging methods). Creating a united metadata schema to understand the relationships between points — as well as establishing standard, consistent naming conventions — are key steps toward streamlining the implementation of FDD tools. Project Haystack and Brick are two such schema.[9]
- **FIXING ISSUES FOUND:** With competing priorities, there is often a lack staff time to review the EMIS dashboards and reports, and to investigate and implement findings. While initially there may be challenges with operation staff acceptance and use of EMIS as a day-to-day support tool, staff buy-in improved with adequate training and support.

While there are challenges with implementing any new technology, common enablers for successful EMIS implementation emerged based on the experiences of Campaign participants:

- **MANAGEMENT BUY-IN AND GOALS:** Corporate-level energy savings or carbon emissions reduction goals have been a driver for EMIS investment because the EMIS helps monitor progress and achieve these goals. When management views EMIS as an essential tool in the building operations staff toolkit, EMIS is not simply an added cost but part of standard operating practices.
- **EMBED EMIS IN STANDARD PROCESS:** Organizations that institutionalized the use of data analytics in their standard meeting and reporting processes found their MBCx process to be valuable, from both cost savings and building comfort perspectives.

Table 7 (next page) summarizes a broader list enablers and barriers found through the course of working with organizations in the Campaign.

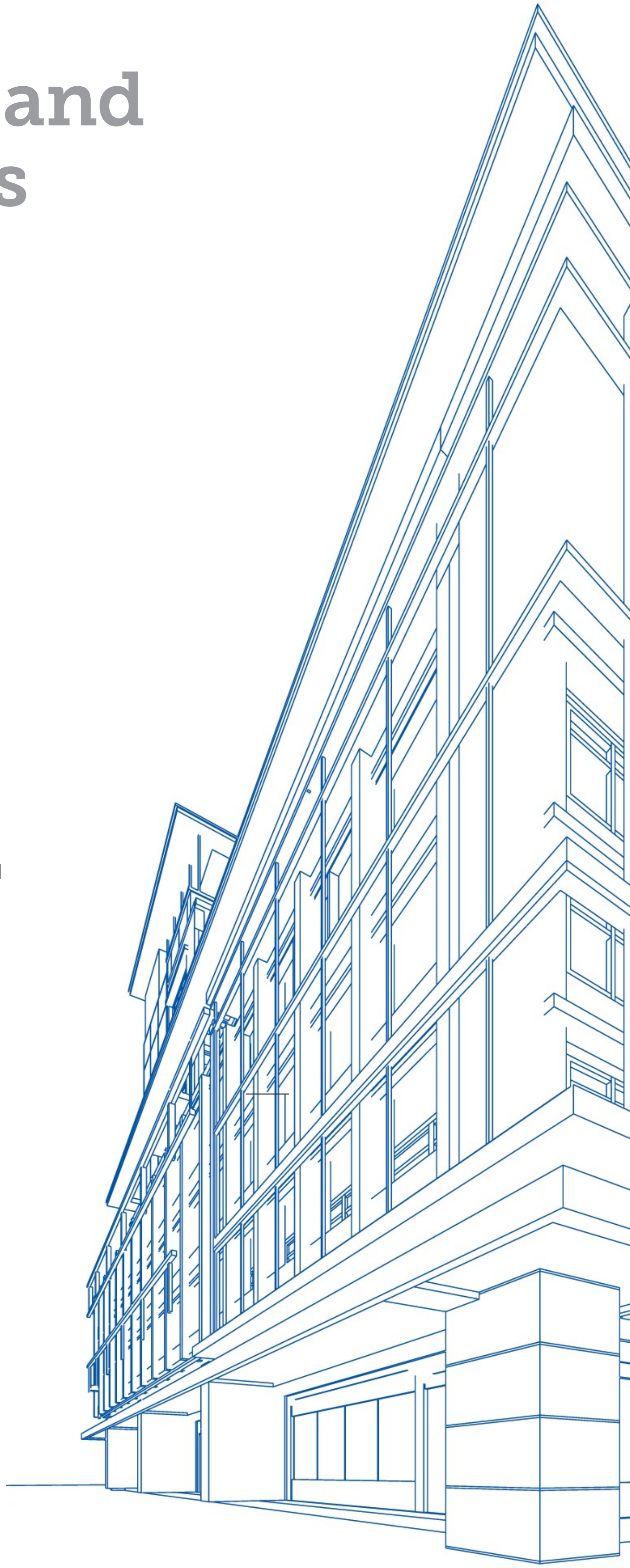
[9] Project Haystack (project-haystack.org) is an open source tag set used to standardize metadata information about equipment and its relationships in control, energy, HVAC, lighting, and other environmental systems. The model includes naming conventions and taxonomies to help exchange information and unlock value from the vast amounts of building data. Brick (brickschema.org) is an open source semantic data model to promote consistent data modeling practices. ASHRAE is pursuing a semantic interoperability standard expected to incorporate elements of these and other buildings-related schema.

TABLE 7: Enablers and barriers to successfully implementing EMIS and MBCx

Category	Enablers	Barriers
EMIS Specification and Selection	– Focus RFPs where there is the most interest in using the data (i.e., operations staff may desire FDD for specifying faults, while energy managers may desire EIS to simplify energy tracking and reporting) – Understand vendor pricing structures (based on # points, floor area, # of sites)	– Users are not clear on which EMIS product features they need – Lack of understanding of differences between EMIS products – Lengthy procurement process through request for proposal
EMIS Installation and Configuration	– Data warehouse provides a single location for all relevant data streams – EMIS service providers support data integration and setup, then if desired, manage the FDD process – Commissioning the EMIS installation avoids problems later	– Data integration problems include difficulty extracting data from older BAS, disparate naming conventions, and difficulty bringing all the data into a single database – Data quality problems (gaps in data, incorrect meter readings) – Lack of existing metering in place
Analytic Process	– Metrics and charts that summarize performance – Analytics are implemented to address specific operational challenges, rather than implementing all possible analytics – Vendors and service providers implement an existing FDD rules library	– Users experience data overload instead of gaining actionable insights – There is difficulty in pinpointing measures or finding root causes of fault conditions – A lack of an M&V process in place to verify savings
MBCx Organizational Process	– Energy savings goals drive EMIS use – Management buy-in for implementing technology to support building operations – Staff that routinely use EMIS in their standard process find value – Ability to reinvest energy cost savings	– Difficulty directing resources to fix issues found – Achieving persistence of savings without a robust MBCx process – Overriding the BAS due to a desire to operate in manual mode

SECTION 4:

EMIS Product and Service Trends



HIGHLIGHTS:

- **Numerous product options exist for selection of EMIS, with a trend toward combined EIS and FDD products**
- **MBCx services that analyze, verify, and help fix issues found through use of EMIS becoming more common**

This section presents trends in EMIS product and services delivery based on interviews with over 100 building engineers or energy managers and software demonstrations from dozens of EMIS developers. As EMIS technology advances, so does the service structures offered to support owners implementing these tools.

4.1 EMIS Products and Selection

Given the wide variety of available features, selecting an EMIS can be a challenging task. Most Campaign participants knew whether they wanted to start with implementing an EIS or with FDD. Whether they started with an EIS or FDD, almost all participants were striving for an EMIS design that was flexible for future expansion. Some participants wanted as many energy management features in one tool as possible to avoid multiple tools and software interfaces, while others brought together solutions using multiple software products.

There are over 100 EMIS products in the market

Organizations either went through a request for proposals (RFP) process or chose an EMIS based on software demonstrations and interviews. In either case, there were a variety of different reasons for choosing their vendor; for example, the desire to program the software using in-house labor, ease of implementation within existing maintenance processes, and known use by peers.

Through the course of the Campaign, more than 100 EMIS products were available in the market (68 EIS products, 34 FDD products, and 8 ASO products), which is a representative snapshot and not intended to be a comprehensive list. Twenty-five of these vendors offered both EIS and FDD capabilities. Through the process of developing and maintaining the EMIS products and services list, several insights emerged:

- **EVOLVING EMIS MARKET:** New EMIS tools are continually being developed, with some vendors consolidating or acquiring products. The field is crowded, with vendors working to differentiate their software based on feature sets, market-sector focus (i.e., small to medium businesses), and partnerships with other EMIS vendors for integrated suites of products.
- **PRODUCT/SERVICE PACKAGES:** Some EMIS products are being embedded in multiple tools as white labeled products, which may be combined with an EMIS service provider's ongoing analytic support. The value-add from the service provider may include enhanced project management and fault prioritization capabilities.

While almost all participants have hourly whole building energy use available in their EMIS, the use of advanced meter-data analytics such as automated load shape analysis and automated M&V using interval meter data is not yet common. Over a dozen EMIS products in the market currently have automated M&V capability built into their products (Granderson and Fernandes 2017); however, the use of this feature was not widespread by Campaign participants. Simpler ways to estimate savings were generally used, including monthly utility bill comparisons and use of the ENERGY STAR Portfolio Manager.

Owners with experienced in-house teams often received training from the FDD vendor to program and tune the FDD rules on their own. Some owners develop a "core" set of rules to roll out across a portfolio and tweak them for each unique building's situation. While most FDD software has built-in estimation of the energy cost waste of each fault to use as a means of prioritization, calculation of cost waste is not standard across tools. Overall, the common benefit from FDD systems was the ability to monitor thousands of data streams that could not otherwise be monitored manually.

Finding a single EMIS that serves the many possible functions (e.g., data management, benchmarking, utility bill management, tenant billing, meter and system analytics, and project tracking) can be a challenge. There are few EMIS software that include all these features. Vendor partnerships may address the scope of software, and tool capabilities are also expanding to meet multiple needs. MBCx service providers can also serve an integration role as they analyze data streams, potentially using multiple EMIS software and providing integrated analysis to owners.

The benefits from implementing both EIS and FDD functionality are clear. We have seen participants who only implement system-level FDD and do not know how much energy they are using or saving. Conversely, those that implement only EIS tend to focus mainly on schedules, baseload, and peak demand, and may miss the more nuanced operational opportunities identified through FDD. EIS and FDD can work together to provide both a top-down and bottom-up analysis of a building's energy use and systems.

The benefits from implementing both EIS and FDD functionality are clear

4.2 MBCx Process and Service Providers

A compelling evolution in the industry is the expansion of EMIS market delivery through MBCx service providers using the tools to bring added value to their customers. This contrasts with earlier models that relied on in-house direct organizational use of the EMIS. MBCx service providers tend to be commissioning firms expanding into MBCx, controls or mechanical services contractors with MBCx offerings, or EMIS software vendors that provide additional engineering services. The expansion in service offerings can make the use of

EMIS 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.

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 numerous FDD software platforms have built-in estimation of the energy cost of each fault to use as a means of prioritization, many owners value the role of MBCx service providers in highlighting the most important measures for immediate action and diagnosing the root cause of faults. In some cases, the owner might seldom access their EMIS directly, only reviewing the service provider's summary reports. FDD users were most active in implementing findings when they had support from MBCx service providers in analyzing and prioritizing faults, and when a routine process was in place for following up on faults with operations teams.

> **Many owners value the role of MBCx service providers in highlighting the most important measures for immediate action and diagnosing the root cause of faults**

Once the EMIS was in place and providing benefits, organizations with top management buy-in tended to receive stable funding for their MBCx process year to year. In other organizations, the cost of MBCx and the EMIS software needed to be justified annually. One organization created a detailed business case documenting the degradation of savings in their portfolio after EBCx and the resulting benefits when MBCx processes were used (Gregory 2015).

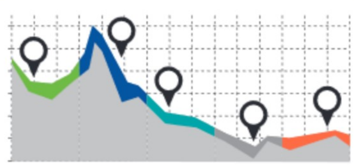
Figure 14 illustrates three different areas of support that owners may obtain from service providers. The most limited support for in-house staff is installation support from EMIS vendors or service providers, and most often this level is included in the product base cost. Additional support in prioritizing and reviewing the output of the EMIS can be provided by EMIS vendors or MBCx service providers. The highest level of assistance includes on-the-ground implementation support for corrective actions and verification of savings by an MBCx service provider.

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.

FIGURE 14: Support options for the ongoing use of EMIS

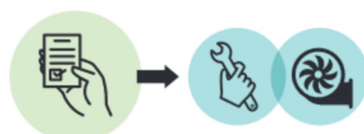
EMIS Installation and Commissioning

- Integrate data from a variety of sources
- Check data quality
- Develop diagnostic rules
- Configure EMIS user interface



Ongoing EMIS Data Review

- Prioritize findings
- Review BAS data to determine root cause
- Develop summary reports and action plans



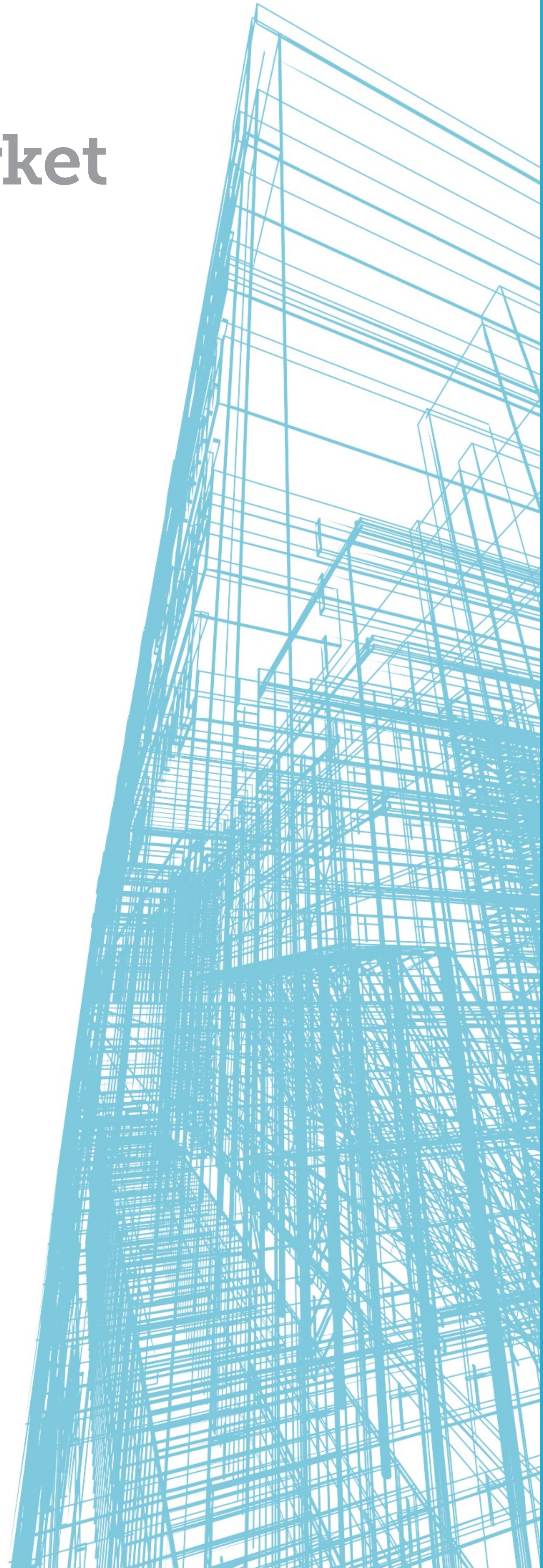
Corrective Action and Verification

- Troubleshoot issues onsite
- Track corrective actions
- Verify faults have been corrected
- Estimate energy and cost savings

Increasing levels of support from MBCx service providers to operations staff

SECTION 5:

A Maturing Market for Analytics



HIGHLIGHTS:

- **Smart Energy Analytics Campaign data reinforces and enhances prior research on EMIS benefits**
- **EIS and FDD offer complementary capabilities when deployed in parallel**
- **Organizations with FDD achieved greater savings than EIS but at a greater cost; overall both EIS and FDD showed a two-year simple payback**

There is a growing national trend in the use of analytics in commercial buildings. EIS are becoming common for portfolio owners that 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 systems. These research conclusions were drawn from a dataset of 104 participants that were involved in the DOE's Smart Energy Analytics Campaign over the course of four years, covering more than 567 million sq ft of commercial floor area and 6,500 buildings. This is the largest known dataset on EMIS technology use.

Greater transparency into building operations using robust analytics results in decision-making informed by data

FDD users achieved 9 percent median savings compared to 3 percent median savings for EIS users (both savings after two years of implementation). These savings are not attributable to specific measures, however the EMIS users shared the measures they most often implemented, including improvements to HVAC scheduling, adjustment of setpoints, reducing simultaneous heating and cooling, and improving airside economizer operation.

While organizations with FDD achieved greater savings than EIS, FDD was more expensive to implement, and most often used in larger buildings.

At $0.06/sq ft, the base cost for FDD software implementation was six times higher than the EIS base cost of implementation, and FDD annual recurring costs ($0.02/sq ft) were double that of EIS. However, FDD served as more powerful tool, providing transparency into building performance datasets and access to actionable information on how to remedy faults. In-house staff utilized their EIS a median of one hour per month per building, and their FDD a median of eight hours per month per building. FDD implementations have more data streams and complexity than EIS; therefore, higher costs than those associated with EIS are expected. This research showed that implementing EIS or FDD each resulted in a two-year simple payback period.

Greater transparency into building operations using robust analytics results in decision-making informed by data. There are a variety of successful approaches (i.e., using an in-house team or a third party) for utilizing an EMIS to find and fix operational measures, and any approach requires successful prioritization and follow-up on analytical findings. Owners that dedicate adequate staff time to review the analytics and address the opportunities identified reap the benefits of their investment. Even beyond the energy benefits, the non-energy benefits EMIS offer for monitoring healthy air quality and supporting building resilience are becoming increasingly important for today's buildings.

Organizations that implement EIS know how much energy they are consuming (and saving). Those that implement FDD find operational improvements they could not have detected without automated analysis. EIS and FDD work together to provide both top-down and bottom-up analysis of a building's energy use and systems, moving from reactive to proactive building operations that are continuously informed by analytics.

The Smart Energy Analytics Campaign data illustrates a maturing market for EMIS, with a wide range of tools being deployed successfully at scale

Taken as a whole, the Smart Energy Analytics Campaign data illustrates a maturing market for EMIS, with a wide range of tools being deployed successfully at scale. Over the past decade EMIS have moved from being a niche tool with great potential, to an essential energy management tool for leading organizations to improve building performance, enhance occupant comfort, and achieve aggressive energy savings goals.

References

ASHRAE. 2013. ASHRAE Standard 202-2013, Commissioning Process for Buildings and Systems. American Society of Heating Refrigeration and Air Conditioning Engineers. ISSN 1041-2336.

Building Commissioning Association. 2018. The Building Commissioning Association Best Practices in Commissioning Existing Buildings. https://www.bcxa.org/resources/existing-building-commissioning-best-practices.html. Accessed September 22, 2020.

Crowe, E., Mills, E., Poeling, T., Curtin, C., Bjørnskov D., Fischer, L., Granderson, J. 2020. Building Commissioning Costs and Savings Across Three Decades and 1,500 North American Buildings. *Energy and Buildings* 227. https://doi.org/10.1016/j.enbuild.2020.110408.

Fernandes, S., J. Granderson, R. Singla, and S. Touzani. 2018. Corporate Delivery of a Global Smart Buildings Program. Energy Engineering Jan 1;115(1): 7–25. DOI: 10.1080/01998595.2018.11950815. https://eta.lbl.gov/publications/corporate-delivery-global-smart.

Fernandez N., S. Katipamula, W. Wang, Y. Xie, M. Zhao, and C. D. Corbin. 2017. Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction. PNNL-25985. Richland, WA: Pacific Northwest National Laboratory.

Granderson, J., and S. Fernandes. 2017. The State of Advanced Measurement and Verification Technology and Industry Application. The Electricity Journal 30: 8–16. DOI: 10.1016/j.tej.2017.08.005. https://eta.lbl.gov/publications/state-advanced-measurement.

Granderson, J., and G. Lin. 2016. Building Energy Information Systems: Synthesis of Costs, Savings, and Best-practice Uses. Energy Efficiency 9(6): 1369–1384. DOI: 10.1007/s12053-016-9428-9. https://eta.lbl.gov/sites/default/files/publications/1006431.pdf.

Granderson, J., G. Lin, and S. Fernandes. 2015. A Primer on Organizational Use of EMIS. Prepared for the U.S. DOE Better Buildings Program. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/A_Primer_on_Organizational_Use_of_EMIS_V1.1.pdf. Accessed September 22, 2020.

Granderson, J., G. Lin, R. Singla, S. Fernandes, and S. Touzani. 2018. Field evaluation of performance of HVAC optimization system in commercial buildings. Energy and Buildings 173: 577–586. DOI: 10.1016/j.enbuild.2018.05.048. https://buildings.lbl.gov/publications/field-evaluation-performance-hvac.

Granderson, J., R. Singla, E. Mayhorn, P. Erlich, D. Vrabie, and S. Frank. 2017. Characteristics and Survey of Automated Fault Detection and Diagnostic Tools. Berkeley, California: Lawrence Berkeley National Laboratory. LBNL-2001075.

Gregory, E. 2015. Commissioning and Emory's Sustainable Performance Program. Facilities Manager January/February. https://www1.appa.org/files/FMArticles/38-431.pdf. Accessed September 22, 2020.

Henderson, P., and M. Waltner. October 2013. Real-Time Energy Management: A Case Study of Three Large Commercial Buildings in Washington, D.C. Natural Resources Defense Council, CS:13-07-A. https://www.nrdc.org/resources/real-time-energy-management-case-study-three-large-commercial-buildings-washington-dc. Accessed September 22, 2020.

Kramer, H., G. Lin, C. Curtin, E. Crowe, and J. Granderson. 2019. Building Analytics and Monitoring-Based Commissioning: Industry Practice, Costs, and Savings. Energy Efficiency. 13: 537-549(2020). DOI: 10.1007/s12053-019-09790-2. https://buildings.lbl.gov/publications/building-analytics-and-monitoring.

Lin, G., R. Singla, and J. Granderson. 2017. Using EMIS to Identify Top Opportunities for Commercial Building Efficiency. Berkeley, California: Lawrence Berkeley National Laboratory. LBNL-1007250.

Meiman, A., K. Brown, M. Anderson. 2012. Monitoring-Based Commissioning: Tracking the Evolution and Adoption of a Paradigm-Shifting Approach to Retro-Commissioning. Proceedings of the 2012 ACEEE Summer Study. https://cxwiki.dk/files/stream/public/ACEEE_Tracking_the_Approach_to_Retro-Commissioning_2012.pdf. Accessed September 22, 2020.

Mills, E., and P. Mathew. 2009. Monitoring Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects. Berkeley: Lawrence Berkeley National Laboratory. LBNL-1972E.

Roth, K., D. Westphalen, M. Feng, and P. Llana. 2005. Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential. Report for the U.S. Department of Energy.

San Diego Gas & Electric (SDG&E). 2015. M&V Report – Model-based Predictive HVAC Control Enhancement Software. Report for the San Diego Gas & Electric Emerging Technologies Program. DR13SDGE0006. https://www.etcc-ca.com/reports/model-based-predictive-hvac-control-enhancement-software. Accessed September 22, 2020.

BERKELEY LAB

Bringing Science Solutions to the World

Design: Laura Myers Design