U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Enhancing Performance Contracts with Monitoring-Based Commissioning (MBCx)

July 2021

FEMP
Federal Energy Management Program

Disclaimer

Preface

This document was prepared for the U.S. Department of Energy Federal Energy Management Program as a resource for federal agency energy management staff. It describes the benefits of integrating monitoring-based commissioning into performance contracts, and highlights applications of monitoring-based commissioning to energy conservation measure identification, commissioning, retro-commissioning, and measurement and verification.

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Acknowledgments

This report was developed for and sponsored by the U.S. Department of Energy Federal Energy Management Program (FEMP). Kurmit Rockwell, FEMP program manager for energy savings performance contracts (ESPCs), served as the report's program manager and lead reviewer. Valuable guidance and reviews were provided by Schuyler Schell and Nael Nmair at FEMP.

Researchers at Pacific Northwest National Laboratory, Lawrence Berkeley National Laboratory, and Oak Ridge National Laboratory provided invaluable direction and guidance for this document, including the ESPC federal project executives Tom Hattery, Scott Wolf, and Doug Culbreth. Phil Coleman with Lawrence Berkeley National Laboratory and Christine Walker with Oak Ridge National Laboratory went above and beyond everyday job duties to provide background documentation, statistical data, and valuable input on the contents and structure of the document. Dave Hunt with Pacific Northwest National Laboratory provided valuable peer review comments.

Numerous NREL staff provided subject matter expertise and conducted technical reviews, including Deb Vasquez, Otto VanGeet, Sheila Hayter, and Michael Callahan. Heidi Blakley, Fred Zietz, and Caitlin Dorsey in the NREL Communications and Public Affairs Office provided illustration, content, and editing support.

Jim Hauswirth with McKinstry provided content for the McKinstry case study on monitoring-based commissioning (MBCx) integration into Municipal, University, School, and Hospital ("MUSH market") ESPCs.

Celeste Cizik with Group14 provided MBCx graphics and consultation on MBCx integration into performance contracts.

Jacob Nicosia and Ana Rawson with the U.S. General Services Administration provided content for the GSAlink case study.

This report was prepared by NREL for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Federal Energy Management Program.

List of Acronyms

AFDD	automated fault detection and diagnostics
AHU	air handling unit
AMI	automated metering infrastructure
ATO	authority to operate
BAS	building automation system
DDC	direct digital control
DOE	U.S. Department of Energy
ECM	energy conservation measure
EMIS	energy management information system
ESCO	energy services company
ESPC	energy savings performance contract
FDD	fault detection and diagnostics
FEMP	Federal Energy Management Program
FISMA	Federal Information Security Modernization Act of 2014
GSA	U.S. General Services Administration
HVAC	heating, ventilating, and air conditioning
IDIQ	indefinite delivery, indefinite quantity
IGA	investment grade audit
IoT	Internet of Things
IT	information technology
LBNL	Lawrence Berkeley National Laboratory
LED	light-emitting diode
M&V	measurement and verification
MBCx	monitoring-based commissioning

MUSH	municipal, university, school, and hospital
NIST	National Institute of Standards and Technology
NOO	Notice of Opportunity
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
OT	operational technology
PA	preliminary assessment
PV	photovoltaic
RCx	recommissioning and retro-commissioning[1]
RTU	rooftop unit
SaaS	Software as a Service
UESC	utility energy service contract
U.S.C.	U.S. Code
VAV	variable air volume

[1] RCx is used as an abbreviation for both recommissioning and retro-commissioning in this report in order to simplify the number of abbreviations. The standard abbreviation for retro-commissioning is RCx and the standard abbreviation for recommissioning is ReCx.

Executive Summary

Integrating monitoring-based commissioning (MBCx) software tools into performance contracts is a timely topic given recent developments in MBCx software offerings and the growing number of MBCx deployments nationwide. Many commercial building owners have started to install MBCx software tools that tie in advanced metering infrastructure, building automation systems, and local weather data to enable ongoing commissioning and identify energy conservation measures.

Greater U.S. market adoption of MBCx software tools presents a unique opportunity to integrate MBCx into energy performance contracts to increase project savings and improve the long-term performance of equipment and building systems. MBCx software tools can be used throughout the entire project life cycle for both energy savings performance contracts and utility energy service contracts, from the preliminary assessment to the investment grade audit and throughout the performance period. Implemented effectively, MBCx can also add significant value through increased savings persistence, ongoing identification of new energy savings measures, and continuous, automated performance monitoring, allowing for more accurate measurement and verification at a potentially lower cost in the performance period. The software tools can benefit both the contractor and the agency in terms of estimating and guaranteeing savings, ensuring onsite personnel operate equipment according to contractual requirements, and identifying additional improvements to increase savings over time for little or no additional cost.

For the federal sector, MBCx software tools can be used to help fulfill several new Energy Act of 2020[2] (the "Energy Act") requirements. The Energy Act requires "covered facilities" to be recommissioned or retro-commissioned every four years, unless the facility is "under ongoing commissioning, recommissioning, or retrocommissioning."[3] MBCx automates the ongoing commissioning process, which should meet the requirements of the exemption. In addition, the Energy Act expands energy and water metering requirements and redefines ongoing metering as an "ongoing process of commissioning using monitored data … to ensure continuous optimum performance of a facility, in accordance with design or operating needs, over the useful life of the facility[.]"[4] An MBCx system that integrates automated metering infrastructure meets this ongoing metering requirement while simultaneously improving the ongoing commissioning process, obviating the need to manually recommission a facility every four years. Finally, the Energy Act requires DOE and GSA to create a "Federal Smart Buildings Program" to implement smart building technology and demonstrate the costs and benefits of smart buildings.[5] While the program details remain to be developed, MBCx is a logical component of a building energy system that is "flexible and automated; has extensive operational monitoring and communication

[2] Public Law 116–260, Energy Act of 2020 (Dec. 27, 2020).
[3] Energy Act of 2020 § 1002(g)(6)(C).
[4] Energy Act of 2020 § 1002(g)(6)((A)(ii).
[5] Energy Act of 2020 § 1007(b).

connectivity, allowing remote monitoring and analysis of all building functions; [and] takes a systems-based approach in integrating the overall building operations[.]"[6]

Integrating MBCx software tools with performance contracts, or executing the two in tandem, often present significant opportunities for building owners as well as the energy services companies and utilities that implement performance contracts. A recent meta-analysis by Lawrence Berkeley National Laboratory characterized new construction commissioning, retro-commissioning, and MBCx energy savings, implementation costs, and simple payback periods (Crowe et al. 2020). Median whole-building MBCx energy savings from the study were 9% and the median simple payback period for MBCx was 3.2 years. In addition, the Pacific Northwest National Laboratory Retuning™ program demonstrated a 15% median whole-building energy savings across 24 projects, and the U.S. General Services Administration's MBCx program has demonstrated a 15.9% whole-building energy savings (Loftness et al. 2020; Katipamula 2020). MBCx implementation's short payback period and significant energy savings would free up capital in performance contracts and could help finance longer-payback measures including efficiency, resilience, and emerging technologies like onsite battery storage.

To support federal and commercial building owners in understanding, procuring, and implementing MBCx software tools, this report provides an overview of their capabilities, the MBCx process, and how MBCx can be integrated into—and benefit—each phase of a performance contract. This report is intended to spur increased use of MBCx in performance contracts, whether an agency has previously installed or is considering adding MBCx at the time of their project. Additionally, case studies illustrate successful experiences using MBCx within performance contracts at a university campus and across a large number of federal buildings managed by the U.S. General Services Administration.

[6] Energy Act of 2020 § 1007(a)(4)(C).

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1 Introduction

Monitoring-based commissioning (MBCx) is the continuous application of the commissioning process to a building or energy system. Utilizing MBCx can be an effective method to sustain performance of energy conservation measures (ECMs), keep energy costs low, and minimize system problems that may be caused by performance deterioration and changes to building operations over time. MBCx is implemented via software tools that compile and analyze real-time building energy system data, identify performance issues, assist with equipment commissioning, and optimize system operations. MBCx software tools have improved considerably over the past several years and are typically available through various Software as a Service (SaaS) offerings. MBCx software tools are also considered a subset of a broader suite of Energy Management Information System (EMIS) software tools (Lawrence Berkeley National Laboratory [LBNL] 2015).

Building commissioning (commonly referred to as "Cx") is important and valuable—without it, building systems may not perform optimally or as designed, which translates into wasted energy and suboptimal occupant comfort (Swegon Air Academy 2017). Following energy efficiency upgrades, federal agencies are required by 42 U.S.C. § 8253(f)(5) to ensure that "equipment […] is fully commissioned at acceptance to be operating at design specifications; and […] equipment and system performance is measured during its entire life to ensure proper operations, maintenance, and repair[.]"[7] In addition, ECM commissioning is contractually required for federal energy savings performance contracts (ESPCs) and strongly recommended for utility energy service contract (UESC) task orders.

Although ECM commissioning is recommended to be included in all energy performance contracts, full-building or equipment-level recommissioning and retro-commissioning (referred to in combination throughout this report as "RCx"), and ongoing MBCx have not been included in the majority of these projects. Building automation system (BAS) or energy management control system upgrades do offer some functionality similar to that of MBCx software—for example, BAS is used for trend analysis and review throughout the contract term in approximately 70% of federal ESPC projects. However, full RCx with MBCx is underutilized in most performance contracts.[8] According to a recent analysis of all U.S. Department of Energy (DOE) indefinite delivery, indefinite quantity (IDIQ) contract ESPCs by Oak Ridge National Laboratory, only 24 projects (roughly 6% of the total IDIQ contract ESPCs to date) included ECMs under the technical category "Commissioning" and mentioned specific activities focused on commissioning or RCx in their description (DOE 2021a). One potential mechanism for increasing the prevalence of RCx in performance contracts is through the implementation of

[7] National Energy Conservation Policy Act, Pub. L. 95-619 (November 9, 1978), "Follow-up on implemented measures," codified at 42 U.S.C. § 8253(f)(5)(a)–(c).
[8] ECMs and ongoing commissioning strategies are not specifically tracked for UESC projects, although performance assurance in UESCs is intended to be achieved through periodic RCx of equipment throughout the performance period.

MBCx, which applies the commissioning process in an ongoing fashion to maintain and continuously improve equipment performance over time. For the purposes of this report, the term MBCx is used to describe:

- MBCx software tools that collect data from BAS and advanced metering infrastructure (AMI) and perform analytics to identify performance improvements
- MBCx processes for implementing and verifying improvements made based on the analytics.

MBCx analytics provide an advantage over BAS trend data because MBCx software programs collect and analyze all of the available BAS points in real time, whereas only a subset of BAS trend data is typically downloaded and analyzed on an ad-hoc basis when MBCx software is not in use. MBCx software tools can also be used throughout the entire project life cycle, including the preliminary assessment (PA) and investment grade audit (IGA), ECM commissioning, and throughout the performance period. For example, MBCx software tools can be used to identify potential energy-saving measures in the PA and IGA, to establish baselines for equipment performance in the IGA, to assist with ECM commissioning during the construction period, and to obviate the need for manual BAS trend log analysis throughout the life of the contract. MBCx software tools continuously track the performance of ECMs, and custom ECM-specific performance assurance reports can be created to assist with annual measurement and verification (M&V) reports. Thus, integrating MBCx into performance contracts can provide benefits for both the contractor and the building owner by ensuring that onsite personnel continue to operate equipment per the requirements of the contract, and by offering the opportunity to identify further low-or no-cost improvements to increase savings over time.

This report is intended to be used by federal agencies, state and local institutions, and the private sector. It presents a framework for integrating MBCx into performance contracts, whether or not the buildings already have MBCx software installed and in use. Technical, economic, and process-related considerations for integrating MBCx into performance contracts are outlined in each section, to help the reader to determine when and how to implement MBCx within their project. The report content is organized in the following sections:

- **Commissioning Landscape: Types, Technologies, Capabilities, and Processes** – describes the greater commissioning landscape, including commissioning, retro-commissioning, recommissioning, and re-tuning.
- **Monitoring-Based Commissioning** – discusses MBCx, including software, capabilities, process, site selection criteria, and implementation considerations.
- **Integrating Monitoring-Based Commissioning into Performance Contracts** – examines contractual considerations, challenges, and practical applications for integrating MBCx into performance contracts. It also addresses approaches to implementation of MBCx in performance contracts and potential impacts on each phase of the project.

- **Case Studies** – Two case studies provide examples of the use of MBCx within the context of performance contracting. These include an ESPC at a university in Colorado and the U.S. General Services Administration's (GSA's) successful use of MBCx within the GSAlink program.

2 Commissioning Landscape: Types, Technologies, Capabilities, and Processes

2.1 Types of Commissioning

2.1.1 Commissioning

Commissioning is the process of planning, documenting, scheduling, testing, adjusting, verifying, and training to provide a facility that operates as a fully functional system per the owner's design requirements (Complete Commissioning, Inc. 2021).[9]

The primary goals of a commissioning effort are to ensure that the building systems operate as originally designed, provide a safe and healthy facility, improve energy performance, minimize energy consumption, reduce operating costs, and ensure adequate operations and maintenance (O&M) staff orientation and training. Commissioning is important and valuable—without it, building systems do not perform optimally or as designed, meaning wasted energy and suboptimal occupant comfort from the beginning of operation (Swegon Air Academy 2017).

2.1.2 Retro-commissioning and Recommissioning

Retro-commissioning is the application of the commissioning process to buildings or systems not previously commissioned.[10] Many buildings or systems that were delivered without undergoing commissioning have deficiencies in design or construction that prevent the building and its equipment from functioning properly or in an energy-efficient manner. The goal of retro-commissioning is to discover these deficiencies and propose or provide solutions to them. Often, solutions recommended through the retro-commissioning process can be implemented at low cost and with little or no disruption to the building's operations (Swegon Air Academy 2017).

Recommissioning is the application of the commissioning process to projects that were previously commissioned. The term "recommissioning" is defined as:

> (1) commissioning a facility or system beyond the project development and warranty phases of the facility or system; and
> (2) the primary goal of which is to ensure optimum performance of a facility, in accordance with design or current operating needs, over the useful life of the facility, while meeting building occupancy requirements.[11]

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[9] The term "commissioning" is defined as a systematic process of ensuring, using appropriate verification and documentation, during the period beginning on the initial day of the design phase of the facility and ending not earlier than one year after the date of completion of construction of the facility, that all facility systems perform interactively in accordance with [I] the design documentation and intent of the facility; [II] the operational needs of the owner of the facility, including preparation of operation personnel; and [III] the primary goal of which is to ensure fully functional systems that can be properly operated and maintained during the useful life of the facility. See 42 U.S.C. § 8253(f)(1)(A).

[10] Similarly, the term "retrocommissioning" is defined as a process of commissioning a facility or system that was not commissioned at the time of construction of the facility or system. 42 U.S.C. § 8253(f)(1)(H).

[11] 42 U.S.C. § 8253(f)(1)(G).

Over time, previously commissioned building systems performance may degrade or be adjusted, leading the building to operate less efficiently. Additionally, facility needs may change as tenants, owners, and technologies change. Recommissioning is intended to resolve operational problems, improve occupant comfort, and optimize energy use, returning the building systems to optimal operation or optimizing operation given current building requirements. Recommissioning can typically be applied relatively inexpensively if documentation from the building's original commissioning process is available (Swegon Air Academy 2017).

Retro-commissioning and recommissioning are similar endeavors as they involve the performance of similar evaluations and adjustments, and they are both intended to tune the facility to optimal performance based on current operational needs. For this reason, and because the considerations for the feasibility of both are largely the same, the terms are sometimes used interchangeably. For purposes of simplifying the number of abbreviations used in this report, "RCx" is used to mean retro-commissioning, recommissioning, or both.[12]

RCx of energy-consuming systems in commercial, federal, and other facilities is cost effective, and for federal facilities, it is also statutorily required. Pursuant to the Energy Act of 2020 each "covered facility"[13] must complete a comprehensive energy and water evaluation and recommissioning or retro-commissioning for approximately 25% of the covered facilities once every four years.[14] The Energy Act of 2020 also includes an exemption that states that recommissioning or retro-commissioning shall not be required if the facility is "under ongoing commissioning, recommissioning, or retrocommissioning."[15] MBCx, as defined in Section 3 below, automates the ongoing commissioning process and would meet the requirements of the exemption.

In addition, the Energy Act of 2020 expands on previous AMI metering requirements by requiring water metering, and redefines ongoing metering as a "process of commissioning using monitored data, the primary goal of which is to ensure continuous optimum performance of a facility, in accordance with design or operating needs, over the useful life of the facility, while meeting facility occupancy requirements."[16] An MBCx system that integrates AMI infrastructure meets the goal of this new ongoing metering objective, and implementing MBCx at federal facilities would not only significantly improve the ongoing commissioning process, but it would also significantly reduce the costs of manually recommissioning a facility every four years.

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[12] In practice, RCx is used as the abbreviation for retro-commissioning and ReCx is used to abbreviate re-commissioning.

[13] For information on the statutory term "covered facilities," see "Facility Energy Management Guidelines and Criteria for Energy and Water Evaluations in Covered Facilities (42 U.S.C. 8253 Subsection (f), Use of Energy and Water Efficiency Measures in Federal Buildings), section III, "Criteria for Covered Facilities," at https://www.energy.gov/sites/prod/files/2013/10/f3/eisa_s432_guidelines.pdf.

[14] Energy Act of 2020 § 1002(g)(6)((A)(ii).

[15] Energy Act of 2020 § 1002(g)(6)(C).

[16] Energy Act of 2020 § 1002(g)(6)((A)(ii).

2.1.3 Re-Tuning

Another commonly used term that is related to RCx is re-tuning. Re-tuning is a systematic process aimed at minimizing building energy consumption by identifying and correcting operational problems that plague buildings at no-cost or low-cost. Re-tuning relies on building automation system (BAS) data to identify and implement control improvements at no cost other than the time to program the changes (Pacific Northwest National Laboratory 2016).

The primary difference between a re-tuning effort and a full RCx effort is that re-tuning typically focuses on optimizing BAS control sequences rather than full functional testing of all heating, ventilating, and air conditioning (HVAC) system components. Re-tuning also typically does not include development of a deficiency list that highlights all of the malfunctioning equipment that needs to be repaired or replaced. Re-tuning efforts generally do not fully capture energy savings from identification of malfunctioning components such as failed damper actuators, leaking control valves, and failed sensors, although a subset of deficiencies are typically identified and fixed or replaced during the re-tuning process.

3 Monitoring-Based Commissioning

MBCx is the continuous application of the commissioning process to a building or energy system and is an effective method to keep energy costs low and minimize system problems that may be caused over time by building performance deterioration and changes to building operations (Swegon Air Academy 2017). The term MBCx as defined in this report includes (1) MBCx software tools that collect data from BAS and AMI and perform analytics to identify performance improvements, and (2) MBCx processes for implementing and verifying improvements made based on the analytics.

Typical RCx efforts evaluate the operational performance of equipment within a building at a given point in time. When a contract is in place for RCx services, either the onsite facility staff or O&M contractor is responsible for repairing HVAC components that are not working correctly—at that time—and to modify control sequences and schedules as needed. After the RCx effort is completed, on-the-job training is typically provided for O&M staff, building managers and O&M contractors. Over time, typically 1–4 years after the RCx effort, equipment starts to malfunction and changes are made to the control system, which results in a degradation of building performance. The improvement in building efficiency from periodic RCx is illustrated by the yellow area in the chart in Figure 1.

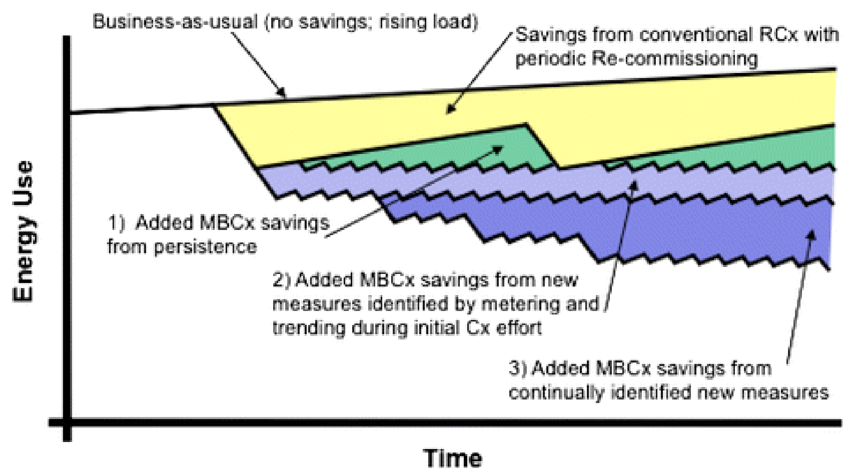


Figure 1. Ongoing building energy use optimization from MBCx

Image Credit: LBNL

In contrast, MBCx applies the commissioning process in an ongoing fashion to help detect—in near-real time—faults and performance degradation problems that would otherwise go undetected for weeks or months (Katipamula and Brambley 2005). The additional energy savings from MBCx are illustrated by the green, purple, and blue areas in Figure 1.

- The green area illustrates additional, persistence-related savings from the MBCx process. Continuous monitoring reveals equipment malfunctions and suboptimal control sequences or schedules that can be adjusted on an ongoing basis, rather than having to wait for the next RCx effort months or years down the line.

- The light purple area reflects energy savings from new ECMs identified and implemented when MBCx software tools are brought to bear during the initial commissioning effort. The performance of these new measures is also continuously monitored and adjusted, as reflected by the sawtooth border at the bottom of the light purple area.
- As time passes, MBCx allows for continual identification of new ECMs. These can include new technologies that did not exist at the time of initial commissioning, or opportunities that arose as a result of other ECMs. Savings from these measures also persist as a result of continuous monitoring for a cumulative effect. Savings from these additional implemented ECMs are illustrated by the dark blue area.

3.1 Software

As illustrated in Figure 2, MBCx software tools collect and record data within a building and perform real-time diagnostics, taking the human element out of processing large numbers of BAS trend logs to identify suboptimal performance. These tools have benefitted from advances in building automation and control network (BACnet®) communication protocols, onsite and cloud data storage capabilities, and electrical submeters, which have made the automated collection of large quantities of real-time building performance data by MBCx software tools cost effective.

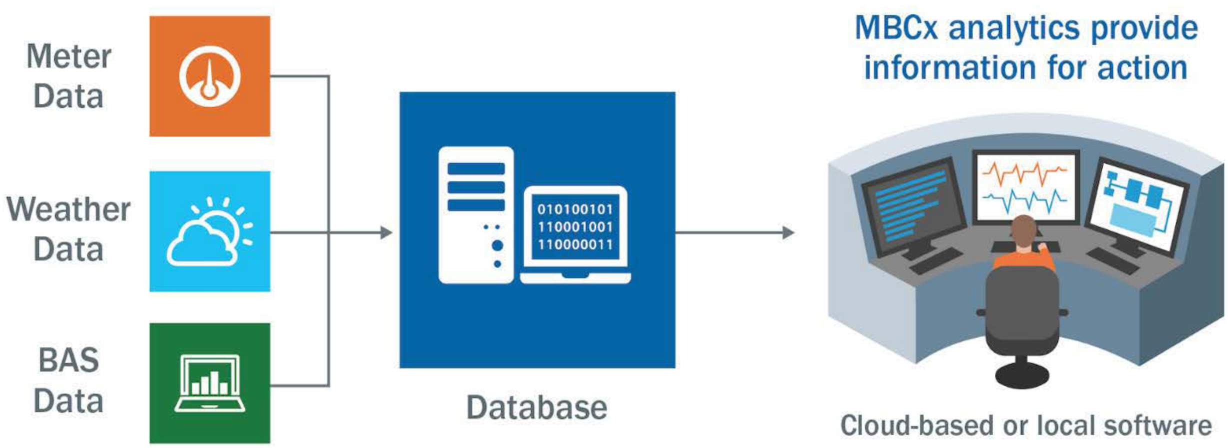


Figure 2. MBCx data flow

Original illustration from Celeste Cizik, Group14 Engineering recreated by Fred Zietz and Jesse Dean, NREL

There are three primary differences among the various MBCx software providers and their service offerings: (1) their approach to identifying and prioritizing suboptimal equipment performance (i.e., prebuilt/standard rules libraries or fully-customized rule sets for each site), (2) the comprehensiveness of the services they provide and the related amount of onsite field work required (which can be either project dependent or based on the provider's typical implementation of MBCx; services may include an onsite RCx effort or be implemented using a remote MBCx data analytics tool), and (3) their approach to data storage and analysis (e.g., an onsite or cloud-based server). The DOE Smart Energy Analytics Campaign website offers more information on available MBCx software tools (LBNL 2021).

3.2 Capabilities

MBCx turns raw data from connected systems into new capabilities that provide value to users. While new functionalities are continuously being released by an expanding marketplace of MBCx providers, a noncomprehensive list of common MBCx capabilities include:

- **Centralize, normalize, visualize data –** Automatically combine data streams from different sources into a common database to allow for visualization
- **Utility bill management –** Track, understand, and process data from utility bills
- **Interval meter analytics –** Tools specifically designed to analyze meter data at intervals of one hour or less
- **M&V –** Quantify and verify the energy savings performance of individual ECMs or efficiency projects
- **Automated Fault Detection and Diagnostics (AFDD) –** Automatically detect and diagnose the causes of equipment- or system-level faults
- **Supervisory control –** Perform automated changes to underlying building systems for optimization
- **O&M optimization –** Tools to integrate the above capabilities with O&M processes to increase efficiency.

Given that a full description of all available capabilities is beyond the scope of this report, the readers are encouraged to read the DOE Federal Energy Management Program (FEMP) Energy Management Information Systems Technical Resource Report for a full description of all capabilities (Dean and Dice 2021). The most relevant capability to this report is AFDD, which is described in the following section.

3.2.1 Automated Fault Detection and Diagnostics

AFDD is a standard MBCx software capability that uses algorithms to detect equipment- or system-level faults and diagnose their causes. AFDD vastly reduces the time required to find these faults as compared to standard methods such as trend visualization and analysis (Stum and Bjornskov 2017). Continuous, automated data collection and analysis using rule-based algorithms can be applied to very large data sets on a real-time basis.

AFDD has been successful for many years in other industries such as manufacturing. In buildings, while popularity is growing, adoption has been relatively slow (Granderson et al. 2017). AFDD is most commonly conducted for HVAC systems, but it is applicable to all building systems. These tools are used to identify air handling unit (AHU) scheduling problems, HVAC set-points that can be optimized, equipment and component failures, performance degradation, system design issues, controllability problems, operator overrides, and incorrect sequences of operation (Stum and Bjornskov 2017). Incorporating AFDD tools within MBCx can add value to agencies' operations in many ways, including:

- **Finding hidden issues** – Many building performance problems are masked and compensated for by other parts of the system in an effort to avoid adverse occupant comfort issues (Granderson et al. 2011). AFDD tools can detect many such issues and prevent them from increasing energy consumption or leading to larger operational problems or unexpected failures.

- **Improving comfort with zone-level diagnostics** – Due to the sheer number of zones and terminal devices in large buildings, operators often do not have time to monitor performance at this level. AFDD transfers this work to the software, which notifies operators of malfunctioning terminal devices. Figure 3 shows zone-level fault detection and diagnostics (FDD) of issues including Variable Air Volume (VAV) reheat valve leaking, VAV airflow not approaching setpoint, and the absence of VAV box airflow when the AHU is operating. The green, blue and red blocks indicate the time of day and duration of each zone-level fault.

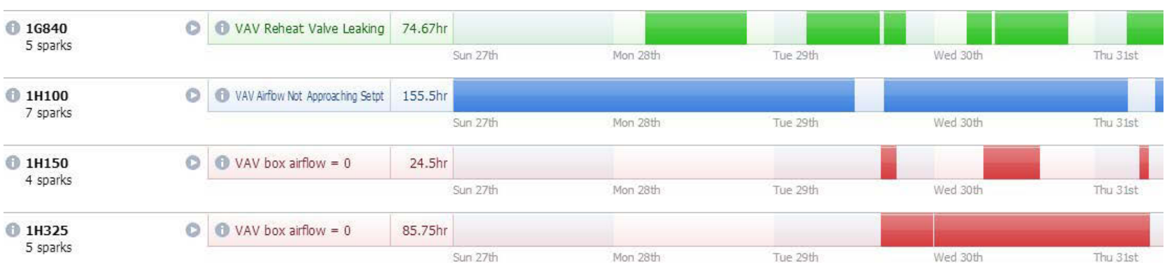


Figure 3. Zone-level fault detection and diagnostics

Image Credit: SkyFoundry 2021

- **Identifying root causes** – Many of the capabilities discussed above are valuable for uncovering problems, but often the underlying cause of an issue is unknown (Stum and Bjornskov 2017). AFDD can be paired with these other capabilities to more specifically identify what can be done to improve operations. For example, while a heat map may be used to determine that HVAC systems are running during unoccupied hours, AFDD tools go further, indicating exactly which systems are the culprits and what the cause might be.

When AFDD software tools are applied to large buildings or an entire campus, the sheer number of identified faults can be overwhelming for facilities staff. Further, some faults are much more important to operators than others. As such, fault prioritization is deployed in many AFDD products. The software typically prioritizes faults with the greatest estimated potential for energy cost savings through correction. Figure 4 shows a list of faults prioritized by energy cost savings potential. AFDD tools vary widely in their ability to calculate accurate energy cost savings. Many are programmed with simplified rule-of-thumb calculations, while others run in-depth equipment-level engineering analysis. Although not the most accurate way of estimating savings, these calculations serve an important role of helping to prioritize faults and are needed when deploying AFDD across a large number of HVAC systems and buildings (Dean and Dice 2021).

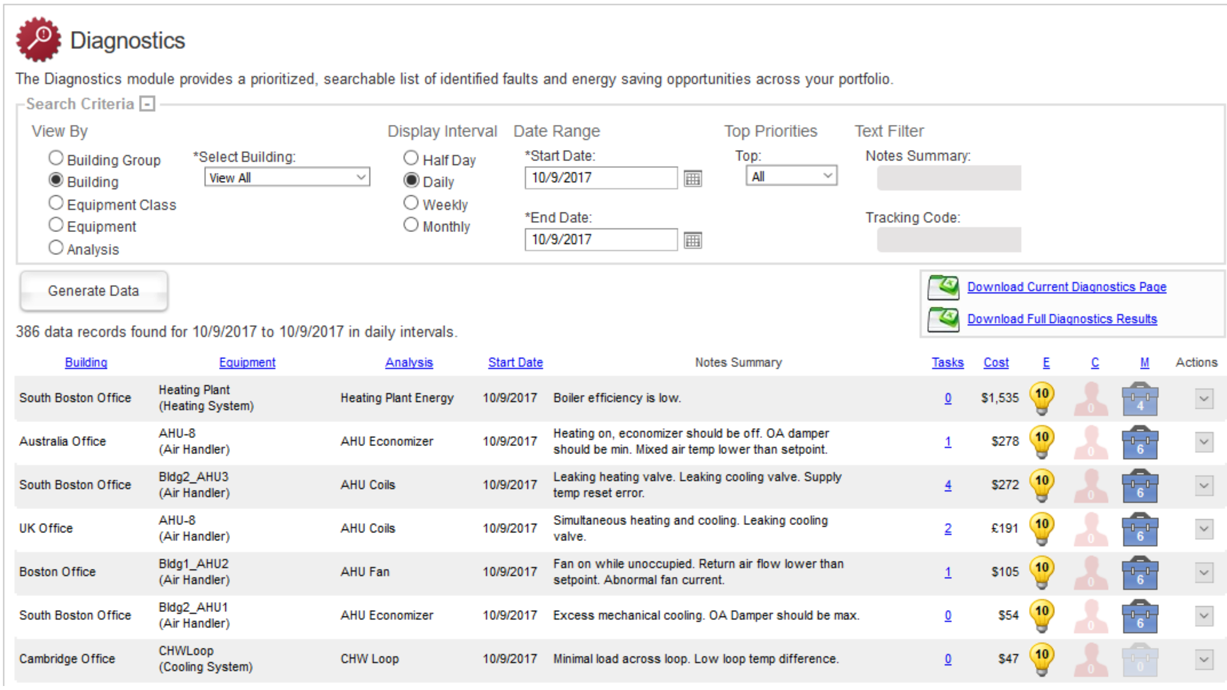


Figure 4. A prioritized list of faults detected

Image Credit: KGS Buildings 2021

Some AFDD systems allow facilities operation staff to deactivate rules for subsystems and focus exclusively on faults within select systems—for example, chillers, boilers, and AHUs. Identifying and correcting faults in these larger systems should take precedence over correcting lower-level faults in terminal units and thermal zones. The National Institute of Standards and Technology (NIST) has also developed hierarchical AFDD schemas that essentially deactivate rules for subsystems until the faults in the larger systems have been addressed. The NIST hierarchical rule schemas prioritize addressing all central plant faults first, followed by faults in AHUs, and then those within terminal units.

3.2.1.1 Approaches to Automated Fault Detection and Diagnostics in Monitoring-Based Commissioning

There are a few different MBCx approaches to AFDD and its integration into building operations. The three primary approaches to identifying faults are rule-based diagnostics, physical model-based diagnostics, and black box methods that include statistically driven models such as regression models, artificial neural networks, and other pattern recognition techniques (Katipamula and Brambley 2005). Some software platforms provide only one type of approach to AFDD, while others are flexible enough to feature two or more types.

Rule-Based Diagnostics

Rule-based diagnostics constitutes the most common approach to AFDD today. Within rule-based diagnostics, simple engineering equations and relationships are used to identify suboptimal operation of individual pieces of equipment and systems. An example of a rule-based fault detection equation for evaluating a demand-controlled ventilation sequence would look at the outside air damper position when the system is not in an outside air economizer mode and when the return air CO_2 level is below setpoint to ensure that the damper is at its minimum position. The logic for this rule would simply state:

> If Outside Air Economizer is disabled, return air sensor is < 800 parts per million, and outside air damper position is above 20% open, then flag this operation as a fault.

Physical Model-Based Diagnostics

Physical model-based AFDD is typically categorized as either a detailed or simplified physical model. Physical models are based on a mathematical simulation of the monitored plant, process, or entire building. At the system level, a model is constructed of a given piece of equipment (such as a large centrifugal chiller) based on the nameplate performance ratings, operational schedules, performance maps, and the targeted control sequence for the given piece of equipment. The behavior of the system is modeled based on a given set of measured inputs (such as outside air temperature and time of day) and the given model parameters (such as the performance specifications and control sequence). Modeled output variables are compared to measured performance to diagnose suboptimal performance. Detailed whole-building energy models offer the potential advantages of providing real-time diagnostics to systems that are not tied into a centralized control system, such as plug loads and lighting systems. Whole-building energy models can also help determine the performance of more sophisticated ECMs—for example, an optimal start/stop control sequence could be used for a given AHU versus using a more simplified mass/capacity factor for the building.

Black Box Models

Black box models differ from physical models in that they often do not require predetermined knowledge of the physical systems and characteristics—they are purely based on qualitative relationships. Qualitative relationships are determined by measured process histories and mathematical pattern identification models. For example, formulating a black box model of a chiller plant would consist of measuring electrical energy use over time and correlating it to time of day and outside air temperature and humidity.

Once the system operation is determined to be optimal by onsite facilities staff, an acceptable deviation can be defined and used to detect suboptimal operation. Model-based and black box methods are growing in popularity as computing and machine learning or artificial intelligence capabilities continue to expand. These methods provide some advantages over rule-based approaches, including the reduced time and effort required to set them up, allowing for increased scalability over large portfolios.

Some AFDD software platforms are flexible enough to utilize all three types of FDD, while others provide only one type.

Customization

Some MBCx vendors provide an open platform and let onsite users and/or third-party engineering firms write and deploy custom AFDD algorithms, while other vendors have developed a library of proprietary algorithms that they apply to specific system types in a one-size-fits-all manner. For example, a vendor library might have a predefined set of chiller, AHU, and VAV box terminal unit rules. When evaluating vendors, agencies and their contractors (such as O&M providers or performance contractors) should consider the level of customization needed for their desired MBCx scope and capabilities.

3.3 Monitoring-Based Commissioning Process

While MBCx software platforms are extremely powerful tools, they should not be considered energy efficiency equipment capable of producing results on their own. With the exception of automated supervisory controls, MBCx software is a human-in-the-loop tool. They require regular use by a well-resourced team to fully convert data to information to insights to action in order to achieve results. While a BAS provides trend log data and fault detection, MBCx software provides data analysis that helps the building owner prioritize the alerts received, increasing the likelihood that important operating deficiencies will be acted on and corrected.

Effective MBCx requires integrating ongoing activities into overall organizational standard operating procedures. Creation of operational processes requires thinking through how the onsite staff and MBCx operations team will review the MBCx reports, dashboards, and RCx faults for improvement opportunities, take action to implement the improvements, verify that the improvements were successful, and communicate the results to key stakeholders. Further, the MBCx software requires regular maintenance and improvements to remain optimized, just like the underlying systems it is monitoring.

3.3.1 Components of the Monitoring-Based Commissioning Process

This section walks through an overview of the components of an effective MBCx process, as shown in Figure 5. Each step of the process is described in this section. The process is continuously repeated throughout the MBCx life cycle.

Figure 5. Overview of recommended steps in MBCx operational process

Image Credit: James Dice and Fred Zietz, NREL

As noted above, the MBCx software landscape is very broad. Software support for operational processes is no exception. Some vendors offer more comprehensive operational tools than others, while many are focused on simply displaying data or lists of issues. When considering incorporation of MBCx into a performance contract, agencies and contractors should consider these capabilities and offerings as they establish software and services selection criteria.

3.3.1.1 Identify and Prioritize

The MBCx software platform is used to identify improvement opportunities, which are compiled in a tracking system and prioritized based on qualitative or quantitative metrics such as calculated energy savings and criticality. Recommendations for enhancing identification and prioritization of opportunities include the following high-level steps (described further in the referenced publications):

- Follow a monitoring action plan, established during the project planning phase to identify opportunities (Kramer, Crowe, and Granderson 2017).
- Utilize automated prioritization tools—if the MBCx software provides them—as a first step. The team should perform manual prioritization only if needed.
- Use an issues log, which can be built into the MBCx software, to track improvement opportunities. The California Commissioning Collaborative (2021) has a sample issues log template.

When the MBCx software platform is first rolled out to a building, this process of identification and prioritization is typically led by the subcontractor responsible for installation and deployment of the platform. In certain cases, a centralized or national office will lead this step and work with local building staff to review issues logs and prioritize opportunities. For example, GSA implemented a nationwide MBCx program across multiple GSA buildings where the MBCx software platform prioritization and rollout is administered by a central office at GSA (GSA 2021a). In either case, onsite building engineers, O&M staff, and customer MBCx staff should be involved in the initial identification and prioritization process. At this phase of the project, on-the-job training is typically provided for O&M staff, building managers, and O&M contractors on how the software works and expectations for its ongoing use. After the initial list of opportunities is implemented, the customer should work with the MBCx provider to clearly outline the responsibilities of the MBCx provider versus those of onsite staff, including identification of future improvement opportunities and issue log tracking.

3.3.1.2 Validate, Diagnose, and Triage

The MBCx provider then uses the platform and underlying systems to confirm the validity of improvement opportunities, determine root causes, and triage into implementation categories. For effective validation, diagnosis, and triage of opportunities, consider the following:

- Use MBCx data analysis and visualization tools to validate issues and determine root causes—a survey of the underlying systems may be required as a second step.
- The complexity and effort involved in implementation will vary for different opportunities. Triage the opportunities into predefined categories. When creating implementation categories, the site or agency should consider:
    - Is the improvement an emergency?
    - Who will be needed to assist in implementing the improvement (e.g., in-house controls technician)?
    - How much will the improvement cost—is it low- or no-cost, or an investment requiring a preapproved budget? Preapproved investment criteria may be useful for evaluating performance improvement opportunities (e.g., preapproval for all measures with less than a five-year simple payback).
- It may be useful to identify common measures and/or groups of similar measures that can be deployed across many sites in bulk to take advantage of economies of scale (DOE 2015).

The team will likely also uncover opportunities to improve the AFDD rules. These types of improvements should be included in the implementation process.

3.3.1.3 Implement Corrective Actions

After validation, diagnosis, and triage, selected improvement opportunities are then implemented. The MBCx provider should develop clear recommendations for the steps to complete implementation (Stum and Bjornskov 2017). The MBCx provider or customer representative will be responsible for ensuring implemented ECMs are functioning as designed via the MBCx platform. For example, when equipment is added to the MBCx platform, its associated performance maps, equipment schedules, and set points are programmed into the MBCx platform. As a next step, AFDD alerts are set up to ensure that the ongoing operation of that equipment matches the original design intent and that energy savings from advanced control sequences are maintained over time. Consideration should also be given as to how improvements will be transferred to or integrated with the customer's work order system or process—MBCx processes assist in identification and prioritization of issues, and the corrective actions will need to be implemented by facility O&M staff or the O&M contractor. After the selected corrective actions are implemented, the customer and MBCx provider should establish a regular MBCx meeting schedule to address new savings opportunities as they are identified. If equipment run times or schedules need to be modified, the AFDD rules can be adjusted to reflect these changes.

3.3.1.4 Verify Improvement

Once measures are implemented, the MBCx provider uses the platform to verify energy and cost savings. M&V capabilities can be used to automatically or manually quantify energy and cost savings and create savings reports.

3.3.1.5 Monitor, Update, and Maintain

While the process steps above are typically executed at weekly, monthly, or quarterly intervals, ongoing monitoring, updates, and maintenance tasks support the overall MBCx process. The organization should keep team members trained on the MBCx process. Additionally, as improvements are made to building systems, building operators should be notified and trained on all changes or modifications. Ideally, the root cause of each issue can be reported back to the MBCx software operator to improve the analytics, prioritization, and diagnosis. As the building itself changes, the building documentation (e.g., sequences of operations), standard operating procedures, and the MBCx platform itself should be updated to reflect the changes.

3.4 Monitoring-Based Commissioning Implementation

As processes are determined, a key consideration is the inclusion of an MBCx service provider on the project team. The MBCx service provider market continues to expand, making MBCx software success achievable for building owners that do not have large or sophisticated in-house facility teams. MBCx service providers can support the deployment of MBCx software and can effectively lead or support ongoing operations including the identification, prioritization, validation, and verification phases. Some customers may not access their MBCx software directly, relying primarily on their MBCx service provider's guidance or reporting (Kramer et al. 2020). This can also occur, for example, where MBCx service providers function as subcontractors within a performance contract project.

3.4.1 Upfront and Ongoing Costs

When MBCx software is considered for performance contracts, both the upfront and ongoing SaaS costs need to be understood and accounted for in the project economics. Given the wide variety of software offerings, it is important to understand what is included in a vendor's proposal and the associated costs. For example, some vendors provide only software, while others provide only services and resell software provided by others. Still others provide both software and services as a bundled package. Software vendors may provide their product via SaaS or another type of agreement.

Financial proposals should explain the pricing structure for all software, hardware, integration, data, commissioning, and other services required for the project. At a minimum, the scope and pricing should be broken out in the following categories:

- **Software licenses** – Based on the MBCx approach and platform selected, associated software costs and licenses need to be determined and integrated into the project's initial and ongoing annual costs (e.g., SaaS fees). The software license fee should include a determination as to whether data will be stored and hosted locally or on a cloud-based service. Annual software maintenance fees include version updates and user support.

  In some instances, if the onsite BAS provider offers MBCx as an add-on component, this additional cost could be included in the licensing costs to the BAS provider and the MBCx components could function as an extension to the functionality of the BAS.

- **Hardware** – Hardware is not always required for the integration of MBCx. In these instances, data can be passed directly via a live link from the BAS or meters, which can be set up to store trend logs of all applicable points. The data can then be passed to the software directly from the database, or it can be manually imported from Excel or CSV files. In some instances, MBCx providers use gateway devices to connect to the BAS, meters, or any Internet of Things (IoT)-connected device. As more IoT devices come online and are used, data from any internet-connected device can be pulled into an MBCx system. In addition to BAS and meters, systems that should be integrated include light-emitting diode (LED) lighting with integrated controls, IoT-based plug load controls, electric vehicle charging stations, and hybrid distributed generation (e.g., onsite photovoltaics [PV] with battery energy storage).

  The installation cost estimate should fully capture additional hardware needs and the associated scope of what is connected to the gateway device (if a gateway is needed). In addition, if the BAS is expanded to include new BAS controllers or the addition of new points to existing BAS controllers, these costs should also be captured in the hardware costs.

- **Low-cost submeters –** Low-cost electrical submeters have emerged over the past few years that can typically be installed for less than $200 per point on most building electrical panels in one to two days. GSA is one federal agency that has implemented submeters at low cost over the past several years. See the GSA Proving Ground report, "Submeters and Analytics: Full Panel" for additional information on low-cost submeters and how they were successfully integrated into GSA's MBCx system (GSA 2019).

  Additional submeters installed and integrated with the MBCx software can allow the site to develop key performance indicators to track the performance of larger pieces of equipment such as chillers, boilers, pumps, and fans. If this additional equipment is added to the scope, these costs should be included in the installed costs.

- **Software and hardware set-up labor** – Initial labor costs should include installation of software and hardware and mapping of BAS and AMI points. Set-up costs should also include training of site energy management or O&M staff on MBCx use and fault alert prioritization.

- **Annual maintenance labor** – Annual maintenance includes labor hours associated with updating software and rules, reviewing MBCx data to identify issues and opportunities, addressing deficiencies, or implementing identified ECMs. Although fixing issues and implementing identified ECMs is not typically part of the MBCx contract, labor hours from onsite staff or an O&M contractor still need to be included and accounted for.

3.5 Site Selection Criteria

Although there are benefits associated with integrating MBCx into energy projects, not all facilities are good candidates for MBCx. Federal agencies that already have MBCx installed are encouraged to utilize it to benefit planned or future energy projects. Agencies that wish to either implement MBCx or expand an existing MBCx system should consider the following:

- Smaller facilities (i.e., facilities under 10,000 ft^2) with packaged HVAC equipment that are not connected to a BAS and have no existing AMI meters are not good candidates for MBCx.

- Older facilities using pneumatic HVAC controls are not good candidates for MBCx.

- Facilities upgrading pneumatic controls to Direct Digital Control (DDC) systems could be considered for MBCx after the DDC upgrade is completed.

- Facilities without BAS that are installing advanced rooftop controls, LEDs with automated controls, IoT-based plug load controls, or new AMI meters should be considered for MBCx.

3.6 The Business Case for Monitoring-Based Commissioning

A recent meta-analysis by Crowe et al. (2020) characterized whole-building energy savings, implementation costs, and simple payback periods for new construction commissioning, RCx, and MBCx. In this report, 298 utility-sponsored RCx projects had a median 5% whole-building savings and 41 utility-sponsored MBCx programs were shown to have a 9% median whole-building savings (Crowe et al.).

These results are similar to a 2019 paper by LBNL which calculated an 8% median site energy savings based on data from 550 buildings where MBCx was implemented with the support of software-based FDD (Lin, Kramer, and Granderson 2020). The LBNL study found a median

RCx project cost of $0.25/ft^2$ across 660 utility-sponsored projects, and a median MBCx project cost of $1.45/ft^2$ across 75 utility-sponsored projects. The median simple payback for RCx projects was 1.8 years across 396 utility-sponsored projects, and 3.2 years for 52 utility-sponsored MBCx projects. Finally, Pacific Northwest National Laboratory's Retuning™ program reported a 15% median energy savings across 24 projects and GSA's MBCx program has demonstrated 15.9% whole-building energy savings (Loftness et al. 2020). Given GSA's years of prior experience with MBCx platforms, they are also able to install MBCx on a new building for around $15,000 per building, resulting in an installation cost of $0.15/ft^2$ for a 100,000 ft^2^ facility (for the software integration fees only—this does not include engineering and equipment costs to fix all RCx measures). Nevertheless, the GSA MBCx numbers indicate that the energy savings and economics could significantly improve for organizations with MBCx experience and a standardized implementation process.

Although the energy savings may be higher in the federal sector, teams installing an MBCx platform and implementing RCx measures in a federal facility that has never deployed MBCx should account for additional cybersecurity accreditation requirements, increased labor rates due to the use of Davis-Bacon prevailing wage determinations, and greater overhead for background checks and site security. All of these issues need to be weighed on a case-by-case basis when developing a business case for MBCx.

3.7 Cybersecurity Accreditation

Cybersecurity is a critical consideration for any energy equipment or system that connects to, can be accessed by, or is controlled through an onsite communication system. This concern increases when remote access to site software or control systems is allowed. While the information and requirements in this section apply to federal agencies, all commercial building owners should consider their organizational and site cybersecurity requirements and procedures when implementing MBCx software.

The Federal Information Security Modernization Act of 2014 (FISMA) requires federal agencies to implement programs to assure the security of information and information systems including agency-owned assets as well as those provided or managed by another agency or contractor.[17] MBCx software systems collect, process, store, maintain, and use information through an onsite communications network, which may introduce information technology (IT) security risk. As data is being collected from building energy systems, there may also be operational technology (OT) security concerns. Therefore, MBCx software tools meet the definition of a federal information system and must demonstrate compliance with information security requirements for authority to operate (ATO).

Cybersecurity ATO is required for MBCx software and all underlying systems that connect to the MBCx software, such as existing or newly installed AMI or BAS. Cybersecurity is vital for MBCx systems to ensure that the software is connected securely to the communications network

[17] Public Law 113–283, Federal Information Security Modernization Act (Dec. 18, 2014).

and existing BAS and AMI and does not open vulnerable pathways to other facility or building networks and operations. Executive Order 13800[18] requires federal agencies to follow the NIST Cybersecurity Framework which consists of standards, guidelines, and best practices to manage cybersecurity-related risk (NIST 2021). If the agency has already obtained an ATO for its MBCx system, that system may typically be applied to ECMs implemented via energy projects.

For agencies interested in installing an MBCx platform that has not received an ATO, FEMP offers a number of webpages with free web-based tools and resources to help agencies conduct cybersecurity assessments and manage cybersecurity risk:

- "Cybersecurity Considerations for Performance Contracts" offers cybersecurity considerations and resources for each phase of project development (FEMP 2021a).
- "Energy and Cybersecurity Integration" provides resources and guidance on enhancing the cybersecurity posture of federal facilities, including the Facility Cybersecurity Framework (FCF) Primer and assessment tool, the Distributed Energy Resource Cybersecurity Framework (DERCF), and other relevant resources (FEMP 2021b).

3.8 Site Staffing Requirements

A list of site staff roles and responsibilities as they pertain to MBCx integration and use is provided below. Specific allocation of responsibilities among the facility staff, performance contractor, and O&M provider (if other than facility personnel or a performance contractor) should be agreed upon and clearly defined in any contracts for MBCx work.

- **Facilities Management/O&M –** Onsite facilities management is responsible for meeting tenant needs, O&M workflow management, O&M staffing and/or contracting, capital expense management, and processing work orders. With respect to MBCx, facilities management and O&M staff manage the improvements that get implemented and many of the low-cost items the MBCx platform identifies may fall under an existing O&M contract for repairs. If onsite staff duties do not allow time, the analysis of MBCx processes and prioritization of issue resolution or measure implementation may be a service included in the MBCx SaaS contract or included as part of a performance contract as a periodic report to the facility owner.
- **Energy Management/Contracting –** Facility energy management staff and the contracting team should be aware of MBCx software program capabilities, their benefits related to performance verification, and how they can be integrated into O&M or performance contracts. This helps guide discussions regarding use of MBCx in energy projects. They must also be aware of roles and responsibilities for monitoring the MBCx system and acting on faults reported (facility staff versus contractor responsibilities).

[18] E.O. 13800, Section 1(c)(ii) (May 11, 2017).

- **Information Technology/Operational Technology –** IT and operational technology (OT) staff should be included in the first stages of issuance of a notice of intent to award or prior to starting the PA. At this phase of the project, the IT/OT team should clearly outline the organization- and/or facility-specific cybersecurity and ATO requirements, architecture of the BAS/AMI system, appropriateness for onsite versus cloud data storage, and so forth. The IT/OT team should be a part of the team throughout the project.

- **Onsite Building Engineers –** Onsite building engineers should be engaged from the earliest stages of the project to help identify what buildings, systems, and equipment should be considered for integration with the MBCx system. They can also provide guidance on how MBCx will be used, either for direct M&V with AMI or submeters, for more general performance verification, and/or to trend performance over time so that manual BAS trend log analysis is no longer required.

- **BAS Controls Technicians –** Onsite BAS controls technicians should be engaged in the same roles as the building engineer. Additionally, they should receive training on how to operate the MBCx and use the data to determine if equipment or control sequences are no longer operating per the requirements of the contract, and who is responsible for implementing corrective action. Training should be recorded, and/or repeated periodically, to refresh the operator's knowledge and to benefit new staff.

Per the last step of the MBCx process discussion outlined in Section 3.3.1.5, Monitor, Update, and Maintain, the contractor should provide training to building operators via their standard ECM trainings for the agency. During this step, additional training should be provided to onsite building engineers, O&M staff, facility managers, and BAS controls technicians to educate them on how to use the MBCx software and ensure BAS setpoint and scheduling compliance are carried out within predefined operating parameters. For some projects, a campus or regional energy management group will use the MBCx software and coordinate work orders, capital planning, and other tasks across a large portfolio of buildings.

The contractor implementing the MBCx software platform is responsible for updating automated reporting and creating periodic reports via the MBCx software tool to support the M&V requirements for the project. Training should be provided to onsite BAS staff to understand how to review and analyze automated reports.

The contractor is also responsible for revising building documentation (e.g., sequences of operations) per the normal contract process. Roles and responsibilities need to be defined regarding updating the MBCx software platform as buildings change. If facility staff are expected to update the system, the contractor needs to be notified of any changes and may need to agree to the changes in advance to ensure task order requirements remain effective; if it is the contractor's responsibility to make MBCx updates, they need to be notified of any modifications to the building made by the facility owner (e.g., space layout changes, usage modifications).

4 Integrating Monitoring-Based Commissioning in Performance Contracts

MBCx supports cost-effective implementation of ongoing commissioning, helping ensure optimal long-term ECM performance. While not yet widely used in energy performance contracts, the MBCx capabilities described in Section 2.2 can provide additional value by facilitating the initial determination of energy and cost savings opportunities, providing automated M&V support throughout the performance period, and potentially identifying additional ECMs during the performance period for implementation at a later date.

The purposes of all forms of commissioning (as defined in Section 2.1, Types of Commissioning) align closely with performance and savings objectives for energy performance contracts. Commissioning furthers these objectives by helping ensure that ECMs installed in a performance contract perform optimally and according to design intent. This is typically achieved through ECM commissioning following installation, potentially followed by periodic RCx to avoid performance degradation over time.

This section describes considerations and approaches for implementing MBCx in performance contracts, including benefits and use cases in each project phase. It should be noted that in this publication, 'energy performance contracts' refers to both ESPC and UESC mechanisms.

4.1 Considerations and Challenges

4.1.1 Impact on Project Development Costs and Timeline

For facilities where MBCx is already installed, project development costs and timeline should not be impacted and the MBCx platform should be used to identify RCx opportunities, integrate with ECM commissioning, and assist with performance assurance. For sites that are not already using MBCx, the site and contractor will need to determine the optimal time for implementation (e.g., prior to the IGA; as an ECM in the project), as well as the cost and risk allocation. This is particularly true for ESPCs where the ESCO must recover project development costs through the resulting cost savings, so any increased development costs and/or negative impact on the project development timeline need to be balanced with the ability of those costs to be realized and recovered (more detail on this is covered in Section 4.3.2). If MBCx is implemented during the IGA, the facility owner should request periodic reports from the ESCO on the project development costs for the MBCx portion of the IGA. This information will be useful in understanding the cost and timeline implications of deploying MBCx in the IGA. Implementation of MBCx during the IGA, or early in the construction phase, may lead to identification of additional savings opportunities, increasing the scale of the project and potentially reducing the cost recovery time, but delays due to the time and costs required to implement MBCx during the IGA can negatively impact the project and need to be weighed against the potential benefits.

4.1.2 Energy Cost Savings Estimation and Guarantee

When implemented as an ECM in a performance contract, MBCx should reliably contribute to cost savings. It may be challenging to accurately predict all potential savings from MBCx measures prior to implementation of the software platform because savings will be a function of the ECMs identified once the MBCx platform is installed. Specific improvements may be unknown prior to installing and running the MBCx software because a typical approach to investigating and identifying performance issues may require monitoring and functional performance testing of equipment, which can be a costly process. The challenge of estimating savings means that performance and savings guarantees may be difficult for an ESCO or utility to provide. However, the increased fidelity of monitoring can help in savings persistence and identifying additional RCx and associated cost savings opportunities during the performance period, so the agency and contractor should consider this early in project development.

4.1.3 Performance Assurance and Measurement & Verification

Automation of the ECM performance measurement process may reduce the cost of ECM performance assurance and M&V activities, as the contractor may be able to gather data remotely and automate the M&V reporting process. Added fidelity in monitoring incorporated into the M&V plan can reduce risk to the contractor by identifying performance issues earlier, allowing them to be corrected quickly rather than potentially resulting in a savings shortfall or dispute when they are discovered at a later date. If implementation of MBCx leads to the use of a more rigorous M&V method, the greater precision may be perceived as risk, resulting in a reduction of guaranteed savings in ESPCs. These potential risks need to be weighed against the cost savings associated with the automation of the M&V reporting process.

4.1.4 Corrective Action and O&M Responsibilities

Clear roles and responsibilities for acting on issues identified through MBCx need to be outlined for contractor and facility O&M staff during the IGA and documented in the task order. In cases where additional O&M staff are provided by the contractor, roles and responsibilities of facility O&M staff versus contractor personnel need to be clearly identified. Based on the predetermined designation of specific roles and responsibilities, training should be tailored and provided for each individual job function and recorded for future use as a refresher and for training new staff.

4.1.5 Data Integration

Getting data into MBCx software can be a challenge for facilities with stringent cybersecurity requirements. Openness of control systems to sharing data, cybersecurity needs, and potential for cloud accessibility (which enables remote monitoring but requires more stringent risk review) all need to be addressed. Facility cybersecurity requirements and contractor access to the MBCx system should be discussed early during project development.

4.1.6 Performance Period Costs

In addition to the original set-up fees, recurring labor fees (i.e., outside MBCx consultants, whether remote or onsite) and SaaS fees need to be budgeted for and incorporated into the cash flow plan of the project. If MBCx is already in use prior to the performance contract, the annual maintenance fee is the only additional expense, and this expense may be offset by cost reductions from automating some of the M&V processes.

4.2 Monitoring-Based Commissioning Throughout the Project Life Cycle

MBCx offers benefits at every stage of the performance contracting life cycle, from ECM identification to performance verification. This section highlights uses and benefits of MBCx in each phase of the project. Figure 6 outlines high-level touchpoints for MBCx in a performance contract.

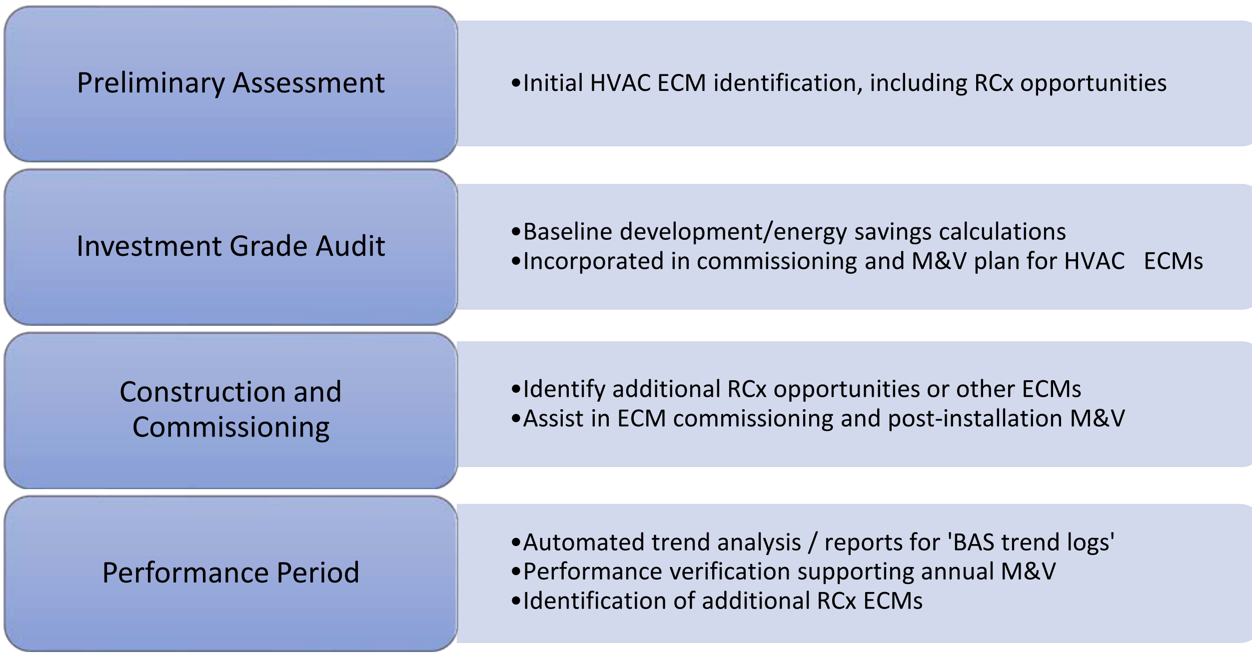


Figure 6. Uses of MBCx software in each performance contracting phase

4.2.1 Project Development

The uses for MBCx during the project development phase—such as more accurate baselining and additional ECM identification—are well aligned with the core purpose and function of energy performance contracting. For facilities with MBCx software already installed, its data collection and analysis capabilities may provide a cost-effective method to reduce both time and costs for developing and verifying baseline energy consumption of existing building systems and identifying ECM opportunities, particularly RCx measures, which are otherwise often costly and difficult to quantify.

Utilizing MBCx in the PA and/or IGA phases may allow for identification of additional ECMs, reduced costs for energy audits, and increased precision of M&V.

Identification of Additional Energy Conservation Measures

MBCx can be used in the PA and/or IGA phases of the project to identify ECM opportunities, including those that might not have otherwise been investigated. It can be used to identify deficiencies including performance issues resulting from deferred maintenance or equipment malfunctions that may be corrected with RCx measures early in the project development process, potentially increasing project scope and cost savings. When used at this phase, MBCx enables the incorporation of thorough RCx as an ECM by identifying and quantifying energy savings opportunities that are typically not well understood upfront and involve too much uncertainty to be estimated.

Reduced Preliminary Assessment or Investment Grade Audit Costs

If an MBCx platform is utilized during the PA and/or IGA, some costs of baseline development and ECM identification may be reduced through contractor use of the MBCx platform's monitoring and data analysis capabilities. There may also be opportunities to allow the contractor to access the MBCx software remotely, reducing travel and labor hours required for site visits during the development of the PA or IGA.

Increased Precision in Measurement and Verification

The intent of M&V is to reduce uncertainty in energy savings and support the persistence of ECM performance over the term of the project. Key performance indicator measurement, automated data analysis, and continuous ECM performance monitoring becomes more cost effective with MBCx than with traditional monitoring practices. MBCx tools offer greater rigor than traditional approaches to ensuring ECM performance, as the tools are designed to facilitate and automate the statistical and mathematical calculations inherent to each of the four M&V options laid out in the FEMP M&V Guidelines (FEMP 2015).

M&V Options A and B are retrofit isolation or system-level approaches intended for ECMs with performance factors (e.g., end-use capacity, demand, power) and operational factors (e.g., lighting hours, cooling ton-hours) that can be measured at the component or system level. Options C and D are whole-facility approaches which focus on total facility energy use rather than performance of specific ECMs (FEMP 2015).

The objective of Option A is to calculate savings using short-term, periodic, or long-term measurement of a key parameter, usually equipment performance. Usage is typically measured when determining baseline energy use and agreed upon for the term of the contract. MBCx can support greater accuracy in Option A by measuring equipment operating hours, for lighting or motors for example, or trending key parameters for HVAC measures such as occupied and unoccupied space temperature set points. MBCx can also provide periodic data collection and analysis for key parameters throughout the project term.

Savings are calculated in Option B through periodic, long-term, or continuous measurement of all relevant parameters needed to calculate energy use—it is generally considered a highly reliable and desirable M&V option to reduce uncertainty. If AMI, submeter, and BAS trend data are available, MBCx allows all available trend data to be collected and analyzed in real time and more easily than relying on trend report sampling and analysis. Simplifying data collection and analysis in post-installation and performance period M&V enables a greater percentage of ECMs to cost-effectively use an Option B approach.

Option C uses historical utility billing data and a mathematical model to describe how the building operated in the past to determine the baseline. Annual savings is determined through analysis of models, typically formulated using linear regression modeling, where the "dependent variable" (i.e., metered energy consumption at a given time) is defined based on the value of the "independent" variables such as weather or occupancy conditions. Some MBCx vendors provide automated baseline modeling features supported by machine learning or similar statistical packages, which can reduce development time for performance contracts being implemented in a large portfolio of buildings and using this M&V option.

The baseline projected energy consumption produced by the model is then compared to actual consumption and the difference is the avoided consumption, or savings (Figure 7). For example, a baseline period might be the year (or more) preceding an RCx project. Once the project is complete, the historical baseline model uses current weather conditions to calculate what the energy use would have been if the improvements had not been made, typically referred to as the "projected" consumption, and this is compared to the current measured consumption. When current consumption is less than projected, this is an indication of the amount of energy the RCx project is saving.

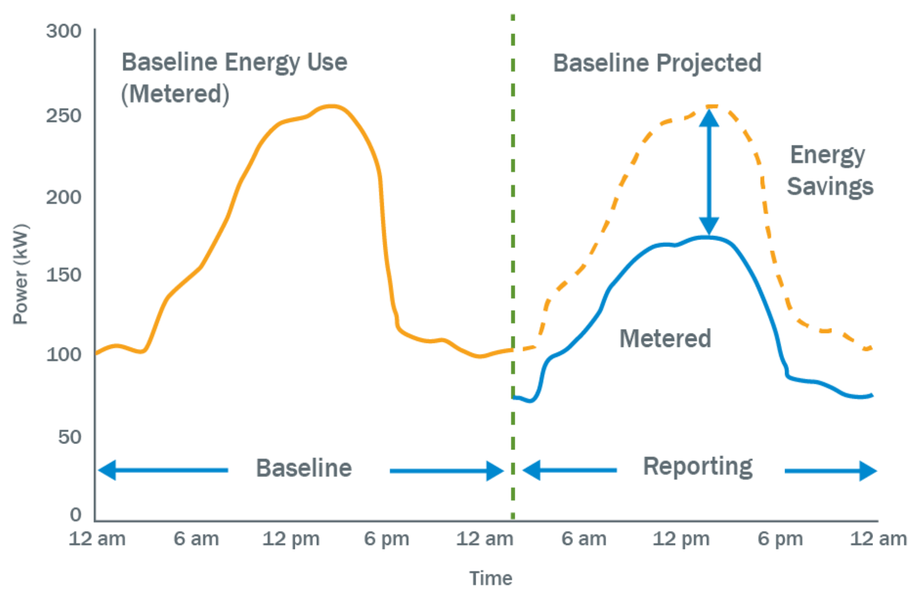


Figure 7. Comparing projected to actual usage

Image Credit: LBNL (Granderson et al. 2011)

For M&V Option C, the ability to automatically calculate weather-normalized whole-building energy savings via the MBCx platform can save a lot of time versus the traditional process of manual data entry and spreadsheet calculations.

Option D is calibrated simulation, or computer modeling, of whole-building energy use before and after ECMs are installed. Because this involves calibrating the model with measured data, MBCx software can be beneficial in collecting power draw on circuits for lighting, HVAC, and other loads, as well as equipment operating parameters and variable load trend data. As Option D typically reverts to Option A after one to two years, utilizing MBCx can provide greater accuracy after switching to Option A or may support choosing Option B instead.

As an example of increasing rigor in M&V, over the last 21 years there have been significant changes in the way M&V options are applied in federal ESPCs. From 1999 to 2003, the initial years of federal ESPC implementation, more than 80% of ECMs applied Option A. Fewer than 50% of ECMs used Option A from 2016 to 2019, with a large shift to greater use of Options B and C (Figure 8).

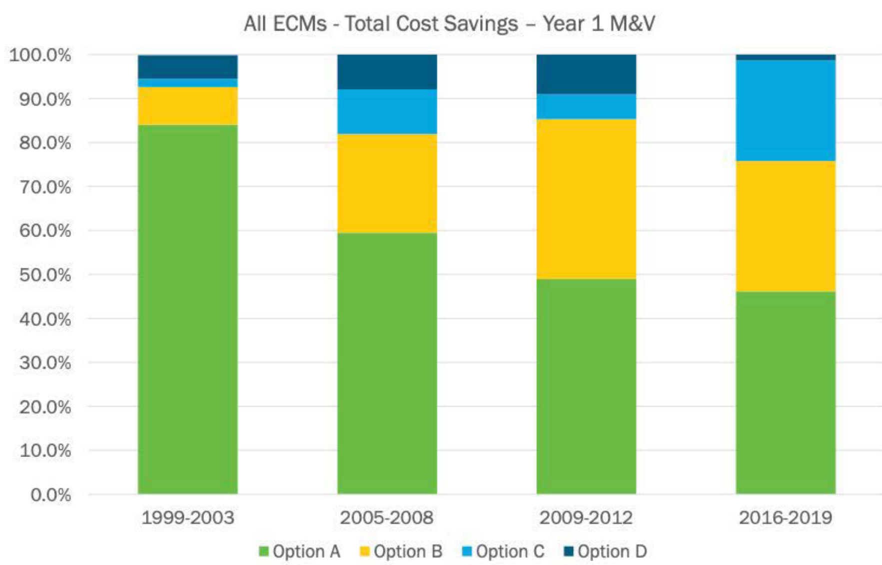


Figure 8. DOE IDIQ—shift in M&V options

Image Credit: Christine Walker, Oak Ridge National Laboratory

Coleman et al. (2020) describe the evolution of federal ESPC M&V implementation:

> In two decades of doing guaranteed savings ESPCs, the U.S. federal government has learned a great deal; the market and its customers have matured. One key facet of that learning has revolved around the way M&V is executed for federal projects. Where rigor was questionable, both as enforced by the customer agencies and also codified by FEMP (their in-house consultant for ESPC), it has evolved. This is evident in the tightening of the government's own guidelines for M&V – in the form of FEMP's setting a progressively higher bar for the minimum acceptable form of M&V (Option A), as well as in providing recommended options and skeleton plans for different ECMs. The evolution is also apparent in the agencies' trend away from reliance on Option A (its increased rigor notwithstanding) over time.

This increasing preference for greater M&V rigor is directly supported via the implementation of MBCx, which also has the potential to reduce the cost of M&V through automated M&V reports across all of the M&V Options (A, B, C, and D).

4.2.2 Construction and Commissioning

Using MBCx during the ECM commissioning process can help to reduce the costs and increase the quality of commissioning. The average construction period for performance contracting projects is currently about 24 months. When MBCx can be implemented within the first few months of the construction phase, it provides an opportunity to begin using the system to analyze how the facility is operated and identify additional RCx measures and other ECMs right away. The contractor can propose these ECMs for facility owner consideration, and the owner can modify the task order during construction to optimize performance of additional building systems and maximize value to the government as soon as possible.

As previously noted, MBCx software can also be used to assist in ECM commissioning and post-installation ECM performance measurement. MBCx compiles, calculates, and analyzes ECM performance data, automating trend log analysis and simplifying some of the performance verification that is required as part of the commissioning effort. When MBCx software is used for post-installation M&V, this allows the contractor to test 100% of the equipment—which would normally only be sampled—ensuring a more complete performance measurement protocol for the ECMs. Similarly, only a sample of certain HVAC devices will typically be included in the post-installation performance verification process, such as a small but statistically valid percentage of VAV boxes. If MBCx is installed and used during the post-installation M&V process, then performance of *all* VAV boxes can be verified and included in long-term MBCx to ensure they all continue to operate correctly over the project term.

There are also benefits from utilizing these capabilities in carrying out RCx, assuming RCx is an ECM to be implemented during construction.

4.2.3 Performance Period

Many of the applications of MBCx directly benefit the facility and contractor by ensuring equipment operational problems are identified and can be corrected before a savings shortfall occurs. This not only avoids potential disputes about the cause of the shortfall, but it also helps assure optimal ECM performance and maximum value for the facility over the term of the task order. To the extent the contractor and facility owner interests are aligned, greater data availability on the performance and realized savings attributable to ECMs is good for all parties. Likewise, timely analysis that improves O&M effectiveness supports consistent equipment performance and actual realized savings.

MBCx applications during the performance period include (1) automated reports and performance verification for each ECM, (2) assurance that agency staff are operating equipment according to project requirements, (3) remote analysis of system performance, and (4) the ability to diagnose O&M problems.

Automated Reports Deliver Ongoing Performance Verification Over the Entire Contract Term

The standard approach to M&V for most HVAC-related ECMs connected to a BAS is for the contractor to sample BAS trend logs on a short-term basis each year to ensure equipment is operating correctly. With this approach, only a subset of BAS points are used in the M&V plan, and only for a portion of the year, which may not fully ensure all equipment operates correctly over the entire performance period. MBCx allows for monitoring of more parameters on a continuous basis, allowing better tracking of real-time ECM performance.

Automation of BAS trend log analysis obviates the need for manual trend log analysis and should reduce the time required for verifying ECM performance by the contractor. Additionally, as many MBCx providers can perform Option C calculations automatically and generate automated reports for Option A and B measurements, annual M&V costs may be reduced accordingly.

As a first step, MBCx software programs should be used for performance verification for all HVAC measures that require BAS or AMI trend log analysis. This verification may be decoupled from the M&V protocol that is used for the specific ECM; the contractor and the facility owner can separately negotiate the most appropriate M&V protocol to determine energy savings for the ECM. For example, for all air-side HVAC measures such as outside air economizers, supply air temperature reset, and demand-controlled ventilation, the MBCx software should be used to ensure these new control sequences are operating correctly over the life of the project, whether or not they are used to directly measure energy savings.

MBCx rules that are specific to each HVAC measure included in the project should be deployed, and custom reports should be created to track system performance automatically over the life of the contract. MBCx software tools continuously track the performance of HVAC equipment so custom ECM-specific performance reports can be created. These automated reports provide the following benefits:

- The contractor should no longer need to perform manual BAS trend log analysis as a part of the M&V plan. Automated M&V reports generated through the MBCx platform could potentially reduce onsite time for the contractor and corresponding annual M&V costs.
- The accessibility of reports from a central location helps to supplement facility representative witnessing of the commissioning and creation of the first-year M&V report.

In the case of larger capital improvements, such as chilled water plant upgrades, BAS trend logs in combination with chiller plant AMI meters can be set up to both ensure the chiller plant is operated correctly and also measure energy savings directly via a key performance indicator such as chiller kW per ton as a function of chiller load (tons). For example, if a new chilled water plant is installed, an automated report such as the one in Figure 9 can be created to track ECM performance, including outside air temperature vs chilled water supply temperature, chiller kW/ton, chiller scheduling and chiller energy usage.

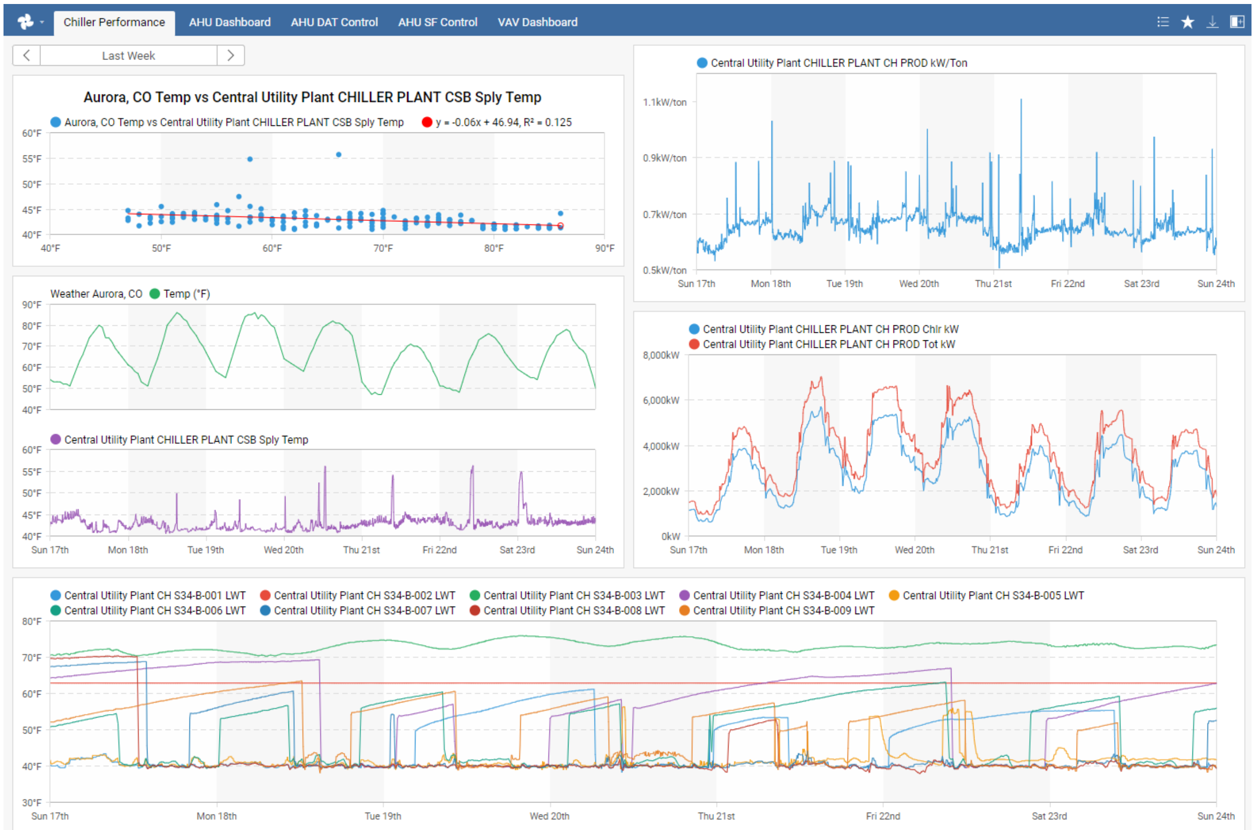


Figure 9. Automated ECM report of chiller plant performance

Image Credit: Celeste Cizik, Group14

Supporting Staff in Operating Equipment per Project Requirements

After the MBCx platform is installed and automated, ECM-level reports are created. If facility staff modify control sequences, set points, or schedules out of compliance with the task order requirements, AFDD notifications will alert both facility and contractor staff, allowing for quick corrections. The MBCx analysis should also help determine if ECM performance issues led staff to override the control settings, allowing those issues to be addressed.

Remote Analysis of System Performance

With the MBCx user interface, a facility owner can remotely analyze system performance for any building that is connected to the MBCx platform. This is a benefit for both the facility staff and the contractor, as it allows for remote system analysis and does not require visits to the site to view or download data for analysis. These reports can provide additional transparency into the ongoing operational performance of ECMs. Cybersecurity requirements may determine where remote access will be allowed for specific sites and facilities (also see Section 3.7).

Reduced Time to Diagnose Operations and Maintenance Problems

Once AFDD rules are set up in the MBCx platform, they constantly monitor system performance and can identify additional O&M issues and opportunities over time. For example, for chilled water, hot water, or steam distribution-related ECMs, contractors typically sample a subset of steam traps, while facility owners are responsible for repair or replacement of failed steam traps. In this scenario, automated steam trap monitors could instead be tied into an MBCx platform, allowing for identification of all deficiencies at the beginning of the project.

Witnessing Performance Assurance and Transparency in Data Analysis

ECM-level reports and analysis are visible to the MBCx provider, performance contractor (which may also be the MBCx provider), and the facility. This allows transparency for performance verification, corrective action recommendations, and identification of new savings measures. This transparency helps to supplement the onsite witnessing of ECM commissioning, RCx, and performance verification activities (a requirement in federal contracts) by cognizant facility staff.

Identification of Additional ECMs and Operational Savings

As the MBCx software monitors and analyzes performance data from various equipment, it is likely to find operational and performance issues that otherwise would not be discovered. The site or contractor can then implement these small adjustments as part of regular O&M duties, resulting in additional savings to the agency. If savings from these efforts were included in the guarantee in the task order, a set amount may also accrue to a reserve account held by the contractor to be used for specific future improvements (this concept is discussed further in Section 4.3.4). As larger opportunities such as additional ECMs or RCx measures are identified, the contractor can propose solutions to the facility for prioritization based on need, cost, and estimated savings. A task order modification would be needed to incorporate the new work and savings.

4.3 Incorporating Monitoring-Based Commissioning in Each Performance Contract Phase

Facilities that already have an MBCx system in use should consider how it will be used within the performance contract early in the project planning phase. Others seeking to install and implement a new MBCx system have an important decision to make regarding timing. The facility wishing to install MBCx may:

- Leverage appropriations to implement an MBCx program prior to the performance contract
- Install MBCx during the IGA
- Request that the contractor determine the opportunity and savings and implement MBCx as an ECM.

If the facility owner decides to implement MBCx in advance of a performance contract, funds would be needed to complete the installation and the savings would accrue directly to the facility. Monthly or annual SaaS payments would be the facility's responsibility. The MBCx system could then be used by the client and contractor when developing a performance contract to find RCx and other savings opportunities that may otherwise be missed. The DOE Better Buildings Solution Center EMIS specification and procurement support materials can be used to define requirements for the MBCx platform and used by the ESCO to select the best MBCx provider for the specific project (DOE 2021b).

Four potential approaches to utilizing existing MBCx or implementing a new MBCx platform in performance contracting projects are discussed below.

4.3.1 Existing Monitoring-Based Commissioning with New Performance Contracts

For facilities that have already deployed MBCx, the process of integrating it into a performance contract should be relatively straightforward, given that it is already installed and the costs of installing and maintaining the software do not need to be covered by the project's savings. During the acquisition planning phase, the customer should include language in the Notice of Opportunity (NOO) that outlines their expectations for using MBCx for the buildings targeted in the project throughout each phase of project development. If only a subset of the facilities included in the project have MBCx, agencies are encouraged to follow the site selection criteria guidance in Section 3.5 to determine if additional facilities may benefit from MBCx.

When incorporating existing MBCx systems in new performance contracts, the contractor and facility owner should consider how costs for system modifications (if necessary) will be covered, and in which project phases the system will be used:

- During the performance contract planning phase, the project team should meet with the operational technology group to determine which buildings already have MBCx installed, which buildings will be recommended for evaluation during the PA, and if MBCx expansion to other buildings is desired.

- For all buildings that already have MBCx installed, the NOO should strongly recommend (or could require) that the MBCx platform be used throughout all phases of the contract in the various ways discussed in this report that will provide the most benefits to the project – ECM investigation, assistance in commissioning and performance monitoring, prioritization of operational issues, and/or automated monitoring and reporting of ECM performance and savings. The NOO should also require the contractors to provide a description of their experience with implementing or utilizing MBCx, or a strategy for bringing expertise to the team, in their response to the NOO.

- During project development (both PA and IGA), the contractor and customer should determine the best uses for the MBCx platform in the project, including identification of current capabilities, modifications needed, expansion opportunities to add additional facilities to the MBCx platform, and associated savings for inclusion in the task order.

Some organizations have extensively installed MBCx software as a part of their smart buildings programs. The GSA Smart Buildings program, for example, has installed MBCx software on 106 of its largest facilities through its GSAlink program. Figure 10 illustrates the information flows facilitated by the GSAlink process.

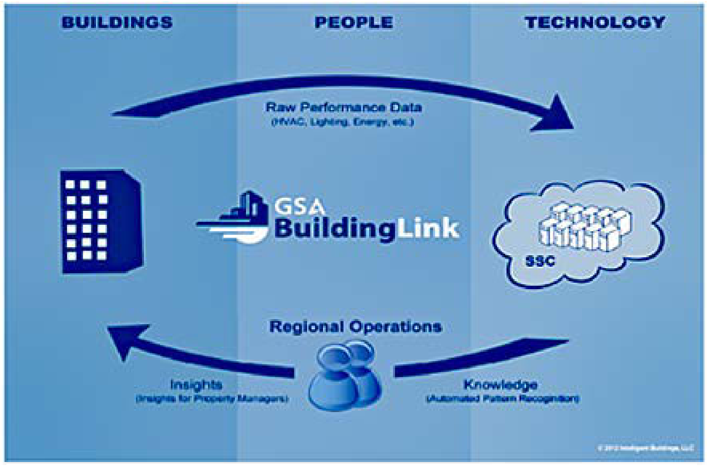


Figure 10. GSAlink process

Image Credit: Chipley 2020

GSA is implementing its smart buildings strategy to improve tenant satisfaction, reduce energy cost and environmental impact, and decrease operational inefficiencies. These advantages will assist GSA in meeting current executive orders and guidance, fulfill GSA administrative objectives, and prepare the agency for future building technologies, security issues, and tenant requirements (GSA 2021b). Given GSA's history implementing MBCx, they can now use a standardized process to add new facilities to GSA's MBCx platform for a fraction of the cost per building versus more conventional MBCx deployments, for a BAS that has already been through the cybersecurity framework, resides on the main GSA local area network, and already uses a standardized point naming convention. Additional information on the GSAlink program can be found in Section 5.2, General Services Administration Prioritizes Use of Monitoring Based Commissioning in Performance Contracts.

Similarly, the U.S. Navy has installed MBCx in over 700 facilities and plans to deploy it across their building portfolio over the next few years through its Navy Smart Grid program. There is an opportunity to utilize these MBCx platforms and those already installed in buildings of other agencies in new performance contracts moving forward.

Agencies like GSA and the Navy that have experience deploying MBCx enjoy some advantages when it comes to using or implementing MBCx in performance contracts. Having a standardized approach and agency-wide national license in place for MBCx software results in significantly lower MBCx integration costs, a streamlined installation process, and lower ongoing SaaS fees. Moreover, the organization is already familiar with the technology and recognizes its benefits.

4.3.2 Implementing Monitoring-Based Commissioning During the Investment Grade Audit

There may be cases where the facility owner and contractor agree to install the MBCx system at the outset of the IGA to assist in baselining energy use and identifying ECM opportunities that otherwise might be missed. For example, RCx measures are typically difficult and costly to identify because functional equipment testing is required to determine which specific issues need to be resolved and which of those would provide sufficient savings to cover the cost of the testing as well as the corrective action. MBCx processes are particularly adept at identifying and prioritizing operational issues that RCx could correct, so the facility owner and/or contractor may determine that MBCx implementation during the IGA would be worth the additional time and expense. This would also allow the MBCx software to be used to improve baseline accuracy in the IGA and for M&V assistance and ongoing commissioning later in the performance period.

The source of funding for MBCx implementation during the IGA—whether appropriations or third-party financing—is an important consideration. If the customer chooses to fund and implement MBCx prior to or during the IGA or outside of the performance contract, it should first determine that the time required for the procurement process to select a vendor and install the system will not result in undue delays for the IGA process. If the contractor selected for the performance contract is tasked to do the work, ensuring that the IGA timeline will not be unduly impacted and that the benefits are worth the costs and time will be top priorities.

Having the contractor implement MBCx prior to task order award poses a number of potential challenges. The IGA is a cost and time-intensive endeavor for the performance contractor, and at this stage there is no formal agreement that the customer will award the task order, so there is a chance the contractor may not recover its project development costs. The facility owner may agree to reimburse the contractor for the MBCx system under a separate agreement in the event the task order is not awarded, so long as the system performs as agreed and the agency receives tangible benefit from the MBCx even without the performance contract. Facility requirements and desires for MBCx implementation during the IGA should be described in the NOO so potential contractors can consider this in their responses.

Agency and contractor considerations for MBCx implementation during the IGA include the following:

- Does the expected improvement in baseline data quality and the additional savings opportunities identified with the MBCx tools warrant the additional time and cost at this stage?

- Will installing MBCx unduly extend the IGA timeline and what is the estimated cost of the delay?

- Do added benefits of MBCx installation prior to contract award outweigh the potential risk of the task order not being awarded, or is there an acceptable approach to managing that risk to the contractor?

4.3.3 Implementing Monitoring-Based Commissioning During Construction

For facilities that are not currently utilizing MBCx, the most straightforward strategy is likely to implement MBCx during the construction period as an ECM for which the savings cover the costs of implementation and annual SaaS fees. Savings resulting from the MBCx system would typically come from identification and implementation of RCx opportunities, as well as the additional persistence of savings through monitoring and remedying of performance degradation, to the extent this can be determined in advance. Since most re-tuning and RCx efforts have very short payback periods (less than five years), the cost of the MBCx could be added to the capital cost for these ECMs in a way that improves the overall economics of the whole project.

For MBCx to be implemented in the task order, it is recommended that the NOO document the facility owner's desire for MBCx to be installed and utilized in the project. Any desired applications of MBCx in addition to achieving energy cost savings (e.g., to automate M&V data collection and/or reporting, to support ECM commissioning, to provide MBCx) should also be included in the NOO. To the extent possible, specific MBCx benefits and guaranteed cost savings will be determined during the IGA, at which point the buildings to be included and functionality of the MBCx system can be agreed upon. If full functional performance tests are not performed during the IGA, the savings guarantees may be based upon the contractor's experience with MBCx in similar facilities. With this approach the contractor may be able to guarantee a relatively small amount of savings compared to the potential savings that will be documented following implementation/construction, when the MBCx processes can be utilized to identify more specific performance issues and RCx opportunities. In most cases, though savings may be small, they should be sufficient to fund the MBCx process that will identify and quantify both cost and savings of additional RCx improvements. If installed and operational early in the construction period, MBCx can be used to verify the magnitude of savings from the RCx opportunities included in the IGA, as well as uncover additional ones, which can be incorporated into the project via task order modification prior to project acceptance.

4.3.4 Maximizing Savings Throughout the Project Life Cycle

As demonstrated in Figure 1, MBCx software not only provides the opportunity to optimize ongoing building and ECM performance, it can also be used to uncover equipment performance issues and cost savings opportunities that otherwise might not be found, both during initial commissioning and throughout the performance period. This provides assurance of optimal ECM performance and persistence of savings, as well as potentially finding additional opportunities to manage or reduce facility energy and maintenance costs.

Once the MBCx system is installed and operational, the contractor, in collaboration with the facility staff, could produce full building performance reports showing operational issues including RCx opportunities and implementation cost and savings. The facility owner would then review, prioritize, and approve measures for implementation, modifying the task order if needed. Inexpensive and routine maintenance measures such as maintaining control strategies, repairing malfunctioning temperature sensors, or addressing improper supply air temperature reset would typically be covered in the task order requirements or O&M contract. While uncommon, more costly measures may occasionally be found, such as full RCx activities requiring a commissioning agent to complete, which may require task order modifications.

This concept—the owner's willingness to consider measures to be implemented at a later date—would ideally be contemplated and documented in the NOO. This should be a repetitive and ongoing process that continues throughout the performance period, ensuring that small performance issues are quickly addressed prior to becoming large problems. If additional savings opportunities are found in subsequent years that require an investment to implement, they could be considered for additional task order modifications. This could occur annually or periodically on an as-needed basis.

For ESPCs, another option is to include the cost and timing of future RCx of equipment (or other planned maintenance, repairs, and/or replacement) in the task order and set aside an amount from the guaranteed annual savings in a reserve account to be used to fund the specified RCx or maintenance work. A reserve account funded by a portion of guaranteed savings can be held by the contractor to be used for an identified future purpose as agreed upon in the task order. The funds held in the reserve account would then be used only to implement energy savings measures, RCx opportunities, or ECM maintenance, repair, or replacement as specified in the task order.

If a reserve account was not set up at task order award, and if MBCx processes result in verified annual savings greater than guaranteed in the task order, the facility owner and contractor may consider a task order modification at a later date to capture the additional savings in a reserve account for specified future maintenance expenses. By planning and setting aside a portion of guaranteed savings, the reserve account ensures that the facility owner has sufficient funds to plan and implement RCx opportunities uncovered by the MBCx processes or cover other planned maintenance expenses.

Reserve accounts for federal ESPCs are described in DOE's Generation 4 ESPC IDIQ contract as follows from Section C.15 (DOE, forthcoming):

> If determined appropriate by the ordering agency CO/KO and legal counsel, a task order under this contract may provide for the establishment of a reserve account by the Contractor. Such a reserve account may accumulate funds from contract payments made by the ordering agency to the Contractor from guaranteed savings. Funds from the reserve account must be used by the Contractor for an identified future expense related to an energy conservation measure or water conservation measure implemented under the ESPC project. Funds from such reserve account shall not be used to offset any guaranteed savings shortfall. All excess funds in the reserve account at the end of the ESPC project period shall be applied to the ordering agency's outstanding balance under the ESPC. Any such reserve account shall be in accord with Federal fiscal law and not alter the rights and responsibilities of the Contractor or ordering agency under this IDIQ contract.

The use of reserve accounts may or may not be allowable for certain federal agencies or other institutions. Please consult your performance contracting team and legal counsel to understand the specific practices of your agency or institution.

5 Case Studies

Two case studies illustrate the use of MBCx within the context of performance contracting. These include an ESPC at a university in Colorado, and GSA's successful use of MBCx within the GSAlink program.

5.1 Colorado School of Mines Monitoring-Based Commissioning Integrates Occupant Engagement, Retro-Commissioning, and Renewable Energy

McKinstry, a national engineering company that serves as an ESCO in many regions of the United States, incorporates MBCx as a standard part of its ESPC service offerings. Through a program called powerED, McKinstry implements a behavioral change program focused on both occupants and operators, utilizing MBCx to inform decision making (McKinstry 2021a). powerED is defined by McKinstry as:

> A behavior-focused energy awareness and operational efficiency program designed to reduce costs, increase efficiency, and promote environmentally friendly operations within facilities. McKinstry's systematic energy and environmental management program promotes active participation from staff and students, careful tracking of resources, and attention to efficient operations. The powerED program uses a highly collaborative approach with three key elements of focus: People, Process, and Performance (McKinstry 2021a).

In 2018, McKinstry completed implementation of an ESPC at Colorado School of Mines that included the integration of an MBCx platform across 32 buildings. The ESPC included a savings guarantee of $234,000 per year for the powerED ECM, which featured both an occupant engagement/behavioral change program and RCx with ongoing MBCx for the building operators. This combined RCx/MBCx measure was implemented during the construction phase of the project. The MBCx system was also used to assist with commissioning and ongoing M&V for ECMs including chiller plant upgrades, campus controls upgrades, and onsite renewable energy, as detailed below.

Chiller Plant Upgrades

Chiller plant ECMs at School of Mines included the following:

- Replace existing 300-ton absorption chiller in Chiller Plant 4 with a new 275-ton variable speed magnetic bearing centrifugal chiller
- Upgrade existing CP4 plant controls to BACNET MS/TP Niagara N4 system
- Remove existing chiller in Berthoud Hall and provide a heat exchanger and tie to Chiller Plant 6 central chilled water loop
- Replace existing Berthoud Hall chiller plant controls with new Schneider Electric controls and tie to existing building LonWorks system.

Campus Controls Upgrades

Campus controls upgrades delivered by McKinstry included:

- Install return air CO_2 sensor (for demand-controlled ventilation) in the single-zone auditorium AHU-3
- Optimize lab AHU-5&6 heat recovery run-around loop controls
- Optimize existing supply direct evaporative cooling and optimize heat recovery run-around loop controls in AHU-1
- Optimize AHU-2 heat recovery run-around loop controls.

Onsite Renewable Energy

The McKinstry ESPC included installation of a PV system on a new garage. The MBCx platform can provide alerts if the PV system output is zero during daylight hours when it should be producing electricity, illustrating an MBCx use case for onsite renewable energy systems in addition to standard building systems and equipment.

MBCx Platform

MBCx platform integration costs were included in the powerED ECM. Data for the MBCx platform is stored on the campus local area network. A second iteration of the database is also stored in the cloud, where McKinstry is able to remotely view ECM performance, track deficiencies, and work with onsite staff to utilize MBCx recommendations to drive further energy savings.

Jim Hauswirth, a senior building energy analyst with McKinstry who is responsible for deploying MBCx at Colorado School of Mines, summarized the benefits of integrating MBCx into ESPCs:

> Having a platform where we can see things in near real time is useful in identifying and implementing energy conservation measures in a streamlined way. Consider we used to have to gather BAS data, load it into Microsoft Excel then perform some level of analysis. Now we can identify, implement and verify measures all in the same day. For example, let's say we observe that an RTU [rooftop unit] is running past its schedule, we can go to the client with data to prove this, ask that the schedule be adjusted (or find whatever the root cause may be) and make sure that the new schedule is holding overnight. Without a tool like this performing this task may have taken two or three days.

As part of this ESPC, McKinstry also deployed a "Reveal" platform that integrates high-level key performance indicators from the MBCX dashboard with ENERGY STAR® Portfolio Manager benchmarking, utility tracking, and M&V at the whole-building level to keep the university informed on progress towards its energy reduction targets (Figure 11 and Figure 12). From an excerpt from McKinstry (2021b):

> Reveal™ is a cloud-based facility management technology for building performance optimization. Through an online portal that is unique to every client, this technology assimilates data from various building operation sources and provides powerful visualizations for facility managers,

operators, and executives to drive critical decisions for performance. Specifically, Reveal integrates utility bill, building meter, building automation system, building asset inventory, renewables, and weather data. It tracks facility performance using client-specific fault detection and diagnostics (FDD), [key performance indicators] and normalized baseline comparison. The result is a complete view of client facility optimization by facility operators, managers and all levels of an organization to inform operation, management decisions and the ability to effectively communicate strategy and results.

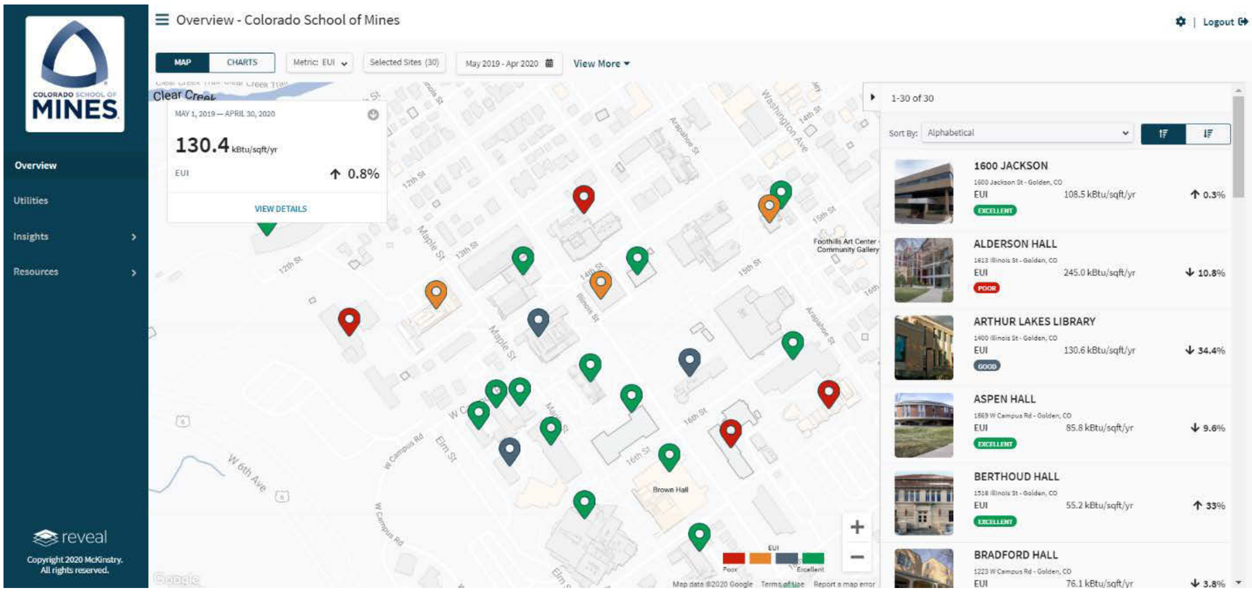


Figure 11. Colorado School of Mines performance dashboard #1

Image Credit: Jim Hauswirth, McKinstry

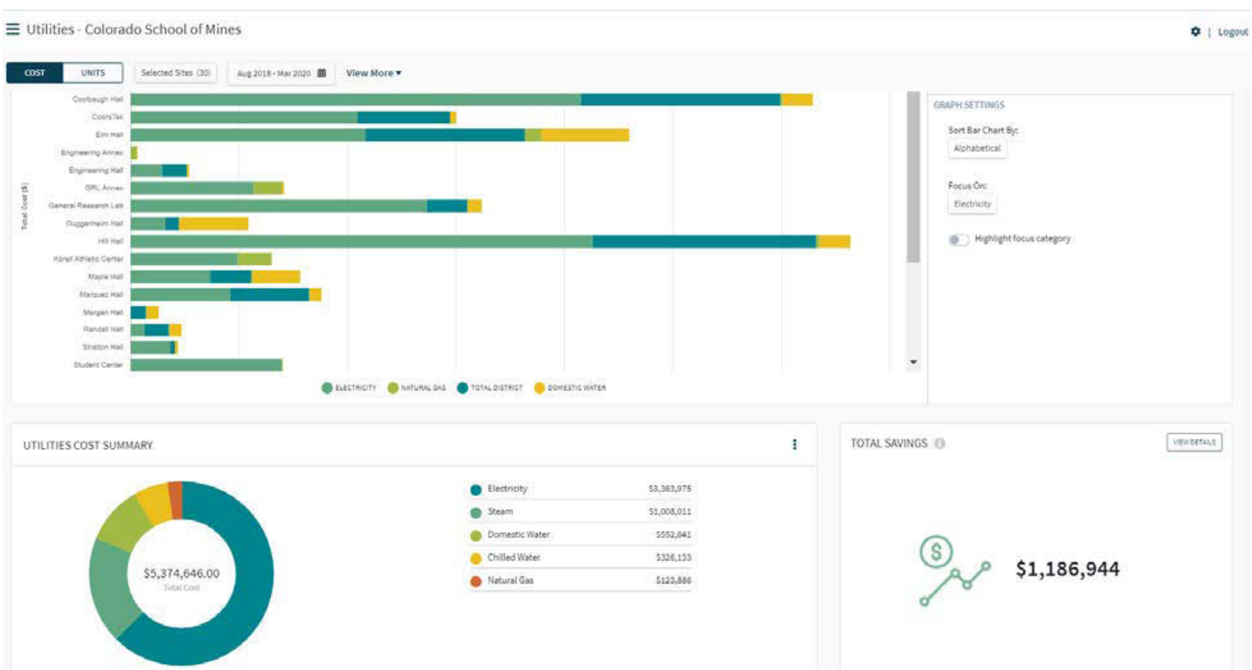


Figure 12. Colorado School of Mines performance dashboard #2

Image Credit: Jim Hauswirth, McKinstry

MBCx platform diagnostics are rolled up to daily summaries by ECM or fault category in the same dashboard to provide high-level diagnostics for issues such as outside air damper malfunctioning or RTUs with excessive runtime (Figure 13).

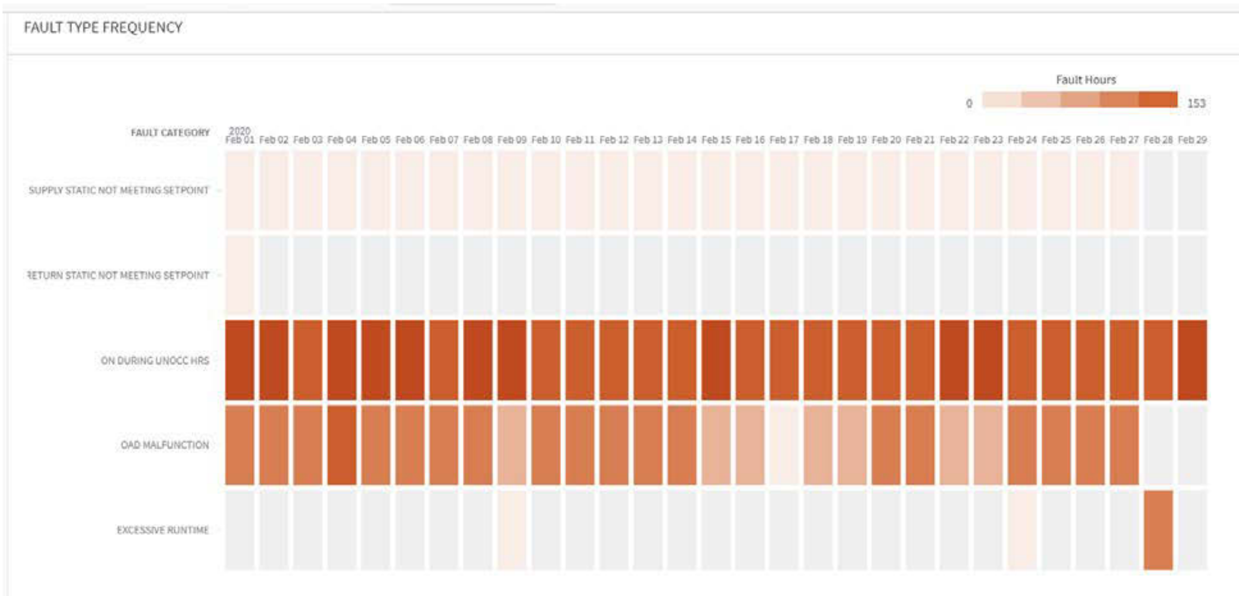


Figure 13. Colorado School of Mines platform diagnostics by fault category

Image Credit: Jim Hauswirth, McKinstry

The combination of the powerED and Reveal programs adds value to the overall project, demonstrating the benefits of integrating MBCx into ESPCs from both the building owner and ESCO perspectives.

5.2 General Services Administration Prioritizes Use of Monitoring-Based Commissioning in Performance Contracts

GSA manages the single largest portfolio of commercial office space in the United States—more than 8,500 properties— including more than 1,500 federally owned properties under GSA's jurisdiction, custody and control. This amounts to more than 370 million ft^2 of building space under its management including more than 180 million ft^2 of federally owned building space (GSA 2018). Annual energy costs for the real estate it owned in 2018 amount to $280 million per year, and at 52.2 kBTU/ft^2/yr, GSA buildings are 33% more efficient than typical U.S. commercial buildings (GSA 2018). Given GSA's large portfolio of buildings and aggressive energy reduction goals, the agency was an early adopter of MBCx software platforms and created a national program to implement GSAlink, a centralized MBCx software platform that is deployed nationwide, starting in 2012. A summary of buildings and meters integrated into GSAlink as of November 2020 is provided in Table 1.

Table 1. GSAlink and Metering Implementation Statistics

Scope of Integration	Count of Buildings	Sum of Square Footage	Electric Meters Integrated	Water Meters Integrated	Gas Meters Integrated	Steam Meters Integrated
GSAlink MBCx and Metering	103	63,018,781	748	183	89	42
Metering Only (No MBCx/FDD)	63	14,777,568	136	72	47	2
Grand Total	166	77,796,349	884	255	136	44

A 2018 analysis of 60 GSAlink sites demonstrated a $17 million cost avoidance, including a $7 million energy cost impact, 15.9% yearly energy usage reduction, 12.2% daily average demand reduction, and a 24.7% yearly peak demand reduction relative to the baseline energy consumption of the 60 sites prior to deploying MBCx (Loftness et al. 2020).

Given GSA's long history implementing both MBCx and performance contracts, GSA recognized the need to use an MBCx software platform when evaluating performance contracts and has prioritized the use of GSAlink to supplement M&V in its performance contracts. GSA leverages GSAlink capabilities for internal reporting to:

- Automatically collect and trend data from multiple sources
- Verify sequences of operation and flag variances from intended performance
- Calculate detailed savings for ECMs
- Create automated reporting similar to those used within performance contracting M&V plans
- Utilize FDD to verify operation and ECM compliance
- Utilize GSA's National Computerized Maintenance Management System to quickly resolve FDD issues through O&M agreements.

Traditionally, this involved manually sifting through BAS, utility bills, and operational technology data to quantify energy savings. Due to the detailed and complex calculations involved, the process was typically labor-intensive and expensive.

The toolset developed in GSAlink allows users to quickly and easily digest large data sets (thousands of points from multiple buildings over many years) to actively monitor, commission, measure, and verify compliance of implemented ECMs and sequences. The tools also collected point-level data. ECM report templates are also continuously developed to provide a uniform look at individual ECM performance.

GSAlink Generates Customized, Automated Reports

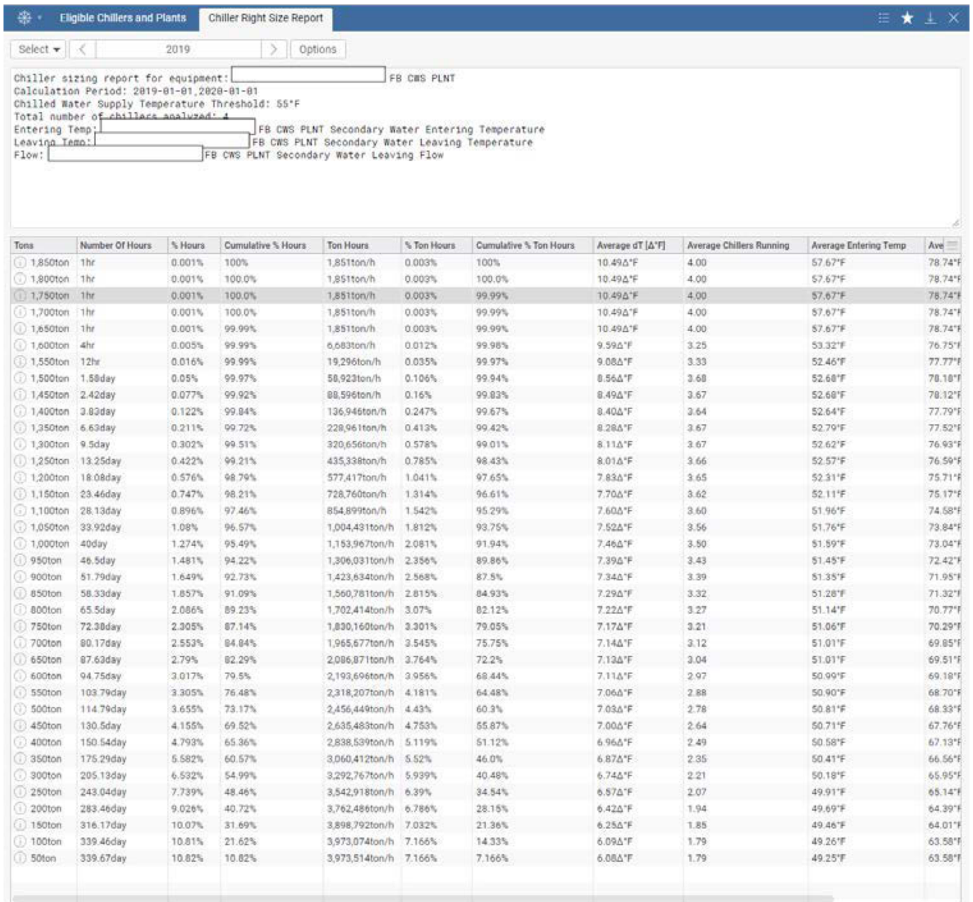
The GSAlink Chiller Plant Improvement Report shown in Figure 14 focuses on a specific ECM and building-level metrics which require ongoing data logging. In this case, GSAlink automatically and continuously extracts data from the BAS, weather, advanced metering, and other systems. It then runs tailored calculations for the ECM, and exports the results as standardized charts, tables, and reports.

The ECM focused on switching from utility-supplied chilled water by installation of high-efficiency, modular chillers. The savings are based on kW/ton calculation. Data is collected through BAS trends and then imported into GSAlink. The GSAlink report provided in Figure 14 calculates savings on a monthly basis and also provides historical data for the user of the report.

Figure 14. GSAlink Chiller Plant Improvement Report

Image Credit: Jacob Nicosia, GSA

The GSAlink Chiller Right-Sizing Report shown in Figure 15 is intended to quickly and easily determine if the chilled water system plant equipment is sized and operating properly. The results of the Chiller Right-Sizing Report were compiled utilizing information integrated to and contained within GSAlink and could be used during the IGA or feasibility assessment phase of a performance contract to help characterize chiller sizing in reference to future ECMs.


Eligible Chillers and Plants | Chiller Right Size Report

Select | 2019 | Options

```
Chiller sizing report for equipment: FB CWS PLNT
Calculation Period: 2019-01-01,2020-01-01
Chilled Water Supply Temperature Threshold: 55°F
Total number of chillers analyzed: 4
Entering Temp: FB CWS PLNT Secondary Water Entering Temperature
Leaving Temp: FB CWS PLNT Secondary Water Leaving Temperature
Flow: FB CWS PLNT Secondary Water Leaving Flow
```

Tons	Number Of Hours	% Hours	Cumulative % Hours	Ton Hours	% Ton Hours	Cumulative % Ton Hours	Average dT [Δ°F]	Average Chillers Running	Average Entering Temp	Ave
1,850ton	1hr	0.001%	100%	1,851ton/h	0.003%	100%	10.49Δ°F	4.00	57.67°F	78.74°F
1,800ton	1hr	0.001%	100.0%	1,851ton/h	0.003%	100.0%	10.49Δ°F	4.00	57.67°F	78.74°F
1,750ton	1hr	0.001%	100.0%	1,851ton/h	0.003%	99.99%	10.49Δ°F	4.00	57.67°F	78.74°F
1,700ton	1hr	0.001%	100.0%	1,851ton/h	0.003%	99.99%	10.49Δ°F	4.00	57.67°F	78.74°F
1,650ton	1hr	0.001%	99.99%	1,851ton/h	0.003%	99.99%	10.49Δ°F	4.00	57.67°F	78.74°F
1,600ton	4hr	0.005%	99.99%	6,683ton/h	0.012%	99.98%	9.59Δ°F	3.25	53.32°F	76.75°F
1,550ton	12hr	0.016%	99.99%	19,296ton/h	0.035%	99.97%	9.08Δ°F	3.33	52.46°F	77.77°F
1,500ton	1.58day	0.05%	99.97%	58,923ton/h	0.106%	99.94%	8.56Δ°F	3.68	52.68°F	78.18°F
1,450ton	2.42day	0.077%	99.92%	88,596ton/h	0.16%	99.83%	8.49Δ°F	3.67	52.68°F	78.12°F
1,400ton	3.83day	0.122%	99.84%	136,946ton/h	0.247%	99.67%	8.40Δ°F	3.64	52.64°F	77.79°F
1,350ton	6.63day	0.211%	99.72%	228,961ton/h	0.413%	99.42%	8.28Δ°F	3.67	52.79°F	77.52°F
1,300ton	9.5day	0.302%	99.51%	320,656ton/h	0.578%	99.01%	8.11Δ°F	3.67	52.62°F	76.93°F
1,250ton	13.25day	0.422%	99.21%	435,338ton/h	0.785%	98.43%	8.01Δ°F	3.66	52.57°F	76.59°F
1,200ton	18.08day	0.576%	98.79%	577,417ton/h	1.041%	97.65%	7.83Δ°F	3.65	52.31°F	75.71°F
1,150ton	23.46day	0.747%	98.21%	728,760ton/h	1.314%	96.61%	7.70Δ°F	3.62	52.11°F	75.17°F
1,100ton	28.13day	0.896%	97.46%	854,899ton/h	1.542%	95.29%	7.60Δ°F	3.60	51.96°F	74.58°F
1,050ton	33.92day	1.08%	96.57%	1,004,431ton/h	1.812%	93.75%	7.52Δ°F	3.56	51.76°F	73.84°F
1,000ton	40day	1.274%	95.49%	1,153,967ton/h	2.081%	91.94%	7.46Δ°F	3.50	51.59°F	73.04°F
950ton	46.5day	1.481%	94.22%	1,306,031ton/h	2.356%	89.86%	7.39Δ°F	3.43	51.45°F	72.42°F
900ton	51.79day	1.649%	92.73%	1,423,634ton/h	2.568%	87.5%	7.34Δ°F	3.39	51.35°F	71.95°F
850ton	58.33day	1.857%	91.09%	1,560,781ton/h	2.815%	84.93%	7.29Δ°F	3.32	51.28°F	71.32°F
800ton	65.5day	2.086%	89.23%	1,702,414ton/h	3.07%	82.12%	7.22Δ°F	3.27	51.14°F	70.77°F
750ton	72.38day	2.305%	87.14%	1,830,160ton/h	3.301%	79.05%	7.17Δ°F	3.21	51.06°F	70.29°F
700ton	80.17day	2.553%	84.84%	1,965,677ton/h	3.545%	75.75%	7.14Δ°F	3.12	51.01°F	69.85°F
650ton	87.63day	2.79%	82.29%	2,086,871ton/h	3.764%	72.2%	7.13Δ°F	3.04	51.01°F	69.51°F
600ton	94.75day	3.017%	79.5%	2,193,696ton/h	3.956%	68.44%	7.11Δ°F	2.97	50.99°F	69.18°F
550ton	103.79day	3.305%	76.48%	2,318,207ton/h	4.181%	64.48%	7.06Δ°F	2.88	50.90°F	68.70°F
500ton	114.79day	3.655%	73.17%	2,456,449ton/h	4.43%	60.3%	7.03Δ°F	2.78	50.81°F	68.33°F
450ton	130.5day	4.155%	69.52%	2,635,483ton/h	4.753%	55.87%	7.00Δ°F	2.64	50.71°F	67.76°F
400ton	150.54day	4.793%	65.36%	2,838,539ton/h	5.119%	51.12%	6.96Δ°F	2.49	50.58°F	67.13°F
350ton	175.29day	5.582%	60.57%	3,060,412ton/h	5.52%	46.0%	6.87Δ°F	2.35	50.41°F	66.56°F
300ton	205.13day	6.532%	54.99%	3,292,767ton/h	5.939%	40.48%	6.74Δ°F	2.21	50.18°F	65.95°F
250ton	243.04day	7.739%	48.46%	3,542,918ton/h	6.39%	34.54%	6.57Δ°F	2.07	49.91°F	65.14°F
200ton	283.46day	9.026%	40.72%	3,762,486ton/h	6.786%	28.15%	6.42Δ°F	1.94	49.69°F	64.39°F
150ton	316.17day	10.07%	31.69%	3,898,792ton/h	7.032%	21.36%	6.25Δ°F	1.85	49.46°F	64.01°F
100ton	339.46day	10.81%	21.62%	3,973,074ton/h	7.166%	14.33%	6.09Δ°F	1.79	49.26°F	63.58°F
50ton	339.67day	10.82%	10.82%	3,973,514ton/h	7.166%	7.166%	6.08Δ°F	1.79	49.25°F	63.58°F

Figure 15. GSAlink Chiller Right-Sizing Report

Image Credit: Jacob Nicosia, GSA

The GSAlink Chiller Right-Sizing Report shows the number of hours the system operates at different capacities (tons). Building experts can utilize and interpret the data. The report also allows users to modify some of the parameters used in the calculation.

GSAlink Energy Application and Energy Demand Dashboard

The GSAlink Energy Application allows users to set baseline parameters and normalized data for specific ECM performance. Within the Energy Application, GSA has created an Energy Demand Dashboard intended to present a variety of information about the site's energy consumption in an easily digestible format. The tool provides a high-level view of the site's energy performance, including year-over-year electrical demand, peak and spike events, average startup and shutdown times, and more. The Dashboard (Figure 16) shows that the week-to-date electric demand in blue is coming in under the baseline electric demand. The red dots represent the daily peak demand events.

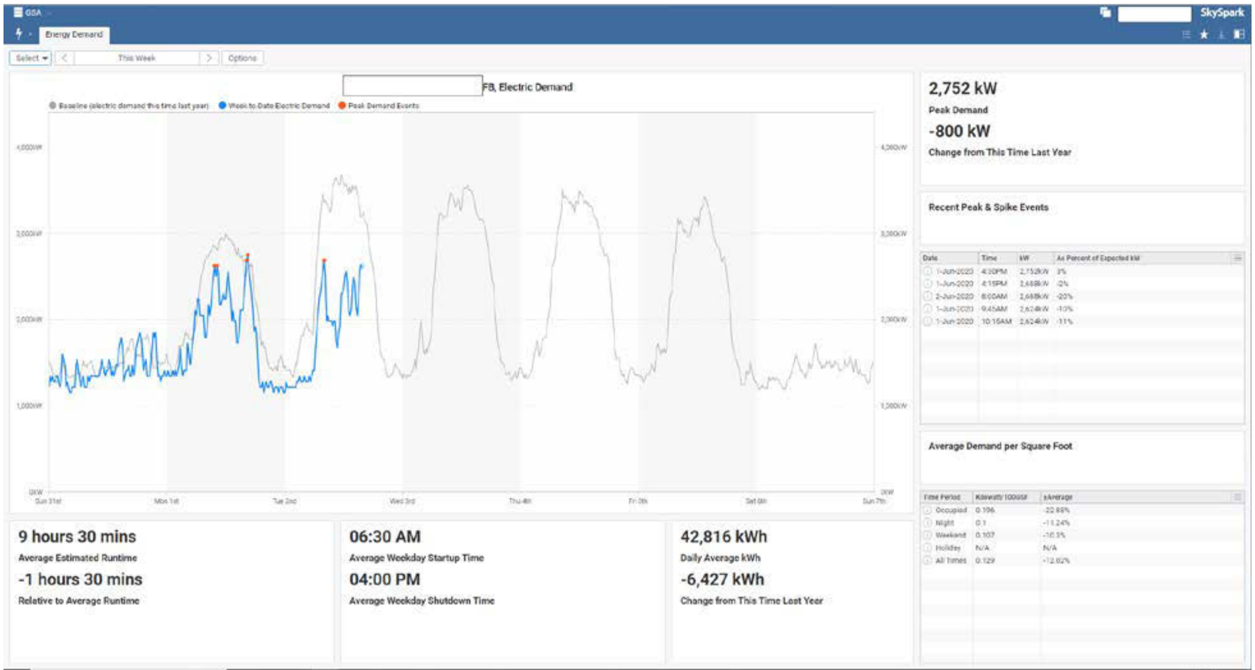


Figure 16. GSAlink Energy Demand Dashboard

Source: Jacob Nicosia, GSA

The GSAlink Energy Application and Energy Demand Dashboard can be modified to create custom reports that automatically calculate energy savings for any ECM or whole building with AMI metering.

GSAlink Fault Detection Diagnostics and National Computerized Maintenance Management System Integration

Analytics are customized for each building based upon the intended design requirements. When equipment does not meet the intended operational parameters, a notification is sent to the National Computerized Maintenance Management System so that action can be taken by the facility staff to resolve the issues. The system has the ability to connect MBCx to the National Computerized Maintenance Management System allows GSA to easily submit work orders for equipment that is malfunctioning, has incorrect control sequences, or has scheduling issues that need to be resolved.

6 Conclusion

Effective commissioning is critical to ensuring building and energy system performance meets design intent. Applying an ongoing commissioning process helps sustain optimal performance over the long term, and MBCx facilitates this process in a cost-effective manner.

Commercial building owners have an opportunity to enhance the value and effectiveness of their energy performance contracts through integration of MBCx. Implemented effectively, MBCx can add significant value by increasing savings persistence, identifying additional measures to increase energy savings, providing more accurate and ongoing performance monitoring, allowing for automation of many M&V functions, and empowering the owner with tools to improve O&M performance.

Even in light of generally higher costs of implementation at federal facilities, MBCx can offer a compelling business case for federal agencies—analysis of a variety of MBCx projects has found energy savings ranging from 9% to over 15%, with simple paybacks as low as 3.2 years. Implementation and utilization of MBCx also enables federal agencies to meet requirements for recommissioning and advanced metering, and directly contributes to facilities meeting the definition of "smart buildings".

Effectively implementing MBCx in performance contracts offers a range of benefits which can significantly improve performance contracting outcomes for both the contractor and the facility. The earlier MBCx is implemented, the more those processes can benefit the project. Recent projects at Colorado School of Mines and within GSA's federal real estate portfolio demonstrate the opportunity that exists with MBCx and multiple methods of implementation within performance contracts.

References

California Commissioning Collaborative (2021). "Commissioning Tools and Templates." Accessed March 12, 2021. https://cacx.org/resources/cxtools/index.html.

CDW (2021). "What is Software as a Service (SaaS)? Move Your Software to the Cloud." Accessed March 12, 2021. https://www.cdw.com/content/cdw/en/articles/cloud/2019/01/08/saas-definition.html.

Chipley, Michael (2020). "Cybersecurity." Accessed November 18, 2020. *Whole Building Design Guide*. February 21, 2020. https://www.wbdg.org/resources/cybersecurity.

Coleman, Philip, Shankar Earni, Bob Slattery, and Christine Walker (2020). M&V in ESPC: The U.S. Federal Experience and Implications for Developing ESPC Markets. Hyderabad, India: Energise 2020 Energy Innovation for a Sustainable Economy paper proceedings, Feb 11–13, 2020.

Complete Commissioning, Inc. (2021). "What is Commissioning." Accessed March 12, 2021. https://completecx.com/what-is-commissioning/.

Crowe, Eliot, Evan Mills, Tom Poeling, Claire Curtin, Diana Bjørnskov, Liz Fischer, and Jessica Granderson (2020). Building commissioning costs and savings across three decades and 1500 North American buildings. *Energy and Buildings* 227, 110408.

Dean, Jesse and James Dice (2021). *Energy Management Systems Technical Resource Report.* Golden, CO: National Renewable Energy Laboratory.

Efficiency Valuation Organization (2016). *International Performance Measurement and Verification Protocol Core Concepts*. Washington, DC: Efficiency Valuation Organization.

Efficiency Valuation Organization (2021). "International Performance Measurement and Verification Protocol (IPMVP)." Accessed March 12, 2021. https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp.

Federal Energy Management Program (2015). M&V Guidelines: Measurement and Verification for Performance-Based Contracts Version 4.0. https://www.energy.gov/sites/prod/files/2016/01/f28/mv_guide_4_0.pdf.

Federal Energy Management Program (2021a). "Cybersecurity Considerations for Performance Contracts." Accessed March 12, 2021. https://www.energy.gov/eere/femp/cybersecurity-considerations-performance-contracts.

Federal Energy Management Program (2021b). "Energy and Cybersecurity Integration." Accessed March 12, 2021. https://www.energy.gov/eere/femp/energy-and-cybersecurity-integration.

Federal Energy Management Program (2020). "Guidance Regarding Refinancing, Restructuring, or Modifying Loan Agreements Entered into by an Energy Services Company Under a Federal Energy Savings Performance Contract." Accessed December 10, 2020. https://www.energy.gov/eere/femp/downloads/guidance-regarding-refinancing-restructuring-or-modifying-loan-agreements.

Granderson, Jessica, Hannah Kramer, and Claire Curtin (2018). "How To Implement Monitoring-Based Commissioning." *Facilitiesnet*. September 10, 2018. https://www.facilitiesnet.com/buildingautomation/article/How-To-Implement-Monitoring-Based-Commissioning--17961.

Granderson, Jessica, Mary Ann Piette, Ben Rosenblum, R. Lily Hu, Daniel Harris, Paul Mathew, Phillip Price, Geoffrey Bell, Srinivas Katipamula, and Michael Brambley (2011). *Energy Information Handbook: Applications for Energy-Efficient Buildings Operations.* Berkeley, CA: Lawrence Berkeley National Laboratory. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/energy-information-handbook.pdf.

Granderson, Jessica, Rupam Singla, Ebony Mayhorn, Paul Ehrlich, Draguna Vrabie, and Stephen Frank (2017). "Characterization and Survey of Automated Fault Detection and Diagnostic Tools." Berkeley, CA: Lawrence Berkeley National Laboratory. https://buildings.lbl.gov/sites/default/files/lbnl-2001075.pdf.

International Organization for Standardization (ISO) (2018). ISO 50001:2018 Energy Management Systems – Requirements With Guidance For Use. https://webstore.ansi.org/Standards/ISO/ISO500012018PlusRedline?gclid=Cj0KCQiAmsrxBRDaARIsANyiD1rmqii6U2xSuiDsCJHrNlQrDIGqhH1J4tcWMkFnJ4hU2DK5TGIW_XAaAnASEALw_wcB.

Katipamula, Srinivas (2020)."Improving Commercial Building Operations thru Building Re-tuning: Meta-Analysis. https://buildingretuning.pnnl.gov/documents/PNNL-SA-156277_Re-tuningMeta-Analysis_2020-09-05.pdf.

Katipamula, Srinivas and Michael R. Brambley (2005). Methods for Fault Detection, Diagnostics, and Prognostics for Building Systems—A Review, Part I. HVAC&R Research, 11:1, 3–25.

KGS Buildings, Inc. (2021). "KGS Buildings." Accessed March 12, 2021. https://www.kgsbuildings.com/.

Kramer, Hannah, Eliot Crowe, and Jessica Granderson (2017). Monitoring-Based Commissioning (MBCx) Plan Template. Berkeley, CA: Lawrence Berkeley National Laboratory.

Kramer, Hannah, Guanjing Lin, Claire Curtin, Eliot Crowe, and Jessica Granderson (2020). Building analytics and monitoring-based commissioning: industry practice, costs, and savings. *Energy Efficiency* 13, 537–549.

Lawrence Berkeley National Laboratory (2015). A Primer on Organizational Use of Energy Management and Information Systems (EMIS). Berkeley, CA: Lawrence Berkeley National Laboratory. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/A%20Primer%20on%20Organizational%20Use%20of%20Energy%20Management%20and%20Information%20Systems%20(EMIS).pdf.

Lawrence Berkeley National Laboratory (2021). "Smart Energy Analytics Campaign." Accessed March 12, 2021. https://smart-energy-analytics.org/.

Lin, Guanjing, Hannah Kramer, and Jessica Granderson (2020). Building Fault Detection and Diagnostics: Achieved Savings, and Methods to Evaluate Algorithm Performance. *Building and Environment* 168, 106505.

Loftness, Vivian, Azizan Aziz, Chenlu Zhang, and Yujie Xu (2020). *Executive Report on the Evaluation of GSA Total Estimated Cost Impact (TECI) Metrics and Building Benchmarking*. https://sftool.gov/Content/attachments/Iswg/iswg-case-studies/GSA%20CMU%20TECI%20ISWG%20October%202020.pdf.

McKinstry (2021a). "PowerED." Accessed March 12, 2021. https://www.mckinstry.com/capabilities/energy/powered/.

McKinstry (2021b). "Colorado School of Mines." Accessed March 12, 2021. https://www.mckinstry.com/1970/01/01/colorado-school-of-mines/.

Mills, Evan (2009). Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions. Berkeley, CA: Lawrence Berkeley National Laboratory. http://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf.

National Energy Conservation Policy Act, Pub.L. 95-619 (November 9, 1978), "Follow-up on implemented measures," codified at 42 U.S.C. § 8253(f)(5)(a)—(c).

NIST (2021). "Cybersecurity Framework." Accessed April 14, 2021. https://www.nist.gov/cyberframework.

Pacific Northwest National Laboratory (2016). "Building Re-Tuning Training: Providing Energy Saving Solutions through Interactive e-Learning." Richland, WA: Pacific Northwest National Laboratory. https://buildingretuning.pnnl.gov/documents/pnnl_sa_83943.pdf.

SkyFoundry (2019). "Connecting GSA building automation systems with Smart Building standards and advanced analytics to deliver scalable and secure performance visibility and operational savings." https://www.skyfoundry.com/file/336/GSALink---The-GSAs-Analytics-Project-Across-44-Million-sq-ft.pdf.

SkyFoundry (2021). "Skyspark." Accessed March 12, 2021. https://www.skyfoundry.com/.

Stum, K. and Bjornskov, D. (2017). *The Building Commissioning Handbook, Third Edition*. Building Commissioning Association and APPA.

Swegon Air Academy (2017). "HVAC Commissioning: Definition, qualified personnel and tips." Accessed November 17, 2020. https://www.swegonairacademy.com/2017/10/26/hvac-commissioning-definition-qualified-personnel-and-tips/.

U.S. Department of Energy (2021a). "eProject Builder." Accessed March 12, 2021. https://eprojectbuilder.lbl.gov/.

U.S. Department of Energy (2021b). "EMIS Specification and Procurement Support Materials." Accessed March 12, 2021. https://betterbuildingssolutioncenter.energy.gov/resources/emis-specification-and-procurement-support-materials.

U.S. Department of Energy (forthcoming). "Generation 4 Indefinite Delivery, Indefinite Quantity Contract."

U.S. Department of Energy Better Buildings Solution Center (2015). *A Primer on Organizational Use of Energy Management and Information Systems.* Berkeley, CA: Lawrence Berkeley National Laboratory. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/A_Primer_on_Organizational_Use_of_EMIS_V1.1.pdf.

U.S. Energy Information Administration (2020). "2018 Commercial Buildings Energy Consumption Survey Preliminary Results." Accessed March 12, 2021. https://www.eia.gov/consumption/commercial/.

U.S. General Services Administration (2018). "Energy Usage Analysis System." Accessed July 13, 2021. https://catalog.data.gov/dataset/energy-usage-analysis-system.

U.S. General Services Administration (2019a). "Submeters and Analytics: Full Panel." Accessed November 22, 2020. https://www.gsa.gov/governmentwide-initiatives/sustainability/emerging-building-technologies/published-findings/energy-management/submeters-and-analytics-full-panel.

U.S. General Services Administration (2021a). "GSA & Smart Buildings." Accessed March 12, 2021. https://www.gsa.gov/real-estate/facilities-management/gsa-smart-buildings.

U.S. General Services Administration (2021b). "Advantages of Smart Buildings." Accessed March 12, 2021. https://www.gsa.gov/real-estate/facilities-management/gsa-smart-buildings/advantages-of-smart-buildings.

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DOE/GO-102021-5438• July 2021