

Unlocking Energy Savings Using Building Energy Management Control Systems

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Note: This brief was written by ACEEE Senior Research Manager Rohini Srivastava. It is based on research conducted for the Industrial Technology Research Institute in Taiwan. Copyright Energy Administration, Taiwan.

Abstract

Building energy management and control systems (BEMCS)—used interchangeably with other terms including energy management system (EMS) or building management system (BMS)—are designed to monitor, control, and optimize energy use within a building. BEMCS include both hardware and software components. They rely on sensors and metering devices, controllers, and communication networks within the building, and a user interface to reduce energy consumption. A BEMCS helps building operators understand where energy is being used, wasted, and what can be done to improve performance. It enables smarter decision-making through continuous monitoring, diagnostics, and automated workflows that result in energy and cost savings. It can also coordinate demand response program participation, manage distributed generation, facilitate electric vehicle (EV) charging and storage, and interface with retail electricity markets.

By incorporating BEMCS with existing building systems, organizations can reduce their energy use by 10–25% and enhance operational efficiency. To successfully implement BEMCS, an integrated approach is essential, which considers the specific needs and challenges of the building. Engaging building occupants, facility managers, and stakeholders is key to successful BEMCS implementation. Clear communication through user-friendly and intuitive interfaces, automated controls, and collaboration amongst facilities staff and the management can encourage support for BEMCS initiatives. Incentives can help offset initial costs and encourage participation. Case studies show that BEMCS effectively achieve energy savings, cost reductions, and operational improvements. By applying best practices from successful implementations, organizations can maximize BEMCS benefits and contribute to a more sustainable built environment.

Introduction

A building energy management and control system (BEMCS)—used interchangeably with other terms including energy management system (EMS) or building management system (BMS)—is a system designed to monitor, control, and optimize energy use within a building. A BEMCS helps building operators understand where energy is being used, wasted, and what can be done to improve performance. It enables smarter decision-making through continuous monitoring, diagnostics, and automated workflows that result in energy and cost savings. It can also coordinate demand response program participation, manage distributed generation, facilitate electric vehicle (EV) charging and storage, and interface with retail electricity markets (Qiang et al. 2023).

BEMCS include both hardware and software components. They rely on sensors and metering devices, controllers, and communication networks within the building, and a user interface to reduce energy (Mischos, Dalagdi, and Vrakas 2023). The sensors and metering devices collect data on variables such as temperature, occupancy, and energy use to monitor the operational functions of a building. Controllers and actuation mechanisms use algorithms to process sensor data and control systems for optimum efficiency. Communication networks ensure integration with systems such as HVAC, lighting, security, and renewable energy sources. The user interface then allows operators and facility managers to monitor and control system performance, adjust parameters, and receive feedback. By leveraging these components, BEMCS enable real-time monitoring, intelligent control, and data-driven decision-making. Figure 1 provides an overview of a BEMCS.

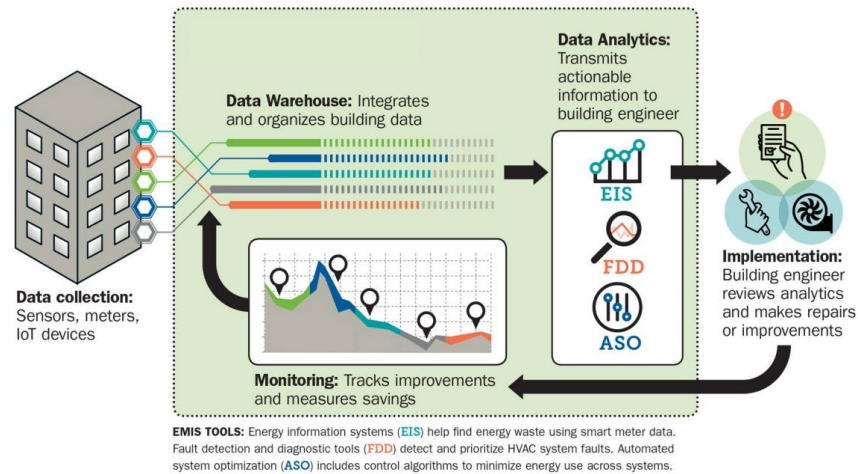


Figure 1. Overview of a BEMCS. Source: Kramer et al. 2020.

This paper examines the different BEMCS capabilities and explores the potential energy savings associated with their application. Additionally, it discusses case studies from projects and programs. Due to rising global energy costs and sustainability goals, optimizing building energy performance is even more critical for businesses now. BEMCS are essential for enhancing operational efficiency and minimizing carbon emissions while ensuring occupant comfort.

BEMCS use cases and capabilities

A BEMCS effectively manages building energy consumption through a range of functions. They vary from basic energy benchmarking, real-time energy analytics, fault detection and diagnostics, and building system optimization.

Energy benchmarking

At their most basic level, BEMCS assist with monthly data analytics, visualization, and reporting (WBCSD 2020). Software tools help manage and validate monthly utility bills and benchmark building energy use against its own past performance or similar buildings. Benchmarking helps identify underperforming buildings to target efficiency improvements.

Energy information and real-time analytics

BEMCS can also support more comprehensive meter-level or portfolio-wide energy analysis on an hourly basis and display the data for facility managers to act. Data are acquired from electricity and gas meters

including submeter and system-level data, and from other external sources such as weather data, energy prices, and demand response information (Berkeley Lab 2021). The combination of portfolio, building, or submeter monitoring, profiling, peak load analysis, and data visualization capability are referred to as energy information systems (EIS), whole-building or continuous energy monitoring systems, energy performance tracking systems, or enterprise energy management systems. Figure 2 shows an example of data visualization from an EIS.

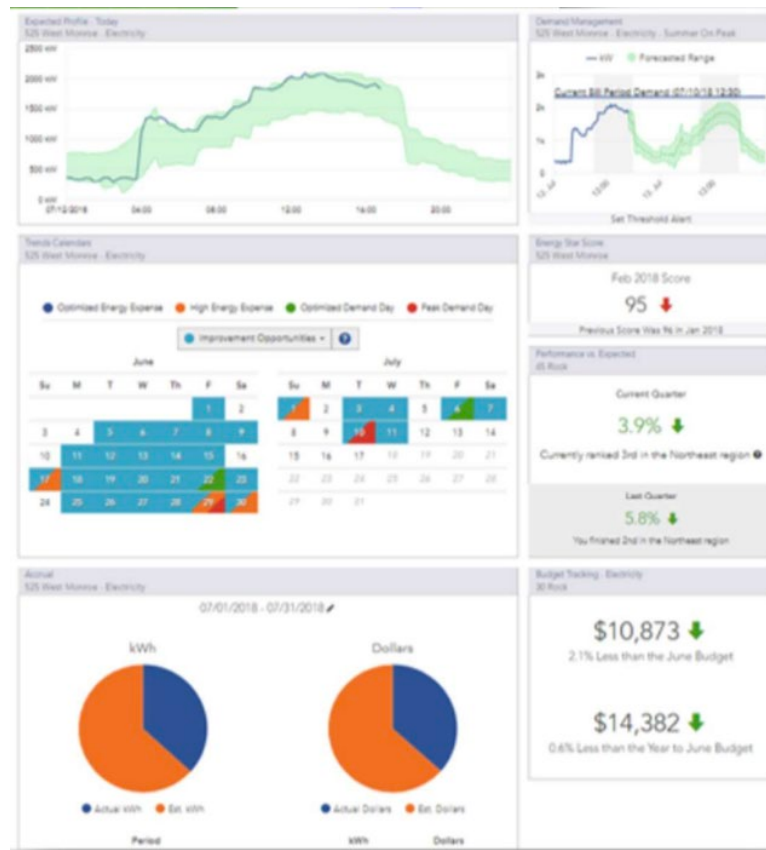


Figure 2. Example of EIS from Tishman Speyer (Mach Energy). Source: Berkeley Lab 2021.

Commercially available EIS solutions in the United States have increased in the past decade, due to greater building energy regulations, including requirements for smart metering and energy reporting. Organizations use EIS to identify overall trends in energy usage relative to a portfolio of buildings, improve building schedules and baseline energy use, and recognize opportunities for reducing peak demand (Kramer et al. 2020). A Berkeley Lab report estimates median annual energy savings of 3% from EIS after two years of implementation as users become familiar with the technology and establish processes to act on the findings, but some organizations have reduced energy use by up to 22% (Lin et al. 2022).

Fault detection and diagnosis (FDD)

BEMCS can help identify deviations from normal or expected building operations, accurately pinpoint issues, and help resolve the type of problem. This improves upon traditional building automation systems (BAS) that notify operators of faults but cannot diagnose the cause (King and Perry 2017). FDD relies on software that monitor system-level data from the building automation system and provide

information on the duration and frequency of faults and possible causes or recommendations for correcting them. Figure 3 shows an example of fault notifications available in FDD tools.

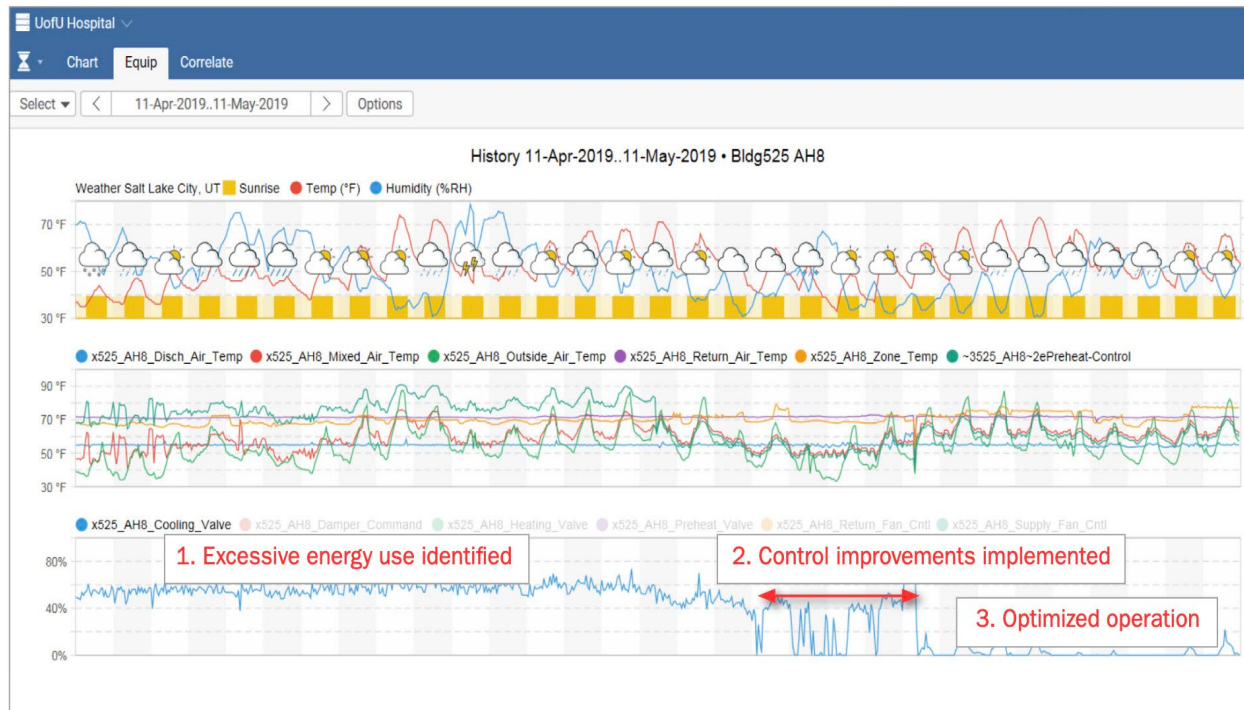


Figure 3. University of Utah Health's FDD module helps identify excessive energy use. Source: Crowe, Kramer, and Granderson 2020.

FDD tools interrelate multiple data points and perform rule-based or model-based diagnostics (Granderson et al. 2020). For instance, a basic BAS alarm may signal that a room is experiencing overheating. In contrast, a more sophisticated BEMCS can identify the underlying cause, such as a stuck damper or an out-of-calibration temperature sensor. This detailed information enables building operators to resolve the issue effectively and assists them in developing accurate preventive maintenance schedules and prioritizing the order in which to address alerts (Managan 2013). Table 1 summarizes common faults detected using FDD capabilities.

Building operators can use FDD as a continuous commissioning tool as it allows the building to be fine-tuned on a more regular basis compared to every few years or when there are major breakdowns. A study of 26 organizations using FDD across 550 buildings reported 8% median savings (Lin, Kramer, and Granderson 2020). Savings could reach up to 25% (Energy Trust of Oregon 2017; ACEEE 2019). Furthermore, FDD can prevent equipment failures by identifying potential issues, which can help reduce maintenance costs. Automated FDD technologies and the integration of artificial intelligence can further improve operational efficiency and streamline operations and maintenance.

Table 1. Common faults detected using BEMCS

System component analyzed	FDD tool analysis
Controllers (actuators/valves/speed drives)	Compare controller output setpoints to the actual condition to find failed devices Determine the stability of controllers
Dampers (air handling units, terminal units)	Identify if a damper is stuck open, closed, at a fixed position or leaking Compare mixed air temperature to return air temperature with the outdoor air damper closed
Cooling/heating valves and coils	Identify if a valve is stuck or leaking Identify a fouled or block coil, detect if temperature difference exists when valve is shut or when the system is not reaching desired temperature drop
Economizer operation/use	Detect if the rooftop units (RTUs) or air handling units (AHUs) are not economizing Detect if RTU/AHU is economizing when it should not Detect if the economizer lockout setpoint is too high or low
Simultaneous heating and cooling	Detect any unnecessary heating, economizer cooling, and/or mechanical cooling happens at the same time

Source: Kramer et al. 2020

Building system optimization

Some BEMCS not only facilitate collection of real-time data across systems and act as a platform for data collection and analysis, but also automatically adjust building systems and other equipment to optimize performance. Automated system optimization (ASO) technology uses two-way communication with the BAS and other types of building systems, such as the security system, to read the data and synthesize it to identify inefficiencies and provide actionable insights for upgrading equipment and improving building operations. The ability for bidirectional communication sets an ASO solution apart from FDD. For example, ASO can use information to optimize the amount of daylight in the building to reduce or maximize heat gain, depending on the season. They can dim or turn off lights in unoccupied spaces, utilize daylight harvesting, and control the use of artificial lighting, resulting in lighting savings of up to 39% (Lee and Cheng 2016). Figure 4 shows an example of an ASO screenshot.

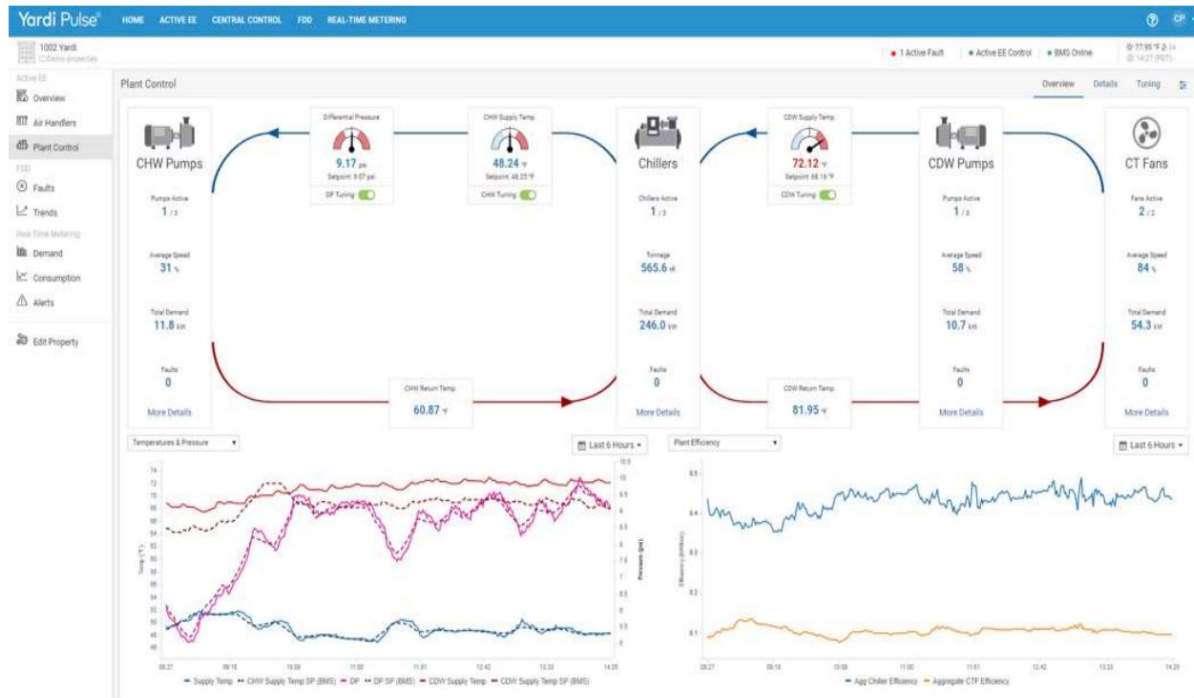


Figure 4. Example of ASO interface from Yardi Pulse demo site. Source: Berkeley Lab 2021.

BEMCS offer several strategies to optimize HVAC systems to improve building performance. By collecting data on indoor and outdoor temperatures as well as occupancy levels, BEMCS can automatically adjust temperature setpoints, ensuring that energy is not wasted when spaces are unoccupied. They can schedule HVAC equipment to operate only during necessary hours, turning systems off during nonpeak times or when the building is empty. They can also stage multiple HVAC systems for optimum performance. BEMCS also continuously monitors HVAC performance, quickly identifying malfunctions or inefficiencies so they can be addressed before they escalate into costly repairs. By tracking energy consumption patterns, BEMCS provide valuable insights to help pinpoint opportunities for additional energy savings, such as replacing inefficient equipment or optimizing maintenance schedules. Organizations can reduce energy use by up to 16% (Lee and Cheng 2016).

Beyond controlling systems to ensure they run only when needed, BEMCS can integrate and optimize the use of renewables. By integrating renewables, buildings can reduce reliance on traditional grid power. Since the BEMCS can make automated adjustments, they can also reduce HVAC and lighting loads in response to utility signals without compromising occupant comfort. Thus, BEMCS enable buildings to participate in demand response programs by adjusting energy usage during peak demand times, lowering energy costs, and contributing to grid stability.

Energy savings from BEMCS

Implementing a BEMCS offers substantial energy savings, typically ranging from 10% to 30%, depending on the BEMCS capabilities, building type and existing infrastructure, and quality of implementation. Table 2 summarizes typical savings by building type.

Table 2. Energy savings from BEMCS by building type

Building type	Savings
Office buildings	3–25%
Industrial facilities	10–20%
Hospitals	10–25%
Educational institutions	15–30%

Sources: Digitemie and Ekemezie 2024; WBCSD 2020; Kramer et al. 2020; PNNL 2018; Perry 2017; Lee and Cheng 2016; Granderson and Lin 2016; Wheeler 1994.

BEMCS capabilities like benchmarking, EIS, analytics, FDD, and ASO can each or collectively contribute to the range of energy savings in table 2 while also enhancing occupant comfort. Basic energy tracking and benchmarking can offer 2.4% average savings annually (U.S. EPA 2012), while hourly whole-building or portfolio monitoring can lead to 3% median annual energy savings (Kramer et al. 2020). Systems that identify faults automatically (i.e., FDD) achieve 9% median annual energy savings (Kramer et al. 2020), and those optimizing building operations can exceed 9% savings (Granderson et al. 2018).

Key features of a BEMCS

Real-time energy analytics and visualization

Continuous monitoring of building energy use and real-time analysis of energy data are essential features of a BEMCS. By constantly tracking energy usage data, BEMCS provide immediate insights into consumption patterns and quickly identify inefficiencies or abnormal trends. Real-time analytics empower facility managers to make informed decisions and implement corrective actions without delay, ensuring optimal energy performance. This proactive approach helps reduce energy waste and operational costs and supports ongoing improvements in building efficiency.

A user-friendly and intuitive interface can help visualize the energy data and is critical to ensure that facility staff use BEMCS effectively. Modern BEMCS analytics platforms are designed with dashboards and straightforward controls, making it easy for users to access critical information and perform necessary actions. Mobile and remote accessibility features can further enable facility managers to monitor and control building systems from any location, using smartphones, tablets, or computers. This enhanced accessibility improves convenience and allows quicker responses to issues, leading to more efficient building management and better overall energy performance.

Fault detection and diagnostics

FDD is a central feature of advanced BEMCS, enabling these systems to go beyond basic energy monitoring. FDD uses real-time data and analytics to detect anomalies or inefficiencies in building operations, such as malfunctioning HVAC components or abnormal energy use patterns. By accurately identifying the source and cause of performance issues, FDD allows facility managers to address problems early—often before occupants notice any discomfort or before minor issues become major failures. This proactive approach not only reduces maintenance costs and prevents unexpected downtime but also helps maintain optimal building performance and energy efficiency.

Automation of processes

By leveraging real-time data and predefined rules, a BEMCS can automatically execute energy management tasks such as adjusting HVAC settings, controlling lighting, and managing equipment schedules. This automation ensures that systems respond instantly to changing conditions—like occupancy, time of day, or weather—without requiring manual intervention. This helps boost operational efficiency and consistency and reduces the workload for the facility, while the BEMCS handles routine adjustments, ultimately leading to improved energy savings, enhanced occupant comfort, and more effective building management.

To achieve comprehensive energy management, a BEMCS must be compatible with existing building systems, particularly through support for industry-standard protocols like the Building Automation and Control Network (BACnet). This compatibility allows the BEMCS to communicate and exchange data with the building automation system, HVAC equipment, lighting system, and security controls. By integrating with these systems, the BEMCS can collect and analyze data from all connected devices, providing a holistic view of building performance.

Challenges in implementing and operating BEMCS

A variety of challenges hinder the widespread use of BEMCS:

- The largest barrier to BEMCS investments is the high upfront cost. Only some organizations are willing to pay for hardware and software integration initially. To reduce these costs, vendors now offer energy management as a service. They provide software, sensors, and services for a monthly fee, allowing customers immediate positive cash flow without capital investment. Essentially the monthly savings more than cover the monthly fee.
- Compatibility with existing building systems is essential. Many BMS are outdated or disconnected from critical systems, reducing a BEMCS' effectiveness. Ensuring BEMCS can integrate with BACnet-compatible BMS is crucial for complete data collection and analysis.
- BEMCS need to be installed properly and maintained properly for optimum results. This requires trained technicians and contractors who can install systems and provide follow-up services. BEMCS companies often send technicians to the building site to install products and provide specialized technician trainings programs for facilities staff to effectively operate and maintain advanced BEMCS. For example, Johnson Controls provides technician training programs through its Johnson Controls Training Institute and partnerships with technical career schools.
- A BEMCS requires comprehensive and accurate data from all critical endpoints in the building to function properly. Incomplete data may lead to inaccurate analysis and missed opportunities for efficiency improvements. Upgrading components of the BMS may be necessary to ensure adequate coverage and data integrity. Rules or algorithms should be established for the system to trigger alerts.
- Ensuring that the onsite team fully adopts and incorporates the BEMS into their daily management strategy can be challenging. Staff turnover contributes to this problem. Addressing these issues often requires training and ongoing support. Developing expertise within the team for using the BEMCS is essential for maintaining optimal performance. Regular engagement with the system is necessary for monitoring, assigning tasks to engineers, and making informed decisions.

- Building owners may have cybersecurity concerns due to BEMCS' reliance on interconnected devices and communication protocols.

Project and program examples

BEMCS systems have achieved notable energy savings, cost reductions, and operational enhancements globally. Customers typically need trained technicians familiar with BEMCS hardware, software, and controls to install and integrate them with existing building systems, sensors, and infrastructure to maximize savings. Furthermore, planning for ongoing system monitoring, data analysis, and maintenance activities with human oversight to manage privacy and cybersecurity concerns can help sustain savings. In this section we review case studies of successful implementations and detail outcomes, lessons learned, and best practices.

1670 Broadway office tower in Denver

1670 Broadway is a mixed-use office building in Denver with 700,000 square feet of rentable space. It is a Leadership in Energy and Environmental Design (LEED) gold certified high-rise, which has been continually enhanced to integrate sustainable initiatives and address tenant needs. The building management team worked with SkyFoundry, Group14 Engineering, and Klok Group Engineering to install BEMCS to upgrade the existing building automation system.

The engineering team selected the system based on its ability to meet the requirements for an open protocol system that will continue to meet the changing needs of the building tenants; accommodate real-time web-based controls and incorporate new direct to digital controls; and integrate with existing lighting, security, fire alarm, and smoke control systems. The new system included a main server, workstations with communication cables and related routers, hardware, and software to control and communicate with the HVAC and lighting systems. Xcel Energy, the local utility, provided a rebate of \$183,527 to offset the cost of new equipment and software licenses to free up funds to invest in future efficiency upgrades (Xcel Energy 2015).

The new software monitored and provided near-real-time interval data for hundreds of devices. The collected data revealed energy-saving opportunities such as upgrading certain equipment (including terminal boxes from pneumatic direct digital control (DDC)) and installing light-emitted diode (LED) lights (ACEEE 2019). The facilities team was also alerted when an electronic or mechanical component drifted and operated outside of its programmed parameters. In the first year, the building reduced its energy costs by 6%. In the second year, the building saved an additional 7.6% through continuous monitoring and operational improvements (SkyFoundry 2017). Overall, the building saw a 20% reduction in overall electricity use (1,116 MWh saved) and a 25% reduction in steam energy use (Xcel Energy 2015).

Microsoft Campus, Redmond

Microsoft implemented a BEMCS at its campus buildings in Redmond, Washington to optimize energy usage across its facilities. Using existing wireless networks and Internet connectivity, technicians integrated thousands of HVAC component sensors and collected data under a single cloud-based software layer, enabling an overview of all HVAC systems. A central dashboard provided information on real-time faults, potential problems, and energy waste. For instance, the BEMCS identified a problem with the chilled water system pressure in one building. The issue was resolved in under five minutes; however, if it had gone unnoticed, it could have led to an annual loss of \$12,000 (Guttapalem 2017).

Technicians use Azure-generated business intelligence dashboards to address problems, with approximately 40% of corrections made remotely. Data are gathered from more than two million connection points on approximately 50,000 pieces of equipment (Guttapalem 2017). A daily chart displays faults of the day, categorized by cost of leaving the fault unresolved and priority, and the impact on business operations and employees. Using the BEMCS, facilities staff can view systems collectively or focus on a specific building, floor, or piece of equipment.

The BEMCS employs advanced analytics and machine learning algorithms to identify opportunities to save energy, resulting in a 20% reduction in energy consumption and significant cost savings (Digitemie and Ekemezie 2024; Guttapalem 2017). In the first year of implementing the solution across the campus, Microsoft saved \$700,000. Subsequently, Microsoft extended the BEMCS implementation to other campuses in Silicon Valley, California, and Los Colinas, Texas, and in Shanghai and Beijing (Guttapalem 2017).

Continuous optimization program, BC Hydro

In 2008, BC Hydro and FortisBC launched the continuous optimization (C-Op) program to help commercial customers save energy without significant capital expenditure. The first round of the program ran from 2008 to 2016. Subsequently, round two commenced in 2017 and is ongoing. The C-Op program includes two interrelated components: recommissioning and an energy management information system (EMIS). Customers opting for the recommission option undergo a comprehensive assessment of their entire building and review energy conservation measures with a follow-up coaching session to ensure savings persist year after year. The EMIS option equips customers with specialized software to help operations staff monitor and manage energy use within buildings (BC Hydro n.d.).

During the first round, a full project cycle lasted three and a half years. The first year involved investigation, in which BC Hydro assessed a building's existing systems and proposed cost-effective ways for their customers to save energy. Customers had the next 18 months to implement the suggested measures. In the final year, BC Hydro installed EMIS technology and coached building owners on how to continue optimizing energy savings (CEE 2018; BC Hydro n.d.). Customers had the option to renew their program participation for an additional four years after this energy management coaching stage.

In the first four years of the program, BC Hydro assumed all financial risk for customers who wanted to implement EMIS or recommission their buildings. This value shrunk to 50% in the final four years of the program. During the implementation phase of round one, BC Hydro offered payments of \$0.25 per square foot for customers who completed all energy efficiency measures within two years. Round two continues to offer this incentive in addition to specialized incentives for each of the two program options (CEE 2018; Slipstream 2021).

BC Hydro served 550 buildings during round one with 493 buildings completing the implementation phase of the project. Academic buildings, large offices, and hospitals were the most common types of buildings served. On average, energy efficiency implementation has saved customers 4.7% in electricity usage and 7.3% in energy costs, with an average simple payback of 1.7 years (BC Hydro 2020). These savings are in addition to what the BEMCS were achieving prior to optimization.

Conclusions and recommendations

To successfully implement BEMCS, an integrated approach is essential, which considers the specific needs and challenges of the building. By incorporating BEMCS with existing building systems, organizations can reduce their energy use by 10–25% and enhance operational efficiency. Regular

performance assessments, data analysis, and optimization efforts empower organizations to proactively identify energy-saving opportunities and correct inefficiencies while ensuring occupant comfort.

Engaging building occupants, facility managers, and stakeholders is key to successful BEMCS implementation. Clear communication through user-friendly and intuitive interfaces, automated controls, and collaboration among facilities staff and the management can encourage support for BEMCS initiatives. Incentives can help offset initial costs and encourage participation. Case studies show that BEMCS effectively achieves energy savings, cost reductions, and operational improvements. By applying best practices from successful implementations, organizations can maximize BEMCS benefits and contribute to a more sustainable built environment.

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Appendix. BEMCS characteristics and energy savings studies

	Monthly Data Analytics	EIS	FDD	ASO
Primary Applications	Utility bill reconciliation, energy use and cost tracking; peer-to-peer building comparisons of energy use	Whole-building or portfolio energy tracking at an hourly data level; data visualization	Automated identification of system-level faults, often with associated causes, usually HVAC focused	Automated modification of control parameters to optimize efficiency, energy use, and/or energy costs
Benefits	Provides insight into whole-building energy performance; assists in streamlining bill payment processing and/or tenant billing	Provides granular energy consumption history and summary of use patterns; notifies user when energy exceeds expectation	Early identification of faults can prevent mechanical failure, extending equipment life; Faults flag energy waste for specific equipment	Dynamically change HVAC settings to optimize energy use and comfort
Frequency of Use	Monthly, annually	Daily, weekly, monthly	Daily, weekly, monthly	Instantaneously with review weekly or monthly
Typical Data Scope	Whole building or campus	Whole building, may include submetering and system-level monitoring	BAS data including central plant, AHUs, and zone-level data	Systems, components, BAS trends; may include whole-building or system-level submetering
Typical Data Interval	Monthly	Hourly to 15-minute	15-minute and less	15-minute and less
Energy Savings	2.4% average annual energy savings ^a	3% median annual energy savings (\$0.03/sq ft) ^b	9% median annual energy savings (\$0.24/sq ft) ^b	Depends on system type Case study: 0%–9% energy savings ^c
Costs	Free or low cost ^d	Base: \$0.01/sq ft Annual: \$0.01/sq ft ^b	Base: \$0.06/sq ft Annual: \$0.02/sq ft ^b	Depends on base HVAC system configuration

Notes: (a) The energy savings estimate for monthly energy analytics tools of 2.4% is based on a study of 35,000 buildings that used ENERGY STAR Portfolio Manager to benchmark energy performance (U.S. EPA, 2012); (b) EIS and FDD savings and cost data were key findings from the Smart Energy Analytics Campaign (Kramer et al., 2020); (c) Field evaluation of five buildings (Granderson et al., 2018); (d) ENERGY STAR Portfolio Manager is free of charge, and monthly data analytics tools may have similar cost to EIS, depending on features.

Source: Berkeley Lab 2021