Lawrence Berkeley National Laboratory

LBL Publications

Title

Operational Excellence in Commercial Buildings: Five Practice Areas for Integrated Energy and Cost Savings

Permalink

https://escholarship.org/uc/item/16p937j1

Authors

Shackelford, Jordan

Regnier, Cynthia

Publication Date

2026-05-01

Copyright Information

This work is made available under the terms of a Creative Commons Attribution-NonCommercial License, available at https://creativecommons.org/licenses/by-nc/4.0/

eScholarship.org Powered by the California Digital Library
University of California

Whole Building Systems Department
Building & Industrial Energy Systems Division
Lawrence Berkeley National Laboratory

Operational Excellence in Commercial Buildings

Five Practice Areas for Integrated Energy and Cost Savings

Jordan Shackelford and Cynthia Regnier

Lawrence Berkeley National Laboratory

Energy Technology Area
May 2026

https://doi.org/10.20357/B72S41



This work was supported by the Assistant Secretary Office of Critical Minerals and Energy Innovation (CMEI) of the US Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or the Regents of the University of California.

Lawrence Berkeley National Laboratory is an equal opportunity employer.

Copyright Notice

This manuscript has been authored by an author at Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Operational Excellence in Commercial Buildings:

Five Practice Areas for Integrated Energy and Cost Savings

Prepared for the
Critical Minerals and Energy Innovation Office
U.S. Department of Energy

Principal Authors
Jordan Shackelford
Cynthia Regnier

Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90R3147
Berkeley CA 94720-8136

May 2026

Acknowledgements

The work described in this study was conducted at Lawrence Berkeley National Laboratory and supported by the U.S. Department of Energy Critical Minerals and Energy Innovation Office under Contract No. DE-AC02-05CH11231.

The authors thank the following experts for reviewing this report (affiliations do not imply that those organizations support or endorse this work):

Eliot Crowe	Lawrence Berkeley National Laboratory
Peter Therkelsen	Lawrence Berkeley National Laboratory
Alan Glynn	Arup
Billierae Engelman	Office of Critical Minerals and Energy Innovation, U.S. Department of Energy
Samuel Petty	Office of Critical Minerals and Energy Innovation, U.S. Department of Energy

Table of Contents

List of Tables iii

Acronyms and Abbreviations iv

1. Abstract vi
2. Introduction 1
   - 2.1 The Imperative for Improved Energy Management and Operation 1
   - 2.2 Commercial Building Operations Practices 1
   - 2.3 Study Objectives 3
   - 2.4 Summary of Costs and Benefits for Operational Excellence Practices 3
3. Operational Excellence Practices 5
   - 3.1 Energy Management Planning 5
   - 3.2 Improved Operations and Maintenance 6
   - 3.3 Energy Audits 9
   - 3.4 Building Performance Benchmarking 11
   - 3.5 Existing Building Commissioning (EBCx) 13
   - 3.6 Overlap, Synergies, and Related Frameworks 18
4. Conclusion and Recommendations 23
   - 4.1 Recommendations for Building Owners and Managers 23
5. References 27
6. AI Tools Acknowledgement 30

List of Tables

Table 1. Cost, Benefits, and Interdependencies of Practices 4
Table 2. Comparison of Commissioning Terminology and Scopes 14
Table 3. Comparing EMP and SEM 20

Acronyms and Abbreviations

ACEEE	American Council for an Energy-Efficient Economy
AI	Artificial Intelligence
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	Building Automation System
BOC	Building Operator Certification
BOD	Basis of Design
CEM	Certified Energy Manager
CFR	Current Facility Requirements
Cx	Commissioning
CxA	Commissioning Authority
DOE	U.S. Department of Energy
DSM	Demand-Side Management
EBCx	Existing Building Commissioning
EEMs	Energy Efficiency Measures
EIS	Energy Information Systems
EMP	Energy Management Planning
EMIS	Energy Management and Information Systems
EnMS	Energy Management System
EPA	U.S. Environmental Protection Agency
ESPM	ENERGY STAR Portfolio Manager
EUI	Energy Usage Intensity
FDD	Fault Detection and Diagnostics
FEMP	Federal Energy Management Program
IRR	Internal Rate of Return
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
LCC	Life-cycle cost
MBCx	Monitoring-Based Commissioning
MEP	Mechanical, Electrical, and Plumbing
O&M	Operations and Maintenance
OCx	Ongoing Commissioning

OPR	Owner's Project Requirements
PDCA	Plan-Do-Check-Act
PECI	Portland Energy Conservation, Inc.
PM	Preventive Maintenance
PNNL	Pacific Northwest National Laboratory
RCx	Retrocommissioning
ROI	Return on Investment
SEM	Strategic Energy Management

1. Abstract

This report presents a comprehensive framework for achieving operational excellence in commercial buildings, shifting the focus from episodic, failure-driven operations interventions and piecemeal capital retrofits, to continuous, data-driven, systematic management practices that secure superior financial returns and long-term asset value. Reviewing over three decades of research on thousands of buildings, we evaluate the collective value of five interdependent practices: Energy Management Planning (EMP), Improved Operations and Maintenance (O&M), Energy Audits, Performance Benchmarking, and Existing Building Commissioning (EBCx). The five practice areas are not siloed; there is significant overlap among them. EMP, for example, incorporates elements of all the other practices to some degree. The synergies between the practices are discussed throughout.

This study's core analysis includes a detailed accounting of the energy savings, financial benefits, and costs for each of these five practices according to the literature, providing the economic justification for implementation. Taken together as a layered program of interdependent operational practices, our analysis demonstrates the potential for financial returns that frequently outperform capital-intensive hardware upgrades. By moving from reactive "run-to-failure" models to a proactive asset preservation strategy, building owners can realize substantial life-cycle returns on investment (ROI, based on cumulative, real returns over the life of the system or measure), driven by benefits such as extended equipment life, reduced energy usage, and the avoidance of emergency repairs. The literature confirms that these proactive strategies provide cost-effective paths to energy savings, offering consistent returns and rapid paybacks (often under two years).

We conclude with four strategic recommendations for owners and managers:

- Adopt a "total cost of ownership" mindset, shifting to preventative/predictive maintenance practices to safeguard asset longevity.
- Integrate operational excellence practices into a "virtuous cycle" binding interdependent elements such as benchmarking, energy audits, building commissioning, and maintenance activities together through comprehensive energy management planning.
- Invest in workforce capacity and "energy champions" empowering and developing staff and fostering the cultural shifts to sustain operational excellence and continuous improvement.
- Implement existing building commissioning to capture whole-building energy savings with minimal capital investment and consider incorporating monitoring-based commissioning to ensure savings are sustained new opportunities are uncovered over time.

2. Introduction

2.1 The Imperative for Improved Energy Management and Operation

The commercial building sector has been undergoing a fundamental shift in how value and performance are defined. Historically, energy and cost saving efforts have focused heavily on design and construction, and on episodic capital upgrades, such as replacing chillers or lighting systems. However, a large body of evidence suggests that rather than defaulting to equipment upgrades, the most significant, untapped opportunities for cost reduction and risk mitigation lie in improving ongoing operational practices with existing assets (Mills 2009, Sullivan et al. 2010).

Communicating the benefits of “operational excellence” to stakeholders is critical for securing the necessary buy-in for prioritizing and investing in improved operational practices. The imperative is driven by the economic pressures of owning and operating commercial real estate; building owners and operators face rising utility costs and the need to improve competitiveness (BOMA 2025, JLL 2025). Integrated energy management and rigorous operations and maintenance (O&M) plans and practices are increasingly recognized as essential strategies to reduce operating expenses and risk for building portfolios. These pressures move building management beyond one-time retrofits to a systematic management approach that sustains performance over the long term. Operational excellence is not just a best practice for high-performing real estate investment portfolios; it is a prerequisite for asset value preservation (Mills et al. 2004, Koo and Van Hoy, n.d.).

2.2 Commercial Building Operations Practices

The "operational" side of the building performance equation is specifically focused on here. While capital retrofits are vital, this study isolates and assesses the value of proactive energy management and operational improvements for commercial buildings. Where the complexity of systems makes "drift" in performance common and costly (Mills et al. 2004, Mills 2009), systematic improved management practices, implemented in commercial facility operations and maintenance has the potential for sustained return on investment (ROI); e.g. improved O&M programs yielding 5%-20% energy cost savings (Sullivan et al. 2010) and a life-cycle ROI of 545% (over a 25 year period) (Koo and Van Hoy, n.d.), and existing building commissioning achieving paybacks under two years (Crowe et al. 2020).

The scope of this study encompasses a framework of five overlapping and interdependent practice areas that shift the focus away from singular project-by-project upgrades toward sustained operational integrity through continuous, systematic, and data-driven building management. The following practice areas are thoroughly elaborated in section 3, with citations and information on benefits and costs:

1. Energy Management Planning (EMP): An overarching governance structure that involves setting clear and measurable energy goals, designating a responsible energy manager or director, making organizational commitments, and establishing rigorous

energy accounting and monitoring practices. The EMP becomes a written plan of action that outlines specific, measurable objectives, including many of the other practice areas detailed here. For example it incorporates benchmarking through an energy accounting and tracking phase, audits through an action planning phase, and operations and training plans that level up O&M practices. Ultimately the EMP is the formal strategy that binds activities like benchmarking, audits, maintenance, and commissioning together into a cohesive cycle. It is the roadmap for achieving goals and is crucial for securing management commitment and budgetary approval.

2. Improved Operations and Maintenance: This practice area focuses on the shift from reactive "run-to-failure" models to proactive O&M planning and adopting preventive maintenance (PM) practices for preservation of assets. This includes low-cost strategies including regular inspections and time-based maintenance schedules to extend equipment life and ensure system efficiency. Advancing this practice area, condition-based maintenance (CBM) triggers interventions based on real-time asset performance and conditions rather than fixed schedules, and predictive maintenance (PdM) takes this a step further, intervening based on real-time monitoring of equipment combined with advanced logic to detect and predict issues and make fixes before failures occur.

3. Building Energy Audits: The diagnostic process used to characterize the state of a building's systems and energy-using components, and to identify specific energy efficiency measures (EEMs), ranging from no-cost operational and controls adjustments to more capital-intensive recommendations. Energy audits progress in scope from Level I site assessments that utilize brief inspections and utility bill analyses to identify low-cost opportunities, to Level II audits that provide in-depth engineering and financial analyses of specific energy efficiency measures, to Level III investment-grade analyses that involve rigorous long-term data collection, monitoring, and energy simulations to financially de-risk major capital upgrades.

4. Building Performance Benchmarking: The systematic tracking of energy performance against historical baselines and expectations for building performance, and performance of peer groups (similar buildings and use types, normalized for location-specific variables like weather). Benchmarking is typically done in a comprehensive platform via tools such as Energy Star Portfolio Manager (ESPM).[1] These tools provide a dashboard to track and quantify performance in terms of energy usage intensity, or EUI (annual energy usage divided by building floor area) and provide a scaled scoring system. Benchmarking frames a given building's performance relative to other buildings to identify underperforming assets and verify savings and improvements over time by re-scoring over new performance periods (e.g. after EEM implementation).

5. Existing Building Commissioning (EBCx): The systematic process of investigating and optimizing systems and controls to ensure they operate efficiently and meet operational needs, typically tuning up rather than replacing equipment. A rigorous quality assurance process ensures that systems function as designed, catching and correcting hidden operational problems and inefficiencies. EBCx activities including retrocommissioning

[1] https://www.energystar.gov/buildings/benchmark

(RCx), to identify and correct existing deficiencies through low-cost adjustments, as well as the more advanced monitoring-based commissioning (MBCx), in which an energy management & information system (EMIS) is used to continuously track facility performance, are key to sustaining energy performance targets and preventing performance drift. EMIS tools like fault detection and diagnostic (FDD) software can automatically detect and prioritize operational faults before they lead to complaints or equipment failure, transitioning facilities to a proactive operations model.

2.3 Study Objectives

The primary goals of this study are to succinctly define, as well as to assess the economics of, operational excellence practices, as detailed in a large body of literature documenting their value in real-world application. Despite the intuitive value of operational excellence, precise financial data is often not available when an organization seeks to justify investment in and prioritization of the practice areas. Compiling credible studies and sources that enumerate the benefits of these practices, this report is intended to provide a convenient and organized reference useful for building owners and operators making the financial justification to move beyond minimum operations burden. Doing so can reframe operational expenditures from "sunk costs" to high-yield investments in building resilience and value.

To this end, a detailed literature review was conducted to accomplish the following objectives.

- Quantify costs and benefits to establish the economic case: Synthesize source information to provide referenceable ranges for the costs of implementation (e.g., cost per square foot for audits or O&M programs) and the resulting benefits (e.g., energy bill reductions) and clearly communicate the value (e.g. ROI, payback periods) that operational excellence offers, including from cost savings as well as from improvements in factors such as asset reliability and occupant comfort.
- Identify barriers and solutions: Highlight common barriers to operational excellence, such as perceived "hidden" costs, and highlight how standardized frameworks as well as supporting resources can lower hurdles.

While the study focuses primarily on operational management practices rather than specific hardware, it employs a "whole-building approach" whose scope encompasses all major energy-using systems, including building envelopes and windows, lighting arrays, HVAC equipment such as chillers and air handling equipment with airside economizers, and their associated control sequences and operational schedules.

2.4 Summary of Costs and Benefits for Operational Excellence Practices

Based on a literature review of over 30 studies, reports, articles, and white papers, the practices required for operational excellence offer superior financial returns, including rapid payback periods, high ROI, and significant energy savings, when compared to traditional capital retrofits. The ranges of costs, energy savings, and financial benefits presented in Table 1 are derived directly from the information compiled during this literature review. Detailed information and specific source references for each practice area are provided in the

subsequent sections of this report. Note that the costs and benefits tabulated here cannot be summed to determine aggregate costs and benefits from the individual practices because there is significant overlap and interdependence among them. The final column in the table describes practice area overlap. Some costs or benefits presented for one area may be inclusive of others in whole or in part. For example, benchmarking is often included in energy auditing, in which case the costs indicated for benchmarking may be a sub-set of the total costs indicated for audits.

Table 1. Cost, Benefits, and Interdependencies of Practices

Practice Area	Reported Costs* ($/ft^2)	Reported Energy Savings*	Reported Financial Benefits*	Overlap with other Practice Areas
Energy Management Planning	$0.42	None given (savings achieved by other practices)	None given (benefits attained by other practices)	Involves benchmarking, development of O&M plans and training. Normally includes audit phases and commissioning actions as well.
Improved O&M (planning, Preventative Maintenance)	$0.33 to $0.43	5% to 20%	Payback: 0.3 to 2 yr. Benefit/Cost: 3.8 Life-cycle ROI: 545% (25-yr projection) Life-cycle IRR: 98% (7-yr projection)	Heavily intertwined with retrocommissioning (RCx), which includes advanced systematic O&M. Proactive O&M impacts equipment lifetimes and efficiencies, influencing audit findings and recommendations.
Performance Benchmarking	$0.01 to $0.02	1.6% to 14% Avg: 2.4%	None given	Often the first step in an audit, helps screen buildings in a portfolio. Cost is often included in audit scope. Also a typical EMP component to evaluate performance and track progress over time.
Building Energy Audits	$0.05 to over $0.50, (depending on audit level)	None given (savings achieved by other practices)	None given (benefits attained by other practices)	Normally includes benchmarking. Diagnostic tool for O&M and RCx. Does not save energy, but identifies opportunities to do so. Feeds into EMP capital management processes.
Existing Building Commissioning (RCx, MBCx)	$0.26 to $0.30. $0.06 for FDD	Avg: 6% to 16%, 9% for MBCx	Payback: 1.7 avg. Life-cycle ROI: 450% (5-yr projection) Cash-on-cash return (1 yr): 91%	Assessment, execution, and verification to address operational deficiencies, focusing on low-cost O&M measures for savings and persistence. Feeds into EMP assessment and planning.

*Cost and benefit ranges are based on figures reported throughout the literature. Figures denoted as averages are averages as reported in individual sources and are not meant to indicate normalized or weighted averages across sources. Cost figures are not adjusted to current dollars.

3. Operational Excellence Practices

The following are detailed explorations of the five core practices that collectively define an operational excellence framework for commercial buildings. For each practice area, Energy Management Planning (EMP), Improved Operations and Maintenance (O&M), Energy Audits, Building Performance Benchmarking, and Existing Building Commissioning (EBCx), the primary activities involved, quantified financial benefits, and associated costs are elaborated.

3.1 Energy Management Planning

3.1.1 Introduction

Energy Management Planning is a structured process through which building owners formulate a plan to monitor and reduce a building's energy consumption. It can involve designating an energy manager, setting measurable goals, and establishing rigorous energy accounting and monitoring practices (EPA 2013, ASHRAE 2024). While formal definitions of EMP vary in their detail and prescriptiveness, the concept is presented here as a general, flexible framework rather than being strictly bound to any single industry standard.

EMP overlaps significantly with all the other practice areas discussed in this study. It integrates the diverse operational activities into a continuous cycle of improvement, embedding performance benchmarking into energy accounting and tracking phases, including building energy audits in the planning phase, relying on O&M planning and preventive maintenance in operations and training phases, and typically including existing building commissioning in implementation and capital management plans. EMP elements may include:

- Accounting and tracking: implementing a system to record annual energy use and comparing this data against established performance targets. This includes net energy use data for at least one year, and reporting energy usage intensity (EUI), and extends cyclically to annual updates comparing net EUI to energy targets and documenting changes in occupancy, operating hours, or equipment that influence these metrics.
- Action planning: identifying energy efficiency measures from audits, documenting implementation, and outlining future projects
- Operations and training: including specific operations and maintenance programs, formal O&M and training plans for personnel, and methods to inform building occupants about efficiency
- Accountability: designating an energy manager to oversee the plan and ensuring the owner reviews and signs it annually. To ensure the highest level of competence, an energy manager may be required to hold a recognized credential, such as the Certified Energy Manager (CEM) designation provided by the Association of Energy Engineers (AEE). Recognized by ASHRAE as a 'qualified person' standard, the CEM credential validates the capacity to lead complex energy use analysis and strategic planning (SLEEAN 2013, ASHRAE 2024).
- Capital Planning: maintaining a capital management plan that identifies future EEMs

and equipment replacement strategies.

3.1.2 Benefits

By establishing performance baselines, ensuring accountability through a dedicated energy manager, and integrating energy considerations into capital planning, EMP programs protect long-term asset value. The primary value of EMP lies in its ability to drive persistent savings through structure and accountability. The EMP in itself does not necessarily reduce energy consumption without the subsequent implementation of the actions and measures identified. Typically the savings will be achieved by the activities facilitated by EMP, like implementation of EEMs, operational savings from improved maintenance, building recommissioning, etc.

3.1.3 Costs

While the operational savings are significant, establishing these programs requires an upfront organizational investment. Data representing 299 buildings in Washington state indicate that the average cost for developing and implementing an EMP is approximately $\$0.42/ft^2$ (Pulles et al. 2024). These costs are administrative in nature and do not, in themselves, directly reduce energy consumption without the subsequent implementation of the practices and measures that EMP identifies.

3.2 Improved Operations and Maintenance

3.2.1 Introduction

According to a U.S. Department of Energy (DOE) *Guide to Achieving Operational Efficiency* (Sullivan et al. 2010): “Operations and Maintenance are the decisions and actions regarding the control and upkeep of property and equipment… inclusive of but not limited to 1) actions focused on scheduling, procedures, and work/systems control and optimization, and 2) performance of routine, preventive, predictive, scheduled and unscheduled actions aimed at preventing equipment failure or decline with the goal of increasing efficiency, reliability, resilience, and safety.”

“Reactive maintenance” represents the standard baseline for many facilities, often characterized by a "run it until it breaks" mentality for equipment maintenance (PNNL 2021) and addressing building performance deficiencies only when occupant complaints surface. This approach involves minimal planning and unscheduled interventions reactive to problems and complaints, meaning maintenance is only performed after equipment has already failed or malfunctioned or intended sequences of operations are not being executed (Keller and Owen 2025). While the reactive approach might seem cost-effective initially due to requiring fewer staff and less upfront investment, it almost always leads to higher long-term expenses. Elevated costs are driven by unexpected system downtime, the need for emergency repairs, secondary damage to surrounding equipment, higher labor and overtime costs, and significant losses in productivity and material inventory.

Preventive maintenance (PM) contrasts with the reactive approach by taking a proactive, time-based or machine-run-based approach (PNNL 2021). PM involves regular, scheduled

inspections and routine servicing, such as lubrication, adjustments, and the early replacement of wearing parts, designed to detect and mitigate degradation before a failure actually occurs. The primary goal of PM is to extend the useful lifespan of machinery, minimize unplanned downtime, and enhance overall operational efficiency. Condition-based maintenance (CBM) and predictive maintenance (PdM) advance the proactive maintenance philosophy even further. With CBM, rather than relying on a strict time-based schedule to perform maintenance, interventions take place based on the actual, real-time condition of the equipment. PdM, which is in the very early stages of development and industry adoption, extends the practice by using specialized measurements, data tracking, and logic increasingly including machine learning, to detect the early onset of system degradation, prompting facilities to service equipment when or even just before needed. “The primary distinction between PdM and CBM is that PdM anticipates future failures and schedules maintenance accordingly, whereas CBM focuses on real-time monitoring to identify current equipment conditions and immediate maintenance requirements (Murtaza et al. 2024).”

To advance O&M practices from a baseline reactive mode to a more proactive approach, building managers and owners often rely on O&M assessments and plans. An O&M assessment is a systematic process for gathering, analyzing, and presenting information to identify low-cost solutions for improving energy usage, occupant comfort, and indoor air quality, as well as obtaining a clear understanding of current O&M practices. It involves conducting detailed interviews with facility managers and operators, reviewing equipment conditions and documentation, and performing spot tests or data logging to find optimization opportunities (PECI 1999).[2] In conjunction, O&M planning involves establishing a formally documented schedule of inspection and maintenance tasks tailored to the specific size, design, and complexity of a facility's systems.

Together, these practices significantly improve daily operations, prioritizing cost-effective repairs, extending equipment life, reducing reactive emergency maintenance, and sustaining energy efficiency over time. Executing proactive O&M strategies also requires a skilled workforce. Enrolling facilities staff in programs like the Building Operator Certification (BOC), a nationally recognized, competency-based training, ensures they possess the necessary skills. BOC Level I training establishes a foundation in energy-efficient maintenance practices, while Level II focuses deeply on advanced equipment troubleshooting to sustain energy savings (Sullivan et al. 2010).

A well-run O&M program employs deep planning and a life-cycle approach that blends preventive, predictive, and reactive maintenance with equipment calibration actions, in a “reliability-centered maintenance” framework to ensure occupant satisfaction and system efficiency (Sullivan et al. 2010). Ultimately, proactive O&M programs do not view maintenance as a "nuisance cost," but rather as a strategic economic engagement. While it is impossible to

[2] An O&M assessment can be a specific component of the broader existing building commissioning (EBCx) processes discussed in section 3.5. Specifically, an O&M assessment would be included in the Planning and Investigation phases of the comprehensive four-phase EBCx approach: Planning, Investigation, Implementation, and Project Hand-off.

eliminate emergency breakdowns entirely, an optimal target mix for a well-run facility is approximately 20% to 30% reactive maintenance, 25% to 35% preventive maintenance, and 30% to 40% predictive maintenance (PNNL 2021).

3.2.2 Benefits

The financial argument for improved O&M is robust, driven primarily by asset preservation and operational savings.

- ROI: Investments in PM were predicted to produce an ROI of 545% over a 25-year period, compared to "no PM" scenarios (essentially reactive maintenance), based on financial and operational data from a proxy portfolio of 14M ft^2 of mixed property types and expert-derived estimates on equipment longevity impacts (Koo and Van Hoy, n.d.). Low-cost O&M improvements can also yield a 98% IRR over a 7-year measure life, driven by annual utility bill savings (PECI 1999).
- Payback period of O&M assessments and improvements: Because the improvements identified in O&M assessments are often low-cost or no-cost (e.g., sensor calibration, schedule adjustments), they offer rapid financial returns. Simple payback periods for O&M assessments are generally under two years, and often less than one year (PECI 1999). A Federal Energy Management Program (FEMP) analysis of federal facilities that implemented low-cost O&M projects found a benefit-to-cost ratio of 3.83, meaning $3.83 was saved for every O&M dollar invested, resulting in a simple payback period of just 0.26 years for operational improvements (Sullivan et al. 2010).
- Extended equipment life: Increasing the useful life of equipment delays expensive capital replacements. Transitioning to PM can extend the lifespan of machinery by 20% to 30% (Keller and Owen 2025).
- Maintenance cost reductions: Proactive O&M strategies are significantly cheaper to sustain. Transitioning to PM results in an average reduction in overall maintenance costs of up to 30%, with average annual PM costs running 20% lower than corrective maintenance (Keller and Owen 2025). Predictive maintenance can deliver further cost reductions of 8% to 12% over preventive maintenance approaches (PNNL 2021).
- Energy savings: Systematic O&M improvements are a low-cost method to reduce utility expenses. O&M assessments typically identify changes yielding energy savings of 5% to 20% of a building's annual utility bill (PECI 1999, Sullivan et al. 2010).
- Capital efficiency: O&M measures are highly efficient compared to retrofits. In one program analysis, O&M projects demonstrated a ratio of dollars saved per dollar invested of nearly 15:1, compared to just 0.7:1 for capital-heavy retrofit projects (Sullivan et al. 2010).

3.2.3 Costs

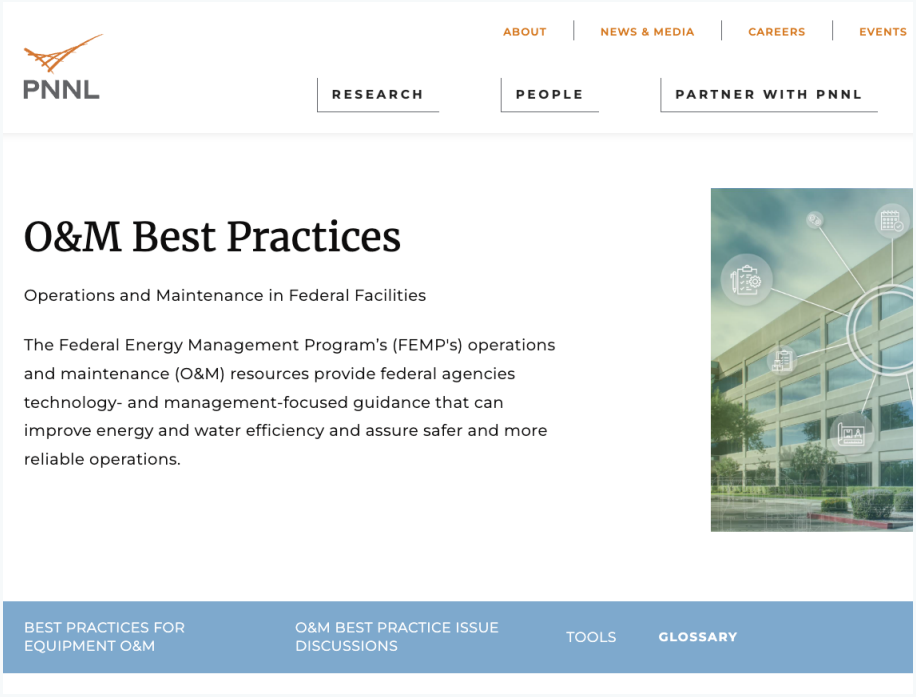
In a Washington state study of over 200 buildings, it was estimated the one-time cost to develop improved O&M programs averaged $0.43/$ft^2$ (Washington State Department of Commerce 2024, Pulles et al. 2024). For a corporate portfolio case study where a benchmark

PM program was implemented, costs were approximately $0.33/ft^2 per year (Koo and Van Hoy, n.d.).

3.2.4 O&M Success Stories

A study highlighting benefits from improved O&M planning (PECI 1999) mentions a 250,000 ft^2 office building in Nashville where an O&M assessment identified over $42,000 in annual savings ($71,700 in adjusted terms, assuming a flat 2% annual inflation rate from 1999-2026 for energy and operational cost); the simple payback for both the assessment and implementation was under seven months. At a Raytheon campus, O&M improvements saved over $400,000 annually ($682,800 in 2026 terms), representing nearly 40% of the total energy use (ibid).

Through the **O&M Best Practices** web portal, Pacific Northwest National Laboratory (PNNL) provides a comprehensive suite of resources and technology-focused guidance to help federal agencies adopt O&M best practices to improve energy efficiency and building operation. The site features a broad range of actionable equipment maintenance summaries, safety checklists, and challenge discussions designed to help building management staff adapt emerging O&M best practices, technologies, and federal performance requirements.



https://www.pnnl.gov/projects/om-best-practices

3.3 Energy Audits

3.3.1 Introduction

An energy audit, also referred to as an "energy assessment" or "energy study," is a systematic

process intended to determine where, when, why, and how energy is used in a facility. Audits are a powerful tool for uncovering operational and equipment improvements that lead to higher performance and reduced costs (Baechler et al. 2011). Unlike a simple walkthrough, a formal audit typically employs a "whole-building approach," examining building systems, operations, maintenance procedures, and schedules to provide an accurate picture of savings opportunities.

It is important to distinguish the audit from the actual saving of energy. Undertaking an energy audit does not, by itself, result in energy savings; rather, it provides building operators with the information needed to make better management decisions (SLEEAN 2013). The audit's main outcome is a prioritized list of recommended EEMs along with an assessment of their financial viability. These recommendations can range from no-cost operational adjustments (such as schedule changes) to capital-intensive retrofits. The process for performing an audit involves close collaboration between the auditor and facility staff.

The DOE *Guide to Energy Audits* outlines a standard four-step workflow (Baechler et al. 2011):

1. Preliminary Review: The auditor collects and analyzes at least two years of historical utility data to account for seasonal variations and determine a facility's EUI. Note that in doing so, particularly if historic EUI data is tracked in a system like Portfolio Manager, the preliminary review step includes the effort and costs associated with benchmarking, the next practice area explored in this study. In many cases benchmarking will be entirely a subset of the audit process.
2. Site Assessment: A physical inspection is conducted to inventory key building elements and interview O&M staff regarding current procedures and concerns.
3. Data Analysis: The auditor calculates baseline energy use and models the financial impacts of potential EEMs using the owner's preferred economic methodology (e.g., simple payback or life-cycle cost).
4. Audit Report: The final deliverable provides a summary of findings, equipment inventory, and detailed EEM recommendations including costs, savings, and impacts on occupant comfort.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines three distinct levels of audits (ASHRAE 2023), allowing owners to choose the depth of analysis that fits their budget and goals:

> Level I (Site Assessment/Preliminary Audit): This involves a brief site inspection and bill analysis to identify no-cost and low-cost opportunities. It provides a general view of potential capital improvements and is often sufficient for smaller facilities without major capital budgets. This audit level yields only rough costs and savings estimates or rankings for potential improvements.
>
> Level II (Energy Survey and Analysis): This level includes a more in-depth analysis of energy costs and usage, providing specific EEM recommendations aligned with the owner's financial plans. A Level II audit requires a detailed engineering and financial analysis of EEMs, featuring a summary table that breaks down estimated measure cost,

energy savings, and O&M savings for each recommendation. This audit level is recommended for facilities that have never been audited or are planning renovations.

Level III (Detailed Analysis/Investment Grade): This involves rigorous engineering analysis, long-term data collection, and monitoring. Level III includes highly detailed financial evaluations and the use of annual energy simulation to more accurately predict savings. This level provides the solid financial analysis required to secure funding for major capital investments, effectively "de-risking" expensive retrofits.

3.3.2 Benefits

The primary benefit of an energy audit is the identification of opportunities. The audit is essentially a decision-making tool that bridges the gap between current performance and potential savings. Audits provide a roadmap for efficiency, identifying a spectrum of measures from simple "re-tuning" to major system overhauls, but do not in and of themselves save energy. Those benefits are realized only if identified EEMs are implemented. Level II and III audits provide the higher-grade analysis necessary to prioritize capital spending. While performing comprehensive audits requires capital outlay, they are often prerequisites for identifying retrofit measures that can then yield significant energy savings if implemented.

Beyond energy savings that can be realized with identified EEMs, the systematic assessment of building systems can yield substantial non-energy benefits. These include ensuring the health and safety of occupants, improving thermal comfort, confirming the design life expectancy of equipment, and other reliability checks to reduce outages, underperformance and occupant inconvenience (Baechler et al. 2011).

3.3.3 Costs

The cost of an energy audit varies significantly based on the building's size, complexity, and the depth of the analysis (i.e. ASHRAE level). Depending on facility complexity, detailed energy audits are reported to range from \$0.12 to \$0.50/ft^2, according to a 2011 study (Baechler et al. 2011), though more current industry information on commercial building audit costs gives ranges from \$0.05 to \$0.15/ft^2 for a preliminary Level I screening, to \$0.10 to \$0.30/ft^2 for a Level II analysis, and \$0.25 to \$0.50/ft^2 or more for complex, investment-grade Level III audits.[3] An industry rule-of-thumb is that to ensure cost-effectiveness, the cost of an energy audit should generally not exceed 10% of the building's annual utility bill (though the audit level is not specified for this rule) (Baechler et al. 2011).

3.4 Building Performance Benchmarking

3.4.1 Introduction

Building performance benchmarking is the systematic process of measuring and tracking a building's energy consumption to compare against the building’s historic performance, standard industry benchmarks, or the performance of peer buildings (Antonoff 2017, EPA 2013). The methodology involves collecting specific building characteristics such as size, occupancy and

[3] https://vutility.com/blog/commercial-energy-audit-cost-per-square-foot-pricing-breakdown

use type, along with utility data (e.g. electricity, natural gas, any other sources, including onsite generation) to calculate key performance metrics like EUI. By quantifying energy consumption per square foot, building owners and operators can evaluate their overall efficiency, track progress over time, and identify specific areas for energy-saving improvements.

This tracking is typically conducted using comprehensive platforms like the U.S. Environmental Protection Agency's free web-based tool, Energy Star Portfolio Manager (ESPM), at https://www.energystar.gov/buildings/benchmark. This tool functions as a dashboard to calculate EUI and provides a scaled 1-to-100 percentile ranking that compares a building's energy performance to similar facilities, adjusted for local weather and business activities in the building. A score of 50 represents the normalized median, while a score of 75 or higher means a building is in the top quartile of performers. Ultimately, this data-driven process allows managers to pinpoint underperforming assets and verify the effectiveness of newly implemented efficiency upgrades over subsequent performance periods (Baechler et al. 2011, Mims et al. 2017, ACEEE 2018).

3.4.2 Benefits

Extensive data demonstrates that the simple act of tracking energy use consistently correlates with measurable reductions in consumption. Analyzing over 35,000 buildings using Portfolio Manager consistently between 2008 and 2011, a study found average annual savings of 2.4%, achieving a cumulative total savings of 7.0% over the four-year period (EPA 2012). Notably, the greatest savings were realized by buildings that started with lower efficiency scores (under 50), which saved twice as much energy as those starting above average. Performance benchmarking and transparency carries an additional economic benefit, with higher performance labels correlating with higher sale and rental prices (Mims et al. 2017).

One study finds energy usage reductions ranging from 1.6% to 14% over two- to four-year periods in cities with widespread benchmarking (ACEEE 2018). Another study finds a 3% reduction in quarterly utility bills (Mims et al. 2017). A meta-review of several U.S. cities highlights specific financial and energy benefits associated with benchmarking (Antonoff 2017):

- Chicago: Properties reporting for three consecutive years reduced energy usage by 4%, leading to estimated savings of $11.6 million per year.
- New York City: Over a six-year period, benchmarked buildings reduced energy use by 10%.
- San Francisco: Properties benchmarking consistently from 2010 to 2014 demonstrated a 7.9% overall reduction in energy use.

3.4.3 Costs

Sources on benchmarking service costs are difficult to locate. The costs associated with benchmarking vary depending on whether they are viewed as internal administrative time, or are contracted out to energy engineering consultants. In the latter case, they are very often included in energy audit services, in which case the additional costs for benchmarking are not

visible. As with audits, benchmarking activities do not save energy directly; benefits are only realized if actions are taken based on benchmarking results.

Benchmarking-only services are typically based on custom quotes; standard fee schedules per building or square foot were difficult to locate in the literature review. An industry contact indicated that energy consultants offer benchmarking as a core service for $1,000-$2,000 per building, and sometimes for $500 or less. Los Angeles's information page for its Existing Buildings Energy and Water Efficiency (EBEWE) ordinance puts benchmarking costs at $200-$400/year per building (20,000 ft^2 or more).[4] The Omaha Public Power District's Energy Star Benchmarking rebate program offers up to $500 to cover what is described as "100% of building benchmarking costs."[5] Elsewhere, industry deployment data for commercial "meter-level" Energy Information Systems (EIS) used specifically for utility tracking and energy benchmarking indicate set-up costs of approximately $0.01 per square foot (Kramer et al. 2019, Lin et al., 2022). Considering all of these sources, benchmarking costs are expected to be in the range of $0.01 to $0.02/$ft^2$.

3.5 Existing Building Commissioning (EBCx)

3.5.1 Introduction

Existing building commissioning (EBCx) is an umbrella term for the systematic process of investigating, analyzing, and optimizing the performance of building systems. EBCx identifies and implements cost-effective measures to ensure buildings function efficiently and meet the owner's current operational requirements. It is a rigorous process, carried out either periodically or on an ongoing basis, to verify and document that systems function as designed (Crowe et al. 2020). Unlike capital retrofits, this process focuses on "re-tuning" via low-cost enhancements to operations and controls (Tiessen 2017). The goal of EBCx is to align building performance with goals, such as those defined in Current Facility Requirements (CFR), commonly through Building Automation System (BAS) trend data analysis, as well as documentation and operator training (ASHRAE 2015).

While terminology varies, retrocommissioning (RCx) can be understood as a single comprehensive, and bounded (rather than open-ended) effort (though it can be repeated periodically) to optimize energy efficiency and operational performance by identifying and correcting equipment and control system deficiencies through low-cost adjustments, cleaning, and repairs (SLEEAN 2013). The RCx term is often used synonymous with the EBCx definition above. However RCx is distinguished as a sub-set of EBCx activities; the key differentiator for RCx is that it is a defined, single intervention, from investigation to implementation of "fixes," though in practice it can be applied cyclically (e.g. one-year or five-year cycles). Because these diagnostic interventions are highly technical, policy guidelines often require that professionals supervising commercial energy audits hold a CEM designation, while commissioning providers may hold certifications from the Building Commissioning Association, the Association of Energy Engineers, or the Associated Air Balance Council Commissioning Group (or ACG)

[4] https://www.ebeweordinance.com/ai-info-page
[5] https://www.oppd.com/business/products-services/save-money-save-energy/energy-star-rebates/

Commissioning Group. Alternatively, building operators without an engineering degree can qualify to lead these complex assessments if they possess significant hands-on experience (e.g., 10 years as an operating engineer) combined with a BOC (SLEEAN 2013).

Monitoring-based commissioning (MBCx) is the branch of EBCx that systematizes the persistence of commissioning performance. MBCx employs energy management and information systems (EMIS) to continuously track facility performance and prevent "performance drift," ensuring that previous energy savings persist and continually identifying new opportunities (Crowe et al. 2020, Sims and Malinowski 2026). Continuous or ongoing commissioning (OCx) are other terms for the continuous application of the commissioning process to a building or energy system (PNNL 2021, DOE 2022). They are in practice inextricably linked to MBCx, which provides the specific data-driven techniques and procedures that make OCx possible. By utilizing EMIS tools like fault detection and diagnostic (FDD) software, facility teams can transition to a proactive operations model. These systems continuously monitor system-level data from the building automation system to automatically detect and prioritize operational faults before they lead to occupant complaints or equipment failure (Kramer et al. 2019, 2020). Table 2 below provides a comparative reference for the EBCx terminology introduced here; this is not a comprehensive list of all of the myriad terms used in reference to commissioning however.

Table 2. Comparison of Commissioning Terminology and Scopes

Term	Stage, Frequency	Primary Purpose	Key Activities & Methods	Typical Practitioners	Overlaps & Distinctions
Commissioning (Cx)	New construction. One time	Verify that newly constructed systems are installed and operating per the Owner's Project Requirements (OPR) and Basis of Design (BOD)	Facilitate OPR/BOD development, design review, functional performance testing, systems checkout, controls verification, O&M training, documentation	Commissioning Authority (CxA)	The foundational concept from which all others derive
Existing Building Commissioning (EBCx)	Any existing building, regardless of Cx history. One time.	Umbrella term for systematically investigating and improving performance of existing buildings	Comprehensive systems investigation, operational benchmarking, EEM identification and prioritization, O&M improvements	CxA	Broad, encompasses RCx; used in LEED for Existing Buildings; the preferred formal/ contractual term in many contexts

Term	Stage, Frequency	Primary Purpose	Key Activities & Methods	Typical Practitioners	Overlaps & Distinctions
Retro-commissioning (RCx)	Existing buildings with no prior Cx history. One time or periodic. **Sub-set of EBCx.**	Achieve intended performance in buildings that were never formally commissioned	Benchmarking, diagnostic monitoring, systems investigation, EEM identification, verification	CxA	Technically a subset of EBCx; the "retro" implies working without original commissioning documentation as a baseline; some practitioners use RCx and EBCx interchangeably
Monitoring-Based Commissioning (MBCx), Ongoing Commissioning (OCx)	Existing buildings. Ongoing. **Sub-set of EBCx.**	Use automated data analysis and energy management and information systems (EMIS) tools to continuously detect and correct operational faults and energy waste	BAS data streaming, automated FDD, issue prioritization by cost/impact, technician dispatch and verification	CxA, energy engineers, facility managers, software platform providers	Technology- and data-driven; strongly tied to FDD platforms and BAS integration

An important industry resource on EBCx is the Building Commissioning Association's *Existing Building Commissioning Best Practices*, which provides a comprehensive, five-phase procedural framework designed to help practitioners optimize building performance, improve energy efficiency, and ensure systems interactively meet a building's documented CFR (BCxA 2024). Another resource for EBCx is ASHRAE 230-22: Commissioning Process Requirements for Existing Buildings and Systems, which defines the minimum commissioning activities for existing buildings, providing procedures, methods, and documentation requirements from investigation, implementation, hand-off, and initial ongoing commissioning (ASHRAE 2022). ASHRAE Guideline 0.2-2015: Commissioning Process for Existing Systems and Assemblies. Standard 230 Guideline 0.2 also provides a comprehensive framework for evaluating and testing existing systems, describing the procedures and methods for a quality-oriented commissioning process to improve the performance of existing building systems and assemblies to meet defined operational requirements (ASHRAE 2015).

The **Existing Building Commissioning Best Practices** (BCxA 2024) report establishes a methodical five-phase framework (Planning, Initial Assessment, Investigation, Implementation, and Hand-off) to optimize existing building systems. Intended for building owners, facility managers, and commissioning providers, the document serves as a quality benchmark to ensure a professional process that improves energy efficiency, occupant comfort, and indoor air quality while reducing operational costs. The document highlights the importance of developing or updating Current Facility Requirements (CFR) during the Planning Phase to define the building's operational needs (such as temperature, humidity, and operating hours) and to then ensure that systems meet the documented CFR through the implementation process. The report also emphasizes trend analysis for identifying operational issues and advocates for robust verification using functional performance testing and trend point monitoring to ensure facility improvement measures are successfully implemented and meet the owner's operational requirements. Finally, EBCx should culminate in a "persistence plan" to maintain performance gains through training and ongoing commissioning.



https://www.bcxa.org/uploads/resources/bcxa1005bestpractice-existingbuildingcommissioning-v3.pdf

3.5.2 Benefits

There is perhaps a more comprehensive body of evidence on the economic case for existing building commissioning than for any other energy management strategy. A landmark meta-analysis by Lawrence Berkeley National Laboratory (LBNL), asserts that EBCx is the single-most cost-effective strategy available for reducing energy costs (Mills 2009), compared primarily to conventional hardware upgrades in the commercial sector (such as lighting retrofits, HVAC equipment efficiency upgrades, and building shell improvements). The meta-analysis included 643 buildings, finding that EBCx projects result in median whole-building energy savings of 16%. Projects achieved a median benefit-cost ratio of 4.5, or a life-cycle ROI of 450%, calculated over an assumed five-year project lifetime. Additionally, these projects yielded a median cash-on-cash return of 91%, comparing first-year cost savings against initial project costs.

A subsequent 2020 LBNL study, which expanded the dataset to 1,482 buildings, found that savings vary by approach: utility-sponsored EBCx programs showed median savings of 6.4%,

while EBCx implemented outside of utility programs achieved median savings of 14% (Crowe et al. 2020). In an analysis of the source of EBCx energy savings, nine specific measures were found to account for the majority of savings (Tiessen 2017). The top contributors include revising control sequences (21%), reducing equipment runtime (15%), and optimizing airside economizers (12%).

When EBCx incorporates advanced analytics through an MBCx approach, the benefits are substantial. Recent data from the Smart Energy Analytics Campaign, which analyzed over half a billion square feet of commercial space, demonstrates that organizations using FDD tools achieved a median annual energy savings of 9% (or $0.24/ft²) by their second year of installation (Kramer et al. 2020). These analytics enable staff to quickly identify the root causes of issues, such as simultaneous heating and cooling or suboptimal economizer operations, ensuring that efficiency gains persist over time.

EBCx investments are recovered quickly, with a reported median simple payback of 1.7 years (Crowe et al. 2020). EBCx provides substantial non-energy benefits as well, such as improved thermal comfort, better indoor air quality, and extended equipment life that can offset the net project cost by an average of 49% (Mills 2009).

3.5.3 Costs

One of the most compelling findings from the literature is that the cost of EBCx is decreasing over time as tools and market maturity improve. The 2009 LBNL meta-analysis reported a median cost of $0.30/ft^2 for existing buildings (Mills 2009). The 2020 LBNL update found that median costs had dropped, with the median cost for EBCx projects in the 2018 sample being just $0.26/ft^2 (Crowe et al. 2020). Another study found “recommissioning” costs ranged from $0.05 to $0.40//ft^2 (Sullivan et al. 2010). The cost per square foot generally decreases as building size increases, making it particularly cost-effective for portfolios of large commercial buildings (Crowe et al. 2020).

Implementing the analytics software necessary for MBCx offers a highly cost-effective entry point to operational excellence. Median software installation and configuration costs are just $0.01/ft² for Energy Information Systems (EIS) and $0.06/ft² for FDD, with both technologies achieving a median simple payback period of only two years (Kramer et al. 2020). However, owners must also account for recurring annual software fees (median $0.01 to $0.02/ft²) and the dedicated in-house labor required to routinely review the diagnostics and execute fixes in order to realize these financial returns

3.5.4 Success Stories

Lawrence Berkeley National Laboratory Ongoing Commissioning (Elliott et al. 2020): The lab has implemented an ongoing commissioning (OCx) program, a rigorous process of short-cycle (4- to 5-week) "sprints" during which a cross-functional, dedicated team of controls engineers, HVAC/controls technicians, an energy engineer, and analytics support team systematically identifies, selects, fixes, and verifies energy-wasting equipment deficiencies. The team relies on regular feedback and sprint reviews to ensure continuous improvement and utilizes fault-

detection algorithms and outputs within a lab-wide analytics platform to identify new building deficiencies and ensure that savings from addressed deficiencies persist over time. As of 2020, this approach generated maintained energy savings of 12.2 million kWh per year, with direct ongoing commissioning savings totaling $446,000 annually. The energy savings across ten facilities averaged 16%, proving the effectiveness of this approach for large portfolios.

3.6 Overlap, Synergies, and Related Frameworks

3.6.1 Operational Excellence as an Ecosystem of Interdependent Practices

While industry may treat energy management planning, O&M, benchmarking, auditing, and commissioning as discrete, line-item activities, they function most effectively as an integrated ecosystem. The practice areas discussed in Sections 3.1 through 3.5 share a common goal: unlocking savings through operational changes and improvements and capital planning. These interdependent activities move energy efficiency from a project-by-project basis to a continuous, systematic business practice. Oftentimes the activities in one of these areas flow naturally into the others, or encompass them fully, and in fact there may not be a strict distinction between them in practice.

Energy management planning forms the foundation and starting point but does not function in isolation. It establishes the strategies and targets (e.g. designating an energy manager, setting performance goals) that direct the other activities for operational excellence. Performance benchmarking can provide the "dashboard" to track the progress of the EMP, while predictive and preventative O&M serves as the mechanism for sustaining the performance levels set by the plan. By viewing these activities as interdependent, building owners can transition from reactive "fire-fighting" to a proactive model where each activity enhances the value of the others.

3.6.2 Cyclical Improvement: Benchmarking, Audits, and Commissioning

The most effective operational strategies follow a logical, sequential flow where data leads to diagnosis, and diagnosis leads to correction. The State and Local Energy Efficiency Action Network's *Energy Audits and Retrocommissioning Guide* outlines this complementary relationship as a cascading process (SLEEAN 2013).

1. Benchmarking to establish the baseline: The cycle begins with benchmarking, which provides the initial performance baseline. Benchmarking is the screening tool that allows owners of large portfolios to identify which properties are underperforming and prioritize them for deeper analysis. It answers the question, "Which buildings are inefficient?"
2. Energy audits and commissioning assessments for diagnosis: Once underperforming assets are identified, energy audits provide the necessary deep dive for energy-saving retrofit discovery while commissioning assessments can uncover low-cost controls tuning and operations improvements through basic trending and analysis. While benchmarking indicates *that* a building is inefficient, the audits and assessments explain *why*, revealing a wide range of opportunities, from simple operational adjustments to

major capital retrofits, and quantify the financial return for each.

3. RCx: Audits and assessments are critical for identifying retrofit opportunities but they do not guarantee implementation or achieve energy savings in and of themselves. RCx can serve as an "action" phase for low-cost/no-cost operational and controls tuning measures, identified through investigative activities in the RCx process such as a commissioning provider's initial assessment. RCx ensures that the building systems are actually "re-tuned" to operate as designed, transforming the potential savings identified in assessments into realized financial returns.

3.6.3 Financial Synergies: Blending Paybacks to Fund Deep Retrofits

One of the most powerful economic arguments for an integrated approach is the ability to leverage the rapid payback of operational improvements to subsidize longer-term capital investments. Systematic O&M assessments and commissioning often yield savings of 5% to 20% with simple payback periods of under two years, and frequently less than one year (PECI 1999). In contrast, capital-intensive retrofits identified in energy audits often have much longer ROI horizons O&M measures are significantly more capital-efficient than deeper capital retrofits, costing approximately 20 times less to achieve the same level of energy savings (Sullivan et al. 2010). Integrating these low-cost strategies first ensures that capital retrofits are not oversized. For example, addressing faulty HVAC equipment and schedules to eliminate "false" loads on the system (i.e. from leaky valves and dampers or, improperly scheduled operation) can reduce total building load, allowing for smaller, less expensive equipment to be installed during a capital replacement.

3.6.4 Ensuring Persistence

Finally, the integration of these tools solves the historic problem of "performance drift," where energy performance degrades over time as equipment ages, sensors drift from their original calibrations, or settings are overridden. An MBCx paradigm fuses the data tracking of benchmarking into an ongoing process that provides rigorous testing and reappraisal of commissioning performance (Mills 2009, Crowe et al. 2020). By using permanent energy information systems (similar to advanced benchmarking tools) to continuously monitor system performance, building operators can ensure that the savings achieved through audits and retrofits persist. This synergistic approach not only maintains savings but continually identifies new opportunities, effectively closing the loop and returning the process to the "Commitment" and "Assessment" phases of the EMP cycle.

3.6.5 EMP within the Framework of Strategic Energy Management

In commercial buildings, EMP and Strategic Energy Management (SEM) are sometimes used interchangeably to describe planning and operational practices that reduce energy consumption. However, they formally differ in scope and focus. Table 3 below compares key aspects of the two concepts. Energy Management Planning is the structured, often written, plan to achieve energy goals, while Strategic Energy Management is the holistic, ongoing, and cultural process of continuously improving energy performance. In other words, EMP is a component of SEM. SEM integrates the range of practices associated with operational

excellence into a systemwide, cultural commitment to continuous cycles of improvement. SEM programs for commercial buildings generally combine behavioral, operational, and capital improvements to drive performance (EPA 2013, Sims and Malinowski 2026). They treat energy management as a business practice, not just a technical project, focusing on training staff and using data to make decisions. SEM often involves multi-year cohorts, where businesses learn from experts and peers to drive consistent reductions. An EMP is the document that defines the strategy, while SEM is the action of implementing that strategy continuously. Both concepts share the same fundamental goals and core elements:

- Continuous Improvement: Ongoing, long-term savings over one-off, short-term fixes.
- Data-Driven: Reliance on measuring, tracking, and benchmarking energy usage to identify inefficiencies.
- Goal Setting: Specific, measurable performance goals to track progress.
- Action-Oriented: Identifying and executing energy-saving opportunities.
- Scope: Assessing facility energy use, equipment condition, and operational procedures.

Table 3. Comparing EMP and SEM

	Energy Management Planning (EMP)	Strategic Energy Management (SEM)
Definition	A structured, written document outlining specific energy goals and actions.	A holistic, continuous, long-term process of managing energy as a core business function.
Scope	Often focused on technical upgrades, compliance, or specific capital projects.	Broad: Includes operations, maintenance, behavioral changes, and culture shift.
Duration	Can be episodic (e.g., a 1-year or 5-year plan).	Long-term and continuous; aimed at persistent, ongoing savings.
Organization	May exist only on paper or within the facility team.	Embedded into the organization's corporate culture and daily operations.

SEM Frameworks

The underlying concept of EMP as described in this report is well-established with different names and minor variations in multiple SEM frameworks, including the following:

ENERGY STAR's Guidelines for Energy Management. Provides a structured strategy for creating an energy management program focused on continuous improvement of energy performance (EPA 2013). The seven-step continuous improvement framework includes: (1) making a commitment by appointing an energy director and crafting an EMP policy; (2) assessing performance through data and baselines; (3) setting clear, measurable goals; (4) creating an action plan; (5) implementing that plan with staff training and incentives; (6)

evaluating progress against goals; and (7) recognizing achievements to sustain momentum.

ISO 50001. An international standard that provides a structural framework for establishing a rigorous energy management system (EnMS) (Therkelsen et al. 2013) to establish the policies and procedures for systematically tracking, analyzing, and improving energy performance in a building[6]. It employs a data-driven "Plan-Do-Check-Act" (PDCA) cycle to systematically integrate energy efficiency into an organization's standard management practices. The episodic EMP discussed above corresponds to the planning component of ISO 50001. By continuously monitoring measured energy data, the standard guides facilities in executing a combination of capital projects and, more predominantly, low-cost or no-cost operational improvements. ISO 50001 serves as one of the leading frameworks for implementing SEM. By utilizing the structures provided by standards like ISO 50001, SEM programs unlock savings through behavioral changes (such as staff training), operational improvements (e.g. adjusting set points and schedules), and proactive maintenance, rather than relying solely on major capital investments. ISO 50001 provides a rigorous business process for continually improving energy performance, reducing costs, and lowering greenhouse gas emissions (Therkelsen et al. 2013). For organizations seeking a streamlined entry point, the DOE's 50001 Ready Program offers a self-paced, no-cost framework to build a culture of structured energy improvement without requiring external certification.[7]

CEE's Strategic Energy Management (SEM) Minimum Elements. Provides a set of threshold criteria for energy management practices, as summarized below. These identify the minimum characteristics of an SEM program, as supported by a consensus of demand side management program administrators (CEE 2014). The SEM Minimum Elements foster persistent, measurable savings streams born from the combination of operational, behavioral and capital improvement.[8]

[6] International Organization for Standardization (ISO) 50001:2018. Energy management systems — Requirements with guidance for use. Edition 2, 2018. Switzerland. See also: https://betterbuildingssolutioncenter.energy.gov/iso-50001/getting-started-iso-50001

[7] https://www.energy.gov/eere/ito/50001-ready-program

[8] https://cee1.org/program-insights/strategic-energy-management-the-business-of-energy-management/

CEE SEM Minimum Elements Summarized

1. Customer Commitment Vital for SEM success, requiring executive-level engagement

- **a. Policy and Goals:** Senior management sets and communicates long-range energy objectives.
- **b. Resources:** Management ensures initiatives are properly funded and staffed, assigning accountability to an energy champion or team and supporting employee engagement.

2. Planning and Implementation Managing energy and translating plans into action

- **a. Energy Management Assessment:** Evaluate current practices with scorecards, facilitated assessment.
- **b. Energy Map:** Map out energy end uses, costs, and variables (e.g., production, weather).
- **c. Metrics and Goals:** Establish measurable improvement goals, Energy Performance Indicators (EnPIs) based on baseline data.
- **d. Project Register:** Maintain a prioritized timeline of multi-year actions (capital projects, O&M improvements, procurement) with estimated savings and costs.
- **e. Employee Engagement:** Educate, empower, and encourage staff to take energy-saving actions within and beyond their work areas.
- **f. Implementation:** Execute projects from the register, update standard operating procedures, and engage staff to ensure persistence.
- **g. Reassessment:** Periodically review performance against expectations and update goals, metrics, and projects to align with business priorities.

3. System for Measuring and Reporting Energy Performance Regularly tracking and analyzing data to continuously manage and improve operations

- **a. Measurement:** Regularly collect data (via utility meters or process submetering) capturing key variables like production and weather.
- **b. Data Collection and Availability:** Store energy data, EnPI progress to ensure long-term availability.
- **c. Analysis:** Establish a baseline to build a predictive model that estimates consumption based on key drivers, re-establishing the baseline when conditions shift.
- **d. Reporting:** Regularly communicate energy achievements, EnPI results to stakeholders.

4. Conclusion and Recommendations

This study aggregates and documents information from over three decades of research on operational excellence practices in commercial buildings, covering thousands of buildings and millions of square feet of real estate. The collective evidence points to a definitive conclusion: operational excellence is a highly cost-effective mechanism for managing and minimizing operating expenses and protecting building assets, reducing risk, and meeting performance targets.

While researchers and leading organizations have been evolving these practices and investigating their substantial financial benefits for some time, systematic operational excellence is still not considered "business-as-usual" across the broader commercial building industry. The prospect of implementing the multiple overlapping and interrelated strategies explored here can appear daunting for building owners and operators that have not yet adopted these practices. Historically, opportunities for energy performance improvement have instead been viewed through the lens of capital upgrades such as new windows, chillers, or lighting equipment. The information presented in Section 3 challenges the traditional preference for capital retrofits, with the literature confirming that the "invisible" work of energy management, preventative O&M, commissioning, and benchmarking, and existing building commissioning can deliver attractive financial returns with low risk profiles.

Facilities implementing energy management programs have demonstrated the ability to achieve energy savings of 10% or more over business-as-usual scenarios. Shifting from reactive to preventive maintenance, deriving value from extending the useful life of expensive equipment by 20% to 30% and delaying millions of dollars in capital expenditures, can yield a 545% ROI over 25 years (Koo and Van Hoy, n.d.). EBCx also remains a "golden opportunity" for savings. Wide-ranging LBNL meta-analyses of commercial building performance found that EBCx projects offer a median simple payback under two years (Mills 2009, Crowe et al. 2020).

Operational excellence represents a paradigm shift; monetizing action that addresses operational inefficiency and substandard operations. By embracing this framework, owners can turn building operational practices into an ROI that outpaces traditional equipment upgrade investments. This study clarifies how these five practices function not as siloed activities, but as an integrated ecosystem of interdependent practices. By identifying the unique role of each, owners can navigate what might otherwise seem like redundant or confusing efforts and instead establish a systematic business practice of continuous operational improvement. Ultimately, by clarifying the specific value of each practice and how they fit together, this paper provides a roadmap for owners to transition from reactive, failure-driven maintenance to a proactive asset preservation strategy that is repeatable and profitable.

4.1 Recommendations for Building Owners and Managers

Based on the synthesis of data and information from the range of resources reviewed, the following strategic recommendations are offered to help owners transition to a position of operational excellence. Each recommendation includes “action” ideas and summary rationale

for its inclusion here.

Recommendation 1: Adopt a "Total Cost of Ownership" Mindset

Building owners should not view energy management planning and preventative O&M programs as administrative or financial burdens. Instead, these proactive practices serve as the vital "discovery phase" of a broader investment strategy, uncovering hidden inefficiencies and safeguarding asset longevity. Embracing this total cost of ownership mindset ensures that equipment functions efficiently and effectively over its entire intended lifespan, rather than incurring sudden emergency replacement costs.

- Action: Implement a proactive, scheduled preventative maintenance plan that tracks equipment condition and establishes regular tuning intervals, rather than relying on reactive, run-to-failure approaches. When scoping energy audits and O&M assessments, ensure the scope includes a financial analysis of *life-cycle* savings, not just immediate energy savings. Simple payback is often used to evaluate actions with good short-term returns, but energy-saving retrofits and operational practices accrue financial benefits over multi-year lifespans. Financial analyses that only consider single-year savings against initial project costs fail to capture the complete economic value of dollars invested toward energy-saving practices, whereas a discounted life-cycle cost (LCC) analysis can more accurately account for the time value of money, energy escalation, and long-term avoided costs (Baechler et al. 2011, ASHRAE 2024).
- Rationale: Shifting to a proactive O&M strategy consistently leads to substantial long-term savings through reduced emergency repair costs, extended equipment useful life, and optimized energy efficiency. O&M measures cost 20 times less than capital retrofits to achieve comparable savings (Sullivan et al. 2010). By implementing the "low-hanging fruit" identified in plans, owners can generate immediate cash flow (payback < 2 years).

Recommendation 2: Integrate Operational Excellence Practices into a "Virtuous Cycle"

Avoid treating benchmarking, energy audits, building commissioning, and daily maintenance as isolated or siloed activities. Best practices demonstrate that these efforts form a highly interdependent, virtuous cycle where data continuously informs diagnostic action and correction. A comprehensive energy management plan binds these elements together, ensuring that efficiency measures are not only implemented but systematically sustained and improved over time.

- Action: Establish a comprehensive energy management plan that formally dictates the use of benchmarking to track performance, energy audits to identify capital upgrades, and retro-commissioning to tune systems, all supported by rigorous daily O&M protocols. Use benchmarking not just for reporting, but to flag underperforming assets. Use audits to diagnose the root cause. Use EBCx to execute fixes. Finally, use preventive maintenance to ensure that fixes persist. Also, see Recommendation 3 for the importance of developing workforce capacity to ensure that operational excellence practices persist over time.
- Rationale: Integrating these activities creates a feedback loop where benchmarking

detects underperformance, audits and commissioning diagnose and fix the root causes, and diligent maintenance prevents the building from drifting back into inefficiency. Benchmarking and audits do not guarantee implementation. Without linking these activities directly to a commissioning or maintenance work order, the intelligence gathered is lost, and the cost of benchmarking and audits becomes waste.

Recommendation 3: Invest in Workforce Capacity and "Energy Champions"

Advanced technology and upgraded equipment alone cannot solve operational inefficiencies if the personnel operating buildings lack the necessary expertise and are not empowered by management to pursue these goals. Workforce investments and professional development are critical to fostering the cultural and operational shifts that sustain continuous improvement and long-term asset value. Designating a dedicated and qualified energy manager can be a key enabler in driving successful energy management strategies.

- Action: To drive institutional follow-through for operational excellence, appoint an energy manager to champion the facility's efficiency goals and oversee plans. Institute a formal energy policy that establishes a clear chain of command, tracks progress, and grants personnel the authority to execute improvements (EPA 2013, ASHRAE 2024). Consistently invest in specialized training and certification programs for the building's operations and maintenance personnel. Specifically, owners may want to establish the CEM designation as a standard qualification for their lead energy champions. Furthermore, creating professional development pathways for O&M staff to achieve BOC can increase the organization's internal capacity to independently troubleshoot and optimize building performance, reducing reliance on external contractors.
- Rationale: The first step of effective energy management is "making a commitment" by investing in and empowering staff (EPA 2013). A well-trained and motivated staff is essential for executing complex operational procedures, recognizing early signs of system degradation, and ensuring that capital investments in energy efficiency actually deliver their expected returns. Designating a specific leader and a cross-functional energy team fosters staff ownership and accountability, ensuring that efficiency goals are embedded into the organization's culture and daily operating procedures rather than being treated as isolated, temporary projects.

Recommendation 4: Implement Existing Building Commissioning and Consider Incorporating Monitoring-Based Commissioning

Existing building commissioning is arguably the single most cost-effective strategy available for reducing energy waste and uncovering hidden operational deficiencies in commercial facilities. While periodic commissioning ensures that building systems are properly tuned to meet current operational needs, owners should ultimately aim to take the next step by treating this optimization as an ongoing process. Evolving into MBCx allows permanent data analytics to prevent the inevitable degradation of savings (performance "drift").

- Action: Conduct periodic existing building commissioning to optimize current equipment, and progressively integrate permanent energy information systems and diagnostic software to establish a continuous monitoring-based commissioning program.

- Rationale: EBCx reliably yields substantial whole-building energy savings and rapid payback periods with minimal capital investment, while the continuous data analysis of MBCx ensures those efficiencies are permanently sustained and uncovers new low-cost opportunities over time.

5. References

American Council for an Energy-Efficient Economy (ACEEE). (2018). Commercial and multifamily building energy benchmarking, transparency, and labeling in US cities. Policy Brief. Washington, DC. ACEEE.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2015). Commissioning process for existing systems and assemblies (Guideline 0.2-2015).

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2022) Standard 230-22: Commissioning Process Requirements for Existing Buildings and Systems.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2023). Standard 211-2018 (reaffirmed in 2023), Standard for Commercial Building Energy Audits.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2024). ANSI/ASHRAE/IES Standard 100-2024: Building Performance Standard for Existing Buildings.

Antonoff, J. (2017). Impact assessment: A guide for city governments to estimate the savings from energy benchmarking and energy efficiency programs. Institute for Market Transformation (IMT).

Baechler, M., Strecker, C., and Shafer, J. (2011). A guide to energy audits (PNNL-20956). Pacific Northwest National Laboratory (PNNL) for the U.S. Department of Energy (DOE).

Building Owners and Managers Association (BOMA). (2025). BOMA BEST Buildings Report. BOMA Canada and Ernst & Young LLP.

Building Commissioning Association (BCxA). (2024). Existing Building Commissioning Best Practices.

Consortium for Energy Efficiency, Inc. (CEE). (2014). Strategic Energy Management Minimum Elements. https://cee1.org/program-insights/strategic-energy-management-the-business-of-energy-management/

Crowe, E., Mills, E., Poeling, T., Curtin, C., Bjørnskov, D., Fischer, L., & Granderson, J. (2020). Building commissioning costs and savings across three decades and 1500 North American buildings. Energy and Buildings, 227, 110408.

Elliott, J., Vitti, R., Weyandt, C., & Carter, D. (2020). Generating significant and persistent energy savings in building operations using an ongoing commissioning approach. American Council for an Energy-Efficient Economy (ACEEE) 2020 Summer Study on Energy Efficiency in Buildings Lawrence Berkeley National Laboratory.

Jones Lang LaSalle (JLL). (2025, December 8). Global real estate outlook: Six forces reshaping commercial real estate in 2026. https://www.jll.com/en-us/insights/market-outlook/global-real-estate

Keller, S., and Owen, A. (2025). A comprehensive cost-benefit analysis of preventive maintenance versus corrective maintenance: Assessing the financial impact and operational benefits in engineering.

Koo, W. L., and Van Hoy, T. (n.d.). Determining the economic value of preventive maintenance. Jones Lang LaSalle.

Kramer, H., Lin, G., Curtin, C., Crowe, E. and Granderson, J. (2019). Building analytics and monitoring-based commissioning: industry practice, costs, and savings. *Energy Efficiency*.

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

Lin, G., Kramer, H., Nibler, V., Crowe, E., and Granderson, J. (2022). Building analytics tool deployment at scale: Benefits, costs, and deployment practices. Energies, 15(13), 4858.

Mills, E. (2009). Building commissioning: A golden opportunity for reducing energy costs and greenhouse gas emissions. Lawrence Berkeley National Laboratory (LBNL). California Energy Commission Public Interest Energy Research (PIER).

Mills, E., Friedman, H., Powell, T., Bourassa, N., Claridge, D., Haasl, T., & Piette, M. A. (2004). The cost-effectiveness of commercial-buildings commissioning: A meta-analysis of energy and non-energy impacts in existing buildings and new construction in the United States (LBNL-56637 Rev.). Lawrence Berkeley National Laboratory (LBNL).

Mims, N., Schiller, S. R., Stuart, E., Schwartz, L., Kramer, C., & Faesy, R. (2017). Evaluation of U.S. building energy benchmarking and transparency programs: Attributes, impacts, and best practices. Lawrence Berkeley National Laboratory (LBNL).

Murtaza, A., Saher, A., Zafar, M., Moosavi, S., Aftab, M., and Sanfilippo, F. (2024). Paradigm shift for predictive maintenance and condition monitoring from Industry 4.0 to Industry 5.0: A systematic review, challenges and case study. Results in Engineering. Volume 24,

Pacific Northwest National Laboratory (PNNL). (2021). O&M best practices: Existing building commissioning procurement. https://www.pnnl.gov/projects/om-best-practices/existing-building-commissioning-procurement
O&M best practices: Operations and maintenance in federal facilities. https://www.pnnl.gov/projects/om-best-practices

Portland Energy Conservation, Inc. (PECI). (1999). Operation and maintenance assessments: A best practice for energy-efficient building operations (O&M Best Practices Series). U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE).

Pulles, K., Reichert, L., Storm, P., & DeBolt, F. (2024). Translating potential into performance: Assessing compliance costs and policy improvements to maximize building performance standards. American Council for an Energy-Efficient Economy (ACEEE) 2024 Summer Study on Energy Efficiency in Buildings.

Sims, E., and Malinowski, M. (2026). Designing utility programs and credit models for BPS support. American Council for an Energy-Efficient Economy (ACEEE).

State and Local Energy Efficiency Action Network (SLEEAN). (2013). Energy audits and retro-commissioning: State and local policy design guide and sample policy language. Prepared by A. Schulte, ICF International.

Sullivan, G. P., Pugh, R., Melendez, A. P., & Hunt, W. D. (2010). Operations & maintenance best practices: A guide to achieving operational efficiency (Release 3.0). Pacific Northwest National Laboratory (PNNL) for the Federal Energy Management Program (FEMP), U.S. Department of Energy (DOE).

Therkelsen, P., McKane, A., Sabouni, R., Evans, T., & Scheihing, P. (2013). Assessing the costs and benefits of the superior energy performance program. American Council for an Energy-Efficient Economy (ACEEE) 2013 Summer Study on Energy Efficiency in Industry.

Tiessen, A. (2017). Chapter 16: Retrocommissioning evaluation protocol. In The uniform methods project: Methods for determining energy-efficiency savings for specific measures (NREL/SR-7A40-68572). National Renewable Energy Laboratory (NREL).

U.S. Department of Energy (DOE). (2022). FEMP existing building commissioning decision tool (PNNL-SA-167772). Office of Energy Efficiency & Renewable Energy, Federal Energy Management Program (FEMP).

U.S. Environmental Protection Agency (EPA). (2012). ENERGY STAR portfolio manager data trends: Benchmarking and energy savings.

U.S. Environmental Protection Agency (EPA). (2013). ENERGY STAR guidelines for energy management.

Washington State Department of Commerce . (2024). Clean buildings workgroup report to the legislature (v3.5).

6. AI Tools Acknowledgement

AI-assisted tools used: NotebookLM: Gemini 3 (Google), Claude Opus 4.7 (Anthropic).

Used for: review and summary of literature, drafting select report sections, generation of the three-step cyclical improvement graphic (benchmark, audit, RCx).

Extent: concise summaries of findings for source materials, and rough drafting of text with comprehensive editing and re-writing by author.

Human review: The authors reviewed and verified source summaries relative to source text to confirm accuracy, and verified all content and citations in draft text.