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Improving Energy Efficiency through Commissioning: Getting Started with Commissioning, Monitoring, and Maintaining Performance

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Improving Energy Efficiency through Commissioning: Getting Started with Commissioning, Monitoring, and Maintaining Performance

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Environmental Energy Technologies Division

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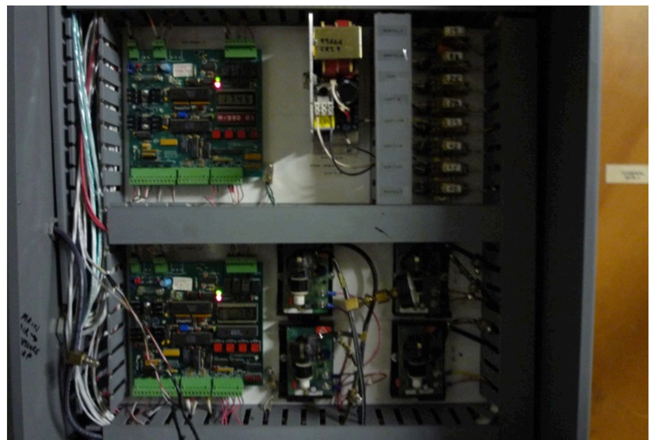

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Disclaimer

About this Guide

Purpose

This guide presents a process for increasing building energy efficiency by commissioning new and existing buildings, monitoring their performance, and taking actions to ensure persistence of savings.

Commissioning existing buildings can provide an energy savings of 10% to 30%. Median energy savings from commissioning existing and new buildings are 16% and 13% whole-building savings respectively. Note that savings can be much greater than these median numbers – 25% of existing buildings saw whole-building energy savings of 30% or more [1]. It can also reduce risk by helping to ensure your building performs as designed. While calculating "savings" for a new building is difficult, researchers estimate that a building that is not commissioned may consume 5% to 10% more energy than one that is commissioned. Commissioning services vary in scope and in cost; one study suggests that median costs for commissioning existing and new buildings are $.30/square foot and $1.16/square foot, respectively [1]. Because commissioning is often not done due to a lack of understanding of the process and benefits, this guide intends to help you to understand both the process and the benefits.

Audience

Target Audience

- Building owners
- Building designers
- Building operators
- Facility managers

Additional Audiences

- Building design engineers
- Energy Service Companies (ESCOs)
- Energy/efficiency program managers
- Leadership in Energy and Environmental Design (LEED) consultants
- General contractors
- Control companies
- Existing building commissioning agents
    - Energy auditors
    - Building controls technicians
    - Testing and balancing (TAB) technicians

Content Overview

Each of the guide's three sections presents a phase of the commissioning process: (1) commissioning your building, (2) monitoring building performance, and (3) maintaining building performance.

- **Section 1: Commissioning Your Building** discusses functional testing, an activity in all new and existing building commissioning projects; existing building commissioning (sometimes referred to as "retrocommisioning" or "recommissioning"); and monitoring-based commissioning, which involves installing energy meters then completing existing building commissioning. Subsections explain each of these in more detail and provide frameworks for determining which method is most appropriate for your project.

- **Section 2: Monitoring Building Performance** discusses the role of energy information systems (EIS) in building commissioning. This section gives you an introduction to the different types and features of an EIS, to help you select and use one to support energy savings.

- **Section 3: Maintaining Building Performance**, provides two methods to help you ensure persistent energy savings, explains how an EIS enables you to evaluate current energy performance, and directs you to resources with fault detection and diagnosis algorithms that you can use for automated maintenance of building performance.

To locate your topic of interest, use the flowchart in Figure 1, the steps to ensure low-energy operations (shown in Figure 2), and the table of contents.

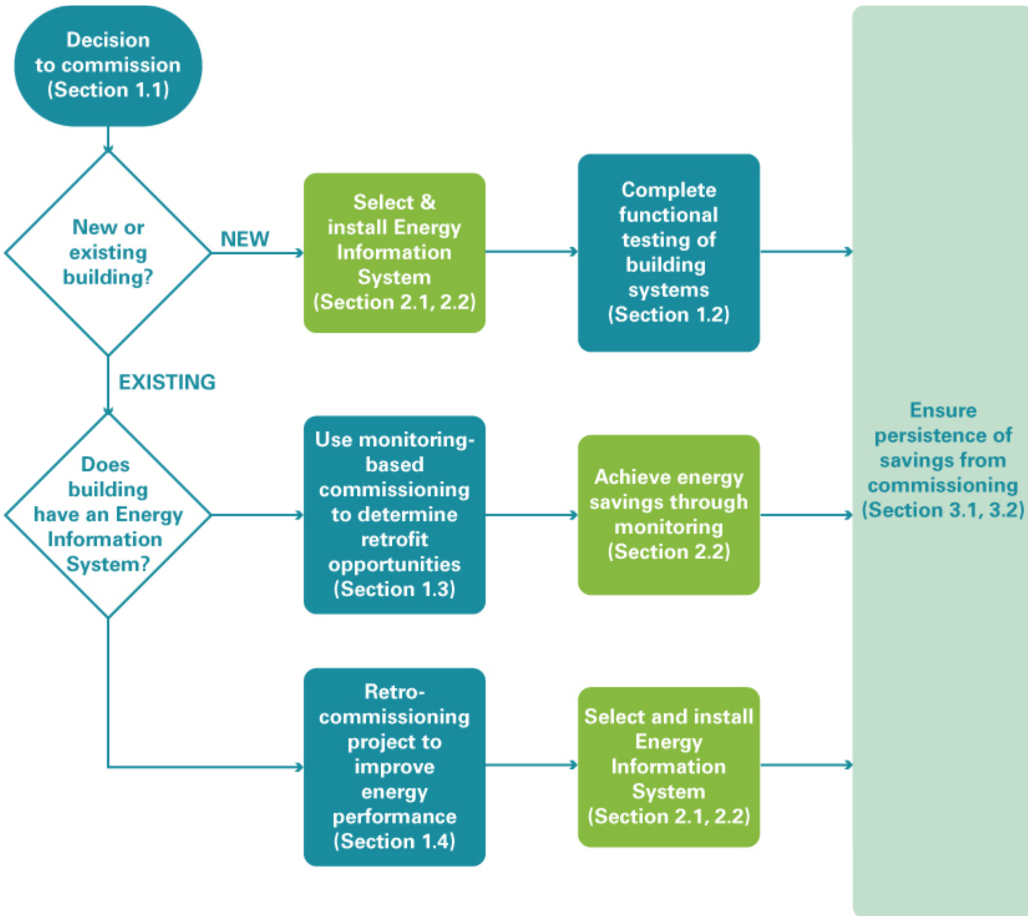

Figure 1. Building commissioning process for different building characteristics

Figure 2. Steps toward ensuring low-energy operations

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Glossary

As Built Drawing	Building drawings that reflect the condition of the building when it was constructed.
Commissioning (Cx)	A quality-focused process that verifies and documents that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner Project Requirements [2].
Design Intent	The documented or non-documented description of how designer(s) envision a building or system to perform. Design intent may be qualitative or quantitative. For example, design intent may consist of a building narrative that describes a building that is comfortable for its occupants in every season. It may also consist of a document stating the HVAC system will not simultaneously heat and cool more than two hours in a given day.
Energy Information System (EIS)	EIS are broadly defined as the software, data acquisition hardware, and communication systems used to store, analyze, and display building energy data. EIS often include analysis methods such as baselining, benchmarking, utility and carbon tracking, load profiling, and energy anomaly detection.
Existing building commissioning (EBCx)	The application of the commissioning process to existing buildings, to improve how building equipment and systems function together [3].
Fault Detection and Diagnosis (FDD)	A term used to describe a set of relationships between components in an HVAC and refrigeration (HVAC&R) system and the rules that govern their interactions.
Functional Testing	A series of procedures that verify the readiness of building systems for building operation.
Monitoring-Based Commissioning (MBCx)	A combination of ongoing monitoring of the energy consumed by building systems and standard commissioning (Cx) practices, with the aim of providing substantial, persistent energy savings.
Measurement and Verification (M&V)	The process of using measurement to reliably determine actual savings resulting from an energy management program within an individual facility. Savings cannot be directly measured, since they represent the absence of energy use. Instead, savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions [4].

1 Commissioning Your Building

1.1 Commissioning Overview

1.1.1 What is Commissioning?

Commissioning ensures that a building's operation is optimized. That is, it operates at least as well, if not better, than the designer intended (and the owner expects), and that building staff are prepared to operate and maintain its systems and equipment. In their handbook, *California Commissioning Guide: New Buildings,* Haasl and Heinemeier [5] define commissioning as follows:

> The term commissioning comes from shipbuilding. A commissioned ship is one deemed ready for service, whose materials, systems, and staff have successfully completed a thorough quality assurance process. To receive this title, it must pass several milestones: equipment is installed and tested, problems are identified and corrected, and the prospective crew is extensively trained.
>
> Similarly, when a new building is commissioned, it undergoes an intensive quality assurance process that begins during design and continues through construction, occupancy, and operations.

Commissioning is generally applicable to new buildings; however, commissioning goals are the same for new and existing buildings: to ensure that the building is performing efficiently. In the case of a new building, performing efficiently generally means meeting its design intent. Design intent is dynamic and may evolve over time as building occupancy and function change. For instance, if office space is turning into storage space, design intent may change. For this reason, you may see the term "current facility requirements" in existing building commissioning, defined by the Building Commissioning Association as "the Owner's current operational needs and requirements for a building" [6]. We use the term design intent in this document. Historically, design intent (and current facility requirements) focused on functional requirements for spaces, such as "a given indoor space requires three air changes each hour." However, it may also consider human comfort and energy consumption. For instance, "a given indoor space should be comfortable for occupants, and should include at least one air change every hour or equivalent through operable windows." Note that buildings may not actually have an energy-related design intent. In that case, the commissioning providers may find themselves "crafting" the design intent; if that is the case, the Design Intent Tool (Accessed October 2013) may be helpful [7].

Commissioning New vs. Existing Buildings

The commissioning activities are different for new and existing buildings due to differences in the accessibility of building systems, occupancy of the building, or other factors. New buildings are commissioned against design intent, and commissioning new buildings is about meeting this design intent and ensuring that a space is ready to meet occupant requirements and applicable standards. Commissioning new buildings for energy efficiency is difficult because you do not have an established baseline for energy consumption. Instead, commissioning agents seek to ensure energy-efficient building operation by ensuring an optimal sequence of control, a balance of ventilation that avoids excessive simultaneous heating and cooling, and installation of efficient components.

By contrast, owners of existing buildings begin *existing building commissioning (EBCx)* projects to save energy while maintaining design intent, rather than meeting original design intent. While some of this material may be applicable to new buildings, the bulk of it applies to existing building commissioning an existing building.

1.1.2 Why Commission?

Buildings are commissioned to ensure that they perform as designed. If, during testing, it becomes clear that the system(s) do not perform as intended, you have the opportunity to remedy these performance issues and bring the system(s) (back) into alignment. Note that commissioning generally does not involve capital improvements to buildings, or retrofits; rather, it involves tuning or otherwise adjusting the building systems to make them perform better.

While commissioning can uncover many flaws or issues, including faulty design or construction, this guide focuses specifically on energy savings. The commissioning process —comprised of commissioning, monitoring performance, and maintaining performance—reveals waste in energy consumption and identifies its causes. By identifying and quantifying it, you can eliminate this waste, either by changing how the building systems operate (such as reducing the number of air changes) or in extreme cases, changing the building systems themselves. Commissioning existing buildings can provide an energy savings of 10% to 15% [8], and this guide will help you realize the greatest energy efficiency gains from your commissioning.

1.1.3 How Much Does Commissioning Cost?

Generally, existing building commissioning is most cost-effective in those buildings with engineered systems, or separate control systems that control separate cooling, heating, and ventilation systems (or rooftop units). Having a separate control system is a significant factor (but not the only one) in determining cost-effectiveness. Buildings with more than 100,000 square feet of floor area tend to find existing building commissioning projects more cost-effective, because EBCx evaluation costs are often similar regardless of building size. However, size is not predictive of cost, so you can achieve savings in a smaller building for the same cost per square foot as in a larger building.

According to a study from the Lawrence Berkeley National Laboratory, the median cost of a existing building commissioning project was $0.30/square foot. The costs ranged from approximately $.10/square foot to $.60/square foot (2009 dollars) [1]. This study also found a median whole-building energy savings of 16%. The savings ranged from 9% to 31%. Finally, the study noted a median payback time of 1.1 years, with a range of ~4 months to ~ 2.5 years. Note this wide range in costs, savings, and payback time is at least in part attributable to variability in project scope. The median project included, at a minimum, the following scope:

- Developing a commissioning plan (includes articulating design intent)
- Performing functional testing
- Performing trend analysis
- Estimating energy cost savings for suggested improvements

- Presenting a findings and recommendations report
- Implementing improvements.

1.1.4 What are the Phases and Requirements?

While each commissioning project will be as unique as the buildings themselves, some constants—such as project phases and the documents required—do apply to all of them. For example, regardless of whether your building is new or existing, you will need to perform functional testing to verify that building systems perform as the designer intended. Also, all commissioning procedures require careful documentation of how the building systems are intended to operate – this supports maintaining performance after the commissioning project is finished.

Phases of a Commissioning Project

Figure 3 lists the four phases of any existing building commissioning project—planning, investigation, implementation, and hand off—and provides a checklist of tasks to complete in each phase. These phases are defined in the *California Commissioning Guide: Existing Buildings* [9]; phases for commissioning a new building are presented in the sister guide for new buildings [5]. This guide serves as a primer for the first three phases. Note that selecting your commissioning project (in the Planning phase) requires that you select both a building and a scope for the project.

PLANNING	INVESTIGATION	IMPLEMENTATION	HAND OFF
☐ Select your commissioning project ☐ Select your commissioning team ☐ Determine project objectives ☐ Document current building perfor-mance ☐ Perform an initial site walk ☐ Develop a Commissioning Plan	☐ Collect design intent ☐ Install monitoring equipment ☐ Perform functional testing ☐ Make "quick fixes" as needed ☐ Develop a Master List of Findings ☐ Prioritize and select improve-ments to be made	☐ Implement selected improve-ments ☐ Verify perfor-mance of those improvements	☐ Ensure that the commissioning team provides the building owner and manager with the documenta-tion required for them to maintain the building performance

Figure 3. Phases of a existing building commissioning project

Depending on building size and project scope, these phases can require a time frame of a couple of months up to two years. Project scope and funding for implementation tend to drive the schedule. Availability of funds for implementation may also cause the project timeline to expand. Where possible, match available funds to the scope, to ensure that projects can be planned and completed with the same staff.

The preferred methods for functional testing are non-invasive, relying on trend logs from building management systems. In some cases, non-invasive testing is not possible. In those cases, commissioning agents will generally perform tests during unoccupied hours, so it may make sense to commission multiple systems at once to maximize value. For example, if you need to commission the lighting systems and the HVAC systems during unoccupied hours, you may decide to perform these processes simultaneously. In these cases, plan for flexibility: allowing existing building commissioning of one or more systems based on availability of resources.

What Documents Are Required?

Before commissioning can begin, you will need to provide the commissioning agent or team with:

- as-built drawings of the building, (or preliminary drawings and program in the case of new-construction commissioning)
- the owner's operating sequences and desired operating performance, and
- any available functional test data.

1.1.5 Which Type of Commissioning is Right for You?

To choose which commissioning project is right for you, answer the questions below to determine whether your building is considered new or existing, and whether or not you have an EIS. Then use the flowchart in Figure 1 to decide which type of commissioning project your building requires. Functional testing will verify that your building systems, whether new or existing, perform as intended.

Is Your Building or System New or Existing?

Characterize your building or system as *new* if:

- ☐ You are beginning with design drawings
- ☐ You have a new heating, ventilation, and air conditioning (HVAC) system for the entire building
- ☐ Your building is not yet occupied
- ☐ Your building has an entirely new lighting scheme
- ☐ Your systems are still under warranty

Characterize your building as *existing* if:

- ☐ The systems are those originally installed in the building or are at least 5 years old
- ☐ Your building is occupied
- ☐ The mechanical, plumbing, electrical, and lighting systems in your building each function well, but do not work well together
- ☐ Your building was commissioned 2 or more years ago

Note that if your building or system is only a year or two old, the commissioning process may be a blend of new building and existing building commissioning.

Do You Have an Energy Information System?

Your building has an EIS if:

- ☐ It includes hardware, software, and communication systems that can store, analyze, and display building energy data
- ☐ It includes a software system that uses energy data from the hardware system to baseline energy performance, benchmark your building, create a building load profile, or all of these
- ☐ You are able to access hourly whole-building electricity consumption via the web. This data may be used for analysis and to make graphs

1.1.6 Commissioning for New Buildings

Commissioning a new building often occurs before the building is approved for occupancy. This is when it can be most effective, because testing will not affect building operations. When systems are new, commissioning may be considered less necessary. However, a rigorous commissioning process offers building owners, managers, contractors, and commissioning agents two valuable services. First, it identifies performance errors from the outset, allowing those to be corrected before the building is occupied. Second, it provides baseline data that can be used to quantify the effectiveness of future energy-efficiency efforts, as well as the degradation of building systems.

***Note**: Brand new systems need commissioning too—to correct errors in installation and troubleshoot potential operational performance issues.*

1.1.7 Commissioning for Existing Buildings

This guide focuses on commissioning existing buildings, and it highlights the energy savings potential from commissioning projects. It addresses two types of commissioning for existing buildings: Monitoring-based Commissioning (MBCx) and Existing building commissioning (EBCx). Note that monitoring-based commissioning is a subset of existing building commissioning involving an additional step of meter installation.

Monitoring-based Commissioning

Monitoring-based commissioning (MBCx) combines ongoing monitoring of the energy consumed by building systems with standard commissioning (Cx) practices, with the aim of providing substantial, persistent, energy savings [10, 11]. Section 1.3 discusses MBCx in more detail.

Existing building commissioning

Existing building commissioning (EBCx) is “commissioning existing buildings for the purpose of improving how building equipment and systems function together” [3]. Depending on the age of the building, existing building commissioning can often resolve problems that occurred during design or construction, or address performance problems that have developed during building operations. Among other things, existing building commissioning improves a building’s operations and maintenance (O&M) procedures to enhance overall building performance.

Existing building commissioning is more common than MBCx, because it does not require permanent building energy monitoring, so more buildings can readily implement it. Section 1.4 of this guide points to many of the resources that define various existing building commissioning processes and can help you to implement your own EBCx project.

1.2 Functional Testing

Functional testing is a series of procedures that verify the readiness of building systems for building operation. It is part of the commissioning process, most often regarded as a procedure for new buildings. In reality, functional tests are at the heart of any commissioning project, either for existing or new buildings, in that they are active tests of HVAC and control system functions. However, functional testing often requires systems be started from the off position, so it may not be feasible to do this in an existing building without significant impact to building operations.

Building systems should be commissioned to ensure that they meet design intent when they are first installed, whether this is when the building is new or when a new system is installed in an existing building. Lawrence Berkeley National Laboraotry (LBNL) and Portland Energy Conservation, Inc. (PECI) developed the Functional Test Guides, which outline standard procedures for functional testing of various building systems [12].

Figure 4 illustrates the general process for functional testing, described below.

1. **Convene:** Ensure that you have a complete testing team, all of whom are aware of their roles and responsibilities on the project. Make sure there is a responsible party for each building system you need to test (you may elect to use the same team for all of the testing).
2. **Prepare**: Make sure you are prepared to conduct the functional tests. This includes verifying that the control system is functioning, all engineering reports are collected, and any construction punchlist items for those systems to be tested have been addressed.
3. **Set up**: Make sure you have the sensors you need for conducting the functional tests. Ensure that the sensors correspond to your planned tests. For instance, if you will be testing your boiler, place temperature sensors in the hot water supply and return, as well as throughout the hot water bridge. Verify also that these sensors are located throughout the hot water loop, but not in locations subject to erratic operation (for example, in pipe bends).
4. **Check**: Once sensors are calibrated and placed, run a spot check to verify that sensors are properly placed and calibrated
5. **Recheck**: Run a second spot check to verify that prerequisites from step two are complete.
6. **Test**: When you are satisfied that your setup is calibrated, perform functional tests. Sample test procedures are available at www.peci.org/ftguide/ftct/testdir.htm (Accessed October 2013)

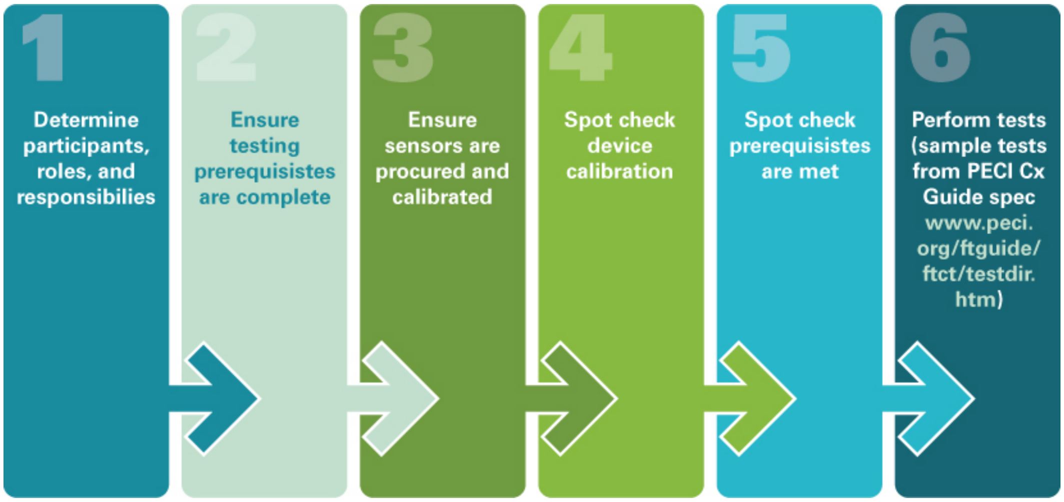

Figure 4. Flowchart describing the functional testing process

Once the equipment itself is tested (Steps 1-6 are complete), you will need to complete a functional test of the sequence of operations (i.e., after completing Step 6, begin again at Step 1 in Figure 4). You will likely need to test the control sequence multiple times to ensure that it responds to various conditions as expected. PECI suggests "working with the design team to develop [a control] sequence [of operations] allows the commissioning provider to clearly document the design intent of the system. The detailed sequence is essential for a systems manual and serves as a firm basis for the control system programming. In retro-commissioning applications, taking the time to develop this sort of information based on existing project documents, reviewing program codes, and observing system performance via functional testing and trending provides excellent documentation of how the system is currently functioning" [12].

1.2.1 Why Perform Functional Testing?

Functional testing is required to ensure that building systems operate according to their design intent [12]. Commissioning agents, therefore, must understand design intent for each system they intend to test. Where possible, the design intent should be documented, to keep a record of this intent beyond the commissioning process. For instance, the technical specification for the building systems may document design intent, and should be kept with the building drawings. In many cases, this documentation will not exist explicitly; rather, commissioning agents may need to assess design intent from drawings and narratives of the building systems. Once design intent is determined, it should be documented for future calibration and commissioning efforts. Lawrence Berkeley National Laboratory's Design Intent Tool [7] offers a methodology for doing this.

At this point, functional testing may begin. It will offer an opportunity (and perhaps the only opportunity) to evaluate system performance and compare it to the intended performance. In their online resource, Portland Energy Conservation, Inc. (PECI) [12] warns commissioning agents that issues uncovered during functional testing may not be well received by building owners, managers, or contractors, and provides suggestions for strategies to present these issues constructively.

1.2.2 Hands-On Versus Hands-Off Testing

Commissioning agents may opt to perform tests themselves (hands-on tests), or to specify a testing procedure for someone else to implement (hands-off tests). Each method has its advantages, and commissioning agents should evaluate both, based on the building system being tested and the complexity of the test. For startup of a system, having a commissioning agent present is almost always a benefit. The commissioning agent can provide an additional (and often fresh!) perspective, and can help implement the test procedures, which are more likely to be complex and complicated the first time they are run.

When commissioning agents perform tests themselves they should document how the system was found, any changes they made, and how the system was left [12]. If a commissioning agent decides to provide a testing specification rather than perform a hands-on test, the agent must ensure that the procedure is clearly written, to facilitate successful testing. Moreover, the agent should clearly identify which data should be collected and the means for documentation (for example, "collect 15-minute temperature readings from the chilled water loop in a specific spreadsheet").

1.2.3 When Should You Perform Functional Testing?

Functional testing may be performed at the time of equipment fabrication in the factory. However, even if equipment arrives factory-tested, you should test it in your building. Functional testing may begin as soon as building systems are installed and the prerequisite requirements, calibrations, and documentation (Figure 4) are complete.

Perform Functional Tests in Different Seasons

Functional testing is most effective when it tests building systems in various modes of operation. In most climates, the HVAC systems operate differently in the summer than they do in the winter. Each element of these HVAC systems should be tested in "summer" and "winter" mode, to verify performance in each. For instance, the chillers, which may be used exclusively for cooling, should be tested in the summer to ensure they are achieving the intended cooling; but they should also be tested in the winter to ensure they are not running unnecessarily during the winter months. Similarly, air handlers, boilers, condensers, and pumping systems should be tested in various seasonal modes. If possible, it is best to test these systems in different seasons rather than simulating a "winter" mode during the summer or vice versa.

Testing during the actual conditions allows the commissioning agent to "catch" any errors that may not show up in the simulated season but will be apparent in actual conditions (for example, chillers turning on due to overheating the building, which may not be seen in "winter" mode, but seen in winter). If testing in different seasons is not an option, simulated "winter" and "summer" modes should be run for enough time to give the commissioning agent confidence in the system's performance.

1.2.4 Where Can You Find a Sample Functional Test Procedure?

Portland Energy Conservation, Inc. [12] provides sample designs for testing various building systems (Accessed October 2013) as well as checklists for functional testing (Accessed October 2013).

1.3 Monitoring-Based Commissioning for Existing Buildings

Monitoring-based commissioning (MBCx) combines ongoing monitoring of the energy consumed by building systems with standard existing building commissioning (EBCx) practices with the aim of providing substantial, persistent, energy savings [10, 11]. Figure 5 displays three primary streams of energy savings you can receive from MBCx, in addition to those received from traditional EBCx.

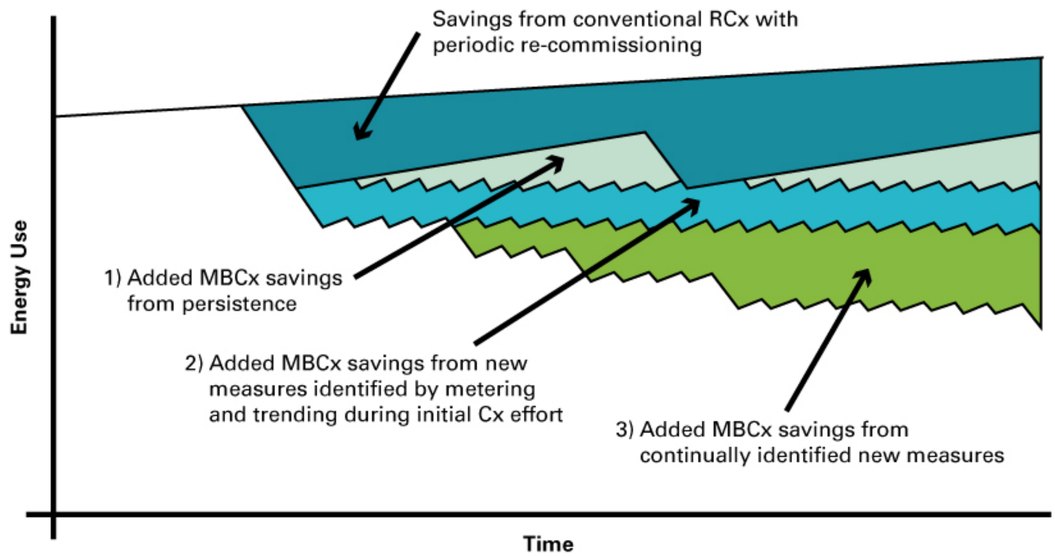

Figure 5. MBCx streams of additional energy savings relative to EBCx (Figure 1 in [1])

If the performance of your building is degrading, but you do not know why, MBCx can help you PIC (Persist, Identify, and Continue) efficiency, as described below.

1. **Persist:** Monitoring-based commissioning helps ensure that the initial savings you gained from your EBCx will persist and be optimized, thanks to early identification of deficiencies through metering and trending. Several studies have shown that EBCx savings can degrade without an explicit effort to monitor and maintain them [8]. Monitoring enables you to determine which actions to take to ensure]your building performs as designed.

2. **Identify:** Monitoring-based commissioning can help you identify savings from measures by metering and trending during the initial commissioning effort. These measures are unlikely to be found from EBCx alone [13]. For instance, monitoring allows you to determine whether control sequences that work in the summer also work in the winter, whether an equipment schedule is good for the long term, and how effective measures identified in functional testing are over time.

3. **Continue:** Monitoring-based commissioning helps you continually identify new measures. Because it is continuous, MBCx can identify new problems that emerge after

the initial existing building commissioning investigation stage, such as equipment cycling and excessive simultaneous heating and cooling. It can also identify whether or not savings from EBCx projects persist.

Figure 5 also illustrates the synergistic effect of MBCx: savings from the Persist, Identify, and Continue process combine to deliver overall savings and ensure that design performance is not only maintained, but also improved.

1.3.1 Evaluating Potential and Completed Projects

Benchmarking plays a critical role in evaluating potential and completed projects in an MBCx effort:

- **Project screening:** System-level benchmarking can help you determine which systems are performing poorly, and therefore most in need of existing building commissioning.
- **Post-completion evaluation:** Benchmarking post-completion can help you assess your savings and thus allow you to determine your commissioning project's cost-effectiveness.

Benchmarking

The appropriate benchmark for your building can vary, depending on your goals. The benchmark can be past performance and energy use trends of the subject building, performance of similar buildings, designed performance, or something else. New tools (for example, http://energyiq.lbl.gov) and methods are emerging to support the growing interest in benchmarking. The screening process for prioritizing potential projects relies heavily on benchmarking. By comparing metrics to benchmark, MBCx project prioritization and decisions can be made based on performance.

Metrics

Table 1 lists the metrics proposed by Mills and Mathew [3] and their application for proposal screening and post-completion evaluation. The metrics are not bound or limited to this list alone, but the more metrics there are available, the more clues you will have to screen projects.

Evaluation

Once you have gathered data for these metrics, PIC projects are based on which is the worst metric relative to benchmark. Which projects are most suitable depends on factors such as building type, primary building use, and size. Detailed performance monitoring supports optimal commissioning. Identifying where potential projects reside in your building can help reduce the time the vendors require to assess your building, thereby saving you money.

Table 1: Benchmarking metrics for MBCx proposal screening and post-completion evaluation (Table 2 in Mills and Mathew [3])

Metrics	Proposal screening	Post-complete evaluation
Baseline		
Source energy kBtu/sf-yr	✓	
Electricity kWh/sf-yr	✓	
Peak elec W/sf-yr	✓	
Fuel kBtu/sf-yr	✓	
Historical vs. revised[1] Elec kWh/sf-yr		✓
Historical vs. revised[1] Peak kWh/sf-yr		✓
Historical vs. revised[1] Fuel kWh/sf-yr		✓
Savings		
Electricity %, kWh/sf-yr	✓	✓
Bldg Elec %, kWh/sf-yr	✓	
Peak Elec %, kWh/sf-yr	✓	✓
Bldg Peak%, kWh/sf-yr	✓	
Fuel %, kBtu/sf-y	✓	✓
Bldg Fuel %, kBtu/sf-y	✓	
Chilled water %	✓	✓
Hot water/steam %	✓	✓
Total source %, kBtu/sf-y	✓	✓
Total site %, kBtu/sf-y	✓	✓
Total energy cost savings $/sf-y	✓	✓
# Deficiencies		✓
# Measure		✓
Proposed vs. reported Elec kWh/sf-y		✓
Proposed vs. reported Peak W/sf-y		✓
Proposed vs. reported Fuel kBtu/sf-y		✓
Implementation Cost		
Simple payback (yrs)	✓	✓
Project cost $/sf	✓	
Metering cost (% of total)		✓

[1]"Revised" refers to the baseline after the installation of any metering equipment

1.3.2 Quality Assurance (QA) Checklist for Data Requirements

This section discusses the data required to assess your energy performance prior to and after completion of an MBCx project. Data can be collected by an energy information system, an energy management system, or from building meters, and Table 2 can help focus your data collection. To ensure that the metrics you are using to assess your energy performance are accurate, you need to collect accurate data for a sustained amount of time. The more data there are, the more accurate your assessments can be.

Table 2 presents a quality assurance (QA) Checklist that itemizes both the data you should collect (Data Item(s)), as well as reality checks for that data (QA Check(s)). The Data Item(s) column can refer to meter readings, setpoints, or building information found in drawings, narratives, or other materials. If you have a large portfolio of buildings, the QA check can be automated within your energy management system. Many of the QA checks require that metrics be calculated from the reported data; this also can be automated within your energy management system.

Table 2. Simple quality assurance checks for MBCx project data

Data Item(s)	QA Check(s)
All descriptive fields (free-form text)	☐ Ensure that the text is in the appropriate field.
Building Area	☐ Is it reasonable (within 10%)?
	☐ Calculate the difference between the proposal and final report. If there is a difference, is it explained? (This is generally only an issue if there were additions to or demolitions from the building)
Building electricity: baseline and post-retrofit	☐ Ensure a non-zero value.
	☐ Calculate building kWh/gsf. Is it reasonable?
	☐ Calculate % savings. Is the magnitude reasonable based on the ECM description?
Building on-peak electricity: baseline and post-retrofit	☐ Ensure a non-zero value.
	☐ Calculate ratio of on-peak to total. Is it reasonable?
	☐ Calculate % savings. Is the magnitude reasonable based on the EBCx description?
Building natural gas: baseline and post-retrofit	☐ Ensure a non-zero value if the building is served by natural gas, and vice versa.
	☐ Calculate building Btu/gsf. Is it reasonable?
	☐ Calculate % savings. Is the magnitude reasonable based on the EBCx description?
Central plant steam/hot water: baseline and post-retrofit	☐ Ensure a non-zero value if the building is served by central plant steam/hot water, and vice versa
	☐ Calculate steam/hot water Btu/gsf. Is it reasonable?
	☐ Calculate % savings. Is the magnitude reasonable based on the EBCx description?
Central plant chilled water: baseline and post-retrofit	☐ Ensure a non-zero value if the building is served by central plant chilled water, and vice versa
	☐ Calculate chilled water ton-hr/gsf. Is it reasonable?
	☐ Calculate % savings. Is the magnitude reasonable based on the ECM description?
Max 15 min. demand: baseline and post-retrofit	☐ Ensure a non-zero value
	☐ Calculate W/sf. Is it reasonable?

Table 2. (continued): Simple QA checks for MBCx project data

Data Item(s)	QA Check(s)
Central plant electricity savings	☐ Ensure a non-zero value if the building is served by central plant chilled water that chills water with an electric chiller
	☐ Calculate implied efficiency (kW/ton) for electric chillers. Is it reasonable? (Between 0.5 and 2.0 kW/ton)
Central plant natural gas saving	☐ If non-zero, ensure that the building is served by central plant steam/hot water or gas-driven chillers
	☐ Calculate implied efficiency (Btu output / Btu input) for boilers. Is it reasonable? (Between 50%–98%)
Central plant natural gas savings	☐ If non-zero, ensure that the building is served by central plant steam/hot water or gas-driven chillers
	☐ Calculate implied efficiency (Btu output / Btu input) for boilers. Is it reasonable? (Between 50%–98%)
Metering and monitoring costs: Contracted out and in-house	☐ Ensure that one or both fields are nonzero, and that the zero value indicates no cost (and that there are no missing data)
	☐ Calculate total metering $/gsf. Is it reasonable?
Baseline and Cx costs: Contracted out and in-house	☐ Ensure that one or both fields are nonzero, and that the zero value indicates no cost (and that there are no missing data)
	☐ Calculate total baseline and Cx $/gsf. Is it reasonable?

Note: kWh = kilowatt-hour, gsf = gross square feet, ECM = energy conservation measure, Btu = British thermal units, W = watts, sf = square foot

1.3.3 Identifying Buildings Appropriate for MBCx in a Large Portfolio

When it comes to metering, targeting sites with high-energy use intensity is a reliable way to maximize the absolute level of savings across a portfolio of buildings. You should use benchmarking to check whether the baseline energy performance for a given building is reasonable with respect to similar buildings either in your portfolio or outside of it.

Percentage Savings, Total savings, and Cost-effectiveness

Note that in terms of costs, payback, and energy savings (as a percentage reduction in whole-building energy consumption), buildings with a lower energy use intensity may prove more cost-effective, even though they may save less energy in an absolute sense. For instance, if your portfolio includes labs and office buildings, you may achieve a greater total energy savings (in kBtu) through MBCx of the laboratory than through MBCx of the office. However, you may save only 5% of the whole-building energy consumption in the laboratory, while saving 15% of the whole-building energy consumption in the office building. Depending on your goals, different projects may seem most advantageous. You can use benchmarking to screen projects, identify the most promising ones, and thereby achieve your own energy goals within your own cost and payback constraints throughout your portfolio.

Metering

Sites that are thinly metered may have high potential for energy savings but may also require particularly high investments in new metering, depending on what data you need to collect. For sites that have chilled water, hot water, and/or steam distribution systems, the significant costs for adding building-level metering ("Btu meters") for these energy streams are higher than those for metering stand-alone buildings. Steam or hot water metering can be more expensive than gas metering, and chilled water metering is an added expense over electricity metering. However, note that short-term metering and data-logging can be relatively inexpensive: many pieces of HVAC equipment have power meters installed and there are cost-effective strap-on sensors that can help reduce the costs of monitoring system performance. So, even if energy metering is cost prohibitive, there may be more cost-effective monitoring options.

If you have a large portfolio, consider these buildings as good candidates for MBCx:

- **Buildings with engineered systems.** If your building includes chillers, boilers, air handlers, a controls system, or some combination thereof, monitoring infrastructure is likely already in place (at least in part), so monitoring will be less expensive than in buildings without these systems.
- **Metered buildings or buildings with metered equipment**. If your building is already being metered, then monitoring is an easy, inexpensive next step.
- **Recently updated buildings.** Monitoring is important to ensure the design performance of your newly renovated building or equipment. An outdated building may require extensive EBCx before investing in MBCx.
- **Buildings without scheduling control.** Large savings have been found in buildings with manual scheduling control when switching to an automated scheduling control, which can then continue to be used as part of MBCx.
- **Buildings that are occupied on a regular schedule.** It is easier to implement Persist-Identify-Continue measures for a building that is occupied on a regular schedule, since loads should ideally follow the same schedule, and load abnormalities should stand out. For example, if your building is only occupied from 8 a.m. to 5 p.m. and monitoring reveals day-high loads from 5 a.m. to 10 p.m., then your building could be powering on and off inefficiently.

1.4 Guide to Existing building commissioning Resources

This section provides a comprehensive, though not exhaustive, list of existing building commissioning resources for building owners, managers, and designers. Table 3 gives an overview of organizations and websites that provide existing building commissioning resources. Table 4 lists individual resources in more detail.

The resources in this guide are divided into six types:

1. **Guidelines, Protocols, and Standards** outline existing building commissioning processes and provide high-level suggestions for implementing existing building commissioning projects.

2. **EBCx Toolkits** provide specific information and often include checklists and documents that you can use in your own EBCx projects.
3. **EBCx specifications and Request for Proposal (RFP) templates for owners** provide sample documents for soliciting a commissioning team and specifying a commissioning project.
4. **Training resources** list training opportunities for building owners, designers, and commissioning agents.
5. **Best Practices Guides** share successful commissioning project strategies.
6. **Case Studies** provide reference cases for building owners, designers, and commissioning agents.

Note that some existing building commissioning resources only cover a specific phase of the commissioning process. Make sure you select the resources that focus on the correct scope and needs of your project.

Table 3: Sources of existing building commissioning information. See Table 4 for more detail.

Organization	Website	Guidelines, Protocols, and Standards	RCx Toolkits	RCx Specs, RFP templates for owners	Training	Best Practices Guides	Case Studies
Building Owners and Managers Association (BOMA)	www.boma.org				X		X
Lawrence Berkeley National Laboratory Commissioning	cx.lbl.gov			X	X	X	X
Portland Energy Conservation, Inc.	www.peci.org	X	X				X
California Energy Commission	energy.ca.gov	X					X
California Commissioning Collaborative	www.cacx.org	X	X	X		X	X
International Facilities Managers Association (IFMA)	www.ifma.org				X	X	X
Institute of Real Estate Management (IREM)	www.irem.org					X	X
American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)	www.ashrae.com	X	X	X	X	X	X
U.S. Green Building Council (USGBC)	www.usgbc.org	X				X	
Building Commissioning Association (BCA)	www.bcxa.org	X	X	X		X	X
Energy Center of Wisconsin (ECW)	www.ecw.org				X	X	X

Table 4: Description of existing building commissioning resources

Resource Type	Resources[1]	Resource Description
EBCx Guidelines, Protocols, and Standards	A Existing building commissioning Guide for Building Owners *(PECI)*	This guide is intended for use by owners or building managers to better understand the impact of the existing building commissioning process and communicate internally to others about issues, benefits, and the need for staff involvement. It also serves as a reference to help owners ensure persistence of energy savings.
	California Commissioning Guide: Existing Buildings (California Commissioning Collaborative)	This guide provides an overview of the existing building commissioning process and discusses the benefits and costs of providing EBCx services in existing commercial buildings. It is very similar to the PECI guide above.
	Cost-Effective Commissioning for Existing and Low Energy Buildings (PECI)	This report addresses the costs and benefits of building commissioning for new and exisiting buildings. It describes the Cx process and potential building performance issues that may be uncovered during the Cx process.
	The Building Commissioning Handbook, Second Edition (Heinz and Casault)	This book (available for purchase) discusses meeting a Cx project schedule and budget, Cx for building quality, and Cx for energy efficiency.
	A Practical Guide for Commissioning Exisiting Buildings (Hassl and Sharp)	One chapter of this report is devoted to EBCx programming; the bulk of the report deals with planning for EBCx.
	Building Commissioning, The Key to Quality Assurance (U.S. DOE)	This guide is designed to help building owners and retrofit project managers understand and successfully oversee the Cx process. Provides a good overview of the process.
	Total Builiding Commissioning Guideline (National Institute of Buildling Sciences)	PowerPoint describing NIBS's Building Cx guideline, a precursor to the ASHRAE Cx guideline. This presentation provides a high-level outline of Cx and its benefits.
	The Commissioning Process (ASHRAE Guideline 0-2005)	The procedures, methods, and documentation requirements in this brief guideline describe each phase of the project delivery and the associated commissioning processes, from pre-design through occupancy and operation, but does not discuss specific elements, assemblies, or systems. The guideline proposes a set of standard Cx procedures.

	Principles of Building Commissioning (ASHRAE)	An all-inclusive, practical guide to the application of the principles of commissioning. The book clarifies the underlying philosophy of commissioning: the way, what, when, and who of this process.

Table 4. (continued): Description of existing building commissioning resources

Resource Type	Resources[1]	Resource Description
EBCx toolkits	ASHRAE Commissioning Process Management Professional Certification	This certification helps building owners, developers, standards writing agencies, and others assess the capability of individuals to manage the whole building commissioning process.
	Building Optimization Analysis Tool (PECI)	This is an Excel® spreadsheet-based tool designed to streamline and standardize the energy savings calculation process for engineering service providers working under the EBCx programs for five California utilities.
	EBCx Toolkit (California Commissioning Collaborative)	This website provides templates for documents required in the EBCx process.
	Building Commissioning Association Resource Center	This website provides templates for documents required in the EBCx process. NOTE: Login required
	California Commissioning Collaborative Existing Building Commissioning Toolkit: Spreadsheet Tools	Spreadsheet tools for EBCx of pumping and fan systems.
	Building Performance Tracking Guide (forthcoming from PECI)	This PowerPoint describes the California Public Interest Energy Research Program's planned Building Performance Tracking Guide. The planned guide emphasizes the need for better measurement in buildings to track energy use and support persistance. It also describes a future fault detection and diagnosis use of these building measurements.
	Commissioning Assistant (Energy Design Resource)™	This website helps design teams determine probable cost and potential scope for Cx based on user-provided building information.
EBCx specifications and RFP templates for owners	Building Commissioning Primer (Whole Building Design Guide)	This website provides a high-level view of the Cx process for building owners and managers.
	How to Select a EBCx Provider (California Commissioning Collaborative)	This website walks building owners through qualifications to look for in EBCx providers, a list of providers, and relevant certification programs.

Table 4. (continued): Description of existing building commissioning resources

Resource Type	Resources[1]	Resource Description
Training	ASHRAE Learning Institute: The Commissioning Process in New and Existing Buildings	A training program for Cx and EBCx providers, with a strong emphasis on existing buildings.
	ASHRAE Learning Institute: The Commissioning Process and Guideline 0	This course targets building owners, facility managers, design engineers, building designers, architects, equipment manufacturers, and others interested in the commissioning process, as outlined in Guideline 0. The course focuses on process intent, activities, and deliverables.
	University of Wisconsin - Madison Commissioning and Existing building commissioning Courses	Training programs provide in-depth training for specific aspects of the Cx or EBCx process.
Best Practices Guide	Energy Design Resources	This website offers articles on daylighting, HVAC, envelope, and lighting design and operations.
	Functional Testing and EBCx: An Overview of Best Practices and Available Resources (PECI)	This article discusses functional performance testing and its relationship to existing building commissioning (EBCx).
Case Studies	California Commissioning Collaborative's Commissioning Case Studies	This website lists many Cx case studies for a variety of climate zones and building types.
[1] Excludes academic research papers and journal articles		

2 Monitoring Building Performance with an Energy Information System (EIS)

This chapter offers a technology introduction for owners and managers with little or no experience in permanent approaches to performance monitoring. It is a first-look primer that emphasizes key concepts (Chapter 3 provides more detail for advanced users). This chapter identifies the distinctions among commercial performance monitoring solutions, and contains an expanded discussion of energy information systems, including: business models and common architectures, a market characterization, technology usage considerations, and pointers to additional resources.

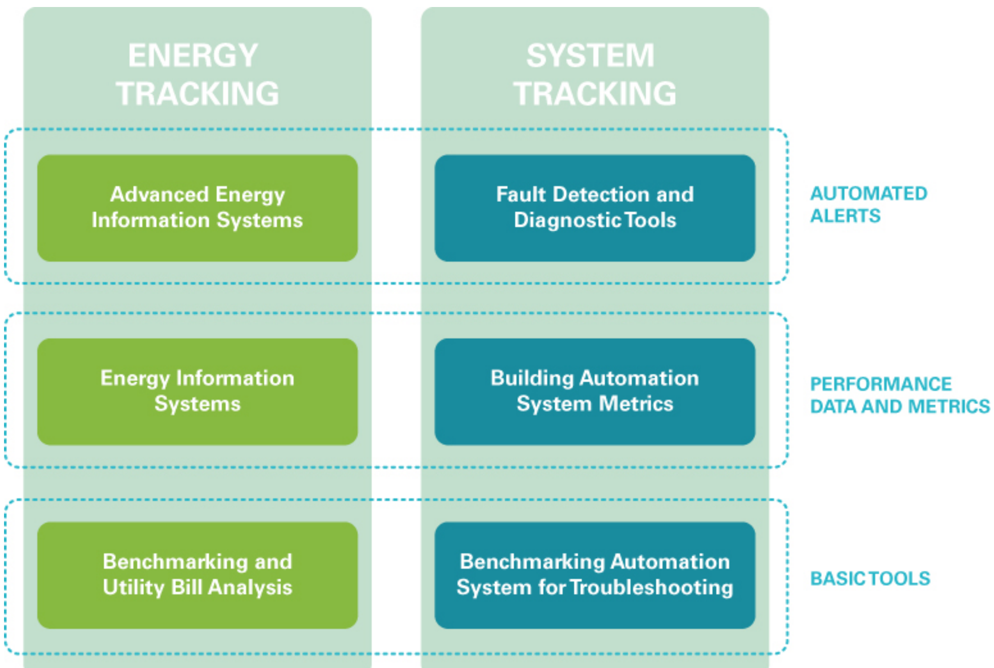

Figure 6. Six types of performance monitoring tools (Figure 6 in [14])

2.1 Energy Performance Monitoring

Successful energy monitoring requires both the technology to monitor energy consumption as well as a process to review the data. We focus here on the technology aspect of energy. Specifically, this section should help you select a technology to monitor energy consumption in commercial buildings. If you are more interested in how to use your EIS, please see the subsection entitled EIS Implementation and Use.

The term *performance monitoring tools* refers to a diverse set of hardware and software systems that work together to provide information about energy consumption. Primarily, these tools are divided into two categories: those with an energy focus and those with a system focus [14]. As Figure 6 shows, these tools can be further segmented according to their level of sophistication. The tools listed at the lowest level, Benchmarking and Utility Bill Analysis and Benchmarking Automation System for Troubleshooting, are the least sophisticated, while Advanced Energy Information Systems and Fault Detection and Diagnostic Tools are the most sophisticated. Of course, the boundaries between tools may be fuzzy, capabilities might be shared across types, and they could be segmented differently. This particular framework was developed specifically for existing building commissioning.

2.2 What is an Energy Information System?

Energy information systems (EIS) are the software, data acquisition hardware, and communication systems used to analyze and display building energy performance [15]. These systems combine visualization, reporting, and analysis, and at a minimum integrate whole-building electric data collected at 15-minute, hourly, or daily intervals. Depending on the level of monitoring at the site, and the particular implementation, EIS may also integrate gas, as well as submetered system and electric loads. Advanced implementations may integrate building automation system (BAS) points, subscription weather feeds, and perhaps utility demand response information. Energy information systems offer a range of analysis and visualization capabilities (which will be discussed in the section below on tracking and benchmarking tools), forming a continuum of basic to advanced solutions.

The remainder of this chapter focuses on EIS, since they are best suited to support continuous, in-house monitoring and reporting of building and portfolio energy performance. Energy information systems combine the features of building automation systems, fault detection and diagnosis (FDD) tools, and tracking and benchmarking tools. Building automation systems (BAS) control HVAC systems and are generally used to control indoor temperature, ventilation, and humidity conditions. FDD tools use system-level time series data from the BAS to identify faults and possibly isolate their causes. Tracking and benchmarking tools allow you to compare your building performance, based on utility bill data, to other buildings or to your previous performance. To best monitor performance, use EIS, rather than BAS, FDD, and benchmarking tools individually.

2.2.1 What Are Building Automation Systems?

The primary purpose of BAS is to control HVAC systems and to maintain indoor temperature, ventilation, and humidity conditions. These systems can be configured to trend time series data such as setpoints, temperatures, system energy, pressure, and flow, and can therefore be used to troubleshoot system-level performance. Modern systems may offer significant storage, visualization, and reporting capabilities, and therefore can be programmed to track key performance metrics related to both energy management and routine operations.

2.2.2 What Are Fault Detection and Diagnostic Tools?

Fault detection and diagnostic (FDD) software tools continuously apply algorithms to system-level time series data to identify (detect) faults and may isolate (diagnose) their cause. The algorithms are usually dedicated to HVAC systems and often applicable to specific system types. These tools tend to rely heavily on data points integrated from the BAS, in some cases supplementing these with additional sensors and/or meters, depending on the application.

2.2.3 What Are Tracking and Benchmarking Tools?

Utility tracking and benchmarking tools have a whole-building or portfolio focus, and are used with monthly utility billing data. They support analyses such as energy performance relative to similar buildings and up/down tracking of consumption and peak demand. They may normalize data to account for weather, building size, and other factors influencing energy use. These tools are useful at the beginning stages of an EBCx project, to understand the initial performance levels and efficiency opportunities at a first-pass level.

2.3 EIS Business Models and Common Architectures

Energy information systems offer an array of service options, varying degrees of customization or configuration, and alternatives for pricing, data, and IT management. They are most commonly offered through an Application Service Provider (ASP) with no hardware, or with optional hardware based on client needs. Application service providers offer solutions in which the ASP owns, operates, and maintains the software and servers for web-based applications that are usually priced according to monthly/annual fees. Beyond these general trends, the following considerations may be used to understand specific offerings:

- **Who houses, owns, and maintains the data acquisition, servers, and software application?** Common ownership models include:
  - ASP/Software as a Service, where the EIS provider or a third party maintains the data acquisition, servers, and software applications and provides reports; and
  - traditional ownership, where you as a building owner own and operate your EIS.
- **Are services bundled or optional?** Services may encompass data quality and IT management, interface customization, and in some cases, data analysis and reporting.
- **What are the hardware requirements?** Does the offering include specific or proprietary hardware, no hardware, or hardware only as necessary for the client's objectives? For example, turnkey solutions are fully packaged to include pre-installed software, hardware, and accessories in a single "bundle."
- **What are the payment options?** These may be per site, per user, billing frequency, subscription or one-time fee, or other agreement,

Energy information systems business models are diverse, but the solutions follow a common architecture, as illustrated in Figure 7. A data acquisition system collects on-site interval meter and sensor data, which is then communicated to a central database. Less commonly, data points collected from the BAS or an Energy Management Control System (EMCS) may also be integrated into the EIS database. An EMCS is essentially a BAS with greater controls capability. It can control HVAC systems, as a BAS can, but it may also control lighting, business processes, lab and data center equipment, and other energy uses in a building. A graphical user interface (GUI) enables users to access the system's reporting, visualization, and analysis functionality.

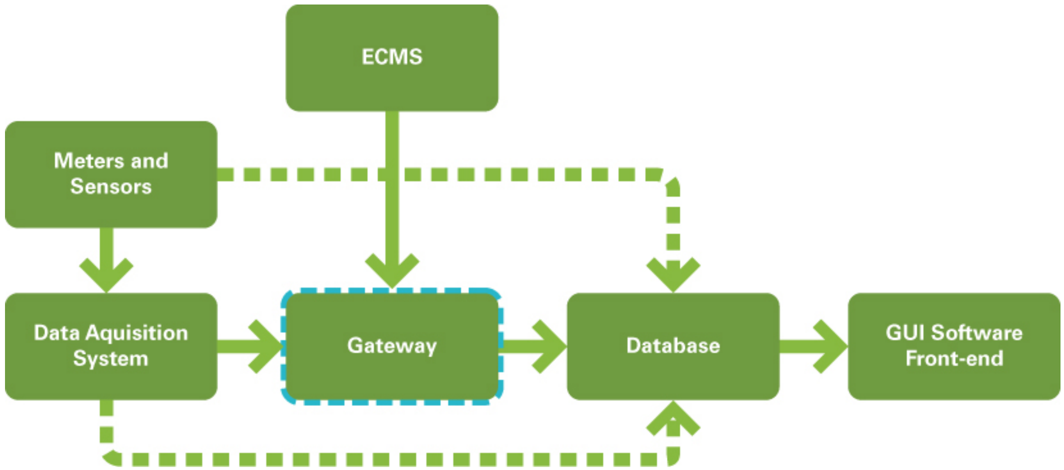

Figure 7. EIS architectures

2.4 What Capabilities Do EIS Have?

The functionality that appears across the landscape of today's EIS solutions can be characterized according to a framework of 8 general categories, with 5 to 10 features each. The 6 categories presented in Figure 8 are those that are the most relevant to EBCx, along with selected features, and key findings and from a 2009 review of the state of EIS technology [16]. Figure 8 displays capabilities of energy information systems and key features and findings related to these capabilities, to acquaint you with what is currently available on the market. Note that in addition to the capabilities, features, and findings cataloged in Figure 8, EIS may also be characterized based on their browser support, purchase and subscription costs, intended user(s) and number of users, and their applicable market segments.

Key distinguishing factors that differentiate one offering from another are flexibility and the robustness of the underlying baseline and related energy analysis methods. Flexibility relates to whether calculation plotting and reporting parameters can be altered by the end user at the front-end GUI or whether these changes require programming.

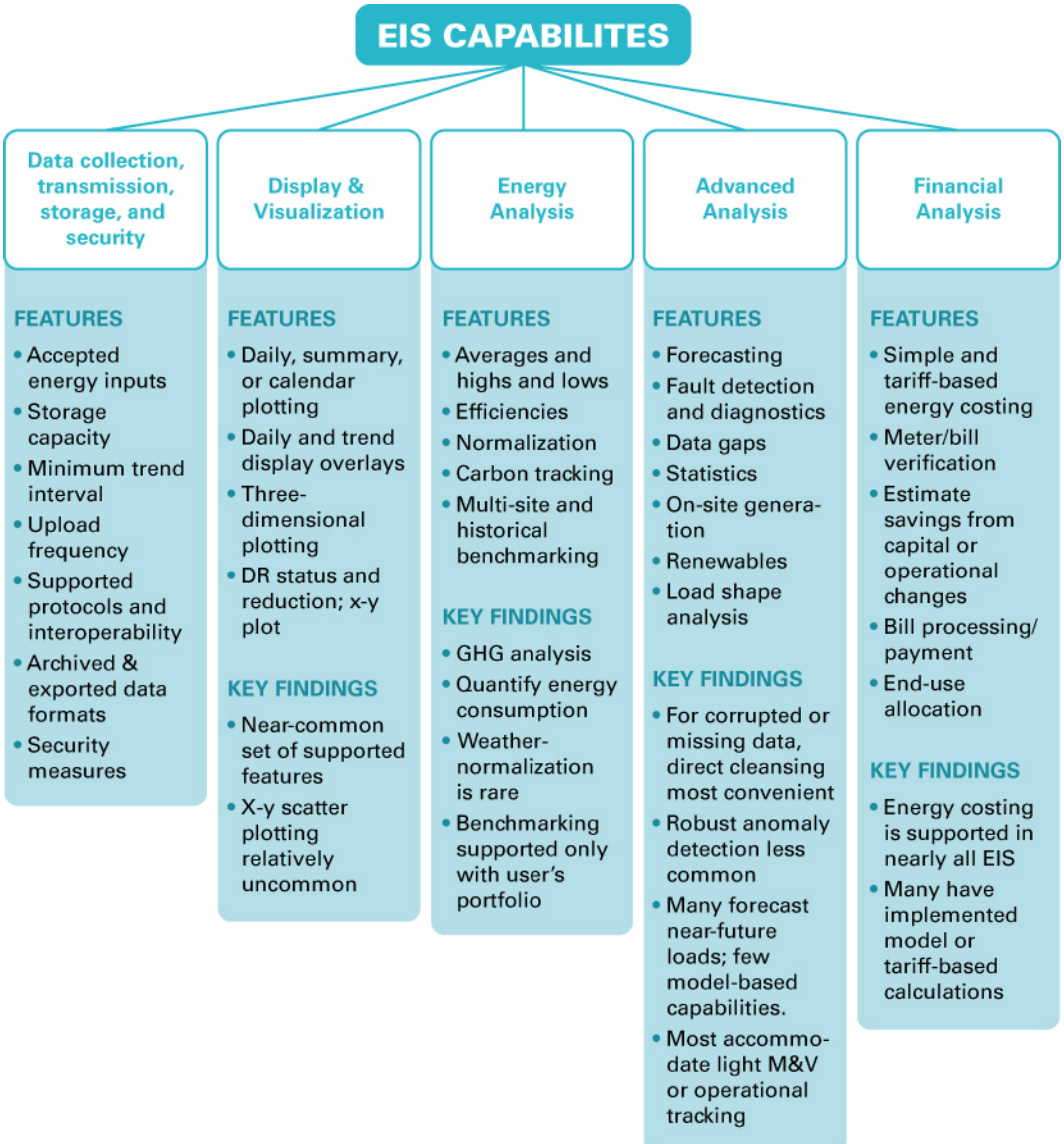

Figure 8. EIS capabilities

2.5 Critical Aspects of EIS Selection

Energy information systems are not yet widely adopted throughout the commercial building stock because many building owners are not aware of the diversity of solutions that exist or their associated energy savings. EIS are becoming more feasible for small- to medium-sized commercial buildings due to the increasing number of vendors (bringing more competitive costs), advanced metering initiatives, utility pilots, and a growth in services dedicated to data analysis and monitoring.

Answering the following three questions will help you determine if EIS are a viable option for your building or portfolio.

1. **What is the availability and expertise of staff to review the data?** EIS require dedicated staff, with either a sufficient knowledge of which areas need to be addressed or the resources to both identify excessive use and resolve the root cause of that waste.
2. **What data and energy performance information is available?** Costs increase with the level of metering, as does the ability to generate actionable information and diagnose performance. Significant factors are the sufficiency of existing interval meters and submeters, and whether BAS data can be cost-effectively integrated.
3. **What is currently known about site or portfolio energy performance?** Energy information systems should be pursued for existing buildings only after the owner has derived as much insight as possible from monthly utility bills, smart meter portals or other utility and benchmarking tools, and any available BAS trending data.

If you determine that EIS are a viable option, the selection process begins. Remember that bigger is not always better. The EIS that supports the most features is not necessarily the most powerful solution for a given building. Identification of the most suitable EIS for a commercial implementation must begin with a purposeful consideration of the site's operational and energy goals. Once the immediate and longer-term needs are understood, high-priority features and functionality can help narrow the options, and the most appropriate technology can be selected. For example, a business with a history of energy awareness that has implemented a phased, multi-year energy plan is likely to have different needs than a business that has just begun to consider building energy performance.

2.6 EIS Implementation and Use

The existence of data or performance monitoring software does not guarantee shared knowledge or actionable information. Energy information systems require continuous user engagement for maximum impact, and users themselves are most commonly employees of an organization for which energy is not the primary business. First-adopters have shown several aspects of technology implementation and use that are critical in achieving and maintaining significant energy savings. Portland Energy Conservation, Inc. (PECI) explain this in terms of people, processes, and performance [14], and we adopt this categorization here.

People: Successful EIS implementations typically have a strong internal technology champion who supports and encourages regular use of the tool throughout the organization. At the facilities and operational level, staff roles and responsibilities should be aligned with use of the tool, and sufficient time allocated to permit a thorough data review. Management can encourage proactive use of the data by 1) including EIS analyses in regular operational and energy management tasks, and 2) taking leadership in instilling a performance-based, data-driven approach to operations. Similarly, executive staff can incorporate EIS information into regularly viewed reports and hold the organization accountable for energy performance. Enterprise-wide EIS use and shared energy awareness is key for maximum impact.

Process: At one end of the spectrum, EIS are exclusively used by in-house staff, with services leveraged primarily during installation and configuration, and for long-term hosting and data management services. At the other end, EIS may be proprietary tools used by energy service providers, who report waste issues and efficiency opportunities to the building owner. The division of roles and responsibilities between in-house staff and service providers can significantly affect how well the technology is leveraged.

Performance: If you have particularly sophisticated performance tracking metrics and benchmark models, you may need more extensive customization of the EIS. Often, supplementary modeling or computational tools are used in conjunction with EIS data. This is to be expected, as no single tool can meet all of an organization's needs, particularly as the use of data becomes more advanced and matures over time.

Conversely, the most advanced energy consumption normalization and forecasting methods that are applied in EIS algorithms may not be universally understood across users and technology champions. Despite this lack of transparency in calculations, these methods can be used to great success, especially if at least one user within an organization has a strong conceptual understanding of the calculations. To attain maximum energy savings, users should be trained in, and encouraged to use, all of the features of the EIS.

Reliable, high-quality data are critical to EIS usability. Embedded data correction and validation routines are important; however, robustness varies significantly across offerings. Data quality becomes increasingly challenging as monitoring is extended beyond whole-building electric metering, into other energy sources such as steam or chilled water, and into zone or system/equipment submetering.

2.7 Resources to Help You Monitor Building Performance

Capehart, B., and L. Capehart, editors 2007. *Web based enterprise energy and building automation systems*. Allen, P., and D. Green, associate editors. Fairmont Press, Inc.

Capehart, B., and L. Capehart, editors. 2005. *Web based energy information and control systems: Case studies and applications*. Fairmont Press, Inc.

Granderson, J., M. A. Piette, G. Ghatikar, and P. Price. 2009. Building Energy Information Systems: State of the Technology and User Case Studies. LBNL-2899E (http://gaia.lbl.gov/btech/papers/2899.pdf). November. (Accessed October 2013)

Hooke, J. H., B. J. Landry, and D. Hart. 2003. *Energy Management Information Systems. Achieving Improved Energy Efficiency. A handbook for managers, engineers and operational staff*. Published by the Office of Energy Efficiency of Natural Resources Canada.

Lawrence Berkeley National Laboratory. 2010. Energy Information Systems. Building Energy Information Systems and Performance Monitoring Tools. Research website. http://eis.lbl.gov. November. (Accessed October 2013)

Motegi, N., M. A. Piette, S. Kinney, and K. Herter. 2003. Web-based Energy Information Systems for Energy Management and Demand Response in Commercial Buildings. LBNL-52510 (http://eis.lbl.gov/pubs/lbnl-52510.pdf). April. (Accessed October 2013)

Portland Energy Conservation, Inc. (PECI). 2011. *The Building Performance Tracking Handbook*. California Commissioning Collaborative. Prepared by PECI for the California Energy Commission.

3 Maintaining Building Performance

This section discusses issues that can help you maintain savings from commissioning. With the exception of benchmarking and utility bill analysis, the tools presented in the previous chapter should be used continuously.

Maintaining building performance is also discussed in Chapter 2 and Section 1.3. This section expands upon the more advanced uses of EIS and FDD—the most advanced, automated energy and system tracking tools for users who regularly maintain performance but want to do more.

3.1 Why Care about Persistence of Savings?

Commissioning savings often erode over time if building and system energy performance is not continuously tracked (Figure 5 shows this phenomenon) [1]. Critical to maintaining persistent energy savings is knowing what "corrections" were made during commissioning, ensuring that they remain in place, and avoiding new problems. For example, setpoints, schedules, and other control system features are often changed and overridden if it is not clear (in good documentation) why the setpoints were chosen in the first place. Further, most commissioning energy savings are estimates. Long-term tracking is necessary to confirm that expected benefits are actually achieved, and ensure that future investments in energy savings can be made more reliably [1]. In fact, monitoring-based commissioning approaches are generally expected to deliver deeper more persistent savings than traditional approaches that do not make use of permanent metering and monitoring packages [3, 17, 18]. Although this guide focuses on energy benefits, performance tracking also has significant non-energy benefits, such as ensuring that occupant comfort and indoor environmental needs are met, and that property value and net operating income are maintained and increased [14].

3.2 How Can You Ensure Persistence with EIS?

Table 2 presents a range of analyses and tracking activities particularly relevant to persistence and ongoing monitoring-based commissioning. These activities can be streamlined or automated using an energy information system. The following analysis methods, which use varying degrees of complexity, can be used to support these activities.

Utility cost accounting and simple tracking to characterize monthly or annual changes in energy consumption. Cost accounting and tracking are usually applied at the whole-building or portfolio level, and are based on utility bills and/or interval-metered data.

Cross-sectional benchmarking. This technique involves comparing the energy performance of a building, system, or component to that of a comparable cohort. In EIS analyses, the cohort is usually the user's portfolio, although automated links to national energy benchmarking databases such as the U.S. Environmental Protection Agency's Portfolio Manger are possible.

Longitudinal benchmarking. This benchmarking compares the energy performance of one building or a portfolio to itself over time. The sophistication of the particular EIS determines if and how weather and other independent variables are handled.

Baselining. Baselining is the process of defining "standard" energy performance. Baselines may be expressed according to a variety of metrics (kWh/sf/yr, or kWh/month/hr-occupied). They may involve simply normalizing energy consumption by building area and weather or be more sophisticated models that may account for independent variables that influence energy consumption.

System operational efficiency. This technique tracks system-specific, as-operated performance metrics (such as kW/ton system efficiency vs. ton system capacity for heating and cooling systems, or kW/installed-load for lighting systems) to provide deeper understanding of operational energy performance.

Energy anomaly detection and smart alarming. Algorithms can be used to identify abnormal energy use. A common approach is to compare current use to a prediction that is based on current conditions and baseline formulas. Advanced EIS may support the ability to alert users when metered consumption surpasses a threshold relative to the prediction.

Cumulative sum. The strategy involves the use of automated algorithms to quantify the aggregate difference between metered and baseline use. Cumulative sums represent the accumulated savings over time, relative to a baseline measure of performance.

3.3 How Can You Ensure Persistence with FDD?

In contrast to energy information systems, which can automate collection of whole-building level data, system-level data, and component-level data for users to view and interpret, fault detection and diagnostic (FDD) tools target HVAC&R systems and apply algorithms to *fully automate* the identification of system-level problems. Fault detection and diagnostics is the term used to describe a set of relationships between components in an HVAC and refrigeration (HVAC&R) system and the rules that govern their interactions.

Based on previous research, developers have created algorithms that use these relationships and rules to determine and eliminate root causes of energy waste in HVAC&R systems. FDD is a complex subject that is comprehensively detailed in other sources. This section briefly summarizes resources that will help you evaluate and select FDD services, as well as additional resources for further information about FDD (even those not targeted at evaluating and selecting FDD services).

3.3.1 Distinguishing Characteristics and FDD Technical Approaches

Fault detection and diagnostic tools most commonly identify problems based on a combination of expert rules, historic trend data, and expected performance models based on manufacturer design intent [14]. An article in the *International Journal of HVAC&R Research* [19] provides a framework for categorizing the various technical approaches upon which FDD algorithms are founded, as well as a review of their relative strengths and weaknesses. The framework comprises a hierarchical classification scheme. At the highest level, FDD methods are sorted into three types: quantitative model-based, qualitative model-based, and process-history based.

- **Quantitative model-based** methods are based on physical models and processes.
- **Qualitative model-based** methods include rule-based systems and may or may not include physics first principles.
- **Process-history based** methods assume no knowledge of physical processes, and include techniques such as neural networks, regression, and other pattern recognition approaches.

Qualitative model-based methods are most commonly implemented in commercial FDD tools.

3.3.2 FDD Vendors and Offerings

The building consulting company Enovity [20] provides a characterization framework and assessment of eight FDD tools that are available and currently used in commercial buildings. The framework includes details such as:

- Reporting options
- Relative cost
- Diagnostic ability
- Applicable system levels
- Data types
- Integration and protocol specifics
- Data resolution
- Vendor type (whether the tool is offered through a BAS vendor, a non-BAS vendor, or is public source tool)

The framework and assessment is complemented with end-user interviews. Enovity [20] includes EIS with energy anomaly detection capabilities, as a variety of fault detection that relies on whole-building data to detect deviation from expected performance. This guide's discussion of FDD tools is limited to systems with fault detection methods that rely on HVAC data to detect deviations from expected performance.

3.3.3 Critical Aspects of Selection and Implementation

In *The Building Performance Tracking Handbook,* PECI [14] presents the commissioning-specific aspects of FDD tool selection. The key points are summarized below.

As with EIS, FDD tools are increasingly implemented according to an application service provider; that is, a software-as-a-service delivery model. In-house use of FDD tools is the most common, with fewer vendors offering full-service third-party analysis and reporting. FDD tools are best suited to implementations where a high degree of automation is required.

The first costs for FDD tools are higher than for other performance monitoring options, yet they can reveal performance issues of a different nature and variety than other monitoring solutions, or issues that might otherwise go entirely undetected. However, non-standard HVAC systems may require special rules and increase costs, and FDD should only be considered when there is sufficient time for system installation, configuration, troubleshooting, and training.

In spite of the name, solutions that offer true diagnostic capability are rare, and given the number of faults that modern systems can detect, it is recommended to work closely with the vendor to calibrate systems and minimize false alarms.

Finally, the most effective implementations will support a link to connect facility work order request and maintenance processes with the actionable information provided in the FDD tool.

3.4 Resources to Help You Maintain Building Performance

Enovity. 2010. Improving the Persistence of EBCx Benefits: Energy Anomaly and System Fault Detection Toolsets. Prepared by Enovity Inc., for the California Commissioning Collaborative Under Task 4.3 of Project 4: Improving the Persistence of Retro-commissioning Benefits.

Friedman, H., and M. A. Piette. 2001. *Comparative Guide to Emerging Diagnostic Tools for Large Commercial HVAC Systems*. LBNL #48629 (http://eetd.lbl.gov/BT/hpcbs/pubs/LBNL-48629.pdf). May.

Katipamula, S., and M. Brambley. 2005. "Methods for fault detection, diagnostics and prognostics for building systems – A review, Part I." *International Journal of HVAC&R Research* 11(1): 3–26.

Katipamula, S., and M. Brambley. 2005. "Methods for fault detection, diagnostics and prognostics for building systems – A review, Part II." *International Journal of HVAC&R Research* 11(2): 169–187.

Mills, E., and P. Mathew. 2009. *Monitoring-based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects*. LBNL 1972E (http://evanmills.lbl.gov/pubs/pdf/MBCx-LBNL.pdf). June. (Accessed October 2013)

Mills, E. 2009. *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions*. Report prepared for the California Energy Commission, Public Interest Energy Research. July.

Portland Energy Conservation, Inc. (PECI) 2011. *The Building Performance Tracking Handbook*. California Commissioning Collaborative. Prepared by PECI for the California Energy Commission.

4 References

1. Mills, E., *Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-gas Emmissions*, 2009, Lawrence Berkeley National Laboratory: Berkeley, CA. 65 pp.
2. ASHRAE, *ASHRAE Guideline 0-2005: The Commissioning Process*2005, Atlanta, GA: American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc.
3. Mills, E. and P.A. Mathew, *Monitoring-Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects*, 2009, Lawrence Berkeley National Laboratory: Berkeley, CA. 44 pp.
4. EVO, *International Performance Measurement and Verification Protocol: Concepts and Options for Determining Energy and Water Savings*. Vol. 1. 2010, Washington, DC: Efficiency Valuation Organization. 136 pp.
5. Haasl, T. and K. Heinemeier. *California Commissioning Guide: New Buildings*. 2006 [cited 2011 17 May]; Available from: http://www.cacx.org/resources/documents/CA_Commissioning_Guide_New.pdf. (Accessed October 2013)
6. BCA, *Best Practices in Commissioning Existing Buildings* 2008, Building Commissioining Association: Portland, OR.
7. LBNL. *Design Intent Tool*. 2006 [cited 2011 25 Oct]; Available from: http://ateam.lbl.gov/DesignIntent/home.html. (Accessed October 2013)
8. Mills, E., N. Bourassa, M. Piette, H. Friedman, T. Haasl, T. Powell, and D. Claridge. *The Cost-Effectiveness of Commissioning New and Existing Commercial Buildings: Lessons from 224 Buildings*. in *Proceedings from 2006 National Conference on Building Commissioning*. 2004. New York, NY: Portland Energy Conservation, Inc.
9. Haasl, T. and K. Heinemeier. *California Commissioning Guide: Existing Buildings*. 2006 [cited 2011 17 May]; Available from: http://www.cacx.org/resources/documents/CA_Commissioning_Guide_Existing.pdf. (Accessed October 2013)
10. Brown, K. and M. Anderson. *Monitoring-Based Commissioning: Early Results from a Portfolio of University Campus Projects*. in *Proceedings from 13th National Conference on Building Commissioning*. 2006. Portland, OR: PECI.
11. Brown, K., M. Anderson, and J. Harris. *How Monitoring-based Commissioning Contributes to Energy Efficiency for Commercial Buildings*. in *Proceedings from 2006 ACEEE Summer Study of Energy Efficiency in Buildings*. 2006. Pacific Grove, CA: American Council for an Energy-Efficient Economy.
12. PECI. *Functional Testing and Design Guides*. 2006 [cited 2011 17 May]; Available from: http://peci.org/ftguide/index.htm. (Accessed October 2013)
13. Haves, P., R. Hitchcok, K. Gillespie, K. Kinney, J. Derringer, and C. Shockman, *Performance Monitoring in Large Commercial Buildings*, 2008, California Energy Commission: Sacramento, CA.

14. PECI, *The Building Performance Tracking Handbook*, 2011, Portland Energy Conservation, Inc.: Portland, OR. 86 pp.

15. Motegi, N., M. Piette, S. Kinney, and K. Herter, *Web-based Energy Information Systems for Energy Management and Demand Response in Commercial Buildings*, 2003, Lawrence Berkeley National Laboratory: Berkeley, CA. 70 pp.

16. Granderson, J., M. Piette, G. Ghatikar, and P. Price, *Building Energy Information Systems: State of the Technology and User Case Studies*, 2009, Lawrence Berkeley National Laboratory: Berkeley, CA.

17. Granderson, J., M. Piette, and G. Ghatikar, *Building Energy Information Systems: User Case Studies* Energy Efficiency, 2010. **4**(1): p. 17-30.

18. Jump, D., M. Denny, and R. Abesamis. *Tracking the Benefits of Retro-Commissioning: M&V Results from Two Buildings*. in *Proceedings from National Conference on Building Commissioning*. 2007. Chicago, IL.

19. Katipamula, S. and M. Brambley, *Methods for fault detection, diagnostics, and prognostics for building systems -- A review, Part I*. International Journal of HVAC&R Research, 2005. **11**(1): p. 3-26.

20. Enovity, *Improving the Persistence of RCx Benefits: Energy Anomaly and System Fault Detection Toolsets*, 2010, California Commissioning Collaborative.