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Sustainability "How-to Guide" Series

Commissioning Existing Buildings

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— Jay Enck

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FOREWORD

It is no secret that a focused, well-defined sustainability strategy is beneficial to an organization's bottom line, whether it is a federal, private-sector, military or nonprofit entity. Sustainable practices are not only the right thing to do for the environment; they also benefit the communities in which they are implemented. Sustainability is the business implementation of environmental responsibility.

Sustainability is all around us. Federal, state and local governments are increasingly applying regulatory constraints on design, construction and facility operations standards. Employees expect their employers to act responsibly, and vice versa. Going green is no longer a fad or a trend, but a course of action for individuals and businesses alike – benefiting the triple bottom line of people, planet and profit.

Today's facility manager needs to be able to clearly communicate the benefits and positive economic impact of sustainability and energy-efficient practices, not only to the public, but also to the C-suite. While there is a dramatic need for each of us – and our organizations – to care for the environment, it is just as important that we convey to executives and stakeholders how these initiatives can benefit our company's financial success.

The document in your hands is the result of a partnership between the IFMA Foundation and IFMA, through its Sustainability Committee, each working to fulfill the shared goal of furthering sustainability knowledge. Conducting research like this provides both IFMA and the foundation with great insight into what each can do as an organization to assist the facility management community at large.

It is my hope that you, as a facility professional, will join us in our mission of furthering sustainable practices. This resource is a good place to start.

Tony Keane, CAE
President and CEO
International Facility Management Association

FOREWORD

IFMA Sustainability Committee (ISC)

The IFMA Sustainablitiy Committee (ISC) is charged with developing and implementing strategic and tactical sustainability initiatives. A current initiative involves working with the IFMA Foundation on the development of a series of "How-to Guides" that will help educate facility management professionals and others with similar interests in a wide variety of topics associated with sustainability and the built environment.

The general objectives of these "How-to Guides" are as follows:

1. To provide data associated with a wide range of subjects related to sustainability, energy savings and the built environment

2. To provide practical information associated with how to implement the steps being recommended

3. To present a business case and return-on-investment (ROI) analysis, wherever possible, justifying each green initiative being discussed

4. To provide information on how to sell management on the implementation of the sustainability technology under discussion

5. To provide case studies of successful examples of implementing each green initiative

6. To provide references and additional resources (e.g., Web sites, articles, glossary) where readers can go for additional information

7. To work with other associations for the purpose of sharing and promoting sustainability content

The guides are reviewed by an editorial board, an advisory board and, in most cases, by invited external reviewers. Once the guides are completed, they are distributed via the IFMA Foundation's Web site (www.ifmafoundation.org) free of charge.

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The mission of the IFMA Foundation is to promote and support scholarships, educational and research opportunities for the advancement of facility management worldwide.

Established in 1990 as a nonprofit, 501(c)(3) corporation, the IFMA Foundation is supported by the generosity of a community of individuals – IFMA members, chapters, councils, corporate sponsors and private contributors – and is proud to be an instrument of information and opportunities for the profession and its representatives.

A separate entity from IFMA, the IFMA Foundation receives no funding from annual membership dues to carry out its mission. Supported by the generosity of the FM community, the IFMA Foundation provides education, research and scholarships for the benefit of FM professionals and students. Foundation contributors share the belief that education and research improve the FM profession.

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1 EXECUTIVE SUMMARY

'Expand knowledge of the built environment, in a changing world, through scholarships, education and research'

The Vision Statement of the IFMA Foundation

Commissioning of new buildings and retro-commissioning of existing buildings are two effective strategies to reduce building energy consumption and help meet sustainability goals. Sustainability is often practically applied by using the triple bottom line: environment, economic and social concepts. Commissioning supports the three concepts of the triple bottom line. Identifying and assisting with resolving issues that degrade building performance and consume O & M staff with firefighting significantly improve energy and water efficiency and reduce costs associated with eliminating complaints. Socially, physiological and physiological perceptions of building occupants significantly impact productivity, their sense of well-being and operating costs. Occupants who are uncomfortable spend a lot of time not working at their daily mission. This has significant financial impacts on their employers and the building operators, and can also affect the value of the brick and mortar asset. Environmentally, reductions in utility consumption and deployment of trucks and staff have direct correlation to reduced environmental impact.

This How-to Guide provides practical guidance from a commissioning expert about what commissioning is and how to complete the commissioning process for a building or campus of buildings. The guide includes detailed outlines of what the commissioning professional should provide to the owner at each phase of a commissioning project and rules of thumb for commissioning costs, as well as clearly defines the roles within a commissioning project.

After introducing the topic of commissioning existing buildings, the guide contains detailed information about the commissioning process, including project selection, how to issue a request for qualifications, how to develop a current facility requirements document, guidance on how to determine the budget for commissioning services, and what deliverables the facility manager should expect to receive from the commissioning team.

The guide also includes a section about how to make the business case. Within Part 4 Making the Business Case, the guide goes beyond a discussion of the financial benefits of commissioning to include environmental and insurance benefits, and how commissioning can help to earn a greenbuilding rating, such as LEED for Existing Buildings: Operations & Maintenance.

Three case studies provide two practical examples of how existing buildings can benefit from commissioning. As the commissioning process includes many roles, the case studies section provides insight into the commissioning process from the perspective of the building owner, occupants and tenants. The case study section closes with a series of lessons learned.

The Appendices of the guide also contain a wealth of information, ranging from a list of additional resources to practical guidance on how to create a request for qualifications (RFQ) to procure commissioning services and a sample scope of work for commissioning services.

2 INTRODUCTION

2.1 The Purpose of Commissioning an Existing Building

Commissioning is the process of verifying and documenting that a facility and all of the systems within a facility are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements (ASHRAE 2005). The purposes of commissioning are to lower operating costs; help resolve occupant complaints and issues consuming operation and maintenance staff resources; and lower the environmental impacts for a building over its useful life. Commissioning can also lower construction costs and project risk in addition to lowering operating costs and environmental impact.

By definition, commissioning of an existing building that has not previously been commissioned is referred to as retro-commissioning (RCx). The commissioning of an existing building that has been previously commissioned is referred to as recommissioning.

The commissioning processes for both new and existing facilities have many of the same elements but different methodologies are applied. The commissioning process begins with the identification of the owner's objectives, criteria and end goals, called the owners project requirements (OPR) for new construction or current facility requirements (CFR) for existing buildings. If the project is a previously commissioned building with an existing OPR, the development of the CFR can begin with modification of the original OPR. If an OPR does not exist, the CFR is typically developed through a nominal group technique workshop with all stakeholders participating. The development of the CFR provides clear goals and the extent of the commissioning scope. It also serves as the foundation for the existing building commissioning effort and subsequent modifications, which can include design, construction and changes to the operation of the facility.

Facilities are constructed, renovated and modified over their useful life to meet the changing mission and needs of the owners, occupants and users. Each stakeholder group has attributes, specific criteria, objectives and goals that the facility must meet in order for their mission to be accomplished. The commissioning process begins with documenting the stakeholder's requirements. In new construction or major renovations, commissioning, when correctly implemented, begins in pre-design and continues throughout the life of the facility. For existing buildings the commissioning process can be implemented at any phase of the life of a facility. Applying the commissioning process to existing buildings provides owners and their operational teams the assistance needed to move from an average performing building and firefighting operational mode to an efficient, long-term high-performance facility where operators spend less time addressing complaints and more time maintaining the facility at peak performance.

Whether commissioning a new or existing facility, the commissioning authority (CxA) can provide a single constant thread, from the starting point of the commissioning process through the life of the facility. If correctly applied, commissioning provides owners and their operation and maintenance teams the resources to achieve and maintain high-performance facilities, as well as the facilitation of effective and efficient delivery of the facility organization's mission over the life of the facility.

The decision to commission an existing building is generally made when an owner or facility manager realizes that he/she needs to improve the asset value of one or more buildings. This decision can be made by comparing the operational cost to similar buildings using the U.S. Environmental Protection Agency ENERGY STAR Portfolio Manager. The author recommends commissioning buildings with an energy use index rating less than 75. If the building does not comply with an ENERGY STAR building type, it is recommended that the building be compared to a building of similar type. A second comparison can be based on operating costs. If the total cost of operating the building (operating costs, utilities and staffing costs) is greater or equal to the average of the operating cost per unit area (square foot or square meter) than similar building types, the building should be commissioned.

ENERGY STAR Portfolio Manager is an interactive energy management tool that can be used to benchmark energy and water consumption across an entire portfolio of buildings in a secure online environment. Whether a building is owned, managed or held for investment, Portfolio Manager can help set investment priorities, identify underperforming buildings, benchmark efficiency improvements and help the building receive recognition for improved energy performance.

The United States Environmental Protection Agency (EPA) developed ENERGY STAR Portfolio Manager to compare similar types of facilities to a national database and rate their performance. Based on building location, size, number of occupants and computers in the facility, ENERGY STAR can provide a benchmark rating. A rating of 75 indicates that the building is in the top 25 percentile of the database. Buildings benchmarking below 75 indicate the facility could benefit from being commissioned. Facilities with ratings of 75 or above can often also benefit from being commissioned, but can have a positive, cost-effective impact in improving occupant satisfaction and operational efficiency. Buildings with a high ENERGY STAR score can have good return on investment from commissioning. For more information about ENERGY STAR Portfolio Manager, see the IFMA Foundation Sustainability How-to Guide: EPA's ENERGY STAR Portfolio Manager at www.ifmafoundation.org/programs/sustain_wp.cfm.

2.2 Research Quantifying the Benefits of Commissioning

Lawrence Berkeley National Laboratory conducted a comprehensive study in 2009 of the costs and benefits of commissioning, focusing on an analysis of whole building energy savings, commissioning costs, reasons for implementing commissioning and other nonenergy impacts (Mills 2009). The projects were mainly large offices and hotels for a wide range of building sizes, 10,500 square feet (975 m^2) to 1.64 million square feet (152,400 m^2) and built between 1912 and 2005. The study found a median investigation and implementation cost of \$0.20/SF to \$0.60/SF (\$2.15/m^2 to \$6.46/m^2) (US dollars) for existing building commissioning projects, savings of 8 to 31 percent (median 16 percent), and project simple payback periods of 0.5 to 2.5 years (median 1.1 years).

The nine measures with the highest savings per unit area are shown in Table 1. These measures tend to be either more labor intensive or have higher capital costs and are more expensive to implement. Some of these high savings measures require newer or more sophisticated control systems. For such reasons, there were only a few projects that implemented these nine measures in utility-sponsored existing building commissioning programs. However, where applicable, the less frequently applied top-savings measures result in significant savings.

Table 1: Most frequently implemented commissioning strategies and strategies with top savings per unit area

Most frequently implemented	Top savings per unit area
Optimize airside economizer	Tune or upgrade controls
Reduce equipment runtime	Add or optimize water supply temperature reset
Reduce or reset duct static pressure setpoint	Relocate or shield temperature sensor
Revise control sequence	Add or optimize boiler lockout
Add or optimize supply air temperature reset	Add small A/C unit
Add variable frequency drive to pump	Add variable frequency drive to chiller
Reduce lighting schedule	Add or optimize chiller staging
Replace, repair or calibrate sensor	Lower or reset variable air volume box airflow
Add or optimize condenser water supply temperature reset	Optimize waterside economizer
Add or optimize chilled water supply temperature reset	
Add or optimize start/stop	
Add variable frequency drive to fan	

A small number of measures were implemented the most frequently (Table 1). These 13 measures, out of 44 measure-types tracked, comprise 75 percent of the total number of measures implemented, which was a surprisingly consistent finding across building type, age and climate zone (Effinger and Friedman 2010).

A study by Evan Mills of Lawrence Berkeley National Laboratory of 643 buildings over the last decade found that "commissioning is arguably the single-most cost-effective strategy for reducing energy, costs and greenhouse gas emissions in buildings today" (Mills 2009).

The author finds that over 70 percent of the existing building stock is consuming more energy than necessary. Similar results are illustrated through research conducted at Texas A&M University by David E. Claridge, who concluded that "energy in buildings can be reduced by 10 to 40 percent by improving operational strategies in buildings" (Claridge et al 1996). Studies from the U.S. National Renewable Energy Laboratory (NREL) found "energy consumption was 25 percent to 70 percent lower than code … in the high performance buildings studied" (NREL 2006).

3 DETAILED FINDINGS

Most well-operated and well-maintained facilities that have been commissioned degrade in performance by 10 to 15 percent between years two and three after the commissioning process is performed. This degradation is the result of multiple factors including heat exchanger fouling, sensor drift, reduction in drive efficiency and component malfunctioning. Changes that result in performance degradation typically go unnoticed.

In this section, the three primary reasons for commissioning existing buildings are reviewed and a detailed approach to the process and its deliverables is fully discussed.

3.1 Commissioning Process for Existing Buildings

3.1.1 Project Selection

There are many reasons to commission an existing facility, including lowering operating costs and assisting to resolve occupant complaints and operational issues. Lowering operating costs helps to:

- Improve building energy and water efficiency
- Reduce or eliminate reactive operations practices
- More efficiently utilize operations and maintenance resources

Assisting to resolve occupant complaints and operational issues consuming significant operations and maintenance staff availability:

- Lowers environmental impacts over the life of the building
- Helps maintain peak performance to control operating costs
- Helps to earn a LEED for Existing Buildings: Operation & Maintenance (LEED-EBOM) rating
- Supports the implementation of a measurement and verification plan

If the facility manager wants to lower operating costs there are several means of determining the level of savings possible for the facility:

- Compare building energy consumption against heating and cooling degree days (see textbox "Degree Days")
- Use ENERGY STAR Portfolio Manager as a benchmarking tool
- Compare energy usage to other similar facilities through data from peers or published benchmarking reports
- Use of the American Society of Heating, Ventilating and Air-Conditioning Engineers (ASHRAE) Level II or III energy audit process

DEGREE DAYS

Degree days are a simple method to calculate the amount of energy needed to heat or cool a facility for a specific geographic location considering the severity of weather (Capehart et al. 2000).

Degree days can be calculated using this equation (McQuiston et al 2000):

$$\text{Degree Days} = \frac{(t - t_a)\,N}{24}$$

Where:

t = 65°F (18°C)
t_a = average temperature
N = number of hours t_a is computed

3.1.2 Commissioning to Lower Operating Costs

Comparison of energy consumption against heating and cooling degree days for the location of the building typically will show seasonal changes in energy consumption. For example, a building with electric cooling and gas heating should have an electrical profile that increases during cooling months and decreases during heating months. Similarly, gas consumption should decrease as outside temperature increases and increase as outside temperature decreases. A relatively flat profile of electrical or gas consumption would suggest the facility could benefit from being commissioned. Figure 1 shows electrical energy consumption for a makeup air unit for an apartment complex in Atlanta, Ga., that provides outside air to the building.

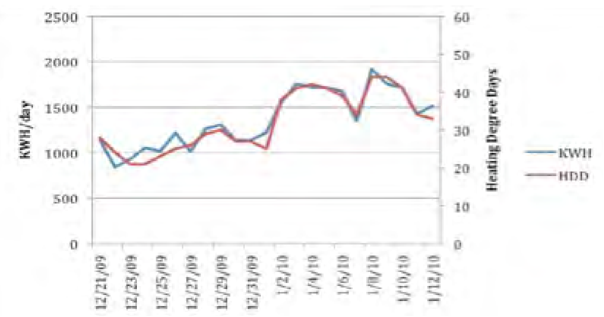


Figure 1: Energy usage (kWh) and heating degree days (HDD) for rooftop air handler providing outside air for an apartment building

According to the 2009 IFMA *Operations and Maintenance Benchmarks Research Report #32*, the average utility cost of commercial buildings in North America is \$2.56/GSF (\$27.56/m^2) (US dollars) (IFMA 2009). Utility costs for office headquarters buildings are \$2.39/GSF (\$25.72/m^2) (US dollars), and \$2.63/GSF (\$28.31/m^2) (US dollars) for regional and branch offices (IFMA 2009). Poorly performing buildings often have energy costs twice or three times this amount, and many buildings are using more energy than they require. Some estimate that, on average, 30 percent of energy consumed by buildings is wasted. Any building experiencing exceptionally high energy costs without adequate explanation is a prime candidate for commissioning.

Not all facility types can receive a score using ENERGY STAR Portfolio Manager. Special facilities, such as athletic training facilities, manufacturing or processing facilities, and other special purpose facilities, are not currently in the ENERGY STAR database. The option for facility managers for these types of facilities requires comparison between other like facilities or utilization of an ASHRAE Level II or Level III energy audit to evaluate the opportunities for improving performance to reduce utility usage. Comparing similar facilities requires an evaluation of many variables, including but not limited to gross area (square footage or square meters), facility processes, climate zone and other factors. A qualified commissioning authority can assist with the assessment of the facility and provide an estimated return on investment for the recommended improvements to the facility.

An ASHRAE Level I or Level II energy audit can quickly identify opportunities to improve a facility's performance and define an initial commissioning scope. An ASHRAE Level III energy audit provides estimated cost benefit of energy conservation measures (ECM), prioritization of ECMs in accordance with an owner's objectives and goals, and implementation scope for commissioning of an existing facility. Retro-commissioning or recommissioning provides an assessment of how the building is operating, which is very different from energy audits that look at energy conservation measures. The commissioning process identifies facility improvement measures (FIM) to maximize the building performance using the existing infrastructure.

ASHRAE ENERGY AUDIT LEVELS

Although the three levels of ASHRAE energy audits do not have sharp boundaries to define what is included at each level, each level generally represents a different level of services provided and tasks completed. Items and tasks commonly included at each level are summarized below (ASHRAE 2004).

Level I: Walk-through analysis

- Assessment of energy cost and efficiency through analysis of utility bills and a brief on-site survey of the building
- Identification of low-cost and no-cost energy savings measures

Level II: Energy survey and analysis

- More detailed building survey and energy analysis than Level I
- Energy analysis includes a breakdown of energy use, such as the calculation of the energy utilization index (EUI) for each energy source
- Identification of all practical energy efficiency measures that meet the owner's constraints and economic criteria
- Discussion of changes in operations and maintenance procedures to improve operational efficiency
- May include a list of capital-intensive improvements that require more detailed data collection and engineering analysis

Level III: Detailed analysis of capital-intensive modification

- Best used for capital-intensive projects identified during a Level II audit
- Analysis includes detailed field data gathering and engineering analysis
- Detailed project cost and savings calculations, accurate to support major capital investment decisions

3.1.3 Commissioning to Resolve Occupant Complaints or Operational Issues

Many building operators do not have the essential information they need to efficiently operate a facility. Doing the best they can with the information available, operators make operational changes, such as overriding automatic controls to minimize an occupant complaint. Additionally, the resources operators have to assess the reason for the occupant complaint are usually very minimal, and they usually have little time to assess the problem in depth. Permanent solutions to resolve the original complaint take time and often special expertise. Thus, finding the root-cause of a problem is often put at the bottom of the pile once the occupant complaint has been resolved. To assist with these challenges, a qualified commissioning authority can:

- Quickly assess the facility and assist the facility manager in identifying issues that compromise facility performance.
- Develop a systems manual that provides current and updated sequences of operation, a location to store institutional knowledge and system modifications, current facility requirements and detailed HVAC system diagrams.
- Identify energy conservation measures and complete cost-benefit analysis to lower operating and repair costs.
- Suggest energy conservation measures for a design and construction team to implement, and verify that systems perform as intended by acting as the owner's advocate.
- Develop and implement a monitoring-based commissioning program that provides real-time feedback to operators to keep their facility operating at peak performance.

The systems manual should include information about location of all control points, isolation and control valves/dampers, and air/water flow rates for each system in its entirety.

3.1.4 Lowering Environmental Impacts for the Life of the Building

The measure of a building's environmental and social impact and economic performance is a function of how efficiently the facility is operated to minimize operating costs while meeting the specific needs of the occupants in execution of their daily mission. The commissioning process is an effective method to implement and achieve a sustainable high-performing building. A qualified commissioning authority can assist by correlating the facility usage and occupant needs to align with the occupant's mission, and document sustainability goals within the CFR to guide current and future construction, retrofit, and operations and maintenance activities.

The commissioning authority can also help to verify achievement of these goals and identify potential issues that could affect goal achievement at early stages of implementation. Commissioning is a collaborative process that guides implementation, sets measurable benchmarks and helps ensure success.

Commissioning also includes ongoing monitoring of the facility. Ongoing monitoring-based commissioning helps owners and their operations teams maintain optimal performance over the life of the building. Utilizing the full commissioning process provides a continuous thread of institutional knowledge to assist operators in permanently lowering environmental impacts and avoiding falling into the firefighting mode of operation. The commissioning process, including monitoring-based ongoing commissioning and the use of sustainable and green principles, makes the process holistic.

However, in the author's experience and in accordance with industry guidelines, maximum benefit from the commissioning process is best achieved when the commissioning authority is the first professional selected before the start of a project, whether it is new construction, major renovation or building tuneup. Using the commissioning process from birth of the idea for a facility until demolition and ultimate rebirth will provide the owner a higher return on investment and environmental benefits that can be leveraged at time of sale, to attract and keep tenants, or to better meet occupant needs to effectively and efficiently deliver their mission.

3.1.5 Issuing a Request for Qualifications (RFQ) for Commissioning Authority (CxA)

A request for qualifications (RFQ), issued by the owner, gives general information on the size, age, mission of the facility, time frame for selection of qualified firms, anticipated start and completion dates, and project budget. A sample RFQ is contained in Appendix D.

Similar to finding any service provider, an owner should ask for qualifications, experience, references and examples of work products from all potential candidates. For existing building projects, example work products should include:

- A summary of the firm's commissioning philosophy
- Description of the existing building commissioning process
- A current facility requirements (CFR) document, including commissioning scope
- Example of the investigation methodology used to assess the existing facility, including analysis and prioritization of recommendations, an implementation plan and the results achieved
- References from clients that have several years of experience with the commissioning authority.

3.1.6 Developing the Current Facility Requirements (CFR) Document

Many owners in the US have the common goal of becoming LEED certified or ENERGY STAR labeled to distinguish themselves from their competition or to lower operating costs and environmental impacts for an improved bottom line. Other common reasons for certification and/or labeling include improving their image in the marketplace, addressing long-term facility operational issues, and increasing effectiveness of operations and maintenance staff. While these goals are common, it is essential to the success of a commissioning project to meet or exceed the owner's expectations – to do this requires documenting the owner's objectives, criteria and goals.

The first step in the existing building commissioning process is to gain a full understanding from the owner, the occupants and/or users and other stakeholders of what the current facility requirements are, including sustainability goals. These goals can include improvements in energy and water efficiency, occupant satisfaction and important social aspects the facility needs to meet. Since most owners or their design firms do not understand the CFR development process, one of the advantages of a qualified commissioning authority (CxA) is the knowledge to develop an effective CFR that guides the process and provides benchmarks to evaluate success.

As user needs and activities typically change over time, it is beneficial to the owner and building operators to have the changing needs of the facility and its occupants documented as they affect building operations. The CFR, similar to the owner's project requirements (OPR), is a living document that is modified to record changes to high-level operational goals over time and communicate how the facility must operate to support the facility occupants and users' daily mission, including building operational needs. The goals for existing buildings can include specific occupant needs, increased energy efficiency, or environmental goals that blend with facility use to maximize both occupant productivity and lower environmental impacts.

The CFR documents owner, occupant and user objectives, criteria and goals that form the foundation for achieving success. A correctly developed CFR clearly defines the requirements for the existing building commissioning process. An effective CFR is developed before the project team and CxA conduct an assessment of the facility to evaluate its performance. The CFR aids in the development of recommendations, strategies and concepts that form the basis for modifications to the facility. The CFR also provides guidance for both minor modifications, which typically occur immediately, as well as major modifications that require design and construction teams to implement. The CFR defines the tools, information and training that are necessary for the building operator's success in meeting and maintaining defined performance goals. See section 3.3.1 for specific content that should be included in the CFR document.

3.1.7 Developing the Commissioning Scope

The CFR defines the objectives and goals of the project as well as the focus of the commissioning effort. The initial commissioning scope should be limited to the development of the CFR, where the commissioning authority (CxA) brings the stakeholders together and facilitates the documentation and flow of information. While developing the CFR, the commissioning scope will be defined.

The breadth and depth of the initial commissioning investigation is directly related to meeting the owner's requirements defined by the CFR. Selection and prioritization of energy conservation measures (ECM), facility improvement measures, water efficiency measures (WEM), occupant needs to effectively and efficiently deliver their mission, occupant productivity goals and corporate image are all dependent on what the owner and other stakeholders have communicated during the development of the CFR.

With the contents of the CFR, the selected CxA can develop the commissioning scope of work for the investigation phase and obtain owner approval of the suggested effort. Based on the approved scope of work for the investigation phase of the retro-commissioning effort, the CxA then develops the project commissioning plan.

3.1.8 Creating a Commissioning Plan

Once the current facility requirements are defined, the CxA assembles a team that will execute the existing building commissioning process. The commissioning plan defines the role and responsibilities of each team member, as well as a schedule of activities that meets the commissioning budget and scope of work elected by the owner. The initial commissioning plan focuses on the facility assessment phase, which typically is a combination of an operational assessment, identification of modifications needed to meet the CFR, and a combination of ASHRAE Level II and III energy audit procedures. If earning a green building certification or label is a goal defined in the CFR, the commissioning plan will have an accompanying certification plan. The certification plan, like the commissioning plan, defines the team's roles and responsibilities and the schedule of activities necessary to achieve the certification goal.

See section 3.3.2 for specific content contained in the commissioning plan deliverable.

3.1.9 Data Collection, Analysis and Findings

Assessment of a facility begins with data collection, which includes obtaining, if available:

- Utility bills for the three most recent years
- Operation and maintenance manuals
- As-built plans and specifications or construction documents
- Work order history

After the commissioning authority reviews available documentation and becomes familiar with the facility, the CxA team must obtain intimate operational knowledge of the facility. Discussions with the building operators about their specific knowledge and experiences with the facility provide the CxA team with valuable information to understand challenges unique to the building and the operations team. This information also helps with the in-depth investigation of the building operation and utility usage. The CxA team conducts observations and field measurements, installs data loggers and collects information from the building automation systems (if installed), as well as climatology data.

The data collected is analyzed, and conclusions and a cost-benefit analysis are developed. Based on the CFR, recommendations are developed and prioritized for the owner's review and selection. A preliminary report is generally provided for review by the owner, and is used to facilitate a meeting between the CxA and the owner to review results and discuss what the next steps will be. After meeting with the owner, the CxA develops a final report addressing any additional comments and concerns provided by the owner. Depending on findings, the CxA may recommend that further monitoring and testing be performed on equipment to better understand causes of performance issues before the final report is issued.

Recommended actions generally fall into one of four categories:

- Changes in sequences of operation
- Operations and maintenance support
- Repair of equipment
- Capital improvements

Changes in sequences of operation include identifying incorrect or nonoptimized controls sequences for building equipment. Nonoptimized controls sequences are generally one of the most common and easily repaired causes of building failure resulting in occupant discomfort and increased energy bills.

Operation and maintenance support includes helping to document building operations information and provide support for building operators. Over the life of a building much of the documentation needed for successful operations and maintenance typically vanishes, leaving operational staff to do the best they can to operate the building with the information available. This is especially problematic because staff changes generally occur over the life of the building, making it difficult to ensure that all staff has received adequate training and has the knowledge needed to efficiently and effectively operate and maintain the building systems. It is vital that staff have the tools and training necessary for optimum building performance to meet occupant and user satisfaction. The CxA can assist with the development of operational plans and system documentation, and system monitoring accompanied with training to achieve and maintain peak performance, as well as help building operators move from a reactive mode of operations to an efficient and reliability-centered maintenance mode of operations.

Equipment naturally degrades over time, reducing efficiency. Thus, the equipment should be repaired. Minor defects commonly overlooked or ignored can often be repaired with minimal effort, greatly increasing equipment effectiveness and lifespan.

Capital improvements are the most extensive and expensive recommendations provided through the commissioning process and involve the overhaul and/or replacement of major building systems.

The findings developed during the analysis phase identify issues and opportunities for the owner's consideration and selection. Based on the selected items, the CFR may need to be updated to refine the owner's objectives, criteria and goals. Implementation phase objectives, criteria and goals must be clearly communicated in the CFR as it provides the benchmark the CxA will use in verifying that the owner's requirements are being met. The commissioning scope for the implementation phase is also adjusted to include the updated owner's objectives, criteria, goals and budget.

While every owner's interpretation of "low cost" is different, it is very common to first implement the low-cost items before proceeding with the implementation of higher-cost recommendations to accommodate the owner's capital improvement plans. Recommendations with the highest return on investment are typically implemented first. Depending on the priorities and schedule of the owner, full implementation can take years.

At the end of the assessment phase, the CxA reviews the assessment report with the stakeholders and receives guidance from the owner about which recommendations to pursue. Based on this guidance, the commissioning and certification plans are updated for the implementation phase of the project.

3.1.10 Initial Delivery of Findings

The initial commissioning report should contain the findings prioritized in accordance with the CFR. These findings and how they were arrived at must be clearly communicated in the initial report in sufficient detail that the owner and stakeholders can understand:

- Methodology used to obtain data and its analysis
- Discoveries from the assessment effort
- Methodology used to prioritize the opportunities to improve the facility
- How the recommendations address the objectives, criteria and goals outlined in the CFR
- Potential impact of suggested recommendations
- Cost and benefit for each of the recommendations
- Impacts of implementing each recommendation

See section 3.3.5 Initial Commissioning Report for what should be contained in the deliverable.

3.1.11 Initial Implementation

After the completion of the assessment phase, the CxA works with the owner to implement the selected recommendations. Typically immediate action is taken to complete changes to controls sequences, make minor repairs to equipment, and provide operations and maintenance staff training, as these are commonly classified as low- and no-cost items. The CxA oversees and documents implementation, witnesses training, and witnesses retesting of the equipment and systems after the changes have been made to verify their functionality and performance.

The initial commissioning report also contains the conceptual modifications and costs associated with the higher-cost recommendations. These higher-cost items typically require the addition of design and construction team members. The concepts, objectives and criteria, and goals are added to the CFR, which the design and construction team will use to guide the development of construction documents that will be used by the construction team. Similar to the commissioning for new construction or major renovation, the CxA updates the commissioning plan to include the new team members by defining their roles and responsibilities in the commissioning process.

During the design process, the CxA reviews the design submissions relative to the requirements set forth in the CFR. The CxA identifies deviations, concerns and opportunities for the project team to consider and resolves issues before solicitation for construction. In addition, the CxA develops commissioning specifications that define the requirements for the constructors and the specific commissioning activities during construction that will be included on the schedule. The specifi-

Table 2: Project team roles and responsibilities

Project team role	Responsibilities
Design team	• Follow CFR to develop design solutions • Develop basis of design documentation 　◦ Basis of design cut sheets 　◦ List of assumptions 　◦ Supporting calculations • Complete design commissioning checklist • Participate in commissioning design reviews • Integrate commissioning requirements into project specifications • Participate in commissioning meetings • Participate in O&M training
Construction team	• Follow CFR • Complete construction commissioning checklist • Participate in construction phase commissioning meetings • Test commissioned systems • Schedule commissioning activities within construction work schedule • Implement and manage quality control process • Provide owner O&M training
Commissioning authority team	• Manage and implement commissioning process • Refine team roles and responsibilities 　◦ Owner 　◦ Designers 　◦ Contractor • Verify design, construction and operational requirements to meet owner's project or current facility requirements 　◦ Develop design and construction checklists 　◦ Develop test procedures 　◦ Direct testing and document results • Log and track issues and concerns until resolved • Document benefits of the commissioning process • Assess O&M staff training requirements and develop training criteria to be delivered by design and construction teams • Verify O&M training • Generate systems manual, which is to include 　◦ Location of O&M documents 　◦ Owner's project requirements 　◦ Basis of design 　◦ Recommended operational record-keeping procedures with sample forms 　◦ Ongoing optimization guidance 　◦ Updated controls documentation, sequences of operation, final set points and control logic 　◦ System schematics 　◦ Commissioning report • Optimize building performance during occupancy 　◦ Perform monitoring and analysis 　◦ Document corrective actions
Owner's team	• Participate in commissioning process 　◦ Develop owner's project requirements or current facility requirement (CFR) document 　◦ Determine with commissioning authority commissioning scope of work based on project requirements 　◦ Include commissioning requirements and deliverables in design scope of work 　◦ Encourage participation in the commissioning process 　◦ Review and understand commissioning reports 　◦ Participate in commissioning meetings 　◦ Provide direction to the team as needed

cations also define the role of the CxA for testing, training of O&M staff and O&M documentation.

When modifications require design and construction, the commissioning plan and implementation of commissioning process begins by defining project team roles and responsibilities in the commissioning process (Table 2).

3.1.12 Final Report Delivery

The final commissioning report includes the essence of the initial report and updates based on the detailed activities completed as part of the retro-commissioning process, along with significant findings from those activities and the disposition of any issues identified during the course of a project. The final report also contains an action plan defining parties responsible for resolving any outstanding issues along with a schedule for correction.

Depending on the scope of the modifications, the final report is commonly a culmination of the retro-commissioning progress reports provided on a regular basis to keep the owner and implementation team up-to-date during the course of the project. These reports are intended to keep the owner and stakeholders informed of issues requiring a collaborative effort to resolve. The progress reports form the basis for the final report provided at the end of modifications, which is known as final completion.

See section 3.3.6 Final Commissioning Report for specific details of what is included in the final retro-commissioning report.

3.1.13 Systems Manual

The systems manual is a commissioning deliverable that contains the institutional knowledge the building operators need to efficiently operate the facility. It is also the repository for operational staff to document system changes and the logic associated with those changes. It contains the essential information needed by operators to understand the following about the facility:

- Operations
- System limitations
- System modifications made by the operator and the associated reasoning for the change(s)
- Original owner or current facility requirements and design parameters
- How systems are assembled and system control points

At the completion of the construction phase, marked by successful completion of acceptance testing, a systems manual is provided to the owner and building operators.

Without the information the systems manual provides, operators do not have complete information to operate the facility, which can result in occupant complaints or demands for HVAC systems to be replaced and/or high energy consumption, increasing the total cost of ownership.

Systems manuals are especially important because as building operators retire, change companies or move to other facilities, their knowledge about the operation of the facility goes with them. This leaves the new operator to make their own assessment about how the systems should be operated. The objectives of the systems manual are to:

- Provide future operating staff the information needed to understand and optimally operate the commissioned systems
- Focuses on operating, rather than maintaining, the equipment, particularly the interactions between equipment
- Include salient operating information not available elsewhere

The systems manual should be:

- Brief and to the point
- Accessible, using page numbering, bold headings, table of contents and dividers
- In its own binder
- Easy to understand

Operators typically do not have the information they need to operate the facility efficiently. For example, the operator may have a set of construction drawings and know the system components, but is not aware of how the designer intended the facility to operate or the interaction between systems. This is why the systems manual contains the sequences of operation, optimum set points, seasonal dynamics and information about system component interaction.

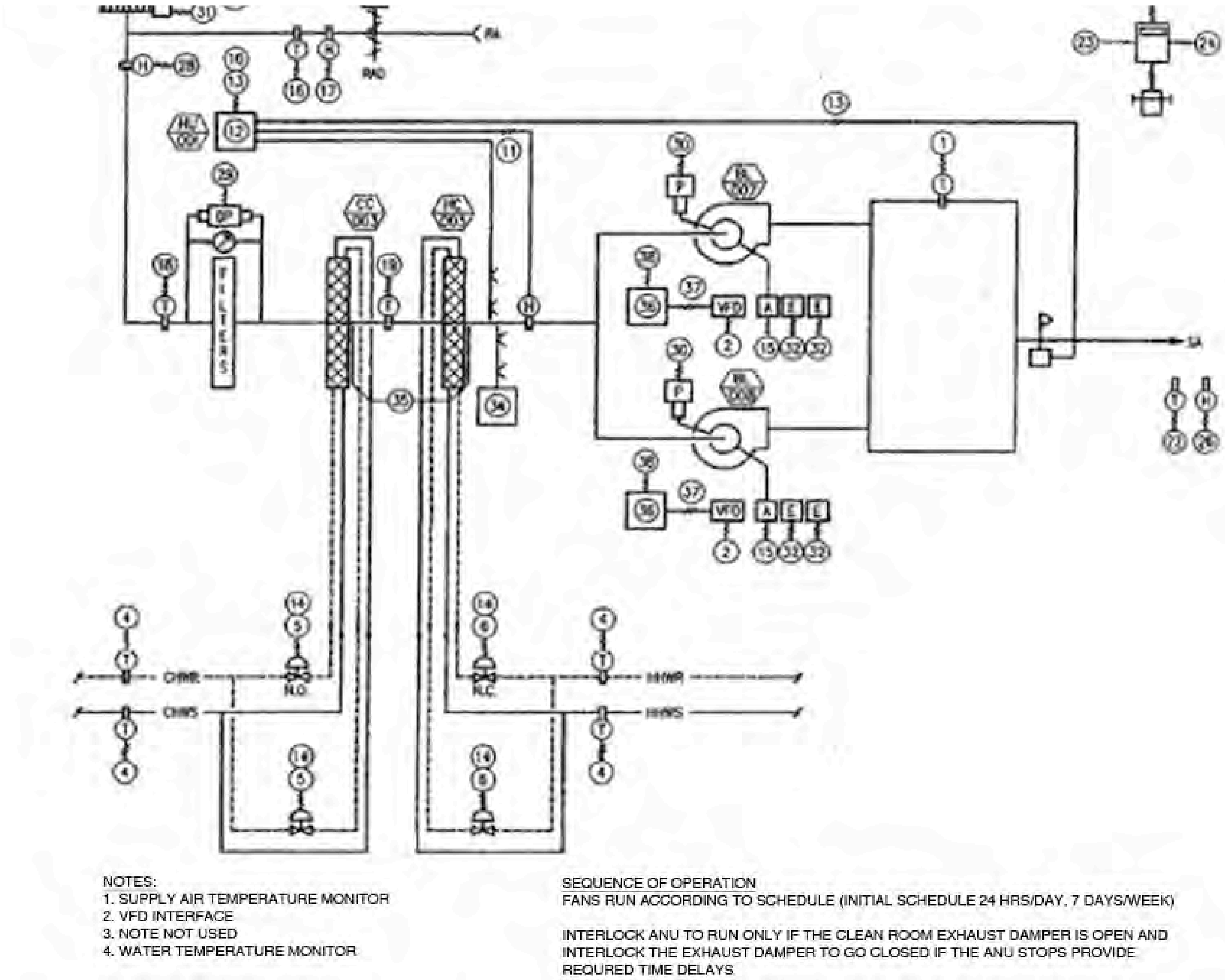


Figure 2: Example of a design document used for construction that is missing information

The systems manual should contain the following:

- Executive summary
- Location of
    - Operation and maintenance manuals
    - As-built drawings
    - Submittals
    - Shop drawings
    - Construction documents
- Most current CFR
- Final basis of design
- Final commissioning report
- Facility operating procedures for normal, abnormal and emergency conditions
- Recommended operational record-keeping procedures
- Optimization recommendations
- System diagrams
- Frequency of calibration for sensors, meters, flow stations and other devices
- Monitoring plan to maintain building performance

As noted above, the systems manual combines information from the design documents with as-built drawings, control submittals and test reports. Figure 2 provides an example of a typical design document used for construction. It is a diagrammatic depiction of the systems and the various components, controls and other components. In many cases, the sequence of operation is very general and does not indicate how the system components are to work together to achieve the designer's intent and does not contain the critical information needed by the operator to troubleshoot a problem. The diagram in Figure 2 is also an example of what a contractor uses to determine what needs to be installed, but not how it is to operate, as the details of how the system is to operate are typically left up to the controls contractor.

Figure 3 is a typical example of a controls contractor's submittal. It contains control points similar to the construction documents with some additional information about the controls. Information miss-

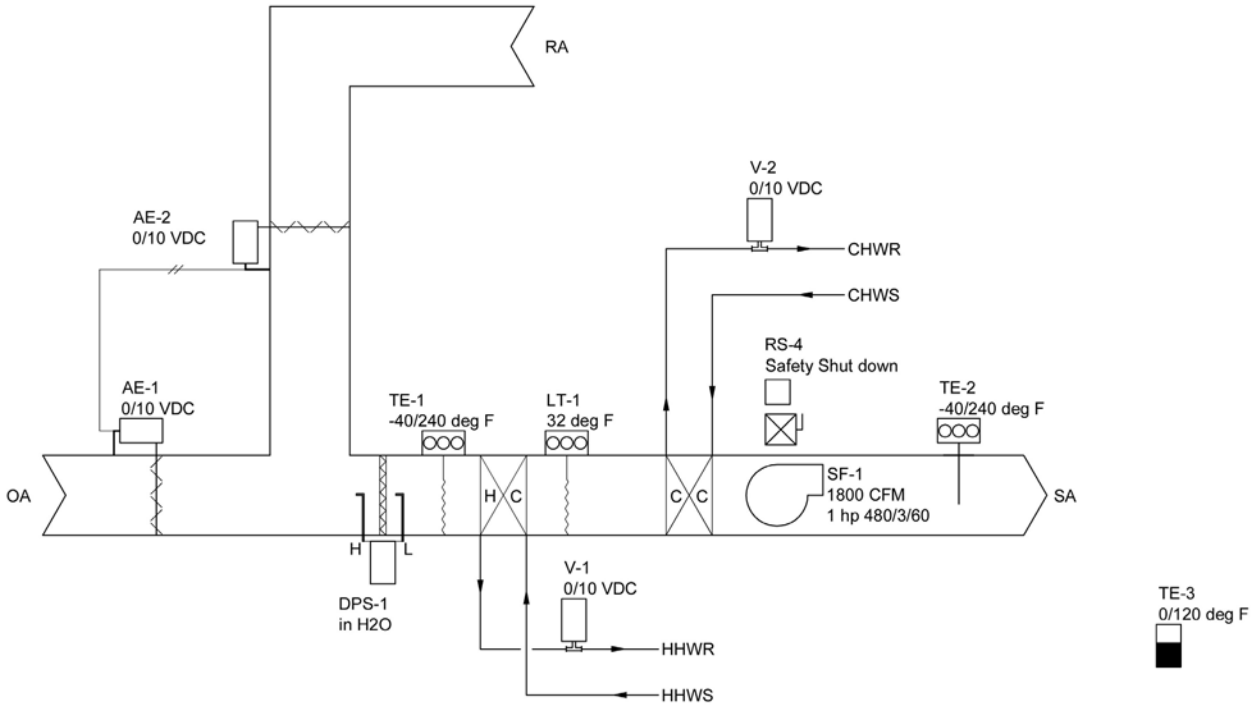


Figure 3: Example of a control's contractor submittal that is missing information

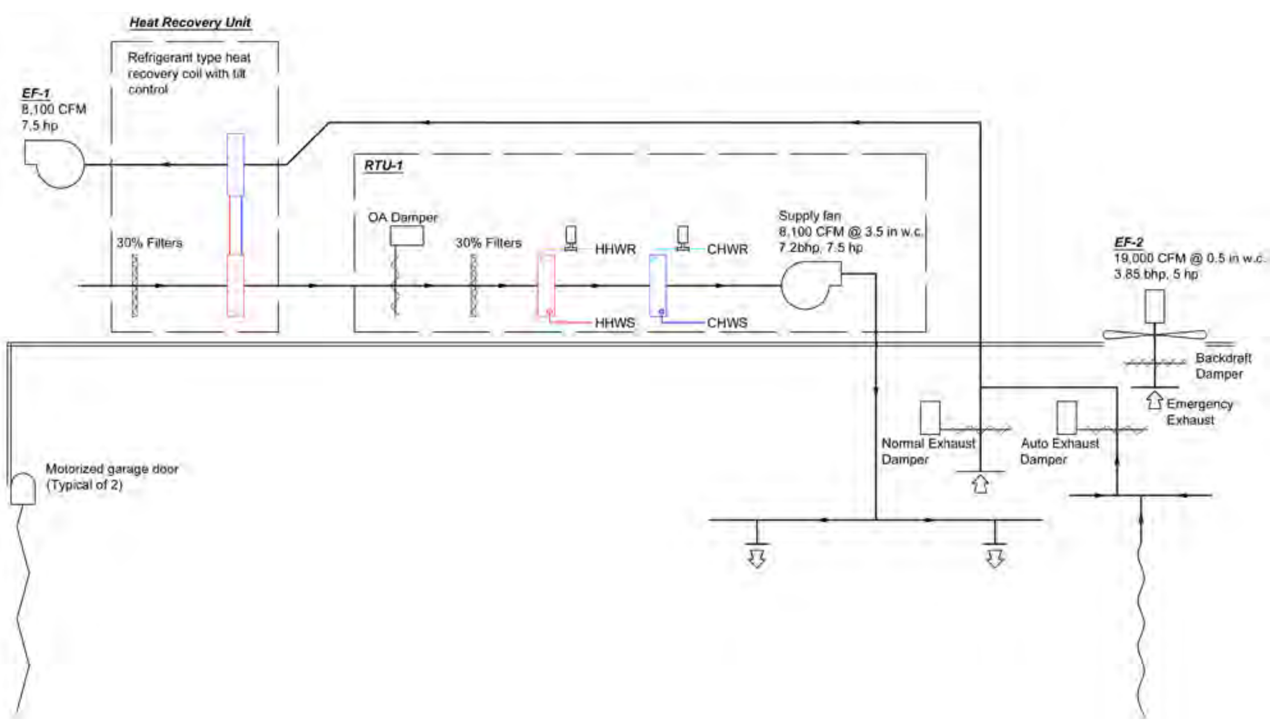


Figure 4: Example of a well-developed systems diagram

ing from Figure 3 is how the system components that are serving the same space interact. Thus, the figure only gives part of the information the operator needs to visualize and understand how the various system components serving the space interact. Looking at the figure, it can be seen that the information about airflow into and out of the space is incomplete. Information about other systems and system components that influence the space is also incomplete, including what sensors in the space provide input to the building automations system that control the systems and system components. This information is needed by the operators to be effective at efficiently operating the facility.

Figure 4 illustrates what a system diagram should contain within the systems manual and how the information should be communicated. As illustrated in Figure 4, it is easy to see the entire system represented, including the various components, control points and interaction between the components serving the space. This is an example of the type of information that:

- Clearly communicates how the parts and pieces of a system serve a space
- Graphically represents interaction of system components
- Shows airflow into and out of the space
- Represents air volume, break house power and static pressure information obtained from design documents or test and balance reports

From Figure 4, it is apparent how an operator can quickly visualize how the system works, easily troubleshoot problems and evaluate the effects of component malfunction.

This information, along with operating strategies, current sequences of operation and final set points implemented during commissioning of the systems, control logic and guidance on optimization strategies for the systems, provide operators with the information they need to efficiently and effectively manage the facility. Modifications made by operators over time should be recorded in the systems manual to provide new operators with the institutional knowledge necessary for continued efficient operation of the facility.

Finally, the systems manual should contain recommendations on the frequency of testing and sensor and actuator calibration to alert operators when such activities should be implemented, in addition to the regular preventative maintenance schedule. Table 3 provides an example of a frequency of retesting or calibration schedule that should be included in the systems manual.

Table 3: Example of system retest schedule

System, assembly or component	Functions to test	Testing frequency	Notes
Chilled Water System			
Chiller	On/off schedules and set points	Annual	Manually check, plus check trend logs. Check all set points, resets and time of day schedules in spring.
	Chilled water supply temperature control loop	Annual	Via trend logs verify resets. Complete during early summer operation.
	Performance	Biennial	Verify rated kW/ton.
Cooling tower	Leaving water temperature control loop	Annual	
	Tower performance	Annual	Verify rated range and approach.
	Freeze protection	Annual	Complete during late fall prior to first freeze.
Pumps	Differential pressure control	Annual	
Sensor and actuator calibration	Chilled water supply temperature	Quarterly	See instructions in Commissioning Record, Construction Checklist tab.

3.1.14 Maintaining Building Performance Through Monitoring-Based Commissioning

Monitoring-based commissioning utilizes sensor inputs from the building's sensors to evaluate in real time the:

- Overall performance of the building
- How each system in the building contributes or detracts from the overall performance of the facility
- Interaction between systems
- Specific performance of individual system components

An example of the value of monitoring and evaluating system operation during the various seasons is shown in Figure 5. The contractors reviewed the operation of the system and trends, and determined that the system was operating correctly. The acceptance testing for this rooftop direct expansion, variable air volume unit with hot gas reheat included monitoring the internal sequences of operation for the unit.

You cannot manage what you do not measure. Monitoring-based commissioning continuously assesses the building and system performance in real time and alerts operational staff when corrections are required to maintain the building's performance.

Within Figure 5, the pink line represents discharge air temperature. The light blue line is return air temperature. The purple line is zone humidity, and the brown line is fan speed. The discharge air temperature (pink line) and zone humidity (purple line) illustrate that the unit is cycling the compressors to maintain zone temperature (dark blue line) but not operating the hot gas reheat as needed in combination with the refrigerant cycle for dehumidification of the space to control humidity (yellow line). A properly operating system would show the relative humidity below 60 percent and a relatively steady discharge air temperature.

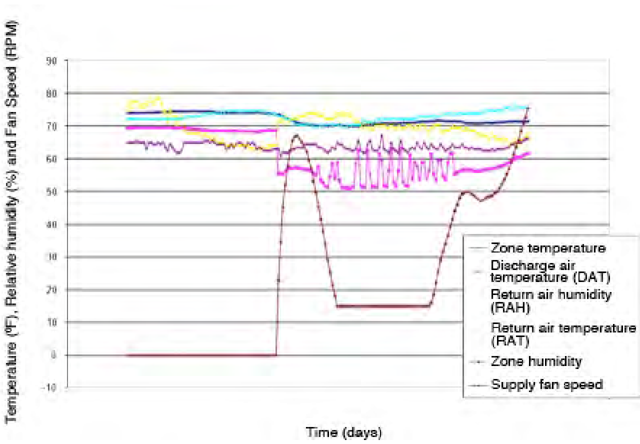


Figure 5: Example of a monitoring-based commissioning trend graph

3.2 Budgeting Time, Money and Resources for Existing Building Commissioning

3.2.1 Costs

It is important that the commissioning effort be broken into two phases. The first phase is investigation and assessment of the building and the second phase is implementation. As outlined above, investigation and assessment phase deliverables should be assessed by the owner for selection of facility improvements, energy conservation and occupant satisfaction measures prior to establishing costs associated with the second phase, implementation.

As with all commissioning projects, the cost is directly related to the size and complexity of the facility. The cost of commissioning is in proportion with complexity and scope of the commissioning process for the same size buildings. Generally there is an economy of scale for commissioning, based on building area (square footage or square meters); larger facilities cost less per square foot to commission. Commissioning costs per unit area generally increase as the project square footage goes down. This results because the amount of work is approximately the same to develop the commissioning documentation and reporting.

Larger facilities cost less per square foot to commission.

Larger buildings can require more time to investigate, but the amount of time required to analyze the data is approximately the same, independent of the building's size. Table 4 provides typical costs associated with investigation and assessment based on building size and complexity

The commissioning scope for implementation varies depending on the energy conservation measures (ECM) selected by the owner. Typical costs to implement low-cost energy conservation measures, such as building tuneup and the development of a systems manual, are summarized in Table 5.

Projects that require a design, bid, build process to implement capital improvements have costs dependent on the extent and type of improvement. Based on the author's experience, smaller projects implementing capital improvements will typically have additional commissioning costs of 5 to 7 percent of the installed energy conservation measures costs. Larger projects will typically range from 0.5 to 1 percent.

3.2.2 Owner's Role in the Commissioning Process

As for any project, the owner sets the tone and is responsible for selecting the right team. The CxA is responsible for providing input and guidance on

Table 4: Typical unit area cost for investigation and assessment

Building type	Building size (GSF)	Building size (m^2)	Cost/GSF (US dollars)	Cost/m^2 (US dollars)
Apartment/condo complex with 30,000 sf (2,787 m^2) of common area	320,000	29,729	$0.04	$0.43
Apartment/condo complex with 15,000 sf (1,393 m^2) of common area	100,000	9,290	$0.10	$1.08
Single tenant office/institutional building	500,000	46,452	$0.20	$2.15
Single tenant office/institutional building	250,000	23,226	$0.30	$3.23
Single tenant office/institutional building	100,000	9,290	$0.50	$5.38
Single tenant office/institutional building	50,000	4,645	$0.70	$7.53
Single tenant office/institutional building	25,000	2,323	$1.00	$10.76
Multitenant office building, common area only	500,000	46,452	$0.10	$1.08
Multitenant office building, common area only	250,000	23,226	$0.14	$1.51
Multitenant office building, common area only	100,000	9,290	$0.25	$2.69
Multitenant office building, common area only	50,000	4,645	$0.40	$4.31
Multitenant office building, common area only	25,000	2,323	$0.80	$8.61
Single tenant retail	100,000	9,290	$0.25	$2.69
Single tenant retail	50,000	4,645	$0.36	$3.88
Single tenant retail	25,000	2,323	$0.56	$6.03
Single tenant retail	10,000	929	$1.20	$12.92
Single tenant retail	5,000	465	$1.40	$15.07
Single tenant retail	1,000	93	$7.00	$75.35

Note: Costs will vary by geographical area and commissioning scope.

Table 5: Typical unit area cost for implementation for low-cost energy conservation measures

Building type	Building size (GSF)	Building size (m^2)	Cost/GSF (US dollars)	Cost/m^2 (US dollars)
Apartment/condo complex with 30,000 sf (2,787 m^2) of common area	320,000	29,729	$0.08	$0.86
Apartment/condo complex with 15,000 sf (1,393 m^2) of common area	100,000	9,290	$0.23	$2.48
Single tenant office/institutional building	500,000	46,452	$0.10	$1.08
Single tenant office/institutional building	250,000	23,226	$0.18	$1.94
Single tenant office/institutional building	100,000	9,290	$0.28	$3.01
Single tenant office/institutional building	50,000	4,645	$0.51	$5.49
Single tenant office/institutional building	25,000	2,323	$0.60	$6.46
Multitenant office building, common area only	500,000	46,452	$0.08	$0.86
Multitenant office building, common area only	250,000	23,226	$0.16	$1.72
Multitenant office building, common area only	100,000	9,290	$0.38	$4.09
Multitenant office building, common area only	50,000	4,645	$0.71	$7.64
Multitenant office building, common area only	25,000	2,323	$1.00	$10.76
Single tenant retail	100,000	9,290	$0.26	$2.80
Single tenant retail	50,000	4,645	$0.42	$4.52
Single tenant retail	25,000	2,323	$0.80	$8.61
Single tenant retail	10,000	929	$0.98	$10.55
Single tenant retail	5,000	465	$1.00	$10.76
Single tenant retail	1,000	93	$4.60	$49.51

Note: Costs will vary by geographical area and commissioning scope.

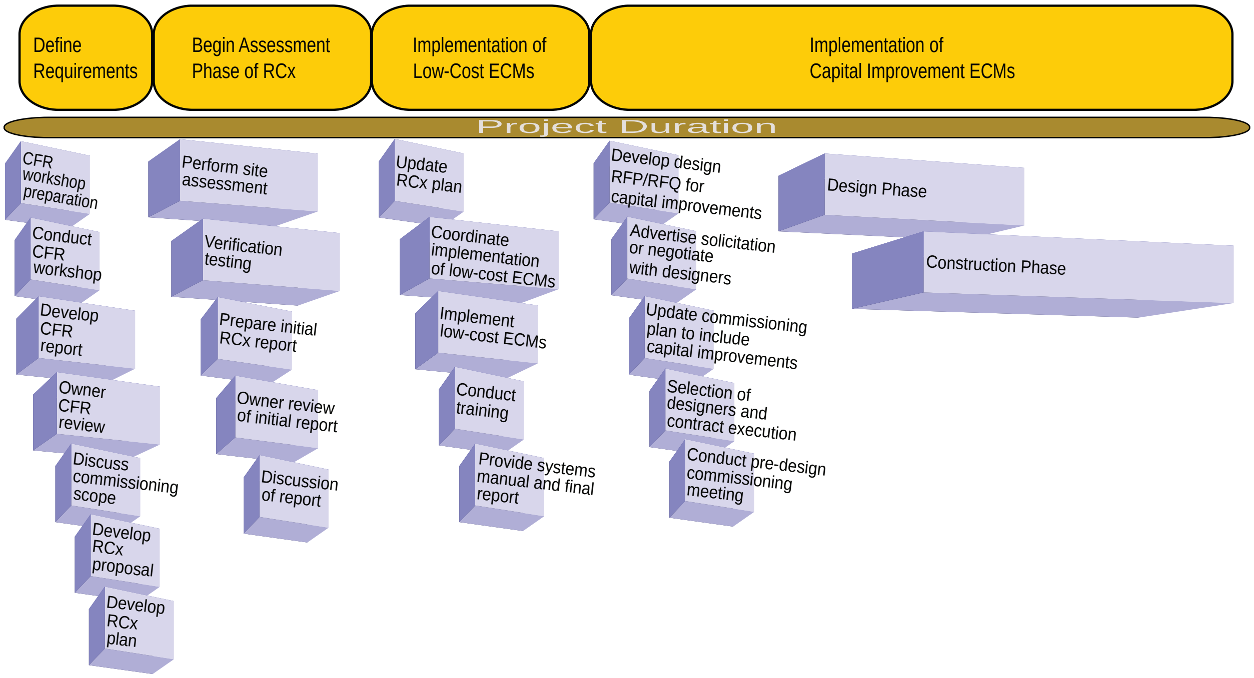


Figure 6: General schedule of the retro-commissioning process

objectives, criteria and goals. How an owner approaches the commissioning process determines to what extent the owner will benefit from commissioning.

3.2.3 Timeline of the Retro-Commissioning Process

The timeline for retro-commissioning is dependent on the size and complexity of the building and what energy conservation measures (ECMs) are selected. Low- and no-cost ECMs are often implemented immediately after completion of the assessment phase of the project. Projects that include capital improvements require use of the design, bid and build process, and are contingent on the extent of the capital improvements selected.

Figure 6 provides a general schedule for the retro-commissioning process, from the beginning through the implementation of low-cost energy conservation measures and selected capital improvements.

The typical duration of each task represented in Figure 6 is provided in Table 6. The purpose of Table 6 is to provide the facility manager with general information to support the planning process. Variation in the retro-commissioning timeline for implementation of capital improvements is due to unknowns in the scope associated with these improvements.

3.3 Commissioning Deliverables

From the current facility requirements (CFR) to the final commissioning report and systems manual, an extensive amount of documentation is created as part of the commissioning process. In creating and maintaining the commissioning deliverables, consideration should be given to using electronic formats and records where appropriate. The following sections detail the commissioning deliverables and can serve as a checklist throughout the process.

3.3.1 Current Facility Requirements (CFR)

The following is a list of information from ASHRAE Guideline 0: The Commissioning Process that is typically contained in a current facility requirements (CFR) deliverable:

- Project schedule and budget
- Commissioning process scope and budget
- Project documentation requirements, including format for submittals, training materials, reports and the systems manual
- Owner directives
- Restrictions and limitations
- User requirements
- Occupancy requirements and schedules
- Training requirements for owner's personnel
- Warranty requirements
- Benchmarking requirements

Table 6: Example project schedule using typical duration

Event description	Work days
Current facility requirements review and commissioning scope formation	
Current facility requirements (CFR) workshop preparation	1
Conduct CFR workshop	1
Develop CFR report	3
Owner review and comment period for CFR Obtain and review facility documentation	7
Discuss commissioning scope of work with owner	1
Development of retro-commissioning (RCx) proposal	1
Develop RCx plan	2
Begin assessment phase of retro-commissioning (RCx)	
Perform site assessment	Varies based on project size and scope
Verification testing and systems analysis	Varies based on project size and scope
Prepare initial RCx report	5
Owner review of initial RCx report	7
Discussion of initial RCx report with owner and selection of ECMs	1
Implementation of low-cost energy conservation measures (ECMs)	
Update RCx plan	2
Coordinate and schedule implementation of low-cost ECMs	14 to 30
Implement low-cost ECMs	1 to 14
Conduct training	2
Provide systems manual and final RCx report of low-cost ECMs	1
Implementation of capital improvement ECMs	
Develop design request for proposal (RFP) or request for qualifications (RFQ) for capital improvements	5 to 10
Advertise RFP/RFQ or negotiate with owner-selected designers	5 to 10
Update commissioning plan to include design of capital improvements	2
Selection of designers and contract execution	5
Conduct pre-design commissioning meeting	1
Design phase	2 months to 1 year
Construction phase	2 months to 1 year
Acceptance phase	2 to 14 days
Conduct training	1 to 5 days
Provide systems manual and final RCx report for low-cost ECMs	1
Ongoing commissioning	
Assessment of operational data	Weekly to quarterly

- Operation and maintenance criteria for the facility that reflect the owner's expectations, capabilities and the realities for the facility
- Expectations for equipment and system maintainability, including limitations of operating and maintenance personnel and additional training requirements
- Quality requirements for materials and construction
- Allowable tolerance in facility system operations
- Energy efficiency goals
- Environmental and sustainability goals
- Community requirements
- Adaptability for future facility changes and expansion
- Systems integration requirements, especially across disciplines
- Health, hygiene and indoor environment requirements
- Acoustical requirements
- Vibration requirements
- Seismic requirements
- Accessibility requirements
- Security requirements

3.3.2 Commissioning Plan

The commissioning plan deliverable should include the following:

- Commissioning plan overview
- Commissioning process description
  - Current facility requirement document
  - Assessments of
    - Operational parameters
    - Systems and assemblies
    - Energy and water efficiencies
  - Selection of modifications
  - Implementation processes for
    - Operational modifications
    - Capital improvements
      - Pre-design activities
      - Design activities
        - √ Develop basis of design
        - √ Design reviews
        - √ Integrate commissioning specifications for capital improvements into construction specifications
        - √ Pre-bid meeting
      - Construction activities
        - √ Pre-construction meeting
        - √ Contractor submittal review
        - √ Completion of construction checklists
        - √ Commissioning observations
        - √ Start-up plan and execution
        - √ Testing
      - Turn over
        - √ Completion of systems manual
        - √ Training of staff and occupants
        - √ Development of resolution plan for outstanding issues
      - Post final completion
        - √ Monitoring system interaction
        - √ System optimization
        - √ Seasonal testing
        - √ Calibration schedule
    - Ongoing commissioning plan
      - Monitoring
      - Adjustments to maintain performance
        - √ Documentation in systems manual
      - Ongoing training
      - Updating CFR

3.3.3 Investigation and Data Analysis Report

The investigation and analysis portion of the initial report should include the following:

- Overview of the facility or campus investigated
- Detailed description of the facility or campus investigated
- Historic energy and water usage
  - Charts illustrating usage
  - Annual billing data for multiple years
    - Month
    - Usage
    - Cost
    - Summary
  - Graphics comparing annual usage of each energy source, similar to Figure 1
  - Graphics comparing month-by-month water usage by system type
    - Irrigation, considering weather conditions
    - Building occupant consumption, including population
    - Food service, such as meals served
    - Process, with process parameters
- Assumptions required for data analysis
  - As-built parameters
  - Operational schedules
    - General
    - Individual components
  - Operational dynamics

- Light fixture energy usage by fixture type
- Costs
  - Utility rates
  - Source of cost data
  - Labor rates used in analysis by activity
  - Material costs used in analysis by component
  - Preventative maintenance costs estimates at the component and task level
- Expected life expectancies
  - Remaining useful service life of existing components
  - New components recommended
- Available documentation
  - Building information
  - Utility information
  - Surveys
- Previously noted documentation and information not available
- Economic
  - Interest rate
  - Owner-required return on investment
  - Owner-defined payback period

- Observations
  - General
  - Mechanical systems
  - Electrical systems
  - Building envelope systems
- Analysis of information
  - Computer models
  - Spreadsheets
  - Graphical analysis
  - Limitations of analysis
- Conclusions, including how the analysis of the data factored into the conclusions
- Cost-benefit analysis
  - Initial costs
  - Operational costs
  - Maintenance costs
  - Salvage value
  - Useful service life
  - Replacement costs
  - Productivity gain or loss
- Recommendations
  - Prioritization in accordance with CFR
    - No-cost and low-cost items
    - Capital improvements

3.3.4 Testing Procedures

Testing procedures are divided into two separate categories. The first category of testing is verification of existing conditions to support the analysis efforts and the subsequent ECM recommendations. The second category of testing is verification that the modifications meet the CFR and basis of design criteria.

Testing procedures for verifying existing conditions should provide detailed information about how system components are operating in sufficient granularity needed to help ensure accuracy of the analysis, conclusions derived from the analysis and the prediction of future performance of recommendations. Testing procedures also include changing system parameters to evaluate if a piece of equipment or system performs as intended and if its operation efficiency can be improved. Verification of what data sensors are reporting is also essential. Incorrect sensor values can result in poor performance from incorrect operation, as shown in Table 7. Table 7 shows the results from testing the sub-metering system to verify its accuracy. As shown in the table, there is a significant inaccuracy between actual values and reported values, demonstrated by the column labled "Difference."

Table 7: Sample of commissioning calibration verification data

Circuit	Current reading from field instrument [Amps]	Current reading from installed metering device [Amps]	Difference	±	Percent inaccuracy
L1A-A	25	45	20	High	44.44%
L1A-B	21	27	6	High	22.22%
L1A-C	7	9	2	High	22.22%
L2A-A	20	30	10	High	33.33%
L2A-B	47	80	33	High	41.25%
L2A-C	5	9	4	High	44.44%
DOAS-A	12	15	3	High	20.00%
DOAS-B	11	13	2	High	15.38%
DOAS-C	7	11	4	High	36.36%
L2L-A	36	18	-18	Low	-100.00%
L2L-B	20	10	-10	Low	-100.00%
L2L-C	13	6	-7	Low	-116.67%
L1L-A	25	24	-1	Low	-4.17%
L1L-B	24	24	0	Low	0.00%
L1L-C	15	8	-7	Low	-87.50%

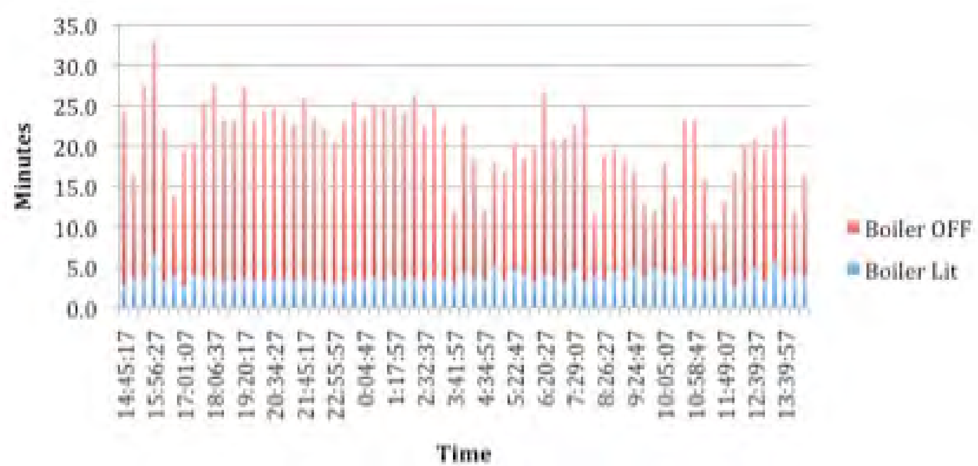


Figure 7: Sample of boiler operation data for a dietary building

Figure 7 illustrates the type of component information that is commonly collected during the investigation phase of a retro-commissioning process. Figure 7 shows data from a boiler in a dietary building for a day in the middle of the summer. The boiler is used to supply the dietary building with heat, hot water and steam used in food preparation. The hot water and steam supply are operated on a continuous basis.

The analysis of the boiler information shown in Figure 7 found that the boiler cycled 69 times during the day, with an average on time of 3.5 minutes and off cycle of 17.0 minutes. The high number of cycles produced a significant amount of cooling during operation. Thus, the number of heat cycles in the boiler chamber and tubes will reduce the life of the boiler.

The data collected from measuring actual operating conditions forms the basis for analysis to determine alternative strategies for inclusion in the recommended energy conservation measures and provides accurate predictions of how well the recommended modifications will improve the performance of the boiler.

Selection of what should be tested and development of the test procedures to either verify an existing condition or performance of a system modification are dependent on many parameters. When reviewing suggested testing procedures recommended by the CxA look for the following:

- Is the suggested test practical?
- Can the suggested test be performed safely?
- Will the test procedure damage any components or cause potential harm to the system?
- What impact will the test have on the occupants or building operation?
- Will the test procedure help achieve the objectives, criteria and goals contained in the CFR?
- What is the cost of the proposed test?

3.3.5 Initial Commissioning Report

The initial delivery of investigation and data analysis report should contain the following:

- Executive summary
- Summary of the building and its systems
- Methodologies used during the investigation to collect information
    - Data loggers
    - Instruments
    - Calibration certificates
    - Use of building automation system and what data was provided
    - Occupant surveys and interviews
    - Observations
- Presentation of data collected
- Assumptions
    - Interest rates used in cost-benefit analysis
    - Operational parameters
- Limitations of the report
- Conclusions
- Recommendations
    - Immediate
        - Safety issues
        - Low-cost and no-cost items
    - Medium cost
    - Long-term, higher-cost items and capital improvements

Categorization and prioritization of recommendations are made in accordance with the owner's defined requirements contained in the CFR. The CFR, if correctly performed, will include business decision criteria such as:

- Return on investment
- Maximum allowable length of return on investment
- Cost of money for projects being evaluated
- Social aspects to be included in the evaluation
- Other owner directives to be considered
- Analysis method utilized to evaluate alternatives equally

The report must provide sufficient detail and granularity of information so that others reading the report can understand the characteristics of the physical interactions between building systems and can reach the same conclusions and assessment of the proposed recommendations.

3.3.6 Final Commissioning Report

A final commissioning report is provided as part of the systems manual and contains the following:

- Final commissioning plan
  - Team contact information
  - Roles and responsibilities performed by each team member
  - Communication protocols
  - Schedule of activities
  - Evaluation procedures used to evaluate achievement of the current facility requirements
- Activities completed as part of the commissioning process
- Significant findings
- A complete list of issues identified and the disposition of issues identified
- An action plan with defined roles and responsibilities to resolve outstanding issues
- Design reviews, with the latest documents with color coding that illustrates each phase
- Field reports
- Final issues log
- Final submittal reviews
- Final test procedures and test data records
- Training
  - Final plans
  - Agendas
  - Sign-in sheets for all training
  - Training videos, as appropriate
- Correspondence specific to the commissioning scope, technical memos and other relevant correspondence
- Commissioning meeting minutes and associated sign-in sheets
- Other backup documentation pertaining to changes to building systems and assemblies that occurred during the commissioning process

The final report should be delivered within 30 days after completion of commissioning activities or final completion of construction activities if a capital project was part of the commissioning process.

3.3.7 Systems Manual

The systems manual should contain:

- Executive summary
- Table of contents
- Index of key building documents that are not included in the systems manual, including
  - As-built drawings
  - Project manual, including specifications
  - Shop drawings
  - Submittals
  - Operation and maintenance manuals
  - Requests for information
  - Architect's supplemental instructions
- The original owner's project requirements, if available, and current facility requirements
- Basis of design
- Final commissioning report
- A list of recommended operational recordkeeping procedures, including sample forms, logs or other means, and a rationale for each
- Ongoing optimization guidance
  - Controls submittal with changes to sequences of operations
  - Final set points and associated reasoning
  - Modification of control points and associated reasoning
  - Recommendations beyond contract document scope
- Systems schematics, one-line diagrams that illustrate valves, sensors, water flows and airflows
  - Air-side systems
    - Major supply air handling systems
    - Major exhaust systems
    - Modes of natural ventilation
  - Water-side systems
    - Chilled and condenser water
    - Heating water
- Procedures for emergency situations, including fire and power outages
- Special seasonal system adjustments
- Special procedures for maintenance shutdown
- Descriptions of interaction between components and systems
- Safety interactions

4 MAKING THE BUSINESS CASE

4.1 Why Commission?

While there are many reasons to commission a building, the most common are financial gain for the owner and reducing environmental impacts. Reduction of operating costs improves the bottom line and increases sales value of the asset and return on investment. Turning an average performing building into a high-performing building increases occupant satisfaction, tenant retention and occupant productivity.

The commissioning process provides the cohesive glue for integration of green strategies that improve operational efficiency. The commissioning process reduces utility consumption and greenhouse gas emissions, while allowing staff to perform efficiently and effectively, improving human resource utilization. High-performing buildings are green buildings, while green buildings are not always high-performing buildings. The measure of sustainability, or how green a building is, is determined by the performance of the building over its lifetime. Performance includes financial return on investment, energy and water efficiency, occupant satisfaction and reduction of risk factors.

Most well-operated and well-maintained facilities that have been commissioned degrade in performance by 10 to 15 percent two to three years after the commissioning was complete. This degradation is the result of multiple factors, including, but not limited to, heat exchanger fouling, sensor drift, reduction in drive efficiency, component malfunction and operational errors. Changes in performance caused by degradation typically go unnoticed.

Buildings that were not commissioned typically consume 30 to 70 percent more energy than their commissioned counterparts.

4.1.1 Financial Performance

The value of high-performing buildings is gaining traction in the marketplace. While how the value plays out is different for various owners, facility types and different commercial real estate submarkets, the facts are that more and more users are starting to demand high-performance facilities with green attributes to meet their corporate sustainability objectives. Vice president of CoreNet Global's Atlanta chapter Eric Bowles reported, "Major corporate space users such as IBM have said that any major building they are in has to be LEED-certified; they will not occupy one that is not" (Sinderman 2010). Many corporate leaders have already established goals to improve not just their performance but the performance of their supply chain.

Walmart announced a goal to eliminate 20 million metric tons of greenhouse gas emissions, "the equivalent of taking more than 3.8 million cars off the road for a year," from its global supply chain by the end of 2015 (Walmart 2010). Walmart is also a leader in improving the performance of its buildings because it makes good business sense. Improving and maintaining the performance of a facility goes directly to the bottom line.

There is a demand for users of built space to have improved living and working environments, and for social aspects to be considered within these requirements. Many of the social aspects of buildings have more to do with the ability for a building to meet the occupants' needs and facilitating effective and efficient delivery of the occupants' daily mission. Social sustainability of built assets are measured in terms of user friendliness, compatibility, the free flow of information and the impacts the building may have on both the work and natural environment.

"Traditionally, the property valuation approach for investment-type buildings calculates the market value using financial analysis – the bottom line. In a market that has been dominated by 'profit-only' goals, this method has been capable of simulating market activity provided the limitations of subjectively assessed variables that are understood" (Boyd and Kimmet 2005). In recent years, advanced economics have increasingly entered into a climate of heightened public scrutiny with respect to corporate and public administration practices. This has implications for the market in terms of the socio-political backdrop forging the demand for built assets of a specific caliber (Kimmet and Boyd 2004).

A good energy rating, such as an ENERGY STAR rating of greater than 75, which conforms to a standard, gives a building a market edge. This is also true for U.S. Green Building Council LEED certified buildings that incorporate both enhanced work, living and natural environmental attributes that facilitate positive physiological and psychological perceptions while achieving good operational, energy and water efficiency. These profit-plus objectives are known as the triple bottom line. Shareholders with vested interests are progressively calling company executives to account, and have in this way become influential in generating support for new corporate values that reach beyond narrow economic constructs (Whiteside 1972).

4.1.2 Reducing Energy Consumption

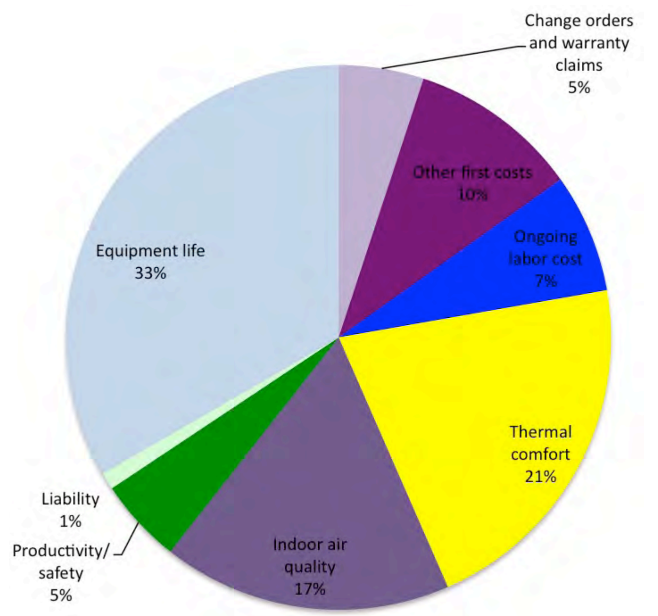
Commercial buildings have a significant impact on energy use and the environment. They account for approximately 18 percent, 17.9 quadrillion BTUs ($5.25x10^{12}$ kWh), of the total primary energy consumption in the United States (DOE 2005). The energy used by the building sector continues to increase, primarily because new buildings are added to the national building stock faster than old buildings are retired. Energy consumption by commercial buildings will continue to increase until buildings can be designed to produce more energy than they consume (NREL 2006).

Research indicates that by 2020, the United States could reduce energy consumption by 23 percent from a business-as-usual (EIA 2008) projection by deploying an array of net present value positive energy efficiency measures, saving 9.1 quadrillion BTUs ($2.67x10^{12}$ kWh) of end-use energy (18.4 quadrillion BTUs [$5.39x10^{12}$ kWh] in primary energy). Office, retail and service buildings are the largest consumers of energy in the US. Between 44 and 59 percent of that energy is consumed by lighting (DOE 2009). However, for most buildings, this energy consumption could be reduced by 10 to 40 percent. Better lighting design of new buildings and lighting retrofits can significantly reduce operating costs, electrical consumption and greenhouse gas emissions. These strategies also can increase occupant comfort and productivity (Enck 2009).

In 2003 there were approximately 4.9 million nonresidential buildings in the United States, of which 75 percent were performing below their designed efficiency. While the number of buildings in the US has increased since 2003, the percentage of buildings operating as intended is still approximately 25 percent of the building stock. Thus, there are great opportunities for building owners to significantly improve the performance of their buildings. Commissioning of the existing building stock can save an owner from 10 to 60 percent of annual energy cost and has a simple payback period from one to 24 months, with the average being 1.1 years (Mills 2009).

4.1.3 Other Benefits of Commissioning Existing Buildings

Reducing energy consumption is far from the only monetary benefit to result from the commissioning process. Figure 8 shows reported results from 36 projects of nonenergy impacts for existing buildings after commissioning was completed. Increasing equipment life, reducing labor costs, reducing other first costs and increasing productivity all reduce operating costs for the owner and increase the bottom line.



Note: Due to rounding, chart numbers do not add up to 100%

Figure 8: Reported nonenergy impacts for existing buildings

Positive benefits are also noticed by building occupants, particularly with improved indoor air quality and thermal comfort. Happier building occupants are not only more productive in their work, but are also less likely to complain, reducing the burden on operations staff and allowing them to focus on properly maintaining the building rather than responding to occupant complaints.

Building operations and maintenance staff work hours are often spent in a firefighting mode focused on eliminating complaints. Once a facility's operations and maintenance staff enters the firefighting mode, it is very difficult for them to return to efficient building operation practices without retro-commissioning the building. Retro-commissioning assists the operation and maintenance staff to identify systemic problems and solutions that allow permanent resolution of issues. In turn, this results in more efficient utilization of the operations and maintenance staff time, allowing necessary maintenance to be completed to maintain building performance and occupant satisfaction.

Ongoing monitoring-based commissioning can quickly pinpoint when systems and their components performance has degraded. Doing so facilitates the use of reliability-centered maintenance, and improves operations and maintenance staff efficiency by quickly providing diagnostic analysis in real time, significantly reducing the time spent troubleshooting.

4.1.4 Commissioning and LEED Certification

The U.S. Green Building Council recognizes the importance of commissioning, as it is necessary to achieve a LEED certification. Commissioning, as practiced by the author, provides the cohesive glue that binds an owner's team together and provides the communication necessary for each team member to understand their specific role and responsibilities in achieving the owner's objectives, criteria and goals. As illustrated within this guide, commissioning documents facility requirements, including sustainability goals, verifies that these goals are being met and assists with maintaining the building's performance for its life.

In the author's experience, the commissioning process can provide some of the greatest value achieved by green buildings by setting a strong foundation in the owner's project requirements for new buildings and major renovations, or current facility requirements for existing buildings, that guide the project team to achieving their end goal at the lowest possible cost. Qualified commissioning authorities can provide insight into achieving LEED certification, monitor the team's progress, and quickly identify issues for team collaborative resolution. The qualified commissioning authority can also provide tools and services that identify issues with building performance in real time, giving the owner the tools to manage occupant satisfaction and building performance for the life of the facility, a key goal of the LEED rating systems.

The LEED for Existing Buildings: Operation & Maintenance (LEED-EBOM) operational effectiveness credits support best management practices for energy and water consumption through implementation of building commissioning. For example, water-saving strategies and technologies applied to cooling towers can affect building performance, and are one of the systems that should be commissioned under LEED certification, as they can be classified as a "major energy-using system" under LEED-EBOM Energy and Atmosphere credit 2.1: Existing Building Commissioning – Investigation and Analysis. Commissioning provides an important service by improving operations, extending the useful service life of building equipment, and reducing maintenance costs by optimizing the efficiency of existing systems. Commissioning assists operational staff in understanding the energy profile of the building, allowing customized efficiency approaches to be determined as operational parameters change.

Commissioning existing buildings involves developing a building operating plan that guides the daily operation. This plan is typically included in the systems manual and provides:

- Updated sequences of operations for systems
- Set point values derived and implemented during retro-commissioning
- Guidance on system optimization
- Documentation procedures for modifications to systems and set points, and logic behind those changes
- Current facility requirements
- Basis of design

LEED for Existing Buildings: Operations & Maintenance Version 3 Energy and Atmosphere prerequisite 1 (EAp1) requires a building operating plan and an ASHRAE Level I energy audit assessment. Energy and Atmosphere EA prerequisite 2 (EAp2) establishes minimum energy efficiency performance requirements. For the various facilities types that can obtain a U.S. Environmental Protection Agency ENERGY STAR label, a minimum score of 69 is necessary to achieve LEED certification. Commissioning helps to attain LEED credits under Energy and Atmosphere credit 1 (EAc1): Optimized Energy Efficiency Performance, assisting with earning up to 18 credits based on measured efficiency. There are six credits available under Existing Building Commissioning:

- EAc2.1: Existing Building Commissioning – Investigation and Analysis
- EAc2.2: Existing Building Commissioning – Implementation
- EAc2.3: Existing Building Commissioning – Ongoing Commissioning

Energy and Atmosphere credits (EAc3.1 and EAc3.2) for performance measurement can gain an additional three credits. Reducing energy consumption also reduces emissions providing the opportunity to gain an additional LEED credit under EAc6: Emissions Reduction Reporting.

Depending on the owner's objectives, criteria and goals, a qualified commissioning authority knowledgeable in LEED can assist with developing policies and procedures, training of operational staff and mentoring the team to achieve LEED certification, as well as represent the owner in adjudication with the Green Building Certification Institute (GBCI), the LEED certification body. LEED recognizes that commissioning optimizes energy and water efficiency by ensuring that systems are operating as intended, thereby reducing environmental impacts associated with energy and water use. Properly executed commissioning can substantially reduce cost of maintenance, repairs and resource consumption, and assist with higher indoor environmental quality, which enhances occupant productivity and feelings of well-being.

4.1.5 Legislation and Commissioning

Energy efficiency, facilitated through existing building commissioning, offers a vast, low-cost energy resource for the United States economy. However, the benefits can only be realized if society recognizes energy efficiency, in conjunction with concurrently developing new no- and low-carbon energy sources, is an important energy resource that can help meet future energy needs. For new buildings and major renovations, energy efficiency requirements are becoming more stringent at one to three year intervals, depending on the jurisdiction. Often this includes the goal of improving building efficiency to near zero energy usage by the year 2030. In the US, there are only legislative requirements for federal facilities to improve existing building energy efficiency. However, utility rates are rising throughout the country. For example, in 2008 *USA Today* (Davidson 2008) stated that utility rates across the United States have increased 29 percent, mainly to pay for soaring fuel costs, build new plants and refurbish the aging power grid.

Commissioning of new buildings over 50,000 square feet (4,645 m^2) is required by the International Building Code, and in many states commissioning is required for all state projects. States, as long-term owners, have often been burdened by projects that were built with low bids and resulted in expensive buildings to operate and maintain. Most states found that commissioning reduces risk and the number of change orders, identifying and resolving issues while the design and construction team are still involved. This experience is similar for private real estate owners and investors.

Other jurisdictions, specifically cities, are requiring LEED certification for new construction, which requires building commissioning. Although few jurisdictions have formally made the commissioning of existing buildings a regulatory requirement, many have begun to move in that direction. For example, Maine and Wisconsin have made adherence with LEED-EBOM requirements mandatory for all state buildings, and five municipalities in the US have requirements at the municipal level. Expansion of such requirements to nonpublic buildings, although not currently widespread, is likely in the future.

Even without direct requirements for commissioning, reducing energy consumption in buildings is going to be vital in the future. Cap and trade legislation, currently being considered in both the US and Canada at the time this guide was written, would greatly increase the costs of energy, making any ability to reduce energy consumption even more cost-effective than it currently is, providing even more reasons to commission buildings.

4.1.6 Insurance Benefits

There is a move in the property insurance industry toward providing discounts for green buildings that have undergone commissioning. One of the forerunners in this field is Fireman's Fund, which in 2008 introduced a green building insurance product that included a 5 percent property discount for buildings that had achieved LEED certification. As of January 2009, there are at least eight different national insurance carriers providing green building insurance policies and endorsements. For residential buildings, in 2010 Traveler's Insurance started offering discounts on home insurance to owners of LEED for Homes certified homes in Pennsylvania. This is a growing trend in the industry and one from which building owners can benefit from now and in the future.

4.2 Cost-Benefit Analysis

One of the most thorough analyses completed about the cost-effectiveness of commissioning was presented at the National Conference on Building Commissioning (NCBC) as a paper in 2005 (Mills 2005). Led by Evan Mills of Lawrence Berkeley Laboratory, the study examined 150 existing buildings undergoing the commissioning process. The findings demonstrate that the median price for commissioning an existing building was \$0.27/SF (\$2.91/m^2) (US dollars), with a typical range between \$0.13/SF (\$1.40/m^2) (US dollars) and \$0.45/SF (\$4.84/m^2) (US dollars). In absolute terms, the median cost to commission an existing building is \$34,000 (US dollars).

Considering only the costs from energy savings provided by the commissioning process, assuming a median cost savings of 15 percent (about US \$0.27/SF or \$2.19/m^2), the payback for commissioning can be one year. When standardizing US energy prices and incorporating some nonenergy monetary savings, Mills et al (2005) found that the median payback time is actually closer to 0.7 years, which is less than nine months.

The author recommends starting with the investigation phase of the existing building process outlined in this guide. This initial investigation phase, if correctly implemented, should yield a report that identifies energy conservation measures prioritized by cost and benefit in accordance with the owner's business model. Cost savings should include not only energy costs, but also maintenance cost savings, life of the suggested modification, salvage value, and the cost of money needed to implement the recommendation. Failing to look at all of the costs in the financial analysis can result in less advantageous and less profitable decisions.

Depending on local, state and federal tax benefits and legislated utility assistance programs, additional cost benefits may be available. To determine what may be available, contact the local utility account representative for more information.

5 CASE STUDIES

The following case studies underscore the real-life benefits of the commissioning process from an owner's, occupant's and tenant's perspective. The owner's perspective is presented from two angles – a university and a government building. The occupant perspectives is primarily about occupant comfort, while the tenenat perspective examines attracting and keeping good tenants.

5.1 Owner Perspective

Lowering the total cost of ownership and the environmental impact of a facility, while increasing the return on investment, are key concerns of owners. Lowering maintenance and operating costs provides improved financial performance and allows owners, when necessary, to be more competitive in the marketplace. Owners must balance potential cost increases with revenue. Thus, it is very important that the owner's team understand what can be achieved through existing building commissioning. The following case studies illustrate the cost benefit.

5.1.1 University Building

Located in the Southeast, this university building (Figure 9) was constructed in 1997 and is a 123,053 square foot (11,432 m^2) building. It has variable air volume heating and air conditioning systems serving classrooms and faculty offices, and four pipe fan coils serving entrance vestibules, stairwells and electrical closets. Steam and chilled water from the central plant are metered by the university. Electrical systems are also metered by the university. As seen in Figure 9, this building has many green features, including clerestories to bring in natural daylight, overhangs to reduce solar heat gain and air conditioning loads, and efficient lighting. The building also has state-of-the-art HVAC and building automation systems.

The owner's maintenance records indicated that only 13 work orders had been generated with no significant issues identified during the first five years the facility was in operation, including no known occupant complaints. Energy usage was monitored by the university's energy manager and was considered to be one of the university's best buildings. The owner's goal was to attain a LEED for Existing Buildings: Operations & Maintenance rating, which requires that the building has at least an ENERGY STAR score of 69 to become certified.

Figure 9: Photos of the university building

Plotting steam and chilled water usage, shown in Figure 10, shows a steady increase in steam usage with steady chilled water usage, except for 2001. The drastic drop in chilled water usage in 2001 was attributed to flow meter issues measuring the volume of chilled water supplied to the building. Plotting the electrical usage, Figure 11, illustrates a steady increase in electrical consumption over the five-year period.

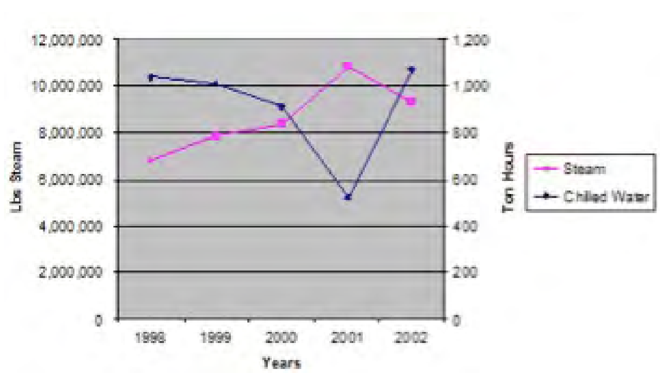


Figure 10: Chilled water and steam usage

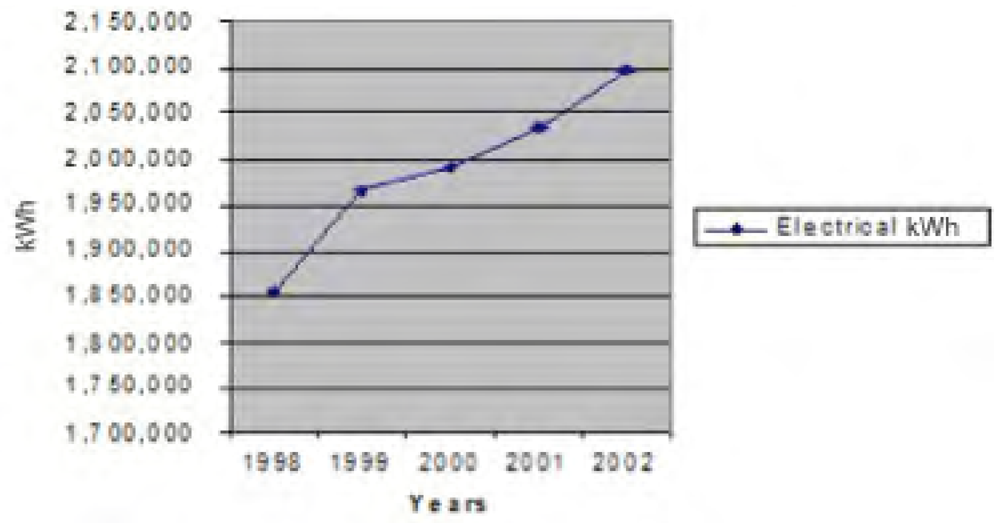
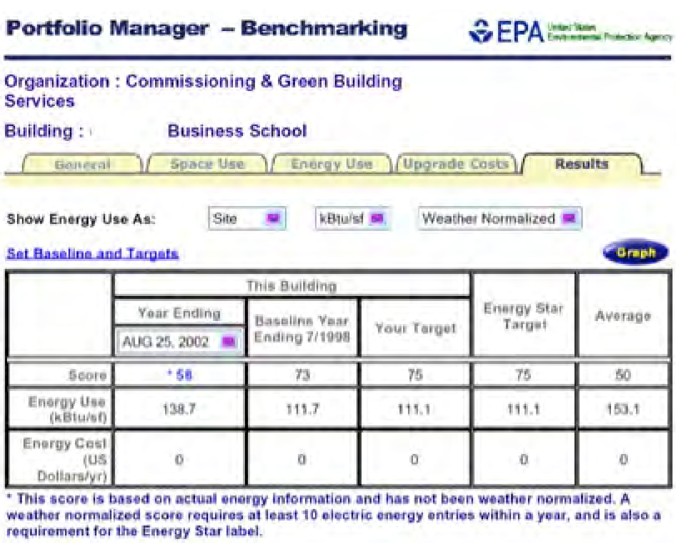


Figure 11: Electrical consumption

Further investigation revealed that the energy manager did not have the tools needed to compare utility usage to operational parameters and weather, nor the ability to analyze data in real time. The data being collected, while valuable, did not factor in the facility's daily operations, allowing years of high operating costs to go unnoticed.

The facility energy usage was compared to similar types of buildings using ENERGY STAR Portfolio Manager. Figure 12, shows how the building compared on a national basis against similar-type buildings. As shown in Figure 12 the building, despite its increases in utility usage, was performing better than the average similar-type building nationally. The building had a score of 58, while the average for similar-type buildings was 50.



Portfolio Manager – Benchmarking

Organization : Commissioning & Green Building Services

Building : Business School

General | Space Use | Energy Use | Upgrade Costs | Results

Show Energy Use As: Site | kBtu/sf | Weather Normalized

Set Baseline and Targets

Graph

	This Building			Energy Star Target	Average
	Year Ending AUG 25, 2002	Baseline Year Ending 7/1998	Your Target		
Score	* 58	73	75	75	50
Energy Use (kBtu/sf)	138.7	111.7	111.1	111.1	153.1
Energy Cost (US Dollars/yr)	0	0	0	0	0

* This score is based on actual energy information and has not been weather normalized. A weather normalized score requires at least 10 electric energy entries within a year, and is also a requirement for the Energy Star label.

Figure 12: ENERGY STAR score compared to average

Graphing the steam and chilled water usage on a monthly basis (Figure 13) provided insight into some of the issues affecting the building operating costs. As illustrated in FIgure 13, both steam and chilled water consumption are high, using a minimum of 400,000 pounds (181.44 metric tons) of steam in August. While simultaneous heating and cooling typically results in increased occupant comfort, it does significantly increase operating costs.

Investigation of how the building was being operated revealed that the building was being heated and cooled simultaneously. This was occurring because:

- Terminal box airflow minimums were set too high
- Control sequences were not optimized
- Makeup air openings were restricted resulting in negative pressurization of the building
- Air handler variable speed fans were operating at higher than necessary static pressure

In addition, building operation schedules had been overridden, and space temperatures were being maintained at 72°F (22°C) 24 hours a day, 365 days a year. The combination of issues identified resulted in the building consuming more than 50 percent more energy than required. Commissioning of the building cost $125,000 (US dollars) and saved $131,000 (US dollars) per year.

The fact that the building benchmarked above the national average clearly illustrates that there is great savings opportunities in existing buildings. Recent studies (EIA 2008) estimate that the US could significantly reduce operating costs at

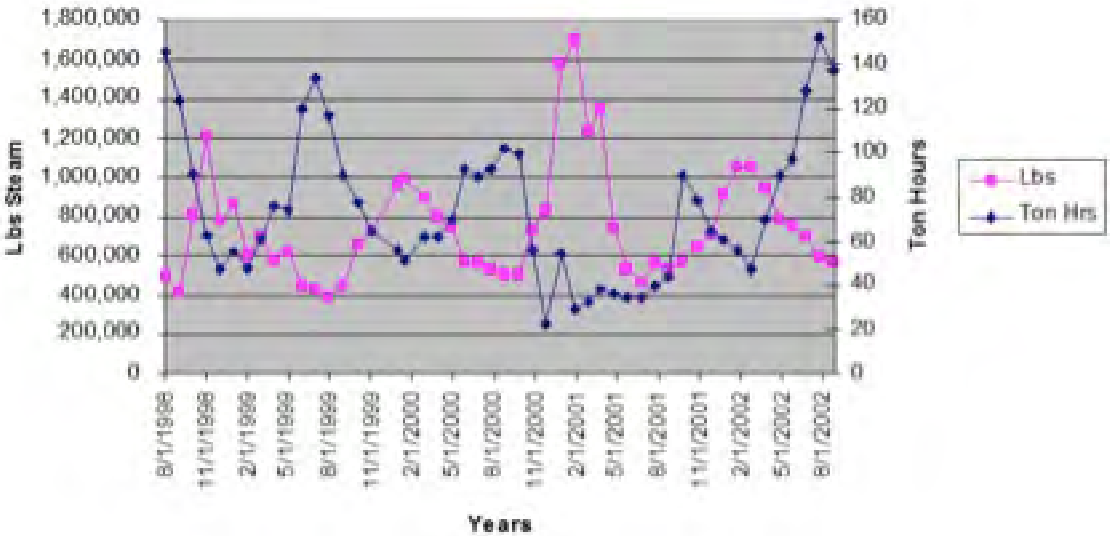


Figure 13: Monthly chilled water and steam consumption

least 23 percent if existing buildings were commissioned and the cost-effective energy conservation measures identified during the investigation phase of the existing building commissioning process were implemented. Additionally, greenhouse gas emissions can be significantly reduced while implementing energy efficiency measures, with return on investment of less than two years.

The university's goal of lowering environmental impact and achieveing LEED certification was met. The building received Gold Certification while also reducing operational costs by an amount equivalent to a professor's annual salary.

5.1.2 Harold D. Donohue Federal Building and US Courthouse

The Harold D. Donohue Federal Building and US Courthouse in Worcester, Mass., had one of the highest energy intensities per unit area of buildings in US General Services Administration (GSA) Region 1. The physical plant for the facility provides chilled and hot water distributed to four pipe fan coils and five constant volume air handlers. Ventilation air is provided by a variable air volume makeup air unit and general exhaust systems. The chilled water system consists of three centrifugal chillers and a waterside economizer. Hot water for space heating consists of three dual fuel on/off boilers.

The heating, ventilating and air conditioning (HVAC) systems and direct digital control (DDC) system were installed when the building was built and were in good operating condition at the time of the retro-commissioning effort.

Figure 14: Harold D. Donohue Federal Building

Review of the utility data for the facility, Figure 15, illustrates a suspicious, consistent level of electrical usage on a year-round basis. Typically, electrical consumption varies with weather. The March site visit identified that the cooling tower basin heater control had been electrically bypassed resulting in 102°F (39°C) basin temperature. The Massachusetts climate typically allows for the use of a waterside economizer to meet the facility's cooling requirements for most of the year, as illustrated in Figure 16.

Other findings from the facility assessment included the following issues:

- Hot water space heating boilers and loop were activated when outside air dry bulb temperatures were below 52°F (11°C), instead of when there was a demand for heat
- Simultaneous heating and cooling throughout the facility
- Many building automation control functions were disabled and manually forced commands were being used

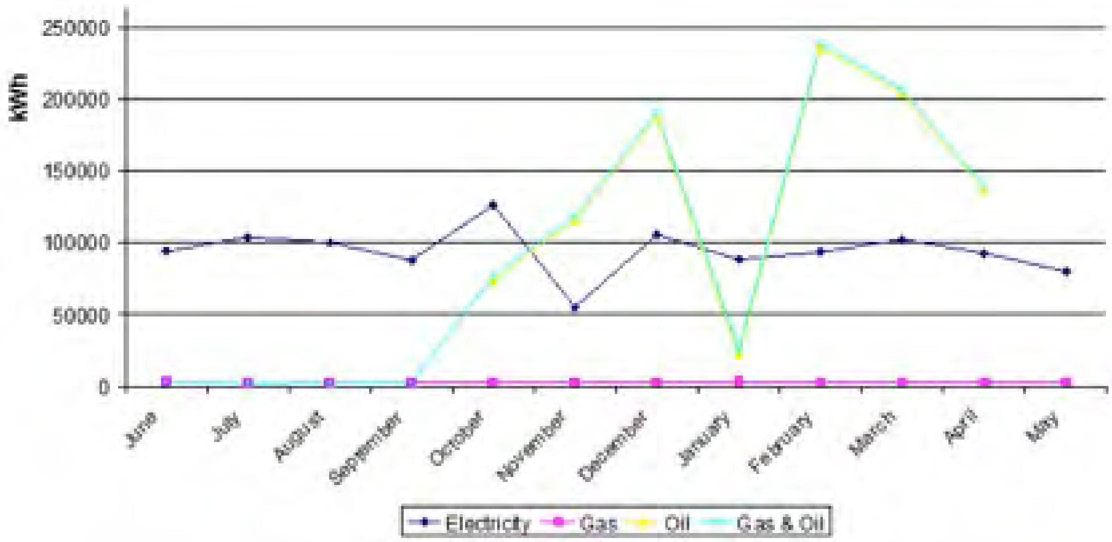


Figure 15: Utility data for Harold D. Donohue Federal Building and US Courthouse

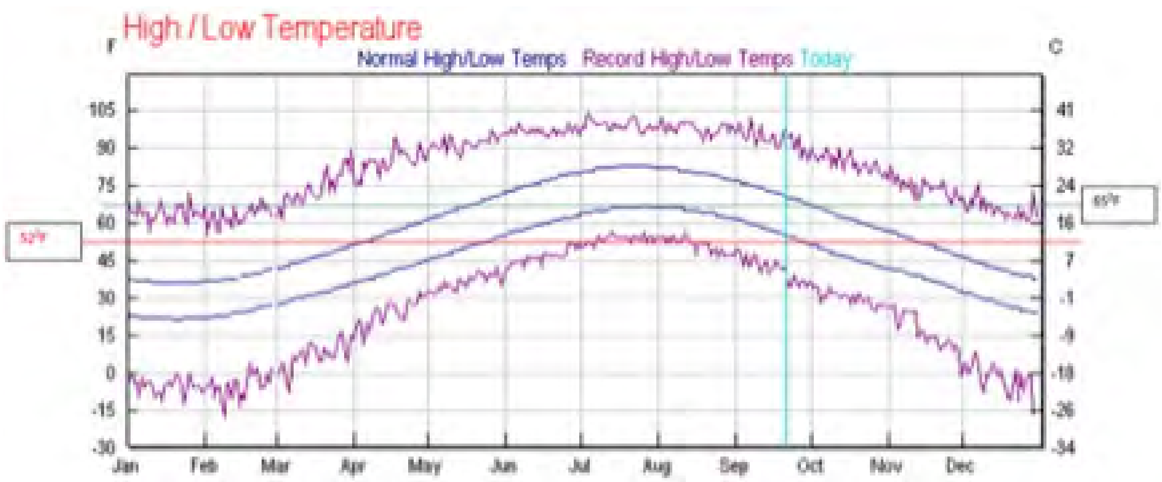


Figure 16: Historic weather information

- Ventilation air volumes did not correlate to actual occupancy requirements, resulting in significant over-ventilation for most occupied periods
- Variable air volume makeup air and exhaust system controls not working correctly to modulate outside and exhaust air in accordance with sequences of operation
- T12 lighting throughout the facility

Based on the author's observations, in general, the facility had been well maintained at the time of the site visit. Equipment was found to be in generally good condition and working. However, there were no tools available for the building operator to know that the building was not operating efficiently. Like most operators, the facility operator was trying to find ways to reduce energy consumption, but lacked the analytical tools necessary to know that the systems were not operating efficiently or how to approach optimizing the building's performance.

To improve the energy efficiency of the building, several energy efficiency measures were implemented, resulting in a 46 percent energy reduction, saving $180,000 (US dollars) in the first year:

- Modifying the original sequences of operation for improved efficiency
- Optimizing the interaction between building systems
- Making simple repairs to cooling tower controls
- Installing temperature resets into heating and chilled water system operation
- Implementing demand-based ventilation control

5.2 Occupant Perspective

Most occupant complaints stem from thermal comfort issues. Often occupants inform building operators, who can change set points, or override control sequences in an effort to eliminate the complaint. If the operator's efforts do not resolve the issue, the occupant generally gives up talking with the building operator and typically does one or several of the following:

- Minimizes their time in the space through absenteeism
- Elevates the issue to their management to obtain permission for unit heater or fan to improve their comfort
- Takes things into their own hands and uses operable windows when the building is in heating or cooling mode, increasing building load
- Finds somewhere else to work

For occupants to be productive, they need good indoor environmental quality to focus on the delivery of their daily mission and generally have little regard to utility costs when uncomfortable. Allowing tenants to achieve comfort through their own means generally drives up operating costs substantially.

5.3 Tenant Perspective

Attracting and keeping good tenants in a renters market is on the mind of many owners and their agents. Many tenants are looking for better lease terms and lower costs. High common area maintenance costs make properties less desirable for prospective tenants. Many prospective tenants are limiting their searches to facilities that have a green rating because they want to be in a facility that has good indoor environmental quality and reduced environmental impacts. Tenants, like the occupants above, generally follow the same pattern with one major exception: Unhappy tenants move out at the end of their legal obligation.

Tenants look for a facility that has the attributes they need to effectively and efficiently deliver their mission; provides the image important to the firm; and is the most economical for them to inhabit. Owner's and agents expend a significant effort to obtain tenants, hoping for a long and profitable relationship. Commissioning can provide an owner with an advantage over their competition by facilitating the development of the current facility requirements, which is beneficial to the tenant to achieve the lowest possible cost through clearly defining and documenting what the space must provide for the tenant to efficiently deliver their mission.

5.4 Lessons Learned

Success is dependent on the project team, which includes everyone involved with retro-commissioning an existing building. To be successful, the team must define the high-level end goals for the project. Not starting correctly will diminish the value the owner receives from the commissioning process. Starting correctly is best achieved through the development of the current facility requirements.

Selection of a qualified commissioning professional is also very important. Owners should obtain information from candidates that illustrates that the commissioning professional has experience in the type of facility being considered for commissioning along with references from the commissioning professional's clients.

Team dynamics are also a critical component. It is recommended that several members of the owner's team participate in the selection of the commissioning professional to gage how well the team can work with the commissioning professional.

Utilizing the complete commissioning process, including monitoring-based commissioning after the completion of the implementation phase, is essential to maintaining performance achieved from retro-commissioning for the life of the facility.

5.5 Conclusion

The performance of a facility continuously degrades from the time the systems are installed. Operators are often forced into firefighting mode from the time they take over the facility, revising sequences of operation and making changes to the systems to eliminate occupant complaints, which typically result in higher costs. Most financial officers do not understand that these problems can be corrected cost effectively, and doing so provides a great return on investment. The simplest way to avoid these problems is through commissioning, and the best way to improve performance of an existing building is through retro-commissioning. This guide has provided reasoning to accomplish retro-commissioning at a facility and has provided a detailed outline of the retro-commissioning process and how it can help add money directly to the bottom line.

6 APPENDICES

6.1 Appendix A: References

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6.2 Appendix B: Additional Resources

General Commissioning Information
California Commissioning Collaborative – California Commissioning Guides:
www.cacx.org/resources/commissioning-guides.html

Green California – Commissioning and Retro-Commissioning Buildings:
www.green.ca.gov/CommissioningGuidelines/default.htm

New York State Energy Research and Development Authority (NYSERDA) – Commissioning Information and Opportunities in New York State: www.nyserda.org/programs/Commissioning/default.asp

ENERGY STAR and Retro-Commissioning
ENERGY STAR – Retrocommissioning:
www.energystar.gov/ia/business/EPA_BUM_CH5_RetroComm.pdf

Retro-Commissioning
A Retrocommissioning Guide for Building Owners: www.peci.org/documents/EPAguide.pdf

National Energy Management Institute (NEMI) Retro-Commissioning:
www.nemionline.org/site/content/reports/view/28

O&M First! A Case Study on In-House Retro-Commissioning at a DOE National Laboratory:
www1.eere.energy.gov/femp/pdfs/om_retrocx.pdf

Oregon Retro-Commissioning Handbook:
www.oregon.gov/ENERGY/CONS/BUS/comm/docs/retrocx.pdf?ga=t

PG&E Retro-Commissioning (RCx) Program:
www.pge.com/mybusiness/energysavingsrebates/rebatesincentives/retrocommissioning

Retrocommissioning – Big Savings for Big Buildings:
www.buildinggreen.com/auth/article.cfm/2010/9/29/Retrocommissioning-Big-Savings-for-Big-Buildings/

Retro-Commissioning Fact Sheet: www.documents.dgs.ca.gov/green/eeproj/retrocommfactsheet.doc

Retro-Commissioning – A Solution for Today's Modern Facilities: www.imt.org/Capital/RCx_Intro.doc

San Diego Retrocommissioning Program: www.sandiegorcx.com

6.3 Appendix C: Glossary

All glossary terms in this section were originally published by the American Society of Heating, Ventilating and Air-Conditioning Engineers in Guideline 0-2005, The Commissioning Process (ASHRAE 2005). Glossary terms are used with the consent of ASHRAE.

Acceptance: A formal action, taken by a person with appropriate authority, which may or not be contractually defined, to declare that some aspect of the project meets defined requirements, thus permitting subsequent activities to proceed.

Basis of design: A document that records the concepts, calculations, decisions and product selections used to meet the owner's project requirements and to satisfy applicable regulatory requirements, standards and guidelines. The document includes both narrative descriptions and lists of individual items that support the design process.

Checklists: Verification checklists are developed and used during all phases of the commissioning process to verify that the owner's project requirements are being achieved. This includes checklists for general verification, plus testing, training and other specific requirements.

Commissioning: See commissioning process.

Commissioning authority: An entity identified by the owner who leads, plans, schedules and coordinates the commissioning team to implement the commissioning process.

Commissioning plan: A document that outlines the organization, schedule, allocation of resources and documentation requirements of the commissioning process

Commissioning process: A quality-focused process for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated and maintained to meet the owner's project requirements.

Commissioning process activities: Components of the commissioning process

Commissioning process progress report: A written document that details activities completed as part of the commissioning process and significant findings from those activities, which is continuously updated during the course of a project and usually incorporated into the commissioning plan as an ongoing appendix.

Commissioning process report: A document that records the activities and results of the commissioning process, usually developed from the final commissioning plan with all of its attached appendices.

Commissioning team: The individuals who through coordinated actions are responsible for implementing the commissioning process

Construction checklist: A form used by the contractor to verify that appropriate components are on site, ready for installation, correctly installed and functional. Also see checklists.

Construction documents: A wide range of documents that will vary from project to project and with the owner's needs and with regulation, laws and countries. Construction documents usually include the project manual specifications, drawings and general terms and conditions of the contract.

Continuous commissioning process: A continuation of the commissioning process well into the occupancy and operations phase to verify that a project continues to meet current and evolving owner's project requirements. Continuous commissioning process activities are ongoing for the life of the facility. Also see ongoing commissioning process.

Contract documents: A wide range of documents that will vary from project to project and with the owner's needs and with regulations, laws and countries. Contract documents frequently include price agreements, construction management process, subcontractor agreements or requirements, requirements and procedures for submittals, changes, and other construction requirements, timeline for completion and the construction documents.

Coordination drawings: Drawings showing the work of all trades to illustrate that equipment can be installed in the space allocated without compromising equipment function or access for maintenance and replacement. These drawings graphically illustrate and dimension manufacturers' recommended maintenance clearances.

Issues log: A formal ongoing record of problems or concerns and their resolution that have been raised by members of the commissioning team during the course of the commissioning process.

Nominal group technique: A formal, structured brainstorming process used to obtain the maximum possible ranked input from a variety of viewpoints in a short period of time. The typical approach is a workshop session where a question is presented, the attendees record their responses individually on a piece of paper, the individual responses are recorded on a flip chart without discussion in a round robin fashion, all of the responses are discussed, and then the participants rank their top five responses.

Ongoing commissioning process: A continuation of the commissioning process well into the occupancy and operations phase to verify that a project continues to meet current and evolving owner's project requirements. Ongoing commissioning process activities occur throughout the life of the facility. Some activities will be close to continuous implementation, and others will be either scheduled or unscheduled, as needed. Also see continuous commissioning process.

Owner's project requirements: A written document that details the functional requirements of a project and the expectations of how it will be used and operated. These include project goals, measurable performance criteria, cost considerations, benchmarks, success criteria and supporting information.

Quality based sampling: A process for evaluating a subset (sample) of the total population. The sample is based upon a known or estimated probability distribution of expected values; an assumed statistical distribution based upon data from a similar product, assembly or system; or a random sampling that has scientific statistical basis.

Re-commissioning: An application of the commissioning process requirements to a project that has been delivered using the commissioning process. This may be scheduled re-commissioning developed as part of an ongoing commissioning process, or it may be triggered by use change, operations problems or other needs.

Retro-commissioning: The commissioning process applied to an existing facility that was not previously commissioned. The same basic process needs to be followed from pre-design through occupancy and operations to optimize the benefits of implementing the commissioning process philosophy and practice.

Systems manual: A system-focused composite document that includes the operation manual, maintenance manual and additional information of use to the owner during the occupancy and operations phase.

Test procedure: A written protocol that defines methods, personnel and expectations for tests conducted on components, equipment, assembles, systems and interfaces between systems.

Training plan: A written document that details the expectations, schedule, budget and deliverables of commissioning process activities related to training of project operating and maintenance personnel, users and occupants.

Verification: The process by which specific documents, components, equipment, assemblies, systems and interfaces between systems are confirmed to comply with the criteria described in the owner's project requirements.

6.4 Appendix D: Creating a Request for Qualifications (RFQ)

This appendix summarizes the information that should be included in a request for qualifications for commissioning services. When developing a request for qualifications:

- Make sure the scope of work the commissioning authority will be responsible for is clearly defined.
- Provide an ample overview of the project and what systems are to be commissioned, as well as the size and location of the project.
- Provide a list of any building certifications, labels or goals and what work has already been done to achieve the certification, label or goal. This will help ensure accurate bids are received.
- Be clear that it is the responsibility of those submitting bids in response to the RFQ to follow the instructions of the RFQ carefully. This should include understanding how many copies are to be submitted, how proposals are to be formatted and the page limit, if desired.

Typical RFQ responses include the following information from the bidder. The points outlined below can be integrated into the RFQ as questions for the bidder to answer:

- Cover letter
    - Describes the firm submitting the bid and states that it understands the contents of the scope of work. It binds the bidder to its bid for a specific time period.
- Technical understanding
    - Using the systems list provided, indicate the type of work the bidder's firm is proposing to perform, such as the types of components or systems the firm will commission under the RFQ. Indicate the firm's technical experience with these systems.
    - Indicate the technical services the bidder's firm specializes in. Particular emphasis should be provided on the method of commissioning used by the bidding firm. Please describe the firm's technical expertise in building commissioning, specifically retro/recommissioning. Also indicate data-gathering methods for the scope of work proposed under the individual work assignments.
    - Show a thorough understanding of HVAC and control systems.
- Experience
    - Describe prior commissioning work performed during the last five years that is similar to the work being proposed under the RFQ. In particular, provide a list of projects, such as school, institutional, commercial and/or government buildings.
    - Provide a brief description of each project, including current client references with names, phone numbers and e-mail addresses; the dates services were performed; specific services provided; size and type of the project; and the project costs at completion.
    - List three client references served in the last 24 months, including name, address, phone number, e-mail and type of work performed.
- Qualifications
    - Describe how the work will be organized, managed and administered so that specified requirements are met.
    - Briefly discuss the firm's ability to coordinate complex projects and work with other people and firms.
    - Demonstrate the ability to accomplish the required tasks and deliver the final product(s) for the type of work being proposed under the RFQ within the specified times. Include the ability to present ideas and written materials in a clear and simple manner.
    - Provide an organization chart to describe how the work flow will go through the bidder's firm.
    - Submit a resume for each person that will be performing the work being proposed under the

RFQ. Be specific about what tasks each person will be responsible for. Provide sufficient information to demonstrate that minimum qualifications are met, and experience and expertise in building commissioning and work with the specific systems have been met. Resumes should focus on education, professional credentials and relevant experience. They should include a brief work history, length of service with the firm and current client references. Also use the resume to describe each individual's unique technical training and experience.

- Include a statement indicating the firm's commitment to maintaining the continuity of the assigned staff throughout the project and an indication that other qualified staff would be available should that not be the case.
- Provide a brief description of how the firm's approach to commissioning and organization could utilize the owner's staff and resources for the commissioning effort and what their tasks will be.
- Provide a brief statement indicating when the firm will be able to start working on this project.
- Provide work samples from past projects of typical written and graphic materials prepared for the type of deliverables for work being proposed within the RFQ. Typically, two samples are sufficient. Each work sample should include:
  - Copy of initial retro-commissioning plan
  - Sample of commissioning specification
  - Sample of functional testing procedures
  - Sample of inspection checklist
  - Sample of commissioning issues log
  - Copy of executive summary of final commissioning report

- Cost proposal
  - Identify hourly rates for all personnel, including subcontractors, who will perform work for the project. Identify personnel by position and the type of work they would perform, such as management, technical or support. Include variations in the rates, if any, for items such as travel time and report writing versus on-site work. Specify the time period for which the rates are guaranteed.
  - Provide the proposed lump sum for the proposed services as outlined in the scope of work provided.

6.5 Appendix E: Sample Scope of Work

The purpose of this appendix is to outline the scope of work performed by the commissioning authority (CxA). To begin, the CxA will conduct workshops with building occupants to develop the current facility requirements (CFR) and conduct an initial site assessment of the campus. During the site assessment the CxA will:

- Review existing design and construction documents, submittals, and operation and maintenance documentation
- Analyze several years of utility consumption data
- Conduct a walk-through of the buildings to observe design and operational conflicts impacting performance of the facility, including lighting, building envelope, and heating, ventilation and air conditioning (HVAC) systems

Specifically the CxA will:

- Assess the scope of the project and develop an optimum retro-commissioning plan and order of magnitude cost estimate
- Execute Phase 1 of the retro-commissioning plan
- Prepare the component verification report and recommendations
- Execute Phase 2 of the retro-commissioning plan, including system testing, system retrofits and retesting
- Enhance operations
- Complete Phase 1 deliverables
- Complete Phase 2 deliverables

Using the information gathered, the CxA will assess the scope of the project and develop an optimum retro-commissioning plan and order of magnitude cost estimate. This includes:

- Conducting an orientation meeting with the owner and occupant to review retro-commissioning process and activities
    - Identifying the level of participation of the owner and operational staff during the orientation meeting
        - Access to facility. It is assumed the occupant’s operational staff will provide master keys to retro-commissioning personnel or provide staff to accompany and open areas requiring access
        - Participation of occupant’s operations and maintenance personnel
    - Developing outline documentation needed from the operational staff
        - Utility bills for last three years
        - Central plant system details, such as steam, hot water and chilled water
        - Metering and sub-metering information, including locations
        - Complete as-built drawings and specifications
        - Test, adjust and balance reports
        - Control drawings with original sequences of operation
        - Maintenance documentation and records
            - Work order history
            - Preventative maintenance schedules and histories
        - Operation schedules
        - Construction submittals and operations and maintenance manuals

        - Controls contractor contact information
        - Access to building automation system
            - Trending
            - Control logic
    - Occupants and operators participation in current facility requirements workshop
- Conducting a current facility requirements workshop and identifying
    - Goals and objectives
        - Energy and water efficiency
        - Occupant comfort
        - Efficiency of maintenance staff and resources
        - Problems needing resolution
    - Benchmarks to measure attainment of goals and objectives
    - Current use requirements
- Performing a walk-through of all spaces
    - Identify retro-commissioning occupancy considerations, including impact on activities, level of interference, potential risks to personnel, and material and liability issues
    - Evaluation of the remaining life of equipment
    - Developing a general assessment of systems to meet user requirements
    - Assessment of available documentation versus identified documentation needed
    - Documenting preliminary issues identified
- Preparing a generalized retro-commissioning scope, plan and order of magnitude cost estimate of proposed commissioning activities including:
    - Updating current facility requirements
    - Utility consumption baseline development requirements
    - In-depth assessment and systems manual development requirements
        - Identify missing information necessary for assessment and systems manual development
        - Identify activities needed to develop facility information not found during the documentation review to be created during the execution of the retro-commissioning effort, such as testing and balancing (TAB) analysis to determine current airflow and water flow, or the development of sequences of operation that are not available
    - Execution schedule and budget
    - Measurement and verification requirements
    - Outline systems manual content and format
- Gaining the owner's approval of the proposed retro-commissioning scope, retro-commissioning plan and project cost
- Formalizing the professional services agreement, which reflects the scope of work agreed upon

After agreement is reached regarding the scope of work, the next step is to execute Phase 1 of the retro-commissioning plan, which includes:

- Reviewing and analyzing available existing documentation
- Analyzing existing physical conditions
- Analyzing historical energy consumption data
- Developing component and system verification test procedures
    - Mitigating potential risks associated with the component verification testing process, including security concerns
    - Notifying occupants and completing testing authorization procedures

- Sampling strategies, if appropriate
- Updating the commissioning plan and reviewing with the owner and occupant
- Performing component verification tests in accordance with testing procedures and communication protocols
    - Reviewing the results of component verification tests
    - Recording corrective actions already taken during the verification testing

The CxA then prepares the component verification report and recommendations, which include:

- Developing initial report that documents findings, conclusions and recommendations
    - Identifying performance goals compatible with existing systems capacities
    - Identifying dysfunctional components and repair estimates
    - Identifying actions needed to attain initial design intent or current requirements, such as modification of system controls, rebalancing and repairs, where appropriate
    - Operations and maintenance staff training recommendations
- Recommending additional services to be added to the retro-commissioning scope for owner's approval
- Suggesting modifications to the current facility requirements, retro-commissioning plan and project cost
    - Document energy and demand goals for building systems
    - Component and system verification testing procedures
    - Mitigating potential risk associated with the component verification testing process including security concerns
    - Notifying occupants and completing testing authorization procedures
    - Sampling strategies, if appropriate
    - Commissioning schedule

Execute Phase 2 of the retro-commissioning plan, which includes:

- Verifying previous issues identified for repair are complete and ready for testing
- Checking calibration and directing technician to, when possible, calibrate sensors and adjust actuators
- Performing system test procedures and documenting results
- Conducting up to two retests of contractor's repairs or changes; additional testing is generally at contractor expense
- Providing appropriate training for the owner's operations staff
- Performing systems diagnostic monitoring
- Developing retro-commissioning report, which should contain
    - Recommendation matrix with table of estimated capital costs
    - Issues log and disposition of issues identified
    - Actions taken
    - Plan of recommendations for outstanding issues resolution
    - Persistence strategy
    - Recommended training

The CxA can enhance operations by:

- Conducting training on how to efficiently operate the facility using problems identified as lessons learned, and recommending changes to operations and maintenance operating procedures.
- Providing a foundation of how to continuously improve performance. If desired, the commission-

ing authority can provide monitoring-based commissioning to identify when operators or contractors actions are negatively affecting building performance and provide training to assist with continuous improvement.

At the end of Phase 1 the commissioning authority should provide the following deliverables:

- Workshop with the owner and occupant/operations
- Meetings, as necessary, with occupant
- Current facility requirements document
- Initial commissioning report

At the end of Phase 2 the commissioning authority should provide the following deliverables:

- Final commissioning report
  - Executive summary describing the retro-commissioning process, methodology used and documentation of completed retro-commissioning activities
  - Introduction
  - Project background
  - Analysis
  - System evaluations, including issues log
  - Verification site visit, including test results
  - Conclusions
  - Recommendations, including capital cost table for remaining recommendations
- Systems manual
  - Index of key document locations for information not included in the systems manual
  - Current facility requirements
  - As-built sequences of operation and controls drawings
  - Set points
  - Operating instructions
    - Emergency situations for fire and power outages
    - Special seasonal adjustments
    - Special procedures for shut down for maintenance
    - Interaction between components and systems
    - Safety interactions
  - Recommended schedule of maintenance requirements and maintenance frequencies that is not already documented in the operations and maintenance manuals
  - Recommended schedule for retesting of commissioned systems with blank test forms
  - Recommended schedule for calibrating sensors and actuators

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