How Much Does Commissioning Cost and How Much Does It Save?

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While the commissioning process is recognized as an important component of reliable, persistent building performance; the technologies, practices and behaviors that cover the range of commissioning activities (hence their costs) are substantially unmeasured. Acquiring information to evaluate the DSM technical potential and prudence of commissioning as a measure in commercial buildings is the goal of this multi-team research study. This paper presents preliminary findings from this research effort designed to:

- Provide cost and savings data to help overcome the current "lack of information" barrier;
- Test new approaches and short-term diagnostic methodologies to reduce commissioning labor costs;
- Develop recommendations for a comprehensive commissioning program for commercial customers.

Introduction

Commissioning is the process of ensuring, verifying, and documenting that *new equipment and systems* are installed and able to operate according to the design intent. The reliable performance of DSM measures, and DSM measures' ability to continue to operate persistently over time will be critical to the long-term viability of utility efforts to acquire conservation as a resource. Until recently, DSM programs in general have effectively installed "parts" but have not directly dealt with the persistence and reliability of the performance of those parts. Increasing attention to commissioning demand side measures and the related systems ensures their performance, while attention to commissioning all energy using systems can be effective enough to constitute consideration of commissioning itself as a demand side measure.

Ideally, traditional building commissioning is a process that begins at the design stage of a project and follows through to the startup and operation of the building (Bonneville 1992). For utilities there are a variety of opportunities and degrees to initiate commissioning or affect the process. The best approach will depend on the utility's DSM program design, customer relations and philosophy, the role of trade allies and the construction community, costs, etc. This project is intended to provide information to answer some of those questions for a utility in southern California.

As noted above, ideally the commissioning process begins as early as possible in the design or construction stage of a project. This study, however, has been designed to take advantage of the commercial building models and metered data available for a range of existing buildings in the utility's service territory. The buildings investigated range from 2 years to over 20 years in age. Therefore, this pilot commissioning study does not involve commissioning activities typically occurring during the design of a project and, as such, the study can best be characterized as an existing building commissioning project. The main difference between new building commissioning and existing building commissioning is the reconstruction or restructuring of design intent to meet the building owner and occupants' present needs. Another consideration is the interface with the commissioning process of existing operation and maintenance (O&M) practices, and the need for O&M repairs to equipment before proceeding. To the extent possible, we have selected newer existing buildings or existing buildings with newer equipment to allow us to focus more on commissioning issues and what could have been saved had commissioning been done in the first place. For the purpose of this paper, the word commissioning will be used to mean both commissioning new and existing buildings.

Research Approach and Objectives

This project is designed 1) to demonstrate the associated costs and benefits of commissioning typical commercial buildings in southern California, 2) to provide an estimate of the demand-side management technical potential in the utility's service territory from commissioning activities, and 3) to make recommendations for appropriate commissioning services offered as part of the utility's commercial programs. To achieve these objectives, there are two parallel research tracks with interactions at key points. One track investigates current commissioning practices and demonstrates the commissioning process at seven sites using standard performance testing as well as short-term diagnostics. The parallel track provides an analysis of commissioning potential through pre- and post-commissioning monitoring, and the application of DOE-2 models to extrapolate commissioning potential for the service territory.

The project team performed 50 on-site assessments to identify potential pilot program participants, to characterize the degree to which building commissioning occurred in the utility's service territory, and to obtain building data required to create or update the DOE-2 models for each building. Information from the on-site surveys was used to identify problems with mechanical systems and lighting controls which could potentially be fixed by commissioning, to evaluate O&M procedures, and to gain experience in modeling non-commissioned buildings. From this information, preliminary DOE-2 models for each of the 50 buildings were developed, one for "as-observed" operation and one for "fixed" operation resulting from commissioning. The difference between these two models provides a first estimate of the savings potential from a building.

More specifically, the as-observed models, which show pre-commissioning energy use patterns, are calibrated to monthly billing data for the buildings, to provide confidence that the models are reasonable representations of the actual buildings (Alereza and Dohrmann 1993). These models are run using actual weather data for a time period corresponding to the available billing data for the site. For most buildings, the time period is represented by twelve consecutive months. For buildings which have been occupied for less than one year, the time period represents the months that the building has been occupied, but in no case is the time period less than six months. The energy results are compared to actual consumption indicated by the billing history. Annual energy use, peak demand and monthly usage are compared and the building model calibrated to within approximately 10 percent of the billing data. The adjustments made to the model to more closely match observed energy use are based on the on-site assessments of likely commissioning problems at each site. These adjustments include modifying the building operating schedules, modifying HVAC systems and operations (such as economizer operation and reducing air flow) to allow for simulation of non-ideal building operation. This set of building models will be revisited later in the project after more detailed pre- and post-commissioning end use monitoring has occurred in the subset of seven buildings.

Our next step is to select seven suitable buildings and proceed to actually commission them. From this activity examples of actual building problems are identified and the steps and costs required to fix them are tracked. These sites are metered for three months before and three months after the commissioning process to further refine the building models and gain more precise estimates of commissioning impacts.

Current Commissioning Practices

Surveys

Our first task was to collect information on existing guidelines and standards for building commissioning in the commercial sector in order to characterize current industry practice. This was done by contacting national organizations that have or are planning to publish commissioning guidelines, standards, or data. Out of 72 organizations contacted, 42 had developed documents that addressed the commissioning process in some manner. From these 42, approximately 44 guidelines, standards, manuals, or codes had been published (Dodds and Haasl 1993).

This literature search was followed by a telephone survey of "targeted" professionals who had performed commissioning in the utility's service area. Results from this survey characterized the extent of commissioning practice among active practitioners that was expected to occur in new commercial construction as well as provided context for program recommendations that will be developed at the conclusion of the study (Haasl 1993). The list of targeted professionals included individuals and firms known by the researchers to actively be working on commissioning projects, individuals certified by the National Environmental Balancing Bureau, engineers qualified as commissioning agents by a neighboring utility, and firms recommended by the client utility.

The survey was performed by telephone to enable respondents to discuss the questions and offer remarks about the commissioning process and the state of the market. Designed to elicit both objective and subjective information from the participating commissioning professionals, our intent was to provide participants with an opportunity to openly express opinions about commissioning success, methods and costs. The purpose was *not* to

rate or in any way judge level of performance or market penetration, but to identify and characterize the activities that affect delivery of commissioning services. To obtain the broadest spectrum of information, including experience with costs and industry obstacles, confidentiality was guaranteed to each participant prior to beginning the interview.

Preliminary results show that all but one of the firms described their experience as primarily systems commissioning as contrasted with whole building commissioning. Seventy-five percent of the participating firms had primarily commissioned office buildings. All other building types represented less than half of the sample. Fourteen of the sixteen subjects stated that the buildings they commissioned were owner-occupied. The other two had commissioned only tenant-occupied office and/or industrial buildings. The owner-occupied buildings frequently offered additional lease space for multi-tenant occupancy.

The emphases of normal commissioning practices are clearly on HVAC, controls, and EMCS. Only two of the surveyed firms verified energy efficiency performance of the building shell. The interviewers recognize that *commissioning* is not yet a universally understood term in the design/build industry, although it is more and more commonly accepted, and is generally used when its meaning is understood by all parties. We found the phrase performance verification also is often used instead of commissioning to describe or sell the service.

Commissioning firms are most often hired by the owner. The experience of the surveyed firms indicated that the owner or an agent of the owner was the driver for securing commissioning services. For the most part, unless they were hired through a utility program, the firms were not hired specifically as commissioning agents. Their role in building performance usually is defined as a design team member or a test engineer. Although they believe commissioning is a discrete service and should be sold with a separately negotiated fee, they find that it is not always possible. Clients do not approach them by asking them to do a "commissioning" job.

The survey participants were also asked to identify the commissioning task(s) that require the greatest time and expense to complete. The greatest proportion of commissioning time and expense is concentrated on functional testing, including both writing test plans and performing the actual tests. Respondents willing to share cost information indicated they had spent anywhere from 48 hours (small area) to 2,000 hours (2.5 million square foot complex building) commissioning their largest projects, depending on the size, complexity, number of failures during testing, and the phase of construction at which they entered the process. Regardless of size, all estimates of the amount of time required for performance testing ranged between 40 percent and 80 percent of the commissioning project, with an average of about 60 percent.

As anticipated, a basis for costing commissioning separately has not been established by most of the firms interviewed. Most participants charged on a time, expenses and materials basis, quoting a not-to-exceed number for all but fixed costs. Generally a fixed price is not offered, although one company provides a cost range ($0.25-$1.25/sf) to give customers an idea of the possible total cost.

On-Site Assessments

The next step in our investigation of commissioning practice and service territory potential involved on-site assessments of 50 commercial buildings. Selection of a representative sample of commercial buildings in the utility's service territory was made using three existing data sets previously developed by one of the team members. These data sets included an air-conditioning study set and an end-use monitoring study set that provided several months' of baseline operational data for several of the buildings. The sample is described by building type in Table 1 and included both newer (2-3 years) and older (3 to more than 20 years) existing buildings.

The objectives of the on-site assessments were to continue to characterize the degree to which building commissioning occurred in the utility's service territory and to identify potential pilot program participants. The on-site survey instrument was designed to:

- Identify actual commissioning practices previously performed
- Investigate availability of building documentation which included the original design intent, owner information, and as-built documents
- Query operation and maintenance processes followed
- Identify, to the extent possible, probable malfunctioning systems or components
- Identify building problems/complaints
- Identify problems that might make commissioning unusually difficult or impossible, such as the owner's willingness to participate as a pilot project site

The analysis of the on-site survey results is in progress. None of the 50 buildings surveyed have gone through a formal commissioning process. Questions we are looking

Table 1. Overview of 50 Buildings Receiving On-Site Assessments

Type	# Bldgs	Sq. Ft. Range	System
Office <50,000 sf	13	1,300 - 43,680	5 Built-up; 8 Package
Office >50,000 sf	4	51,500 - 266,900	3 Built-up; 1 Package
Retail	10	3,060 - 178,000	1 Built-up; 9 Package
Grocery	7	2,150 - 51,072	3 Built-up; 4 Package
Restaurant	6	11,260 - 12,300	Package
School	6	20,060 - 102,140	Package
Misc. (Church, Rec)	4	7,000 - 60,000	Package

at include: how many of the buildings had service contracts compared to in-house maintenance staff, what are the ownership characteristics - national account, institutional and local government, private ownership or corporate, etc.; and what types and age of equipment was found?

DOE-2 Models: "As-Observed" and "Fixed"

In addition to gaining a greater understanding of commissioning practices in the utility's service area, the on-site visit also was designed to collect building data and/or confirm and refine previously collected data required to create or update DOE-2 models for each of the 50 buildings. Information collected to model the "as-observed" buildings included:

- Current building description
- History of expansions, upgrades, or downgrades to the existing (as opposed to new) buildings surveyed including additional HVAC equipment
- Updated schedules
- Updated set points
- Obvious broken or poorly maintained equipment or systems
- Information on building and equipment operation
- Calibration of controls

Information from the on-site surveys also was used to identify measures which could potentially be fixed by commissioning, and to determine how to model a non-commissioned building. As described above, preliminary DOE-2 models for each of the 50 buildings are being developed, one for "as-observed" operation and one for "fixed" operation resulting from commissioning. The difference between these two models will provide a first estimate of the savings potential from the commissioning of a building.

Pilot Sites

In this phase of the project we are selecting seven pilot sites for commissioning; five from the fifty that participated in the on-site assessments and two newer buildings that have participated in the utility's new construction DSM program. These seven sites represent a range of building types and a variety of mechanical equipment systems commonly installed in commercial buildings.

Because this is ultimately a DSM potential study of building commissioning, it is necessary that we acquire clean measurements of energy savings attributable to commissioning. The best and most practical way to do this is with metering of each site before and after commissioning. These data are collected for a long enough period to develop data on HVAC system operating characteristics. Typically, three to six months of data are sufficient for this purpose.

Site Selection and Recruitment

Participation in the project involves the building owner signing a contract that outlines the responsibilities of Edison and the building owner, the extent of building commissioning performed, monitoring requirements, payment arrangements, schedules and definition of information that will be provided to participants about their buildings. The commissioning pilot site selection process has given consideration to end-use monitoring

requirements since any project which cannot be properly monitored will not be useful to the overall objectives of the study. The buildings selected for participation are briefly described in Table 2.

Monitoring

Pilot building with existing end-use monitoring data immediately enter into the commissioning phase of the project. Monitoring at those buildings that have never been monitored will be conducted for three months. In these buildings the electric load of the commissioned equipment will be metered to provide before and after detailed energy use information. The equipment load profiles will be recorded on a periodic basis to collect time-of-use information. As necessary, indoor temperature loggers will be installed to record variations in the indoor temperature. The metering will provide information on the total energy and demand usage of the equipment as well as information on the equipment operating patterns.

Commissioning Plan

The building-specific commissioning process includes writing and implementing a commissioning project plan and final report with recommendations for building fixes. Four of the sites will be commissioned using a traditional test approach, while at three of the larger sites we will use pre- and post-commissioning short-term diagnostics. All labor and building fix costs associated with the implementation of the commissioning plans, conducting pre-functional and fictional tests, and performing fixes will be tracked.

The commissioning plan customized for each site describes the commissioning process from start to finish. The primary purpose of this outline is to provide the commissioning team with a comprehensive planning road map necessary to accomplish the commissioning. It includes:

- Commissioning objectives
- Scope of the commissioning process
- Responsibilities and requirements of each party involved in the process
- Schedule and timeline of events
- Documentation requirements
- Building/System description
- Short-term diagnostics requirements
- Pre-functional test requirements
- Functional test requirements
- Identifying requirements for needed fixes
- Operation and maintenance manual requirements
- Operation and maintenance training requirements

Table 2. Description of 7 Buildings Participating in the Project

Type	Sq. Ft.	kWh/sf	System Type	System Age	Control	O&M
Office (City)	43,660	14.78	Built-up	1994 rebuild	EMCS	In-house except chiller rebuild
Office (City)	51,500	17.4	Built-up	Built-up 1978, SZS 1992	Pneumatic	In-house and Contractor
Office	152,000	17.4	Packaged RTUs (120 ton)	1993	EMCS	In-house
Library (City)	72,000	10.3	Built-up	1992	EMCS	In-house
Grocery	30,427	49.22	Built-up	1983	Electric	In-house
Retail	143,000		Built-up/Evap Pre-Cooler	1991	EMCS	In-house
Retail	166,777	23.65	Package RTUs; minor built-up	1990	EMCS	In-house

Commissioning Applications for Short-term Diagnostics

The objective of the short-term diagnostic tests at three of the seven sites is to demonstrate that systems being commissioned are operating and complying with specified performance requirements through all modes of operation occurring during the test period. Using data loggers to obtain continuous measurements on equipment and system performance in each building over a two-week period, we analyze this data to help identify equipment and systems that need further investigation and/or fixing.

The objective is to clearly identify specific building system operational problems and prepare specifications for solutions which fix these problems. For example, short-term diagnostic tests might indicate that capacity is much lower than the nameplate rating of a particular piece of equipment. This information is then used to develop functional test plans for those system components that may be contributing to the problem.

Short-term diagnostic tests using the same data loggers will be repeated to collect data on the equipment performance after the initial set of problems have been identified and corrected. This analysis allows us to assess the effectiveness of the repair procedures and make recommendations for correction to remaining problems, if appropriate. The duration of these tests will vary from one to two weeks depending upon the system being investigated.

Super Commissioning

The utility has requested that the team identify super commissioning opportunities in the pilot projects; that is, where energy savings might be realized beyond the normal commissioning process through the retrofit of new measures or other equipment. This task involves going beyond the "design intent" and could potentially involve expanding the scope of work to quantify the potential benefits of the improvements.

Commissioning Potential

DOE-2 Models Revisited

DOE-2 models similar to the "as-operated" and "fixed" models developed for the 50 buildings will be created for each of the pilot project sites. The as-operated (pre-commissioning) models will provide baseline estimates that can be used to later estimate the energy savings from commissioning. Using three months of end-use monitoring data, models of these seven buildings will be calibrated to closely match the observed energy performance of the equipment, not only in terms of total energy and demand usage but also in patterns of usage. For the three buildings with short-term diagnostic data, the models also will be adjusted to reflect information about building system efficiency and operation obtained from this testing.

Next we will take these "as-operated" models and re-adjust them to reflect how we anticipate the buildings will operate after commissioning. These "fixed" models provide preliminary savings estimates before the buildings are actually commissioned.

At the completion of the commissioning process, post-fix short-term diagnostic test data and three months of post-commissioning monitoring data will be used to refine the "fixed" DOE-2 models to reflect the post-commissioning building operation. These direct measurements of the energy and demand consumption differences will be attributed to the commissioning activities and changes that occurred in the building during the participation in the project. To the extent possible, the pre- and post-monitoring data will be normalized to account for variation in weather conditions.

The information developed in making these refinements to the seven commissioned buildings and their energy savings will be used to improve the savings potential estimates for the 50 building sample. The models of the 50 building sample will be refined based on the experience gained in refining the models of the seven commissioned buildings to reflect the measured energy and demand savings.

Extrapolating to the Service Area

Based on the savings estimates generated from the DOE-2 runs for the sample buildings and using the statistical weighting developed in the original sampling work, the savings potential will be projected back to the population of commercial buildings in the utility service territory. Several estimates reflecting the sensitivity analysis variations for the systems in the individual building models will be produced. This will improve the system wide estimates of energy savings potential. The results will be a range of estimates of the DSM potential of commissioning for the service territory.

Program Recommendations

The final report on the project findings will recommend conceptual program design components for a building commissioning program covering the commercial sector of the utility's service territory. We will outline a set of conceptual program components that includes and expands upon the following:

- Program introduction, purpose, goals
- Eligibility or screening criteria
- Commissioning and recommissioning protocols, standards, and procedures
- Document requirements, including:
  - Scope and outline of commissioning process
  - Design intent formats
  - Field-test procedures
  - Market-segmentation priority
  - Training

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