Building Commissioning for Demand-Side Resource Acquisition Programs

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Experience in demand-side resource (DSR) acquisition programs points to the need for commissioning of energy conservation measures, so that expected savings can be realized. One approach to defining and implementing cost-effective, programmatic commissioning is described. The application of this approach to several buildings participating in a DSR program for new commercial buildings and major retrofits is discussed. Key elements of this commissioning approach include training for qualified commissioning agents, use of standardized forms and procedures, a comprehensive approach to developing field test plans, and training for building operators. Early experience indicates this commissioning process effectively identifies and solves problems. Commissioning procedures are further refined in response to field experience.

Introduction

Building commissioning is a topic of great interest in demand-side resource (DSR) circles. Everyone with program experience in the commercial sector has stories to tell about efficient technologies that were only half as effective as they should have been because of installation problems--an outside air damper was stuck open, a sensor that fed information to the controller was wired backwards, the controller was programmed wrong, and so on. These are some examples of the type of problems commissioning can prevent.

There are several reasons why commissioning has become more critical in the past 10-20 years:

(1) Building systems have become more diverse--there are many more systems with which designers and installers must be familiar;

(2) Building systems, particularly controls, have become more complex;

(3) HVAC systems are being designed with less excess capacity;

(4) Increasing energy costs make efficient operation more critical; and

(5) Building codes are becoming more stringent: energy codes mandate reduced energy use at the same time that health and safety codes mandate minimum ventilation rates and air quality standards that tend to result in increased energy use (Trueman 1989).

The experience of Energy Edge, a Bonneville Power Administration program to promote energy efficiency in new commercial buildings, shows that even when a commitment is made by the owner to build an efficient building, energy conservation measures (ECMs) do not always deliver savings. Specific examples include economizers that did not work, daylight-sensing controls that were not properly installed or calibrated, back-up heating that delivered only half the capacity specified in the HVAC design, and complex programmable thermostats that were routinely programmed wrong.

When commissioning deals with such problems, both the owner and the utility benefit. The owner gets a building that operates as intended, which usually translates into a more comfortable building that costs less to operate. The utility benefits because the risks associated with investing in energy efficiency in lieu of a new power plant are reduced.

Commissioning is a vital part of The Energy FinAnswer, Pacific Power's DSR program for new commercial construction, but defining the scope of commissioning proved to be a difficult task. To some installers commissioning simply means their equipment start-up tests. At the other extreme is a definition encompassing complete verification and documentation of the operation of all building systems and equipment. Yet another variation of commissioning focuses on occupant comfort and satisfaction, including indoor air quality analyses. The focus of the commissioning process described in this paper is the energy-efficiency of the ECMs funded by the utility. The following definition reflects this focus:

> Commissioning is a set of procedures, responsibilities, and methods involved in advancing a total system from a state of static physical installation to a state of full working order in accordance with the design intent. At the same time, the operating staff are instructed in system operations and maintenance.

As commissioning procedures continue to evolve, the primary concern is that they support the savings goals of the DSR program. In order to do this, commissioning must (1) be cost-effective; (2) contribute to customer satisfaction; (3) ensure that the installed ECMs deliver the intended energy savings; and (4) be efficiently managed in order to keep pace with the increasing volume of projects.

Program Background

A brief description of the Energy FinAnswer program will help to establish the context for the commissioning procedures which are the topic of this paper. This program offers financing and engineering services for new commercial buildings larger than 12,000 square feet and for major remodels that include efficiency improvements affecting at least 50 percent of the building's walls or windows. Those who participate in the program receive up-front funding for the incremental costs of installing ECMs, which may include windows, lighting, insulation, HVAC systems, or other measures that, as a package, reduce electricity consumption by at least ten percent, compared to state energy codes. Through an energy service charge, the utility's initial investment in efficiency improvements is recovered directly from the beneficiary. The interest rate associated with this charge is based on the prime rate and the term varies from building to building, with a maximum of 20 years. Participants realize a positive cash flow because the total monthly bill, made up of a reduced electric bill plus an energy service charge, is less than what they would have paid without the investment in energy efficiency.

The utility works closely with the owner's design team in the early stages to identify energy conservation opportunities. The DOE-2 energy-use simulation model is used to develop energy savings estimates for applicable ECMs; these estimated savings become the basis for setting funding limits. Throughout measure installation and start-up, the program's inspectors and commissioning agents (CAs) make sure that all funded measures are installed properly and operating at optimum efficiency per the designers' intent. CAs are also responsible for training building personnel in proper operation and maintenance of equipment so that savings can be maintained over the life of the ECMs.

When the building is completed and sufficient measured energy consumption data have accumulated, the actual performance of the building is compared with the predicted performance. If the savings have not been realized, the owner's obligation to repay the ECM funding is reduced accordingly, provided the measures have been installed and the building occupied as specified in the contract the owner signed with the utility.

First-hand Energy Edge experience as well as ample anecdotal evidence led the DSR program developers to include a commissioning element from the start. Even with the best of intentions, important design or installation details may be overlooked, especially as a project approaches the deadline for completion. Energy efficient equipment and building systems should not be expected to save energy unless they are commissioned.

Initial development of commissioning procedures began in late 1989. The draft ASHRAE commissioning guidelines were already in print and development of the Bonneville Power Administration's commissioning how-to document was underway. In some respects the development of commissioning protocols for a specific DSR program was easier than these more general approaches, because the structure of the program to be supported was known. For example, commissioning costs had to be within defined program cost-effectiveness limits because the program was committed to minimizing the rate impact on the utility's non-participating customers. Also, since commissioning served as the verification mechanism for installation of certain ECMs, it had to be completed in a timely manner so that payments to the building owner could be made. These real program issues set limits on the cost and time that could be spent in commissioning, which in turn determined the scope of activities to be included in a commissioning job.

In the protocol that was developed, CAs are under contract to the utility and are paid directly by the utility. While a CA from a network of contractors is assigned to each of the projects, the program management and technical oversight team remains constant. This team takes on responsibility for adjusting commissioning procedures to incorporate lessons learned in each of the jobs. Such a programmatic approach becomes a type of demonstration project, providing a working model of the commissioning process. Further, when the utility requires commissioning of all funded ECMs, it signals to building owners the value of commissioning in achieving savings. Another advantage of CAs being under contract to the utility rather than the building owner is that commissioning remains a separate task from construction work. The CA is free to focus on verifying that design intent is being met, without

the possibility of being pulled away to help with last-minute construction details.

While this approach puts a heavy management load on the utility, similar effort would be required to verify that adequate commissioning had been carried out under the building owner's direction. As the number of completed jobs grows, there will be a basis to judge whether some of that direct control over the commissioning process could be relinquished without reducing the quality of the work.

The Development of a Commissioning Protocol

The initial set of commissioning "tools" included formats for recording the design intent (building envelope description, lighting design, and mechanical design--design conditions, load calculation method, internal load assumptions, ventilation requirements, equipment schedules and sizes, intended operation, seasonal factors and part-load performance, and fire and life safety requirements) and for writing a field test plan and recording the results of field measurements. From this basis field testing began in August 1990, with the understanding that lessons learned in the field would direct the evolving commissioning protocols.

One of the early jobs resulted in adding a "pre-commissioning" step to the process. In pre-commissioning the CA defines specific tests to be run by the installer to verify that the equipment and controls are actually operational. Once these tests are completed and documented, the CA can proceed with more detailed testing. Such a sequence will reduce the chance that the CA will travel to the site only to find that field testing is impossible.

In preparation for a May 1991 workshop to train a group of CAs, the components of a commissioning job were put together into a coherent package. Some aspects have been fine-tuned since that first training, but the basic structure has not changed.

Field experience since that training has highlighted the importance of maintaining a manageable system, including assigning jobs, reviewing commissioning plans, and responding to the results of field work. Direct field supervision of CAs is not possible--both because of the number of jobs going at one time and because these jobs are spread across Washington, Oregon, California, Idaho, and Utah. This implies the need for confidence in the CAs who are doing the work, and conscientiousness about maintaining contact with them. One tool for relaying general information to CAs is a periodic newsletter that covers new improved procedures, lessons learned through current jobs, and hints, tips, and warnings to help jobs go smoothly. CAs in turn are responsible for submitting regular status reports of work in progress. As appropriate, their comments are also relayed back to the front end of the program, where sales contacts are made and energy modeling is done. A final communication link occurs when the sales staff provide feedback on the implementation of commissioning procedures from their field perspective and contact with the customer.

A Commissioning Protocol

The following is a summary of the commissioning protocol currently in use.

Commissioning Steps

Commissioning is effectively quality control work. When a building owner enters into an agreement to install a specified set of ECMs and signs the participation contract, a commissioning agent from a network of contractors is assigned to the job. Depending on the project, the building may be still in the design phase, or it could be under construction and just a few weeks from completion. In either case, preliminary information on the project is reviewed and a commissioning scoping meeting is scheduled.

Scoping Meeting. The primary goals of the commissioning scoping meeting are to (1) introduce the CA and the commissioning process to the key players from among the owner's designers and contractors, (2) establish the roles and responsibilities each of them will take, and (3) set the schedule for completing the various tasks. In addition to the owner's team and the CA, the field sales person who made the initial contact with the customer also attends; and for novice CA's, the technical coordinator is present to help coach them through the process.

At times it is difficult to get the appropriate members of the construction team to take the time for a meeting. But the information exchanged at such meetings often proves invaluable to the owner as well as the commissioning agent. In one case, when a dozen people had reluctantly assembled for a scoping meeting, it was discovered that several members of the owner's team had been looking for an opportunity to talk to each other. Issues they dealt with among themselves included (1) finalizing the specifications for equipment that had to be ordered immediately and (2) making arrangements with a supplier for ongoing remote monitoring of equipment performance. When the formal meeting ended, the owner's team stayed on and dealt with other issues that never seemed to get the necessary attention when they were on the job site together.

Design Intent Documentation. The owner's design team is asked to supply details of the design intent. Thorough design intent documentation can serve as an invaluable guide for commissioning work. While the physical size of the document forms can appear rather formidable to the architect, or whoever is coordinating the effort to get the information, the requested information should be readily at hand in their own project documentation. Extensive work is required only when the designers have not been conscientious in their record-keeping.

Commissioning Outline. Based on the preliminary information, the CA writes a commissioning outline. This document lays out the entire commissioning job before any work actually begins. A standard format is provided that requires the following information: (1) proposed schedule for completing all of the work, (2) roster of the commissioning team (including representatives from the owner's team and the DSR program management), (3) responsibilities expected to be covered by the owner's contractors, (4) information yet to be supplied by the owner's design team, (5) equipment and system features and modes of operation to be tested, (6) monitoring requirements, and (7) building operator training topics. While the outline is not long, it is detailed enough to allow the commissioning technical coordinator to review the proposed approach and recommend any necessary changes before the job gets underway. It also provides the structure for the CA to begin to put together a complete plan for what must be done in the field.

One key step in assembling the commissioning outline is to decide what should reasonably be included in the scope of commissioning. Commissioning is limited to funded ECMs, but in some cases the performance of a funded measure is tied to that of a non-funded measure in such a way that when the latter fails it eliminates the savings from the funded measure as well. In such cases the CA must judge whether it is reasonable to broaden the scope.

The following guidelines have been set up to help CAs set appropriate limits to the scope of work:

(1) In the case of ECMs that are subject to automatic controls, commissioning must extend to the level of the controls.

(2) Virtually all HVAC ECMs should trigger an owner-funded and CA-inspected HVAC system test and balance. Often an improper air or water flow can directly contribute to the defeat of an HVAC ECM. But even where the defeat is not a direct result, improper flow often influences the building operators to make HVAC system adjustments which in turn defeat the ECM.

(3) Any ECM that can be defeated by operator ignorance should trigger compilation of a section for the operations and maintenance (O&M) manual and training of the operators.

(4) ECMs whose savings depend on efficiency improvements should trigger efficiency measurements. Examples might include efficient motors, heat recovery devices, efficient compressors, efficient kitchen exhaust hoods, and so forth.

Pre-Commissioning Tests. As mentioned above, field experience resulted in adding a pre-commissioning step to the process. The CA is responsible for defining the pre-commissioning tests to be carried out by installation contractors. Such tests serve to verify that the equipment and controls are actually operational. The CA also assumes responsibility for reviewing the test results, waiting to begin functional performance testing until the pre-commissioning tests are satisfactorily completed. While this step is not appropriate for all projects, its inclusion will cause the CA to anticipate problems in an installation and take steps to minimize them.

Functional Performance Testing. Functional performance testing is often seen as the heart of commissioning. To guide CAs through the planning process that must take place before field work, they are given guidelines on how to approach the project and a recommended structure for the written plan. No two buildings are alike, so test procedures for various systems cannot be pre-written. Instead, the CA must ask questions and collect information to be used to develop the comprehensive commissioning field-test plan. Answers to the following questions will have an impact on the final plan:

(1) Is the design adequate to the task at hand?

(2) Were the proper hardware components installed and were they installed properly?

(3) Are control sensors and other pieces of control hardware properly calibrated?

(4) Are control set-points appropriate to the task at hand?

(5) Does system operation follow the intended control sequence? Do the correct gross controlled actions occur in response to the correct stimuli?

The CA defines and carries out tests to determine whether systems are operating as intended. For highly specialized systems the installer or supplier may be brought in to help define or carry out testing.

End-Use Monitoring and Seasonal Testing. Field testing usually relies on observations recorded during one-time measurements. However, in some cases continuous measurement over an extended period of time or during more than one season would be valuable. The primary function of monitoring in this program is to serve as an extension of functional performance testing, and it is written into the field test plan. CAs are encouraged to consult with monitoring specialists, either on their own or through the utility, when preparing monitoring plans.

Possible variables for monitoring include (1) equipment and lighting circuit power, to track control functions; (2) damper position, to track economizer or heat recovery controls operation; (3) temperature, including indoor, outdoor, supply air, and mixed air; and (4) computed values such as run-time, maximum value, minimum value, and conditional average.

The utility has a few multi-channel data loggers that are available to CAs, as well as some small one-function loggers with built-in data storage capacity. Additional monitoring is possible in many buildings through their central energy management systems.

Operations and Maintenance Summary and Training. It is essential that the O&M staff of a building know what must be done to maintain energy efficient operation over the life of the ECMs. Without this commissioning of the human element, energy savings can be quickly lost. O&M commissioning tasks take two forms. First, the CA is responsible for gleaning the most important information from the collected O&M manuals for the project. The second responsibility is to verify that the building personnel have been adequately trained in both daily operations and periodic maintenance requirements. Depending on the project, adequate provision for training may already be provided by the owner. The CA is responsible for reviewing existing contractual agreements for training, then supplementing this training as necessary. Because the program encounters such a wide range of building sizes and functions, O&M training may include an additional session at the product manufacturer's training facility for the building operator. In other cases it will be a matter of showing the office manager how to maintain appropriate set-points and schedules on a programmable thermostat. The CA's goal is to review and supplement training that is already being provided.

Documentation. In addition to status reports on work in progress, CAs also submit two types of final reports. An ECM Report is completed for each measure that is subject to commissioning. These reports indicate whether the measure complies with the description given in the owner's agreement with the utility and whether it is properly installed and operating as intended. Any non-conformance that has been observed is summarized in the ECM Report. This report becomes the basis for making final payment to the owner for that ECM.

The Final Report is a summary of the full commissioning job for a building. As such, it includes the following information:

(1) A brief characterization of the building location, occupancy, construction, mechanical systems, and ECMs;

(2) A copy of the pre-commissioning test procedures and results;

(3) A copy of the functional performance test plan and results of field tests;

(4) A summary of the monitoring effort and the resulting data;

(5) Operations and maintenance procedures, training plan, and report on implementation of training plan;

(6) Design intent documentation; and

(7) Equipment submittals.

Commissioning Agents

Approximately 20 contractors with experience in the fields of engineering design, air and water testing and balancing, systems trouble-shooting, and equipment installation compose the CA network. As each commissioning job is assigned the utility provides the CA with a package of information specific to that project; in addition, the commissioning technical coordinator provides oversight and direction to the CA. The coordinator, who is familiar with the broader context of the DSR program and has a wide range of technical experience including commissioning and system design and trouble-shooting, is responsible for reviewing test plans, the results of field work, and reports. This guidance is critical in keeping the

commissioning process on track while CAs become familiar with program requirements and program management becomes familiar with each CA's performance record. As CAs gain experience, the oversight required in the early years of the program is expected to decrease.

CA Qualification. Potential commissioning agents are screened using a qualification criteria checklist. The use of such a list for self-screening is not perfect, but it allows program management to specify the skills and experience CAs must have. Among the key requirements are (1) a demonstrated ability to schedule and manage large construction projects; (2) control system experience, including design, specification, and trouble-shooting; and (3) a range of experience from among equipment design, installation, and troubleshooting; familiarity with instrumentation or monitoring; large building equipment start-up; testing and balancing; and participation in government or utility programs.

Training. Qualified persons must also attend a two-day training workshop to familiarize themselves with specific program requirements and with the program's perspective on commissioning. About 20 percent of the training time is used to establish the context in which commissioning takes place, including a description of the overall DSR program, reporting requirements, and contractual details. The rest of the training focuses on how to get the job done, with roughly equal time periods allowed for how to plan the field tests and how to carry them out, and about half that amount allotted to a discussion on training building staff for ongoing equipment maintenance and operations. Program-specific topics are covered by the utility's management personnel while the commissioning technical coordinator takes responsibility for material related to planning and carrying out field work.

Experience To-Date

Thanks to successful marketing efforts, the number of buildings moving through the commissioning process is growing. By the end of May 1992, 25 projects requiring commissioning had signed on with the DSR program. Commissioning work is being carried out in ten of these projects and another nine are expected to start soon (see Table 1).

Lessons Learned from Early Commissioning Jobs

On-the-job testing of these commissioning procedures has yielded a number of lessons about the process, some of which will be discussed here. It should also be noted that certain aspects of this process have not been tested yet. Most notably, developing and implementing a training plan for building personnel in a large project has not occurred, either because the projects are not yet to that stage or because training was provided by the installation contractor.

What Has Worked Well. CA training has proved to be useful not only in preparing CAs to implement the procedures in the field, but also in leading program management to think through the entire commissioning process in some detail in preparation for conducting the training workshop. Because there is a very specific protocol for doing the work, the desired end-product is unlikely without training. The CAs, talented professionals with field-proven skills, report that the training is useful in helping them to keep on track to meet program expectations. Two-day intensive workshop have proven to be an efficient method for communicating a lot of information to a group of potential CAs.

Technical review of CAs' work is especially critical at the beginning of the program, since it will take time for them to fully understand program requirements and objectives. In effect, the technical oversight is an extension of classroom training. Among the specific responsibilities included in overseeing the work are enforcing deadlines to ensure that work is done in a timely manner and intervening when the commissioning process appears to be misdirected.

Several standard forms have been developed for the commissioning program. Some, such as status reports and test plans, impose a discipline that would not otherwise be there to fully document progress and field work. Other standard documents that have proven successful are a commissioning outline, a standard agenda which can be used for commissioning scoping meetings, and the task order agreement used to assign commissioning jobs.

Commissioning scoping meetings may be viewed as a nuisance by building contractors with deadlines to meet, but these face-to-face meetings have proven to be very useful. In one case an issue that had already consumed several hours of negotiation over the telephone was readily settled within ten minutes when all parties were in the same room. The scoping meeting is an opportunity for program management both to support CAs as they establish contact with the owner's team and to evaluate their approach to the job.

In order to keep commissioning costs down, there must be flexibility in establishing the scope of a commissioning job. In a multi-story office building, for example, it would have been very expensive, and probably unnecessary, to

Table 1. Status of Commissioning Projects

Building Type	Project Phase: Design	Construction	Performance Verification	Report	Evaluation	Primary ECMs
Pilot Project					■■	- heat pump; economizer
Small Office		■	■■■	■		- EMS; heat pump
Large Office		■	■	■		- EMS; chiller; VAV; lighting sweep controls
Recreation	■	■	■			- EMS; heat pump; air conditioner; dehumidifier
School		■■■				- EMS; heat pump; chiller; VAV; heat recovery
Lodging			■■■		■	- EMS; heat pump; dehumidifier
Grocery		■	■■			- EMS; heat recovery; parallel unequal compressors; floating head pressure; anti-sweat heater controls
Residential		■				- heat pumps
Assembly		■				- economizer

Each ■ represents one project.
Status as of May 31, 1992.

conduct detailed tests on each of the approximately 400 fan-powered boxes to be installed. To further complicate the job, the boxes would be installed over a period of several months as tenant improvements were made in leased office spaces. An alternative was to check all boxes on the first four floors that were occupied. The building operator helped with some of this testing and so was prepared to verify the operation of the remaining boxes as they were installed. Since no problems were found, there was a high level of confidence in this ECM, and commissioning of the fan-powered boxes was considered complete. If there had been problems, a sample of the boxes on the other floors would have been tested as well before full funding was paid on this ECM.

Flexibility in defining the depth of commissioning for specific ECMs is also important. For example, if a system is complicated and comprehensive testing would be expensive, and very little energy savings are at stake, then commissioning tests should be less detailed.

What Has Not Worked Well. A common theme in many of the problems encountered is lack of good communication. The owner's contractors frequently delay providing the CA with the design intent document and other necessary information because they do not understand their importance. This results in the delay of all subsequent commissioning tasks. One approach to resolving this problem is to give the field sales staff a clearer picture of what happens during commissioning and what the owner's obligations will be. They can then include this information in their sales presentation when first introducing the DSR program.

On occasion, by the time commissioning work can begin, errors have been made that are beyond a quick fix. One such example is a motel where through-the-wall heat pumps were installed which were incompatible with the intended central energy management system; since no reasonable retrofit options could be identified, the central controller could not be utilized. More often ECMs are simply left out because initial design work was not updated to incorporate all of the ECMs. To limit such problems in future jobs, a confirmation letter is now sent out when a new program participation contract is signed. This informational letter, which goes to the owner and all relevant contractors and designers, explains how the commissioning process works and the importance of the information they will supply; it also includes a listing of the agreed-upon ECMs. Getting CAs on the job as early as possible also improves the chances of identifying and solving problems.

Issues and Concerns

A number of issues have been raised regarding these commissioning procedures. Some issues come out of the experience of this particular DSR program and some are raised by other utilities as they develop and carry out their own commissioning programs.

Payment Schedule

Because the program offers "up-front funding", an equitable balance must be established between paying the owner for out-of-pocket expenses while maintaining the financial leverage to ensure the owner makes any necessary repairs. The current procedure allows for 50 percent of the cost of an ECM to be paid upon the owner's presentation of progress billings from contractors, an additional 20 percent on progress billings upon satisfactory completion of pre-commissioning tests, and the final 30 percent upon satisfactory completion of functional performance testing. For very large projects with long time frames, ECM payments may also be prorated on the basis of floor area completed, or some other estimate of the energy value of the installed portion of the ECM.

Commissioning Schedule

The optimum time to assign a commissioning job has not yet been determined. The drawback of starting early is that it costs more. However, if the CA is not assigned until just before the building is completed, valuable opportunities may be lost to review designs and specifications and suggest changes when they can be readily made. Currently, the CA holds the scoping meeting and starts to gather documentation one to three months prior to equipment installation. This starting schedule will continue to change, until the best balance is achieved between commissioning costs and lost opportunities for making necessary corrections to building plans.

Whole-Building Commissioning

While the early decision to support only ECM-related commissioning has been retained, outside questions about the scope of commissioning are common. The key issue in whole-building commissioning is similar to that discussed above, namely, the wider the scope of commissioning, the greater the cost. Since whole-building commissioning primarily benefits the owner, the program response has been to leave that responsibility with the owner as well. As the value of commissioning becomes more widely accepted, the owner should be willing to cover the cost for commissioning building systems that are not part of the DSR program.

Recommissioning

The only thing that is really known as the result of commissioning tests is how the ECMs functioned at the time tests were performed. Performance one or two years from that point remains an unknown. Recommissioning is the process of periodically revisiting the building and repeating the commissioning tests. The commissioning protocols discussed in this paper do not include recommissioning. Instead emphasis is placed on operations and maintenance training for building staff.

This raises questions about staff turnover and the effectiveness of a written procedures manual to be used by the new staff. Also, to be truly effective the operations staff must be committed to the efficient operation of the building. To that end, program managements looks for opportunities to commend O&M staff for a job well done. Efficient operation should be reflected in consistently low monthly energy bills. Alternatively, performance data may be gathered from a building's energy management system or whole-building hourly load data. Initially, recording hourly load meters will be installed on all buildings in the program.

Liability

Before functional performance testing begins, the CA gets an authorizing signature on a form that states all equipment has been tested and shown to be operational and commissioning testing can begin. This form is intended to limit potential liability and it is used only when pre-commissioning tests are not part of the job. Liability is limited as well whenever the owner's team does the actual

testing and equipment manipulation. On the design side, both modelers and CAs are very careful to pass any necessary redesign work to the owner's team. Finally, CAs are told to thoroughly document the as-found condition in addition to any problems or irregularities they uncover. Even though the potential exists, liability has not been a problem on any building thus far.

Development Tasks

Several development tasks have been identified that will help to refine the commissioning procedures currently in use.

Monitoring Protocols

For some ECMs, monitoring is the best way to determine whether they are operating as intended. This is particularly true of controls and equipment that respond to ambient conditions such as temperature or light levels. To ensure that monitoring is cost-effective and focused on answering specific questions about ECM operation, very specific guidelines need to be established. Such guidelines should include how to develop a monitoring plan, collect accurate data, and analyze the data.

Field Test Plans

Rather than attempting to predefine field test procedures for each of the ECMs on the modeler's standard list, a library of plans from jobs that have been completed is being established. Information from this library will be available to CAs for reference on future assignments.

Estimating Energy Benefits and Costs Associated With Commissioning

In order to evaluate the benefits of commissioning, the energy impact of repairs and adjustments made in response to commissioning findings must be quantified. Because the intent of commissioning is to have buildings that operate properly from the beginning, before-and-after energy-use data is not typically available. The alternative is to use some type of engineering calculations. Two approaches to this task have been suggested: one would assign the job to the modeler who created the original DOE-2 model; the second approach would assign responsibility for all such calculations to a design engineer with extensive analysis experience. This person would select the appropriate analysis approach for each situation. While only limited analysis has been done to date, the intent is to use the second approach.

Benefit calculations are only part of the picture--actual commissioning costs are also needed. The chosen approach has been to define a commissioning protocol and test it on a limited number of buildings. As more jobs are completed, the data become more representative of actual program costs. These data will impact decisions about the future scope and form of commissioning in this DSR program. Decisions will seek to find a balance between the efficiency improvements commissioning delivers and the cost. Figure 1 shows very preliminary commissioning cost data for ten buildings. These costs are based on projections made from the to-date billings of the CAs and technical coordinator. CAs have billed an estimated 50 percent and the technical coordinator 75 percent of the full cost of these jobs. While Figure 1 seems to indicate that larger buildings are less expensive to commission on a cost-per-square-foot basis, it is too early to draw any conclusions. Other factors besides building size may have a major impact on the cost of commissioning; for example, the complexity of the ECMs and the level of cooperation from the owner's contractors play key roles.

A second cost issue relates to the full cost of installing an ECM. A relatively inexpensive measure may require extensive commissioning in order to deliver savings. In program planning, the cost of that ECM should include the commissioning overhead. Procedures for tracking such costs are being developed.

How Will We Know If We Are Successful?

The success of commissioning can be judged on several levels. First of all, did it identify significant problems in the building? The most successful commissioning jobs will be the ones that bring to light the worst offenses. While evidence so far is heavily in favor of success, commissioning is a comprehensive process, not merely troubleshooting. In particular, O&M training can keep a smoothly operating system on track.

A second test of the success of commissioning is the value to the building owner and occupants of the repairs and adjustments that were made in response to commissioning findings. As discussed above, quantifying the benefits will always be a judgment call. The difficulty increases when attempts are made to quantify not only electric energy and load benefits but also occupant comfort, increased productivity, and other human benefits. Thus the approach has been to collect the anecdotes and use them as qualitative evidence of program success and as marketing tools.

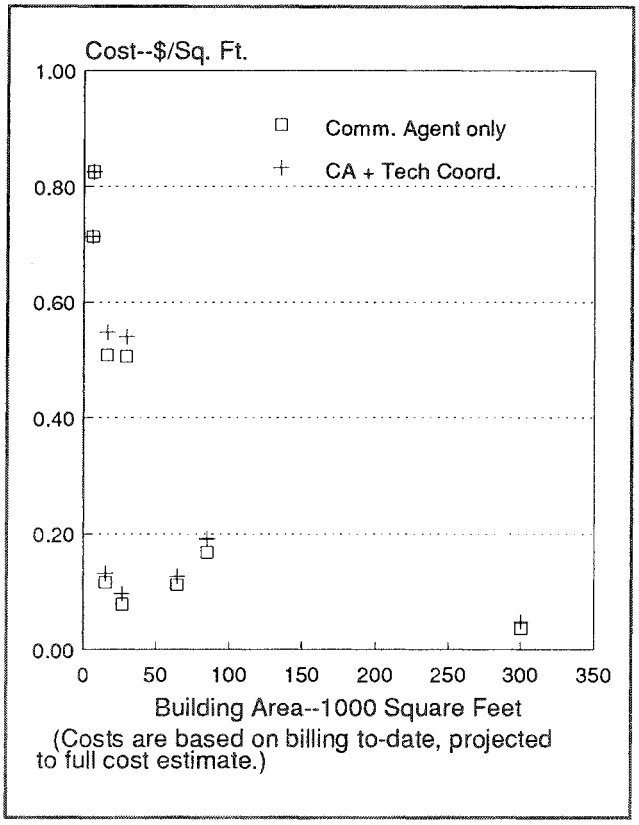

Figure 1. Preliminary Data on Commissioning Costs

The commissioning program will be successful when building owners and their contractors begin to view the CA as an ally instead of another inspector to endure. As this happens, commissioning will become a more routine step in the construction of any building, and commissioning requirements will be written into bid specifications. Involvement with ongoing commissioning work allows observation of the response to commissioning work and making program adjustments to improve the process.

Finally, within the DSR program, commissioning will be successful if the cost of the program does not exceed the value of the resulting energy savings. Trueman estimates that there is a 2:1 benefit to cost ratio for commissioning, when occupant satisfaction and productivity are factored in. Program management is committed to reviewing the performance of this program at the end of 1992 and making decisions about the nature of ongoing commissioning work.

With each commissioning job a little more is learned about how it can best be done. The focus of this paper has been the development of the process; sufficient experience is just beginning to accumulate to allow an evaluation of the impact of commissioning as a DSR program element.

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