Building Commissioning Guidelines

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A Source Book on Building Systems Performance

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Prepared for Pacific Gas and Electric Company by Portland Energy Conservation, Inc. (PECI) for the statewide Energy Design Resources program (www.energydesignresources.com). Certain sections of this document were excerpted and modified from *Commissioning for Better Buildings in Oregon*, written by PECI for the Oregon Office of Energy, and *Building Commissioning—The Key to Quality Assurance*, written by PECI for the United States Department of Energy's Rebuild America program.

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PART 1: Introduction to Commissioning

Building owners spend more on complex building systems than ever before, yet many find they are not getting the performance they expect. A 1994 study of 60 commercial buildings found that more than half suffered from control problems. In addition, 40% had problems with heating, ventilation and air-conditioning (HVAC) equipment and one-third had sensors that were not operating properly.[1] An astonishing 15% of the buildings studied were actually missing specified equipment. And approximately one-quarter of them had energy management control systems, economizers, and/or variable speed drives that did not run properly. Problems also frequently occur on the envelope, structural and electrical systems of many new buildings.

Every new building constructed is unique. In essence, each building design is a prototype, which is expected to perform as if it were something that had been built before. Combining a new building design with sophisticated technology, a tight construction schedule and a fixed budget can lead to a building that does not perform as anticipated. A building is an investment. A building that performs poorly does not reflect the desired outcome of the design team or the owner's wishes. Excessive repair and replacement costs, employee absenteeism, indoor air quality problems, construction team liability, and tenant turnover cost U.S. building owners, employers and the construction industry millions of dollars each year. Building commissioning is one way to improve the outcome of a construction project.

Building commissioning can ensure that a new building begins its life cycle at optimal productivity, and improves the likelihood that the building will maintain this level of performance.

BUILDING COMMISSIONING CAN ENSURE THAT A NEW BUILDING BEGINS ITS LIFE CYCLE AT OPTIMAL PRODUCTIVITY, AND IMPROVES THE LIKELIHOOD THAT THE BUILDING WILL MAINTAIN THIS LEVEL OF PERFORMANCE.

[1] Piette, Mary Ann. *Quantifying Energy Savings from Commissioning: Preliminary Results from the Northwest*, in Proceedings of the National Conference on Building Commissioning, 1996.

Commissioning can optimize the energy-efficient design features of a new building and improve overall building performance.

Commissioning is a quality-assurance process that increases the likelihood that a newly constructed building will meet client expectations. Commissioning spans the entire design and construction process. Ideally it should begin at the design phase, with the selection of a commissioning provider who helps ensure that the building owner's and designers' intent gets written into project documentation. The building designers then incorporate commissioning requirements into their specifications. Later, the commissioning provider is responsible for inspecting building systems and components during construction, and when the project is near completion, the provider and contractor conduct rigorous performance tests. At the end of the commissioning process, building operators receive training and documentation to ensure proper operation and maintenance of the building.

Commissioning can optimize the energy-efficient design features of a new building and improve overall building performance. It is a proven, systematic approach to reducing change orders and liability exposure, and ensuring that the building owner receives a building that functions according to the original design intent.

Acronyms List

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BCA	Building Commissioning Association
HVAC	Heating, Ventilation and Air-conditioning
OSHA	Occupational Safety and Health Administration
RFP	Request for Proposal
RFQ	Request for Qualifications
TAB	Testing, Adjusting and Balancing

Definition of Commissioning

What Exactly is Building Commissioning?

Commissioning is a systematic process of ensuring that all building systems perform interactively according to the contract documents, the design intent and the owner's operational needs. This is achieved ideally by beginning in the pre-design phase with design intent development and documentation, and continuing through design, construction and the warranty period with actual verification through review, testing and documentation of performance. The commissioning process integrates and enhances the traditionally separate functions of design peer review, equipment startup, control system calibration, testing, adjusting and balancing, equipment documentation and facility staff training, and adds the activities of documented functional testing and verification.

Commissioning is occasionally confused with testing, adjusting and balancing (TAB). Testing, adjusting and balancing measures building air and water flows, but commissioning encompasses a much broader scope of work. Building commissioning typically involves four distinct "phases" in which specific tasks are performed by the various team members throughout the construction process. The four phases are pre-design, design, construction, and warranty. As part of the construction phase, commissioning involves functional testing to determine how well mechanical and electrical systems meet the operational goals established during the design process. Although commissioning can begin during the construction phase, owners receive the most cost-effective benefits when the process begins during the pre-design phase at the time the project team is assembled.

A properly commissioned facility can result in fewer change orders during the construction process, fewer call-backs, long-term tenant satisfaction, lower energy bills, avoided equipment replacement costs, and an improved profit margin for building owners once the building is occupied. Commissioning also assures that the building's operational staff is properly trained and that the operations and maintenance manuals are compiled correctly at project turn-over.

Commissioning Approaches

Commissioning can begin during pre-design, design, construction or building start-up. The process offers significantly greater and more cost effective benefits when it begins during pre-design or early design.

In recent California focus group studies, building owners and their representatives repeatedly stressed that the lack of communication between the design team and construction team is a major problem. This lack of communication means that the original design intent of a project is unlikely to be carried through to project completion. (Documenting design intent—that is, the owner's expectations for building performance—is a critical component of commissioning and is discussed in more detail later in this document.) Commissioning provides a means of linking the traditionally fragmented phases of the design and construction process, because it encourages the project team to view the process holistically. The commissioning process encourages parties to communicate and solve problems earlier in the construction process. Proper commissioning that begins during design can help identify and solve problems that later may turn into performance problems, occupant comfort complaints, indoor air quality issues, and decreased equipment life. Although commissioning works best when it begins during design, projects already under construction can still benefit from commissioning. Bringing a commissioning provider into a project during the construction phase can be invaluable in helping solve start-up problems that have stumped both designers and contractors. The commissioning provider can also document the start-up and functional testing results, thereby reducing

future liability exposure for the designers and owners. The provider also oversees operation/maintenance staff members training, thus improving the operating procedures of the facility.

Benefits of Commissioning

Until recently, the most frequently mentioned benefit of commissioning was its energy-related value. Building commissioning ensures that the energy savings expected from the design intent are implemented correctly. While these benefits are significant, they are far outweighed by the non-energy-related benefits of commissioning. These include:

- Proper and efficient equipment operation
- Improved coordination between design, construction and occupancy
- Improved indoor air quality, occupant comfort, and productivity
- Decreased potential for liability related to indoor air quality, or other HVAC problems
- Reduced operation and maintenance costs

Existing Building Commissioning

Commissioning also can be applied to existing buildings to restore them to optimal performance. ***Retrocommissioning*** is a systematic, documented process that identifies low-cost O&M improvements in an existing building and brings that building up to the design intentions of its current usage. In many cases as a building is used over time, equipment efficiency and tenant build-outs or renovations change how the building functions. Retrocommissioning identifies and solves comfort and operational problems, explores the full potential of the facilities energy management system, and ensures that the equipment performs properly after space changes have been made. ***Continuous commissioning*** is similar to retrocommissioning and begins by identifying and fixing HVAC and comfort problems in the building. In continuous commissioning, when the commissioning is complete, the team continues to work together to monitor and analyze building performance data provided by permanently installed metering equipment. This process works to ensure that the savings achieved from the commissioning continue to persist over time.

Proper and Efficient Equipment Operation

Commissioning verifies that equipment is installed and operating properly. Equipment that operates as intended lasts longer, works more reliably and needs fewer repairs during its lifetime. By promoting equipment reliability, commissioning reduces service, energy and maintenance costs. Equipment that operates properly tends to use less energy, requires fewer service calls and replacement parts, and demands less "crisis maintenance" from onsite staff (or expensive outside contractors), allowing them to concentrate on their normal duties.

Improved Coordination Between Design, Construction and Occupancy

Commissioning can result in greater cooperation among the professionals involved in the project and provides a platform for cross-checking the performance of a building's equipment and combined systems. This ultimately results in fewer call-backs and litigation problems.

A good design features systems that are sized correctly rather than the oversized mechanical systems found in many commercial buildings.[2] On many projects a lack of understanding and coordination between the design, installation, and/or operational team members can lead to systems that function inefficiently. Commissioning allows for a broad perspective and consistent focus throughout the design and construction process on whether the building will function as intended and identifies the best long-term solutions for problems that arise during project. Commissioning can facilitate improved integration and communication among team members throughout these phases and can also ensure that correctly-sized systems function as intended and specified.

Many owners mistakenly believe that adding commissioning quality assurance procedures to their design process will lead to delays of their projects schedule and increase costs. Owners who have incorporated commissioning into the design phase of their projects have discovered that commissioning can significantly reduce change orders.[3] This in turn reduces the requests for project delays and decreases the use of the owner's contingency funds for change orders. Thus, beginning commissioning during design can contribute to the on-time and on-budget completion of projects. It should be noted that these benefits will not be realized if the commissioning process begins during the equipment start-up phase of a project.

OWNERS WHO HAVE INCORPORATED COMMISSIONING INTO THE DESIGN PHASE OF THEIR PROJECTS HAVE DISCOVERED THAT COMMISSIONING CAN SIGNIFICANTLY REDUCE CHANGE ORDERS.

Improved Indoor Air Quality, Comfort and Productivity

Surveys indicate that comfort problems are common in many U.S. commercial buildings. A recent Occupational Safety and Health Administration (OSHA) report noted that 20-30% of commercial buildings suffer from indoor air quality problems. Building occupants complain of symptoms ranging from headaches and fatigue to severe allergic reactions. In the most severe cases, occupants have developed Legionnaire's disease, a potentially fatal bacterial illness. The National Institute of Occupational Safety and Health surveyed 350 buildings with deficient indoor air quality and found that more than half of the complaints stemmed from HVAC systems that were not operating properly.

[2] York, Dan. Co*mmissioning Green Buildings*, in Proceedings of the National Conference on Building Commissioning, 1998.

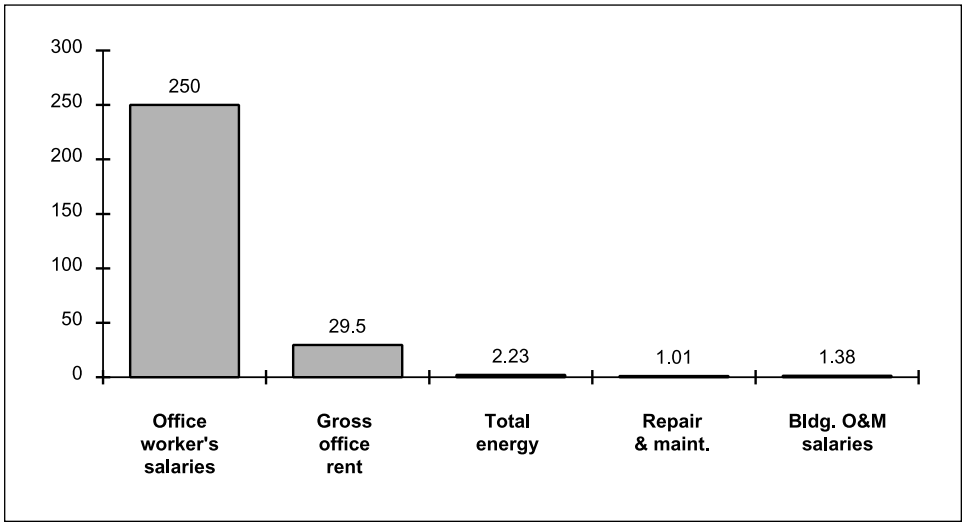
[3] Savage, Jerry. *Commissioning a Materials Research Laboratory*, in the Proceedings of the National Conference on Building Commissioning, 2000.

Although little research has been completed to document the link between comfort and productivity, common sense tells us that comfortable employees are more productive than uncomfortable employees. The few studies that have been conducted on this topic agree. An example of productivity losses in a typical office building where occupants complained of discomfort could be calculated in this manner:[4] Assume that a typical building has one occupant per 200 square feet of space and an annual payroll cost of $40,000/person or $200/square foot of office space. If one out of every five employees spends only 30 minutes a month complaining about the lighting or the temperature or both, the employer loses $.12/square foot in annual productivity. For a 100,000 square foot office building, this is equivalent to $12,000 per year. Because uncomfortable employees probably spend more than just half an hour each month complaining about building comfort, the actual losses would likely be higher.

If comfort problems are severe enough to make employees ill, business owners sustain additional productivity losses to cover sick time. Building operation costs also increase, as operators respond to more tenant complaints. Figure 1 below shows a typical allocation of operating costs in a 140,000 square foot office building.

Operating Costs for a 140,000 square foot Office Building
(1998-99 $/rentable square foot)[5]

FIGURE 1



[4] Updated by PECI from original example developed by Cedric Trueman for his *Presentation to the National Electric Light and Power Association*, 1989.

[5] Original graph developed by E Source. Calculation from Building Owners and Managers Association (BOMA) and Electric Power Research Institute (EPRI) data 1990. Data has been revised by PECI using 1998 Occupation Employment Statistics (OES) and 1999 Building Owners and Managers Association (BOMA) data.

Commissioning also improves the productivity of processes, especially in industrial facilities. By ensuring that equipment performs optimally and efficiently, commissioning can help reduce equipment downtime and improve production rates.

These problems do not only concern building owners who occupy their buildings. They affect owners who rent building space as well. How long will tenants who are experiencing comfort-related productivity problems remain tenants? Tenant turnover can be costly, according to the following estimated cost of losing a tenant in Class A office space. (See table 1)

Cost of Losing a Tenant[6]

Table 1

Five-year lease value	$875,000
Rent loss due to vacancy	$43,750
Improvements for new tenant	$87,500
Leasing commission	$43,750
Total cost of losing tenant	**$175,000**

Assuming a 3,500 square foot Class A office space rented at $50/square foot a year, a typical five-year lease has a value of $875,000. If a tenant leaves, this space will remain vacant an average of three months, for a total rent loss of $43,750. Improvements and build-outs to satisfy a new tenant usually cost $25/square foot, or $87,500 in this case. In addition, the building owner often pays a leasing commission of 5% of the five-year lease value, or $43,750. Thus, the total cost of losing one tenant could run $175,000, or 20% of the five-year lease value. If a building develops a reputation for being uncomfortable and unproductive, the vacancy period could last longer. Word of uncomfortable building conditions is likely to spread among business peers; market research shows that dissatisfied customers, in this case tenants, are likely to complain to 7-10 of their peers.

Building commissioning is one tool building owners can use to avoid the expenses and productivity losses associated with poor indoor air quality and employee discomfort.

Building commissioning is one tool building owners can use to avoid the expenses and productivity losses associated with poor indoor air quality and employee discomfort. Because commissioning assures that HVAC and other building systems are installed and operating properly, commissioned buildings tend to have fewer comfort-related problems.

[6] Data revised by PECI based on format developed by David Zier of Melvin Mark Company, 2000.

Liability Related to Indoor Air Quality

Sick building syndrome and the court cases associated with it continue to make headlines across the country. In fact, the government of Polk County, Florida won nearly $26 million in damages for problems with its "sick" courthouse. Although this award was paid by the general contractor, many building owners are also feeling the sting of indoor air quality lawsuits brought by occupants who complain of illnesses resulting from building air quality. And even when owners are on the receiving end of litigation settlements, they and their tenants still suffer the inconvenience of acquiring other work space for use during the repair process, not to mention the inconvenience of the litigation process itself, which can drag on for months and even years.

Both local and state government agencies in California have begun using commissioning as a tool to ensure that indoor air quality standards are being met when a building is constructed. (See page 12 for a case study example.)

THE COMMISSIONING PROCESS ESTABLISHES SOUND BUILDING OPERATION AND MAINTENANCE PRACTICES AND TRAINS OPERATORS TO CARRY OUT THESE PRACTICES.

Building commissioning protects owners in more than one way. First, it provides documented verification of a building's performance and operation. Ventilation rates are a good example of a primary factor that affects indoor air quality. HVAC commissioning typically includes testing these flow rates under varying load conditions to assure that the ventilation systems are operating properly. If a building has deficiencies, the commissioning provider documents the original condition and records the repairs made. Commissioning should be repeated throughout the life of a building, and performance documentation should be updated regularly. This documentation provides owners with a record of building performance that can be used as evidence in the event of a lawsuit.

Commissioning also helps prevent many indoor air quality problems through its focus on training building operators in the proper maintenance of building systems. Properly run and maintained HVAC systems, with clean coils and air intakes and regularly-changed filters, are less likely to contribute to indoor air quality problems. In addition, trained operators can spot potential air quality and ventilation problems before they develop.

Reduced Operation and Maintenance and Equipment Replacement Costs

Operation and maintenance and equipment replacement costs will always consume a portion of building budgets. However, more building owners and businesses are realizing that operation and maintenance departments can minimize life cycle costs by changing operation and maintenance practices. That is, proper operation and maintenance can actually save money compared to poor operation and maintenance, and many businesses are reinvesting their operation and maintenance savings in more efficient building systems. The commissioning process establishes sound building operation and maintenance practices and trains operators in carrying out these practices. (Some of these practices are discussed in more detail in the Operation and Maintenance for Persistence section of this booklet.)

The Bottom Line

The bottom line is that commissioning improves a building's value. Properly functioning buildings with reliable equipment kept in good condition are worth more than their uncommissioned counterparts. Commissioned systems and equipment retain their value longer. Additionally, there is an ongoing demand for comfortable, healthy working space. Finally, systems that function properly use less energy, experience less down time, and require less maintenance, thereby saving money for building owners.

Costs of Building Commissioning

There is currently no standard method of reporting the costs and savings associated with commissioning. For many projects, commissioning costs are not separated from other project costs. For projects where these costs have been tracked separately, various methods have been used to report both the costs and associated benefits. The table below lists some of the most common cost estimation methods. No matter which estimation method is used, however, commissioning accounts for only a very small portion of overall construction and retrofit budgets.

Estimated Commissioning Costs for New Equipment[7]

TABLE 2

Commissioning Scope	Estimated Cost Range
Whole building (controls; electrical; mechanical)	
Commissioning from design through warranty	0.5 to 3% of total construction cost
HVAC and automated controls system, only	1.5-2.5% of mechanical contract
Electrical system, only	1-1.5% of electrical contract

Savings from Building Commissioning

Building owners and their servicing utilities are interested in the energy (kWh) hour savings achieved from commissioning energy systems and equipment. Additionally, building owners are also interested in how much the commissioning will save them in operation and maintenance costs. Just as commissioning costs can vary from project to project, so do commissioning savings. Savings will depend on the scope of the

[7] Estimated costs adopted from PECI Data and Ron Wilkinson's article Establishing Commissioning Fees, *ASHRAE Journal*-February, 2000.

commissioning. Table 3 shows the reported savings for three different types of buildings commissioned during the past few years. When commissioning is done properly, the savings can be quite substantial.

Many owners question how they can pay for commissioning with a limited design and construction budget. Because commissioning can identify potential problems earlier in the design or construction process, this can result in a lower overall construction budget, fewer contractor call-backs and lower operating costs during the first year of operation. By transferring those potential savings to the design and commissioning team budgets, the building owner's total project costs can be equivalent to a project that is not commissioned, as illustrated in Figure 2.

The Savings from Commissioning New Equipment (Mechanical Systems)[8]

TABLE 3

Building Type	Annual $ Savings	Annual Energy Savings
110,000 sq. ft. Office	$22,320	279,000 kWh
22,000 sq. ft. Office	$13,080	130,800 kWh
60,000 sq. ft. High Tech Manufacturer.	$26,880	336,000 kWh

How to Pay for Commissioning-One Option

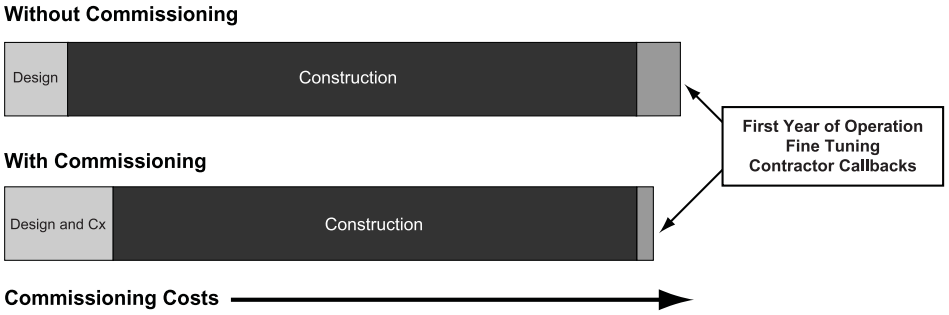


FIGURE 2:
SHIFT 2% OF TOTAL PROJECT COSTS TO THE COMMISSIONING PROVIDER AND 3% TO THE DESIGN TEAM.[9]

[8] Annual energy savings calculated from three Northwestern United States commissioning projects. Cost savings estimates based on a blended 2000 California kWh rate of $0.10 for smaller office buildings and $0.08 for larger offices and industrial facilities.

[9] The Farnsworth Group, *ASERTTI Introductory Training Module*, 1998.

Fresno Community Regional Medical Center Commissioning Project

Increasing population growth in the central San Joaquin Valley has put immense pressure on the existing infrastructure of the Community Medical Centers in Fresno. To continue meeting the medical needs of the community, the corporation has launched an ambitious project to build a 350,000-square-foot addition and extensively remodel its existing 450,000-square-foot downtown hospital. The project will occur over five years. One of the first steps in the project is to build a new $25 million central-plant complex to serve the entire medical campus. The central plant will house the chillers, cooling towers, boilers, domestic hot water heaters, distribution pumps, high voltage service, electrical distribution equipment, generation equipment, and medical gas systems. Excavation work has begun on the $100 million new addition, a trauma center and critical care building. A future phase of the project will remodel the existing hospital spaces.

The hospital recognized that proper planning and quality assurance strategies would be necessary to assure success on this complex and expensive design-build project. Starting in schematic design the owner retained a consultant to develop a master plan for the entire projects electrical and mechanical specifications. This comprehensive plan was used to direct the engineers subcontracted for the actual design work under the design-build contract. Mazzetti and Associates of San Francisco, the consultant that developed the master plan, was also tasked with providing peer review of all mechanical and electrical designs as they were completed. Although they were not formally contracted as a commissioning provider at the beginning of this project, the consultant's master plan development and peer review responsibilities resembled those of a commissioning provider. The design review process for the central plant identified two key findings, a lack of isolation valves in the chilled water loop design and inadequate controls for the emergency electrical generation system. Identifying and rectifying these issues during design allowed the team to make changes on paper—at low expense—rather than through the change-order process during construction. The entire design package is now undergoing regulatory approval by the State of California with construction expected to begin later this year.

The contractor sees commissioning as a way to ensure customer satisfaction with building performance.

With this level of quality assurance integrated into the design phase, both the consultant and the general contractor, Clark Construction, recognized that commissioning during construction was the next logical step to assure that the high-quality designs were implemented correctly during the construction phase of the project. The project executive for the contractor, had seen positive results from three commissioned health care projects her company had worked on previously. The contractor supports the commissioning process. They see commissioning as a way to ensure that a complex project functions at peak performance when turned over to their customer and ensures that the facilities operation and maintenance staff is properly trained to sustain this performance. After further

discussions between the consultant, hospital, and the general contractor, the hospital allocated additional funds and gave the go ahead to expand the consultant's scope of work to include commissioning of the new central plant.

State of California's Capitol Area East End Project, Block 225, California Department of Education

The first phase of the Capitol Area East End Complex project consists of constructing a new 497,000 square foot building to house California's Department of Education at a budgeted cost of approximately $70 million. Commissioning has been incorporated into the project to ensure adequate indoor air quality and energy efficiency, and to verify the proper function of the green building enhancement strategies. Ground was broken in April of 2000 and completion and occupancy is expected to occur in July, 2002. Although this project is being constructed with a bridge design-build contract, prior to design completion the State sponsored a competition in which design-build teams submitted proposals on how to make the building design more energy-efficient and sustainable. Basic schematic and design development documents prepared by the State's master architect were given to the competing design-build teams at the beginning of the competition. The teams then had an allotted amount of time to formulate "revised" designs and ideas on how to achieve a more green project.

The Capitol East End project is using commissioning to ensure indoor air quality.

The winning proposal for Block 225, included approximately 125 green building enhancements. These enhancements are intended to reduce energy consumption, improve indoor environmental and air quality in the final occupied building, utilize resource efficient materials and systems, and ultimately improve the building performance within the allocated construction budget. The green building enhancements included a building and indoor air quality commissioning plan for the remainder of the design process, the construction phase, and for one year post occupancy. The State's goal for this competition was to end up with a building 30% more efficient than required by the 1998 California Title 24 baseline. The winning design team expects to achieve at least a 31% efficiency improvement.

Upon award, the winning green building architect, SMWM implemented the design/construction documents phase commissioning plan. Although the schematic design and the design development work had already begun prior to this award, the consultant was able to recommend changes that were incorporated into the final Construction Documents. Changes included supply ductwork locations using a raised floor that will reduce energy consumption and specifying traditional high-efficiency chillers rather than the originally specified absorption chillers based on life cycle cost analysis. SMWM is now in the process of selecting low and no-VOC green furnishings and finishes for the building and the interiors. SMWM and its sub-consultants are developing functional performance commissioning tests (multi-point air quality tests) for the building's indoor space and mechanical systems to ensure that indoor air quality parameters will be met when the building is occupied.

San Francisco International Airport Aviation Museum

San Francisco International Airport recently completed a $1 billion addition of the new international terminal. During the latter part of 2000, while construction was being completed on the terminal, an 11,000 square foot Aviation Museum located within the new terminal faced an ambitious completion date that coincided with the planned opening dedication party for the international terminal. With 12 weeks worth of work still to do, and only 6 weeks left remaining in the project schedule, the general contractor and the project manager realized that their subcontractor's work was progressing more slowly than expected. Among other problems, system integration issues with the fire/life-safety systems were threatening their eligibility for the temporary occupancy permit necessary for the museum's opening. The project manager was familiar with building commissioning from other projects he had worked on and understood the dramatic benefits of methodical and comprehensive functional testing of each system to verify and document proper performance. The project manager states "If you don't take a proactive approach (to identify and fix problems early) you will end up spending more money on callbacks and have unhappy owners and facility managers. This is why we commission our projects." LCI, the general contractor on the project, promptly contracted with Mazzetti and Associates of San Francisco, a consulting engineering firm that provides commissioning services, to assist them in getting the job closed out. Commissioning was performed on the HVAC, electrical, lighting controls, sprinkler plumbing, and fire/life-safety systems. To manage any potential conflicts of interest, since the commissioning provider was contracted to the general contractor, all the commissioning findings were simultaneously reported to the design engineering firm, the airport projects fire marshal representative, and the airport's owner representative. Since both the museum's fire/life-safety and HVAC air-handlers were connected to the larger airport terminal equipment, special attention was paid to equipment integration issues. Commissioning identified and corrected some minor problems with the air-handlers and also involved methodically testing and debugging the fire/life-safety system. Most significantly, commissioning resulted in on-time substantial completion, proper functioning of the fire/life-safety system (as verified by the fire marshal tests), and the issuance of a temporary occupancy permit in time for the terminal's grand opening celebration.

Commissioning resulted in on-time substantial completion of the Aviation Museum.

Selecting a Commissioning Provider

One of the most important commissioning decisions a building owner can make is selecting the commissioning provider and determining who will hold the commissioning provider's contract. Two primary methods exist for selecting a commissioning provider: competitive bid and selection by qualification. You can obtain a list of commissioning providers from the Building Commissioning Association (BCA). Contact information for the BCA can be found in the resources section at the end of this booklet. In the Request for Qualifications, be sure to ask for details on previous, relevant commissioning experience, including the

depth of commissioning experience (what some call commissioning is no more than traditional equipment startup).[10] Make sure that the provider's definition of commissioning corresponds to the one at the beginning of this booklet. Recommended commissioning provider qualifications are discussed in more detail in the following pages. Based on the responses, develop a list of firms to receive a Request for Proposal that details exactly what services your construction project will need to be properly commissioned. A sample RFP is included in Appendix 1. Owners can also select a commissioning provider based on qualifications and rate schedules, rather than by competitive bid. This process warrants careful interviewing and contact with the providers' current or past clients.

Owners can assign any of the following parties to select and manage the commissioning provider's contract:

- Owner or Owner's project manager
- Architect/Engineer
- Contractor

IF THE COMMISSIONING PROVIDER IS NOT AN INDEPENDENT PARTY UNDER CONTRACT DIRECTLY WITH THE OWNER THEN HE OR SHE MUST DEVELOP A FORMAL PLAN FOR MANAGING THE POTENTIAL CONFLICT OF INTEREST.

Each option has its advantages and disadvantages. The final choice will depend on the complexity and the specific needs of the particular project. As building commissioning has evolved and more practitioners with different ideas have entered the field, a group of interested parties worked to form a professional association, the Building Commissioning Association (BCA), in 1998. "The BCA's goal is to achieve high professional standards, while allowing for diverse and creative approaches to building commissioning that benefit our profession and its clients. For this reason, their focus is on identifying critical commissioning attributes and elements, rather than attempting to dictate a rigid commissioning process." The association believes that "the basic purpose of building commissioning is to provide documented confirmation that building systems function in compliance with criteria set forth in the project documents to satisfy the owner's operational needs" (Building Commissioning Association Web site-www.bcxa.org). Paramount to this is the understanding that if the commissioning provider is not an independent party under contract directly with the owner then he or she must develop a formal plan for managing the potential conflict of interest. One method that has been used successfully to manage, but not eliminate these potential conflicts of interest, is parallel and simultaneous reporting of all findings to the owner's representative and contract manager for the commissioning services.

Independent Third Party Under Contract to the Owner

Many owners who have commissioned their buildings recommend using an independent third party as the commissioning provider. An independent commissioning provider, under contract to the owner or to the owner's project manager, can play an objective role

[10] "Start up" refers to the process of starting up equipment to determine whether it operates. Commissioning goes beyond start up to ensure that new equipment performs in conformance with design expectations in all modes and conditions of operation.

and ensure that the owner will truly get the building performance he or she expects. For large and/or complex projects, especially in buildings with highly integrated, sophisticated systems, future savings from commissioning outweigh the slightly higher costs with an additional contract. Independent third party commissioning providers bring a fresh perspective to the project as they collaborate with the design team. By joining the project team during the design, the commissioning provider can identify more opportunities for improvements and savings early on when changes can be made on paper. This approach is preferable to waiting to fix the problems through the change order process as the building is being constructed.

Selecting an Independent Third Party Commissioning Provider. Independent commissioning providers, who are often trained as design engineers, should have the qualifications listed under "Commissioning provider Qualifications," plus they should be able to write commissioning specifications for bid documents. Hands-on experience with building systems is especially critical. It is important to involve the independent authority as early in the project as possible. This allows the provider the opportunity to review the design intent for the project, begin scheduling commissioning activities, and begin writing commissioning specifications into bid documents for other contractors.

Architect or Design Engineer Overseeing the Commissioning Process

If commissioning requirements in the project specifications are rigorous and detailed, owners may consider having the architect manage the contract of a commissioning provider. When the architect or the mechanical designer has qualified field engineers on staff and those engineers do not have responsibility for the design of the project, the architect or engineer may be considered for directly overseeing the commissioning process. One advantage of using the architect or mechanical designer is that he or she is already familiar with the design intent of the project. Owners considering this option should bear in mind that commissioning is not included in a design professionals basic fees. Owners should require that all findings of the commissioning process be directly reported to both the designer and to the owner as they occur, to manage the potential conflict of interest created by having the commissioning services under the designer. Owners must also recognize that even if this option is not chosen, and an independent third party is used, designers might increase their fees slightly to offset the additional time requirements to coordinate their work with the commissioning provider.

Contractor

It used to be standard practice for many contracting firms to conduct performance tests and systematic check-out procedures for equipment they installed. As construction budgets became tighter, this service was dropped from most projects. Although contractors may have the knowledge and capability to test the equipment they install, they may not be skilled at testing or diagnosing system integration problems. In addition, some contend that it

is difficult for contractors to objectively test and assess their own work, especially since repairing deficiencies found through commissioning may increase their costs. For owners that only wish to have the commissioning process begin during the construction phase, it may be appropriate to use the installing contractor as the commissioning provider in cases where:

- The building size is less than 20,000 square feet
- The project specifications clearly detail the commissioning requirements
- The owner has skilled staff that can review the contractor's commissioning work

Another option for owners that have a good relationship with the general contractor is to require that the general contractor hire a test engineer to commission the equipment. This scenario can work well when specifications and contract documents clearly detail the commissioning requirements and when the owner has technical staff who are qualified to oversee the test engineer. Still, many general contractors welcome the opportunity to work with an independent commissioning provider, because of the objectivity they bring and because they assist in ensuring that the subcontractors perform their work properly, improving client satisfaction, and ultimately reducing callbacks.

MANY GENERAL CONTRACTORS APPRECIATE WORKING WITH AN INDEPENDENT COMMISSIONING PROVIDER BECAUSE OF THEIR FOCUS ON IMPROVING CLIENT SATISFACTION AND ULTIMATELY REDUCING CALL BACKS.

Commissioning Provider Qualifications

Currently there is no broadly recognized and approved certification or licensing process for commissioning providers. It is therefore up to each owner to determine the commissioning provider's qualifications appropriate for a given project. Below are some guidelines for selecting a qualified commissioning provider.

Regardless who you choose to act as the commissioning provider, there are certain minimum qualifications any commissioning provider ought to have, and the following list is by no means all-inclusive. Certain projects may require more or less experience, depending on size, complexity, and specific building characteristics. The commissioning provider chosen should be directed to subcontract work in which he or she lacks sufficient experience.

Commissioning Provider Qualifications Checklist. In general, for complex projects, a commissioning provider who will personally develop the commissioning test plans and directly supervise the commissioning work should meet these qualifications. These qualifications are focused on HVAC and control systems. Where electrical and other systems will be commissioned, the firm's experience in these areas should also be considered. However, often the prime commissioning provider will team with other sub-consultants to provide a team that can expertly address all the systems being commissioned. In such cases, the management skill of the prime commissioning provider is also important.

Recommended Minimum Qualifications

- Experience in design, specification, or installation of commercial building mechanical and control systems and other systems being commissioned.
- History of responsiveness and proper references.
- Meet owner's liability requirements.
- Experience working with project teams, project management and conducting scoping meetings; good communication skills.
- Experience commissioning at least two projects of similar size and of similar equipment to the current project, one of the last three years. This experience includes the writing of functional performance test plans.

Optional Qualifications

- Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs.
- Experience in design installation and/or troubleshooting of direct digital controls and energy management systems, if applicable.
- Demonstrated familiarity with metering and monitoring procedures.
- Knowledge and familiarity with air/water testing and balancing.
- Experience in planning and delivering O&M training.
- Building contracting background.
- Overall understanding by the commissioning team of all building systems including building envelope, structural, and fire/life safety components.

BCA Attributes of Building Commissioning

The Building Commissioning Association (BCA) is a newly formed organization tasked with educating the public and its members about what constitutes effective building commissioning. The BCA considers the following attributes to be so fundamental to effective building commissioning that all members agree in writing to adhere to them whenever they serve as a projects Commissioning Authority (referred to as the commissioning provider in the rest of this document):

1. The Commissioning Provider (CP) is in charge of the commissioning process and makes the final recommendations to the owner regarding functional performance of the commissioned building systems.
2. The CP is an objective, independent advocate of the Owner. If the CP's firm has other project responsibilities, or is not under direct contract to the Owner, a conflict of interest exists. Wherever this occurs, the CP discloses, in writing, the nature of the conflict and the means by which the conflict shall be managed.
3. In addition to having good written and verbal communication skills, the CP has current engineering knowledge, and extensive and recent hands-on field experience regarding:

a. Building systems commissioning,
b. The physical principles of building systems performance and interaction,
c. Building systems start-up, balancing, testing and troubleshooting,
d. Operation and maintenance procedures, and operations
e. The building design and construction process.

4. For each project, the commissioning purpose and scope are clearly defined in the CP contract.
5. The CP recommends the commissioning roles and scope for all members of the design and construction teams be clearly defined in:
   a. Each design consultant's contract,
   b. The construction manager's contract,
   c. General Conditions of the Specifications,
   d. Each division of the specifications covering work to be commissioned, and
   e. The specifications for each system and component for which the suppliers' support is required.
6. Each project is commissioned in accordance with a written commissioning plan that is updated as the project progresses. The commissioning plan:
   a. Identifies the systems to be commissioned,
   b. Defines the scope of the commissioning process,
   c. Defines commissioning roles and lines of communications for each member of the project team,
   d. Estimates the commissioning schedule.
7. On new building commissioning projects, the CP reviews systems installation for commissioning related issues throughout the construction period.
8. All commissioning activities and findings are documented as they occur. These reports are distributed as they are generated, and included in the final report.
9. The functional testing program objectively verifies that the building systems perform interactively in accordance with the Project Documents. Written repeatable test procedures, prepared specifically for each project, are used to functionally test components and systems in all modes of operating conditions specified for testing. These tests are documented to clearly describe the individual systematic test procedures, the expected systems response or acceptance criteria for each procedure, the actual response or findings, and any pertinent discussion.
10. The commissioning authority provides constructive input for the resolution of system deficiencies.
11. Every commissioning project is documented with a commissioning report that includes:
    a. An evaluation for the operating condition of the systems at the time of functional test completion,
    b. Deficiencies that were discovered and the measures taken to correct them,
    c. Uncorrected operational deficiencies that were accepted by the owner,

d. Functional test procedures and results,
e. Reports that document all commissioning field activities as they progress, and
f. A description and estimated schedule of required deferred testing.

(Excerpted from the BCA Web site at www.bcxa.org)

The Commissioning Team

Members of a design-construction project team, like components of integrated building systems, need to interact in order to perform their tasks successfully. Commissioning actually facilitates this interaction, because it sets clear performance expectations and requires communication among all team members.

Members of a design-construction project team, like components of integrated building systems, need to interact in order to perform their tasks successfully.

Any project involving commissioning should begin with a commissioning scoping meeting, which all team members are required to attend. At this meeting, the roles of each team member are outlined and the commissioning process and schedule are described.

Commissioning team members most often include the building owner or project manager, commissioning provider, design professionals, installing contractors and manufacturer's representatives. The team may also include facility staff and possibly testing or diagnostic specialists and utility representatives. The commissioning team does not manage the design and construction of the project. Its purpose is to promote communication among team members and the early identification and resolution of problems. To that end, the design professional and owner are key members of the commissioning team.

Of course, few situations are ideal. Budget considerations and special project characteristics may expand or minimize the commissioning roles and responsibilities described below. Owners should consult with their commissioning providers about potentially combining some of the following roles. The commissioning provider can review the scope of commissioning and advise the owner on how to consolidate roles and tasks to best fit the size and complexity of the project.

THE COMMISSIONING TEAM DOES NOT MANAGE THE DESIGN AND CONSTRUCTION OF THE PROJECT. ITS PURPOSE IS TO PROMOTE COMMUNICATION AMONG TEAM MEMBERS AND THE EARLY IDENTIFICATION AND RESOLUTION OF PROBLEMS.

Building Owner/Property Manager

The building owner's most significant responsibility is to clearly communicate expectations about the project outcome. Often a property manager or project manager, who is given the authority over project budgets and goals, represents the owner. The owner's expectations are used by the designer to establish the design intent of the project and by the commissioning provider to evaluate whether this intent is met. Other responsibilities of the building owner or owner's representative include:

- Determining the objectives and focus of the project.
- Hiring the commissioning provider (if using an independent third party) and other members of the project team.
- Determining the projects budget, schedule, and operating requirements.
- Working with the commissioning provider to determine commissioning goals.
- Facilitating communication between the commissioning provider and other project team members.
- Approving start-up and functional test completion (or delegating this task to a construction or project manager).
- Attending building training sessions when appropriate.

Commissioning Provider

The commissioning provider's primary tasks include:

- Ensuring the completion of adequate design intent documentation.
- Providing input on design features that facilitate commissioning and future operation and maintenance.
- Assisting in developing commissioning specifications for the bid documents.
- Developing a commissioning plan that includes equipment and systems to be commissioned.
- Ensuring that team members understand their specified commissioning responsibilities, work to promote a positive, solutions-based team approach, and facilitate bringing a quality project to completion.
- Developing diagnostic and/or test plans for systems to be commissioned.
- Writing construction, functional, and performance tests.
- Submitting regular reports to the building owner or project manager.
- Witnessing selected contractor start-up tests, air and water testing and balancing, and duct pressure testing.
- Overseeing all functional and performance testing of systems.
- Reviewing and commenting on technical considerations from design through installation, in order to facilitate sound operation and maintenance of the building.
- Reviewing contractor and manufacturer training plans prior to delivery to facility staff.
- Reviewing operation and maintenance manuals documentation for completeness.
- Writing a final commissioning report documenting the final evaluation of the systems' capabilities to meet design intent and owner needs.

- Developing a systems concepts and operations manual that details the most important operation parameters and equipment instructions.

Design Professionals

The responsibilities of the design professionals will vary with the interests of the designers and the needs of the project and owner. The primary commissioning-related responsibilities of design professionals are to document the design intent (owner's project requirements and related acceptance criteria) for all systems, if this was not completed in pre-design, to write system descriptions and record design basis information, answer questions and issues brought up by the commissioning provider during design, and to make sure that commissioning is included in the bid specifications. If the design professional is hiring the commissioning provider, he or she should do so as early in the design process as possible. During construction, the designers are tasked with clarifying design issues related to system operation and design intent and to assist in resolving construction and operational deficiencies illuminated by the commissioning process. For complex projects, the designer may review commissioning plans, functional performance test plans, and may witness selected functional testing. If this is the case, the design professional's proposal should include funds to cover these activities. As mentioned before, the design firm may be responsible for hiring and overseeing the commissioning provider.

One of the primary commissioning responsibilities of design professionals is documenting design intent for all systems.

Installing Contractors and Manufacturer Representatives

Contractors and manufacturer representatives are responsible for performing commissioning functions described in the specifications. These may include assisting with developing the commissioning schedule, conducting performance tests (under the supervision of the commissioning provider or facilities staff) of the systems they install, adjusting systems where appropriate, and documenting system startup. Contractors and manufacturer representatives are also responsible for training building operators in the proper operation and maintenance of systems and providing operation and maintenance manuals on the equipment they install.

Facility Manager/Building Operator

The building operator should assist with (or at least observe) as much of the functional testing as possible. To achieve even greater impact on the commissioning process, as early as possible the owner should try to hire its new operator, or assign an existing operator who will be responsible for this building, to become closely involved with the construction commissioning team. The insights of an operator in the final phases of design can be quite beneficial. Often times there are details of the design that can be adjusted and modified at no cost yet will provide significant benefits to the ongoing operation of the building. Specific examples might include point naming conventions, alarm messages and graphic layouts of the energy management system. The operator can also help in interfacing any existing facilities management software, owners standards, and equipment preferences into

The building operator should assist with (or at least observe) as much of the functional testing as possible.

the project. As this employee observes the commissioning tests this will improve the operators understanding of the equipment and control strategies. It also trains the operator to be able to retest systems periodically as part of their ongoing O&M. The operator should also attend training sessions provided by manufacturer's representatives and or contractors.

In selected large scale projects, a member of the owner's operations and maintenance personnel has been fully integrated into the commissioning team. Sprint Telecommunications is using this approach while constructing its 4,000,000 square foot world headquarters campus in Overland Park, Kansas. A Sprint employee has been assigned permanently to the commissioning provider for the express purpose of providing full-time field representation for the duration of this project. This employee attends all commissioning team meetings and witnesses tests. The goal is to have this employee obtain significant hands on experience and understanding of campus equipment so that they may ultimately take charge of the operation and maintenance activities when the project is completed.[11]

Testing Specialists

If the complexity of the project requires special testing, the specialists performing these tests should also be involved in commissioning. Test results and recommendations from these specialists should be submitted to the commissioning provider for review. They may also be required to review documentation relating to the systems they test and to train operators on the proper use of this equipment.[12]

Commissioning Phases

The commissioning process helps facilitate and connect each step of the construction process. Commissioning enhances communication among project team members and ensures that they all understand the project goals. This allows the project team to identify problems early, before they can affect later phases of the project and cause delays.

Predesign Phase

The predesign phase is the ideal time for the owner to select a commissioning provider. Early selection allows the commissioning provider to play an advisory role during the conceptual process. He or she may suggest ways to make the overall building more energy

[11] Lovetere, David P. et al. *Commissioning the Sprint World Headquarters Campus*, in Proceedings of the National Conference on Building Commissioning, 2000.

[12] Dunn, Wayne. *Roles and Responsibilities*, in Proceedings of the National Conference on Building Commissioning, 1995.

efficient and identify key design strategies that can facilitate operation and maintenance. Involving the provider early can also increase buy-in for commissioning from other team members because the provider is involved from the beginning. Otherwise, the team may view the commissioning provider as an outsider who does not really understand the project. During this phase, the commissioning provider may assist in developing the owner's project requirements (OPR).

The OPR documents the ideas, concepts and criteria that are defined by the owner to be important. Typically this document is developed by the owner or the owner's programming representative. It should generally describe the project both physically and functionally, and it should include specific acceptance criteria for each OPR item. The level of detail will vary with the size and complexity of the project, the demands of the owner, and the experience of the design team. The OPR should describe how the project will be used and operated, and should present known goals and objectives as measurable metrics when possible. It may also state specific contractual performance requirements or energy consumption targets, if they are established by the owner. The OPR sets the criteria for all subsequent design decisions.

The owner's project requirements list the ideas, concepts and criteria that are defined by the owner to be important.

Design Phase

The goal of commissioning during the design phase is to ensure that the efficiency and operational concepts for building systems that were developed during programming are included in the final design. The main commissioning tasks during this phase are compiling and reviewing design intent documents (owner's project requirements and their related acceptance criteria), if not already developed, incorporating commissioning into bid specifications, and reviewing bid documents. During the beginning of design the designer develops their design concepts which they propose to use to meet the owners project requirements. They also document the assumptions (design basis) used in their design for sizing and selection of systems (i.e. codes followed, temperature parameters, occupancy loads etc.) The design concepts and design basis are compiled into a design narrative document which the commissioning provider reviews for clarity, completeness and compliance with the design intent. As the design progresses, the design narrative is updated and compared to the design intent.

The bid specifications developed during the design phase include commissioning requirements for the contractors. Specifications should include any special equipment or instrumentation that must be installed for obtaining measurements during performance testing. They should also describe the responsibility that contractors will have for preparing operation and maintenance manuals and for training facility staff. The commissioning provider reviews these bid documents, updated design narratives and all other design intent and contract documents.

The optimum time to hold the commissioning scoping meeting is during the design phase. At this meeting, the commissioning provider outlines the roles and responsibilities of the project team members with respect to commissioning and reviews the commissioning plan outline and schedule. Team members provide comment on the plan and schedule, and the commissioning provider uses these suggestions to complete the final commissioning plan. The final plan will include:

- The scope or level of commissioning
- Commissioning schedule
- Team member responsibilities
- Communication, reporting and management protocols
- Documentation requirements of each team member
- Detailed scope of testing
- Detailed scope of monitoring
- Recommended training format

THE COMMISSIONING PROVIDER DOES NOT APPROVE THE DESIGN. HE OR SHE MAKES RECOMMENDATIONS TO FACILITATE COMMISSIONING AND IMPROVE BUILDING PERFORMANCE IN A COLLEGIAL MANNER IN CONCERT WITH THE DESIGN TEAM.

The commissioning provider attends selected design team meetings and formally reviews and comments on the design at various stages of development. They note potential system performance problems, and may provide input on energy efficiency, indoor environmental quality, maintainability, commissionability, sustainability, life cycle cost, etc., depending on the skills of the commissioning provider and design team and interests of the owner. Making these changes during the design phase, rather than after construction begins, reduces costly change orders, which saves money in the long run. It is important for the building owner to understand that the commissioning provider does not approve the design. He or she makes recommendations to facilitate commissioning and improve building performance in a collegial manner in concert with the design team.

During this phase, the commissioning provider can also play a significant role in developing a building's operation and maintenance program or suggesting improvements for a program already in place. The provider interviews the facility manager to determine operating staff ability and availability to operate and maintain building equipment and systems. Careful consideration is given to whether the proper level of staffing resources are available to fully implement a successful long-term operation and maintenance system to ensure continued building performance. The commissioning provider also reviews the design documents and drawings to ensure that equipment is accessible for maintenance.

Construction Phase

During this phase, the commissioning provider reviews contractor submittals of commissioned equipment and the operation and maintenance manuals and may write test plans for each system and piece of equipment to be commissioned. The provider also visits the construction site periodically and notes any conditions that might affect system performance or operation.

During the construction phase, verification checklists, sometimes referred to as "prefunctional tests" are used to ensure that equipment is properly installed and ready for functional testing. These checklists are usually completed by the contractors. The commissioning provider approves and may oversee start-up and the use of construction checklists and makes sure that any deficiencies are remedied before functional testing begins. Appendix 2 contains a sample verification checklist.

The commissioning provider should involve the building operation staff in the construction checklist procedures and functional testing as much as possible. Doing so improves operator understanding of the proper operation of equipment and systems. It also provides operators with valuable hands-on training in running and troubleshooting the equipment they will manage.

Expected Deliverables

Owners who decide to commission their buildings should expect to receive the following written deliverables:

1. Commissioning plan and schedule detailing each step of the commissioning process and each team member's role and responsibilities.
2. A diagnostic and functional test plan detailing how each test will be accomplished and noting expected performance parameters.
3. A list of findings and potential improvements identified by the commissioning provider for design phase and construction phase activities
4. A training plan recommending specific topics and training schedules
5. At the completion of the project, a final commissioning report detailing all of the commissioning provider's findings and recommendations including copies of all functional performance testing data.
6. A systems concepts and operations manual which gives a description of each system with specific information about how to optimally operate and control the system during all modes of operation such as during fire, power outage, shutdown, etc., including special instructions for energy efficient operation and recommissioning.
7. Energy savings and implementation cost estimates for recommendations developed in the process are also deliverables in retrocommissioning projects.

The commissioning provider may write various progress reports during construction that document testing progress as well as deficiencies that may affect future building performance. These reports may be submitted to the owner, design engineer, project manager or contractors, depending on the contract arrangements for the project. (Establishing a clear process prior to the construction phase for delivering correction orders to the responsible contractors and tracking their responses is critical to the success of commissioning.)

The commissioning provider uses the functional tests to document and verify the proper operation of equipment and systems according to the building specifications, plans and change orders, and architect's instructions. Most often, the commissioning provider directs the tests, but actual equipment operation during the tests is performed by subcontractors, particularly the controls contractor. If corrective measures are required, the commissioning provider makes sure that they meet the owner's criteria and the design intent and may involve the owner and architect for resolution of responsibility or strategy. Acceptable performance is reached when equipment or systems meet specified design parameters under full-load and part-load conditions during all modes of operation, as outlined in the commissioning test plan. Appendix 3 contains a sample functional test plan.

After completing functional testing, the provider writes a final commissioning report and submits it to the owner for review. In addition to the final report some commissioning projects include a more comprehensive documentation package to assist the owner in understanding, operating and maintaining their systems. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) calls this package a systems manual and recommends that it include:[13]

- Index of all commissioning documents with notations as to their storage locations
- Commissioning report
- Initial and final design intent documents
- As-built documents
- Description of systems, including capabilities and limitations
- Operating procedures for all normal, abnormal, and emergency modes of operation
- Sequence of operation as actually implemented, with control systems data including all set points, calibration data etc.
- Location of all control sensors and test ports
- Seasonal startup and shutdown procedures
- Control schematics and computer graphics
- Complete terminal interface procedures and capabilities of the DDC system
- A list of recommended operation recordkeeping procedures including sample forms, trend logs
- Maintenance procedures

The construction phase is complete when the facility has moved from the static construction state to the dynamic operating state essentially free of deficiencies. Control of the building may have been transferred from the design/construction team to the owner and building operators prior to the completion of the this phase. Part of this transfer involves training building operators in the operation and maintenance of equipment and systems. Preferably this training begins during the construction/installation phase, as discussed above.

[13] ASHRAE, *Guideline 1-1996: The HVAC Commissioning Process,* American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta Georgia, 1996.

Training. The commissioning provider is responsible for interviewing the project manager and operation and maintenance staff to determine their training needs. With the owner, the provider then selects the appropriate topics, level of detail, sequence of training, and training methods. Training may include both classroom sessions and hands-on site demonstrations of proper equipment operation and maintenance.

In addition, the commissioning provider oversees training sessions as specified in the bid documents that installing contractors, designers and manufacturers representatives will conduct. The provider also verifies that operation and maintenance manuals are complete and available for use during the training sessions. The commissioning provider may arrange for videotaping of the training and coordinate this videotaping with vendors. Videotaping training sessions often provides an extra incentive for vendors to ensure the quality of the sessions.

Warranty Phase

Upon turnover the building is in the hands of the owner and operators. Even though the project is considered complete, some commissioning tasks from the initial commissioning contract continue throughout the typical one year warranty period.

Any testing that was delayed because of site or equipment conditions or inclement weather, will be completed during warranty. Although some testing of heating and cooling systems can be performed under simulated conditions during the off-season, natural conditions usually provide more reliable results. Seasonal testing is conducted to verify proper operation during, at minimum, both winter and summer.

When performing testing during post-occupancy, the commissioning provider or test engineer must be careful not to void any equipment warranties.

When performing testing during post-occupancy, the commissioning provider or test engineer must be careful not to void any equipment warranties. The building owner should require that contractors provide the commissioning provider with a full set of warranty conditions for each piece of equipment to be commissioned. Some warranty provisions may require that the installing contractor actually perform the testing, under the supervision of the commissioning provider.

The commissioning provider may also be tasked with returning a few months prior to the expiration of the contractor's one-year warranty to review system operation and interview facility staff. Acting as the owner's technical resource, they assist the facility staff in addressing any performance problems or warranty issues.

It is a good idea for owners to consider recommissioning their facilities periodically to ensure that equipment performance levels continue to meet design intent. If building operators have been involved in the original commissioning effort, and if they received training that included the components listed on page [30], they may be able to conduct the recommissioning process themselves.

When Does Commissioning End?

Operation and management staff should recommission selected building systems on a regular basis.

Commissioning ensures that a building is performing as intended at the time that commissioning occurs. This means that to maintain this level of performance, commissioning, in a sense, never ends. Certainly no one could reasonably expect building operation staff to perform functional tests on equipment and systems daily. However, operation and management staff should be encouraged to recommission selected building systems on a regular basis, perhaps every 2-3 years depending on building usage, equipment complexity, and operating experience. Your commissioning provider can recommend an appropriate interval for your building and systems. In the meantime, implementing regular, sound operation and maintenance practices ensures that the savings from commissioning last.

Operation and Maintenance for Persistence

To ensure that the benefits gained from commissioning persist over time, sound operation and maintenance practices must be in place. Some of these practices include:

- Establishing and implementing a preventive maintenance program for all building equipment and systems.
- Using commissioning documentation such as commissioning checklists and functional tests as a basis for periodic testing of equipment.
- Reviewing monthly utility bills for unexpected changes in building energy use.
- Using energy accounting software to track building energy use.
- Tracking all maintenance, scheduled or unscheduled, for each piece of equipment. Periodic reviews of these documents will often indicate whether certain pieces of equipment require tuning up.
- Updating building documentation to reflect current building usage and any equipment change-outs.
- Establishing an indoor air quality program for the building.
- Assessing operator training needs annually.

Good Operation and Maintenance Begins During Design

Like commissioning, successful operation and maintenance begins in the design phase of a project. Soliciting input from operation and maintenance staff during the early stages of building design can facilitate good operation and maintenance practices. The more convenient it is for staff to perform regular checks and maintenance on building systems, the better building performance needs can be met and costly maintenance can be avoided.

Examples of some design recommendations to help simplify operation and maintenance are:[14]

- Provide ground floor access to the chiller room through a connected loading dock.
- Provide one or more roll-up doors of sufficient size to permit removal and replacement of chillers or other major equipment without having to disassemble equipment.
- Provide sufficient clearance on all sides of the chiller and other major equipment to perform all maintenance.
- Install hoist or crane equipment over banks of chillers or other major equipment.
- Install sufficient valves to permit the isolation of an individual chiller without having to shut down the entire air conditioning system.
- Install walkways around elevated equipment.
- Provide roof access with adequate openings via stairs, not ladders.

In addition, during the design stage the installing contractor's responsibilities concerning operation and maintenance should be clearly detailed in the project contract specifications, so that the contractor can adjust the bid price accordingly. For instance, specifications should explicitly state that contractors will be required to provide comprehensive operation and maintenance manuals for equipment and provide training for staff.

Operation and Maintenance Manuals

Operation and maintenance manuals for each piece of equipment are prepared by the contractor. The commissioning provider reviews each manual for compliance with the specifications as part of the commissioning process. Operation and maintenance manuals should contain:

- Name, address, and telephone number of installing contractor
- Product data
- Test data
- Performance curves (for pumps, fans, chillers, etc.)
- Installation instructions
- Operation requirements
- Preventive maintenance requirements
- Parts lists
- Troubleshooting procedures specific to the equipment design and application

If the provider believes it would be beneficial, additional information, already gathered during the commissioning process, can also be included in the operation and maintenance manuals. This information may include equipment submittals, design intent documents

[14] *Building Operation Management*, April, 1990.

including control strategies and sequence of operations (normal and emergency) and copies of the commissioning tests (pre-functional checklists and functional performance test forms).

Operation and maintenance manuals are useful reference tools for current facilities staff and can also be used as a training resource for new staff members.

Operation and maintenance manuals are useful reference tools for current facilities staff and can also be used as a training resource for new staff members. The operation and maintenance manuals should be placed in three-ring binders. Contractors should be required to provide at least three copies of each manual to the owner. Typically, one copy, the master copy, remains in the facility manager or engineers office. The second copy functions as a field copy, and selected pages from it may be removed for use during site work. The third copy resides in the building owner or management firm's office. Some companies have found it beneficial to "hard bind" the master copy, so that pages cannot be removed and misplaced. If building equipment will be maintained and operated by an outside firm, a fourth copy should be requested and provided to them as a reference. Because manuals lose their usefulness if they are not kept up to date, any pages added to them, such as checklists or preventive maintenance work orders, must be included in each copy.

Training

Perhaps the most essential component of operation and maintenance is training.

Perhaps the most essential component of operation and maintenance is training. Unless building operators and managers are given the skills to perform quality operation and maintenance practices, there is no hope that a building will continue to perform optimally.

As with all training, instruction should be structured to meet the needs of building operator staff. Training session topics should ideally be specified in the bid documents.

Suggested Training Topics

- Descriptions of equipment and systems installed and their warranties or guarantees.
- Equipment start-up and shutdown procedures, operation in normal and emergency modes, seasonal changeover, and manual/automatic control.
- Requirements and schedules for maintenance on all operation and maintenance-sensitive equipment.
- Health and safety issues.
- Recommendations for special tools and spare parts inventory.
- Emergency procedures.
- Operation and adjustment of dampers, valves and controls.
- Hands-on operation of equipment and systems.
- Common troubleshooting problems, their causes and corrective actions.
- Review of operation and maintenance manuals and their location on-site.
- Building walk-through.
- Review of related design intent documents.

- Energy management control system operation and programming.
- Control sequences and strategies.
- Thermostat programming.
- Relevant commissioning reports and documents.
- When and how to recommission building systems.
- The maintenance work order management system.
- Sound energy management practices.

By videotaping each training session, including the hands-on start-up and shut-down procedures for equipment, building operation staff gains a permanent and inexpensive on-site training aid. When new staff are hired, they can view the videos as part of their training. For buildings where a facility manager without a technical background provides maintenance, the commissioning provider can still coordinate with contractors to ensure that the manager is educated about the capabilities, intended function, and required maintenance of the building systems. This education should enable the facility manager to respond to occupant complaints in a manner that does not circumvent the systems' design intent. It is important to provide a list of resources for the manager to call for maintenance assistance when necessary.

Once a building is operating and occupied, problems occasionally develop that were not apparent during the commissioning process. These problems often occur during the first year of operation after construction or renovation. Sometimes the service contractor or operating staff can effectively troubleshoot and solve the problem. However, if a problem becomes chronic (for example, repeated comfort complaints), or if operating staff is unable to solve a problem in a reasonable amount of time, the owner should request expert troubleshooting assistance.

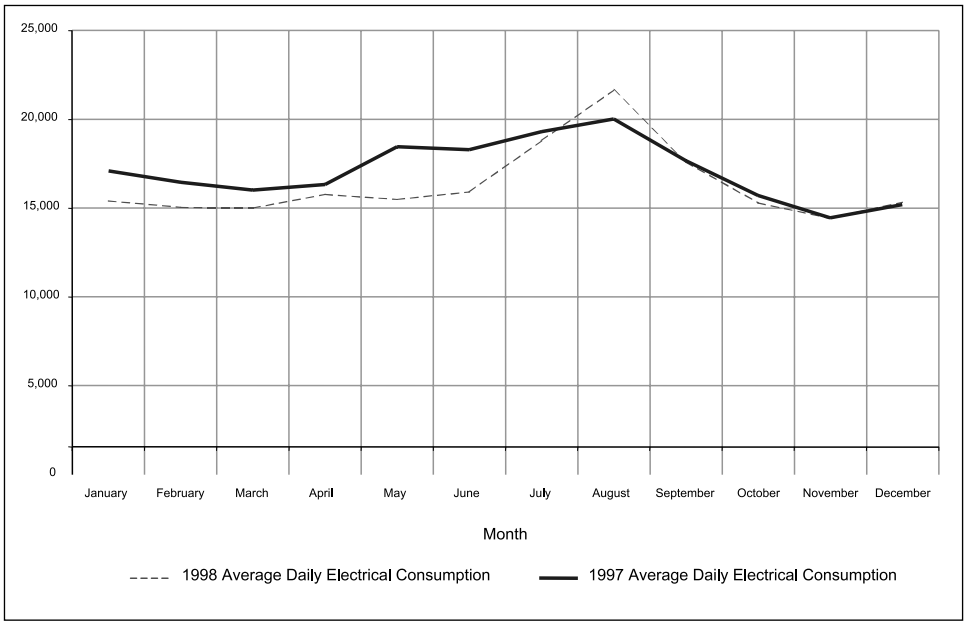
Because the commissioning provider and design engineer are very familiar with the building systems, the owner may want to consider contracting with one and/or both of them for the first year of operation to provide troubleshooting assistance on an as-needed basis. In traditional construction projects the mechanical engineer is only responsible to help correct problems if their contract stipulates a warranty period and the problems are "design" related. The Owner may find that it is more cost-effective to purchase troubleshooting services from the commissioning provider or engineer, because their knowledge of the building systems and design saves them time in diagnosing problems. This contract could be written in a "fee-for-service" or an "amount-not-to-exceed" manner. In the long run, owners may also find it beneficial to train operation and maintenance staff in energy accounting. In addition to tracking the building's energy use, energy accounting can also indicate problems or potential problems with equipment operation.

Energy Accounting

Energy accounting is a method of tracking a facilities energy use over time. Many facility managers seeking peak performance in their building have found that energy

accounting software gives them a better understanding of their utility expenditures. Each month's usage and expenditures are input into a software program. The software then tracks the usage while normalizing for temperature changes over the period being analyzed. The energy "accountant" can then watch and see whether the facility performs as expected or uses more energy than expected over time. If higher than expected usage occurs, further investigation can identify the occupancy and or usage changes, equipment problems, or other unknown problems that have increased the energy bills.

Figure 3:
Average Daily Electrical Consumption



Preventive Maintenance

Another important operation and maintenance practice is preventive maintenance. Preventive maintenance can save buildings owners time and money by:

- Maintaining facility operation
- Extending equipment life
- Identifying equipment degradation
- Preventing losses of equipment, time, productivity, and resulting revenue

The relationship between a properly maintained and operating facility and higher occupancy rates and profitable building operation does not need much explanation. A properly functioning air conditioning system is no longer a privilege but a necessity. Properly functioning air handling systems are crucial in buildings where indoor environments are directly linked to occupant safety (for example, hospitals) and staff productivity (such as high-rise, enclosed buildings).

When estimating service life, manufacturers usually assume regular preventive maintenance of the equipment and system components. Many preventive maintenance procedures recommended by manufacturers are intended to extend the life of the component and the system as a whole. Lack of preventive maintenance reduces equipment life.

Identifying degradation of the system's components is another benefit of preventive maintenance. A proper facility operation and maintenance system that includes reporting and documentation reduces the incidence of failure. For example, if a component of the system is identified as potentially failing to operate as intended, a work order for replacement parts can be set up immediately and work scheduled during unoccupied hours. Preventive maintenance can reduce the number and cost of emergency corrective maintenance bills.

Performing regular preventive maintenance can result in energy and cost savings. For example, simply replacing worn fan belts on a regular basis can save 2-4% of the energy used to run the fans. Cleaning air filters and cooling coils regularly can save 1-3% of the building's energy use for cooling. These basic activities cost very little to perform, but can add up to dramatic savings.

Preventive maintenance also makes buildings safer and can reduce potential owner liability. Increasingly, building ventilation systems function as part of an engineered smoke control system and therefore proper maintenance can decrease liability.

Developing a Preventive Maintenance Plan. The commissioning provider can assist the owner or facility manager in developing a preventive maintenance plan for a building's HVAC and electrical systems. Most of the information required for developing a preventive maintenance plan is gathered as part of the commissioning process or can be obtained from the operation and maintenance manuals.

LOW-COST PREVENTIVE MAINTENANCE ACTIVITIES CAN ADD UP TO DRAMATIC ENERGY SAVINGS.

A preventive maintenance plan consists of a checklist of tasks that are performed at manufacturer-recommended intervals (usually measured in hours of equipment run time). This checklist is usually kept in the form of a log and updated manually when tasks are performed. In buildings that use computerized maintenance management systems, the equipment that requires preventive maintenance should be entered into the system. If the computerized system is used for generating preventive maintenance work orders, update the system when work is performed and keep hard copies of completed work orders in a file or notebook. Another low cost measure to consider is programming the energy management system to track and archive equipment run times. This is most easily, and least expensively, done when the initial system programming takes place, and should be specified in the original equipment specification in the contract.

The preventive maintenance plan for each piece of equipment should include the following fundamental information, gathered during the commissioning process:

- Unique equipment identification number
- Name plate information
- Manufacturer's name
- Vendor's name and telephone number
- Equipment location
- Date installed
- Expected equipment life
- Expected annual energy use

Preventive maintenance should be performed according to manufacturer requirements. Consult the manufacturer's operation and maintenance manual for each piece of equipment for requirements such as frequency, chemical treatments, proper lubricants, special tools, etc. This information should also become a part of the preventive maintenance plan.

The preventive maintenance work order form or task list for each piece of equipment should have a verification section with at least two signature lines: one for the technician performing the preventive maintenance and one for the supervisor verifying that the maintenance was performed.

Preventive Maintenance Software Modules

Many major controls contractors also offer preventative maintenance (PM) modules for their software that will track and automatically advise operation and maintenance staff when equipment maintenance needs to occur. These systems can offer good value because the controls system already knows a lot about many of the building systems. To set these systems up properly, so that it will be operational when the building is first occupied, the owner should allow some extra budget for a facilities operator to assist in set-up during construction. This will also allow the operator to become familiar with the system and maximize it benefits once the building is occupied.

Outsourcing Preventive Maintenance. According to maintenance contracting firms, most office and retail buildings smaller than 50,000 square feet contract out the maintenance services on their HVAC equipment. If a new piece of equipment does not require frequent maintenance, and current staff time is committed, a contract for outside help may be less costly than hiring and training full-time staff. If a sophisticated new piece of equipment is purchased, compare the cost of training in-house staff to the cost of hiring a trained outside contractor to perform maintenance on the equipment to determine the best option for your particular situation.

In buildings where operating staff is not available or trained to perform the required preventive equipment maintenance, owners may obtain a service contract from the vendor, installing contractor, or a maintenance service contractor. Ensure that the service contract covers all of the manufacturer's recommended preventive maintenance procedures as described in the operation and maintenance manuals. After each site visit, require the contractor to provide an invoice or preventive maintenance form stating clearly which preventive maintenance activities or repairs were performed. Keep these forms on site in a file or three-ring binder for future reference. Regardless of who actually performs the preventive maintenance, the building owner is responsible for making sure that the preventive maintenance plans are complete.

Maintenance contracts tend to be site-specific, but in general, there are two basic types of services.

Preventive maintenance contract. Normally, this variety of contract does not cover the cost of replacement parts, but does include labor and supplies. The equipment owner is responsible for parts replacement. The duration of a preventive maintenance contract is usually one year. Frequency of site visits may depend on the equipment being serviced. Corrective maintenance may or may not be included.

Guaranteed service and repair contract. This type of contract is usually offered by large maintenance contractors. Under this arrangement, the contracting firm not only maintains but also replaces failed components. It is essentially an insurance policy with a low deductible, and typically is a multi-year contract. The cost for this type of contract is comparatively high.

Regardless of the type of contract used, when the contract is up for renewal it is important to carefully evaluate your cost for the service, quality of service, and your existing contractor's familiarization with your facilities equipment and operating procedures. Because there is a learning curve that any new contractor will face when taking over a facility, it might not be a wise decision to choose a new contractor just because they offer you a lower price. Careful consideration of the quality service you have already received and successful renegotiations with your existing service contractor might reward you with better long-term value.

PART 2: Commissioning Guide for Design Professionals

Commissioning is a quality-assurance process for new construction and installations that helps ensure that building equipment and integrated systems perform as owners and designers expect. Commissioning implements a systematic process to verify and cross-check performance from pre-design through warranty, increasing the likelihood that a newly constructed building will meet client expectations. In return for investing in commissioning, the building owner can save money during construction and throughout the operation and maintenance of a quality building. The designer can be an essential part of the commissioning process, helping to facilitate successful commissioning, and promoting overall client satisfaction.

What *Is* Building Commissioning?

Commissioning is a systematic process of ensuring that building systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs.[1] Ideally, the process begins in the pre-design phase with the development and documentation of owner's project requirements and design intent acceptance criteria, and continues through design, construction and the warranty period with actual verification through review, testing and documentation of performance. Commissioning integrates many traditionally separate project activities, including aspects of design peer review, equipment startup and verification procedures, control system calibration, testing, adjusting and balancing, O&M manual preparation and facility staff training and functional testing.

[1] ASHRAE, *Guideline 1-1996: The HVAC Commissioning Process*, American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia, 1996.

Why Commission Your Projects?

Consider a common commissioning problem with a VAV terminal unit. The unit is installed as part of a remodeling project (thus, served by an existing system) and it is not maintaining the required space comfort conditions. When the commissioning provider investigates the problem, he finds a group of qualified contractors/tradesmen who have all done their specific tasks.

- The tinner hung the unit, connected the ducts, installed the diffusers and balanced the system.
- The pipe fitter connected the reheat coil, insulated the lines and balanced the water system.
- The controls contractor installed the controller, verified wiring connections and calibrations, and installed the software.
- The designer extended the existing systems—as instructed—to serve the new loads, and the systems and equipment the designer specified have been installed as shown and connected to the existing systems.
- The building operator is running the existing systems to the best of his ability and really doesn't know if they are capable of handling the new load.

Everyone has done their part to the letter of their contract, yet the space is not comfortable. No one has taken ownership of the interactive parts *as a system* and looked beyond the boundaries of their contract for a cause and solution to the problem. This is the heart of commissioning—to take a big picture, systems oriented perspective on the project, develop an understanding of the interactions of the systems and then develop solutions.

COMMISSIONING BRINGS A BIG PICTURE, SYSTEMS ORIENTED PERSPECTIVE TO PROJECTS.

Today, commissioning typically begins with the selection of a commissioning provider. The commissioning provider may be an individual or a firm. The owner may also choose to use a designated in-house staff member, or the services of the designer or construction manager to implement the commissioning process. The first task of the commissioning provider is to work with the team of project stakeholders to develop the projects commissioning plan. The commissioning provider helps ensure that the building owner's project requirements are properly documented. The provider also promotes O&M and energy efficiency improvement opportunities during the design phase.

For instance, a designer may document the reasons for combination fire/smoke dampers and their ratings where a duct passes through a particular fire separation. A commissioning provider could advocate for accessibility for these devices and promote the use of energy-efficient configurations (airfoil blades vs. conventional blades, and damper out of the air stream vs. damper in the air stream).

The commissioning provider and/or designers then incorporate commissioning requirements into their specifications. During construction, the commissioning provider inspects building systems and components for compliance with contract documents and related acceptance criteria. When the project is near completion, the provider and appropriate contractors conduct rigorous functional tests. In most cases, the commissioning provider will also coordinate and provide oversight for the start-up process. At the end of the commissioning process, building operators receive training and ideally a systems manual, that documents the key information to ensure proper O&M of the building.

A properly commissioned facility has several advantages over a non-commissioned building. These can include fewer change orders during the construction process, fewer call-backs, long-term tenant satisfaction, lower energy bills, lower O&M costs, lower equipment replacement costs and an improved profit margin for building owners once the building is occupied. Commissioning also assures that the building's operational staff is properly trained to run the building as the designer intended.

Commissioning can help optimize energy-efficient design features and improve overall building performance. Design professionals can use this proven, systematic approach to reduce change orders and liability exposure, and ensure that the building owner receives a building that functions according to the owner's project requirements.

DESIGNERS CAN USE COMMISSIONING TO REDUCE CHANGE ORDERS AND LIABILITY EXPOSURE.

A Brief History

Over the past 20 years, the construction industry has changed dramatically in the United States. Older building systems were less complex, requiring less sophisticated equipment to perform successfully. Control systems, even sophisticated ones, were generally electro-mechanical because electronic and digital technology was not considered cost effective in the commercial buildings industry. Low energy costs made the more complex HVAC systems, like variable air volume (VAV) fan systems, less attractive than the energy intensive but easy-to-operate constant volume reheat fan systems. The low energy costs provided little incentive to schedule equipment and systems, and the continuous operation of systems often masked operational problems or simply eliminated them. In addition, building envelopes allowed greater air infiltration because energy costs were lower and efficiency was not a priority. At the same time, designers and contractors that delivered higher quality buildings commanded higher fees.

Today, energy efficiency receives more attention. Buildings have more sophisticated controls and equipment and building envelopes are tighter. Most significantly, the transition from a design-bid-build to a bid-design-build contract process has increased the pressure on the design community to reduce fees and consequently curtail the extent of their work.[2] New construction design fees typically are governed by a percentage of the capital

[2] Nolfo, Andrew, "Commissioning and the Design Build Process," in *Proceedings of the National Conference on Building Commissioning*, 1998.

cost of the facility. Focusing on capital costs, rather than the life-cycle costs associated with a facility, encourages owners to ignore long-term considerations such as O&M costs, energy efficiency, ease of use and occupant productivity.[3] It also discourages designers from investigating innovative system alternatives that could cut long-term costs and improve the overall performance of the building.

The construction process is an increasingly complex maze of specialized tasks. In most cases, the architect or general contractor controls the project. Specialized mechanical and electrical design work is subcontracted out, leading to a disjointed construction process. But despite this added complexity, project budgets are shrinking, leaving little room for error. Construction teams have relatively little money for "contingencies" when problems occur. Mistakes that might have been corrected with teamwork are now overlooked in the name of completing the job on time and within a budget. It used to be standard practice for many contracting firms to conduct performance tests and systematic check-out procedures for equipment they installed. As construction budgets have become tighter, this service has been dropped from most projects. The net result can be poor building performance and increased operating costs. When problems occur, the building owner and/or tenants may file litigation against the construction and design teams for what they perceive as inadequate product delivery. Many owners do not understand that they are not currently paying for the level of quality assurance that commissioning provides. Given today's sophisticated building systems, tight construction budgets and short construction timelines, owners need to use the commissioning process to help deliver buildings that perform as intended.

Who Takes Advantage of Commissioning?

Commissioning is standard practice for many facilities at the Walt Disney Company, Sprint, Kaiser Permanente Health Care, the Boeing Company and other firms.

The commissioning process has been successfully demonstrated in both the government and private sectors. Executive Order 12902 requires all federal agencies to "establish and implement facility commissioning." Several state governments are developing policies to establish commissioning infrastructures. The California Energy Commission (CEC) is helping to develop and promote the practice of commissioning within California's construction industry. Private corporations have embraced commissioning after recognizing that better building performance reduces their energy and long-term maintenance costs, reduces their liability and improves occupant productivity. Commissioning is standard practice for many facilities at the Walt Disney Company, Sprint, Kaiser Permanente Health Care, the Boeing Company, Hewlett Packard, Chevron Oil, Target Stores and Westin Hotels.

[3] Tamblyn, Tom, "Commissioning a School: A Case Study," in *Proceedings of the National Conference on Building Commissioning,* 1994.

Why Should Designers Be Involved?

Commissioning offers designers an opportunity to view the entire building delivery process, to work through design questions in a team environment, see the results of their designs and, ultimately, provide a higher quality product to their customers. In turn, designers who participate in commissioning should command higher fees for providing these services. In traditional construction compensation models, the designer's fee is based indirectly on a percentage of the building's cost. The designer gets no reward for extra effort to make the building perform better, or perform more efficiently, or to make construction less costly. This is not desirable for owners, designers, or anyone interested in energy and resource efficiency. Commissioning provides an opportunity to rethink this compensation model. By systematically documenting efficient design, construction and performance, commissioning saves money in construction and subsequent operations. Implementation of the commissioning process often necessitates expanded designer services—services that ensure better building performance and satisfied customers.

Innovation in design can be intimidating. Every building design is unique, even seemingly "standard" designs. In essence, each building is a prototype, yet it is expected to perform as if it had been built before. Commissioning can provide a safety net to review and support the design, whether it is a new design or a reworking of a tested design. Commissioning allows designers to observe the implementation of their designs in the field. Without commissioning, the best design ideas may be negated in the field due to change orders or contractor oversight. Through the commissioning process, the designer will see proof that his or her designs are implemented.

Commissioning allows designers to observe the implementation of their designs in the field.

The commissioning process encourages everyone involved in a building project to function as a team, from design initiation through building acceptance and warranty. It allows owners and operators to decide how they want their building to function, and to convey these expectations clearly. It offers the design and construction professionals a systematic process to develop and complete the project based on these expectations. Many owners accept that in return for investing more in a design process that includes commissioning, they will receive a completed building that meets their quality expectations at a lower ultimate cost. By shifting a portion of total project costs from construction and first-year fine-tuning to the commissioning provider and the design team, the owner can potentially save significant sums of money.[4] Owners who have experienced the benefits of commissioning are typically willing to pay more for design services on future projects that include commissioning.

[4] The Farnsworth Group, as presented in *How to Achieve Top Performance in Your Building: Commissioning Benefits, Process and Performance,* a workshop series by the Association of State Energy Research and Technical Transfer Institutes, 1998.

What Does This Guide Include?

This guide addresses commissioning issues from the designer's perspective. Assuming that readers have a basic knowledge of the commissioning process,[5] the guide describes how designers can use commissioning to enhance their services and maximize client satisfaction. Readers will gain an understanding of how commissioning can benefit designers, the role of designers in various commissioning activities, and how designers interface with other commissioning team members. The guide also offers tips for marketing commissioning services to clients, commissioning plan outlines and sample owner's project requirements documentation. Sample commissioning specifications and other commissioning resources can be found in the EDR CD-ROM of Building Commissioning Guidelines.

Acronyms List

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BCA	Building Commissioning Association
DDC	Direct Digital Control
EDR	Energy Design Resources
EMS	Energy Management System
HVAC	Heating, Ventilation and Air-Conditioning
LEED	Leadership in Energy and Environmental Design
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PID	Proportional plus Integral plus Derivative
RFI	Request for Information
RFP	Request for Proposal
RFQ	Request for Qualifications
TAB	Testing, Adjusting and Balancing
USGBC	U. S. Green Building Council
VAV	Variable Air Volume

Commissioning and Green Buildings

Building owners are increasingly concerned with issues of resource efficiency, environmental impact, and occupant health and productivity. They are beginning to request that their facilities be designed and constructed with "green" features that minimize

[5] For a description of the commissioning process, see Part One of this guide: *Introduction to Building Commissioning*.

environmental impact and maximize occupant productivity. Certain federal, state and local government agencies, as well as a number of private owners, now require their facilities to meet a "green" standard.

Commissioning is especially important for green buildings because these projects use new construction techniques and materials. Green buildings often employ systems that use renewable resources such as solar energy or wind power and low-energy HVAC systems with natural ventilation or evaporative cooling. They may also employ systems that conserve water through rainwater and gray water recovery. All of these technologies can make a significant contribution to the sustainability of a project, but they add complexity to building design and construction, as well as commissioning, since the technologies are less thoroughly understood. Commissioning can help ensure that the green ideas and concepts of the designer are developed for the individual needs of the facility and clearly articulated within the design documents. In addition, commissioning can verify that the green design features perform adequately once the building is completed.

Commissioning a green building includes ensuring that:

- The design meets the desired green building certification criteria.
- Green materials are adequately specified and installed.
- The green products or features will not have a negative impact on other building systems or ongoing O&M.
- The design decisions and rationale behind them are adequately documented.
- Specifications and drawings are clear and complete.
- Specific performance criteria are developed for each green feature, if appropriate.
- The appropriate O&M documentation and staff training is provided so facility staff can properly maintain the green features.

The United States Green Building Council (USGBC) has developed Leadership in Energy and Environmental Design (LEED), a green building rating and certification system to provide guidance to designers. Under LEED, buildings earn points in six general categories: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, and Innovation & Design. Buildings can earn a bronze, silver, gold or platinum rating.

COMMISSIONING IS A PREREQUISITE FOR LEED RATING ELIGIBILITY.

The USGBC requires six commissioning tasks as prerequisites for LEED rating eligibility.[6] These "Fundamental Building Systems Commissioning" requirements for mechanical systems are:

- Hire a commissioning provider for the project.
- Collect and review the owner's project requirements and basis of design documentation.
- Include commissioning requirements in the construction documents.

6 U.S. Green Building Council, *LEED Reference Guide*, Version 2.0, 2000.

- Develop and use a commissioning plan.
- Verify the installation, functional performance, operational training and maintenance documentation for each commissioned system.
- Complete a commissioning report.

Although these steps are part of any good commissioning process, the need to document these steps for LEED purposes and coordinate with other members of the LEED team may add costs to the commissioning work. In addition, LEED requires that the functional testing of the heating and cooling systems occur during the heating and cooling seasons respectively. While this is desirable, it is not mandatory for a non-LEED commissioning process, and thus, it may incur additional commissioning costs.

An additional credit toward a LEED rating can be earned by completing all five of the following tasks:

- Conduct a focused review of the design before the construction document phase.
- Conduct a focused review of the construction documents just prior to completion.
- Conduct a selective review of contractor submittals of commissioned equipment.
- Develop a Recommissioning Management Manual.
- Establish a contract for a near-warranty-end or post-occupancy review.

Recent experience has shown that many owners and construction project managers assume that the LEED process and the commissioning process are identical—that the commissioning provider is handling all LEED requirements and coordination. This is not usually the case. LEED requires commissioning of all credit-earning mechanical systems and energy-efficiency measures under the Energy and Atmosphere and the Indoor Environmental Quality categories. However, it does not stipulate that the commissioning provider will handle all LEED-related design and coordination issues, such as LEED document coordination, specification, implementation or engineering. Such coordination is beyond the scope of the commissioning associated with a LEED project. While the commissioning provider is a good candidate for performing this coordination, it should not be assumed that he or she will be providing this coordination simply because they have been engaged to perform the commissioning work. The specifications for a LEED project must clearly stipulate which parties will be responsible for which LEED activities. A matrix like the one below can help make sure that each party understands his or her role in the process.

Sample LEED Certification Responsibilities Matrix

Designate the party responsible for each credit activity in the spaces on the matrix below—the first two lines are filled in as an example. Note that the prerequisites and credits listed below are a selected sample, not a complete list, of LEED activities.

TABLE 4

LEED Credit Category	Coordination of Documents	Specification/ Engineering	Implementation	Commissioning
Energy and Atmosphere				
EA Prerequisite 1 (Fundamental commissioning)	LEED Coordinator	Commissioning Provider	Commissioning Provider	Commissioning Provider
EA Prerequisite 2 (Minimum energy performance)	LEED Coordinator	Mech. Designer	General Contractor	Commissioning Provider
EA Prerequisite 3 (CFC Reduction in HVACR equip.)				
EA Credit 1.0 (Optimize energy performance)				
EA Credit 3.0 (Best practice commissioning)				
EA Credit 5.0 (Measurement & verification)				
EA Credit 6.0 (Green power)				
Indoor Environmental Quality				
EQ Prerequisite 1 (Minimum IAQ performance)				
EQ Prerequisite 2 (Envrmntl. tobacco smoke control)				
EQ Credit 1.0 (C02 monitoring)				
EQ Credit 6.1 (Controllability of Systems)				
EQ Credit 7.1 (Thermal comfort)				
EQ Credit 8.2 (Daylight and views)				

How Designers Benefit from Commissioning

Becoming involved in a commissioning process offers many benefits to the designer:

- The team approach promotes project success.
- Coordination between designers, contractors and owners improves building performance.
- Designs become more realistic, robust, practical and achievable in the field.
- Designers spend less time answering questions from the construction team, due to improved communications.
- Problems are detected and corrected early, keeping projects on time and within budget.
- The designer gains an ally on the project (the commissioning provider).
- Commissioning reduces the likelihood of claims against the designer.
- Increased customer satisfaction can lead to higher fees and more repeat business.

A Team Approach

In recent California focus group studies, building owners and their representatives repeatedly stressed that a major obstacle to achieving optimal building performance is the lack of communication between the design team and construction team. Without proper communication between designers and contractors, the original owner's project requirements are likely to be "lost in translation" as a project moves from concept to completion. (Documenting the owner's project requirements is a critical component of commissioning and is discussed in more detail later in this document.) Commissioning links the traditionally fragmented phases of the design and construction processes by facilitating a team approach and encouraging the project team to view the building process holistically. Owners, designers and contractors meet to review plans, document intent, identify acceptance criteria and clarify issues before they become in-the-field problems.

Commissioning can create a cooperative team approach to a project. If the commissioning provider facilitates a collegial relationship among all team members, the project team is likely to resolve issues effectively, with the least amount of wasted time and money. In contrast, a group of professionals who do not work as a team may resort to "finger pointing" and defensive tactics when issues arise.

Coordination Among Designers, Contractors and Owners

Commissioning can foster greater cooperation among the professionals involved in a project and provide a platform for cross-checking the performance of a building's equipment and systems. On many projects, a lack of coordination among the design, installation and operational team members can lead to systems that function inefficiently or fail to function

at all. For example, the mechanical systems found in many commercial buildings are oversized,[7] a result of uncertainty over future loads and the use of excessive safety factors. This leads to unnecessary energy use to run these systems. It can also lead to an unnecessary and significant increase in first costs, which ripple through the project. A larger-than-necessary fan may mean a larger motor, which can mean a larger starter or variable speed drive, which can mean a larger distribution feeder, which can mean a larger electrical service. The commissioning process encourages the review of performance requirements and the design to ensure that appropriately-sized mechanical systems are specified and installed.

Commissioning can also ensure that design details, especially those related to commissioning, are not changed in the field. In-the-field decisions (such as substituting a saddle joint for a manufactured tee, or changing the pitch of the roof slightly) can drastically affect building performance. One cannot expect the contractor to be aware of the ramification of making such changes if he or she is not familiar with the motivation behind the design specifications. Moreover, changes can affect the ability to test building performance—essential for a successful commissioning—and O&M—process.

COMMISSIONING CAN FOSTER GREATER COOPERATION AMONG THE PROFESSIONALS INVOLVED IN A PROJECT AND PROVIDE A PLATFORM FOR CROSS-CHECKING THE PERFORMANCE OF A BUILDING'S EQUIPMENT AND SYSTEMS.

Finally, commissioning sees that designs account for continued building performance by providing adequate access to systems and equipment that may require maintenance, replacement or retesting. Doors and access panels should be sized and situated appropriately, where they are not obstructed by last-minute changes in construction plans or by field changes. By establishing and sustaining team communication, as well as functionally testing systems and equipment, commissioning can help team members ensure that systems are sized correctly and function as designed.

Designs Work in the Field

Bringing designers and contractors together to solve problems improves the work of both. Designers learn the practical aspects of implementation, leading to designs that are easier to construct and maintain and that are more energy-efficient in the field. Contractors learn the importance of each design detail—why they should not substitute a saddle joint when the designer specified a manufactured tee, or why two seemingly identical pieces of equipment can mean very different levels of energy-efficiency.

By becoming involved in the commissioning process, designers learn the practical implications of their designs. Designers see how their designs address real world problems such as energy efficiency, constructability and maintainability. All too often, a technically superior design is plagued by implementation problems. A designer may create a

[7] York, Dan. "Commissioning Green Buildings," in *Proceedings of the National Conference on Building Commissioning,* 1998.

sophisticated design and address every conceivable problem. However, if the design is beyond the available construction, operation and maintenance capabilities in the field, the building will not perform as intended.

> For example, consider PID control algorithms. Current DDC equipment can do PID control on almost any control loop. Designers often specify PID control for everything from the central system control loops to the space temperature control loops, although tuning a PID loop (as compared to a proportional-only loop) is quite complex. A proportional-only loop can be set up in less than an hour and will work predictably after that. A PID loop can take hours or days to tune and may require seasonal adjustments. If not properly adjusted, it can become unstable and drive other loops into instability. This wears out equipment, significantly affects the building environment and often wastes energy. The advantage of the PID loop over the proportional-only loop is that it eliminates the proportional offset, offering more precise control. If the loop is applied to a discharge air temperature control system, this can mean a significant savings in energy and a significant improvement in performance, and the PID is probably worth the extra tuning effort. On the other hand, to control space temperature—where occupants will adjust the set point as a function of how they feel—PID control is an unnecessary layer of complexity in this case.

By getting involved in the commissioning process, the designer has the opportunity to witness the problems associated with tuning a PID loop. A designer who has never encountered this problem might specify it for everything, unaware that this could result in significant increases in construction and operating costs, and ongoing performance issues. Thus, the designer involved in commissioning will learn to produce designs that achieve optimal performance under real world constraints.

The commissioning process gives the designer an opportunity to get out in the field to see the result of their efforts—an opportunity that doesn't usually exist, at least in a billable mode. This benefits the overall construction process because ultimately, the designer knows the project drawings and specifications better than anyone. Often, designers can look at a situation in the field and, based on knowledge of the assumptions behind the design, solve a problem in minutes that might have taken the contractor or the commissioning provider hours to address.

Designers Save Time

The commissioning process promotes well-documented designs and collegial relationships, both of which reduce the time designers spend answering questions from the construction team. In a commissioning process, the designer, with assistance from the owner and the commissioning provider, documents the owner's project requirements, acceptance criteria and basis of design at the inception of the project. Clarity from the outset reduces ambiguity, smooths the process of design review and produces construction documents

that convey exactly what is to be built. In addition, the commissioning process includes regularly scheduled meetings with the entire commissioning team. If a question arises during construction, the construction team can consult the design documentation or engage designers in an ongoing dialogue without waiting for small questions to become big problems.

Early Detection Saves Money

The commissioning process encourages parties to communicate and solve problems earlier in the construction process, while there are still low-cost or no-cost solutions available.

> For example, a design for a grocery store included a rooftop air-handling unit. The commissioning provider pointed out that the air intake was close to the loading docks, where the unit would draw in exhaust from the trucks. The design team decided to change the position of the rooftop unit, avoiding hundreds of thousands of dollars in lost worker productivity, potential health complaints, litigation fees and lower sales over the life of the building.[8] If they had attempted to correct the problem after construction, the cost (to filter the air or relocate the unit) would have been exorbitant.

By saving the owner money on construction and first costs, commissioning can free up money to be spent on design. Commissioning incorporated into the design phase of projects can significantly reduce change orders. This, in turn, reduces the requests for project delays and decreases the use of the owner's contingency funds for change orders.[9] Commissioning can also reduce first costs (see preceding oversizing scenario) and ongoing operating costs through better access and maintainability, improved efficiency and smarter resource use. Better access to equipment can have a significant impact on long-term costs and efficiency. For instance, if a chiller room is easily accessible, the costs to upgrade to better or more sustainable refrigeration technology when it becomes available are not prohibitive. If, on the other hand, it costs $50,000 in temporary ramps, rigging and access accommodations to install a $30,000 chiller, then chiller replacement will be delayed until it is an absolute necessity. Thus, commissioning during design can help projects meet schedule and budget goals—and the resulting facilities continue to save money in lower operating costs over the life of the buildings.

By saving the owner money on construction and first costs, commissioning can free up money to be spent on design.

[8] Altwies, Joy. "Quantifying the Cost Benefits of Commissioning," in *Proceedings of the National Conference on Building Commissioning*, 2001.

[9] Savage, Jerry. "Commissioning a Materials Research Laboratory," in *Proceedings of the National Conference on Building Commissioning,* 2000.

Designers Gain an Ally

THE COMMISSIONING PROVIDER BECOMES THE DESIGNER'S ALLY, HELPING TO ENSURE THAT DESIGNS ARE WELL DETAILED AND REALIZED IN THE FIELD.

Designers without previous commissioning experience may feel that commissioning adds an unnecessary layer of oversight. However, if the process unfolds as intended, the commissioning provider becomes the designer's ally, helping to ensure that designs are well detailed and realized in the field. A designer's internal process of design review includes reviewing load calculations, verifying design details, verifying coordination among the various design specialties, reviewing control system sequences, verifying specifications, spot checking equipment selections and reviewing the final check set. A commissioning provider reviews the design specifically for commissionability and operability. For example, a commissioning provider will check that the design includes access for testing and O&M procedures—reading gauges, entering doors and panels, and inspecting and replacing filters.

> On one job, a commissioning provider discovered that a single sensor in a six-foot-high mixed-air plenum was installed at the top of the plenum. Due to stratification of air within the plenum, the sensor indicated the mixed air temperature was at set point 55°F when in fact the average air temperature was 48°F. A second sensor was installed to produce an average temperature reading, avoiding endless building control nightmares. Thus, commissioning had a significant impact on system performance, energy efficiency and occupant comfort.

The commissioning provider can also help make sure that contractors do not make equipment or component substitutions that might affect the final performance of the design or alter the owner's or designer's original intentions.

Reduced Claims

By taking care of problems before the owner occupies the building, commissioning can significantly reduce the likelihood of errors and omissions claims against the design/construction team. In 1996, the Design Professional Insurance Companies (DPIC) studied 44 of their claims on buildings that were not commissioned. The average settlement was $584,000 or roughly 1 percent of the total construction costs.[10] Common themes that ran through many of these claims were a lack of coordination among parties (owner, designers, contractors and operational staff), equipment changes during the construction phase of the project and improper maintenance practices once the building was occupied. All of these issues could have been addressed by building commissioning.

Some designers might argue that they carry insurance to cover these types of losses. However, the damages of a lawsuit extend far beyond the expenses covered by insurance.

[10] Thomson, Jeane P. "Can Commissioning Impact Professional Liability Claims?" in *Proceedings of the National Conference on Building Commissioning,* 1997.

Each firm in the DPIC study lost the time and expenses to investigate and prepare their defense, paid out large insurance deductibles and lost the opportunity to earn future revenues from the affected clients.

Increased Customer Satisfaction

As indicated earlier, commissioning increases the likelihood that a project will meet the client's expectations. Satisfied clients will be more inclined to hire the design team again and more willing to pay more for a proven product. Designers will have documentation that paying more for commissioning and commissioning-related design activities will save money on construction and future facility operations.

Benefits During Construction

Although designers and owners benefit most when commissioning begins during the design phase or earlier, designers can also benefit from a commissioning process that begins during construction. A commissioning provider who comes into a project during the construction phase can bring a valuable new perspective and help solve start-up problems faced by both designers and contractors. The commissioning provider can also document the start-up and functional testing results, thereby reducing future liability exposure for the designers and owners. By documenting the owner's project requirements and witnessing their implementation, the commissioning provider also can provide feedback to the designer. This improves future designs and earns customer good-will and satisfaction. A building owner who is satisfied at final turnover is more likely to contract with the design team again and, in turn, becomes an excellent reference.

Reduced Litigation Exposure

Every new building is essentially a prototype—unique and untested until it is built. With proper project planning, adequate time to develop and review the design, an able construction team to implement the design, and adequate training for the operators who run and maintain the building, occupants can be comfortable and productive over the life of the building. However, in today's construction environment, low design budgets, highly complex building systems, increased specialization and fast track construction timelines have become the norm. These factors can result in building systems that have not been adequately designed, fully tested or made to function as intended. In some cases this can result in unsatisfactory building performance, or worse, complete system failures.

There are many reasons a building may fail to perform as expected. Perhaps the owner's project requirements are not clear; perhaps the design is inadequate, or an adequate design lacks clarity; perhaps the design is misinterpreted or inadequately constructed. And at any

point in the design and construction process, simple human error may occur. A well-developed commissioning process mitigates each of these situations. Commissioning promotes the clear definition of owner's project requirements, achievable acceptance criteria, a clearly documented design, specifications that accommodate testing, and thorough documentation of system testing and its results. Commissioning not only proves the adequacy of the design, but also documents that at one time the design performed as intended. It also promotes the continuance of that performance via operations staff training and access to improved facility documentation, such as system manuals.

COMMISSIONING CAN PROVIDE ADDITIONAL DOCUMENTATION THAT AN ADEQUATE STANDARD OF CARE WAS USED DURING DESIGN.

Owners use lawsuits to contest inadequate building performance and system failure problems. Designers in turn have tried to protect themselves from these lawsuits while facing the increased pressures of completing their projects with fewer resources. While commissioning offers a quality assurance process for the owner, it also safeguards designers by improving the quality of their designs, which improves the final built product. Commissioning also provides additional documentation that an adequate standard of care was used in their design process.

Michael Hornreich, an attorney who specializes in construction litigation, believes that commissioning provides a basis for better communication and documentation between the building owner and the construction team. "Commissioning seeks to have the owner recognize at the beginning of their project what the overall project costs will be to properly design and construct a building to their desired performance parameters. Within a well-defined commissioning process, the owner is directly involved in helping the designer and the commissioning provider answer the following questions:

- "What is the desired product (i.e. owner's project requirements with acceptance criteria)?"
- "How will the work be inspected during installation?"
- "How will the performance be evaluated?"
- "What are the warranty obligations?"
- "How will the system need to be maintained?"

"The challenge of using this is not checking off discussion points, but rather using each point to force a deliberate approach to making decisions."[11] This communication, and the documentation that results, helps improve the outcome of the project and provides evidence that the performance expectations of the owner were met at building turnover. This documentation can also help reduce or eliminate future judgments because it demonstrates that proper care was taken during the design and construction process.

[11] Hornreich, Michael, "The Practical Legal Aspects of Commissioning Building Systems–Why Owners Should Pay for Commissioning Services," in *Proceedings of the National Conference on Building Commissioning,* 1994.

Increased Designer Profits

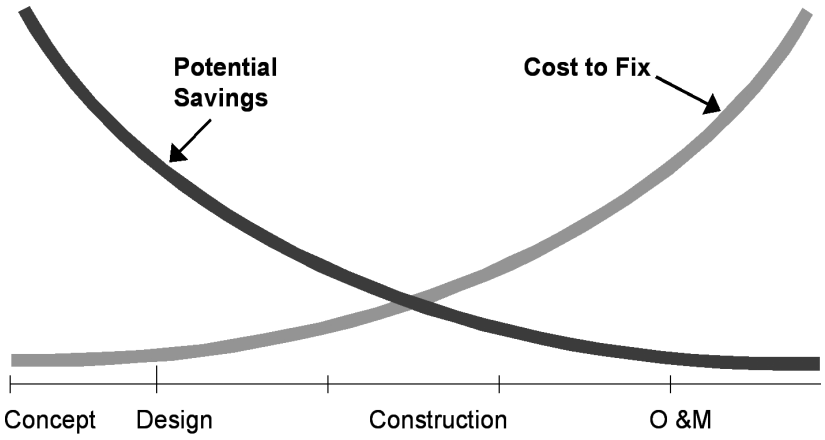
A designer's first impression might be that commissioning will add work to projects without additional compensation. As partners in the commissioning process, designers do take on some additional tasks and responsibilities. However, the services provided by the design team as part of the commissioning process (such as documenting design decisions, assuring that the contract documents reflect commissioning requirements and participating in commissioning meetings) will not only increase design revenue but will, in many cases, reduce or eliminate problems that have caused cost overruns and conflicts on non-commissioned projects. Commissioning results in a product that meets owner expectations, thus potentially reducing liability claims. After receiving a commissioned, well-performing building at turnover, owners are more likely to recognize the designer's efforts to deliver high-quality design services, and they will be more likely to hire that team on future projects.

Building owners who subscribe to the commissioning process are more willing to pay more for these design activities because they know that they will save money in the long run. Owners who are reluctant to invest the extra money will be persuaded after their first successful project involving commissioning. When they receive a building that works exceptionally upon turnover, they will realize they can afford to pay designers more.

Because commissioning can identify potential problems earlier in the design or construction process, it can result in a lower overall construction budget, fewer change orders, fewer contractor call-backs and lower operating costs. The earlier in the process that commissioning begins, the more potential savings are realized, freeing up more of the budget for design and commissioning services. The following figure shows how the savings potential of commissioning varies over the course of a project.

Cost and Savings vs. Project Timeline

FIGURE 4



Who Provides Commissioning Services?

Many people believe that commissioning is best performed by an independent third party who works directly for the owner. There are several reasons for this. First, most firms working in the design/construction field do not have the commissioning experience to properly plan and execute the majority of commissioning tasks. A qualified outside provider brings experience from a number of projects and may have expertise that in-house staff may not have, such as engineering analysis experience or diagnostic skills. Second, an outside provider is better able to identify problems that might have been missed by those intimately involved with the project. An outside provider offers a fresh perspective and new ideas to resolve problems and will not have a conflict of interest when reporting findings to the owner. Third, an outside provider has no investment in doing things "the old way." An outside provider can help project team members see the value in using new methods to perform old tasks.

It is also possible for someone affiliated with the design or construction team to act as the commissioning provider if they are properly experienced. The Building Commissioning Association (BCA)[12] recommends that when the commissioning provider is not an independent party under contract directly with the owner, then he or she should develop a formal plan for managing the potential conflict of interest. One method to manage (but not eliminate) these potential conflicts of interest is to institute parallel and simultaneous reporting of all findings to the owner's representative and contract manager for the commissioning services.

Provider Qualifications

To properly plan, schedule and execute a successful commissioning project, the chosen provider should have broad experience working as a team member in other commissioning projects. Additionally, a commissioning provider must have excellent communication and conflict management skills. On any commissioning team, there are likely to be differences of opinion. The commissioning provider's most challenging task is crafting the diverse opinions of all team members into an action plan that identifies possible conflicts and resolves them to the satisfaction of all involved.

[12] The BCA is a professional organization of independent commissioning providers, founded in 1998, that promotes high professional standards in the commissioning industry. For more information, see the Building Commissioning Association Web site at www.bcxa.org.

In general, for complex projects, a commissioning provider who will personally develop the commissioning test plans and directly supervise the commissioning work should meet the qualifications in the following checklist. These qualifications are focused on HVAC and control systems. Where electrical and other systems will be commissioned, the commissioning provider's experience in these areas should also be considered. However, often the prime commissioning provider will work with other consultants to address all the systems being commissioned. In such cases, the management skill of the prime commissioning provider is also important.

Recommended Minimum Qualifications

- Experience in design, specification or installation of commercial building mechanical and control systems and other systems being commissioned.
- History of responsiveness and proper references.
- Meets owner's liability requirements.
- Experience working with project teams, managing projects and conducting scoping meetings.
- Experience commissioning at least two projects of similar size and of similar equipment to the current project; one in the last three years. This experience includes the writing and execution of verification checks and functional test plans.

Optional Qualifications

- Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs.
- Experience in design installation and/or troubleshooting of direct digital controls and energy management systems, if applicable.
- Demonstrated familiarity with metering and monitoring procedures.
- Knowledge and familiarity with air/water testing and balancing.
- Experience in planning and delivering O&M training.
- Background in building contracting.
- Overall understanding of all building systems including building envelope, structural and fire/life safety components.

Independent commissioning providers, who often have design engineering or operations training, should have the recommended minimum qualifications. Hands-on experience with building systems is especially critical. It is important to involve an independent provider as early in the project as possible. This allows the provider to review the owner's project requirements, begin scheduling commissioning activities and begin writing commissioning specifications into bid documents for other contractors.

Who Manages the Commissioning Contract?

The commissioning process is a team effort involving all of the traditional stakeholders of the construction process plus a commissioning provider with the specialized knowledge and experience to help plan and direct the commissioning activities. The traditional contractual relationship among the owner, design team and construction team remains the same. The only change is the addition of language outlining the design and construction teams' responsibilities to ensure that the appropriate commissioning activities take place. A separate contract for commissioning services can be managed by the owner/project manager, the architect or the contractor. Each option has its advantages and disadvantages. The final decision will probably depend on the complexity and the specific needs of the particular project.

Independent Third Party Under Contract to the Owner

Many owners who have commissioned their buildings recommend using an independent third party who reports directly to the owner. An independent commissioning provider, under contract to the owner or to the owner's project manager, can play an objective role and ensure that the owner will get the building performance he or she expects. For large and/or complex projects, especially in buildings with highly integrated, sophisticated systems, future savings from commissioning often outweigh the slightly higher costs of an additional contract. Independent third party commissioning providers bring a fresh perspective to the project as they collaborate with the design team. By joining the project team during the design phase, the commissioning provider can suggest more improvements and savings at the stage when changes can be made on paper. This approach is preferable to waiting to fix the problems through the change-order process while the building is under construction.

Architect or Design Engineer

On many construction projects, the owner delegates to the architect or design firm the responsibility of managing expenditures and approving payments to the various design engineers and contractors. If the owner has developed rigorous commissioning requirements and specifications, the firm may also be asked to manage the commissioning provider's contract. In some cases, if the managing architectural or design engineering firm has a qualified field engineer who does not have responsibility for the design of the project, he or she may even be charged with overseeing the commissioning activities (witnessing tests, etc.). This option has some advantages because the architect or mechanical designer is already familiar with the owner's project requirements and doesn't need to spend time getting up to speed. Overseeing the commissioning is not included in a design professional's basic fees, so the owner must pay the designer for managing the contract. To manage the

potential conflict of interest created by having the commissioning services managed by the design firm, all findings of the commissioning process should be directly reported to both the designer and to the owner.

Contractor

Although contractors may have the knowledge and capability to test the equipment they install, they may not be skilled at testing or diagnosing system integration problems. In addition, some contend that it is difficult for contractors to objectively test and assess their own work, especially since repairing deficiencies found through commissioning may increase their costs.

If an owner has a good relationship with the general contractor, he or she may require that the general contractor hire a test engineer to commission the equipment. This scenario can work well when specifications and contract documents clearly detail the commissioning requirements and when the owner has a technical staff that is qualified to oversee the test engineer. Still, many general contractors prefer to work with an independent commissioning provider because they are objective and they help oversee the quality of the subcontractors' work. This improves client satisfaction and ultimately reduces callbacks.

Commissioning and Design-Build Projects

At one time, construction projects were primarily designed and constructed using a design-bid-build process. The building owner contracted architects and engineers to develop a set of building plans and specifications based on his or her project requirements. Once these documents were completed, they went out to bid and the owner selected a contractor from the pool of respondents. Much of the discussion in this guide assumes this traditional design-bid-build approach. However, this section briefly touches on the design-build process.

Over the last 20 years, a new method of design and construction has appeared in the building industry. Largely contractor driven, design-build project delivery is an attempt to contain costs and improve construction timelines. In theory, selecting a combined design and construction team in one bidding process can result in lower overall project costs and shorter construction timelines. In reality, many owners have been dissatisfied. In some cases, owners didn't understand the implications of different quality levels of building materials and mechanical equipment. In other cases, the general contractor who won the design-build contract did not understand or give importance to the design process and so did not allocate proper funding for the design of appropriate building systems.

To avoid the potential pitfalls of the design-build process, owners must develop a strong set of design/performance criteria before placing their project out to bid. They should hire an experienced independent commissioning provider to help develop the criteria and work with the owner's representative, to determine whether the criteria are met. During the pre-bid meeting, owners must make the general contractors aware of their performance requirements and commitment to the commissioning process. With these precautions, a design-build project can be successfully commissioned, and the designer's role in the commissioning process will be the same as their role in commissioning a design-bid-build project.

If the owner decides to add commissioning into the design-build project after the project has gone out to bid, designers will find that their role differs somewhat. They may be charged with documenting the building owner's project requirements and acceptance criteria while the project is under construction and developing an addendum to the project specifications that includes commissioning. Designers may need to request more money to cover documentation tasks that were not in the original scope of work. In addition, designers can expect to encounter more RFIs and change orders than they would if commissioning had been part of the project from the beginning.

Project Phases and Commissioning

Commissioning activities occur during each phase of design and construction. Throughout all project phases, commissioning activities promote clear communication and teamwork. Ideally, commissioning begins in the pre-design phase and continues through design, construction and warranty. This provides the most overall benefit. In each phase, a commissioning provider works with various project team members to coordinate the commissioning process, with the aim of ensuring system integration and promoting overall quality assurance. In practice, commissioning often begins during the construction phase.

A description of the commissioning activities in each project phase is outlined below.

1. Pre-design Phase

Pre-design is the optimal time to begin the commissioning process. The initial commissioning team should be convened to lay the groundwork for the team effort and to plan for commissioning at later phases. In pre-design, the team includes at least the owner/project manager, commissioning provider and designers. The contractors and building operators should be added as they are hired.

One of the most significant tasks that occurs during commissioning begins during pre-design: developing project documentation necessary for commissioning—sometimes referred to as

design intent documentation. This documentation forms the foundation of the commissioning process, and its contents evolve over the course of a project. Because this documentation is not produced consistently and is not typically easily accessed for design and construction projects, there is some debate in the industry as to what exactly it should include. However, industry experts agree that this enhanced level of project documentation is critical to producing buildings that perform well and meet owner requirements. ASHRAE is currently working to better define this aspect of commissioning for its upcoming revision of the Commissioning Guideline.

For the purposes of this publication, this design intent documentation includes owner's requirements for the project, design intent acceptance criteria for each requirement, and references to the portions of the design basis and design narrative that relate to each requirement. These pieces of documentation are described in more detail later in this section and in the Design Phase section.

Design Intent documentation forms the foundation of the commissioning process.

The main commissioning tasks of the pre-design phase are outlined below. These tasks are especially critical for large or complex facilities (such as labs, hospitals, office buildings with innovative systems or special usage or IAQ requirements). Some of these tasks may be scaled down for smaller, less complex projects.

Commissioning Provider Selection. The project manager sends out requests for proposals or requests for qualifications for the commissioning services and contracts with a commissioning provider or designates one from the owner's, designer's or construction manager's organization. When a commissioning provider is involved from the beginning of a project, he or she can identify design strategies that facilitate later commissioning activities and offer commissioning-focused review of design documents. In addition, if the commissioning provider is involved from the start, the project team will accept him or her as someone who really understands and is invested in the project. The team's positive attitude about commissioning will result in a more successful commissioning effort. See Provider Qualifications on page 54 for recommended selection criteria.

Design Phase Commissioning Plan. The commissioning provider begins to develop a design phase commissioning plan, including recommended schedule and staffing requirements, documentation processes, and lists of potential checks and tests that should be considered. The plan will be enhanced as the design progresses. See Appendix 4 for a commissioning plan outline.

Owner's Project Requirements: Development and Review. Owner's Project Requirements, along with their related acceptance criteria, are the most critical piece of design intent documentation. The commissioning provider or design team may assist the owner in developing the owner's project requirements (OPR), or at a minimum, ensure that they are clearly documented. The OPR is an explanation of the ideas, concepts and criteria that the owner deems important. The owner or the owner's programming

representative typically develops this document, but the designer is often responsible for ensuring that it is clear and comprehensive. Designer responsibility in this area depends on their contract and their relationship with the owner. Some designers routinely develop this type of documentation; some rarely do so. The important factor—in terms of successful commissioning and in the performance of the building—is that the owner designates either the designer or the commissioning provider to spearhead the development of the OPR.

As the design progresses, the designer, owner and commissioning provider enhance the OPR by adding basic acceptance criteria to each item. As these criteria evolve over the course of a project, the commissioning provider and designer update the documentation. Appendix 5 contains an example of OPR .

Owner's Project Requirements

The owner's project requirements should generally describe the project both physically and functionally, and they should begin to set the performance requirements for design, construction and operation. The level of detail will vary with the size and complexity of the project, the building use needs and sophistication of the owner, and the experience of the design team. The owner's project requirements should describe how the project will be used and operated, and should present measurable goals and objectives when possible. They may also state specific contractual performance requirements or energy consumption targets, if the owner establishes them. The owner's project requirements set the criteria for all subsequent design decisions. Appendix 5 contains a sample format for developing this documentation.

2. Design Phase

During the design phase, the commissioning provider performs a commissioning-focused design review, ensures that the owner's project requirements are clearly documented and followed, and checks that commissioning for the construction phase is adequately reflected in the bid documents. Design-phase commissioning facilitates construction-phase commissioning and provides additional design review in areas of special concern to the owner. Note that commissioning during design is not intended to provide quality assurance for the entire design process; however the owner may choose to enlist the commissioning provider to perform a more rigorous design review, depending on the commissioning provider's experience and qualifications. Rather, it ensures that the final design includes all efficiency and operational concepts for building systems developed during pre-design.

A primary commissioning task for designers during this phase is continuing to develop the design intent documentation with assistance from the commissioning provider and the owner. (Depending on the commissioning provider's scope of work, the commissioning provider may take the lead on this task with assistance from the designer.) The main commissioning tasks during the design phase are outlined below.

Commissioning Scoping Meeting. The commissioning provider holds a scoping meeting at the beginning of the design phase. At this meeting, the commissioning provider outlines the roles and responsibilities of the project team members and reviews the commissioning plan and schedule. Team members comment on the plan and schedule, and the commissioning provider uses these suggestions to revise the commissioning plan.

Commissioning Plans. The commissioning provider updates the design-phase plan and develops a preliminary construction-phase plan to guide development of the commissioning specifications. The plan contains a list of the systems and specific equipment to be commissioned, along with the general modes to be tested and the probable testing methods. In addition, the plan more fully defines various team member responsibilities, O&M documentation, training and scheduling. Appendix 4 contains a design phase commissioning plan outline.

Design Intent Acceptance Criteria. The designer works with the owner to establish acceptance criteria for each item in the OPR. These criteria should be "project-specific and measurable in a practical way."[13] The criteria may include measurement and verification methods, such as functional testing or construction observation. The designer, commissioning provider and owner must be careful to clearly link each OPR item to its corresponding acceptance criteria. See Appendix 5 for an example of acceptance criteria associated with Owner's Project Requirements.

Who Develops Design Intent Documentation?

Developing the Owner's Project Requirements and Design Intent Acceptance Criteria is a team effort that involves the owner, design team and commissioning provider. Either the designer or the commissioning provider may be responsible for leading this effort. Their specific roles and level of effort should be specified in their contracts. Designers embarking on projects that will be commissioned should work with the owner as early as possible to define their role in this area. For instance, designers may take the lead in documenting OPR for the owner (with review by the commissioning provider), but the commissioning provider may take the lead in assigning acceptance criteria for each OPR (with review by the designer). Obviously, many combinations of roles are possible. This makes it essential for designers and commissioning providers to get clear direction, ideally in their contracts, from the owner.

Basis of Design. The design team develops documentation of the assumptions behind design decisions that were made to meet the owner's project requirements. The basis of design describes the systems, components, conditions and methods chosen to meet the

[13] Stum, Karl, "Understanding Owner Project Requirements Documentation (Design Intent)" in *Proceedings of the National Conference on Building Commissioning,* 2001.

requirements. For example, it describes which codes, temperature parameters and occupancy levels were used to size and select the systems. Some reiteration of the owner's project requirements may be included. The portions of basis of design that directly relate to the OPR are referenced in the design intent documentation.

Design Narrative. The designer compiles the design concepts and design basis into a design narrative document that the commissioning provider reviews for clarity, completeness and compliance with the owner's project requirements. Portions of the design narrative that directly relate to the OPR are referenced in the design intent documentation.

THE COMMISSIONING PROVIDER DOES NOT APPROVE THE DESIGN, BUT MAKES RECOMMENDATIONS TO FACILITATE COMMISSIONING AND IMPROVE BUILDING PERFORMANCE.

Design Review. The commissioning provider attends selected design team meetings and formally reviews and comments on the design at various stages of development. He or she notes potential system performance problems, energy-efficiency improvements, indoor environmental quality issues, O&M concerns, and other issues, depending on the scope of commissioning and needs of the project. The commissioning provider does not approve the design, but makes recommendations to facilitate commissioning and improve building performance. For example, the commissioning provider reviews designs to ensure that equipment is accessible for maintenance. It is the responsibility of the project manager to evaluate and discuss all findings with the design team and implement those approved. Of course, legal responsibility for the design ultimately rests with the Engineer of Record. The commissioning provider should work with the designer to incorporate commissioning requirements in such a way as to minimize liability issues for the designer.

Commissioning Specifications. The commissioning provider develops (or assists the designer to develop) detailed commissioning specifications to be included by the design team in the final contract document. Specifications should include any special equipment or instrumentation that must be installed for obtaining measurements during functional testing. Extra monitoring points, test ports and gages can make a building more "commissioning-friendly." These features facilitate commissioning and can reduce commissioning costs. They also make it easier for operating staff to monitor building performance and troubleshoot problems in the future. Appendix 6 contains sample specification language requesting additional monitoring points, test ports and gages, as well as a list of potentially valuable monitoring points to include. Finally, the commissioning specifications should also describe the responsibility that contractors have for preparing O&M manuals and for training facility staff.

Contract Documents. The design team is responsible for producing the formal contract or bid documents. Ideally these documents should include a complete set of mechanical, electrical and structural drawings, as well as a detailed set of specifications with equipment performance requirements and comprehensive sequences of operation. An update of the design record may be included as an attachment. The commissioning provider reviews these bid documents, including updated design narratives, for consistency with the owner's project requirements, testing and commissioning requirement, and acceptance criteria.

O&M Planning. The commissioning provider can help develop a building's O&M program or suggest improvements for a program already in place. The provider can interview the facility manager to determine whether sufficient personnel resources are available to ensure continued building performance once the building is operational. The commissioning provider and owner also begin planning for O&M staff participation in functional testing as part of their training.

COMMISSIONING DURING THE CONSTRUCTION PHASE IS MOST EFFECTIVE WHEN COMMISSIONING HAS BEEN PART OF THE PROJECT SINCE THE DESIGN PHASE OR EARLIER.

Pre-bid and Pre-construction Meetings. Although these meetings are not uniquely commissioning tasks, commissioning needs to be emphasized here so that all of the bidders and project participants are aware of commissioning and its role in the project. These meetings set the tone for working with the contractors on the commissioning effort.

3. Construction Phase

Commissioning during the construction phase is most effective when commissioning has been part of the project since the design phase or earlier. The project team can use the documents developed during the building's design to ensure that systems are installed, testable and maintainable as intended. The main construction phase commissioning tasks are listed below. As in the pre-design phase, the promotion of clear communication is one of the most important roles of commissioning.

Construction Phase Commissioning Plan. The commissioning provider updates the construction phase commissioning plan to include a list of all systems and specific equipment to be commissioned; the process to be followed; communications, reporting and documentation protocols; and an estimated schedule for the commissioning process.

Construction Phase Commissioning Kick-off Meeting. The commissioning provider coordinates a construction phase commissioning kick-off meeting. The meeting should include the project manager, construction manager, design team, commissioning provider, and representatives from the general contractor and mechanical, electrical, controls and TAB subcontractors. At this meeting, the commissioning provider outlines the roles and responsibilities of the project team members, specifies procedures for documenting commissioning activities and resolving issues, and reviews the preliminary construction phase commissioning plan and schedule. Team members, including designers, comment on the plan and schedule, and the commissioning provider uses these suggestions to complete the final commissioning plan.

Issues Log. The commissioning provider develops a record of issues and findings that require further attention. The log is updated regularly and shared with the project manager, construction managers and contractors for discussion and resolution during construction meetings.

Submittal Review. The commissioning provider reviews contractor submittals of equipment to be commissioned, comments on each submission and forwards them to the project manager or designer. The review allows the commissioning provider to check for adherence to the owner's project requirements and acceptance criteria.

Prior to formal O&M manual submittals, the commissioning provider requests a list of installation and start-up procedures, O&M information, equipment performance data, control drawings and other specific information. The data is used to write verification checklists and functional test procedures. Project manager support for obtaining these additional documents from the contractors is critical.

Coordination Drawing Review. The commissioning provider may assist the project manager in monitoring the development of coordination drawings to ensure reasonable harmonization among the trades.

Change Order Review. To monitor impacts on commissioning and owner project objectives, all RFIs and change orders applicable to the commissioned systems should be submitted for review to the commissioning provider.

Construction Observation. The commissioning provider and the designer should visit the construction site periodically. The provider notes any conditions that might affect system performance or operation. The designer notes any instances where the design is not properly implemented. For more information on field observation, refer to the design brief on Field Review, available on the Energy Design Resources Web site at www.energydesignresources.com.

Verification Checklists. Verification checklists (sometimes referred to as start-up checklists, construction checklists, or prefunctional checklists) transfer the information in the specifications and drawings to the workers in the field. Verification checklists are used to ensure that equipment is properly installed and ready for functional testing. The contractor or commissioning provider creates a checklist for each piece of equipment, consisting of simple questions that must be answered as the installation progresses. Sometimes, the commissioning provider just oversees this process and the contractor is charged with actually developing the checklists. The contractors usually complete these checklists. The commissioning provider approves and may oversee start-up and the use of verification checklists, often through a spot-check process. If a spot check reveals a problem, then they review more checklists. The commissioning provider makes sure that any deficiencies are remedied before functional testing begins.

Functional Testing. The commissioning provider develops and witnesses the functional tests to document and verify the proper operation of equipment and systems according to the building specifications, plans and change orders, and architect's instructions. Often,

the commissioning provider meets with the contractors and suppliers to assure that the tests they develop are comprehensive and safe to execute. But the actual test is written by the provider and tailored to the building or system. Subcontractors carry out the test procedures. Equipment or systems must meet specified design parameters under full-load and part-load conditions during all modes of operation, as described in the commissioning test requirements of the specifications. If corrective measures are required, the commissioning provider makes sure that they do not jeopardize the owner's project requirements or the acceptance criteria. The owner and designer normally are consulted for strategies to resolve these types of issues.

O&M Manuals Review. The commissioning provider and designers review the O&M manuals and verify that they are complete, clear and available for use during the training sessions.

Training Review. Ideally, enhanced training requirements are included in the specifications. The commissioning provider augments the training provided by contractors and manufacturers with an overview, questions list and other types of training to ensure that the operating staff is fully conversant with the operation of the building in all circumstances. In some cases, the designer gives a systems overview as part of building operator training.

The designer may present a systems overview as part of building operator training.

Final Commissioning Report. After completing functional testing, the provider writes a final commissioning report and submits it to the owner for review. The report summarizes the commissioning effort, specifically addressing the projects success in meeting the project acceptance criteria. The report also includes the commissioning provider's feedback on each piece of commissioned equipment and system relative to installation and start-up, function, performance, O&M documentation and staff training.

Systems Manual. In addition to the final report, some commissioning projects require the completion of a systems manual: a more comprehensive documentation package to assist the owner in understanding, operating and maintaining the building's systems. This manual may be the most important document the commissioning process generates. ASHRAE's *Guideline 1-1996: The HVAC Commissioning Process* recommends that the Systems Manual include:[14]

- An index of all commissioning documents with notations as to their storage locations.
- The final commissioning report.
- Initial and final owner's project requirements and acceptance criteria documents.
- As-built documents.

[14] ASHRAE, *Guideline 1-1996: The HVAC Commissioning Process* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia, 1996.

- A description of systems, including their capabilities and limitations.
- Procedures for all normal, abnormal and emergency modes of operation.
- Sequences of operation as actually implemented, with control systems data including all set points, calibration data, etc.
- The location of all control sensors and test ports.
- Seasonal start-up and shutdown procedures.
- Control schematics and computer graphics.
- Complete terminal interface procedures and capabilities of the DDC system.
- Recommended operation record-keeping procedures including sample forms and trend logs.
- Maintenance procedures.

THE DESIGNER OFTEN CONTRIBUTES THEORETICAL INFORMATION FOR THE SYSTEMS MANUAL.

The commissioning provider is typically in charge of developing the Systems Manual. In compiling the relevant documentation, the provider may request specific pieces of information from the designer. For instance, the designer often contributes theoretical information for the systems manual (excerpts from the design narrative and design basis) and may also provide sequences of operation.

Other Written Work Products. The commissioning provider may write various reports during construction to document testing progress and deficiencies that may affect future building performance. These reports may be submitted to the owner, design engineer, project manager or contractors, depending on the contract arrangements for the project. (A clear process for delivering correction orders to the responsible contractors and tracking their responses should be established before the construction phase.)

Final Acceptance or Substantial Completion. Final acceptance (also referred to as substantial completion) occurs when the building moves from the static construction state to the dynamic operating state. The design and construction team transfers control of the building to the owner and building operators during this phase. Part of this transfer involves training building operators. At this stage all project documentation is provided to the owner and operating staff, including the final commissioning reports and the systems manual.

4. Post-acceptance/Warranty Phase

Upon turnover, the building is in the hands of the owner and operators. Although the project is considered complete, some commissioning tasks from the initial commissioning contract continue throughout the typical one-year warranty period.

Seasonal Testing. Seasonal testing is conducted to verify proper operation, at minimum, during both winter and summer. Although some testing of heating and cooling systems can be performed under simulated conditions during the off-season, natural conditions provide

more reliable results. (LEED certification requires testing the equipment under actual operating conditions at or near design, thus it requires seasonal testing.) Any testing that was delayed because of site conditions, equipment status or inclement weather needs to be completed during warranty. When performing post-occupancy testing, the commissioning provider or test engineer must be careful not to void any equipment warranties. The commissioning provider should work with the owner to ensure that all warranty conditions are obtained from the contractors before testing. (Designers can assist in this task by stipulating in the specifications that contractors must provide these documents. Owners should also note this stipulation during pre-bid meetings.) Some warranty provisions may require that the installing contractor actually perform the testing, under the supervision of the commissioning provider.

Warranty Review. The commissioning provider may also return a few months before the expiration of the contractor's one-year warranty to review system operation and interview facility staff. Acting as the owner's technical resource, he or she can assist facility staff in addressing any performance problems or warranty issues.

Recommissioning. Building owners may consider recommissioning their facilities periodically to ensure that equipment performance levels continue to meet their project requirements. If building operators were involved in the original commissioning effort, and if they received training, they may be able to conduct the recommissioning process themselves. Designers who have long-term relationships with their clients may assist in troubleshooting during the recommissioning process.

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Commissioning Team: Roles and Responsibilities

Commissioning is a team process in which members of the project team each play defined roles. The commissioning team often includes the building owner or project manager, commissioning provider, design professionals, general contractor, subcontractors and manufacturer's representatives. For LEED projects, the LEED coordinator should also be a member of the commissioning team. (Although LEED certification requires commissioning, the commissioning process does not automatically cover all LEED issues or LEED coordination.) The team may also include facility staff, testing specialists or utility representatives. It is important to remember that the commissioning team does not manage the design and construction of the project. It merely promotes communication among team members to identify and resolve issues in a collegial and systematic fashion.

The responsibilities of each team member are outlined below. Budget considerations and special project characteristics may expand or reduce the commissioning roles

and responsibilities. The commissioning provider can review the scope of commissioning and advise the owner on how to consolidate roles and tasks to best fit the size and complexity of the project.

The Design Professional

At a minimum, the designer's role is to embrace the concept of commissioning and specify the process in the projects bid documents. (The commissioning provider sometimes provides the specification language.) If the design professional is hiring the commissioning provider, he or she should do so as early in the design process as possible. Likewise, if the design professional is providing the commissioning services, he or she should begin commissioning as early as possible. (See the earlier section, "Who Provides Commissioning Services," for a discussion of possible conflicts of interest.)

At a minimum, the designer's role is to embrace the concept of commissioning and specify the process in the projects bid documents.

Outlined below are the basic commissioning-related tasks of the design professional at each phase of commissioning:

Pre-design

- Assist with developing or reviewing the owner's project requirements document.
- Attend the commissioning scoping meeting.
- Review the draft design phase commissioning plan submitted by the commissioning provider.
- Work closely with the commissioning provider to keep the overall project and the commissioning tasks on schedule (in some cases).

Design

- Review and comment on the commissioning plan.
- Document or review the owner's project requirements for all systems.
- Assist with the development of acceptance criteria.
- Write system descriptions and record design basis information.
- Respond to issues raised by the commissioning provider during design review.
- Review and incorporate the commissioning-related specifications for construction (developed by the designer and/or the commissioning provider).
- Map the location of the incorporated commissioning specification items to facilitate their review by the commissioning provider.
- Attend the pre-bid meeting to answer bidder questions in general and to emphasize the importance of commissioning to the success of the design.

Construction

- Attend the pre-construction meeting to answer contractor questions in general and to emphasize the importance of commissioning to the success of the design.
- Clarify design issues related to system operation and owner's project requirements.
- Conduct periodic field visits to assure proper implementation of the design.
- Assist in resolving construction and operational deficiencies illuminated by commissioning.

- Prepare and submit final as-built documentation for inclusion in the O&M manuals (sometimes it is more effective to delegate this to the contractors, especially if they are doing detailed coordination drawings or fabrication drawings).
- Review and approve the O&M manuals.
- Present a systems overview during facility staff training (if requested).
- Review commissioning plans, functional test plans (optional, but highly desirable on complex projects).
- Witness selected functional testing (optional, but highly desirable on complex projects).
- Prepare content as necessary for the Systems Manual. See page 65-66 for a list of items to include in the systems manual.

Warranty

- Coordinate resolution of design non-conformance issues identified during warranty-phase commissioning.
- Participate in review close to warranty expiration (optional).

The following section discusses some of the above responsibilities in more detail.

Selected Commissioning Tasks for Designers

Working with the Commissioning Provider. The designer may be called on to handle overall coordination of the commissioning during design. This includes scheduling and coordinating the meetings of the commissioning team. Designers who assume this role also ensure that commissioning issues are part of design team meeting agendas and that the leads for each task understand their commissioning responsibilities and execute them. By working closely with the commissioning provider, the architect helps keep the project on schedule.

Documenting the Owner's Project Requirements. The owner's project requirements explain the ideas, concepts and criteria that the owner considers important. It should cover the following for each system, major component, facility and area:

- Specific corporate policies and required codes, standards and/or guidelines to be followed.
- Objectives and functional use of the facility, system, or equipment.
- General quality of materials and construction.
- Occupancy requirements.
- Indoor environmental quality requirements (such as space temperature, relative humidity, noise level and illumination level).
- Energy performance goals.
- Budget considerations and limitations.
- Restrictions and limitations of the system or facility.
- Critical system functions important to the owner.

Documenting Acceptance Criteria. The owner, commissioning provider and designer work together to assign appropriate, specific acceptance criteria to each OPR item. (As discussed previously, either the designer or the commissioning provider will lead this effort.) For instance, if a space temperature requirement is listed in the OPR, the acceptance criteria might require that the system be functionally tested to demonstrate its ability to meet that criteria. Appendix 5 contains an example of how Acceptance Criteria link to the Owner's Project Requirements.

Documenting Basis of Design. The basis of design is the documentation of the rationale behind design decisions that were made to meet the owner's project requirements. It includes:

- Specific descriptions of systems and methods for meeting owner's project requirements.
- Equipment maintainability information.
- Fire, life and safety information: a general strategy narrative and detailed sequences.
- Energy performance statistics.
- Ventilation strategies and methods.
- Complete sequences of operation, including setpoints and control parameters.
- Schedules.
- A list of applicable codes and standards.
- Primary load and design assumptions.

For example, for a rooftop air conditioning unit, the basis of design describes why the system was chosen above others. It records details of size, efficiencies, areas served, capacity, setpoints, control type, noise and vibration criteria, sequences of operation under all modes of operation, control strategies and other relevant information. Appendix 5 contains a sample format for documenting the owner's project requirements and their related basis of design.

The architect or the commissioning provider documents the owner's initial project requirements. If the architect takes the lead on this task, the commissioning provider reviews the OPR, and vice versa. The architect then coordinates the creation of the full design documentation by the design team. Each member of the team provides the written basis of design and detailed sequences of operation for the areas of design that are their responsibility. The following parts of the owner's project requirements and basis of design should be selected from the project documentation and included as an integral part of the bid specifications or as an attachment to the specifications:

- A design narrative describing the system in general.
- The objectives of each system and its functional use.
- The full sequence of operations under all modes and conditions.
- The setpoints and operating parameters.
- Performance criteria and applicable codes and standards.

Incorporating Commissioning into Specifications. There are two approaches for incorporating commissioning in the specifications. The first approach is to write separate sections for commissioning within each applicable division (for example, Division 15 for HVAC, Division 16 for electrical) as well as a separate division for commissioning (Division 17). The second approach is to integrate commissioning specifications into existing applicable divisions. Each has its advantages. Under the "separate" approach, the commissioning provider can write complete sections and pass them to the architect for inclusion in the specifications. This is more common practice, and it is easier for the architect because he or she does not actually write the commissioning specifications. However, this approach may give the appearance that commissioning is a large additional task, and it may result in higher bids. Under the "integrated" approach, the designer must work closely with the commissioning provider to weave the commissioning specifications into existing sections. This may make commissioning less intimidating to contractors, and may result in lower bids.[15] If the integrated approach is taken, the designer must map the location of the commissioning-related specification items, so that commissioning provider can review them without reading through the entire specification package.

Regardless of who writes the commissioning specifications and whether they are separate or integrated, they must provide information to help bidders understand the commissioning process and their role in it. The specifications provide the process and requirements for executing the commissioning work. For example, the mechanical design engineer works with the commissioning provider to develop commissioning guide specifications for pre-functional and functional test plans. The commissioning specifications provide the bidders with a clear description of the scope of verification testing. They detail what to test and under which conditions, acceptance criteria and acceptable test methods. They include requirements for documentation, reporting and general scheduling. The specifications should also outline the relationship among start-up, pre-functional checklists, manual functional performance tests, control system trend logs and stand-alone data logging. The inclusion of example tests and checklists is recommended.

Reviewing and Commenting on the Commissioning Plan. The designer reviews and comments on the commissioning plans for both the design and construction phases. These plans, developed by the commissioning provider, are not static documents, but evolving outlines of the commissioning process. They provide direction for the commissioning process during design and construction, and guide the development of the commissioning specifications by the architect (or commissioning provider) during the latter part of the design phase. The construction phase plan resolves issues that could not be fully developed during design, such as scheduling, participation of various parties, actual lines of reporting and approvals, and coordination. The commissioning provider develops

THE SPECIFICATIONS MUST PROVIDE INFORMATION TO HELP BIDDERS UNDERSTAND THE COMMISSIONING PROCESS AND THEIR ROLE IN IT.

[15] Altwies, Joy, in "Commissioning and Green Building Design," a National Conference on Building Commissioning Pre-conference Workshop, May 2001.

separate plans for design and construction, but the plans share the following features:

- A description of the objectives of the particular phase of commissioning.
- A list of players and their contact information.
- An outline of the management structure.
- A list of roles, responsibilities and tasks for each of the players.
- A timeline of the process and scheduling: meetings, reviews, tests and submission deadlines.
- Specific details about design or construction reviews.
- A list of systems and components being commissioned.
- Documentation and reporting formats for designs or construction phase activities.
- Plans for reporting findings and resolving conflicts.

Appendix 4 contains commissioning plan outlines. See the EDR CD-ROM of Building Commissioning Guidelines for sample commissioning plans.

Commissioning Provider

The commissioning provider's role is to promote a positive team approach to facilitate a quality project. The commissioning provider works closely with the owner or project manager, the designers and the contractors to document the quality design and construction process systematically. The commissioning provider's primary tasks include:

- Documenting or reviewing the owner's project requirements and acceptance criteria.
- Reviewing drawings and specifications for design features that facilitate commissioning and future O&M.
- Assisting the designer in developing commissioning specifications for the bid documents (or writing the specifications for the designer to include in the bid documents).
- Developing a commissioning plan.
- Reviewing construction start-up checklists.
- Writing functional and performance tests.
- Submitting regular reports to the building owner or project manager.
- Witnessing selected contractor start-up checklists and all functional and performance testing.
- Reviewing contractor and manufacturer training plans before facility staff training.
- Reviewing O&M manuals for completeness.
- Writing a final commissioning report and a systems manual that details the most important operation parameters and equipment instructions.

Interaction with the Design Team. From pre-design through warranty, the commissioning provider makes sure the building is designed, built and operable as the owner intended. To this end, the commissioning provider works with the design team to see that the owner's project requirements are well documented and that designs facilitate commissioning and future O&M activities.

At the end of design development, the commissioning provider reviews the design with the other design team members. As discussed earlier, the provider is not responsible for overall design review; the provider's review focuses on whether the design is commissionable. The commissioning provider may also consider energy efficiency, O&M needs, indoor environmental quality, constructability, coordination issues between trades and disciplines, functionality for tenants, environmental sustainability and life-cycle costs.

The construction-phase commissioning process can be easier and more effective if certain features are included in the design. The commissioning provider may bring these to the attention of the design team so that they can incorporate these features into the construction documents. Some of these features are:

- Easy access for entering, inspecting and maintaining the interior of ducts, plenums, vessels and other equipment; observing and replacing filters; removing coils; equipment removal and maintenance or replacement; service clearances; and National Electrical Code (NEC) required clearances.
- Isolation valves, dampers, interlocks, piping, etc. that allow for manual overrides, failure simulations, season changes and other testing conditions.
- Sufficient monitoring points in the EMS to facilitate performance testing, LEED measurement and verification requirements, and O&M. See Appendix 6 for specification language requesting these points as well as a list of potential monitoring points to include.
- Pressure gauges, thermometers, pressure-temperature ports and flow meters in strategic areas to verify system performance, meet LEED measurement and verification requirements, and facilitate ongoing O&M.
- Specification of the location and criteria for the systems sensors.

Along with the traditional design team members, the commissioning provider reviews the full set of construction documents and specifications when the project is approximately 50 percent and 95 percent complete, budget allowing. These reviews are a requirement for the additional LEED point for commissioning. The commissioning provider compares the design with the owner's project requirements. He or she is not responsible for design concept, design criteria or compliance with codes. The provider does not verify the designer's calculations, proof schematics or perform a constructability review unless specifically assigned. For example, the commissioning provider does not verify appropriate pipe or duct sizing, but may comment on unusually tight or restrictive duct layouts and bends, or a poor location of a static pressure sensor. As in the design development review, the commissioning provider reviews the design for commissionability and should only review design in areas where he or she has expertise. These reviews of construction documents are written and forwarded to the design team members who issue a written response. Suggested areas for review are:

The commissioning provider reviews the design for commissionability and should only review design in areas where he or she has expertise.

- Commissioning specifications.
- Equipment and system commissionability.
- O&M facilitation.

- Control system design and control strategies.
- O&M documentation.
- Building operator training requirements.
- Component and system energy efficiency.
- Indoor environmental quality.
- Environmental sustainability.
- Functionality for tenants.
- Life cycle costs.

Through this process of design review, the commissioning provider becomes the designer's ally, ensuring that the systems the designer designed will produce a quality building that meets the owner's usage and performance requirements.

Other Team Members

This guide addresses the distinction and interaction between the roles of the commissioning provider and the design professional. The roles of the other team members involved in commissioning are described in the Introduction to Building Commissioning. (See pp. 20-22 of the introduction guide for a description of the Building Owner/Project Manager, General Contractor, Installing Contractors, Subcontractors and Manufacturers, Facility Manager and Building Operator roles in commissioning.)

Marketing Commissioning Services to Your Clients

Designers are uniquely qualified to promote commissioning to their clients. They can attest that commissioning links high-quality design services to an efficient construction process and results in a smooth turnover and a building that performs as intended. In a traditional non-commissioned project, the implementation of the design is largely left to the contractors. If owners were willing to pay for quality designs, why would they jeopardize that investment by failing to ensure proper implementation?

A successful marketing message promotes the many benefits to owners, including the potential for overall project cost savings and ongoing operational savings. Common sense tells us that resolving issues on paper is less expensive than resolving them in the field. Furthermore, a building that is efficient and easy to maintain is likely to see lower operating costs. Evidence suggests that commissioning can significantly reduce a building's energy use, saving thousands of dollars per year over the life of the building. Buildings that perform as intended make for productive, healthy occupants. As building owners look for additional ways to improve their bottom line, commissioning can be marketed as a risk management tool.

When the commissioning process is successful, the change orders, requests for information, scheduling problems and conflicts are reduced. In fact, they may be so minimal that the owner may think the commissioning process was unnecessary. It is imperative to point out to the owner that the relatively problem-free project was a direct result of the commissioning process.

Excessive repair and replacement costs, employee absenteeism, indoor air quality problems, design and construction team liability and tenant turnover cost U.S. building owners and employers millions of dollars each year. Building commissioning is one way to improve the outcome of a construction project, providing a critical link between high-quality design services and a building that performs as intended.

Commissioning Case Studies

There are numerous examples of costs that have been avoided through the commissioning process. First, commissioning can avoid the costs of resolving problems after installation: costs for repair, replacement, reinstallation, and the professional services to fix mis-sized, misplaced, or otherwise inappropriate equipment. Second, commissioning can avoid the costs of the adverse effects of unresolved problems: costs for energy, maintenance, revenue loss and employee productivity loss.[16] Furthermore, a successfully commissioned building that performs as designed is more attractive to tenants, saving owners the expenses associated with tenant turnover.

Case studies of commissioning projects are available on the EDR CD-ROM of Building Commissioning Guidelines and also at some of the Web sites listed at the end of this publication.

16 Altwies, Joy. "Quantifying the Cost Benefits of Commissioning," in *Proceedings of the National Conference on Building Commissioning,* May 2001.

Procedural Guidelines, Specifications and Functional Tests

*Denotes documents available on electronic disk.

[RCX] = dedicated solely to retrocommissioning;

[rcx] = contains some data on retro-commissioning.

D = for design phase, C = for construction phase.

All CAPS source denotes document is more comprehensive than lower case.

Source	Guide-lines	Guide Specs	Sample Tests
Appendix VII Idaho New Building Commissioning Guidelines, State of Idaho, 2000. Available at: http://www2.state.id.us/adm/pubworks/archengr/app7nbcg.pdf	YES	No	No
Building Commissioning Assistance Handbook Appendices. Seattle City Light, 1999. (standardized functional test procedures http://www.ci.seattle.wa.us/seattle/light/conserve/business/bdgcoma/cv6_bcam.htm)	No	No	*Yes
Procedural Standards for Building Systems Commissioning, National Environmental Balancing Bureau (NEBB), 1999. (301) 977-3698.	Yes d,c	Some d,c	Some
A Practical Guide for Commissioning Existing Buildings, PECI and Oak Ridge National Labs (ORNL), 1999. NTIS (800) 553-6847 *[RCX]*	YES	No	No
Model Commissioning Plan and Guide Commissioning Specifications, USDOE/PECI, 1997.NTIS: # DE 97004564 (800) 553-6847. or download from http://www.peci.org/cx/mcpgs.html	*Some D,c	*YES D,C	*YES
Building Commissioning Guide, U.S. GSA. & USDOE, 1995, revised in 1998 (Ver. 2.2). Ver. 1 by Enviro-Management & Research, Inc. Version 2.2 available on the web: http://www.eren.doe.gov/femp/techassist/bldguide.pdf	*Yes D,C	No	No
The HVAC Commissioning Process, ASHRAE Guideline 1-1996, 1996. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329. (404) 636-8400 http://www.ashrae.org	Yes d,C	Some d,c	No
Functional Test Protocol Library, Pacific Gas & Electric Company, 2001. Available on the EDR CD-ROM of Building Commissioning Guidelines (for ordering information visit www.energydesignresources.com) or by calling 925-866-5329	No	No	YES
The Building Commissioning Handbook, The Association of Higher Education Facilities Officers (APPA), written by John Heinz and Rick Casault, 1996. APPA, 1643 Prince Street, Alexandria, VA 22314. (703) 684-1446 http://www.appa.org	YES d,C	YES C	No
Beyond Lighting DSM: Life After Green Lights, Montgomery Co., MD, 1995. *[RCX]* Existing building commissioning case study with sample process and detailed procedures. 70 pgs. (301) 217-6000	Yes	No	Yes
Engineering and Design Systems Commissioning Procedures, U.S. Army Corps of Engineers, 1995 (ER 1110-345-723). Dept. of the Army, U.S. Army Corps of Engineers, Washington, DC 20314-1000	Some d,c	Some d,c	No
Commissioning Specifications, C-2000 Program, Canada, 1995. C-2000 Program, Energy Mines & Resources, Energy Efficiency Division, 7th Floor, 580 Booth St., Ottawa, Ontario, Canada K1A 0E4	No	*YES C	No
Model Construction Document Specifications and A/E Services Contract Clauses, Bonneville Power Administration/John Heinz, U. of WA, 1995. 503-230-7334 Also available on the Univ. of Washington Web site at http://depts.washington.edu/fsesweb/fdi2001/15_mech/doc/19-15t.doc	No	*YES C	Some

Source	Guide-lines	Guide Specs	Sample Tests
Commissioning Guidelines, Instructions for Architects & Engineers, State of WA., 1995. Dept. of General Admin., Div. of Engin. & Arch., (360) 902-7272	Yes d,c	No	No
C*ommissioning of HVAC Systems,* seminar/workshop training materials, Univ. of Wisconsin, Madison, 1994. (800) 462-0876 or (608) 262-2061	Some C	Some C	Some
Laboratory HVAC Systems: Design, Validation and Commissioning, ASHRAE collection of 11 papers, 1994. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329. (404) 636-8400 www.ashrae.org	Yes C	No	No
Commissioning Smoke Management Systems, ASHRAE Guideline 5-1994. ASHRAE Publications Dept., 1791 Tullie Circle, NE, Atlanta, GA 30329. (404) 636-8400 www.ashrae.org	Yes d,c	No	No
Standard HVAC Control Systems Commissioning and Quality Verification User Guide, U.S. Army Const. Engineering Research Labs, 1994. Facilities Engineering Applications Program, U.S. Army Engineering and Housing Support Center, Ft. Belvoir, VA 22060-5516. FEAP-UG-GE-94/20	No	No	Yes
Contractor Quality Control and Commissioning Program—Guidelines and Specification, Montgomery Co. Gov., St of Maryland, 1993. (301) 217-6071	*Yes c	*YES C	*Some
HVAC Systems Commissioning Manual, Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), 1993. SMACNA, 4201 Lafayette Center Dr., Chantilly, VA 22021	Yes c	Some c	Some
Commissioning Guide, Public Works Canada, Western Region, 1993. (403) 497-3770	Some d,c	Yes d,C	No
Guide Specification for Military Construction—Commissioning of HVAC Systems, Dept. of the Army, U.S. Army Corps of Engineers, 1993. Washington, DC 20314-1000	No	*Some c	*Yes
Building Commissioning Guidelines, Bonneville Power Administration/PECI, 1992. (503) 230-7334	YES d,C	Some c	Some
HVAC *Functional Inspection and Testing Guide,* U.S. Dept. of Commerce and the General Services Administration, 1992. NTIS: (800) 553-6847	No	No	YES
AABC *Master Specification,* Associated Air Balance Council. (Primarily for how the TAB fits into the commissioning process) AABC National Hdqrs, (202) 737-0202	No	*Yes d,C	No

Commissioning Overviews and Case Studies

Building Commissioning: The Key to Quality Assurance. USDOE Rebuild America / PECI., 1998. *[RCX]* Commissioning retrofits and existing buildings: overview, process and case studies. 68 pgs. 1-800-363-3736.

Beyond Lighting DSM: Life After Green Lights, Urban Consortium Energy Task Force of Public Technologies, Submitted by Montgomery County Government, MD, Div. of Facilities and Services, 1998. Existing building commissioning case study with sample process and detailed procedures. 70 pgs. (301) 217-6000.

Commissioning For Better Buildings in Oregon. Oregon Office of Energy / PECI, 1997. *[rcx]* New construction overview, benefits, process and case studies. 44pgs. (503) 378-4040 or download at http://www.energy.state.or.us/bus/comm/bldgcx.htm

What Can Commissioning Do For Your Building? PECI, 1997. *[rcx]* Commissioning overview and report of 175 building case studies. 12pgs. (503) 248-4636.

Commissioning Four New Science Laboratory Buildings (U. of WA). Bonneville Power Admin. / Phoebe Caner, 1997. Commissioning case studies with detailed "lessons learned" information in all sections. ~70 pgs. *(503) 230-7334.*

Commissioning the Physics/Astronomy Building Control System (U. of WA). Bonneville Power / Phoebe Caner, 1996. Commissioning case study and report with lessons learned. ~110 pgs. (503) 230-7334.

Four case studies. Seattle City Light. http://www.ci.seattle.wa.us/seattle/light/conserve/business/bdgcoma/cv6_bcam.html.

Web Sites Containing Commissioning Documents

Building Commissioning Association	http://www.bcxa.org/
Florida Design Initiative	http://www.state.fl.us/fdi/index.html (ongoing articles & forum)
National Institute of Health Model Commissioning Guide	http://des.od.nih.gov/farhad2/Commissioning/nih_cx_guide/ComGuideTitle.htm
NEBB	http://www.nebb.org (certification program and manuals)
Oregon Office of Energy	http://www.energy.state.or.us/bus/comm/bldgcx.htm (benefits of Cx, case study, the full text of *Commissioning for Better Buildings in Oregon*) *[rcx]*
PECI	http://www.peci.org/ (NCBC information, downloadable Model Cx Plan and Guide Specifications, Cx and O&M resources)
Seattle City Light	http://www.ci.seattle.wa.us/seattle/light/conserve/business/bdgcoma/cv6_bcam.htm (standardized test procedures and case studies)
Texas A&M Energy Systems Lab	http://www-esl.tamu.edu/ (retro-commissioning process and software, for purchase) *[RCX]*
University of Washington	http://depts.washington.edu/fsesweb/fdi2001/15_mech/doc/19-15t.doc Univ. Cx guide specs distributed throughout the specs. Vol's 1-4)
USDOE / FEMP	http://www.eren.doe.gov/femp/techassist/bldgcomgd.html (full text of GSA/USDOE Building Commissioning Guide; early version of *Model Cx Plan and Guide Specifications*)
USDOE	http://www.eren.doe.gov/ (Links to commissioning doc's. Search on "commissioning.")
Whole Building Design Guide (NIBS)	http://www.wbdg.org/ National Institute of Building Sciences (find commissioning information by searching on "commissioning"

For further information please contact Pacific Gas and Electric Company's Savings By Design Program at 1-800-468-4743 or visit their Web site at http://www.savingsbydesign.com. Information is also available at www.energydesignresources.com.

Reference Notes

ASHRAE Guideline 1-1996. American Society of Heating Refrigerating and Air-Conditioning Engineers. Atlanta Georgia. 1996.

Association of State Energy Research and Technical Transfer Institutes. *How to Achieve Top Performance in Your Building: Commissioning Benefits, Process and Performance, 1998.*

Altwies, Joy. "Commissioning and Green Building Design." National Conference on Building Commissioning Pre-conference Workshop. May, 2001.

Altwies, Joy. *"Quantifying the Cost Benefits of Commissioning." Proceedings of the 9th National Conference on Building Commissioning*. May, 2001.

Dunn, Wayne. *"Roles and Responsibilities." Proceedings of the 3rd National Conference on Building Commissioning*. May, 1995.

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Savage, Jerry. *"Commissioning a Materials Research Laboratory." Proceedings of the 8th National Conference on Building Commissioning*. May, 2000.

Tamblyn, Tom. *"Commissioning a School: A Case Study." Proceedings of the 2nd National Conference on Building Commissioning*. May, 1994.

Thomson, Jeane P. *"Can Commissioning Impact Professional Liability Claims?" Proceedings of the 5th National Conference on Building Commissioning*. May, 1997.

U.S. Green Building Council, *LEED Reference Guide,* version 2.0, 2000.

York, Dan. "Commissioning Green Buildings." *Proceedings of the 6th National Conference on Building Commissioning*. May, 1998.

Commissioning

The process of ensuring that systems are designed, installed, functionally tested and capable of being operated and maintained according to the owner's operational needs [based on ASHRAE Guideline 1-1996]. This term is used in regard to new construction or major capital improvements/retrofits.

Commissioning Plan

A living document that outlines the roles and responsibilities for each commissioning team member throughout the design, construction and turnover phases of a project.

Commissioning Provider

An independent third party or a member of the design/construction team that is responsible for coordinating the commissioning process, facilitating the development of the design intent documentation and commissioning specifications, verifying the completion of the prefunctional tests, writing and verifying the functional performance tests, overseeing the building operator training and writing the final commissioning report.

Commissioning Team

The key members of each party involved with a construction project designated to provide insight and carry out tasks necessary for a successful commissioning project. These members can include the building owner or owners representative, commissioning provider, design professionals, installing contractors, facility operators, testing specialists and utility representatives.

Continuous Commissioning

An on-going process to resolve operating problems, improve comfort, optimize energy use and recommend retrofits. Performance is monitored and assistance provided as needed to maintain continued optimum performance.

Design Basis

A written document describing the rationale and assumptions for calculations, decisions, schemes and system and assemblies selected to meet the Owner's Project Requirements and to satisfy applicable regulatory requirements, standards and guidelines.

Design Intent Acceptance Criteria

Those specific criteria required to demonstrate that the owner's project requirements and designer's basis of design have been met. Criteria may include project and design goals, budgets, limitations, schedules, environment and performance requirements, owner directives and supporting information.

Design Narrative

A written description of the concepts and features the designer intends (during schematics) to incorporate into the design or what they have incorporated (during the balance of design) to meet the Owner's Project Requirements and associated Performance Criteria.

Functional Test Procedure

A procedure identifying the appropriate steps to test, verify, and document the operation and performance of a specific system.

Owner's Project Requirements

A written document, sometimes called the "design intent statement," outlining the owner's expectations of how the facility will be used and operated. Each OPR will have specific design intent acceptance criteria attached to it.

Recommissioning

A periodic event that reapplies the original commissioning procedures in order to keep the building operating according to design or current operating needs.

Retrocommissioning

An event in the life of a building that applies a systematic investigation process for improving and optimizing a building's O&M procedures. Retrocommissioning occurs post-construction and typically focuses on energy-using equipment. It may or may not emphasize bringing a building back to its original operational goals, as expressed in the Owner's Project Requirements.

Scoping Meeting

A meeting at the beginning of the commissioning process, ideally during the design phase, where the commissioning provider outlines the commissioning roles and responsibilities of the project and reviews the commissioning plan and schedule.

Sequence of Operation

A narrative describing the how the mechanical, electrical and control systems are intended to operate during startup, shutdown, unoccupied, manual, fire, power failure, security lockdowns and other modes of operation.

Specifications

A written package of standards and procedures that dictates the contractors responsibilities for delivering the final completed construction project.

Verification Checklist or Procedure

A procedure identifying the appropriate steps to verify the functional test-readiness of a specific piece of equipment. This is also known as a pre-functional test procedure or checklist.

Appendix 1 – Sample Request for Proposal

REQUEST FOR PROPOSAL OR QUALIFICATIONS FOR INDEPENDENT COMMISSIONING PROVIDER SERVICES

--Basic Version--

RFP Writer:
This template is intended to be applicable for cases when commissioning starts in design or when it starts during early construction, and for cases where the commissioning work is done under a fixed fee or a negotiated contract. The instruction boxes guide the modifications to fit each scenario.

For the construction phase tasks, the Writer should understand clearly the management and responsibility scenario in the specifications and contracts.

When the contractor is required to hire a "test engineer" or "commissioning coordinator," etc., the roles of that party can easily be confused and overlapped with the commissioning provider or authority that may be hired by the owner.

This RFP is intended for the independent commissioning provider or authority when there is not a contractor-hired test engineer or commissioning coordinator performing many of the day-to-day commissioning functions.

(Name of Facility or Issuer's Name)

REQUEST FOR PROPOSAL OR QUALIFICATIONS FOR COMMISSIONING PROVIDER SERVICES

Issuance Date: _____

Closing Date: _____, 5 PM

The Owner _____ requests written proposals to secure Commissioning Provider (CP) services for the _____ (Name of Facility) _____ (Location). The Owner is committed to commissioning this facility to ensure that all systems are complete and functioning properly upon occupancy, and that Owner's staff have adequate system documentation, and training.

BACKGROUND

Provide description of the proposed building.

SCOPE OF SERVICES

Timeline:

The Owner intends a project start date in _____. The Owner anticipates completion of the Commissioning Provider's services in _____.

Commissioning Process

The following is a summary of the commissioning process, which the Owner intends to have implemented on this project. The CP may provide the Owner with suggested changes and improvements to this process.

- CP will ensure that the design objectives and intent are clearly documented.
- CP will perform a focused review of design development.
- CP will develop a Commissioning Plan.
- CP will conduct a scoping meeting where the commissioning process is reviewed with the commissioning team members. CP will schedule additional meetings, as necessary, throughout construction, to plan, scope, coordinate and schedule future activities and resolve problems.
- Equipment documentation is submitted to the CP during normal submittals, including detailed start-up procedures.
- CP works with the subcontractors in developing start-up plans and start-up documentation formats. The subcontractors will be provided pre-functional checklists to be completed during the startup process.
- In general, the checkout and performance verification proceeds from simple to complex; from component level to equipment to systems and intersystem levels, with pre-functional checklists being completed before functional testing.
- Subcontractors, under their own direction, execute and document the pre-functional checklists and perform start-up and initial checkout. The CP documents that the checklists and startup were completed according to the approved plans. This may include the CP witnessing startup of selected equipment.
- CP develops specific equipment and system functional performance test procedures. The subcontractors review and execute the procedures under the direction of, and documented by, the CP.
- Items of non-compliance are corrected at the subcontractors expense and the system re-tested.
- The CP reviews the O&M documentation for completeness.
- Commissioning is completed before Substantial Completion.
- The CP reviews, pre-approves and coordinates the training provided by the subcontractors and verifies that it was completed.

Commissioning Provider Responsibilities

The CP is not responsible for design concept, design criteria, compliance with codes, design or general construction scheduling, cost estimating, or construction management. The CP may assist with problem-solving or resolving non-conformance or deficiencies, but ultimately that responsibility resides with the general contractor and the A/E. The primary role of the CP is to develop and coordinate the execution of a testing plan and observe and document performance, that is, determine whether systems are functioning in accordance with the Contract Documents. The Contractors will provide all tools or the use of tools to perform start-up checkout, and functionally test equipment and systems, except for specified testing with portable data-loggers, which shall be supplied and installed by the CP.

Specific tasks the CP shall be responsible for include:

- Coordinate and direct the commissioning activities in a logical, sequential and efficient manner using consistent protocols and forms, centralized documentation and clear and regular communications and consultations with all necessary parties.
- Ensure that the design objectives and intent are clearly documented and carried out in the design.
- Develop clear commissioning specifications and the functional testing requirements included in the construction bid documents.

- Before startup, gather and review the current control sequences and interlocks, and work with contractors and design engineers until sufficient clarity has been obtained to be able to write detailed testing procedures.
- Review Contractor submittals applicable to systems being commissioned for compliance with commissioning needs.
- Write and distribute pre-functional tests and checklists.
- Develop an enhanced start-up and initial systems checkout plan with subcontractors
- Perform site visits, as necessary, to observe component and system installations. Attend selected planning and job-site meetings to obtain information on construction progress. Review construction meeting minutes for revisions/substitutions relating to the commissioning process. Assist in resolving any discrepancies.
- Witness all or part of the HVAC piping test and flushing procedure, sufficient to be confident that proper procedures were followed. Document this testing, and include documentation in O&M manuals. Notify PM (project manager) of any deficiencies in results or procedures.
- Witness all or part of any ductwork testing and cleaning procedures, sufficient to be confident that proper procedures were followed. Document this testing, and include documentation in O&M manuals. Notify PM of any deficiencies in results or procedures.
- Approve pre-functional tests by reviewing pre-functional checklist reports or by direct site observation.
- Approve air and water systems balancing by spot testing and by reviewing completed reports and by selected site observation.
- With necessary assistance and review from installing contractors, write the functional performance test procedures for equipment and systems. This may include energy management control system trending, stand-alone data-logger monitoring or manual functional testing. Submit to PM for review.
- Analyze any functional performance trend logs and monitoring data to verify performance.
- Coordinate, witness and approve manual functional performance tests performed by installing contractors. Coordinate re-testing as necessary until satisfactory performance is achieved.
- Maintain a master deficiency and resolution log and a separate testing record. Provide to the PM written progress reports and test results with recommended actions.
- Oversee and approve the training of the Owner's operating personnel.
- Review and approve the preparation of the O&M manuals.
- Provide a final commissioning report, which shall include:
  a. An executive summary, list of participants and roles, brief building description, overview of commissioning and testing scope, and a general description of testing and verification methods.
  b. For each piece of commissioned equipment, the report should contain the disposition of the commissioning authority regarding the adequacy of the equipment, documentation and training meeting the contract documents in the following areas:
     1) Equipment meeting the equipment specifications;
     2) Equipment installation;
     3) Functional performance and efficiency;
     4) Equipment documentation and design intent; and
     5) Operator training. All outstanding non-compliance items shall be specifically listed.
  c. Recommendations for improvement to equipment or operations, future actions, commissioning process changes, etc., shall also be listed. Each non-compliance issue shall be referenced to the specific functional test, inspection, trend log, etc., where the deficiency is documented.
  d. The functional performance and efficiency section for each piece of equipment, shall include a brief description of the verification method used (e.g. manual testing, BAS trend logs, data loggers, etc.) including observations and conclusions from the testing.

e. Appendices shall contain acquired sequence documentation, logs, meeting minutes, progress reports, deficiency lists, site visit reports, findings, unresolved issues, communications, etc. Pre-functional checklists and functional tests, along with blanks for the operators, and monitoring data and analysis will be provided in a separate labeled binder.

- Develop a Systems and Concepts Manual that consists of the design narrative (design intent, design concept descriptions, design basis and systems description), space and use descriptions, single line drawings and schematics for major systems, control drawings, sequences of control, table of all setpoints and implications when changing them, schedules, instructions for operation of each piece of equipment for emergencies, seasonal adjustment, startup and shutdown, instructions for energy savings operations and descriptions of the energy savings strategies in the facility, recommendations for recommissioning frequency by equipment type, energy tracking recommendations, and recommended standard trend logs with a brief description of what to look for in them.
- During the warranty period coordinate and supervise required seasonal or deferred testing and deficiency corrections and provide the final testing documentation for the commissioning record and O&M manuals. Two months before warranty expiration date review with facility staff the building operation and condition of outstanding issues related to the original and seasonal commissioning.

Systems to be Commissioned

The following systems, including all components and controls, shall be commissioned:

List the systems to be commissioned.

The following outlines the level of effort expected for each commissioned system:

- The CP shall review the design documentation (design intent, basis of design and sequences of operation) for completeness. The CP shall develop pre-functional checklists for the installing contractors to include in their start-up and initial checkout. The CP shall develop detailed written test procedures for guiding and documenting performance during functional testing.

- The functional testing shall include operating the system and components through each of the written sequences of operation, and other significant modes and sequences, including startup, shutdown, unoccupied mode, manual mode, staging, miscellaneous alarms, power failure, security alarm when impacted and interlocks with other systems or equipment. Sensors and actuators shall be calibrated during pre-functional check listing by the installing contractors and spot-checked by the commissioning authority during functional testing.

- Tests on respective HVAC equipment shall be executed, if possible, during both the heating and cooling season. However, some overwriting of control values to simulate conditions shall be allowed. The central plant shall have its efficiency bench-marked for later use by operations staff. Functional testing shall be done using conventional manual methods, control system trend logs and read-outs or stand-alone data loggers, to provide a high level of confidence in proper system function, as deemed appropriate by the commissioning authority and the Owner.

DESIRED QUALIFICATIONS

It is the Owner's desire for the person designated as the site commissioning authority to satisfy as many of the following requirements as possible:

1. Acted as the principal Commissioning Provider for at least three (3) projects over 25,000 sf.
2. Extensive experience in the operation and troubleshooting of HVAC systems, energy management control systems and security systems.
3. Extensive field experience is required. A minimum of five (5) full years in this type of work is required.
4. Knowledgeable in building operation and maintenance and O&M training.
5. Knowledgeable in test and balance of both air and water systems.
6. Experienced in energy-efficient equipment design and control strategy optimization.
7. Direct experience in monitoring and analyzing system operation using energy management control system trending and stand-alone data logging equipment.
8. Excellent verbal and writing communication skills. Highly organized and able to work with both management and trade contractors.
9. Experienced in writing commissioning specifications.
10. A bachelor's degree in Mechanical Engineering is strongly preferred and P.E. certification is desired; however, other technical training, past commissioning and field experience will be considered.
11. Membership of the Building Commissioning Association will be considered a plus.

The required expertise for this project will be based on skill and experience set of the prime firm making the proposal. A member of that firm will be the designated Commissioning Provider. The Commissioning Provider must be fully qualified to commission most of the above listed systems. If the Commissioning Provider or prime firm does not have sufficient skills to commission a specific system, the prime firm shall subcontract with a qualified party to do so. That party's qualifications shall be included and clearly designated in the response to this RFP.

Pre-Proposal Meeting

A pre-proposal meeting will be held to answer questions and clarify any project issues. Attending the meeting is not required to submit a proposal. The meeting will be held at:

State the location and time of the meeting.

PROPOSAL

Proposals need not be voluminous, but shall provide sufficient information to allow the Owner to evaluate the Consultant's approach, experience, staff and availability. Proposals shall include the following information:

- Discussion of Consultant's approach to the Project. For example, what information is needed, how functional tests are developed and what test equipment is typically used for this type of Project.
- Description of relevant Projects the Consultant(s) has accomplished including a client contact and phone number for at least three projects.
- Resumes of staff to be assigned to the Project and a statement regarding availability of staff to begin the Project.

RFP Writer: If this is a fixed lump sum proposal for the work, include the following paragraph, otherwise delete it.

- Provide a fixed lump sum total cost to accomplish the work with the breakdown in the budget table format below. Also, provide an hourly rate for each team member for work that may exceed the scope. For each phase, provide the percentage level of effort for each of the primary team members.

RFP Writer: If this is a request for qualifications, include the following paragraph, otherwise delete it.

- This project will be set up on a negotiated time-and-materials basis. Provide an hourly rate for each team member, along with estimated rates and fees for all other costs that the building owner could incur from the proposer in this contract (travel, mileage, per diem, communications, etc.). For each phase, provide the percentage level of effort for each of the primary team members.

The respondent must submit three (3) copies of the proposal, each signed by an authorized representative of the Consultant. Proposals must be submitted to arrive no later than close of business, 5:00 p.m. on _____ , _____ to:

Owner _____

State the address, contact person, telephone number, fax number, e-mail address.

SELECTION PROCESS

The Owner's staff shall review all proposals and select and rank the three most qualified Consultants. The selection and ranking shall be based on the following criteria:

1. Proposed approach to the project.
2. Past experience in performing similar projects.
3. Experience of the staff to perform the services required by the Project.
4. Cost or fee proposal and projected timeline to accomplish the scope of work.

The Owner shall negotiate with the highest ranked Consultant on the tasks, staffing, schedule and a maximum not-to-exceed fee consistent with Consultant's proposal and fair and reasonable to the Owner. Negotiations may be formally terminated if they fail to result in a contract within a reasonable amount of time. Negotiations will then ensue with the second ranked Consultant, and if necessary, the third ranked Consultant. If the second and third round of negotiations fail to result in a contract within a reasonable amount of time, the solicitation may be formally terminated.

Appendix 2 – Sample Verification Checklist

This section includes a sample pre-functional checklist for a packaged air conditioning system. This checklist is intended as an example that could be used as a "boilerplate" form and adapted to fit specific projects.

PREFUNCTIONAL CHECKLIST FOR PACKAGED AIR CONDITIONING SYSTEM

Project Information

Building Name	
Date	
Building Contact Name	
Phone	
Commissioning Provider Name	
Address	
Phone	

Equipment

Equipment Name	
Type	
Manufacturer	
Model Number	
# of Identical Units	

Unit Number	Serial Number	Location

- **Is the installed equipment what was specified? . . . . . ☐YES / ☐No**

Documentation

Documentation Available on Site (check all that apply):

☐ Manufacturer cut sheets
☐ Submittals
☐ Manufacturer product design data (curves)
☐ Operation and maintenance manuals
☐ EMCS points list
☐ Hard copy of EMCS program
☐ Other (list): _____

☐ Installation manual
☐ Water treatment report
☐ Record drawings
☐ Schedules
☐ Balance report
☐ Written control strategies

- **Is the documentation complete according to specifications? . . . . . ☐YES / ☐No**

Purpose of the Test or Checklist:

Equipment Description

Nameplate Information

(Volts, Amps, Phase, BTUs, Efficiency, etc.)

Building:	Commissioning Provider:	Phone:
Date:	Contractor:	Phone:

General Checklist

Check if okay.

Enter comment number if deficient, and document comments by number in form provided below checklist.

Checklist Item	Unit #				
Casing condition good: no dents, leaks, door gaskets tight?					
General condition appears good					
Attached duct work is properly sealed (boot in good condition)					
Pipe fittings complete and pipes properly supported					
Condensate drain in place and properly trapped					
Protective shrouds for belts in place and secure					
Alignment of motor driven components correct					
Correct refrigerant charge					
Correct oil level (check site glass)					
Compressors and piping was leak tested					
Crankcase heater on when unit is off					
Disconnects in place and labeled					
All electric connections tight					
Proper grounding installed					
Auxiliary heaters operate					
Control system interlocks functional					
Safeties installed (see mfg. information)					
Smoke detectors in place					
All dampers stroke fully and easily					
Dampers close tightly					
Enthalpy control and sensor properly installed (if applicable)					
Related thermostats are installed					
Related EMCS points are installed					
OSAT, MAT, SAT, RAT sensors properly located and secure (OSAT shielded) State which sensors are installed.					
Supply fan belt: tension and condition okay					
Supply fan acceptable noise and vibration					
Supply fan area clean					
Supply fan rotation correct					
Filters clean and tight fitting					
Construction filters removed					
Indoor coils clean and in good condition					
Unit starts and runs with no unusual noise or vibrations					
Condenser fan rotation correct					

Checklist Item	Unit #				
Condenser fan acceptable noise and vibration					
Condenser fan clean and in good condition					
Condenser coils clean and in good condition					
Other (list):					

The Following Items Need Correction:

General Comments

Signature: _____ Company: _____ Date: _____

Commissioning Provider

Appendix 3 - Sample Functional Test Plan

FUNCTIONAL TEST

Project:_____

FT-_____ SPLIT AC UNITS ACCU-1 thru 7; FCU-1 thru 7

1. Participants

Party	Participation
_____	_____
_____	

Party filling out this form and witnessing testing _____

Date of test _____

2. Prerequisite Checklist

a. The following have been started up and startup reports and prefunctional checklists submitted and approved ready for functional testing:

__ ACCU-1-7; FCU-1-7

b. __ All control system functions for this and all interlocking systems are programmed and operable per contract documents, including final setpoints and schedules with debugging, loop tuning and sensor calibrations completed.

_____ _____

Controls Contractor Signature or Verbal Date

c. __ Test and balance (TAB) completed and approved for the hydronic systems and terminal units connected.

d. __ All A/E punchlist items for this equipment corrected.

e. __ These functional test procedures reviewed and approved by installing contractor.

f. __ Safeties and operating ranges reviewed.

g. __ Test requirements and sequences of operation attached.

h. __ Have all energy savings control strategies, setpoints and schedules been incorporated that this equipment and control system are capable of? If not, list recommendations below.

i. __ **BAS Program Review**. Review the BAS software control program(s) for this equipment. Parameters, setpoints and logic sequences appear to follow the specified written sequences.

j. __ **Packaged Control Program Review**. Review the packaged control program(s) for this equipment. Parameters, setpoints and logic sequences appear to follow the specified written sequences.

k. __ Record of All Values for Current Setpoints changed to Accommodate Testing:

		Returned to
Parameter	**Pre-Test Values**	**Pre-Test Values √**
FCU-1 Setpt, occup.		
FCU-2 Setpt, occup.		
FCU-3 Setpt, occup.		
FCU-4 Setpt, occup.		

		Returned to
Parameter	**Pre-Test Values**	**Pre-Test Values √**
FCU-5 Setpt, occup.		
FCU-6 Setpt, occup.		
FCU-7 Setpt, occup.		

3. Sensor Calibration Checks

Check the sensors listed below for calibration and adequate location. This is a sampling check of calibrations done during prefunctional checklisting. Test the packaged controls and BAS readings.

"In calibration" means making a reading with a calibrated test instrument within 6 inches of the site sensor. Verify that the sensor reading (via the permanent thermostat, gage, packaged control panel or building automation system (BAS)) compared to the test instrument-measured value is within the tolerances specified in the prefunctional checklist requirements (_____). If not, install offset in BAS, calibrate or replace sensor. Use the same test instruments as used for the original calibration, if possible.

Sensor & Location	Location OK[1]	**1st** Gage or Pkg & BAS Values	Instru. Meas'd Value	**Final** Gage or Pkg & BAS Values	Pass Y/N?
FCU-1 stat temp.		Stat:		Stat:	
FCU-2 stat temp.		Stat:		Stat:	
FCU-3 stat temp.		Stat:		Stat:	
FCU-4 stat temp.		Stat:		Stat:	
FCU-5 stat temp.		Stat:		Stat:	
FCU-6 stat temp.		Stat:		Stat:	
FCU-7 stat temp.		Stat:		Stat:	

4. Device Calibration Checks

--none--

[1] Sensor location is appropriate and away from causes of erratic operation.

5. Verification of Misc. Prefunctional Checks

Misc. site checks of the prefunctional checklist and startup reports completed successfully. Pass? Y / N _____

1. ___ All OK? Read sight glass at the condenser during operation. If temperature is over 70F outside, there should be no bubbles. OK? Circle unit # 1, 2, 3, 4, 5, 6, 7, 8.
2. ___All OK? Moisture indicator in sight glass reads green. OK? Circle unit # 1, 2, 3, 4, 5, 6, 7, 8.

6. Functional Testing Procedures (record results in Section 7)

Proced. No.	**Seq. ID[1]**	**Test Procedure[2]** (including special conditions)	**Expected and Actual Response[3]** [Write ACTUAL response in brackets or circle]	**Pass Y/N & Note #**
1		FCU-; ACCU-1 Occupied Mode. A) In occupied mode, lower the FCU- setpoint to be 3F lower than current space temp. b) Raise the setpoint to be = to the space temperature. Return setpoints to original.	a) FCU- starts. ACCU-1 starts and ~55F air is delivered to space. Observe that there is no excessive noise in the evaporator fan or condenser fan. b) FCU- and ACCU- shut OFF.	
2		ACCU Failure. With the units running in normal mode, shut off power to the ACCU.	Observe the FCU shut down.	
3		Low Temp. Operation. During outdoor weather between 20F and 30F, verify that the unit functions and does not shut down on safeties.	Unit operates at specified low ambient temperatures.	
4		TREND LOG 1. For 3 of the units, during near design conditions in summer, trend the OSAT and the space temp, in 15 min. intervals for 3 days.	Verify that the unit keeps the space within +/- 3F of setpoint.	
5	--	**Return all changed control parameters and conditions to their pre-test values[4]**	**Check off in Section 2 above when completed**	

MONITORING AND TREND LOGGING. Five monitoring via BAS trend logs are required per test Procedure 4. Trend logs none shall be provided in electronic continuous columnar spreadsheet compatible format. Trends all shall be provided in hard tabular format (continuous columnar with time in left column and at least four columns of point values in adjacent columns). All points for a given trend will begin at exactly the same time. Provide a key to all abbreviations. Attach representative graphs or columnar data and explanatory analysis to this test report.

Record Foot Notes

[1] Sequences of operation specified in Contract Documents (attached).

[2] Step-by-step procedures for manual testing, trend logging or data-logger monitoring.

[3] Include tolerances for a passing condition.

[4] Record any permanently changed parameter values and submit to Owner.

Procedure	FCU / ACCU ID #						
	1	2	3	4	5	6	7
1a. Lower space setpoint. FCU starts and then ACCU starts (Y/N)							
1a. ~ 55F air delivered (record air temp)							
1a. No excessive evap or cond. Noise (Y/N)							
1b. Raise space setpoint to meet space. FCU and ACCU shut OFF, (Y/N)							
2. Lower setpoint till running. Shut off power to ACCU. FCU shuts down. (Y/N)							
3. Observe operation during 20-30F. Units run OK. (Y/N).							
4. Trend 3 of the units. Maintain setpoint? (Y/N)							
5. Return setpoints to original? (Y/N)							

7. TEST RECORD SHEET

List any tests that were deficient:

-- END OF TEST --

Appendix 4 – How to Develop a Commissioning Plan

Developing a commissioning plan is crucial to implementing a successful commissioning process. The plan outlines each team member's role and commissioning responsibilities for a project and includes a schedule and scope of commissioning activities. This "living" document is likely to change over the course of a project.

Ideally, the initial development of the commissioning plan occurs in the early stages of design. The commissioning provider develops and maintains the plan. However, if a commissioning provider has not already been contracted in the early phases of the design process, the owner's representative or lead designer can begin the basic development of the plan. Initially this could include mapping out some of the major commissioning milestones of the project and making each team member who will be involved with the commissioning process aware that commissioning will occur. Once a commissioning provider is selected for the project, he or she develops the formalized plan with substantial input from the other commissioning team members.

This appendix includes outlines for Design Phase and Construction Phase commissioning plans.

Design Phase Commissioning Plan Outline

A typical design phase commissioning plan includes:

General Building Information. A very brief description of the building's location, size, type of use, projected design phase and construction phase timelines, etc.

Commissioning Team Information. A list of the commissioning team members and their contact information.

Commissioning Task Matrix. A matrix or narrative describing major commissioning activities and the commissioning team member(s) designated to lead and assist with fulfilling those objectives.

Commissioning Scope of Work. A detailed scope of work highlighting which systems will be commissioned, and what commissioning tasks will need to occur over the design process. This section also covers the level of detail needed for the project's design documentation and the content of the commissioning specifications.

Commissioning Schedule. A "preliminary" commissioning schedule which is cross-referenced with the construction project's schedule highlighting dates when key commissioning activities need to be completed.

Commissioning Forms. A description of the forms to be completed for various phases of the commissioning process and where they are located or can be obtained.

In addition to acting as a guide for the commissioning process, the design phase commissioning plan will become the first piece of commissioning documentation. Commissioning-related correspondence, checklists, test forms, and operation and maintenance training documentation, combined with the updated construction phase commissioning plan, form the commissioning record once the project is complete.

Construction Phase Commissioning Plan Outline

A typical construction phase commissioning plan includes:

Commissioning Scope. A detailed description about the commissioning process and the goals of this process.

Commissioned Systems. A revised description of which systems and sub-systems will be commissioned, based on the final design documents.

Commissioning Forms. A description of what forms will need to be completed for various phases of the commissioning process and where they are located or can be obtained.

General Building Information. A general description about the building, size, use, etc.

Revised Commissioning Team List. A team list revised to reflect any changes and/or additions to the commissioning team since the design phase commissioning plan list was drafted.

Roles and Responsibilities. A revised description of the roles and responsibilities of the construction phase commissioning team

General Management Plan. A description of who holds and manages the commissioning providers contract, how the commissioning responsibilities will be coordinated with the overall project specifications and contract documents, and what chain of reporting for the commissioning findings will follow.

Commissioning Process. This section describes the commissioning process by commissioning task or activity, in the order they will occur.

Written Work Products. A description of the written commissioning deliverables from all parties involved in this process. Sometimes this is done in a "table" format. The table can describe each product, who is responsible for producing it, the general due date, the parties who receive it and who approves it, etc.

Training. A restatement of the training requirements, based on the specifications, and who is responsible for them. Also, a statement requiring each contractor to submit a proposed training plan and schedule to the commissioning provider for review and approval prior to the actual training.

Operation and Maintenance (O&M) Manuals. A description of what the final O&M manuals will include, who will compile them and who will receive them upon completion.

Schedule. A revised and updated schedule to reflect the required commissioning tasks for the rest of the project.

Further Information about Design Phase and Construction Phase Commissioning Plans

See the EDR CD-ROM of Building Commissioning Guidelines or Web site (available through www.energydesignresources.com) for samples of design and construction phase commissioning plans.

Appendix 5 – Design Documentation Necessary for Commissioning

This appendix includes an example of the level of design documentation needed to commission an air handling system serving an office environment. The Owner's Project Requirements and Acceptance Criteria sections of this documentation make up what is commonly referred to as "design intent." This example illustrates the relationship between the various components of design intent, which are:

- Owner's Project Requirements
- Design Intent Acceptance Criteria
- Design Basis

The first section has been extracted from the Owner's Project Requirements, where the Owner documented his or her needs for the area served by the air handling system.

The second section, Design Intent Acceptance Criteria, shows an example of the criteria for verifying that the operating building meets the design basis and the Owner's original project requirement. Note: in the example provided here, the designer has added acceptance criteria for some elements of the design where the Owner had no particular preference and left the requirement up to the discretion of the designer (for example, the space pressure relationships category).

The final section, an excerpt of a sample Design Basis, shows how the design team translates the Owner's temperature requirement (circled in red on the Owner's Project Requirements) into Design Basis information. This information includes the codes, standards and assumptions that will be used to address the Owner's Project Requirements. Ideally, every important requirement identified by the Owner should have a corresponding element in the acceptance criteria or design basis that identifies how the design will meet the requirement. The Design Basis information is then used to develop system configurations and operating sequences, make equipment selections and size distribution systems. The results of the development work are documented in the Design Narrative information (not shown in this appendix).

NOTE: The sample OPR and Acceptance Criteria forms provided here show the Design Team representative signing off on the entries. If the commissioning provider takes the lead in developing the OPR and the Acceptance Criteria, he or she would be the appropriate party to sign these forms.

Owner's Project Requirements

Complete the following table for each function or process listed above. If there are no special requirements and/or the requirement is to be left to the discretion of the designer, indicate "None."

Operating Parameters and Requirements for the Functions and Processes Served by this Air Handling System

Item	Office Area Functions	Conference Rooms	Computer Room
Temperature requirements and limitations	72°F - 75°F	72°F - 75°F	68°F - 70°F (computer mfg. spec.)
Humidity requirements and limitations	None	None	30% - 50% RH (computer mfg. spec.)
Pressure relationship requirements and limitations	None	None	None
Filtration requirements and limitations	Good indoor air quality	Good indoor air quality	65% (computer mfg. spec.)
Air change requirements and limitations	None	None	None
Sound and noise level requirements	Normal office levels	Suitable for telephone and video conferencing	None
Special air handling requirements including hazardous or noxious effluents discharged to the air stream or occupied space by the process	None	None	None
Integrated performance requirements with other air handling systems	None	None	None
Normal operating schedule for occupancy and/or production	M-F 7:00 am - 6:00 pm Sat., Sun. - As req'd.	As req'd. during normal hours	24 hours per day, every day

Item	Office Area Functions	Conference Rooms	Computer Room
Process and office equipment status during evening/night time hours	See above	See above	See above
Process and office equipment status during holiday hours	None	None	See above
Process and office equipment status during scheduled maintenance shutdowns	Not applicable	Not applicable	Not applicable

Initial Owner/Architect entries complete.

Date: 9-20-00 By: Irving Glick
(Owners Rep)

Information finalized and agreed to.

Date: 10-12-00 By: Irving Glick
(Owners Rep)

Date: 10-12-00 By: Susan Sunshine
(Design Team)

Design Intent Acceptance Criteria

Acceptance Criteria for the Office Area Functions Served by this Air Handling System

Item	Acceptance Criteria
Temperature requirements and limitations	1. Space sensor accuracy verified by factory calibration certificates and spot checks via the commissioning process; ±1.5°F required. 2. Terminal unit performance verified by testing and balancing work and spot checks by the commissioning process; ±10% of design flow rate required, stable operation required (no hunting); reheat only after volume reduction to minimum air flow required.
Humidity requirements and limitations	1. Summertime humidity levels controlled by controlling the cooling coil discharge temperature. No active winter humidity control is required or provided; therefore no verification of wintertime humidity is required. Verify accuracy of all central system sensors for ±0.5°F for temperature and ±5%RH for humidity. 2. Trend central system temperatures for a year via the commissioning process and spot check at critical points (peak heating, peak cooling, swing season, first month of operation) for stable control, no simultaneous heating and cooling, coordinated operation of the economizer function, warm-up function and chilled water cooling function per the operating sequence. 3. Spot check space humidity levels during peak cooling season to verify 50%RH ±5% via the commissioning process.

Item	Acceptance Criteria
Pressure relationship requirements and limitations	1. The building is to be held slightly positive relative to the atmosphere under all occupied operating conditions. Verify that the relief dampers are controlled to provide a stable building pressure of .01-.05 inches w.c. during the economizer cycle per the operating sequence via trending and the commissioning process. Spot check at critical points (peak heating, peak cooling, swing seasons and first month of operation. 2. Verify proper minimum outdoor air flow control during all operating modes (full and partial occupancy) including verification of the set point reset via the CO_2 sensors per the demand controlled ventilation portion of the sequence of operation. Sensor accuracy verified by factory calibration certificates; ±50 ppm required. 3. Verify reset of the minimum flow settings on all terminal units equipped with the CO_2 sensors per the demand controlled ventilation portion of the sequence of operation. Sensor accuracy verified by factory calibration certificates; ±50 ppm required. 4. Minimum outdoor air flow sensor calibration to be verified by testing and balancing contractor; ±10% of reading required. 5. Over-all building air flow balance (supply, return, minimum outdoor air and exhaust) to be verified by testing and balancing contractor via traverse of the supply, return and exhaust mains and the minimum outdoor air flow sensor; ±10% of design required and the supply flow should be equal to the return flow plus the minimum outdoor air flow and the exhaust flow should be equal to the minimum outdoor air flow minus 1,000 cfm for building pressurization. 6. Verify pressurization at minimum outdoor air flow during peak cooling season; .01-.05 inches w.c. positive relative to the outdoors, measured at the entry vestibule required.

Item	Acceptance Criteria
Pressure relationship requirements and limitations	1. The commissioning agent and general contractor shall verify via inspection, photographs and other controls and documentation that duct cleanliness was maintained during the construction cycle. 2. The commissioning agent shall spot check diffuser locations during the first year of operation for visible signs of soiling due to supply air flow contamination. 3. Verify filter installation per the specification requirements; 65% ASHRAE dust spot efficiency filters required. Filters are to be extended surface area type. 4. Verify clean filter pressure drop meets the manufacturers specifications ±2%. 5. Verify photohelic gauges are installed and properly set to trip at the required change-out pressure. Indicators should be set for the clean and maximum allowable dirty filter pressure drop requirements stated previously. 6. Verify photohelic gauge calibration is ±5% of reading. 7. Verify proper cooling coil condensate drain pan trap construction and operation per the details on the drawing. 8. Verify by inspection on a peak cooling day that the cooling coil drain pan drains completely when the unit is shut down and that there is now carry over from the cooling coil beyond the drain pan with the fan operating at full flow and that the drain pan does not overflow with the filters at their maximum allowable dirty filter pressure drop. 9. Verify that the intake compartment remains relatively free of moisture during a heavy rain and that any moisture that does enter the compartment flows to the compartment drain.
Air change requirements and limitations	1. Review the balancing report to verify system performance per design. 2. The commissioning agent shall spot check testing and balancing measurements per the requirements of the commissioning specifications.
Sound and noise level requirements	1. Spot check 10% of the office square footage for sound power levels; maximum allowable NC = 35. Include locations directly below and adjacent to the mechanical room in the areas checked.

Item	Acceptance Criteria
Special air handling requirements including hazardous or noxious effluents discharged to the air stream or occupied space by the process.	1. Verify positive exhaust at all copy machine locations per the requirements of the construction documents via the testing and balancing process; design flow ±10% required.
Integrated performance requirements with other air handling systems	1. Functionally test the assembled systems per the requirements of the commissioning specifications. Acceptance criteria is as indicated in the commissioning specifications. Generally, stable operation with no hunting is required in all operating modes. Systems should be able to recover safely from power outages, equipment failures and scheduled shut-downs. 2. Spot check ongoing system performance via trending and site visits per the requirements of the commissioning specifications.
Normal operating schedule for occupancy and/or production	Verification covered by functional testing.
Process and office equipment status during evening/night time hours	No verification required
Process and office equipment status during holiday hours	No verification required

Initial Owner/Architect entries complete.

Date: 9-20-00 By: Irving Glick
(Owners Rep)

Information finalized and agreed to.

Date: 10-12-00 By: Irving Glick
(Owners Rep)

Date: 10-12-00 By: Susan Sunshine
(Design Team)

Design Basis: Assumptions, Calculations, and Safety Factors

For each function or process described in the Owner's requirements indicate what assumptions are being made in the design of the system to serve it as well as calculation techniques and safety factors that will be employed in the design process. If some items are common to all processes or functions, simply refer to the preceding information rather than duplicating it if that is easier.

Assumptions, Calculations, and Safety Factors for Function or Process 1

Item	Preference
Load Calculations: Technique (check appropriate option)	1. _____ Estimate (indicate basis) _____ 2. _____ Manual peak only 3. _____ Manual hour by hour 4. _____ Computer model peak only 5. __X__ Computer model hour by hour
Assumptions:	1. Weather conditions Location Gresham, Oregon Cooling design percentage 97% Heating design percentage 2% 2. Indoor Conditions (temperature and RH) 75°F, 50% RH Summer, 75°F winter (no active humidification) 3. Occ Building occupied or unoccupied for cooling load calculation. Loads in hour by hour calculation will represent scheduled operation. 4. On Process and office equipment on or off for cooling load calculation. Loads in hour by hour calculation will represent scheduled operation. 5. On Lighting on or off for cooling load calculation. Loads in hour by hour calculation will represent scheduled operation. 6. Occ Building occupied or unoccupied for heating load calculation. Loads in hour by hour calculation will represent scheduled operation. 7. On Process and office equipment on or off for heating load calculation. Loads in hour by hour calculation will represent scheduled operation. 8. On Lighting on or off for heating load calculation. Loads in hour by hour calculation will represent scheduled operation. 9. Other (list specific assumptions) _____
Safety Factors	1. Cooling load 10% 2. Heating load 10%

Item	Preference
Air Flow Rate Calculations: Technique (check appropriate option)	1. _____ Estimate (indicate basis) _____ 2. __x__ Space cooling load and sensible heat ratio 3. _____ Air changes 4. _____ Make up requirements 5. _____ Other (describe)
Assumptions:	1. Cooling coil discharge condition (t_{wb}/t_{db}) 56.5/56°F 2. Fan heat Base on final fan motor bhp, motor in air stream 3. Duct system temperature rise (use low flow/worst case) 1°F (estimate, reconfirm after final air flow and duct calculations) 4. Leakage losses SMACNA Leakage Class II for mains, SMACNA Leakage Class 1 for distribution downstream of terminal units 5. Other (list specific assumptions) _____
Safety Factors:	1. % total air flow 5%
Duct Sizing Calculations: Technique (check appropriate option or options)	1. __x__ Equal friction rate (List rate or rates used for each duct type such as mains, branches, etc.) Mains .15 in.w.c./100 ft Risers .15 in.w.c./100 ft Branches to terminal equipment .15 in.w.c./100 ft Branches after terminal equipment .15 in.w.c./100 ft 2. _____ Static regain 3. _____ T-Method optimization. 4. _____ T-Method simulation. 5. _____ Other (describe) _____

Item	Preference
Assumptions and limitations	1. Maximum duct velocities shall be at or below the following levels. Mains 2,000 fpm Risers 2,000 fpm Branches to terminal equipment 1,500 fpm Branches after terminal equipment 1,500 fpm Intake louvers 500 fpm Discharge louvers 800 fpm Central equipment coil face velocities 450 fpm Terminal equipment coil face velocities 500 fpm Filter face velocities 450 fpm
Assumptions:	1. (List, add lines as required)
Fan Static Pressure Calculations: Technique (check appropriate option) (repeat these rows for each fan in the system such as supply, return, etc.)	1. _____ Estimate based on similar systems. 2. __x__ Estimate based on individual components and duct system in terms of a friction rate and an equivalent length of duct. Duct equivalent length based on length of run and estimated complexity of run (number of turns). 3. _____ Detailed fitting by fitting calculation, manually generated. 4. _____ Detailed fitting by fitting calculation, generated by duct sizing program. 5. _____ Other (describe)
Assumptions:	1. Clean filter pressure drop .19 in.w.c. 2. Dirty filter pressure drop .9 in.w.c. 3. Cooling coil condition (wet or dry) Wet 4. (Other, add lines as required)
Safety Factors:	1. % of calculated value 10%
Fan Selections Technique (check appropriate option) (repeat these rows for each fan in the system such as supply, return, etc.)	1. _____ Manual selection from fan curve based on flow and static requirements. 2. _____ Manual selection from fan performance table based on flow and static requirements. 3. __x__ Computer selection using fan selection software. List software used Pace fan selection program 4. _____ Equipment supplier selection based on scheduled or specified data.
Assumptions:	1. (List, add lines as required)
Safety Factors:	1. (List, add lines as required) Covered by the air flow and static pressure safety factors

Item	Preference
Cooling Coil Calculations:	
Technique (check appropriate option)	1. _____ Manual selection from coil performance tables and curves based on performance requirements. 2. __X__ Computer selection based on modeling and simulation using coil selection and modeling software. List software used Pace cooling coil selection software 3. _____ Equipment supplier selection based on scheduled or specified data.
Assumptions (setting some parameters will automatically set others):	1. Cooling coil cooling source __x__ Chilled water/glycol _____ Refrigerant (direct expansion) _____ Refrigerant (energy recovery heat pipe) _____ Well water or domestic water _____ Other (list) _____ 2. Cooling coil capacity basis Load calculation 3. Cooling coil entering condition (t_{wb}/t_{db}) 85/68°F 4. Cooling coil discharge condition (t_{wb}/t_{db}) 56.5/56°F 5. Cooling coil air flow rate basis Air flow calculation 6. Maximum air side pressure drop, inches w.c. 1.5 in.w.c 7. Cooling coil entering water temperature 46°F 8. Cooling coil water temperature rise Match chiller plant 9. Cooling coil water flow rate basis Temperature rise to match the plant and load on coil
Safety Factors:	1. (List, add lines as required) Covered by load calc safety factor

Appendix 6 – Specification Language for "Commissioning-Friendly" Features

Extra monitoring points, test ports and gages can make a building more "commissioning-friendly." These features facilitate commissioning and can reduce commissioning costs. They also make it easier for operating staff to monitor building performance and troubleshoot problems in the future.

Designers can specify these features in the controls specification section (15950), under PART 2 – PRODUCTS. To follow is some sample specification language and a list of monitoring points (excerpted from the US DOE Model Commissioning Plan and Guide Specification). The A/E and the design phase commissioning provider should review this list and determine which points should be included in this project (including any not listed). Do not assume that all of the points listed here are needed. The value of any given point depends on the equipment and system, the expertise of the operating staff to make use of the points, and the size of the equipment.

2.3 COMMISSIONING AND MONITORING POINTS

A. All control points of the central building automation system, required to automatically control the equipment specified in the Contract Documents and to execute all specified control sequences, shall be installed and be able to be monitored. To simplify TAB and commissioning of the systems and to provide better control during occupancy, the following points shall be provided as monitored points in the control system, even if they are part of equipment integral controls, or are not required in any control sequence or intermediate calculation. Some points may be measured values or output signals, while others may be calculated or virtual points. Many points listed below may already be required to control the equipment.

Chiller System

Primary CHW supply flow (gpm)
Primary pump status
Percentage of load on chiller
KW of chiller
KW/ton (instantaneous value)
Secondary CHW supply flow (gpm)
Secondary pump status
System load (calculation from temperature difference and gpm)
Secondary pump rpm or Hz
Return CHW temperature
Supply CHW temperature
Alarm

Cooling Tower

Tower status (lead, lag, etc.)
Fan step status, current or speed
Damper status
Spray pump status
Leaving water temperature
Entering water temperature
Bypass valve position
Condenser pump status
Condenser pump current
Sump level
Alarm (low water, fan vibration)

Boiler System

Primary HW supply flow (gpm), if no secondary
Primary pump status
Lead/lag status of boiler
Firing rate status (high/low)
Primary HW return temperature
Primary HW supply temperature
Secondary HW supply flow (gpm)
Secondary HW return temperature
System load (calculation from temperature difference and gpm)
Secondary pump rpm or Hz
Boiler in alarm
3 way mixing valve position

Air Handler Units (AHUs) of 100 tons capacity or greater

Supply Fan

Discharge static pressure
Flow at discharge (cfm)
Supply fan rpm or Hz if on VFD, else vane or vane-axial blade position or current
Mixed air temperature (unless a tight packaged unit where a goodmixed air reading is difficult)
Cooling coil leaving air temperature
Heating coil leaving air temperature
Supply air temperature
Return air temperature
Outside air temperature
Mixed air damper position
Return air damper position
Exhaust or relief damper position, optional
Outside air dampers position (min. damper and economizing damper)
Leaving RH
Inside RH
Outside RH
Cooling coil valve position
Heating coil valve position
Coil CHW supply temperature
Coil CHW return temperature
Coil HW supply temperature
Coil HW return temperature
Duct static pressure

Return Fan/Relief Fan (associated with AHUs of 100 tons capacity or greater)

Flow near inlet
Return fan rpm or Hz, if on VFD or current
Relief damper and return damper position, optional
Flow of minimum outside air (OSA), if varies with VAV boxes
CO2 sensor for OSA control
Building static, if control point

Air Terminal Units

Flow (primary)
Percentage of design flow cooling
Percentage of design flow heating
Reheat fan status
Supply air temperature to zone
Zone space temperature
Reheat valve position

The Spec Writer should specify all additional monitoring points desired for all systems in the project.

Air Handler Units (AHUs) of less than 100 tons capacity
Packaged Rooftop Units (RTUs) greater than or equal to 100 tons capacity
Packaged Rooftop Units (RTUs) less than 100 tons capacity
Computer Room AC Units
Spot AC Units (greater than 1.5 ton)
Spot Unit Heaters (greater than 1.5 ton)
Elevator Shaft Fans
Stairwell Fans
Restroom Central Exhaust Fans
Garage Exhaust Fans
Emergency Generator
Domestic Hot Water Systems
(boiler, HW heaters, leaving temp, recirc pumps)
Domestic Water Booster Pump
Sewage Ejector
Fire Alarm Interface
Lighting and Controls

2.4 TEST PORTS

A. The controls contractor shall provide test ports for handheld instrument readings near all piping system sensors in the primary system (not at the zone level).

2.5 GAGES

A. The controls contractor shall provide gages in the following locations, even if included as a sensor and monitored point in the control system:
   1. Pressure gages on both sides of all pumps greater than 1 hp.
   2. Mercury thermometers in the return and supply of all primary thermal plant equipment (chillers, cooling towers, boilers, converters, etc.).

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