COMMISSIONING

FOR BETTER BUILDINGS IN OREGON

Prepared for Oregon Office of Energy by PECI. Revised from *Commissioning for Better Buildings,* written by PECI for Florida Power and Light.

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Why Commission Your Building?

Introduction

Building owners spend more on complex building systems than ever before, yet many find they are not getting the performance they expect. A recent study of 60 commercial buildings found that more than half suffered from control problems. In addition, 40 percent had problems with heating, ventilation and air-conditioning (HVAC) equipment, and one-third had sensors that were not operating properly. An astonishing 15 percent of the buildings studied actually were 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.

Your building is an investment. Poor performance means you may be losing money. Excessive repair and replacement costs, employee absenteeism, indoor air quality problems and liability and tenant turnover cost U.S. building owners and employers millions of dollars each year. *Building commissioning* is one way to keep this money in your pocket.

Building commissioning can restore an existing building to high productivity. It 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.

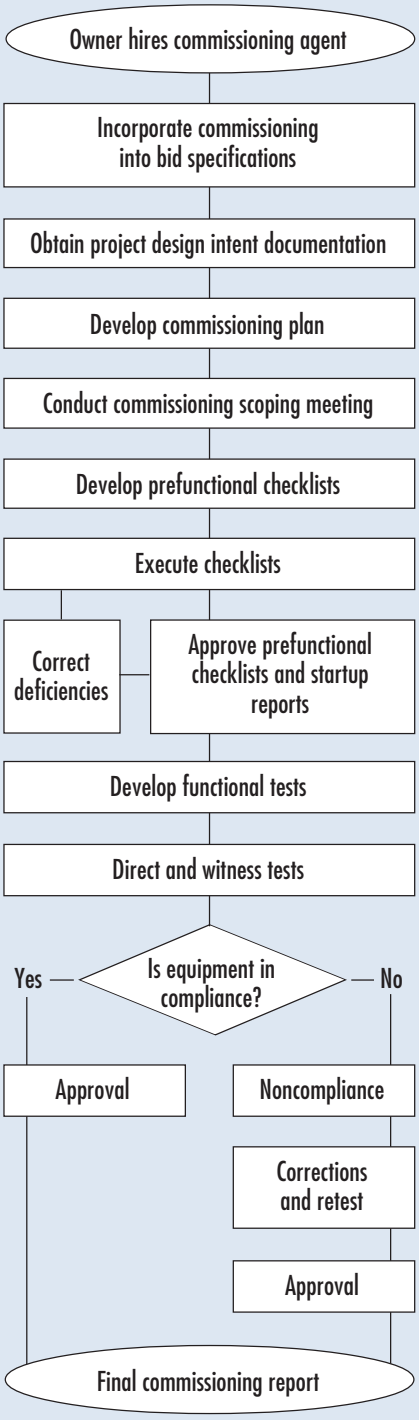
What exactly is building commissioning?

Commissioning is a systematic process—beginning in the design phase, lasting at least one year after project closeout and including the training of operating staff—of ensuring, through documented verification, that all building systems perform interactively according to the documented design intent and the owner's operational needs.

Commissioning occasionally is 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. Commissioning involves functional testing to determine how well mechanical and electrical systems work together. Functional tests of equipment and systems also help determine whether the equipment meets operational goals or whether it needs to be adjusted to increase efficiency and effectiveness. Commissioning results in fewer callbacks, long-term tenant satisfaction, lower energy bills, avoided equipment replacement costs and an improved profit margin for building owners.

The Commissioning Process

The typical commissioning process involves the following steps. This process is discussed in detail on pages 22 to 27.



Benefits of Building Commissioning

Until recently, the most frequently mentioned benefit of commissioning was its energy-related value. The energy savings and improved performance expected from facility upgrades are ensured by building commissioning. While this benefit is significant, it is far outweighed by the non-energy-related benefits of commissioning. These include:

- Fewer system deficiencies at building turnover
- Improved indoor air quality, occupant comfort and productivity
- Decreased potential for liability related to indoor air quality
- Reduced operation and maintenance and equipment replacement costs

Fewer System Deficiencies at Building Turnover

All too often, building owners accept buildings at turnover whose systems may "work" but do not work optimally or as intended. During the rush to complete essential building elements prior to occupancy, owners frequently are forced to temporarily overlook incomplete or deficient systems. Many owners have neither the time nor the resources to deal with the burden of remedying deficiencies perceived as "less important." Some system deficiencies are never even noticed during close-out, because inspections and punchlists focus primarily on items that are critical to obtaining regulatory occupancy permits and opening the building.

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Once the building is turned over to the owner, the overlooked deficiencies must be addressed. Getting contractors to return to the job after substantial completion and occupancy can be difficult, with the result that, again, "less important" deficiencies are never fully addressed. Deficiencies that were not identified before occupancy may come to the attention of facility staff by tenant complaints or through routine operations. Often facility staff spend their own time correcting items that still fall under the responsibility of the contractor. Other deficiencies may be significant enough that the facility staff attempt the difficult process of asking the contractor to return and make the corrections. Still other deficiencies go permanently undetected, to the detriment of building control, energy use, equipment reliability and tenant comfort.

The primary goal of commissioning is to prevent or mitigate all of these problems. The commissioning agent's task is to identify system deficiencies as early in the project as possible and to track their status until they are corrected. By identifying deficiencies early and by using a systematic process for making corrections, the commissioning agent assists the construction

team in providing building systems, prior to occupancy, with significantly fewer defects.

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 report noted that 20 to 30 percent 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 maintained properly.

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. Below is an estimate of productivity losses in a typical office building where occupants complained of discomfort[1]:

Common sense tells us that comfortable employees are more productive than uncomfortable employees.

Table 1. Comfort and Productivity

Payroll costs	$150/ft²/year
Productivity lost to complaint time	$.10/ft²/year

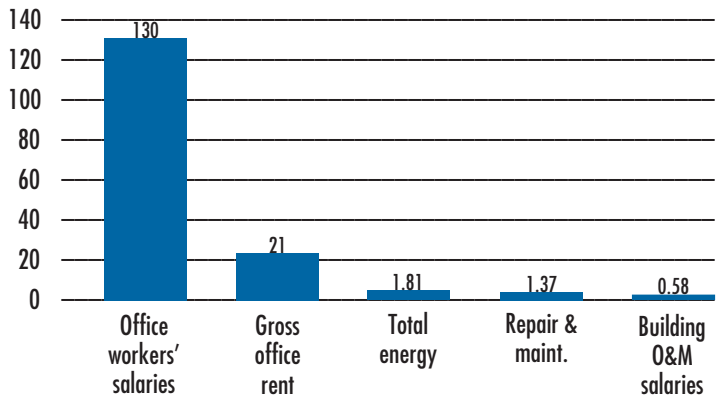
This example assumes that this typical building has one occupant per 200 ft² of space and an annual payroll cost of $30,000/person or $150/ft² of office space. If one out of every five employees spends only 30 minutes a month complaining about the lighting or the temperature or both, the employer loses $.10/ft² in annual productivity. For a 100,000 ft² building, this amounts to $10,000 per year. Because uncomfortable employees probably spend more than just half an hour each month complaining about building comfort, the actual losses likely would 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 (page 6) shows a typical allocation of operating costs in a 140,000 ft² office building.

Commissioning also improves the productivity of processes, especially in industrial facilities. By ensuring that equipment

[1]Presentation to National Electric Light and Power Association, 1989, by Cedric Trueman, Senior Technical Advisor for British Columbia Buildings Corp.

Figure 1. Operating costs for a 140,000 ft² office building[2] (1990 $/rentable ft²)



By ensuring that equipment performs optimally and efficiently, commissioning can help reduce equipment downtime and improve production rates.

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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 discomfort and low productivity remain tenants? Tenant turnover can be costly, according to the following estimated cost of losing a tenant in Class A office space.[3]

Table 2. Cost of Losing a Tenant

Five-year lease value	$262,500
Rent loss due to vacancy	$26,250
Improvements for new tenant	$52,500–$70,000
Leasing commission	$13,125
Total cost of losing tenant	$91,875–$109,375

Assuming an average office size of 3,500 ft², rented at $15/ft² a year, a typical five-year lease has a value of $262,500. If a tenant leaves, this space will remain vacant an average of six months, for a total rent loss of $26,250. Improvements and build-outs to satisfy a new tenant usually run $15 to $20/ft², or $52,500 to $70,000 in this case. On top of all this, the building owner often pays a leasing commission of 5 percent of the five-year lease value, or $13,125. Thus, the total cost of losing one tenant could run from $91,875 to $109,375, or 35 to 42 percent 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 to 10 of their peers.

[2]E-Source calculation from BOMA and EPRI data.
[3]ASHRAE presentation by David Zier of Melvin Mark Company.

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, proper commissioning can prevent these problems. In existing buildings, commissioning detects current and potential indoor air quality/comfort problems and helps identify solutions.

Liability Related to Indoor Air Quality

Sick building syndrome and the court cases associated with it continue to make headlines across the country. The government of Polk County, Florida recently won nearly $26 million in damages for problems with its "sick" courthouse. Although this award was paid by the general contractor, many building owners also are 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.

Building commissioning protects owners in more than one way. First, it provides documented verification of a building's performance and operation. Owners should request that the commissioning process include testing of outside-air flow rates, a primary factor affecting indoor air quality. If an existing building has deficiencies, the commissioning agent also 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 always will take up a portion of building budgets. However, more building owners and businesses are realizing that operation and maintenance departments can minimize life cycle costs by

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changing operation and maintenance practices. That is, proper operation and maintenance actually can 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 operation and maintenance building practices and trains operators in carrying out these practices. (Some of these practices are discussed in more detail in "Operation and Maintenance for Persistence," starting on page 27.)

Commissioning also allows building owners to avoid premature equipment replacement costs.

Commissioning also allows building owners to avoid premature equipment replacement costs. 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 uses less energy, requires fewer service calls and demands less "crisis maintenance" from onsite staff (or expensive outside contractors), allowing them to concentrate on their normal duties.

The Bottom Line

The bottom line is that commissioning improves a building's asset 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. There is a higher demand for comfortable, healthy working space that promotes productivity. And systems that function properly use less energy, experience less downtime and require less maintenance, which save building owners money.

Costs of Building Commissioning

There currently is no standard method of reporting the costs and savings associated with commissioning. For many projects, commissioning costs were never separated from other project costs. For projects where these costs have been tracked separately, various methods have been used to report them. Table 3 (page 9) lists some of the most common methods. No matter which estimation method is used, however, commissioning accounts for a very small portion of overall construction and renovation budgets.

Table 3. Estimated Commissioning Costs

Commissioning Scope		Estimated Cost Range
Whole building (controls, electrical, mechanical)		
Commissioning from design through acceptance		0.5–1.5% 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
Various energy-efficiency measures		
	53,000 ft² avg.	$.08–$.64* ft²/yr
	102,000 ft² avg.	$.13–$.43** ft²/yr

**$.23 avg. cost for 16 buildings*
***$.28 avg. cost for 7 buildings*

Commissioning costs can vary considerably from project to project. Actual costs depend on the size and complexity of the project, and the extent and rigor of the commissioning specified.

Savings from Building Commissioning

Methods for reporting the savings associated with commissioning vary depending on who is receiving the report. Utilities typically have been interested in determining the kilowatt-hour savings associated with commissioning energy-efficient systems and equipment. Building owners, however, usually are more interested in learning how much commissioning will save them in annual utility bills and operation and maintenance costs. Just as commissioning costs can vary from project to project, so do commissioning savings. Savings depend on the scope of the commissioning. Table 4 shows reported savings for certain types of buildings.

When commissioning is done properly, the savings can be substantial.

Table 4. The Savings From Commissioning

Building Type	$ Savings	Energy Savings
110,000 ft² office	$.11/ft²/yr ($12,276/yr)	279,000 kWh/yr
22,000 ft² office	$.35/ft²/yr ($7,630/yr)	130,800 kWh/yr
60,000 ft² high-tech manu.	$.20/ft²/yr ($12,000/yr)	336,000 kWh/yr

When commissioning is done properly, the savings can be substantial. “Deciding the Appropriate Level of Commissioning” on page 18 of this booklet contains valuable information on how to maximize your savings from commissioning by determining the appropriate level of commissioning for your building systems.

Commissioning Case Studies

Aster Publishing Building, Eugene

In 1994, the Aster Publishing Building (A.P.C. Inc.) upgraded the HVAC system, energy management control system, lighting controls and variable frequency drives; removed inlet vanes from air handlers; modified duct structures; and repaired economizers in its downtown headquarters building. At the time of the upgrades, this 66,300 ft^2 office building was approximately 11 years old. Because A.P.C. wanted to ensure that their new systems performed well and resulted in occupant comfort and energy savings, the company, with the support of Eugene Water and Electric Board, decided to commission the upgrade. Commissioning began during the project design stage and continued during and beyond the construction. Major deficiencies identified included excessive infiltration in the return air plenum and a failure of the existing controls to function consistent with the original design's control strategy. Commissioning of the upgraded systems was included in the scope of the project and was bid as part of the total project package. The commissioning was performed by the general contractor/designer. As a result of the system corrections, A.P.C. now saves more than $40,000 annually on its electric bill. In addition, the company believes the commissioning project resulted in improved temperature control, improved air balance, reduction in tenant complaints, extended equipment life and fewer equipment failures.[4]

As a result of the system corrections, A.P.C. now saves more than $40,000 annually on its electric bill.

Oregon State University Library, Corvallis

Oregon State University began the commissioning of its new, 336,000 ft^2 library in 1995. The University wanted to ensure the performance of systems in the new building, promote energy savings and ensure thermal comfort. The HVAC system, energy management control system, variable frequency drives, economizers and air handlers are included in the commissioning. Commissioning was incorporated into the project specifications, which outlined commissioning responsibilities of the architect, the mechanical engineer and the commissioning agent. The estimated cost of commissioning the library is $335,000, or 1 percent of the total construction cost. As a result of commissioning, the University expects to see energy savings, improved temperature and relative humidity control, improved air balance, improved indoor air quality and reduced occupant complaints. They also expect to have fewer change orders than usual in this construction project. Commissioning already has resulted in improved communication between the design team and the building operating staff.[5]

[4]Hawley, Brian, et al. "The Aster Building Commissioning: Total Quality Assurance by Another Name," in *Proceedings of the Northwest Conference on Building Commissioning* published by PECI, 1996.
[5]Based on case study information provided by SRG Partnership, PC, Portland, Oregon.

Local Government Center, Salem

The Local Government Center, a new 40,000 ft^2 office building in Salem, was commissioned to resolve installation and operating problems and to promote energy-efficient HVAC operation. To accomplish these goals, the commissioning agent focused on energy, operation and training issues. Some of the deficiencies identified during commissioning included: higher-than-average carbon dioxide levels in one room, air balance problems that affected thermal comfort, economizer wiring problems, intake of fireplace smoke from adjacent buildings and inaccurate as-built documents. The building's tenants have noticed several non-energy benefits from the commissioning process:

- Numerous construction-related system problems were discovered and corrected at contractor expense
- Outside air quantities, air temperatures and carbon dioxide levels were documented
- Operating staff received additional training
- The construction and design team may have been more diligent in carrying out their responsibilities because of the involvement of a third-party commissioning agent[6]

Highrise Office Building, Portland

A 278,000 ft^2, 18-year-old office building located in downtown Portland was commissioned to identify low-cost operation and maintenance improvement opportunities. The building's duct heaters, chiller system, energy management control system, lighting controls and air handlers were commissioned (that is, tuned up to optimize performance) in 1995. Because of the narrow scope of the tune-up, the costs and savings associated with it are low. The commissioning effort cost $12,700. This cost included the commissioning agent fee, the cost to pre- and post-monitor equipment to document commissioning savings and the cost to repair deficiencies. The major deficiencies identified by commissioning included:

- Electric reheat scheduling and setpoint problems
- Chilled water setpoint was too low
- Space sensors were out of calibration
- The chiller was short-cycling due to improper time delay setting

Repairing these deficiencies has resulted in annual energy bill savings of $8,145. In addition, the operating staff have found that building temperature control and thermal comfort have improved. The O&M documentation available for troubleshooting also was improved by commissioning.[7]

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[6]"Local Government Center Commissioning Report" prepared for Oregon Office of Energy by Systems Commissioning Consultants, Portland, Oregon.
[7]Based on a building tune-up report prepared by PECI for a U.S. EPA/U.S. DOE study. The names of the buildings in the study have not yet been released.

How to Commission Your Building

This section outlines the commissioning process and the decisions a building owner must make in order to start the process. Remember, the earlier commissioning is incorporated into a new construction or renovation project, the better the cost-benefit ratio will be. It's easier—and cheaper—to make changes on paper during the design phase than on the site once the project is underway.

Steps in Commissioning

1. Engage a commissioning agent (see "Selecting a Commissioning Agent" at right).
2. Hire a designer amenable to commissioning. Make sure they include commissioning in their bids.
3. Include commissioning in the design phase.
4. Include clear commissioning specifications in the bid documents.
5. Take an active part in the commissioning process. Monitor the commissioning work, read the commissioning reports and act on recommendations for fixing deficiencies.

Selecting a Commissioning Agent

One of the most important commissioning decisions a building owner can make is selecting the commissioning agent. Owners can use a competitive request for proposal (RFP) process to make the selection. To obtain a list of commissioning providers in the Northwest, request the Building Commissioning Services Directory of Firms from the Oregon Office of Energy Commissioning Tool Kit (see page 36). After you develop a list of the commissioning agents that seem appropriate for your project, request a statement of qualifications from each of them. A sample commissioning agent solicitation is included in the tool kit.

In the RFP, be sure to ask for details on previous, relevant commissioning experience, including the depth of commissioning experience. Make sure that the agent's definition of commissioning corresponds to the one at the beginning of this booklet. What some call commissioning is no more than traditional startup or TAB. Recommended commissioning agent qualifications are discussed in more detail in the following pages.

Owners have several parties to choose from when selecting a commissioning agent. They include:

- Independent third party
- Design professional
- General contractor
- Mechanical contractor

Each option has its advantages and disadvantages. The final choice may depend on the complexity and the specific needs of the particular project. *Owners must remember that costs for commissioning services are not included in standard contracts for these parties*.

Independent Third Party

Many owners who have commissioned their buildings recommend using an independent third party (that is, someone who is not otherwise a part of the design-construction team) as the commissioning agent. An independent commissioning agent, under contract to the owner (or to the owner's construction or project manager) rather than the general contractor, can play an objective role and ensure that the owner truly will get the building performance he or she expects. The commissioning agent could work with the owner's project manager. The independent third-party option offers owners the most objectivity, but also entails managing an additional contract, which may result in higher first costs than some of the other options. For large and/or complex projects, especially in buildings with highly integrated, sophisticated systems, these higher first costs are outweighed by future savings from commissioning.

Selecting an Independent Third-Party Commissioning Agent

Independent commissioning agents, who often are trained as design engineers or architects, should have the qualifications listed under "Commissioning Agent Qualifications," *and* they should be able to write commissioning specifications for bid documents. Hands-on experience with building systems is especially critical. It's important to involve the independent agent as early in the design phase as possible. This allows the agent the opportunity to document the design intent for the project, begin scheduling commissioning activities and begin writing commissioning specifications into bid documents for other contractors. For existing buildings, the commissioning agent must try to determine from building documentation what the original design intent was, what the current use of the building requires of its systems and how it relates to any planned renovations or upgrades. The earlier this relationship is understood, the clearer the commissioning specifications can be.

Design Professional

For projects ranging from 20,000 to 100,000 ft^2, using the design professional as the commissioning agent is often a good option, provided that the project specifications detail the commissioning requirements. The advantage of using the design professional as the commissioning agent is that he or she already is familiar with the design intent of the project. This familiarity somewhat reduces first costs. Most design professionals have the ability to write specifications and oversee the commissioning process. However, they may not have adequate experience in day-to-day construction processes and troubleshooting systems. Owners considering this option should bear in mind that commissioning is not included in most design professional fees. Commissioning provisions must be written into the design professional's contract, so that firms can include these services in their bids.

General Contractor

General contractors, provided they have experience with projects of similar size and complexity, have the scheduling and construction background necessary to supervise a commissioning agent in the quality control manager sense. However, they typically need to hire a commissioning agent to directly supervise tests performed by installing contractors. It has been argued that it is not in the owner's best interest to have the commissioning agent work for the general contractor because of the obvious conflict of interest. On the other hand, because they want to meet project deadlines, general contractors have more of an incentive to cooperate in scheduling and completing the commissioning work. Commissioning often reduces the number of callbacks on a project, and thus improves the general

Commissioning Agent Qualifications Checklist

In general, for complex projects, a commissioning agent who personally will develop the commissioning test plans and directly supervise the commissioning work should meet these qualifications:

Recommended Minimum Qualifications

- ☐ Experience in design, specification or installation of commercial building mechanical control systems. This experience also may be related to general HVAC systems.
- ☐ Experience with at least four projects involving successful troubleshooting and/or performance verification of buildings of at least similar size as the current project. Experience with new and/or existing buildings, depending on the current project.
- ☐ History of responsiveness
- ☐ Meets owner's liability requirements
- ☐ Experience working with project teams and conducting scoping meetings; good communication skills
- ☐ Experience with at least two projects involving commissioning of HVAC, mechanical controls and lighting control systems in buildings of similar size to the current project. This experience includes the writing of functional performance test plans.

Optional Qualifications

- ☐ Direct responsibility for project management of at least two commercial construction 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 testing instrumentation
- ☐ Knowledge and familiarity with air/water testing and balancing
- ☐ Experience in planning and delivering O&M training

contractor's profit margin. If the commissioning agent will be under contract to the general contractor, it's recommended that the agent be hired as an independent contractor without affiliation to any firm on the design or construction team and that the agent report to the owner's representative (usually the construction or project manager).

Mechanical Contractor

It used to be standard practice for many mechanical contracting firms to conduct performance tests and systematic checkout procedures for equipment they installed. As construction budgets became tighter, this service was dropped from most projects. Mechanical contractors may have the knowledge and capability to test mechanical equipment. Using them as commissioning agents, however, has been referred to as "letting the fox guard the henhouse." Some contend that it's difficult for mechanical contractors to objectively test and assess their own work, especially since repairing deficiencies found through commissioning may increase their costs. But many owners have good relationships with their contractors, and it may be appropriate to use them as commissioning agents in cases where:

- The project size is less than 20,000 ft^2
- One mechanical contractor performs all of the mechanical work on a project
- The project specifications clearly detail the commissioning requirements

Commissioning Agent Qualifications

Although some groups are looking into the possibility of developing commissioning agent certification, currently there is no standard certification or licensing process for commissioning agents. It is therefore up to each owner to determine the agent qualifications appropriate for a given project. At left are some guidelines for selecting a qualified commissioning agent.

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

Roles and Responsibilities of Project 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. Commissioning actually facilitates this interaction, because it sets clear performance expectations and requires communication among all team members.

The whole construction project 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.

The project team most often includes the building owner or developer, general contractor, commissioning agent, design professionals, contractors, subcontractors and manufacturer's representatives. The team also may include the facility manager and/or building operator, and possibly testing specialists and utility representatives. Ideally, each of these parties contributes to the commissioning process.

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 agents about potentially combining some of the following roles. The commissioning agent can review the scope of commissioning and advise the owner on how best to consolidate roles and tasks.

Members of a design-construction project team need to interact in order to perform their tasks successfully.

Building Owner/Developer

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

- Hiring the commissioning agent and other members of the project team, preferably using a competitive request for proposal process
- Determining the project's budget, schedule and operating requirements
- Working with the commissioning agent to determine commissioning goals
- Facilitating communication between the commissioning agent and other project team members

- Approving startup and functional test completion (or delegating this task to a construction or project manager)
- Attending building training sessions when appropriate

The general contractor facilitates the commissioning schedule by coordinating activities with owner representatives and subcontractors.

General Contractor

The general contractor assists with the development and implementation of functional performance testing for all systems. This involves assisting in gathering information (for existing buildings these may include shop drawings, operations and maintenance manuals and as-built documents) for review by the project team. The general contractor facilitates the commissioning schedule by coordinating activities with owner representatives and subcontractors.

Commissioning Agent

The commissioning agent'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 the commissioning plan
- Writing prefunctional and functional performance tests
- Ensuring that team members understand their specified commissioning responsibilities and fulfill them on schedule
- Submitting regular reports to the building owner or project manager
- Directing all functional performance testing and approving contractor startup tests, air and water testing and balancing, and duct pressure testing (the commissioning agent also may perform some functional performance tests)
- Writing a final commissioning report documenting the final evaluation of the systems' capabilities to meet design intent and owner needs
- Reviewing and commenting on technical considerations from design through construction, to facilitate sound operation and maintenance of the building
- Reviewing contractor and manufacturer training plans prior to delivery to operators and facility managers
- Reviewing operation and maintenance manuals and design intent documentation for completeness

Design Professionals

The primary commissioning responsibilities of design professionals are to document the design intent for all systems and controls and to make sure that commissioning is included in the bid specifications. The designer also should monitor construction activities and review and approve project documentation (shop drawings, operation and maintenance manuals, as-built drawings). For very complex projects, the commissioning agent may ask the designer to review commissioning plans and functional performance tests. The commissioning agent also may ask the designer to visit the site during construction or renovation (beyond the designer's typical construction observation responsibilities) to ensure that work is performed according to plans. If this is the case, the design professional's bid should include funds to cover these visits. As mentioned before, the design firm may be responsible for hiring and overseeing the commissioning agent.

Contractors/Subcontractors

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

Contractors and subcontractors are responsible for performing commissioning functions described in their bid specifications.

Manufacturers' Representatives

Manufacturers' representatives provide the commissioning agent with manufacturer specifications for the equipment installed. They also may assist contractors with operation and maintenance training and with functional performance testing, especially in situations where warranties may be affected by test results or procedures.

Facility Manager/Building Operator

The building operator should assist with (or at least be present for) as much of the functional testing as possible. This improves operator understanding of equipment and control strategies. The operator also should attend training sessions provided by manufacturers' representatives and contractors.

Testing Specialists

If special testing is needed due to the complexity of the project, the specialists performing these tests also should be

involved in commissioning. Test results and recommendations from these specialists should be submitted to the commissioning agent for review. They also may be required to review documentation relating to the systems they test and to train operators on the proper use of this equipment.

Utility Representative

Some utilities offer services that can complement the commissioning process. Call your utility to find out what services they can provide.

Deciding the Appropriate Level of Commissioning

Because commissioning all building systems is rarely practical or even necessary, owners need to determine what level of commissioning is best and most cost-effective for their project. Many factors affect this decision, including

- The complexity of the building systems
- Building type and size
- Building usage
- Whether the project is new construction, or the renovation or tune-up of an existing building
- How much the owner is willing to spend
- Building tenant or occupant demographics

This section includes information about various factors owners should consider when determining the extent of their commissioning efforts.

The level of commissioning detail usually is dictated by the complexity of the systems and controls installed. The more complex the project, the higher the risk of systems not performing as intended. Systems that are considered "complex" have:

- Sophisticated controls and control strategies
- Complicated sequences of operation
- A high degree of interaction with other systems and building equipment

For example, an upgrade from incandescent lighting to T8 fluorescent lamps with electronic ballasts would not be considered a complex project, and probably would not need more than an inspection. On the other hand, if the lighting upgrade also included lighting controls (such as sweep controls, occupancy sensors and daylighting controls), it would be considered complex and would benefit from commissioning. As a general rule, all projects that include controls, energy management control systems, pneumatic equipment, integrated systems, HVAC-

"Must Commission" Checklist

Experts commonly place the following energy conservation measures on their "must commission" lists:

- ☐ Lighting sweep or daylighting controls
- ☐ Energy management systems and control strategies
- ☐ Variable-speed drives
- ☐ Ventilation air control
- ☐ Building pressurization control
- ☐ Grocery refrigeration floating head pressure
- ☐ Grocery case anti-condensate heater controls

related plant equipment and air distribution systems should be commissioned.

But how much commissioning is enough? Unfortunately, the answer to this question is not straightforward. Certain types of equipment require less commissioning, *under most conditions*, than others. Because every building is different, and because building owners and occupants may have specific building performance needs, there are no hard and fast rules for determining the level of commissioning.

Two different levels of commissioning are described below, followed by a table listing various types of equipment and their recommended commissioning levels. Again, these are merely guidelines. Some owners may find that they really need Level 2 commissioning for a piece of equipment, when the table suggests Level 1 commissioning, and vice versa. In these cases, owners should consult with their commissioning agents to determine the most appropriate level of commissioning.

Level 1 Commissioning

Level 1 commissioning is a less formal process and requires the involvement of fewer players. Commissioning agents performing this less rigorous form of commissioning may find a "boilerplate" commissioning plan is sufficient, and thus less time and money are spent developing the commissioning plan.

During the design phase, the commissioning agent reviews design documents and ensures that commissioning is incorporated into the project specifications. For existing buildings, the commissioning agent may interview building operation staff about maintenance practices, building usage and their concerns.

Steps in Level 1 Commissioning

1. A site inspection of the installation, including verifying that the specified equipment was properly installed
2. Calibration checks for most sensors and thermostats and checks for proper setpoints
3. Simple functional performance tests, often using "boilerplate" forms
4. Verification of occupancy schedules to ensure proper settings
5. Verification that the owner and the persons required to operate the equipment have had proper training
6. Preparation of a final report detailing the commissioning findings

Level 2 Commissioning

Level 2 commissioning is a more rigorous process that involves more players. The commissioning agent performing this level of commissioning generally develops a customized commissioning plan and conducts a project scoping meeting to review the plan with other players.

With complex projects, there are two approaches to Level 2 commissioning of HVAC and controls systems:

- Point-by-point verification
- Specialized testing to assure performance without the expense of point-by-point testing

Specialized testing may follow a proprietary approach that varies depending on the commissioning agent. When using specialized instead of point-by-point testing, the owner must rely on the commissioning agent to ensure that testing meets the desired rigor and thoroughness.

Steps in Level 2 Commissioning

1. Commissioning agent review of design documentation that clearly describes design intent and includes such details as equipment specifications, sequence of operation, equipment submittals, setpoint schedules, occupancy schedules and manufacturers' performance data
2. Development and execution of prefunctional performance tests and checklists for each piece of equipment or system, or documentation of completed startup tests
3. Completion of rigorous functional performance tests (to test and verify such performance indicators as capacity, efficiency, sequence of operation, proper flows and how other equipment influences equipment performance)
4. Verification that O&M manuals are complete, available and accessible on site
5. Verification that operating staff have been trained to properly operate and maintain the equipment or system and that they have been instructed on how the equipment or system is integrated with the rest of the building's systems
6. Development or verification of a preventive maintenance plan or service contract (service contracts should have a preventive maintenance component that goes beyond merely responding to trouble calls and needed repairs)
7. Preparation of a final report detailing the commissioning findings

As with Level 1 commissioning, the commissioning agent reviews design documentation, interviews building operators and ensures that commissioning requirements are clearly spelled out in the project specifications.

Selecting the Right Level for Your Project

Level 1 commissioning is less expansive, and thus often less expensive, than Level 2 commissioning. However, it also provides less performance assurance. Owners and commissioning agents must find the proper balance between cost and performance assurance before beginning the commissioning process. Owners and commissioning agents can ask the following questions to help determine the complexity of the system or equipment and therefore the need for commissioning.

Place a checkmark in the box by each question where the answer is *"Yes."*

❑ Is the equipment relatively simple in operation and design?

❑ Does the equipment operate relatively independent of other equipment and systems?

❑ Is the investment in the equipment relatively small?

❑ Is the equipment expected to yield only small energy savings?

❑ Is the equipment free from adverse operating influences, such as a dirty environment, that affect proper operation?

❑ Does the equipment have a history of reliable performance?

❑ Is it difficult for occupants to circumvent or override equipment settings or operation?

❑ Is startup documentation available?

❑ Is test and balancing documentation available?

❑ Are detailed, written specifications available onsite?

❑ Are operation and maintenance manuals available onsite?

❑ Is the manufacturer closely involved with the project?

If an owner or commissioning agent can answer "Yes" to most of these questions, Level 1 commissioning probably is appropriate for the project. Questions in bold, however, are especially critical in determining the appropriate level of commissioning. If you can answer "No" to any of the first four questions, you should strongly consider Level 2 commissioning. Regardless of your answers to the questions in bold, if even some of the remaining questions are answered with "No," Level 2 commissioning still should be strongly considered.

Table 5 (page 21) provides general guidelines for selecting commissioning levels for representative equipment. These

Table 5. Equipment Type and Suggested Level of Commissioning

Equipment Type	Equipment Name	Level 1 Commissioning	Level 2 Commissioning
Lighting	Lighting timer controls	■	
	Automatic daylighting controls		■
	Combination of related equipment		■
	Lighting sweep controls		■
HVAC System	Automatic night setback	■	
	Automatic economizer cooling		■
	Heat pump systems		■
	Outside air control	■	■
	Hot and cold deck reset		■
	Reheat system primary air optimization	■	■
	Heat recovery—HVAC systems	■	■
	Deadband thermostat	■	
	Time clocks on circulating pumps	■	
	Chiller system (chiller, pumps, controls)		■
	Separate make-up air for exhaust hoods	■	
	Variable air volume		■
	Variable speed drives		■
	Direct tower cooling (chiller strainer cycle)		■
	Multiple chiller control		■
	Radiant heating	■	
	Cooling tower flow control		■
	Evaporative cooling		■
	Direct expansion cooling system COP		■
	Building pressurization		■
	Combination of related equipment		■
Domestic Hot Water	Unoccupied period control of water heaters	■	
	Heat pump water heater		■
	Circulating pump control	■	
	Heat recovery—DHW systems	■	■
	Combination of related equipment		■
Power-Related	Motors	■	
	Motor controls		■
	Combination of related equipment		■
Refrigeration	Optimize defrost controls		■
	Refrigeration pressure optimization		■
	Case anti-condensate heaters	■	■
	High-efficiency compressors		■
	Combination of related equipment		■
Miscellaneous	Energy management control system		■
	Combination of related equipment		■

recommended levels should be evaluated based on your answers to the questions above.

The Commissioning Process

The commissioning process is integrated with the phases of the construction, renovation and retrofit processes.

Once you have selected your commissioning agent and determined the level of commissioning your facility needs, you can begin the actual commissioning process. The commissioning process is integrated with the phases of the construction, renovation and retrofit processes. These include:

- Predesign phase
- Design phase
- Construction/installation phase
- Acceptance phase
- Post-acceptance/occupancy phase

Table 6 shows how these phases correspond to construction and renovation project phase designations.

Table 6. Commissioning Phases and Tasks Corresponding to Project Phases

Commissioning Phase	Project Phase
Predesign ■ Commissioning agent hired	**Planning Phase** ■ Design team chosen
Design ■ Develop commissioning plan ■ Hold commissioning scoping meeting ■ Submit design intent documentation ■ Develop commissioning specifications ■ Review of design by commissioning agent	**Design Phase** ■ Building designed ■ Bid documents prepared ■ Job awarded to general contractor
Construction/Installation ■ Submitted documentation reviewed ■ Develop and execute prefunctional checklists ■ Develop functional test plans	**Construction Phase** ■ Construction of facility ■ Startup of equipment
Acceptance ■ Execute functional tests ■ Verify operator training ■ Approve O&M manuals	**Acceptance Phase** ■ Training completed ■ Documentation completed ■ Building accepted by owner
Post-acceptance/Occupancy ■ Perform deferred tests (if any)	**Occupancy Phase** ■ Ongoing O&M

The following sections briefly describe the commissioning activities associated with each phase of a project, emphasizing the role of the commissioning agent.

Commissioning Phases

Predesign phase

The predesign phase is the ideal time for the owner to select a commissioning agent. Early selection allows the commissioning agent to play an advisory role during the conceptual process. It also can increase buy-in for commissioning from other team members because the agent is involved from the beginning. Otherwise, the team may view the commissioning agent as an outsider who doesn't really understand the project.

Design phase

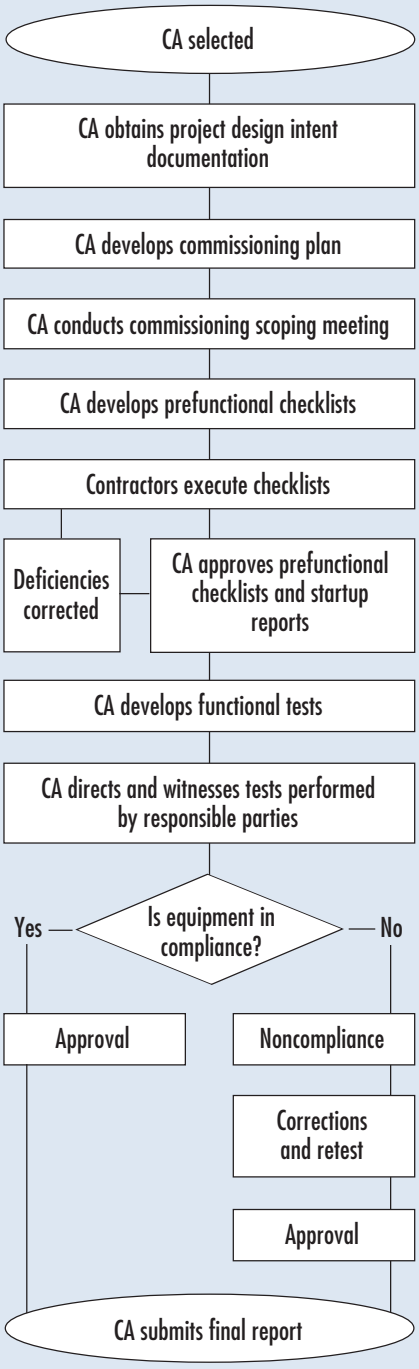
The goal of commissioning during the design phase is to ensure that the efficiency and operational concepts for building systems developed during programming are included in the final design. The main commissioning tasks during this phase are compiling and reviewing design intent documents, incorporating commissioning into bid specifications and reviewing bid documents.

The bid specifications developed during the design phase define the design intent of each system and include commissioning requirements for the mechanical, electrical and controls contractors. Specifications should include any special equipment or instrumentation that must be installed for obtaining measurements during performance testing. They also should describe the responsibility that contractors will have for preparing operation and maintenance manuals for equipment installed. (For more details on operation and maintenance manuals, see page 28.) The commissioning agent reviews these bid documents and all other design intent and contract documents. At a minimum, design intent documentation includes:

- Objectives and purpose of each system
- How the objectives will be met
- Indoor/outdoor design conditions
- Occupancy, usage and schedule assumptions
- Internal loads assumptions
- Zoning descriptions
- Ventilation requirements
- Envelope requirements
- Equipment sizing calculations and criteria
- All sequences of operation
- Energy efficiency control strategies
- Design intent for all efficiency measures
- Reference to pertinent local or state compliance documents

Commissioning Agent Tasks

The commissioning agent (CA) performs the activities listed in this chart.



The commissioning scoping meeting should be held during the design phase. At this meeting, the commissioning agent outlines the roles and responsibilities of the project team members and reviews the commissioning plan outline and schedule. Team members provide comment on the plan and schedule, and the commissioning agent 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 agent recommends changes to improve energy efficiency, operation and maintenance and equipment reliability.

The commissioning agent attends selected design team meetings to review the design and note potential system performance problems. The commissioning agent recommends changes to improve energy efficiency, operation and maintenance and equipment reliability. Making these changes during the design phase, rather than after construction begins, saves money in the long run.

During this phase, the commissioning agent also can play a significant role in developing a building's operation and maintenance program or suggesting improvements for a program already in place. The agent interviews the facility manager to determine operating staff ability and availability to operate and maintain building equipment and systems. The commissioning agent also reviews the design documents and drawings to ensure that equipment is accessible for maintenance.

Construction/Installation phase

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

Prefunctional testing, which ensures that equipment is properly installed and ready for functional performance testing, occurs during the construction phase. The commissioning agent approves and may oversee startup and prefunctional testing and makes sure that any deficiencies are remedied before functional testing begins.

The commissioning agent should involve the building operation staff in the prefunctional 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.

The commissioning agent may write various 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 for delivering correction orders to the responsible contractors and tracking their responses is critical to the success of commissioning.)

If corrective measures are required, the commissioning agent makes sure that they meet the owner's criteria and the design intent.

Acceptance phase

The functional performance tests written during the construction phase are modified, if necessary, during the acceptance phase to reflect any changes in installations. The commissioning agent then uses the tests to document and verify the proper operation of equipment and systems according to the contract documents. Most often, the commissioning agent 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 agent makes sure that they meet the owner's criteria and the design intent. 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.

After completing functional performance testing, the agent writes a final commissioning report, which includes all project documentation, and submits it to the owner for review.

The acceptance phase is complete when the facility has moved from the static construction state to the dynamic operating state 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 acceptance 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. If training was not included in the construction/installation phase, it should begin before the end of the acceptance phase.

The commissioning agent is responsible for interviewing the project manager and operation and maintenance staff to determine their training needs. The agent then selects the appropriate topics, level of detail, sequence of training and training

Videotaping training sessions often provides an extra incentive for vendors to ensure the quality of the sessions.

methods. Training may include both classroom sessions and hands-on site demonstrations of proper equipment operation and maintenance.

In addition, the commissioning agent oversees training sessions as specified in the bid documents that installing contractors, designers and manufacturers' representatives will conduct. Typical training topics are listed on page 30. The agent also verifies that operation and maintenance manuals are complete and available for use during the training sessions. Finally, if any modifications to operation and maintenance practices are made based on the training, the agent makes sure that the manuals are updated to reflect these changes. All building staff responsible for operating and maintaining complex building equipment, especially energy management systems, should be required to participate in the training.

The commissioning agent 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.

Post-acceptance/Occupancy Phase

After acceptance, the building is in the hands of the owner and operators. Even though the project is considered complete, some commissioning tasks continue throughout the life of the building. These tasks include ensuring that equipment and systems continue to function properly and documenting changes in equipment and building usage. It may be appropriate to continue working with the commissioning agent at the beginning of this phase, so the agent can review and recommend methods for carrying out these functions.

When performing testing during post-occupancy, the commissioning agent or test engineer must be careful not to void any equipment warranties. The building owner should require that contractors provide the commissioning agent 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 agent.

If any testing was delayed because of site or equipment conditions or inclement weather, this testing should be completed during this phase. Any necessary seasonal testing also should be performed during post-acceptance. 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. Simulation can be more expensive than testing under natural conditions. If the building already is occupied (especially if it's occupied 24 hours a day), simulation may be impossible. When performing seasonal testing during

post-acceptance, the commissioning agent, as noted above, must be careful not to void existing warranty conditions.

Owners should consider recommissioning their facilities periodically to ensure that 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 topics listed on page 30, they may be able to conduct the recommissioning process themselves.

When Does Commissioning End?

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 two to three years depending on building usage, equipment complexity and operating experience. Your commissioning agent can recommend an appropriate interval for your building and systems. In the meantime, staff should implement sound operation and maintenance practices to ensure 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
- 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; reviewing these documents periodically often will 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

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

Good Operation and Maintenance Begins During Design

Like commissioning, successful operation and maintenance begins in the design phase of a project.

Like commissioning, successful operation and maintenance begins in the design phase of a project. Building owners have begun to recognize the importance of soliciting input from operation and maintenance staff during the early stages of building design. Building operation and maintenance staff can make design recommendations that 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[8] are:

- 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 without having to disassemble equipment
- Provide sufficient clearance on all sides of the chiller to perform all maintenance
- Install hoist or crane equipment over banks of chillers
- 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 agent 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

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

- 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 agent believes it would be beneficial, additional information, already gathered during the commissioning process, also can be included in the operation and maintenance manuals. This information may include equipment submittals, design intent documents including control strategies and sequence of operations (normal and emergency) and copies of the commissioning tests (pre-functional checklists and functional performance test forms).

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. Typically, one copy—the master copy—remains in the facility manager's or engineer's 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's 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 the firm 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.

Operation and maintenance manuals are useful as a reference tool for current facilities staff and as a training resource for new staff.

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

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 ideally should be specified in the bid documents.

Suggested Training Topics

- Descriptions of equipment and systems installed and their warranties or guarantees
- Equipment startup 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
- The 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 onsite
- 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 startup and shutdown procedures for equipment, building operation staff gain a permanent and inexpensive onsite 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 agent still can 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 doesn't circumvent the systems' design intent. Training also should include a list of resources for the manager to call for maintenance assistance when necessary.

Once a building is operating and occupied, problems occasionally will 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 are unable to solve a problem in a reasonable amount of time, the owner should request expert troubleshooting assistance.

Because the commissioning agent 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. This contract could be written in a "fee-for-service" or an "amount-not-to-exceed" manner. Owners may find that it is more cost-effective to purchase troubleshooting services from the agent or engineer, because their knowledge of the building systems and design saves them time in diagnosing problems.

In the long run, owners also may find it beneficial to train operation and maintenance staff in energy accounting. In addition to tracking the building's energy use, energy accounting also can indicate when problems or potential problems exist with equipment operation.

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 doesn't 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 the life of equipment.

Identifying degradation of the system's components is another benefit of preventive maintenance. If the operation and maintenance system in a facility is properly set up and proper reporting and documentation practices are in place, the incidence of failure will be reduced. 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.

If the operation and maintenance system in a facility is properly set up and proper reporting and documentation practices are in place, the incidence of failure will be reduced.

Perhaps the most-cited reason for performing preventive maintenance is the energy savings (which translate into cost savings) that it provides. For example, simply replacing worn fan belts on a regular basis can save 2 to 4 percent of the energy used to run the fans. Cleaning air filters and cooling coils regularly can save 1 to 3 percent 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 are incorporated into the fire sprinkler and smoke detection systems. A properly functioning air handling system is required to handle smoke and dangerous fumes in case of fire.

Developing a Preventive Maintenance Plan

The commissioning agent 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 already has been gathered as part of the commissioning process or can be obtained from the operation and maintenance manuals.

A preventive maintenance plan consists of a checklist of tasks that are performed at manufacturer-recommended intervals.

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 usually is kept in the form of a log and updated manually when tasks are performed (see example on page 33.) 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, the system should be updated when work is performed and hard copies of completed work orders should be kept in a file or notebook.

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. The manufacturer's operation and maintenance manual for each piece of equipment should be consulted for requirements such as frequency, chemical treatments, proper lubricants, special tools, etc. This information also should 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.

Outsourcing Preventive Maintenance

According to maintenance contracting firms, most office and retail buildings smaller than 50,000 ft^2 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, the cost of training in-house staff should be compared to the cost of hiring a trained outside contractor to perform maintenance on the equipment.

Preventive Maintenance Log

Nameplate Data

Fan:

Manufacturer	***Big Fans, Inc.***
Model number	***BF 727***
Serial number	***12344-02***

Motor:

Phase	***3 phase***	Full load amperage	***30.0***
Voltage	***460***	RPM	***1745***
Frame size	***284T***	Service factor	***1.15***
Horse power	***25 hp***	Efficiency	***93.6***
Belt size/description	***(1) a-44***		

Place the date in box when task is completed and state any problems and solutions under "Comments."

Preventive Maintenance Task	Frequency	Date(s)	Measurement (if applicable)	Initial/Comments
Visual inspection for noise and vibration	Weekly	***1/5, 1/13, 1/19, 1/26***		***BK/ Tighten shroud to eliminate noise. 1/19***
Check schedule	Monthly	***1/5***		***BK***
Check belts	Quarterly*	***1/19***		***BK/ Replace belt***
Check bearings	Quarterly*	***1/19***		***BK***
Check bypass timer function	Quarterly*	***1/19***		***BK***
Measure and record amperage for phase A	Quarterly*	***1/19***	***26.0***	***BK***
Measure and record amperage for phase B	Quarterly*	***1/19***	***26.0***	***BK***
Measure and record amperage for phase C	Quarterly*	***1/19***	***27.5***	***BK***
Measure and record voltage: phase A to B	Quarterly*	***1/19***	***460***	***BK***
Measure and record voltage: phase A to C	Quarterly*	***1/19***	***460***	***BK***
Measure and record voltage: phase B to C	Quarterly*	***1/19***	***460***	***BK***
Measure and record voltage: phase A to ground	Quarterly*	***1/19***	***277***	***BK***
Measure and record voltage: phase B to ground	Quarterly*	***1/19***	***277***	***BK***
Measure and record voltage: phase C to ground	Quarterly*	***1/19***	***277***	***BK***

**Perform quarterly tasks in January, April, July and October.*

After each site visit, the contractor should provide an invoice or preventive maintenance form stating clearly which preventive maintenance activities or repairs were performed.

In buildings where operating staff are not available or trained to perform the required preventive maintenance on equipment, owners may obtain a service contract from the vendor, installing contractor or a maintenance service contractor. The service contract should cover all of the manufacturer's recommended preventive maintenance procedures as described in the operation and maintenance manuals. After each site visit, the contractor should provide an invoice or preventive maintenance form stating clearly which preventive maintenance activities or repairs were performed. The owner or facility manager should 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.

The various types of 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 usually is 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 usually is offered by large maintenance contractors. Under this arrangement, the contracting firm not only maintains but also replaces failed components. It's 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.

Tools for Proper Operation and Maintenance

Regardless of building size, building operating staff should have on hand certain tools (in addition to basic hand tools) that enhance their ability to operate and maintain equipment and systems. These tools are relatively inexpensive and are essential for basic troubleshooting. They include:

- Inspection mirror for observing equipment components that are difficult to reach or see
- Digital thermometer or temperature meter for measuring space temperatures of both air and liquids. A digital thermometer allows operators to assess the seriousness of occupant comfort complaints.
- Ammeter or multimeter for measuring volts, ohms and amps. Operators can use the ammeter to troubleshoot electrical problems and detect potential motor failures.

- Light meter for measuring light levels. Operators use this tool to determine whether light levels in occupant spaces are sufficient, or perhaps too high.
- Psychrometer to measure humidity

Once these basic tools are available, owners and operating staff may consider adding more sophisticated instrumentation. This is especially true in larger, more complex buildings with in-house operation and maintenance staff. Some companies may be interested in investing in more sophisticated monitoring and software tools.

Monitoring Tools

The following monitoring tools can provide staff with more detailed information about building performance and problems:

- Tachometer for reading the revolutions per minute (rpm) of fans and motors. Operators can check this measurement against the design intent rpm and troubleshoot for air flow problems.
- Flow hood for measuring air flow and detecting air balance problems. This tool is especially useful during space changes and remodels.
- Combustion analyzer for measuring boiler efficiency. This measurement can indicate whether there are problems with boiler function.
- Power monitor to measure kilowatt usage and power factor and troubleshoot electrical problems. This tool is similar to the multimeter and ammeter, but it provides readings over time rather than spot measurements.
- Dataloggers to measure flow, temperature, current, light levels and pressure. These small, portable devices provide measurements over time and are excellent tools for more sophisticated troubleshooting.

EMCS Trending

Many commercial buildings now use energy management control systems (EMCSs) to improve building efficiencies. These systems also have the capability to assist with the commissioning process. A quality EMCS that includes data points for diagnostic purposes can assist the commissioning agent in diagnosing controls problems. Prior to its use as a commissioning tool, the EMCS itself should be commissioned. Features that improve EMCS usefulness in commissioning[9] include:

- Graphical user interface
- Capability to automatically download data when system memory starts to fill up

Many commercial buildings now use energy management control systems to improve building efficiencies.

[9]Koran, William, et al. "Problems With and Potential of Using EMCS for Commissioning." Unpublished report.

Oregon Office of Energy Commissioning Tool Kit

The Oregon Office of Energy has compiled a tool kit of commissioning resources that includes:

- Language for including commissioning in RFPs
- Sample commissioning specifications for large facilities
- Directory of firms providing commissioning services
- Tips for project managers on managing the commissioning process
- Sample commissioning plan
- Boilerplate prefunctional and functional tests for selected equipment
- Bibliography of commissioning resources

To order any or all of the tool kit components, call the Oregon Office of Energy at 1-800-221-8035 (toll-free in Oregon) or 503-378-4040 (Salem/TTY).

- Capability to specify starting times for trending requested parameters
- Capability to create time-series plots of up to eight parameters simultaneously
- Capability for the operator to "zoom in" on a plotted time period by drawing a box around the region of interest
- Capability to plot one or more parameters against another (x-y plots)

These features allow for quick data analysis. They also reduce the training time for an operator to collect commissioning data. Owners who are installing a new EMCS system should consider listing specific EMCS points that will be used for commissioning in the construction documents and the commissioning plan.

Software Tools

Automated maintenance systems range from computer assistance for planning and scheduling work orders to equipment monitoring and fault diagnosis. The most popular areas of maintenance automation include basic capabilities such as time keeping, cost and energy accounting, work requests and preventive maintenance planning or scheduling. Software with varying levels of detail has been developed for automated maintenance systems.

Appendix 1—Sample Prefunctional Checklist

This section includes a sample prefunctional 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 agent name	
Address	
Phone	

Equipment

Equipment name	
Type	
Manufacturer	
Model number	
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, Btu, efficiency, etc.)

Building:	Commissioning agent:	Phone:
Date:	Contractor:	Phone:

General Checklist

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

	Unit #				
Checklist Item					
Casing condition good: no dents, leaks, door gaskets tight					
General condition appears good					
Attached ductwork 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 were 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)					

	Unit #				
Checklist Item					
Supply fan belt: tension and condition OK					
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					
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 Agent

Appendix 2—Commissioning Resources

Building Commissioning Guide. Prepared by Enviro-Management & Research, Inc. for U.S. General Services Administration and U.S. Department of Energy, 1995.

Building Commissioning Guidelines, Second Edition. Portland, Oregon: Bonneville Power Administration, 1992. Prepared by Portland Energy Conservation, Inc.

[The] Building Commissioning Handbook. Heinz, John, Rick Casault and Phoebe Caner. Alexandria, Virginia: The Association of Higher Education Facilities Offices (APPA), 1996.

Catalogue on Procedural Standards for Building Systems Commissioning; NEBB Procedural Standards for Building Systems Commissioning, First Edition. Rockville, Maryland: National Environmental Balancing Bureau, January 1993.

Commissioning Guide Specification, Facility Management Office, University of Washington, 1993–96. http://weber.u.washington.edu/~fsesweb/

Guideline for Commissioning of HVAC Systems. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1989. ISSN, 1049-894X.

Model Commissioning Plan and Guide Specifications. Prepared by Portland Energy Conservation, Inc. for U.S. DOE Region 10, 1996.

Montgomery County Government—Contractor Quality Control and Commissioning Program—Guidelines and Specifications. Montgomery Engineering Institute, Department of Facilities and Services, Capital Projects Management Division, December 1993.

Panel 5: Commissioning, Operation and Maintenance. Volume 5 of the Proceedings of the ACEEE 1994 Summer Study on Energy Efficient Buildings. Washington, D.C.: American Council for an Energy-Efficient Economy, 1994.

Proceedings of the National Conferences on Building Commissioning, 1993–1996. Portland Energy Conservation, Inc. Portland, Oregon.

U.S. Department of Commerce. National Institute of Standards and Technology. *Commissioning Manual for Mechanical Systems in Federal Buildings*. Gaithersburg, Maryland: National Institute of Standards and Technology.

U.S. Department of Commerce. National Institute of Standards and Technology. *HVAC Functional Inspection and Testing Guide*. Prepared for the General Services Administration by James Y. Kao, March 1992. NISTIR 4758.

Washington State Department of Services Administration. Division of Engineering and Architectural Services. “Appendix XVI: Commissioning Guidelines” in *Guidelines for Architects and Engineers*. Olympia: Washington State Energy Office, 1993.

Appendix 3—Operation and Maintenance Resources

Avedesdian, David A. "How to Design and Manage Your Preventive Maintenance Program" (booklet and software). Washington, D.C.: Building Owners and Managers Association, 1996. To order call 1-800-426-6292.

Bonneville Power Administration Guidelines for Applying Commissioning and O&M Requirements in the Energy Smart Design Program. Prepared by Portland Energy Conservation, Inc. for Bonneville Power Administration, 1993.

Claridge, David, et al. "Implementation of Continuous Commissioning in the Texas LoanSTAR Program: 'Can You Achieve 150% of Estimated Retrofit Savings' Revisited," in *Volume 4, Proceedings 1996 ACEEE Summer Study on Energy Efficiency in Buildings*. Washington, DC: American Council for an Energy-Efficient Economy, 1996.

Herzog, Peter. *Energy-Efficient Operation of Commercial Buildings: Redefining the Energy Manager's Job*. New York: McGraw-Hill, 1997.

International Facilities Management Association, "1994 Winter Best Practices Forum on Facility Management," *Proceedings IFMA Best Practices Forum,* March 1994.

"O&M Best Practices for Energy-Efficient Buildings." Prepared for U.S. EPA and U.S. DOE by Portland Energy Conservation, Inc., 1996. To order call 1-503-248-4636.

"Operation and Maintenance Practices in Commercial Buildings: Bibliography." Prepared for U.S. EPA and U.S. DOE by Portland Energy Conservation, Inc., 1995. To order call 1-503-248-4636.

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