energydesignresources

design brief

BUILDING COMMISSIONING

In projects all over the country, building-industry professionals are finding that commissioned buildings are more energy efficient, more comfortable, and easier to maintain.

Summary

Commissioning is a quality-assurance process designed to increase the likelihood that a newly constructed building will meet client expectations. Although commissioning was originally created to ensure that HVAC systems were correctly specified and properly installed in building projects, the process can be applied to nearly any building system. In projects all over the country, building industry professionals are finding that commissioned buildings are more energy efficient, more comfortable, and easier to maintain.

Commissioning stretches over the entire design and construction process. It should ideally begin at the design phase, with the selection of a commissioning agent who helps ensure that the building owners and designers' intent is written into project documentation. The building designers then incorporate commissioning requirements into their specifications. Later, the commissioning agent is responsible for inspecting building systems during construction, and when the project is near completion, the agent and contractors conduct rigorous performance tests. At the end of the commissioning process designers and vendors provide building operators with training and documentation to ensure the proper operation and maintenance of the building.

Commissioning a new building costs about \$0.30 to \$0.90 per square foot. On average, simple payback periods for such investments range from about three to four years, as a result of energy savings, improved occupant comfort and productivity, and reduced rework costs.

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What Is Building Commissioning?

Commissioning is a quality-assurance process conducted throughout a construction project to increase the likelihood that a building will meet client expectations. Tersely defined by ASHRAE (the American Society of Heating, Refrigerating, and Air Conditioning Engineers) as "the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent,"[1] commissioning starts as soon as a new facility is conceptualized, and it continues until the building is occupied. Through this process, expectations for the performance of the building systems are established and procedures are put in place to determine whether those expectations have been met. Although commissioning was originally formulated to be applied specifically to HVAC systems, the process can be applied to nearly any building system.

Commissioning includes careful documentation from the beginning to the end of a project, inspections during construction, testing to ensure that the installed systems meet the design requirements, and training for operations and maintenance personnel.

Commissioning procedures include careful documentation from the beginning to the end of the project, inspections during construction, testing to ensure that the installed systems meet the design requirements, and training for operations and maintenance (O&M) personnel to ensure that the building will be operated as designed. The process begins with the creation of a design intent document that becomes the basis for all subsequent design planning and evaluation. That document is used throughout the commissioning process as a benchmark for determining whether the building meets the design intent. During construction, inspections are conducted to identify any installation or design problems that can be more easily dealt with during—rather than after—construction. After the systems have been installed, a series of tests are performed to make sure that the equipment operates properly and meets the design intent.

In projects all over the country, industry professionals are finding that commissioned buildings are more energy efficient, more comfortable, and easier to maintain. They are also finding that in many cases, these buildings are less expensive to own and operate over the long haul.

The Division of Facilities and Services of Montgomery County, Maryland, has included commissioning on about ten of its projects. The division is very happy with the results. Although the commissioning process requires more time and money for planning and review, checking and correcting work throughout the design and construction process has dramatically reduced the amount of rework required at the end of the construction cycle. The division's overall costs have been about the same as without commissioning. However, the benefits of the process have been immediate: Occupants have been able to move into the commissioned buildings sooner that would otherwise have been possible, and there have been far fewer post-occupancy problems.

Companies are able to move into commissioned buildings sooner than would have been possible without commissioning, and they tend to experience far fewer post-occupancy problems.

On two representative Montgomery County projects, the division estimates that commissioning saved them $1.57 per square foot due to reduced mechanical/electrical change orders and claims, plus another $0.48 per square foot in energy costs during the first year of occupancy.[2] Because Montgomery County requires all contractors to include commissioning as a part of their bids, the specific cost of commissioning on these two projects is difficult to determine, but based on typical commissioning costs ranging from $0.30 to $0.90 per square foot, and the savings noted above, the process easily paid for itself.[3]

Are the energy savings the division noted typical? In 1994, Southern California Edison (SCE) ran a study that compared the before and after performance of buildings that had not previously been commissioned. In their "before" evaluations, SCE found quite a few system flaws that would probably have been found and corrected if the buildings had originally been commissioned. Some of the most significant problems included:

- Evaporative coolers that had been disconnected because they did not operate correctly and created bad odors inside the building.

- A pneumatic air compressor that was pumping oil throughout the control system.
- Miscalibrated thermostats.
- Some outside air sensors erroneously located in the exhaust air stream.
- Economizers that were nonfunctional, either due to failed controls or to inoperative linkages.
- No battery backup for the energy management and control system (EMCS), which caused all programming to be lost, since there was also no electronic or hard copy backup of the program.
- Incorrect EMCS programming that allowed a 150-ton chiller to run excessively during unoccupied hours.

It is important that one person—the commissioning agent—be assigned the responsibility of seeing that every facet of the commissioning process is carried out.

Before the buildings were put through a commissioning process, SCE monitored energy use to establish baselines. Energy use was remeasured after the commissioning process had identified the flaws and corrected them; estimated savings due to commissioning ranged from 3 to 27 percent.[4]

Who Does Building Commissioning?

Commissioning requires continuity from the design stages through construction, testing, and building occupancy. Therefore, it is important that one person be assigned the responsibility of seeing that every facet of the commissioning process is carried out. This individual is known as the commissioning agent (CA). This agent leads the commissioning team and coordinates commissioning activities. He or she is the "glue" that holds the process together. The agent might be the building owner, an architect, the HVAC engineer, or a contractor. There are also many specialized consultants who now offer commissioning as a service. **Table 1** summarizes the advantages and disadvantages inherent in having different types of individuals serve as the commissioning agent.

Because the commissioning agent represents the owner's interests, the agent often contracts with and reports directly to the owner. However, this is not the only arrangement that works. Agents have also been successfully hired by the design firm, or by the general contractor.

It is common for some government agencies and for design/build contracts to have the commissioning agent hired by the general contractor because it results in a single contract for the entire construction project, which simplifies overall contract arrangements. Because the agent works for and with the general contractor, the relationship may be less adversarial than in some other arrangements. The agent tends to be treated as part of the construction team, and he or she is often included in less-formal discussions that an independent agent hired by the owner

Because the commissioning agent represents the owner's interests, the agent often contracts with and reports directly to the owner, although other arrangements have worked well, too.

Table 1: What do different types of commissioning agents bring to the process?

The commissioning agent can be one of a variety of individuals from the project team. Each type of player brings different skills to the process.

Commissioning agent	Advantages	Disadvantages
Owner	Owner has control over the process. Highly motivated to ensure that the contractor delivers the building properly. Understands need of building occupants better than any other party.	May lack appropriate staff to perform commissioning.
Independent CA who reports to the owner	Reports directly to the owner. No conflict of interest.	May be difficult for independent agent to coordinate efforts of subcontractors during commissioning activities. Need to clearly define line of authority.
Engineer of record	Engineer has full knowledge of system design.	If design is flawed or incomplete, there may be a conflict of interest.
General contractor	Usually willing to hire engineer to perform agent's duties. Experienced at scheduling subcontractors.	Potential conflict of interest. Some may be unwilling to hire independent engineer to perform the agent duties.
Subcontractors	Familiarity with individual systems.	May lack engineering expertise required to commission all the systems. Potential conflict of interest.

Source: *HPAC Magazine* and other industry sources

From the agent's point of view, one disadvantage of working for the general contractor is losing the kind of influence that comes from reporting directly to the building owner.

might not be invited to. From the agent's point of view, however, one disadvantage of working for the general contractor is losing the kind of influence that comes from reporting directly to the building owner. Also, when the general contractor hires the commissioning agent, it usually happens after the design has been completed and a general contractor has been selected. In that instance, all design-phase commissioning activities must be performed by the architect/engineering team, by the owner, or by an agent hired by one of these parties. Nonetheless, many owners and general contractors believe these disadvantages are outweighed by the advantages.[5]

When the Portland, Oregon, headquarters building for the Bonneville Power Administration was remodeled, the commissioning agent had to be contracted by the project mechanical engineer because of the way the budget for the project was structured.[6] Although both the mechanical engineer and the agent were initially skeptical about the arrangement, it turned out to not be an issue since the project team had committed to a "no-blame" mind-set and had espoused non-defensive attitudes. If the project team had been less willing to work together, then this contracting relationship might not have turned out as well as it did.

Five Steps for Successful Building Commissioning

How can you increase the probability that your building commissioning process will go smoothly? The five steps discussed below are essential to a healthy commissioning process.

1. Put the Design Intent in Writing

The entire process is put in motion when the owner and the design team come to an agreement on their expectations for the building. This step is critical, because the designers and contractors will be held accountable for meeting those expectations in every other phase of the building project. All decisions are incorporated in the design intent document that is usually created through interviews and discussions between the owner and the design team. The owner needs to convey the requirements and expectations for each room or type of space in the building, including offices, common areas, conference rooms, break rooms, and so on. This information will in turn establish many of the overall characteristics of the building, including size, type of construction, internal loads, the kinds of systems required, the energy efficiency requirements, and the budget needed to meet these goals. At a minimum, the design intent document should include the following information:

It is essential to put the intent of the design in writing, with full detail.

- *Usage pattern for the facility, for all hours and days.* For example, a hospital will be used continuously, but a school may be largely unused during summer months.

- *Occupancy requirements.* How many people will be using the facility, and when?

- *Quality of material and construction.* A luxury building may require that higher-quality materials be used than would be necessary for a more cost-conscious facility such as a school.

- *Environmental and air quality requirements.* Will there be special requirements for air quality? Areas in the building that will require high-purity air or special temperature humidity control need to be identified.

- *Levels of illumination.* Lighting requirements not only drive the design of the lighting system; they also affect the cooling requirements for a given space or building. If the illumination system is to be commissioned—as is likely to be the case for a building with a daylighting system—the illumination levels will be part of the functional performance test criteria.

- *Energy performance criteria.* The building's energy performance criteria will drive many design decisions, and they will be used to set acceptance requirements for functional performance tests.

- *Description of all systems and how each one should operate under a range of defined conditions.* This section should cover how systems are to operate under a variety of conditions, including normal occupancy, partial occupancy, and emergency situations.

- *Acceptable performance criteria and operating strategy for each system.* The criteria spelled out in the design intent document will form the basis for the functional tests that will be conducted to determine whether the systems have been correctly selected and installed.

- *Budget considerations and limitations.* The inclusion of budget considerations and limitations in the design intent document helps ensure that the design and construction of the facility will not exceed the allowable budget.

The design intent document forms the basis for all subsequent design documents, including the Commissioning Plan.

After the design intent document has been completed, it forms the basis for all subsequent design documents. The commissioning agent uses it as the basis for creating the Commissioning Plan, which lays out the requirements for commissioning, including staffing and labor requirements, the systems that will be tested, documentation requirements, scheduling and acceptance procedures, and training requirements for the building operators.

2. Incorporate Commissioning Requirements into the Specifications

We recommend that all specifications include commissioning requirements. That allows contractors to understand their responsibilities and to know in advance what they will be held accountable for. There should be requirements for testing, a rundown of the expected results, a record of necessary operator training, and a description of any documentation that will be needed. Putting commissioning requirements in the specifications clearly defines the scope of the commissioning and the standards that will have to be met for acceptance.

Sample commissioning guidelines and specifications have been published by several organizations. Sponsored by the U.S. Department of Energy and developed by the Portland Energy Conservation, Inc. (PECI), *Model Commissioning Plan and Guide Specifications* is an excellent example of such documents.[7] This comprehensive set of commissioning requirements and specifications covers commissioning from the design phase all the way through construction and testing. PECI has also created the *Oregon Commissioning Toolkit*, under the auspices of the Oregon Office of Energy.[8] These documents include guidelines; boilerplate language; and content, format, and forms for specifying and executing commissioning. Sample tests and inspections are also included in the documents. Naturally, the sample documents must be tailored to meet the specific requirements of each building project. Tests and inspections appropriate to the particular system design and to equipment installed in the building must be substituted for the examples given in the documents, as indicated by notes detailing the required changes.

Sample commissioning guidelines and specifications are available from several state and national organizations.

ASHRAE Guideline 1-1996, another good reference, includes samples of commissioning statements that should be included in project specifications.[9] They cover the following topics:

- Submittals, to include performance information and O&M manuals
- Training requirements
- Documentation requirements
- Meetings
- Construction observations and inspections
- Pre-start tests and equipment tests
- Equipment start-up
- Control system calibration
- Testing and balancing
- Verification
- Certification of completion of construction
- Functional performance testing

- Training
- Post-acceptance activities

If all commissioning requirements are spelled out in the project specification, the process will go much more smoothly.

If requirements in all of these areas are written into the specifications, the commissioning process will go much more smoothly. For example, the specifications might require installation of thermowells or flowmeters that are needed in order to commission some of the equipment. If these items are not included in the initial specifications, they will have to be added during testing, at greater expense.

In addition to specifications for acceptance testing, the roles and responsibilities of the various team members need to be included in the specifications. **Table 2** offers a brief summary of the duties and responsibilities of the different team members.

Table 2: Customary roles and responsibilities of commissioning team members

For any commissioning project to be successful, all the players must understand their roles and responsibilities.

Team member	Responsibilities
Building owner	Clearly communicate building-project expectations Work with agent to define commissioning goals Facilitate communication between the commissioning agent and other project team members
A/E team	Document the design intent Include commissioning in the bid specifications Monitor construction activities Review and approve project documentation
Commissioning agent	Ensure completion of design intent documentation Assist in development of commissioning specifications Write prefunctional inspection and functional performance tests Enforce need for commissioning throughout the project Witness all tests Review contractor training plans Review commissioning documentation provided by contractors
General contractor	Assist with development and implementation of functional tests. Assist agent by coordinating subcontractor commissioning activities
Contractors and subcontractors	Perform commissioning functions described in specifications. Train building operators Provide O&M manuals
Building operators	Assist with functional testing as possible Attend training sessions

Source: *HPAC Magazine* and other industry sources

Problems occur when the specifications do not adequately describe the commissioning requirements, or when the contractors bidding on the project do not fully understand the level of commissioning required. For example, when the University of Chicago's business school facility was constructed, commissioning was not initiated until construction was nearly complete. The problems that were found—including inadequate service access to the supply fan motors, air-balancing problems, and economizer damper binding and over-stroking—required extensive work to remedy.[10] The contractors did not know that commissioning was planned and had no idea what their role was to be. Many of the commissioning activities were performed after the building was occupied, and after the contractors had left the site, believing the project to be substantially complete. As a result, the contractors were not very cooperative during the commissioning problem-resolution phases. Resolving the problems was time-consuming, difficult, and expensive.[11]

Because it is much easier to remedy problems that are caught early in the construction process, it is best to have commissioning agents inspect building systems as they are being installed.

3. Inspect Building Systems During Construction

Because it is much easier to remedy problems that are caught early in the construction process, commissioning agents inspect building systems as they are being installed. During these inspections the agent verifies that equipment has been installed properly and that the systems will be up to the more intense functional tests that happen later in the process. If errors are not caught at this early stage, it can take far longer to perform those functional tests. For example, assume that some dampers are operating contrary to their proper functioning. Without early detection, that problem might take longer to pinpoint in the midst of whole-system functional testing. Once identified, the errors would have to be fixed, and then the functional tests would have to be repeated.

Informal inspections can be made by simply observing construction activities. More formal inspections, sometimes called pre-start or pre-functional inspections, follow specific checklists

Two methods for testing system functionality may be part of the commissioning process: functional performance tests and short-term monitoring.

that are part of the commissioning specifications. **Figure 1** shows an example of a prefunctional inspection checklist for a water cooled chiller. Prefunctional inspections involve the contractor(s) associated with the equipment, the commissioning agent, and an owner's representative. The checklists cover a series of areas, such as:

- *Documentation.* Ensure that all required documentation has been provided, such as performance data and O&M manuals.
- *Model verification.* Verify that the equipment installed matches specifications.
- *Installation checks.* Checking installed equipment to ensure that all associated equipment and accessories are in place—such as vibration isolators, required pipe fittings, test plugs, instrumentation, and equipment labels—and that the electrical power and controls are installed correctly.
- *Operational checks.* Verify that start-up procedures for the equipment have been completed and that the equipment operates without any obvious problems, such as unusual vibration or noises.
- *Sensor calibration.* Verify that all equipment control sensors are labeled and located properly, and that they are within tolerances.

After these inspections have been completed, the results are documented, and any deficiencies are resolved by the contractor or other parties as necessary.

4. Test the System Functions

There are two different methods of testing the system functions: (1) functional performance tests, in which the systems are subjected to a series of tests laid out in the commissioning plan and specifications, and (2) short-term diagnostic monitoring, in which trend logs or portable data-logging equipment are used

Figure 1: Pre-start inspection checklist for a water-cooled chiller

The commissioning agent and contractor complete this type of checklist before the functional tests are performed. This ensures that the equipment is ready for final acceptance testing.

Excerpts of Prefunctional Checklist

Project ______________________________

PC-01____ CHILLER #'s____________________________

Associated checklists: Cooling Tower, Chilled & Condenser Water Piping, CHW and CDW Pumps

1. Submittal / Approvals

Submittal. The above equipment and systems integral to them are complete and ready for functional testing. The checklist items are complete and have been checked off only by parties having direct knowledge of the event, as marked below, respective to each responsible contractor. This prefunctional checklist is submitted for approval, subject to an attached list of outstanding items yet to be completed. A Statement of Correction will be submitted upon completion of any outstanding areas. None of the outstanding items preclude safe and reliable functional tests being performed. ___ List attached.

Mechanical Contractor	Date	Controls Contractor	Date
Electrical Contractor	Date	Sheet Metal Contractor	Date
TAB Contractor	Date	General Contractor	Date

Pre-functional checklist items are to be completed as part of startup & initial checkout, preparatory to functional testing.

- This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report.
- Contractors assigned responsibility for sections of the checklist shall be responsible to see that checklist items by their subcontractors are completed and checked off.

Approvals. This filled-out checklist has been reviewed. Its completion is approved with the exceptions noted below.

Commissioning Agent	Date	Owner's Representative	Date

2. Requested documentation submitted

Check if Okay. Enter comment or note number if deficient.

Check	Equip Tag->						Contr.
(list of required documentation)							

- ***Documentation complete as per contract documents***................................ ___ ***YES*** ___ ***NO***

3. Model verification [Contr = ________]

- ***The equipment installed matches the specifications for given trade***...... ___ ***YES*** ___ ***NO***

4. Installation Checks

Check if Okay. Enter comment or note number if deficient.

Check	Equip Tag->						Contr.
General Installation							
(list of specific inspection items)							
Electrical and Controls							
(list of specific inspection items)							

- ***The checklist items of Part 4 are all successfully completed for given trade***......................
___ ***YES*** ___ ***NO***

5. Operational Checks (These augment mfr's list. This is not the functional performance testing.)

Check if Okay. Enter comment or note number if deficient.

Check	Equip Tag->						Contr.
(list of specific inspection items)							

6. Sensor Calibration [ ]

(List of specific calibration inspections)

- ***All sensors are calibrated within required tolerances***................................ ___ ***YES*** ___ ***NO***

-- END OF CHECKLIST --

Source: Portland Energy Conservation, Inc. [8]

to monitor the performance of the building for a short period of time—perhaps one or two weeks. These two testing methods are complementary. Short-term diagnostic monitoring can be used to evaluate the overall performance of building systems, including interactions between associated systems, over a range of naturally occurring conditions.

The benefit of short-term diagnostic monitoring is that it can readily identify problems that might not be revealed by manual tests alone.

The benefit of short-term diagnostic monitoring is that problems can be readily identified that might not be captured by manual tests. The disadvantage is that the performance of building systems can only be observed under the conditions that exist during the monitoring period. It may be necessary to do periodic short-term monitoring to detect problems in both the heating and the cooling system. Short-term diagnostic testing can be used either as a stand-alone method, or to augment the manual functional performance tests, depending on the type of system being monitored. Software systems have been created to automate the diagnostic analysis of the short-term data.[12]

Functional testing, in which the equipment and systems are subjected to a set of specific tests, is more rigorous and time consuming. Its advantage is that the equipment is forced through a large variety of control sequences and conditions, making systems operate under a larger range of conditions than may be possible during short-term diagnostic monitoring. If there are large numbers of essentially identical equipment in a system (as, for example, multiple VAV terminals), it may be possible to reduce the time required for the functional tests by testing only a representative sample of the equipment.

The purpose of performing either type of test is to prove that building systems meet the design intent. The tests, which are detailed in the commissioning specifications, are witnessed by the commissioning agent and other interested parties. Note that the tests included in the initial bid specifications may be modified if changes in design or equipment specifications occur during construction.

The document shown in **Figure 2** is an excerpt from a set of tests that would typically be performed for a water-cooled chiller. The required functional tests included in the commissioning specifications usually stipulate a sequence of operation for the chiller and associated auxiliary equipment such as pumps, cooling towers, controls, and so on. This description is very detailed, specifying proper operation of the equipment

Figure 2: Functional performance tests for a water-cooled chiller

The procedure outlined below references multiple checklists and criteria for the chiller. The tests, which allow system performance to be verified as meeting the requirements set forth in the specifications, are also designed to uncover deficiencies in performance that need to be addressed.

Excerpt from Chiller Functional Test

1. **Participants.**
   (List of participants)
2. **Test Prerequisites.**
   (Test prerequisites, such as completion of prefunctional inspections)
3. **Sensor Calibration Checks.**
4. **Device Calibration Checks.**
   (This is a spot-check on a sample of the calibrations done during prefunctional checklisting and startup)
5. **Verification of Miscellaneous Prefunctional Checks.**
6. **Notes on Methods Used to False Load Chiller.**
   (For reference, see note 6 at end of test)
7. **Seasonal Testing and General Conditions of Test**
8. **Test Procedure Table of Contents**

9. **Testing Procedures and Record**

Proced. No. & Spec. Seq. ID[1]	Req ID No.[2]	Test Procedure (including special conditions)	Expected and Actual Response [Write ACTUAL response in brackets or circle]	Pass Y/N	Note #
CHILLER SYSTEM STARTUP AND STAGING					
1	...	...	...		
2 Seq 8	Specs 15682 3.3.; 15683 3.2	1st Lag Chiller Staging ON. Staging sequence: CH-___ -->CH-___ -->CH-___ With chillers in auto, and loaded such that only lead chiller is running, lower space setpoints so CCVs open. Wait ~10 minutes. Record time that primary flow and secondary flow become equal. Wait 20 minutes.	Total primary flow = [________gpm]. Secondary CHW flow => primary CHW flow = [______gpm] and lead chiller is at least 95% loaded (by % of rated current). [________ amps]. Time: [__________]. After 20 minutes, 1st lag chiller should start (PCHWP - oil pump - CDP - chiller). Time when 1st lag chiller started = [__________]. Observe that the amps on both chillers are within 5% of each other.		
...	...	...	...		

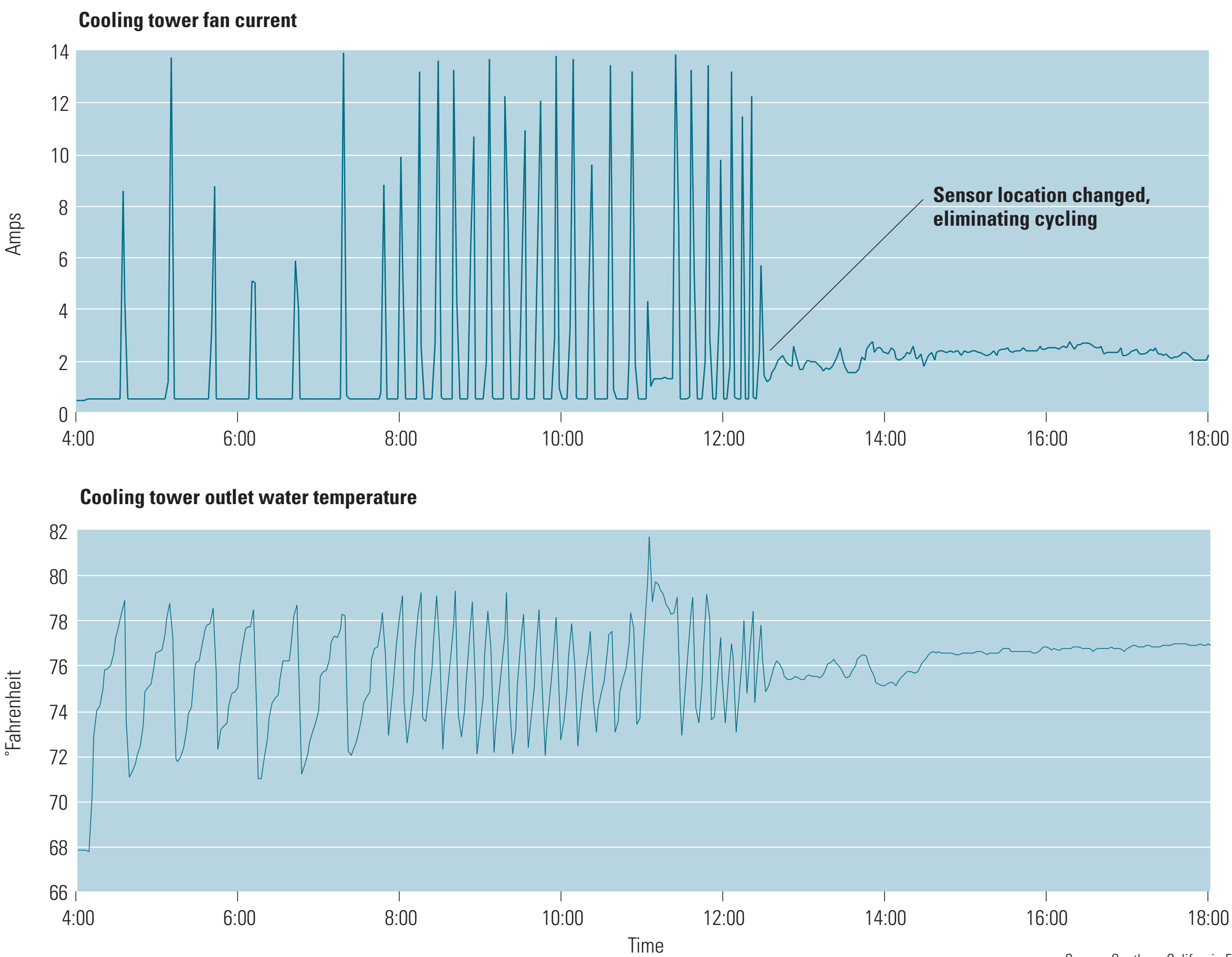
SEQUENCES AND COMPONENTS NOT TESTED					
59		Vibration Isolators.			
MONITORING AND TREND LOGGING		Monitoring via BAS trend logs are required per test procedures 14, 17, 29, 31, 34; 57. Attach representative graphs or columnar data and explanatory analysis to this test report.			

Source: Portland Energy Conservation, Inc. [8]

under all expected conditions. This functional test documentation lists a series of test procedures for verifying each component of the sequence of operation. If the system fails a test, the failure is documented and the problem must be resolved through a procedure similar to that used for inspections. Although the commissioning agent is present during the testing as a witness, the contractors should be in charge of performing the tests, since they are responsible for the equipment and are charged with evaluating and correcting any problems that arise.[13]

Figure 3: Cooling tower performance data

The oscillation problem is clearly visible in the original monitoring data. As the post-fix data show, moving the outlet water temperature sensor closer to the cooling tower improved the control of the fan's VSD, eliminating cycling, reducing energy consumption, and increasing the life of the equipment.



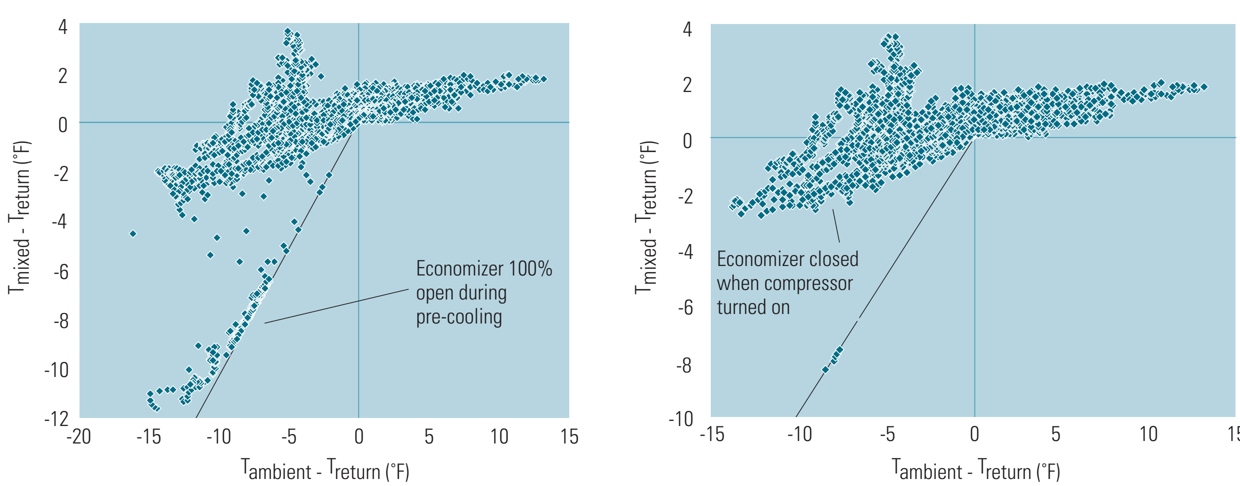
Source: Southern California Edison [14]

Short-term diagnostic data was extremely helpful in a case in which the sensor controlling the variable-speed drive (VSD) on a fan had been incorrectly located. (See **Figure 3**.)[14] The data plot shows the outlet water temperature and fan current for the cooling tower for one day. The fan speed is oscillating, causing both the fan current consumption and the outlet water temperature to vary widely. The oscillation problem was caused by the outlet water temperature sensor being positioned too far from the cooling tower. Moving the sensor closer to the tower eliminated the oscillation, greatly improved cooling tower performance, and made for less wear and tear on the equipment.

Figure 4 provides another example of how monitoring data can help identify problems. In this building, the economizer was not functioning properly. The economizer controls were shutting the outside air dampers to the minimum-flow position whenever the compressor came on, regardless of the ambient temperature. Changing the control software to keep the outside air dampers open when the ambient temperature was lower than the return air temperature increased the amount of "free cooling" within the building and improved the indoor air quality in the process.

Figure 4: Economizer performance plots

The data in the left plot shows that the economizer operates in two different modes. The data to the left of the vertical line should all lie along the steep diagonal line, indicating 100 percent outside air fraction. When the compressor is off, during morning pre-cooling, the economizer is open, as shown by the grouping of data along the diagonal line. When the compressor is turned on, as shown in the right plot, the economizer closes, regardless of the ambient temperature.



Source: Architectural Energy Corporation

5. Train the Building Operators

A system may be fully functional and meet all performance requirements, but the people that operate the building must also be trained to ensure that it continues to operate according to design intent. The building operators are the final component in the system, and unless they fully understand the controls and how the systems are supposed to operate, performance will deteriorate over time.

There have been cases where it was impossible to properly commission a building because the operators were overriding the controls so that they could manage the building systems the way they were familiar with. The problem was not with the building or the controls; the operators simply had not been sufficiently trained to understand how to use the new control system.[15]

The building operators are a critical part of the commissioning process: unless they fully understand the controls and how the systems are supposed to operate, performance will deteriorate over time.

Training should be performed during the construction phase, especially if the building operators will be involved in building start-up and testing (which we recommend). Observing the systems as they are put in place helps the operators understand what will be required of them to correctly operate the building. O&M personnel need to understand the design intent; they should be made familiar with the design intent document as part of their training.

Building operators should receive both component training and systems training. Contractors typically perform component training. Well before any formal sessions are held, the contractors should submit training plans to the commissioning agent for approval and scheduling. The intensity of the necessary component training will depend on the complexity of the equipment, but it must always meet the training requirements as set forth in the original bid specifications. Systems training takes the larger view, integrating all of the components and smaller systems into an overall building system. Either the commissioning agent or the design engineers may perform this training; sometimes both parties are involved.

As part of building handover, complete documentation must be provided ensure that O&M staff will be able to run the building properly and to train new staff. The documentation should include:

- training materials;
- design intent documents;
- specifications for all equipment and controls;
- O&M manuals for all equipment, supplemented as necessary so that they are specific for the installation; and
- as-built records of the building.

O&M staff should be given complete system documentation as part of building handover.

Videotaping on-site training is a useful way to document this critical information, and it should be seriously considered when the project is sufficiently large to warrant the cost.

Case Studies

1. Commissioning the Hard Way

When the University of Montana constructed a new building for its Gallagher School of Business Administration (**Table 3**), the university contracted with the mechanical and electrical engineer to facilitate the commissioning process. Unfortunately for the university, even though commissioning requirements were

Table 3: Gallagher School of Business Administration project elements

Building size	110,000 ft^2 on four levels
Occupancy type	Classrooms, lecture halls, offices
Building construction cost	\$125/ft^2 (above-average construction cost)
HVAC description	DDC energy management and control system VAV air-distribution system Chiller and groundwater cooling

included in the specifications, the commissioning contract was executed so late in the construction process that commissioning tests did not begin until the building was nearly completed.[16]

When the university moved into the building, serious flaws became evident. The building controls were so unstable that temperatures and air flows varied widely from their intended values. Some rooms were too cold, some rooms were too hot, and odors were so prevalent in one lecture hall that the class had to be moved. Some air handlers were inaccessible, and the filters could not be properly maintained (**Figure 5**). The filter in one air-handling unit was found to be so dirty that it was being sucked into the fan by the airflow.

In one instance, commissioning was not listed as a requirement for substantial completion (payment), and once the building was occupied, the contractors left the site—leaving behind many problems that still needed to be resolved.

What Went Wrong? First, the commissioning requirements in the specifications were incomplete. Although commissioning information for the mechanical and electrical systems had been added during the design process, the overall commissioning process had not been described in a specific commissioning section. In addition, commissioning was not listed as a requirement for substantial completion (payment), so once the building was occupied, the contractors departed—leaving behind many problems that still needed to be resolved.

Second, the commissioning process was initially underfunded and was restricted to an unreasonably short schedule. As a result, the commissioning agent tried to reduce his costs by relying on contractors to perform many of the checks. Unfortunately, because the contractors did not understand the commissioning requirements, the tests and inspections that did get done were often done incorrectly—and were therefore useless.

Third, commissioning tests were not started until construction was nearly complete. Even then, poor communication between the commissioning agent and the contractors led to misunderstandings—many inspections either were not done or were not witnessed by the commissioning agent. Problems that could have been identified and corrected during the construction phase went unnoticed until it was too late for efficient solutions.

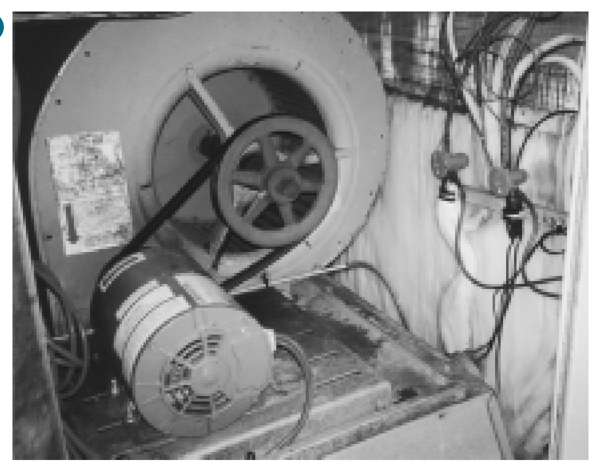
After it became apparent that the initial building commissioning effort had been inadequate, a specialized commissioning firm was hired to do the job properly. At considerable cost, a detailed commissioning plan was developed that included static inspections as well as functional performance tests. The second commissioning agent found hundreds of discrepancies, including incorrectly programmed controls, misplaced sensors, standard-efficiency motors provided where high-efficiency motors were specified, and incorrectly set outside-air damper stops. Most of these problems were ultimately corrected, but it would have been far less expensive—and more effective—to have done the commissioning right the first time.

Figure 5: Signs of trouble in air-handling systems

Like the filters in the Gallagher School of Business Administration Building, the poorly maintained filters shown here became very dirty (A). That restricted airflow, which caused the cooling coil to ice up (B). Maintenance personnel had to remove half of the dirty filters to increase the airflow enough to avoid the icing problems.

A

B



Source: Architectural Energy Corporation

Most of the problems that surfaced in this case could have been caught during the design phase and easily resolved.

Lessons Learned. This project provided object lessons that every project administrator can benefit from.

- Include specific language in the design specifications to indicate that the project will be fully commissioned. Make sure that the contractors are aware of what they will be held accountable for.

- Start the commissioning process early—preferably during the design phase. Some of the problems outlined here could have been caught during the design phase and easily resolved. Catching and correcting problems early will eliminate rework and free up resources that can be used for other projects.

- Fund the commissioning process adequately. Investing in a thorough commissioning process definitely pays off in the long run. Make sure the commissioning agent has the resources necessary to witness all tests and inspections and that the commissioning plan includes the right inspections and tests to ensure that commissioning requirements are met.

- If at all possible, complete commissioning activities before occupancy and before substantial completion of the project. It is best to carry out all commissioning while the construction team is still on site, and there is a strong financial incentive for them to resolve problems quickly and effectively.

2. The Benefits of Doing It Right

Frustrated with a recently completed office building that was not performing well, the Boeing Company in Seattle, Washington, opted to fully commission its new Flight Test Engineering Laboratory, a 100,000-square-foot facility containing a variety of laboratories. Boeing started the commissioning process during the planning phase and continued all the way through to occupancy.[17]

During the design development stage, Boeing's construction management department hired a commissioning firm to help develop the commissioning plan and the acceptance specifications for systems in the new facility. The specifications included the inspections and tests required to verify that the building met the design intent. Once these documents had been created and the design phase was complete, Boeing staff handled the rest of the commissioning activities.

In the fully commissioned building, early detection of some 250 small errors allowed for timely, cost-effective corrections that prevented what could have amounted to big headaches later on.

Boeing always monitors contractor performance as part of project management. In Boeing's experience, monitoring construction activities reduces the number of problems that show up during functional testing, and it tends to improve the overall quality of the completed facility. Although the contractors Boeing uses are involved in a partnership with the company and understand the special needs that Boeing has, it still is critical for commissioning inspections to take place, since mistakes or misunderstandings *can* happen—and they can lead to costly problems if not detected early on. On this particular job, most of the errors Boeing's commissioning activities uncovered were relatively small, but a few were very significant. For example, on one air handler, the supply- and exhaust-fan sections had been installed backwards.

Whenever possible, Boeing's O&M staff took part in inspection walk-throughs. That helped familiarize the O&M staff with the building and its systems as they were taking shape. Also, Boeing has found it useful to have input from the O&M staff—they have front-line experience with how systems operate over time and can provide valuable observations from their practical perspective.

On this project, functional testing turned up about 250 items that did not meet design specifications. Although most of the items were small errors, had they not been remedied, the overall impact on building function would have been significant. The deficiencies included humidity-control system problems and VAV dampers that were not operating correctly. Fixing the prob-

For More Information

"The HVAC Commissioning Process," ASHRAE Guideline 1-1996 [1]. This document is the classic reference on how to manage a commissioning project.

Portland Energy Conservation, Inc. (PECI) offers a wide range of commissioning-related documents, all of which are referenced on their Web site at www.peci.org. Some of the documents are available online; others are available only in print form.

University of Washington, Facility Design Manual.[18] Although this document is specific to University of Washington projects, it shows how commissioning is incorporated in their projects. It is available online from the university's Web site at http://weber.u.washington.edu/~fsesweb/fdi/fdi.htm.

Southern California Edison, Customer Technology Applications Center (CTAC). At this 45,000-square-foot conference facility, visitors can learn about HVAC technologies by attending workshops, seminars, and product demonstrations. Contact Southern California Edison, CTAC, 6090 N. Irwindale Avenue, Irwindale, CA 91702, tel 800-336-2822, web www.sce.com.

lems before occupancy saved the O&M staff from trying to resolve problems in busy work environments. In fact, had the problems not been fixed earlier, O&M staff might have opted for workarounds to quickly address the symptoms rather than actually correcting the problems.

The O&M staff received extensive training after the building had passed its functional tests. The training, which was provided by the vendors, covered the various pieces of equipment and systems in full, as required in the commissioning documentation.

Overall, the benefits of commissioning were very high for this building. Boeing's return on its investment included:

- control systems that operate properly,
- complete O&M manuals that document the baseline operation of the building,
- low maintenance costs, and
- few comfort complaints from building occupants.

Notes

1 “The HVAC Commissioning Process,” *ASHRAE Guideline 1-1996* (Atlanta: American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 1996), p. 2, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, tel 404-636-8400, fax 404-321-5478, e-mail ashrae@ashrae.com, web www.ashrae.org.

2 Fred C. Edwards, Ronald J. Balon, and Edward Walters, Montgomery County, Maryland, Division of Facilities and Services, “Budgeting for Contractor Involvement in Commissioning: An Owner’s Perspective,” *Proceedings, Fifth National Conference on Building Commissioning* (1997).

3 Karl Stum, personal communication (September 24, 1998), Director of Technical Services, Portland Energy Conservation, Inc., 921 SW Washington Street, Suite 312, Portland, OR 97205, tel 503-248-4636 ext 214, fax 503-295-0820, e-mail kstum@peci.org.

4 C.R. Kjellman, D. Dodds, and T. Haasl, “A Building Commissioning Study in the Home Stretch: Obstacles, Benefits, and Discoveries,” *Proceedings, Third National Conference on Building Commissioning* (1995).

5 Jack Wolpert, personal communication (August 1998), President, E-Cube, 1900 Folsom Street, #109, Boulder, CO 80302, tel 303-443-2610, fax 303-443-3704, jwolpert@ecube.com.

6 M. Kaplan, et al., “Team Relations for Successful Commissioning: A Case Study,” *Proceedings, Sixth National Conference on Building Commissioning* (May 1998).

7 *Model Commissioning Plan and Guide Specifications* is available from the Portland Energy Conservation, Inc., 921 SW Washington, Suite 312, Portland, OR 97205. It is also available at PECI’s Web site, www.peci.org.

8 *Oregon Commissioning Toolkit*, Oregon Office of Energy and Portland Energy Conservation, Inc. Available at the Oregon Office of Energy’s Web site, www.cbs.state.or.us/external/ooe/cons/ bldgcx.htm.

9 ASHRAE [1].

10 Jack Wolpert, "Commissioning a New University Facility: From Energy-Efficiency Design Through First-year Occupancy," *Proceedings, Third National Conference on Building Commissioning* (1995).

11 Jay Stein, personal communication (August 1998), Research Manager, E SOURCE, Inc., 4755 Walnut Street, Boulder, CO 80301, tel 303-440-8500, fax 303-440-8502, e-mail jstein@esource.com.

12 One such system, the ENFORMA™ Portable Diagnostic System, is available from Architectural Energy Corporation, 2540 Frontier Avenue, Suite 201, Boulder, Colorado 80301, tel 303-444-4149, fax 303-444-4304, web www.archenergy.com.

13 Rick Casault, "The Benefits of Contractor Involvement in Commissioning: A Case Study," *Proceedings, Fifth National Conference on Building Commissioning* (1997).

14 Southern California Edison, "City of Santa Monica Main Library, Santa Monica, California, Commissioning Report" (April 1997).

15 Sandy Starkweather, personal communication (August 1998), Staff Engineer, Architectural Energy Corporation, 2540 Frontier Avenue, Suite 201, Boulder, CO 80301, tel 303-444-4149, fax 303-444-4304, e-mail sstarkweather@archenergy.com.

16 R.J. Wilkinson, "The Evolving Building Commissioning Process in Montana: The Gallagher Business Administration Building at the University of Montana, Missoula, Montana," *Proceedings, Sixth National Conference on Building Commissioning* (1998).

17 Michael Prittie and Scott Jackson, "Commissioning the Flight Test Engineering Building," *Proceedings, Fourth National Conference on Building Commissioning* (1996).

18 Rick Casault, "The University of Washington's Role in Strengthening the Infrastructure," *Proceedings, Third National Conference on Building Commissioning* (1995).

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