CHAPTER 42

NEW BUILDING COMMISSIONING

COMMISSIONING is a quality assurance process for buildings from predesign through design, construction, and operations. It involves achieving, verifying, and documenting the performance of each system to meet the building's operational needs within the capabilities of the documented design and equipment capacities, according to the owner's functional criteria. Commissioning includes preparing project operational and maintenance documentation and training operation and maintenance personnel. The result should be fully functional systems that can be properly operated and maintained throughout the life of the building.

This chapter gives an overview of the general commissioning process, plus best practices from the May 2002 working draft of ASHRAE *Guideline* 0-200X, The Commissioning Process, developed for the National Institute of Building Sciences' total building commissioning program. This chapter generally provides less detail and is less prescriptive, but provides more narrative discussion on some issues than the cited commissioning guideline draft.

Retrocommissioning involves systematically investigating, analyzing, and optimizing performance of existing equipment, systems, and assemblies that have not been recently commissioned, and ensuring their continued performance over time. Although retrocommissioning has broad application to virtually every building type and vintage with excellent cost-benefit and ratios, it is not covered in this chapter. For more information, see PECI/ORNL (1999) and Idaho Department of Administration (1999).

Applicability

The commissioning process described here applies to new construction and major renovations and to all systems and assemblies, not just HVAC. Commissioning can be applied to the building as a total system, which includes structural elements, building envelope, life safety features, electrical systems, communication systems, plumbing, irrigation, controls, and HVAC systems. Which building systems should be commissioned and how rigorously varies with the systems and assemblies used, size, and project type and objectives. Owners and commissioning providers often include systems and assemblies under the commissioning umbrella that have (1) historically not performed well at turnover (e.g., outside air economizers and variable-speed drives), (2) are mission-critical (e.g., air cleanliness in a clean room, emergency power in a hospital), (3) will be costly to fix during occupancy if they fail (e.g., chilled water piping, window flashing assemblies), or (4) present a life-safety risk if they fail (e.g., fire alarm, smoke control, moisture penetration). Recommendations in this chapter should be appropriately tailored to each project. Commissioning may begin at any time during delivery, but benefits are limited when the process is not started in predesign.

Background

Equipment, components, systems, and assemblies have become more complex and disciplines and trades more specialized, with increased interactions between all elements. This increased specialization and interaction has not been matched by increased integration between disciplines and specialized systems by the delivery team. Owners often use low-bid policies, and scopes of design professionals are often narrowed. The result has been buildings that do not meet owner expectations and do not work as intended because of design and construction deficiencies. Commissioning was developed to help overcome these infrastructure inadequacies and to fundamentally improve the way building systems are delivered.

Benefits

The primary benefits of commissioning are improvements in

- Designs, through
  - Owners understanding better what they want and need through clear, documented project requirements
  - Designers understanding better what the owner is requesting
  - Owners understanding better what the designers are proposing through clear, documented basis of design
  - Commissioning peer reviews by experts
- Construction and system and assembly performance, through
  - Improved specifications and drawings
  - Specifying systems that can be properly commissioned and tested
  - Tools to assist contractors perform better installations (construction checklists)
  - Performance accountability through construction observation, issue management, and testing
  - Documented verification of system and assembly performance
- Training of building personnel, through
  - Thorough training requirements in the construction documents
  - Verifying training completion
- Operations and maintenance documentation, through
  - Thorough documentation requirements in the construction documents
  - Verifying documentation submittals

Commissioning also reduces potential change orders, contractor callbacks, time required to fine-tune and debug systems during occupancy, and smooths turnover. Building performance improvements give better building and system control, enhance indoor environmental quality, and may contribute to increased occupant productivity.

Definitions

Basis of Design (BOD). The basis of design is the documented primary decision-making process and assumptions behind design decisions made to meet the owner's project requirements (OPR). It describes the systems, assemblies, conditions and methods chosen to meet these requirements.

Commissioning Authority (CA). The commissioning authority is the owner's advocate, who leads and manages the commissioning process for the owner. The CA reviews the commissioning effort and recommends acceptance of commissioned systems and assemblies to the owner. The CA functions an independent party to approve the process, regardless of who performs the commissioning tasks.

The preparation of this chapter is assigned to TC 9.9, Building Commissioning.

Commissioning Plan. This is an overall plan, developed before or after bidding, that provides the structure, schedule, and coordination planning for commissioning. The commissioning plan includes details of

- Commissioning scope
- Systems to be commissioned
- Rigor of commissioning
- Team contact information
- Roles and responsibilities of all parties
- Communication and reporting protocols
- Commissioning overview and details of submittal activities
- Construction observation, checklisting, and start-up activities
- Process for dealing with deficiencies
- Test procedure development and execution
- Operations and maintenance (O&M) manual review and training issues
- Warranty period activities
- Description of summary report, progress and reporting logs, and initial schedule (including phasing, if applicable)

The commissioning authority updates the plan as construction progresses.

Construction Checklists. These checklists verify that the specified equipment has been provided, is properly installed, and initially started and checked out adequately in preparation for full operation and testing (e.g., belt tension, fluids topped, labels affixed, gages in place, sensors calibrated, voltage balanced, rotation correct, etc.).

Owner's Project Requirements (OPR). Also referred to as the **design intent**, the OPR is documentation of a project's functional requirements and expectations of how it will be used and operated. This includes project and design goals, measurable performance criteria, budgets, schedules, success criteria, and supporting information.

Systems Manual. The systems manual is an archive of documentation that provides information needed to understand, operate, and maintain systems and assemblies, and to inform those not involved in design and construction about the systems and assemblies. The systems manual expands the scope of traditional operating and maintenance manuals to include other project information such as plans and specifications, operating and optimization procedures, and additional information developed and gathered during commissioning.

Test Procedures. Test procedures are written, repeatable procedures, prepared specifically for each project, designed to functionally test components, systems, and assemblies. Tests clearly describe the test prerequisites, required test conditions, individual systematic test procedures, expected system response and acceptance criteria for each procedure, actual response or findings, and any pertinent discussion. Test procedures differ from **testing requirements** found in the specifications, which describe *what* modes and features are to be tested and verified and under what conditions. Test procedures describe the step-by-step method of *how* to test. Simple checklists may be appropriate for testing simple components, but dynamic testing of interacting components requires more the detailed procedures and forms described in this definition.

OBJECTIVES

The goal of commissioning is to provide documented confirmation that a facility fulfills the performance requirements of the building owner, occupants, and operators. To reach this goal, it is necessary to (1) establish and document the owners criteria for system function, performance, and maintainability, and (2) verify and document compliance with these criteria throughout design, construction, start-up, and initial operation.

MANAGEMENT AND RESPONSIBILITIES

Management Strategies

In each project, a qualified party should be designated as the commissioning authority.

Predesign and Design. Commissioning during predesign and design is most often managed by an independent CA who is not part of the formal designer-of-record team. An independent, objective view is critical. The CA normally does not have ultimate authority over design, but provides input to the owner and designers. The CA may also coordinate, conduct, or approve activities like developing the OPR, conducting peer reviews, and developing commissioning specifications. In some projects, commissioning is the designer's responsibility using either their own staff or a subconsultant. Owners typically feel this presents too much conflict of interest.

Construction. During construction, because of the variety of players, construction management scenarios, and the owner's objectives, numerous methods are used to manage the commissioning process. To maintain objectivity, the CA is ideally independent, though sometimes the contractor or designer hires the CA. The two primary methods to manage commissioning during construction are commissioning-authority-managed and contractor-managed. In the **commissioning-authority-managed approach**, the CA performs many of the planning and technical tasks, like writing the commissioning plan and test procedures and directing, witnessing, and documenting execution of tests performed by the contractor or themselves. In the **contractor-managed approach**, the contractor may write the commissioning plan, write test procedures, and direct and document testing, with the CA witnessing selected tests and reviewing completed test reports. The contractor may assign staff, subcontractor or subconsultant to manage and coordinate their commissioning responsibilities. This approach gives the contractor more responsibility. Some view this method as less objective, but others consider it more integrated into the building delivery process than the CA-managed approach.

Some project plans use both management approaches, particularly when a substantial amount of electrical equipment is being tested. HVAC and controls follow the commissioning-authority-managed approach, and electrical system commissioning follows the contractor-managed approach, but the entire process is still overseen by the single CA.

Team Members

Effective building commissioning requires a team effort. The size and makeup of the team depends on the size and complexity of the project and the owner's desire for quality assurance. Each team member is documented in the plan. Participants include the CA, owner, design professionals, construction manager, general contractor, subcontractors, operation and maintenance (O&M), suppliers, and equipment manufacturers. The O&M manager needs to be brought into the commissioning process early, preferably during predesign.

The level of effort of team members changes during the different project delivery phases. For example, during design, the designer is a key player in the commissioning process, whereas the contractor may not have been selected. During construction, the general contractor's and installing subcontractors' roles increase.

The scope of work of the CA, design professionals, and contractors should be clearly and completely identified in their contracts. Without this, change orders, incomplete or missed tasks, and otherwise dysfunctional commissioning will result.

Roles and Responsibilities

The commissioning team's responsibilities are to conduct commissioning activities in a logical, sequential, and efficient manner using consistent protocols and forms, centralized documentation, clear and regular communications and consultations with all necessary parties, frequently updated timelines and schedules, and

appropriate technical expertise. The following sections summarize the responsibilities of each party. Additional detail is found in the Commissioning Process section.

Commissioning Authority. Specific responsibilities vary with the management scenario and the CA's specific scope of services. Ideally, the same party or firm acts as CA through all project phases.

Predesign. During predesign, the CA develops the predesign and design-phase commissioning plan and ensures the OPR is developed.

Design. During design, the CA directs commissioning activities, possibly performing many of them, depending on the management scenario in place. The core commissioning responsibilities are

- Reviewing the designer's BOD, plans, and specifications, ensuring they meet the OPR
- Developing the initial construction-phase commissioning plan
- Ensuring that commissioning, training, and documentation requirements are reflected in construction contract documents.

Construction. During construction, the CA is in charge of the commissioning process and makes the final recommendations to the owner about functional performance of commissioned building systems and assemblies. The CA is an advocate for the owner, acting as independently and objectively as possible. The core commissioning activities during construction are to

- Review construction submittals
- Observe installations and start-up
- Organize, plan, develop, and execute testing
- Develop the systems manual
- Review traditional O&M manuals
- Verify operator training.

These tasks may vary (e.g., some commissioning scopes involve preparing the O&M or electronic facility's manuals, preparing detailed maintenance management plans, or conducting operator training).

Occupancy and Operations. During occupancy and operations, the CA helps resolve commissioning issues and directs opposites season testing. Often they participate in a near-warranty-end review of system and assembly performance.

Independence. If the CA's firm has other project responsibilities, or is not under direct contract to the owner, a conflict of interest exists. Wherever this occurs, the CA should disclose in writing the nature of the conflict and the means by which it will be managed.

Qualifications. The CA should fully understand commissioning, design, and construction processes and have technical design, operations, maintenance, and troubleshooting knowledge of the systems and assemblies being commissioned. The CA may represent an individual or a team of commissioning experts, depending on system complexity, the number of disciplines involved, and commissioning scope. The ability to manage diverse disciplines over long timelines is also important.

Construction Manager. The construction manager's role varies with construction responsibilities. When they have significant oversight for the owner (e.g., schedule management, submittal review, change order authority), their commissioning role is more like the owner's: they ensure the contractor is executing their commissioning responsibilities according to the commissioning plan and help resolve issues.

General Contractors.

Design. The general contractor (if yet selected) reviews commissioning requirements and performance criteria for coordination, schedule, and cost implications.

Construction. The contractor's role and responsibilities are

- Ensuring subcontractors' commissioning work is completed and cooperating with CA in executing the commissioning plan
- Providing input into the commissioning plan
- Integrating the commissioning schedule into the overall project schedule
- Participating in commissioning meetings
- Responding to questions and issues raised by the CA
- Resolving issues identified during commissioning and coordinating correction of identified deficiencies
- Providing equipment, system and assembly data and information needed by the CA
- Performing specified training
- Submitting required portions of the systems manual

In the contractor-managed approach, the general contractor is often required to hire a party with direct commissioning skill to manage and execute the contractor commissioning requirements.

Trade Contractors.

Design. Trade contractors of specialty or complex systems or designs should review commissioning requirements and performance criteria of their systems for coordination, schedule, and cost implications.

Construction. The responsibilities of the installing trade contractors (and vendors, as appropriate) include

- Cooperating with the CA (and the contractor's commissioning manager, when applicable) in executing the commissioning plan
- Providing input into the commissioning plan
- Coordinating with other trades as necessary to facilitate a smooth and complete commissioning process
- Participating in commissioning meetings
- Responding to questions and issues raised by the CA
- Executing and documenting tasks in the construction checklist and start-up process
- Performing and documenting tests when in their scope
- Participating in resolving issues identified during commissioning
- Correcting identified deficiencies

Commissioning-related activities of trade contractors are to prepare O&M manuals and submissions to the systems manual and provide training on commissioned systems and assemblies.

Architect and Engineers (Designers).

Design. The design professionals should develop complete basis-of-design (BOD) documentation, including design narratives, rationale, and criteria, according to their scopes of services, and update this document with each new design submission. They provide input to the commissioning plan, respond to questions and concerns by the CA and others, respond to design review comments, and incorporate commissioning requirements in construction contract documents.

Construction. During construction, designers

- Review the commissioning plan
- Attend selected commissioning meetings
- Answer questions about system design and intended operation
- Update design narratives in the BOD to reflect as-built conditions
- Respond to or incorporate CA comments on construction submittals and O&M manuals
- Help resolve design-related issues raised during commissioning
- Perform specified training
- Submit required portions of the systems manual.

Additional tasks sometimes required are to present system description overviews for primary systems during O&M staff training, review and approve testing plans and procedures, review completed test forms, or witness selected tests.

Owner's Project Management Staff. The owner's project management staff's ultimate responsibility is to see that the commissioning plan is executed. The owner should include commissioning responsibilities in all commissioning team members' scopes of services, make sure there is sufficient time for commissioning in the project schedule, ensure the CA is receiving cooperation from other team members, and ensure that other owner responsibilities (e.g.,

developing the OPR, having O&M staff participate during construction) are fulfilled. The owner ensures that all design review and construction-phase issues identified through commissioning are resolved in a timely manner.

Owner's Operations Staff.

Predesign. The owner's O&M staff should establish the OPR during predesign.

Design. During design, these staff contribute to reviews of the designer's BOD, plans, and specifications.

Construction. During construction, these staff may

- Assist in reviewing selected submittals
- Assist in construction observation, verifying completion of construction checklists and observing start-up
- Participate in or witness testing
- Review O&M and systems manual
- Participate in training.

COMMISSIONING PROCESS

Commissioning ideally begins during predesign and formally continues through the first year of occupancy and operations. Although circumstances may require owners to begin commissioning at the design or construction stage of a project, such later implementation should, when possible, capture the same information and verifications developed when commissioning begins at project inception.

COMMISSIONING DURING PREDESIGN

Objectives

The primary activities and objectives of commissioning during predesign are the following:

- Develop the OPR
- Identify a scope and budget for the commissioning process
- Develop the initial commissioning plan
- Accept the predesign-phase commissioning process activities

Activities

Commissioning Team and Management. During the predesign phase, a team is formed to oversee and accomplish commissioning. Responsibility for leadership of the commissioning team should be defined and assigned to the CA at the beginning of predesign.

Owner's Project Requirements (OPR). The OPR is a document describing the functional requirements of the facility and expectations of how it will be used and operated. It includes project and design goals, budgets, limitations, schedules, owner directives, and supporting information, as well as necessary information for all disciplines to properly plan, design, construct, operate, and maintain systems and assemblies.

The OPR is generally a set of concise objective qualitative statements, each with one or more quantitative performance metrics or criteria. The following types of content typically make up the qualitative OPR statements:

- Functional requirements, needs and goals for building use, operation, maintenance, renovation, and expansion, including user requirements
- Occupancy schedules and space plan requirements
- Sustainability, reliability, durability, and aesthetic goals
- Quality of materials and construction
- Warranty, project documentation, and training requirements
- Goals relative to the process and outcome of design and construction (e.g., budgets, schedules, change orders, safety, aesthetics, effects on adjacent or integral occupied spaces and tenants)
- General commissioning scope and objectives
- General statements about codes and standards to be followed
- Limitations likely to affect design decisions
- Specific features, systems, assemblies, or brands the owner requires (these will be repeated in the design narrative)
- Instructions to designers on types of design tools and aids expected to be used

The CA ensures that the OPR is developed and is clear and complete. They may develop the OPR with the owner or provide direction and review of the OPR developed by others. Facilitated workshops, surveys, and questionnaires are useful methods for developing the OPR. Later during design, additional OPR statements with performance criteria may be added to the formal list, as desired by the owner and commissioning team. The OPR should still be developed, even if not originally generated in predesign, and included in the systems manual.

Scope and Budget for Commissioning. During predesign, the owner (with the aid of experience from previous similar projects or from the CA) develops a scope and a rough budget for commissioning. At minimum, design-phase activities should be initially scoped. Once a design-phase commissioning plan is developed, the scope and budget may need to be adjusted. The scope and budget should reflect the commissioning objectives in the OPR.

Selecting areas to commission is typically based on the budget, systems or assemblies where the owner has experienced previous problems, complexity of systems and assemblies, and criticality of the system or assembly in meeting the OPR. During predesign and design, the list of areas to be commissioned may be general (e.g., electrical lighting controls, emergency power, general electrical equipment, HVAC, domestic water system, and envelope fenestration). Later in design and before scoping construction-phase commissioning, additional detail should be added to each of these categories, and others added as needed to ensure the scope of commissioning is clear.

Historically, commissioning focused on HVAC. Owners are now asking for more systems to be commissioned, including lighting controls, fire and life safety systems, vertical and horizontal transport systems, envelope, plumbing, landscaping, sustainability features, structural elements, many electrical equipment components, security, data, and communications. Refer to the section on Commissioning Costs for budgeting guidelines.

Design-Phase Commissioning Plan

One of the predesign-phase commissioning tasks should be drafting the commissioning plan for the design phase. The CA develops this plan with review and comment by the owner and designer, and the plan is updated as the project progresses. The design-phase commissioning plan should include the following:

- Objectives and scope
- Overview of the process
- Roles and responsibilities
- Deliverables
- Communication protocols
- Acceptance and verification procedures
- Schedule

Acceptance of Predesign Commissioning

The owner's project requirements and commissioning plan should be formally accepted during the predesign, after review and comment by the CA.

COMMISSIONING DURING DESIGN

Objectives

Design-phase commissioning objectives include the following:

- Update the design-phase commissioning plan developed during predesign.
- Update the OPR.
- Verify the BOD document against the OPR.
- Verify plans and specifications against the BOD and OPR.

- Develop the commissioning plan for the construction and occupancy/operations phases.
- Develop and incorporate commissioning requirements into project specifications.
- Begin developing the systems manual.
- Define training requirements for O&M personnel.
- Perform commissioning-focused design reviews.
- Accept the design-phase commissioning.

Activities

Update Design-Phase Commissioning Plan. The initial design-phase commissioning plan is developed during predesign. As more becomes known about systems and assemblies likely to be a part of the project and as project objectives are clarified, the commissioning plan may need to be updated and more detail added. The number, scope, and rigor of design reviews is finalized. The CA's participation in any value engineering, value management, or constructability review sessions is determined. The owner and designer review and comment on the updated plan, which becomes the guide for the rest of the design phase.

Update the OPR. As design progresses, additional OPR and performance criteria are likely to be identified. Other criteria may need to be altered or dropped as more detailed budget and design data become available.

Basis of Design. All BOD elements can be grouped under one of two terms: design narrative or design rationale. These two terms provide a useful separation when writing the design basis.

The **design narrative** is the written description and discussion of the concepts and features the designer *intends* (during schematic design phase) to incorporate into the design or what they *have* incorporated (during the balance of design) to meet the project requirements and associated performance criteria. It should be understandable by all parties of the building delivery and operation process, though it may address fairly technical and specialized issues. The design narrative is updated and increases in detail with each phase of design.

The **design rationale** is the reasoning and underlying assumptions for calculations, decisions, schemes, and system and assemblies selected to meet the OPR and to satisfy applicable regulatory requirements, standards, and guidelines. It includes design assumptions that vary from one project to another and are necessary to make design calculations and other decisions, such as

- Diversity and safety factors used in sizing
- Classes of systems and components (duct class, clean room class, etc.)
- Level of redundancy
- Occupant density
- Limitations and restrictions of systems and assemblies
- Indoor and outside conditions assumed (space temperature, relative humidity, lighting power density, glazing fraction, U-value and shading coefficient, wall and ceiling R-values, ventilation and infiltration rates, etc.)
- Summary of primary HVAC load calculations and the methods used to determine them

The rationale also gives the reasons for system selection, facility, system and assembly performance assumptions; analytical and design tools used; any limitations and restrictions; operational and use assumptions, including assumptions about level of expertise of operating personnel; guidelines and owner polices; directives; and interpretations of codes.

Development and Use. The BOD is written by the designer and increases in detail as design progresses. The CA may need to elicit this explanatory information from the designer through a questionnaire or form. An updated BOD with increased detail should be submitted with each new design submission. Each submission is reviewed by the owner and CA as part of design reviews.

Develop Commissioning Plan for Construction and Occupancy/Operations Phases. The commissioning plan for the construction and occupancy/operations phases describes the following:

- Commissioning process for the project
- Scope of commissioning effort, including systems, assemblies, and components being commissioned
- Roles and responsibilities of each team member
- Communication protocols
- Procedures for documenting commissioning activities and resolving issues
- Preliminary schedule for commissioning activities

The first draft of this plan is developed in early design, based on the commissioning objectives established as part of the OPR. At this point, the plan is general and is used primarily to guide the development of commissioning specifications. The owner and designer review and comment on the plan. As design progresses, the plan is updated and finalized at the completion of the construction documents. The commissioning plan can be issued with the bid documents for reference.

Develop and Incorporate Commissioning Requirements into Project Specifications. The commissioning specification is a detailed description of the scope, objectives, and process of commissioning during the construction and occupancy/operations phases of the project. It must specify the scope of work, roles, responsibilities, and requirements of the construction contractor. This specification is needed by contractors so they can include commissioning responsibilities in pricing and understand how to execute the work. Because commissioning is still relatively new to the building industry, descriptive process language is included, rather than just delineating requirements. Frequently, for reference, the responsibilities of other team members not bound by the specifications (e.g., owner, CA, construction manager, architect) are given in the commissioning specifications to ensure the contractor's responsibilities are clear and in context.

The specification should include definitions, a list of equipment and systems to be commissioned, submittal, construction checklist, testing and documentation requirements, and sample checklists and test forms. If the project is using contractor-managed commissioning, the specification should identify skills and qualifications required of the contractor's commissioning lead.

The OPR, along with as much BOD information as possible, should be included in the construction documents and labeled as "Informational Purposes Only" to differentiate from the contractor's contractual obligations. Training and O&M manual requirements of the contractor are also included.

It is also critical that the specification clearly define how the quality control and testing functions that have traditionally been a part of many construction projects (e.g., fire alarm, elevator, duct pressure, emergency power testing), will be integrated with commissioning. Responsibility for checkout and test procedures, including test procedure review, direction, execution, witnessing, documentation, and approval, must all be clearly described.

It is recommended to place the *general* commissioning requirements and process descriptions common to all disciplines in a single section; for detailed recommendations, see CSI (1995). The exact location is not as important as having sufficient references to alert each contractor to where their commissioning responsibilities are found and to be consistent in terminology.

The CA ensures that commissioning specifications are appropriately incorporated into the project specifications. Often the commissioning authority writes the commissioning specifications and then works with the designer to integrate them into the project specifications. Alternatively, the designer can develop the commissioning specifications, with the CA reviewing and approving.

Begin Developing Systems Manual. During design, the systems manual contains the OPR, design basis, and drawings and

specifications, updated at each design submission and during and after construction. The CA is often responsible for assembling and maintaining the systems manual.

The systems manual differs significantly from traditional O&M manuals, expanding the scope to include other project information developed and gathered during commissioning, such as traditional equipment O&M data, design and construction documents (OPR, BOD, plans, specifications, and construction submittals), system schematics, final commissioning report, training records, commissioning test procedures (filled-in and blank), special operations, and optimization and diagnostic data (e.g., operation during emergency, seasonal changeover, fire and emergency power response matrix, energy efficiency recommendations, troubleshooting guide, recommissioning frequency, standard diagnostic building automation system trend logs and interpretations). Some practitioners include all this documentation in the systems manual; others restrict its contents to special operations, optimization, and diagnostic instructions and some commissioning documentation. Often the scope of the systems manual is limited to the commissioned systems and assemblies. Scopes of work should clearly identify whether the systems manual includes all project systems and assemblies or just commissioned ones. For more information, see ASHRAE *Guideline* 4, Preparation of Operations and Maintenance Documentation for Building Systems.

The owner, designer, contractor, and commissioning authority each have development responsibilities for parts of the archive. Construction documents should list the contents and requirements for the systems manual and the responsible party for generating, compiling, and finishing the archive.

Electronic Media. Much of the systems manual can be put into electronic format. Searchability and auto-update features can enhance the usability and accessibility of the data.

Define Training Requirements. During design, the training requirements of O&M personnel and occupants are identified relative to the systems and assemblies to be installed in the facility. It is critical that O&M personnel have the knowledge and skills required to operate the facility to meet the OPR. Occupants also need to understand their effect on the use of the facility and the ability to meet project requirements.

Training needs can be identified using a group technique workshop, interviews, or surveys with the owner and occupant representatives after the systems and assemblies have been specified, and before issuing the construction documents. The training needs of the contractor are incorporated into the project specifications and should include requirements for the number of training hours for each piece of equipment or assembly and submittals of training plans and qualifications of trainers. Training will likely require participation of the designer (for system overviews), the CA (for system overviews, recommissioning, optimization, diagnostics, and using and maintaining the systems manual), and possibly the contractor, and should be included in their scopes of work.

Perform Design Reviews. Design review by parties not part of the formal designer-of-record team are conducted to provide a fresh perspective on performance, operations, and maintenance. These peer reviews, conducted by experts in the field, should be done as early as possible, when there are more options and issues can be more easily resolved. The reviews are coordinated by the CA and should include the owner's technical staff. The CA may attend some design team meetings, and formally reviews and comments on the design at various stages of development (ideally, at least once during schematic design, design development, and construction document phases).

A targeted design review may cover the following:

- General quality review of the documents, including legibility, consistency, and level of completeness
- Coordination between disciplines
- Specification applicability to project and consistency with drawings
- Verification that BOD assumptions and rationale are reasonable. and system and assembly narrative descriptions are clear and consistent with the OPR. Issues are resolved and BOD is updated.
- Verification that plans and specifications are consistent with BOD and OPR. Issues are resolved and plans and specifications are corrected as needed.

Potential system performance problems, issues likely to result in change orders, areas where correct installation is difficult, energy efficiency improvements, environmental sustainability, indoor environmental quality issues, operation and maintenance issues, and other issues may be addressed in these design reviews, depending on the owners desires and CA's scope. Reviews also ensure that training and systems manual requirements are adequately reflected in construction documents.

Some reviews use sampling, giving 10 to 20% of the drawings and specifications an in-depth review; if only minimal issues are identified, the submission is accepted. If significant issues are identified in the sample, additional samples are reviewed; the design submittal may ultimately be rejected and returned for thorough revamping by the designers.

The CA does not approve the design, but makes recommendations to facilitate commissioning and improve building performance. It is the responsibility of the owner or project manager to evaluate all review findings with the design team and implement those approved. All issues are tracked to resolution and verified in later reviews to have been incorporated as agreed.

Accept Design-Phase Commissioning Activities. Commissioning should include formal acceptance of the BOD and updated OPR by the owner, after review and comment by the CA.

Additional Commissioning Team Tasks. Additional design-phase responsibilities of the commissioning team (led by the CA, who is frequently responsible for these requirements) include the following:

- Build and maintain cohesiveness and cooperation among the project team.
- Assist owner in preparing requests for project services that outline commissioning roles and responsibilities developed in the commissioning plan.
- Ensure that commissioning activities are clearly stated in all project scopes of work.
- Develop scope and budget for project-specific commissioning process activities.
- Identify specialists who will be responsible for commissioning specific systems and assemblies.
- Conduct and document commissioning team meetings.
- Inform all commissioning team members of decisions that result in modifications to the OPR.
- Integrate commissioning into the project schedule.
- Track and document issues and deviations relating to the OPR and document resolutions.
- Write and review commissioning reports.

COMMISSIONING DURING CONSTRUCTION

Objectives

Commissioning during construction (also known as the **acceptance phase**) should document and verify that

- All systems and assemblies are provided and installed as specified.
- All systems and assemblies are started and function properly.
- The systems manual is updated and provided to facility staff.
- Facility staff and occupants receive specified training and orientation.

Activities

The following primary commissioning activities (in approximately sequential order) are used to meet commissioning objectives. The CA coordinates and ensures that all activities are accomplished.

Bidding and Contract Negotiation. A member of the commissioning team (usually the CA) may attend the prebid conference to present an overview of commissioning requirements and answer questions. Changes that occur during bidding and contract negotiations related to commissioned systems and assemblies are also reviewed to ensure they agree with the OPR.

Commissioning Planning and Kickoff Meetings. The CA coordinates construction-phase planning and kickoff meetings. The planning meeting is held with the contractor, owner, designer, and CA to review requirements and establish communication and reporting protocols. The commissioning plan is updated from this meeting. The kickoff meeting is held with additional construction team members, generally the mechanical, controls, electrical, and test and balancing contractors. At this meeting, the commissioning provider outlines the roles and responsibilities of each project team member, specifies procedures for documenting activities and resolving issues, and reviews the preliminary construction commissioning plan and schedule. Team members provide comment on the plan and schedule, and the CA uses these suggestions to help finalize the commissioning plan and schedule.

Commissioning Plan Update. The commissioning plan is updated as necessary after planning and kickoff meetings. Later, any project phasing or other schedule and scope-related issues (e.g., testing and training plans and schedules) are clarified in further updates.

Submittal Reviews.

Construction Submittals. Equipment and material submittals of commissioned systems and assemblies are reviewed by the CA to obtain information necessary to develop construction checklists, make meaningful observations of construction progress. and aid in developing comprehensive tests. Submittals are also reviewed to identify construction-related performance issues before construction progress makes them more difficult and expensive to address. Submittals should be reviewed concurrently by the design team to allow any discrepancies to be identified and communicated to the design team before formal approval.

Controls Submittal and Integration Meeting. Before the contractor develops the controls submittal, the CA coordinates a controls integration meeting to discuss and resolve methods for implementing performance specifications or strategies, interlocks between systems, priority of control between packaged controls and the central control system, the control system database, point names, graphic details and layout, access levels, etc.

Coordination Drawings. The commissioning provider may help the owner monitor the development of coordination and shop drawings to ensure reasonable harmonization between trades.

Early O&M Data. Information beyond typical construction submittals requested by the CA includes installation and start-up procedures, operation and maintenance information, equipment performance data, and control drawings before formal O&M manual submittals. These data are used by the CA to become familiar with systems and assemblies and to help develop construction checklists, start-up plans, and test procedures.

Contract Modifications Review. Construction documentation issued during this phase, including requests for information, construction field directives, and change orders, should be reviewed by the CA to identify issues that may affect commissioning and compliance with construction documents, BOD, or OPR.

Schedule Commissioning Field Activities. The CA works with the contractor or construction manager to coordinate the commissioning schedule and ensure that commissioning activities are integrated into the master construction schedule.

Construction and Commissioning Meetings. The CA attends periodic planning and job-site meetings to stay informed on construction progress and to update parties involved in commissioning. During initial construction, the CA may attend regular construction meetings and hold a line item on the agenda. Later, the CA may coordinate entire meetings devoted to commissioning issues, with more frequent meetings as construction progresses. Attendees vary with the purpose of the meeting. Team members should be represented at meetings by parties with technical expertise who are authorized to make commitments and decisions for their respective organizations. The CA should distribute minutes from these meetings.

Progress Reports. The CA provides periodic progress reports to the owner and contractor with increasing frequency as construction progresses. These reports indicate current progress, next steps and critical issues affecting progress and construction schedule.

Update Owners Project Requirement and Basis of Design. When contract negotiations and/or changes and clarifications made during construction alter or add to the OPR or BOD, these documents should be updated. Normally, the CA will update the OPR and the designer the BOD. Final construction updates to these documents are made at the end of testing, typically a few months into occupancy.

Coordinate Owners Representatives Participation. The commissioning plan should describe participation of the owners representatives in such work as submittal review, construction checklist verification, construction observation, test procedure review and execution, and O&M manual review. The CA normally coordinates this participation with the contractor.

Construction Observation. The CA should make planned, systematic visits to the site to observe installation of systems and assemblies. Owner staff may assist in construction observation. Any conditions not in compliance with the construction documents or BOD or that may affect system performance, commissioning, operation, or other project requirements should be documented. These observations normally focus on areas where observers have found problems before, or spot-check items on construction checklists. Less often, practitioners are tasked with validations or detailed inspections verifying that equipment or assemblies have been installed properly in every detail. Some practitioners make formal construction observation reports; others merge the findings into the regular issue logs and progress reports. Site visits verify completion of construction checklists.

The CA normally witnesses parts of the contractor's start-up activities for major equipment to ensure checklists and start-up are documented properly and to gain additional feature and function information from installing technicians.

Construction Checklists and Start-up. At the beginning of construction, construction checklists are developed (usually by the CA, but sometimes by the contractor or the equipment manufacturer) for most commissioned systems and equipment. They are attached to or integrated with manufacturer's installation and start-up procedures. In most projects, contractors fill out the checklists during installation, start-up, and normal checkout of equipment and systems, though some commissioning practitioners fill out the checklists themselves. The contractor fully documents start-up and initial checkout, including the construction checklists, and submits them to the CA, who reviews the forms and spot-checks selected items in the field to ensure systems are ready for testing.

Some practitioners statistically sample items on checklists to verify proper completion (typically random or targeted sampling 2 to 20%). If an inordinate fraction of the same items that are deficient (typically more than 10%), the contractor is required to check and document all remaining items.

Commissioning Issues Management. The CA keeps a record of all commissioning issues that require action by the design team, contractor, or owner. The issues should remain uniquely identified, be tied to equipment and systems, and prioritized relative to performance, cost, and schedule. Issues are tracked to resolution, which is

documented. The log is updated and distributed to the owner, contractor and construction manager at construction and commissioning meetings and through project web sites. In the contractor-managed scenario, the contractor's commissioning manager or subconsultant may manage the contractor's issues log; in that case, to minimize conflicts of interest, the commissioning manager is often required to report all issues simultaneously to the contractor and to the owner (or the CA).

Developing Test Procedures. Step-by-step test procedures and project-specific documentation formats are used for all commissioned equipment and assemblies. **Manual tests** evaluate systems with immediate results. **Monitoring testing** uses the building automation system or data loggers to record system parameters over time and analyze the data days or weeks later. **Automated testing** gathers or analyses system performance data completely electronically, or with significant help from electronic tools.

Tests are written after submittal review, but early enough to allow review by others and to allow at least three to six weeks of scheduling lead time before test execution. Test procedures may be based on specifications, applicable standards and codes, submittal data, O&M data, data shipped with the equipment, approved control drawings and existing test procedures of similar equipment or components. Tests should cover all functions and modes.

In the commissioning-authority-managed approach, the CA writes most of the procedures. The contractor reviews test procedures written by the CA to ensure they will not endanger equipment, warranties, or personnel. In the contractor-managed approach, the contractor or their commissioning manager or subconsultant writes test procedures and has them approved by the owners CA. However, in either management approach, for tests that are regulated (e.g., fire alarm, fire protection, elevators), given in industry-accepted standards [e.g., National Electrical Testing Association (NETA) or National Fire Protection Association (NFPA)] with detailed test and documentation requirements, or common enough that codes, industry standards, or guidelines provide detailed testing requirements (e.g., ducting, piping, drainage, and venting tests), the existing specifications suffice as the written test procedures and may only need to be adapted to the specific project at hand by addenda.

Testing and Verification.

Responsibilities and Management. Not all testing and verification falls under the commissioning umbrella. Traditional air and water testing, adjusting, and balancing is often the sole responsibility of the contractor or by independent contract to the owner. Roofing and elevator inspectors and electrical equipment testing have also generally been excluded from commissioning. There is some movement in the industry to centralize coordination for quality assurance/quality control (QA/QC) functions under the commissioning team. Each project is unique, and different approaches are warranted. The critical issues are ensuring that (1) appropriate testing rigor is applied, (2) technically qualified parties execute and document the testing, (3) objectivity is maintained, and (4) testing is well documented.

For systems not usually thoroughly tested by the contractor [e.g., HVAC systems and controls, lighting controls, specialty plumbing, and envelope and interfaces between systems (security, communications, controls, HVAC, emergency power)], the CA writes test procedures, directs, witnesses, and documents each test executed by the contractor. For these systems, the controls subcontractor most often executes the tests, although for some equipment, the CA may perform testing without the contractor present.

Testing that has traditionally been conducted by the contractor (e.g., fire alarm, fire protection, elevator, duct and pipe tests, emergency power, and some electrical equipment) ideally should be centrally coordinated under the commissioning team. However, one recommended alternative is to give the contractor more testing responsibility and autonomy than with other systems. The specifications should clearly establish testing and documentation requirements. The level of confidence and objectivity can be increased by requiring more extensive expertise of the contractor's commissioning manager and of the CA in the discipline of concern, or by increasing the amount of field witnessing by the CA. The designers may also have test-witnessing responsibility parallel to the CA, particularly in some electrical system and envelope assembly field testing.

Within a given discipline there may be differing levels of autonomy. For example, in tests of electrical equipment (e.g., circuit breakers), the contractor may conduct and document the bolt torque tests, but be required to hire an independent certified testing agency to conduct other NETA-required tests that require more specialized expertise and test equipment.

The owner's technical staff can assist in and benefit from participation in any of the above scenarios. The designer and owner project management staff may witness selected tests.

Testing Scheduling. Testing should be performed after equipment and assemblies are complete; construction checklists submitted, system testing, adjusting, and balancing is complete with a draft report submitted; and when the contractor is ready to turn the system over to the owner. Some practitioners require a *certificate of readiness* from the contractor certifying that the system has been thoroughly checked out and is completely functional. Ideally, manual testing occurs before substantial completion, but often slipped schedules require testing to occur after this milestone. Some short-term monitoring may be completed with manual testing, but most is postponed until early occupancy. Opposite-season and other deferred testing is conducted during seasonal changes or peak seasonal conditions.

Testing Scope. At a minimum, testing includes observing and documenting system operation and function during normal operation, through each of their sequences of operation, and all other modes of operation and conditions, including manual, bypass, emergency, standby, high and low load, and seasonal extremes, and comparing actual performance to that specified in the construction documents. Testing may also be conducted to verify performance criteria found in the BOD and OPR, including system optimization, though deficiencies in these areas are not normally the contractor's responsibility.

Manual Testing Methods. Testing includes observing normal operation; changing set points, schedules, and timers; and exercising power disconnects, speed controls, overwriting sensor values, etc., to cause perturbations in the system. System response and results are recorded on test procedure forms and any issues are documented. Small corrections are often made during testing. Less pressing corrections or issues with unknown solutions are investigated later, corrected, and retested.

Building automation systems (BAS), when present, are the backbone for conducting much of the testing. Before using the BAS, critical sensors, actuators, and features are verified as calibrated so the system readouts are reliable (even though all sensors and actuators will have been calibrated by the contractor during construction checklisting). The results are viewed on the building automation system screen or at the equipment. Other tests require handheld instruments or visual verification (e.g., evaluating caulking and flashings on window installations).

Monitoring. Some testing requires monitoring (trending) system operation over time through the BAS or data loggers (when the BAS does not monitor desired points). Monitoring can document that systems are performing properly during normal conditions during the monitoring period, but is not a substitute for manual testing. Most monitoring is not conducted until a few weeks after occupancy, for a view of system interactions over the course of normal, start-up, shutdown, and weekend operation. Normally, the CA analyzes monitored data and submits a report, with any concerns added to the issues log.

Automated Testing. Various semiautomated testing is conducted in permanent onboard equipment controllers. Currently, most truly

automated testing focuses on identifying electrical faults in controller components and is used during vendor start-ups and troubleshooting. Some use logic to identify parameters outside bounds that indicate component malfunctions such as hunting and calibration issues, which are more in line with commissioning tests. Different types of automated testing intended to help commissioning are under development. Some are primarily tools to gather and display monitored data; others help the analyzer make diagnoses. Equipment manufacturers are being encouraged to develop automated commissioning testing capabilities into onboard controllers on their equipment.

Training. Training should include, as appropriate, (1) the general purpose of the system; (2) use and management of the systems manual; (3) review of control drawings and schematics; (4) start-up, normal, shutdown, unoccupied, seasonal changeover, and manual operation; (5) controls set-up and programming; (6) diagnostics, troubleshooting, and alarms; (7) interactions with other systems; (8) adjustments and optimizing methods for energy conservation; (9) relevant health and safety issues; (10) special maintenance and replacement sources; (11) tenant interaction issues; and (12) discussion of why this feature is environmentally sustainable. Occupants may also need orientation on certain systems, assemblies, and features in the building, particularly sustainable design features that can be easily circumvented.

The CA helps the owner ensure that adequate training plans are used by the contractor and that training is completed according to the construction documents. (See the discussion of defining training requirements in the section on Commissioning During Design.) Some practitioners conduct testing with a sample of trainees to verify the efficacy of the training.

Most training should be accomplished during construction, before substantial completion; however, for complex systems (e.g., control systems), multiple trainings over time are recommended. Training for systems that will not come into operation until the next season may be delayed. A meaningful training program typically includes using the operation and maintenance components of the systems manual, which must be submitted before training begins. Selected trainings can be video-recorded as desired by the owner.

Commissioning Record. The CA compiles all commissioning documentation and project data, but only some of the data are compiled in the commissioning record, which is submitted and becomes part of the systems manual. The commissioning record contains the salient documentation of commissioning: the commissioning final report, issues log, commissioning plan, progress reports, submittal and O&M manual reviews, training record, test schedules, construction checklists, start-up reports, tests, and trend log analysis, grouped by equipment.

Final Commissioning Report. The CA should write and submit a final commissioning report detailing, for each piece of commissioned equipment or assembly, the adequacy of equipment or assemblies meeting contract documents. The following areas should be covered: (1) installation, including equipment meeting specifications; (2) functional performance and efficiency; (3) O&M manual documentation; and (4) operator training. Noncompliance items should be specifically listed. A brief description of the verification method used (manual testing, trend logs, data loggers, etc.) and observations and conclusions from the testing should be included. The final commissioning report is updated after occupancy/operations-phase commissioning.

Systems Manual Submittal. The CA usually compiles the systems manual and provides it to the owner. At the end of construction, the designer, contractor, owner, and CA provide elements of the systems manual generated during the construction phase. The CA normally reviews and approves systems manual submissions by the contractor and designer, not unlike traditional O&M manual reviews. Electronic systems manuals, now developed occasionally, will likely become standard in the future.

COMMISSIONING DURING OCCUPANCY AND OPERATIONS

The occupancy/operations phase typically begins with resolving the findings from monitoring a month or two into occupancy, and ends when the one-year equipment warranties expire.

Objectives

Commissioning during this phase should ensure the following:

- Training is complete.
- Systems and assemblies receive functional opposite-season verification.
- Outstanding performance issues are identified and resolved before warranty expiration.
- Commissioning process evaluation is conducted.

Activities

Verifying Training Completion. The CA ensures that any remaining training is conducted according to the contract documents, by reviewing documentation of the training or through witnessing portions of the training. This normally applies to control systems and training on major systems whose peak season is not near the end of the construction phase.

Opposite-Season Testing. Opposite-season testing is conducted to verify proper operation during, at minimum, both winter and summer conditions, where sufficient variations in seasonal conditions exist; it may also be appropriate at swing seasons. Presumably, one season was tested under at building turnover. Testing should be performed by the appropriate contractor and witnessed by the CA and building operators. However, the owner's operations staff and the CA, if sufficiently proficient with the controls system, can execute the tests and recall contractors only if there are problems.

Near-Warranty-End Review. The CA may also be asked to return a few months before the contractor's one-year warranty expires, to interview facility staff and review system operation. Acting as the owner's technical resource, the CA helps facility staff address any problems or warranty issues.

Documentation Update. Any identified concerns are added to the issues log, and the final commissioning report is amended to include occupancy/operations-phase commissioning activities. Changes to the BOD, OPR, or record documents, particularly to the sequences of operation, are documented by updating the systems manual near the end of the warranty.

Commissioning Process Evaluation. The CA should meet briefly with the owner; general, controls, mechanical, and electrical contractors; and mechanical and electrical designers to discuss the commissioning process for this project: what went well, what could be improved, what would best be done differently next time, etc. This will benefit all parties in commissioning future projects.

Additional Activities. The CA may also be given other responsibilities during the warranty period, such as helping develop a maintenance management program, optimizing system performance, and developing electronic facility manuals.

Ongoing or Recommissioning. Ongoing monitoring and periodic retesting and calibration of selected systems and assemblies is recommended to ensure they comply with the OPR, operating and functioning optimally throughout their life. This is sometimes called "continuous commissioning." Some recommissioning methods rely more on semi-continuous monitoring of primary system performance parameters with periodic analysis. Other approaches consist of recalibrating and retesting targeted systems and components on a regular schedule, including both manual testing and monitoring. Calibration and test frequency vary with equipment and its application.

COMMISSIONING COSTS

Commissioning costs vary considerably with project size and building type, equipment type, scope, and traveling requirements. Historically, commissioning has focused on HVAC and controls and has started during construction. However, QA/QC for increasing numbers of systems is being included in commissioning, and the process now frequently begins in the design phase. Currently, the commissioning industry is not mature; budget estimates, even for relatively detailed scopes of work, vary widely.

Clear definition of tasks, deliverables, systems and components to be commissioned, rigor, and testing methods must be provided for comparative pricing. The costing guidelines that follow must be used with great caution and are provided only for rough planning purposes. Understanding what is and is not included in each cost number is critical. *Owners should consult commissioning providers with their planned projects to obtain budget estimates, and practitioners should use detailed cost breakdowns for their pricing.*

PREDESIGN AND DESIGN-PHASE COSTS

For a project that includes the discussed tasks for all HVAC and controls components, a moderate level of electrical systems commissioning, and minor plumbing and envelope commissioning, the total commissioning costs (the CA cost plus the additional work of the designers) may range from 0.2 to 0.6% of the total construction cost for a typical office building. This estimate is based on two moderate design reviews. Costs for buildings over 200,000 ft^2 will typically be near the bottom of the range; for buildings less than 200,000 ft^2, near the top. More complex buildings and larger scopes of design review may cost considerably more.

CONSTRUCTION AND OCCUPANCY/OPERATIONS-PHASE COSTS

Table 1 estimates the CA's costs for the construction and occupancy/operation phases under the CA-managed approach. It includes commissioning the HVAC system (including fire, life, safety and controls) and the electrical system (including lighting controls, emergency power, and limited connection and grounding checks). It does not include full infrared scanning, power quality, switch gear, transformer, or low-voltage-system testing. Complex systems and critical applications have higher costs. *For a given building type and complexity*, larger buildings tend to come in at the lower end of the range and smaller buildings at the higher.

The listed costs cover only the CA fees; there are also costs to the contractor, designers, and owner staff. For the CA-managed approach, costs for the mechanical contractor attending meetings, documenting construction checklists, and assisting with testing will approximate 10 to 20% of the CA's mechanical commissioning costs. The electrical contractor's costs may equal the CA's electrical commissioning costs for electrical commissioning (because contractors are usually responsible for hiring their own electrical testing company to perform electrical tests). NETA electrical tests are often already part of the normal construction program and the only *additional* commissioning costs are for the CA to coordinate testing, spot-witness, and review reports.

Table 1 Estimated Commissioning Authority Costs to Owner for Construction and Occupancy/Operations Phases

Commissioned System	Total Commissioning Cost
HVAC and controls[a]	2.0 to 3.0% of mechanical
Electrical system[a]	1.0 to 2.0% of electrical
HVAC, controls, and light electrical[b]	0.5 to 1.5% of construction

[a]*Source*: Wilkinson (2000). [b]*Source*: PECI (2000).

However, in the larger picture, the savings to the contractor in callback costs and holding of final payment retention may exceed the first costs, resulting in little if any net commissioning cost to the contractor. The designers' costs for commissioning during construction is fairly insignificant when their scope is limited to review of the commissioning plan and a few meetings.

Commissioning costs for the contractor-managed approach are similar overall, but more costs are shifted from the CA to the contractor and their commissioning manager.

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