CHAPTER 44. HVAC COMMISSIONING

COMMISSIONING implements a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria. The defined objectives and criteria are often referred to as the **owner's project requirements (OPR)**. The commissioning process uses the owner's project requirements as the reference to determine acceptance of the design and construction. Commissioning includes verifying and documenting that the project operational and maintenance documentation and training of operation and maintenance personnel occur. 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 as covered in ASHRAE *Guideline* 0-2013, developed for the National Institute of Building Sciences' total building commissioning program, as well as the best practices for applying the process from ASHRAE *Guideline* 1.1-2007. The minimum acceptable process for commissioning is detailed in ASHRAE *Standard* 202-2013. This chapter provides more narrative discussion on some issues than these two guidelines and the standard.

Recommissioning applies commissioning to a project that has been previously delivered using the commissioning process. This may be a scheduled recommissioning developed as part of ongoing commissioning, or it may be triggered by use change, operational problems, or other needs. **Existing building commissioning** (often called **retrocommissioning**) applies commissioning to an existing facility that may or may not have been previously commissioned. It consists of systematically investigating, analyzing, and adjusting operations of existing building equipment, systems, and assemblies, as well as training and documentation for operators to ensure that required performance (including energy, comfort, and IAQ) is achieved. Buildings require maintenance and tuning to prevent performance degradation. Existing building commissioning should be performed as part of ongoing efforts to maintain a comfortable and efficient environment within the building. It has broad application to virtually every building type with excellent cost/benefit results and payback ratios. Existing building commissioning starts with development of the owner's current facility requirements, reviewing the existing design, and testing of the existing systems. Any major retrofits required follow the process for new building commissioning as defined in this chapter.

1. CONSIDERATIONS

Applicability

The commissioning process described here applies to new construction, major renovations, and all systems and assemblies. Although this chapter focuses on HVAC systems, 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 (ASHRAE *Guideline* 0). Based on owners' preference and project contract scope, total commissioning can include industrial process and process equipment, systems, piping, instrumentation, electrical, and related control, or these topics may be treated as an independent phase of project commissioning.

Systems to be commissioned vary with the systems and assemblies used, building size, project type, and objectives. Owners and commissioning providers often focus on 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 cleanroom, 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 modified for each project. Although commissioning may begin at any time during the project life cycle, owners obtain the highest benefits when commissioning begins at the conceptual or predesign phase.

Background

Equipment, components, systems, and assemblies have become more complex. More specialization has occurred in the disciplines and trades, with increased interactions between all elements. This increased specialization and interaction requires 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 often do not work as intended because of programming, design, and construction deficiencies. Commissioning is a value-added service that helps overcome these infrastructure inadequacies and fundamentally improve the performance of building systems and living conditions for occupants.

Benefits

The primary benefits of commissioning include improvements in all of the following areas:

- **Predesign and design**

  Owners develop better understanding of what they want and need through clear, documented OPR

  Designers understand better what owner is requesting

  Designers reduce their risk with better communication and input from owner

  Owners understand better what designers are proposing through a clear, documented **basis of design (BOD)**

  Experts review and improve commissioning documents

  Resolves many potential issues more cost effectively before construction phase

  Verifies planned systems can be commissioned and tested, and are within owner's ability to maintain

  Improves specifications and drawings, resulting in improved coordination between all groups

  Includes thorough training requirements in the construction documents

- **Construction (including system and assembly performance)**

  Increases accountability in submittal process, leading to higher-quality installation

  Provides tools to help contractors perform installations that meet the project requirements (e.g., construction checklists)

  Provides performance accountability through construction observation, issue management, and testing

  Documents verification of system and assembly performance

  Verifies training completion

  Includes formal functional testing at completion

- **Occupancy and operations (including maintenance)**

  Improves performance (IAQ, comfort, energy) from start of occupation

  Reduces amount of troubleshooting

  Has fewer contractor call backs

- Ensures thorough documentation in **operation and maintenance (O&M)** manuals

  Provides a systems manual

  Verifies documentation submittals

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

Key Contributors

- Owner/end user
- Architect
- Mechanical engineer
- Electrical engineer

- Commissioning authority (CxA)
- Mechanical contractor
- Electrical contractor
- Controls contractor
- Sheet metal contractor
- Testing, adjusting, and balancing (TAB) agency
- Owner's O&M staff
- General contractor/construction manager

Definitions

Basis of Design (BOD). A document that records the concepts, calculations, decisions, and product selections used to meet the OPR and to satisfy applicable regulatory requirements, standards, and guidelines. The document includes both narrative descriptions and lists of individual items that support the design process.

Commissioning Authority (CxA). An entity identified by the owner who leads, plans, schedules, and coordinates the commissioning team to implement the commissioning process.

Commissioning Plan (Cx Plan). A document that outlines the organization, schedule, allocation of resources, and documentation requirements of the commissioning process.

Construction Checklist. A form used by the contractor to verify that appropriate components are on site, ready for installation, correctly installed, and functional.

Current Facility Requirements (CFR). A written document in which the owner details a facility's current functional requirements and the expectations of how it should be used and operated. This may include goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information to meet the requirements of occupants, users, and owners of the facility.

Existing Building Commissioning (EBCx) Process. A quality-focused process for attaining the CFR of an existing facility and its systems and assemblies being commissioned. The process focuses on planning, investigating, implementing, verifying, and documenting that the facility and/or its systems and assemblies are operated and maintained to meet the CFR with a program to maintain the enhancements for the remaining life of the facility.

Facility Guide (FG). A basic building systems description and operating plan with general procedures and confirmed facility operating conditions, set points, schedules, and operating procedures to properly operate the facility.

Owner's Project Requirements (OPR). A document that details the functional requirements of a project and the expectations of how it will be used and operated. These include project goals, measurable performance criteria, cost considerations, benchmarks, success criteria, and supporting information. (The term **project intent** is used by some owners.)

Systems Manual. A system-focused, composite document that includes the operation manual, maintenance manual, and additional information of use to the owner during occupancy and operations.

Test Procedures. A written protocol that defines methods, personnel, and expectations for tests conducted on components, equipment, assemblies, systems, and interfaces among systems.

1.1 COMMISSIONING OBJECTIVE

The commissioning objective focuses on documented confirmation that a facility fulfills the specified performance requirements for the building owner, occupants, and operators. To reach this objective, it is necessary to (1) clearly document the owner's project requirements, including performance and maintainability; and (2) verify and document compliance with these criteria throughout design, construction, acceptance, and initial operation phases.

Specific goals for commissioning include

- Providing documentation and tools to improve quality of deliverables (e.g., forms, tracking software, performance calculation tools)
- Verifying and documenting that systems and assemblies perform according to OPR by end of construction with building occupancy
- Providing a uniform and effective process for delivery of construction projects

- Using quality-based sampling techniques to detect systemic problems
- Verifying proper coordination among all contractors, subcontractors, vendors, and manufacturers of all furnished equipment and assemblies in the completed systems
- Verifying that adequate and accurate system and assembly documentation is provided to owner
- Verifying that operation and maintenance personnel and occupants are properly trained

1.2 MANAGEMENT AND RESPONSIBILITIES

Management Strategies

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

Predesign and Design. Commissioning during predesign and design is most often managed by an independent CxA who is not part of the formal designer-of-record team. An independent, objective view is critical. The CxA normally provides input to the owner and designers but does not have ultimate authority over design decisions. The CxA should also coordinate, conduct, or approve activities such as assisting in development of the OPR, conducting statistical sampling reviews, and developing commissioning specifications and test procedures. The CxA may also review plan designs.

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 CxA should be independent. If the contractor or designer hires the CxA, the potential conflict of interest must be carefully managed. The two primary methods to manage commissioning during construction are commissioning-authority-managed and contractor-managed.

In the **commissioning-authority-managed approach**, the CxA performs many of the planning and technical tasks, such as developing the commissioning plan and test procedures and directing, witnessing, and documenting execution of tests, performed by either the contractor or the CxA.

In the **contractor-managed approach**, the contractor may develop the commissioning plan, write test procedures, and direct and document testing, with the CxA reviewing and approving the plan, witnessing selected tests, and reviewing completed test reports. The CxA should report to the owner on the adequacy of a contractor-managed commissioning plan. The contractor may assign staff, a subcontractor, or a subconsultant to manage and coordinate 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 CxA-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 CxA.

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. Team members include the owner, occupants, design professionals, construction manager, general contractor, subcontractors, suppliers, equipment manufacturers, and the CxA.

The level of effort of team members changes during the different project 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 CxA, 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 may 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 CxA's specific scope of services. Ideally, the same party or firm acts as CxA through all project phases. The CxA organizes and leads the commissioning team throughout the project.

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

During design, the CxA develops detailed commissioning activities. The core CxA responsibilities are

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

Construction. During construction, the CxA 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 CxA directs commissioning activities, and is an independent and objective advocate for the owner. The core commissioning activities during construction involve

- Reviewing selected construction submittals to verify conformance with OPR, with updates in commissioning plan as needed
- Observing selected installations, start-up, and functional performance tests, including documenting any conditions that require correction
- Co-organizing with the discipline design engineer, and planning, developing, reviewing, and observing testing
- Codeveloping or assisting with systems manual
- Reviewing O&M manual submissions
- Verifying operator and maintenance personnel training and documentation
- Submitting documented results to owner on all commissioning performed

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 and maintenance personnel training).

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

Independence. If the CxA's firm has other project responsibilities, a potential conflict of interest exists. Wherever this occurs, the CxA should disclose in writing the nature of the conflict and the means by which it will be managed. If the CxA is not under direct contract to the owner, the owner's interests need to be protected through appropriate oversight of the CxA's work.

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

Construction Manager. The construction manager's role varies on each project. 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 contractors execute 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 CxA in executing the commissioning plan
- Providing input into commissioning plan for CxA's review and approval
- Integrating commissioning schedule into overall project schedule
- Participating in commissioning meetings
- Responding to questions and issues raised by CxA
- Resolving issues identified during commissioning and coordinating correction of identified deficiencies

- Providing equipment, system, and assembly data needed by CxA
- Performing specified training
- Submitting required portions of systems manuals

In the contractor-managed approach, the general contractor is often required to hire a third party with direct commissioning skills 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

- Participating with CxA (and the contractor's commissioning manager, when applicable) in executing commissioning plan
- Providing input into commissioning plan for CxA's review and approval
- Coordinating with other trades as necessary to facilitate a smooth and complete commissioning process
- Participating in commissioning meetings
- Responding to questions and issues concerning their work raised by CxA
- Executing and documenting tasks in construction checklist and start-up process
- Performing and documenting tests when in their scope
- Participating in resolving issues within their scope identified during commissioning
- Correcting identified deficiencies within their scope
- Providing required documentation for systems manuals and commissioning reports

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. To avoid confusion, the OPR should specify which commissioning activities are the trade contractor's responsibility, and which are the CxA's.

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 CxA 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 CxA comments on construction submittals and O&M manuals
- Help resolve design-related issues raised during commissioning
- Perform specified training
- Submit required portions of systems manuals

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, with guidance from the CxA, should include specific responsibilities in all commissioning team members' scopes of services, make sure there is sufficient time for commissioning in the project

schedule, ensure the CxA 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 Representatives. The owner's representatives are individuals or firms hired to represent the owner's interest during specified phases of the building process. The owner typically retains the project architect or project engineer responsible for HVAC design and the CxA as a team of owner's representatives.

Owner's Operations and Management (O&M) Staff.

Predesign. The owner's O&M staff should participate in the development of the OPR during predesign.

Design. During design, O&M staff may contribute to reviews of the designer's BOD, plans, and specifications.

Construction. During construction, the owner's O&M staff should

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

Occupancy. During occupancy, the O&M staff should identify any warranty or operational issues and report back to the commissioning team. They should participate in the warranty review and may participate in any seasonal testing. O&M staff might also participate as needed in additional training, particularly any related to the control system or other complex or unfamiliar technology.

Occupants and Users.

Predesign. The occupants and users should participate in the development of the OPR during predesign.

Design. During design, occupants and users may contribute to reviews of the designer's BOD, plans, and specifications.

Construction. During construction, occupants and users may participate in select training and final inspection and walk-throughs.

Occupancy. The occupants and users report back to the owner and/or the commissioning team about warranty items and other issues they observe related to the performance of the building.

2. COMMISSIONING PROCESS

Commissioning should begin during predesign, and formally continue 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, this later implementation should, when possible, capture the same information and verifications developed when commissioning begins at project inception.

2.1 PREDESIGN-PHASE COMMISSIONING

Objectives

The primary activities and objectives of commissioning during predesign are to

- Develop owner's project requirements (OPR)
- Identify scope and budget for commissioning process
- Develop initial commissioning plan
- Review and accept predesign-phase commissioning-process activities
- Review and use lessons learned from previous projects

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 CxA at the beginning of predesign.

Owner's Project Requirements (OPR). The OPR forms the basis from which all design, construction, acceptance, and operational decisions are made. It describes 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 (ASHRAE *Guideline* 0).

The OPR is generally a set of concise objective qualitative statements, each with one or more quantitative performance metrics or criteria. The following information should be included:

- Functional requirements, needs and goals for building use, operation, maintenance, renovation, and expansion, including user's requirements and space temperature requirements
- Occupancy schedules and space plan requirements, including zone-based control areas
- Sustainability, reliability, durability, safety, and aesthetic goals
- Quality of materials and construction
- Warranty, project documentation, and training requirements
- Goals for 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, standards, and regulations 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 CxA ensures that the OPR is developed and is clear and complete. The CxA may develop or help develop the OPR with the owner or provide direction and review of the OPR developed by others. Facilitated workshops, surveys, and questionnaires are useful 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 assistance from the CxA, 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 with which the owner has experienced problems on previous projects, 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, etc.). Later in design but before scoping construction-phase commissioning, additional detail should be added to each of these categories, and others added as needed to ensure that the scope of commissioning is clear. Adding this detail increases the cost of commissioning, and needs to be specified early in the design phase.

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.

Predesign-Phase Commissioning Plan

One predesign-phase commissioning task should be drafting the commissioning plan for the design phase. The CxA 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 of commissioning
- Overview of the process
- Detailed commissioning-process activities for design phase

- General commissioning-process activities for construction and operations/occupancy phases
- Roles and responsibilities
- Deliverables
- Communication protocols
- Schedule
- Checklist of requirements and formats
- Verification and acceptance procedures

Acceptance of Predesign Commissioning

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

2.2 DESIGN-PHASE COMMISSIONING

Objectives

Design-phase commissioning objectives include the following:

- Update the owner's project requirements (OPR)
- Verify basis of design (BOD) document against OPR
- Update the design-phase commissioning plan developed during predesign
- Develop and incorporate commissioning requirements into project specifications
- Develop commissioning plan for construction and occupancy/ operations phases, including draft construction checklist
- Verify plans and specifications against BOD and OPR
- Begin codeveloping with relevant discipline design engineer for systems manual
- Define training requirements for O&M personnel
- Perform commissioning-focused design reviews
- Accept 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 with additional details. The CxA must participate in value engineering and constructability review sessions to ensure that commissioning can be performed. The owner and designer then review and comment on the updated plan, which then 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 as more detailed budget and design data become available.

Verify the Basis of Design. All BOD elements can be grouped under one of two terms: design narrative or design criteria. 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 designers *intend* (during schematic design phase) to incorporate into the design or what they *have* incorporated (during the balance of design) to meet the OPR and associated performance criteria as well as codes, standards, and regulations. This narrative should be understandable by all parties of the building construction and operation process, though it may address fairly technical and specialized issues. It includes a brief section on what systems were considered and why they were accepted or rejected, along with the rationale for the system selected. The design narrative should be updated with each phase of design.

The **design criteria** are the project-specific information, including underlying assumptions for calculations, calculation methodology, codes and standards followed, equipment used as the basis of design, and design assumptions needed to

make design calculations and other decisions, such as

- Diversity and safety factors used in sizing
- Classes of systems and components (duct class, cleanroom class, explosive or other hazardous classifications, etc.)
- Level of redundancy
- Occupant density
- Limitations and restrictions of systems and assemblies
- Inside and outside conditions (space temperature; relative humidity; lighting power density; glazing fraction; U-value and shading coefficient; roof, wall, and ceiling R-values; ventilation and infiltration rates; etc.)
- Fire and life safety issues
- Summary of primary HVAC load calculations and the methods used

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

Develop Commissioning Plan for Construction and Occupancy/Operations Phases. The commissioning plan (Cx plan) is a document that outlines the organization, schedule, allocation of resources, and documentation requirements of the commissioning process. This is an overall plan, developed during the predesign, design, and construction phases, that provides the structure, schedule, and coordination planning for commissioning. The Cx plan includes specifications detailing 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. For the construction and occupancy/operations phases, it describes the following:

- Commissioning process
- Scope of commissioning effort, including systems, assemblies, and components being commissioned
- Rigor of commissioning
- Roles and responsibilities of each team member
- Team contact information
- Communication protocols between team members, including documentation requirements
- Commissioning overview and details of submittal activities
- Construction observation, following checklists, and performing start-up activities
- Preliminary schedule for commissioning activities
- Process for dealing with deficiencies
- Test procedure development and execution
- Prefunctional/functional test procedures
- Operation and maintenance (O&M) manual review
- Warranty-period activities
- Operation training procedures
- Systems manual development
- Description of summary report, progress and reporting logs, and initial schedule (including phasing, if applicable)
- Procedures for documenting commissioning activities and resolving issues

The commissioning plan developed during predesign is updated to include construction-phase activities. At the beginning of the design phase, the plan is general and is used primarily to guide development of commissioning specifications. The owner and designer review and comment on the plan. As design progresses, the CxA updates and finalizes the plan when the construction documents are completed. The commissioning plan can be issued with the bid documents for reference.

Develop and Incorporate Commissioning Requirements into Project Specifications. The specifications in the Cx plan are 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 should be included, rather than just delineating requirements. Frequently, for reference, the responsibilities of other team members not bound by the specifications (e.g., owner, CxA, construction manager, architect) are given in the commissioning specifications to ensure clarity and put the contractor's responsibilities 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 uses 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 also should be included.

It is critical that the project specifications in the Cx plan 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, room pressurization, emergency power testing) will be integrated with HVAC commissioning. Responsibility for checkout and test procedures, including test procedure review, direction, execution, witnessing, documentation, and approval, must all be clearly described. The acceptance criteria for the test should be included in the specifications. Acceptance criteria should be based on the OPR and the systems selected. For example, a project may require tight temperature or humidity tolerances to meet certification criteria. Systems designed for these projects should be able to control to those tolerances. A system with staged cooling (direct expansion with compressor staging) may not be able to meet a ±1°F level of control. This should be taken into consideration when selecting the systems for the project.

The CxA ensures that contractor responsibilities for commissioning are appropriately incorporated into the project specifications. Placing the general commissioning requirements, process descriptions, and specifications in a single section is one method that makes it easy for all parties to know where to look for their responsibilities and find common terminology. The weakness of this method is that some contractors may not realize that this is part of their responsibilities, because it is not described in their sections; therefore, it might be beneficial to split at least part of the commissioning requirements into the applicable sections, with a reference back to the section that describes the common commissioning processes.

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 CxA reviewing and recommending revisions.

Begin Developing Systems Manual. During design, the systems manual contains the OPR, BOD, and drawings and specifications, updated at each design submission and during and after construction. The CxA is often responsible for assembling and maintaining the systems manual; however, the contract documents for the CxA or design professionals should delineate who is responsible for this task.

The systems manual differs significantly from traditional O&M manuals. This manual expands 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 approved construction submittals), system schematics, final commissioning report, training records, commissioning test procedures (filled-in and blank), and optimization and diagnostic data (which can include operational procedures for specific emergency situations, seasonal changeover procedures, fire and emergency power response matrix, smoke management system operation during and after fire, energy efficiency recommendations, troubleshooting guide, recommissioning frequency, and diagnostic building automation system trend logs). 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* 4-2008.

The owner, designer, contractor, and commissioning authority each have development responsibilities for parts of the systems manual. Construction documents should list the contents and requirements for the systems manual and the responsible party for generating, compiling, and finishing each part of the required documentation. Systems manuals should be available for and used in operator training. Much of the systems manual can be put into electronic media format. The ability to search and auto-update enhances the usability and accessibility of the data.

Define Training Requirements. During the design phase, the training requirements of O&M personnel and occupants are identified relative to the systems and assemblies to be installed in the facility. O&M personnel must 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. Both groups require training.

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

contractor's training responsibilities need to be incorporated into the project specifications and should include requirements for the number of training hours for each item of equipment or assembly and submittals of training plans and qualifications of trainers. Training likely requires participation of the designer (for system overviews), the CxA (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. Because turnover in O&M and occupants will occur, training materials should be reusable (e.g., video, written manuals, computer presentations).

Perform Design Reviews. Design review by parties not part of the formal designer-of-record team should be conducted to provide an independent perspective on performance, operations, and maintenance. These document reviews, conducted by experts in the field, should start as early as possible, when options and issues can be more easily resolved. The reviews may be coordinated by the CxA and should include the owner's technical staff. The CxA 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 (predesign), design development, and construction document phases]. The CxA's design review is not intended to replace peer-to-peer design reviews that check for accuracy and completeness of the design and calculations.

A targeted design review may cover the following:

- General quality review of 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
- Verification that system and assembly narrative descriptions are clear and consistent with OPR and the BOD is updated with resolved issues
- Verification that plans and specifications are consistent with BOD and OPR, and plans and specifications are updated with resolved issues

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, fire and life safety issues, operation and maintenance issues, and other issues may be addressed in these design reviews, depending on the owner's desires and CxA's scope. Required reviews 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 for an in-depth review; if only minimal issues are identified, the owner accepts the submission. If significant issues are identified in the sample, either the submittal is sent back to the designer for revamping and a thorough review, or the CxA may perform a thorough review, depending upon the scope of work defined in the CxA's contract. After the design team has addressed the issues, the CxA performs a new review. In this type of review, the design team is still responsible for their traditional peer review of construction documents for accuracy. The CxA makes recommendations to facilitate commissioning and improve building performance, without approving or disapproving either design or documents. The design team is ultimately responsible for design. The CxA should be able to justify all of the recommendations made. It is the responsibility of the owner or project manager to evaluate all review findings with the design team and see that the responsible team member implements the approved ones. All issues are tracked to resolution and verified in later reviews to have been incorporated as agreed.

If the CxA is contracted through a designer, the designer's commissioning manager or subconsultant may manage the contractor's issues log. In that case, to minimize conflicts of interest, the CxA is often required to report all issues simultaneously to the designer and to the owner.

Accept Design-Phase Commissioning Activities. Commissioning should include the owner's formal acceptance of the BOD, updated OPR, Cx plan, and the design, after review and comment by the CxA.

Additional Commissioning Team Tasks. Additional design-phase responsibilities of the commissioning team (led by the CxA, 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 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

2.3 CONSTRUCTION-PHASE COMMISSIONING

Objectives

Commissioning activities should take place throughout the construction phase and include verification and documentation that

- All acceptance testing requirements are documented
- All systems and assemblies are provided and installed as specified
- All systems and assemblies are started and function properly
- All acceptance testing requirements are documented
- All record documents are updated
- The systems manual is updated and provided to facility staff
- Facility staff and occupants receive specified training and orientation
- Acceptance testing occurs

Activities

The following primary commissioning activities (in approximately sequential order) address commissioning objectives. The CxA coordinates and ensures that all activities occur and perform successfully.

Bidding and Contract Negotiation. A member of the commissioning team (usually the CxA) 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 CxA coordinates construction-phase planning and kickoff meetings. The planning meeting held with the contractor, owner, designer, and CxA focuses on reviewing requirements and establishing specific communication and reporting protocols. The commissioning plan is updated from this meeting. The kickoff meeting is held with additional construction team members, who generally include 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 comments on the plan and schedule, and the CxA uses these suggestions to help finalize the commissioning plan and schedule.

Commissioning Plan Update. The planning and kickoff meetings usually result in an updated commissioning plan. 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. The CxA reviews equipment and material submittals of commissioned systems and assemblies to obtain information needed to develop construction checklists, make meaningful observations of construction progress, and aid in developing comprehensive tests. This process also verifies that contractors are providing high-quality submittals that meet the construction document requirements, and that architects and engineers provide a quality review so construction-related performance issues are identified before construction progress makes them more difficult and expensive to address. Submittals could be reviewed concurrently by the design team to allow any discrepancies to be identified before formal approval, but the construction submittal review should also be compared to the architects' and engineers' reviews to verify that the architects and engineers are providing a thorough review of the submittals.

Controls Submittal and Integration Meeting. Before the contractor develops the controls submittal, the CxA 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 CxA may help the owner monitor the development and coordination of shop drawings to ensure synchronization between trades.

Early O&M Data. Information beyond typical construction submittals requested by the CxA includes installation and start-up procedures, operation and maintenance information, equipment performance data, and control drawings before formal O&M manual submittals. This information allows the CxA to become familiar with systems and assemblies to 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 CxA to identify issues that may affect commissioning and compliance with construction documents, BOD, or OPR.

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

Construction and Commissioning Meetings. The CxA attends periodic planning and job-site meetings to stay informed on construction progress and to update parties involved in commissioning. During initial construction, the CxA may attend regular construction meetings and hold a line item on the agenda. Later, the CxA may convene 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 CxA should distribute minutes from these meetings.

Progress Reports. The CxA 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 Owner's 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 CxA updates the OPR and the designer updates the BOD. Final construction updates to these documents are made at the end of testing, typically a few months into occupancy.

Coordinate Owner's Representatives Participation. The commissioning plan should describe participation of the owner's representatives in work such as submittal review, construction checklist verification, construction observation, test procedure review and execution, and O&M manual review. The CxA normally coordinates this participation with the contractors.

Construction Observation. The CxA should make planned, systematic visits to the site to observe installation of systems and assemblies. The owner's staff may assist in construction observation. The CxA should verify that the first few of any large-quantity items (e.g., variable-air-volume terminal units) are installed properly and used as a mock-up or standard to judge the rest of the installation. 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, whereas others merge findings into the regular issue logs and progress reports. Site visits should be used to verify completion of construction checklists.

The CxA normally witnesses many 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.

Record Documents. Contractors should be required to immediately update the record drawings when any deviations from the construction document occur. During the construction phase, the CxA should verify that the record documents are kept up to date by comparing the installation with the construction documents, and verify that any changes have been recorded on the record documents.

Construction Checklists and Start-up. At the beginning of construction, construction checklists are developed (usually by the CxA in cooperation with the discipline engineer, but sometimes by the contractor or 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, during normal checkout of equipment and systems, and before and during system start-up, though some commissioning practitioners fill out the checklists themselves. The contractor fully documents start-up and initial checkout, including the construction checklists to ensure systems are ready for testing, and submits them to the CxA, who reviews the forms and spot-checks selected items in the field later in the project.

Some CxAs statistically sample items on checklists to verify proper completion (typically random or targeted sampling of 2 to 20%). If an inordinate fraction of the sampled items are deficient (typically more than 10%), the contractor is required to check and document all remaining items. The contractual documents need to contain details of the sampling and actions based on the results.

Commissioning Issues Management. The CxA 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 and completely documented. The CxA distributes the updated log to the owner, contractor, construction manager, and HVAC design engineer at construction and commissioning meetings. This log can also be placed on project web sites. If the CxA is hired through a contractor, the contractor's commissioning manager or subconsultant may manage the contractor's issues log. In that case, to minimize conflicts of interest, the CxA is often required to report all issues simultaneously to the contractor and to the owner.

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 analyzes system performance data completely electronically, or with significant help from software.

Test procedure writing begins immediately after the submittal, because test procedures need to be reviewed and approved before testing occurs, which is generally scheduled about three to six weeks after the submittal review. 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.

Procedural documents 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 detailed procedures and forms.

The responsible HVAC design engineer should organize the preparation of HVAC system testing, adjusting, and balancing (TAB) procedure together with the test and balancing professional and the commissioning authority, depending on their scopes of work. The CxA is responsible for verifying that the test procedures are written and appropriate for determining that equipment, assemblies, and systems function correctly. All parties should have input into the final test procedures to ensure that equipment, assemblies, systems, or people will not be endangered or warranties voided. Industry standard test procedures [e.g., ASHRAE, Air-Conditioning and Refrigeration Institute (ARI), American Composites Manufacturers Association (ACMA)] should be referenced whenever possible.

Testing and Verification.

Responsibilities and Management. Traditional air and water testing, adjusting, and balancing is often performed by the contractor or by an independent contractor employed by the owner. Building envelope, elevators, and electrical system testing are generally excluded from HVAC commissioning, but may be included in whole-building commissioning. The CxA reviews the testing and verification plan and results, and may spot-check the results to verify the testing was completed. 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 can be warranted.

Critical issues include ensuring that

- Appropriate testing rigor is applied
- Technically qualified parties execute and document the testing
- Objectivity is maintained
- 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, fire protection, emergency power)], the CxA may write test procedures that go beyond HVAC tests. The CxA then directs, witnesses, and documents each test executed by the contractor after the contractors have ensured that the systems will pass these tests. The controls subcontractor usually executes the tests, although the CxA may test some equipment with or 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, some electrical equipment) ideally should be centrally coordinated. This can be the responsibility of the contractor or of the CxA. The specifications should clearly establish testing and documentation requirements and define

the responsible party. The level of confidence and objectivity can be increased by requiring experts in specific disciplines to witness tests, particularly in some electrical system and envelope assembly field testing. Increasing the required amount of field witnessing by the CxA also improves the confidence that commissioning was correctly performed.

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, and also be required to hire an independent certified testing agency to conduct other necessary 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's project management staff may witness selected tests.

Verification Testing Scheduling. Verification testing should be performed after equipment and assemblies are complete and started up, construction checklists checked out and submitted, air and water balancing completed, and the contractors' systems testing finished. The contractor is then ready to turn the system over to the owner. Most projects require a certificate of readiness from the contractor certifying that the system has been thoroughly checked out and verified to be completely functional. Ideally, manual testing occurs before substantial completion, but schedule slippage may require testing to occur after this milestone. Some short-term monitoring may be completed with manual testing, but sometimes is postponed until early occupancy. Opposite-season and other deferred testing should be 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, can be the backbone for conducting much of the testing, collecting, and archiving data. Before using the BAS, critical sensors, actuators, and features should be verified as calibrated so the system readouts are reliable (although all sensors and actuators should have been calibrated by the contractor and documented on construction checklists). The results are viewed on the building automation system screen or at the equipment. Other tests may require hand-held 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 be used to document that systems are performing properly during test conditions over the monitoring period. However, this is not a substitute for manual testing, which can cover a wide range of conditions. Monitoring provides a view of system interactions over the course of normal, start-up, shutdown, and weekend operation. Normally, the CxA 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-up and troubleshooting activities. Some use logic to identify parameters outside limits, which indicate component malfunctions such as hunting and calibration issues. 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 often integrate 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, shutdown, seasonal changeover, and normal, unoccupied, 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 specific features are 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 CxA 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 CxAs 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 training sessions should occur before and after substantial completion. 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 training materials can be video-recorded as desired by the owner.

Commissioning Record. The CxA compiles all commissioning documentation and project data, which are submitted and become part of the systems manual. The commissioning record contains the salient documentation of commissioning, including 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 CxA should write (or review) 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 procedures used for testing equipment with respect to specifications; (2) functional performance and efficiency, including test results; (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 CxA updates the final commissioning report after occupancy/operations-phase commissioning. The commissioning documents also should include, among other things,

- Certificates and warranties of system completion with a complete set of as-built drawings submitted from mechanical, electrical, piping, plumbing, control, and fire protection contractors
- Complete records of all problems and solutions occurred during start-up, testing, and adjustments submitted by every individual contractor or subcontractor
- Certified system testing and balancing report from the licensed TAB company, with verified major equipment models, capacities, and all tested performance records conforming to system design criteria
- If room pressurization is required, a complete room-to-room pressurization map in the TAB report
- If room cleanliness is required, a certified as-built room cleanliness report of testing during completion of construction and installation

Systems Manual Submittal. The CxA usually compiles the systems manual and provides it to the owner. At the end of construction, the designer, contractor, owner, and CxA provide elements of the systems manual generated during the construction phase. The systems manual should include commissioning test procedures, results of commissioning tests, issue logs and resolution, system schematics, O&M information, record drawings, construction checklists, start-up reports, and trend log analysis, grouped by equipment. The CxA normally reviews and approves systems manual submissions by the contractor and designer, similar to traditional O&M manual reviews. Electronic systems manuals, now developed occasionally, will likely become standard in the future.

2.4 OCCUPANCY- AND OPERATIONS-PHASE COMMISSIONING

Occupancy- and operations-phase commissioning typically begins with resolving the findings from performance monitoring over the first month or two into occupancy, and ends with the completion of the first year of occupancy.

Objectives

Commissioning during this phase should ensure the following:

- Initial maintenance and operator training is complete.
- Systems and assemblies received functional opposite-season verification.
- Outstanding performance issues are identified and resolved before warranty expiration.
- Commissioning process evaluation is conducted and satisfactorily resolved.

Activities

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

Seasonal Testing. Seasonal testing verifies proper operation of those systems for which peak-load conditions are not available before substantial completion. Additionally, intermediate-season testing may be required for part load, and

changeover testing may be required. For example, when completion occurs in winter, final full-load cooling system testing must wait until the following summer. Intermediate-season testing verifies system changeover controls and ability to maintain space conditions per OPR. Testing should be performed by the appropriate contractor and witnessed by the CxA and building operators. However, the owner's operations staff and the CxA, if sufficiently proficient with the controls system, can execute the tests and recall contractors only if there are problems.

Near-Warranty-End Review. The CxA 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. By acting as the owner's technical representative, the CxA assists facility staff to address any problems or warranty issues.

Documentation Update. Any identified operations-phase 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 are documented by updating the systems manual near the end of the warranty. Changes to sequences of operation require particular care in ensuring that these updates occur.

Commissioning Process Evaluation. The CxA 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. Topics to be addressed include 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. The CxA will submit a report on this meeting to the owner.

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.

Additional Activities. The CxA 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 are recommended to ensure they comply with the OPR, operating and functioning optimally throughout their life. This is sometimes called recommissioning. Some recommissioning methods rely more on semicontinuous 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.

2.5 LIFE AND PROPERTY SAFETY CHECK

Human life and property safety should be considered in all types of new or renovation projects, during all phases. The National Fire Protection Association (NFPA), American Conference of Governmental Industrial Hygienists (ACGIH), and U.S. Occupational Safety and Health Administration (OSHA) have detailed regulations for dealing with hazardous conditions that may be present, especially in industrial settings. The following are some of the essential categories to be checked during the entire project commissioning process.

Hazards Generated on Site

Hazards present on the project property require proper attention to safety issues; otherwise, the consequences could affect not only the occupancy's personnel and the property, but also the surrounding communities. Therefore, the CxA must understand the hazards generated in the property and how to minimize them. Typical sites with hazards include laboratories, manufacturing facilities, chemical plants, or other industrial facilities.

Different project properties include many different areas, each with distinct equipment or operating processes that have unique hazards; examples include fuel handling (gas, fuel oil, or coal), chemical emissions, heated lubrication and seal oil, oil-filled transformers, cable vaults, coal handling, and control rooms in industrial properties; and cross contamination in hospitals.

Implementing comprehensive human health and life protection requirements, as well as fire protection systems that include hazard detection, alarm, and suppression systems, can be a complex challenge that requires the CxA's thorough understanding and experience of the intricacies of different type of individual projects.

Effective Fire and Hazardous Gas Detection and Alarm Systems

The fire and hazardous gas detection system provides early and reliable detection of fire or hazardous gas, where such events are likely to occur, alerts personnel and initiates protective actions automatically or manually upon operator intervention. Call points include but are not limited to the following:

- Gas detectors for oil and gas skids
- Hydrogen (H_2) detectors for battery rooms
- Spark and flame detectors for coal conveyors and fuel oil tanks
- Heat detection for oil-filled transformers

- Lubrication oil and seal oil skids
- Linear heat detectors for cable galleries and fuel oil tanks
- Smoke and heat detection for plant and nonplant buildings
- Carbon dioxide (CO_2) detectors for school classrooms

Active Fire Protection Systems

These are automatic or manually activated systems involved in actual firefighting: for example, pumping systems, network with fire and gas detection and alarm systems, deluge spray systems, foam systems, CO_2 systems, clean agent systems, portable and mobile extinguishers, and fire station and fire tenders.

Careful design, high-quality installation, and continuous maintenance of explosion prevention and fire protection systems ensures proper safety to the industrial plants.

National Security and Emergency Response Plan

National security and emergency response have become increasingly prominent, and protecting first responders during extraordinary events is highly important. Emergency response plans need to include scheduled routines for training, drills, and fire protection system testing for the fire protection crew and others on staff, as well as instructions for cooperation with national security and civil defense programs. Major concerns include firefighter safety, and making sure that first responders have adequate training and clothing and equipment to deal with any emergency (e.g., hazardous materials, radiological attack, ordinary fires or explosions).

NFPA *Standard* 1600, one of NFPA's most widely implemented standards, establishes a common set of criteria for disaster management, emergency management, and business continuity programs. Also, Chapter 59 of this volume discusses security concerns and measures for HVAC systems.

3. COMMISSIONING COSTS

Commissioning costs vary considerably with project size and building type, equipment type, scope, and traveling requirements (Mills et al. 2004; Wilkenson 2000). Historically, commissioning focused on HVAC and controls, and started during construction. However, quality assurance/quality control (QA/QC) for increasing numbers of systems is 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.*

3.1 DESIGN-PHASE COSTS (INCLUDING PREDESIGN AND DESIGN)

Predesign-phase costs include the CxA's efforts in attending predesign meetings and design reviews with the architect's consulting team and owner's representatives. This portion of work may range from 8 to 12% of the CxA's contract. Design-phase costs include the CxA's reviewing design submittals, coordinated with the designer, and developing sections of the systems manual (design intent and basic operations from the control submittal). This portion of the work may range from 15 to 20% of the CxA contract.

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 (CxA 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 assumes two moderate design reviews. Different types of buildings or more complex buildings with larger scopes of design review may cost considerably more.

3.2 CONSTRUCTION- AND OCCUPANCY/OPERATIONS-PHASE COSTS

Table 1 estimates the CxA's costs for the construction and occupancy/operation phases under the CxA-managed approach. It includes construction- and occupancy/operations-phase commissioning for the HVAC system (including fire and life safety controls, changeover season, and opposite season) and electrical system (including lighting controls, emergency power, and limited connection and grounding checks). It does not include specialty testing such as full infrared scanning, power quality, switchgear, 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 CxA fees; there are also costs to the contractor, designers, and owner's staff. Costs for the mechanical contractor attending meetings, documenting construction checklists, and assisting with testing approximate 10 to 20% of the CxA's mechanical commissioning costs. The electrical contractor's costs may equal the CxA's electrical commissioning costs for electrical commissioning (because contractors are usually responsible for hiring their own electrical testing company to perform electrical tests). International Electrical Testing Association (NETA) tests are often already part of the normal construction program, and the only additional commissioning costs are for the CxA 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] Wilkinson (2000).
[b] PECI (2000).

3.3 EXISTING BUILDINGS

Existing building commissioning (EBCx) is a quality-focused process for attaining the current facility requirements (CFR) of an existing facility and/or its systems and assemblies. The process focuses on planning, investigating, implementing, verifying, and documenting that the facility and/or its systems and assemblies are operated and maintained to meet the CFR, with a program to maintain the enhancements for the remaining life of the facility. System performance normally degrades with use and time, at a rate depending on the quality of maintenance and operations and the number of hours of operation. Quality of maintenance also affects equipment life expectancy. An EBCx effort should include updating or developing an owner's current facility requirements, documenting existing systems, surveying the facility to identify operational inefficiencies, quantifying and prioritizing the inefficiencies found, determining how best to optimize equipment or operation, implementing changes, training operating personnel, documenting operations, and then reverifying with ongoing measurements that the EBCx process activities produced and continue to produce the desired effect.

EBCx is used by owners and facility decision makers to optimize the operations of their existing facilities to meet their current facility requirements. The process has five basic steps, with an additional step for multifacility projects:

- Multifacility planning (if multiple buildings are involved)
- Assessment
- Investigation
- Implementation
- Hand-off
- Ongoing commissioning

After assembling the team for commissioning, the goals and objectives of the process are defined and documented. Existing information on the facilities is gathered and analyzed to determine the order in which the facilities should be commissioned. The order is based on the goals and objectives of the process. Facility ranking can be based on a number of factors, including energy usage, occupant satisfaction, maintenance issues, or other factors determined during development of the goals and objectives. A plan is developed and documents how the EBCx process will proceed among the buildings in the multifacility EBCx program.

The assessment phase includes development of the CFR, an initial assessment of the facility, and development of the EBCx plan. The CFR is developed with the help of users, occupants, and owners to define their specific requirements for the facility based on its current use. The CFR may be different from the original OPR if the facility's use has changed. The initial assessment of the facility is based on existing documentation, benchmarks, interviews with building personnel, and a tour of the facility. From the assessment report, an EBCx plan is developed that defines the project's scope, schedule, team members, and approach of subsequent project phases.

The investigation phase includes more detailed interviews with maintenance personnel, testing and documentation of existing building performance, and identification and analysis of recommended changes. When existing systems may not have the capacity to meet the CFR, system deficiencies need to be documented with a decision on when (or whether) upgrading will be done. For example, indoor air quality objectives may not be met because a system was designed under an older standard or code; temperature objectives may not be met because additional computer equipment loads have been added, and the original system was designed to handle a lower load. In each case, a documented recommendation on the options available should be provided to the owner. After the EBCx team identifies recommended changes, the CxA develops an investigation report that documents the recommended changes and their associated costs and benefits. This report can be used by the owner to select recommendations for implementation.

The implementation phase begins with the owner selecting recommendations for implementation. The selected capital, repair, and upgrade projects are implemented and verified. Informal training on the systems and equipment is provided to the owner's personnel as the projects are implemented.

The hand-off phase transitions the improvements to the owner's O&M personnel. This phase includes developing and reviewing the systems manual, owner training, verification of training, and finalizing the existing building commissioning report.

The ongoing commissioning phase includes EBCx activities that will continue throughout the facility's life. This phase includes verifying achievement of the CFR, reviewing measurement and verification data, investigating unacceptable performance, implementing recommended changes to improve performance, updating facility personnel training, and updating building documentation.

EBCx has been shown to be a very cost-effective way to improve occupant comfort and productivity and optimize operational costs. Energy savings of 13 to 16% with a one- to four-year payback have been reported (Mills 2009).

Buildings with systems ranging from older pneumatic controls to newer **building automation systems (BASs)** have been successfully commissioned. Pneumatic controls limit the number of EBCx options that can be implemented, and may also require separate data logging for monitoring parameters used to calculate energy savings. Modern BASs allow lower-cost EBCx as well as trend logging of various parameters to sustain the savings achieved when the systems are verified to be functioning properly and calibrated.

3.4 CERTIFICATION

Several groups offer certification of commissioning authorities and providers, including the following:

- ASHRAE's Commissioning Process Management Professional (CPMP) program targets individuals who manage and oversee the commissioning process and commissioning team members. Recipients are usually design/consulting professionals and technologists.
- The AABC Commissioning Group (ACG) offers a certification program for TAB engineers.
- The American Society of Healthcare Engineering offers a Health Facility Commissioning® (HFCX) certification.
- The Association of Energy Engineers (AEE) offers a Certified Building Commissioning Professional (CBCP®) certification.
- The Building Commissioning Association (BCA) offers certification for a Certified Commissioning Professional™ (CCP™).
- The National Environmental Balancing Bureau (NEBB) offers certification for commissioning providers by system type (e.g., HVAC, plumbing, fire protection).
- The University of Wisconsin offers three levels of certification: professional, managerial, and technical support.

REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

ASHRAE. 2013. The commissioning process. ASHRAE *Guideline* 0-2013.

ASHRAE. 2007. HVAC&R technical requirements for the commissioning process. ASHRAE *Guideline* 1.1-2007.

ASHRAE. 2008. Preparation of operating and maintenance documentation for building systems. ASHRAE *Guideline* 4-2008 (RA 2013).

ASHRAE 2013. Commissioning Process for Buildings and Systems. ANSI/ASHRAE/IES Standard 202-2013.

Mills, E. 2009. Building commissioning: A golden opportunity for reducing energy costs and greenhouse-gas emissions. *Report* DE-AC02-05CH11231. Lawrence Berkeley Laboratory, Berkeley, CA. Available from cx.lbl.gov/2009-assessment.html.

Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette. 2004. The cost-effectiveness of commercial-buildings commissioning: A meta-analysis of energy and non-energy impacts in existing buildings and new construction in the United States. Lawrence Berkeley National Laboratory *Report* LBNL-56637.

NFPA. 2012. Standard on disaster/emergency management and business continuity programs. *Standard* 1600. National Fire Protection Association, Quincy, MA.

PECI. 2000. *The National Conference on Building Commissioning Proceedings*. Portland Energy Conservation, OR.

Wilkinson, R. 2000. Establishing commissioning fees. *ASHRAE Journal* 42(2):41-47.

BIBLIOGRAPHY

ASHRAE. 2012. The commissioning process for smoke control systems. *Guideline* 1.5-2012.

ASHRAE. 2002. Measurement of energy and demand savings. *Guideline* 14-2002.

ASHRAE. 2002. *Laboratory design guide*.

Claridge, D.E., W.D. Turner, M. Liu, S. Deng, G. Wei, C.H. Culp, H. Chen, and S.Y. Cho. 2004. Is commissioning once enough? *Energy Engineering* 101(4):7-19.

DOE. 2002. *Continuous commissioning guidebook*. www1.eere.energy.gov /femp/operations_maintenance/om_ccguide.html.

Idaho Department of Administration. 1999. *State of Idaho retrocommissioning guidelines*. Available at dpw.idaho.gov/pdf/app7rcg.pdf.

Idaho Department of Administration. 2000. *New-building commissioning guidelines*. dpw.idaho.gov/pdf/app7nbcg.pdf.

Kats, G.H., A.H. Rosenfeld, T.A. McIntosh, and S.A. McGaraghan. 1996. *Energy efficiency as a commodity: The emergence of an efficiency secondary market for savings in commercial buildings*. U.S. Department of Energy Protocol. Available from www.eceee.org/library/conference _proceedings/eceee_Summer_Studies/1997/Panel_2/p2_26.

MDAE. 2000. *Best practices in commissioning in the state of Montana*. Montana Division of Architecture and Engineering.

NEBB. 2009. *Procedural standards for retro-commissioning of existing buildings*. National Environmental Balancing Bureau, Gaithersburg, MD.

NEBB. 2014. *Procedural standards for whole building systems technical commissioning*. National Environmental Balancing Bureau, Gaithersburg, MD.

NFPA. 2015. Flammable and combustible liquids code. *Standard* 30. National Fire Prevention Association, Quincy, MA.

NFPA. 2015. National fuel gas code. *Standard* 54. National Fire Protection Association, Quincy, MA.

NFPA. 2012. Standard for fire and explosion prevention during cleaning and purging of flammable gas piping systems. *Standard* 56. National Fire Protection Association, Quincy, MA.

NFPA. 2013. Standard for the production, storage, and handling of liquefied natural gas (LNG). *Standard* 59A. National Fire Protection Association, Quincy, MA.

NFPA. 2011. Boiler and combustion systems hazards code. *Standard* 85. National Fire Protection Association, Quincy, MA.

NFPA. 2015. Life safety code®. *Standard* 101. National Fire Protection Association, Quincy, MA.

NFPA. 2012. Standard for the prevention of fires and explosions in wood processing and woodworking facilities. *Standard* 664. National Fire Protection Association, Quincy, MA.

SMACNA. 2013. *HVAC systems commissioning manual*. Sheet Metal and Air Conditioning Contractors' National Association, Chantilly, VA.

U.S. DOC. 1992. HVAC functional inspection and testing guide. NTIS *Technical Report* PB92-173012. U.S. Department of Commerce, Washington, D.C., and General Services Administration, Washington, D.C.

U.S. DOE/PECI. 1997. Model commissioning plan and guide commissioning specifications. NTIS *Technical Report* DE97004564. U.S. Department of Energy, Washington, D.C., and Portland Energy Conservation, OR.

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