AABC Commissioning Group




ACG COMMISSIONING GUIDELINE

For Building Owners, Design Professionals
and Commissioning Service Providers

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Comments, criticisms, and suggestions about the subject matter are invited. Any errors or omissions should be brought to the attention of the ACG headquarters.

Table of Contents

Foreword

The first edition of this guideline was published by the Associated Air Balance Council (AABC) in 2002, and has been used as reference material for candidates taking the AABC commissioning certification examination. In 2004, the AABC Commissioning Group (ACG) was founded as a separate nonprofit organization for the primary purpose of administering the AABC commissioning certification program to architects and engineers. The copyright for the guideline was subsequently granted to ACG and the guideline is now used as the primary reference for the new ACG commissioning certification exam.

The only substantive change to the guideline is Chapter 3, "Selecting a Commissioning Provider." This chapter has been completely reorganized and rewritten to include information about provider qualifications and the new ACG certification program for architects and engineers.

The ACG Commissioning Guideline focuses on HVAC commissioning because it was written by industry professionals experienced in the testing of HVAC systems. Nevertheless, *Environmental Building News* referred to the guideline as "one of the clearest descriptions of the commissioning process we've seen."

CHAPTER 1 Introduction

1.1 HVAC Commissioning

Today's HVAC systems must be energy efficient, satisfy stringent indoor air quality and comfort expectations, and still be designed and constructed within tight budgets. System designs meeting these demands typically have many components, sub-systems, and controls. Additionally, building construction involves many specialized trades that often work independently of one another. Ineffective communication and coordination between designers and contractors, and among contractors, can produce HVAC systems with installation deficiencies that do not perform properly. Without verification of the correct interaction and operation of all systems and components, system performance as specified and intended is unlikely to occur.

Commissioning is a systematic process that addresses these issues. It facilitates and ensures the required communication, coordination, testing, and verification, and results in the delivery of a building whose HVAC systems perform as intended. Effective HVAC commissioning is an intentional, visible, cooperative and proactive process. It includes design review, installation verification, proper system start-ups, functional performance tests, operations and maintenance (O&M) training, and complete documentation of the HVAC systems. It assists in the coordination of construction schedules and sequences to facilitate an efficient construction process and challenges systems to perform as designed under all specified modes of operation. O&M staff training provides a basis for continued optimum HVAC systems performance throughout a facility's existence. In summary, commissioning serves the owner's best interests by delivering a facility with systems that perform as specified, intended, and paid for.

For the best possible results, commissioning should be included in all phases of the design and construction process:

- pre-design
- design
- construction
- acceptance
- post-acceptance

Commissioning requirements are then considered and incorporated from project inception. The ACG Commissioning Guideline refers to this recommended approach as "comprehensive HVAC commissioning."

In many cases, however, commissioning is not considered until a project reaches the construction phase. While still valuable, implementing commissioning after construction begins will be less effective than comprehensive commissioning, which starts at the pre-design phase, because there is less opportunity to organize and plan ahead. Because construction commissioning is widely used, this Guideline includes a "construction HVAC commissioning" methodology as an alternative to comprehensive commissioning.

The commissioning authority works directly for the owner and is independent of designers, contractors, vendors and suppliers on the project.

Regardless of the commissioning process used, there are many benefits from commissioning. Some of these benefits are:

- Reduction of change orders and additional claims
- Fewer project delays
- Managed start-up requirements
- Shorter building turn-over transition period
- Less post-occupancy corrective work
- Minimized effects from design changes
- Improved indoor air quality and occupant productivity
- Better operation, maintenance and reliability
- Lower energy and operations costs
- Value-added quality construction
- Complete and useful O&M documentation
- Owner advocacy for design and construction decisions
- Documentation of the entire construction process

1.2 HVAC Commissioning Service Providers

HVAC commissioning requires a team approach. The leader of the commissioning team is the commissioning authority.

The HVAC commissioning authority works directly for the owner and is independent of designers, contractors, vendors and suppliers on the project. Such independence is essential for the authority to be seen as totally objective in leading the commissioning process. The HVAC commissioning authority must maintain an unbiased approach to problem solving and conflict resolution.

Important qualifications and skills of HVAC Commissioning Agencies include:

- Knowledge of HVAC systems, covering design, common control strategies, installation, operations and maintenance
- Experience in controls for HVAC systems, including familiarity with current technology, both conventional and direct digital control
- Practical field construction background
- Demonstrated ability to organize many specific activities into a coherent commissioning plan
- Communications skills, both written and verbal
- Proficiency in documentation
- Experience working with multi-disciplinary teams
- Familiarity with testing and balancing

ACG has established its Commissioning Certification Program to ensure quality performance in the industry and to help owners select a commissioning authority.

Commissioning is a quality assurance process, and ACG has established its Commissioning Certification Program to ensure quality performance in the industry and to help owners select a commissioning authority that has the requisite skills and expertise. The program provides a way to identify and certify companies with the qualifications needed to provide superior HVAC commissioning services.

1.3 Scope

The scope of the ACG Commissioning Guideline:

- Provides information on the ACG commissioning certification program
- Provides detailed methodology for both comprehensive and construction HVAC commissioning
- Covers commissioning in both new construction and existing buildings
- Covers HVAC systems typically found in commercial and institutional buildings
- Provides standards for proper documentation and reporting, with sample forms
- Defines the roles and responsibilities of all commissioning team members

The detailed methodology contained in this Guideline for HVAC commissioning can be adapted to the commissioning of non-HVAC systems. Organization, coordination, scheduling, and documentation concepts and basic methodology will be similar for all types of systems. However, the commissioning team membership and content of the system verification, start-up, and functional performance test checklists and system documentation will have to reflect the technical requirements of whatever system is being commissioned.

1.4 Purpose

The purposes of the Guideline are:

- To educate the industry about the commissioning process
- To provide standardized, practical methodologies for commissioning
- To introduce a program for certifying qualified commissioning providers

CHAPTER 2 HVAC Commissioning Cost/Benefit Analysis

2.1 HVAC Commissioning Benefits

HVAC commissioning promotes a quality assurance approach resulting in significant value to the owner. The specific benefits of the HVAC commissioning process include:

- **Reduction of change orders and additional claims—**In Comprehensive HVAC Commissioning, the commissioning authority carries out reviews of the design and of contractor submittals as part of planning for commissioning. These reviews often identify potential problems that can be considered by the designer and result in revisions that avoid future change orders and claims.
- **Fewer deficiencies at substantial completion—**During construction, commissioning identifies incorrect or incomplete work early, allowing corrections to be done, documented, followed-up, and re-tested. Thus most problems are corrected before substantial completion so the building will be fully operational at that time.

  When deficiencies do remain at substantial completion, commissioning ensures they are well documented and that responsibility for correction has been established.
- **Fewer project delays—**The detailed schedule and coordination information provided by the commissioning process allows contractors to schedule and sequence the required work efficiently. Problems are therefore identified and resolved with minimal delay, and the project stays on schedule.
- **Managed start-up procedures—**Preparations for equipment and system start-up involve many interrelated contractor tasks. Commissioning's focus on planning and coordination facilitates implementing those tasks more efficiently.
- **Shorter building turnover transition period—**When a building's HVAC systems operate as intended, and its O&M staff is properly trained, the building moves quickly to a fully operational status. The O&M staff can focus on keeping the systems operating properly, and not on modifying poorly performing systems to correct installation problems.

- **Less post-occupancy corrective work—**Functional performance tests, as part of the commissioning process, identify problems that a physical inspection cannot detect. Diagnosis is facilitated by the logical test protocols used in commissioning, and because contractors are still on-site, correction and re-testing occur quickly. As a result, fewer problems show up after occupancy, and any corrective work is minimized in cost and disruption.
- **Minimized impact from design changes—**Comprehensive commissioning identifies, early on, potential design problems, such as lack of access for commissioning or maintenance, provisions (or lack thereof) for TAB work, and incomplete control sequence descriptions. Design revisions can be made on paper, and not in the form of physical changes on-site, greatly reducing their negative impact.

Functional performance tests identify problems that a physical inspection cannot detect.

- **Improved indoor air quality and occupant productivity—**When HVAC system designs meet occupancy needs, and they are operated and maintained properly, good indoor air quality results. This includes good temperature and humidity control, correct outside airflows, good air distribution within the space, cleaner air, and reduced odors. Good indoor air quality contributes to satisfied occupants and improved productivity.
- **Better operation, maintenance and reliability—**Effective training ensures the O&M staff has the information and documentation needed to operate and maintain the HVAC systems correctly. This includes a planned preventive maintenance (PM) program that results in maintaining efficiency, keeping systems clean, keeping accurate temperature control, reducing equipment failures, extending equipment life, and keeping good records.
- **Lower energy and operations costs—**HVAC systems typically use a substantial portion of a building's total energy consumption. Thus improved efficiency is an important and tangible benefit. An optimized PM program improves reliability and extends equipment life.
- **Value-added construction quality—**Commissioning produces a focus on schedule, sequence of work, coordination, and ensuring a quality product. Quality buildings result in satisfied occupants, more lease renewals for tenant-occupied buildings, and a favorable reputation as a good place to work or visit.
- **Complete and useful documentation—**The commissioning process produces valuable documentation throughout the project that has value in providing owners and O&M staff with relevant information. Examples are: the commissioning plan and final commissioning report (both including systems verification, start-up and functional performance test checklists), complete and usable O&M manuals, and a videotape record of O&M training sessions.

- **More knowledgeable O&M staff—**Even the best building will encounter problems from time to time. The commissioning process emphasis on training and documentation should result in a more knowledgeable O&M staff, both initially and over time as personnel change. Thus, when problems do arise, the O&M staff is better equipped to diagnose and correct the problems themselves, or to understand when outside expertise is needed.
- **Improved future designs—**Feedback from additional design reviews and from documentation of on-site commissioning activities give planners and designers a broader perspective and knowledge of installation and commissioning issues needing design attention. This information can be applied to improve future designs.
- **Owner advocacy for design and construction decisions—**As owners experience all the foregoing benefits of commissioning, they will have information that enables them to advocate its use more widely and to put a greater emphasis on quality and value in their projects from design through construction to operation and maintenance.

Most commissioning benefits continue for the life of the building.

2.2 HVAC Commissioning Cost/Benefit Analysis

Experience indicates that the overall cost of comprehensive HVAC commissioning is usually between 2% and 5% of the HVAC construction cost. A building with simple HVAC systems, few zones, and simple control strategies will be at the lower end of this cost range. Buildings with complex systems and intricate control strategies, particularly with interfaces between systems, will be at the upper end of this cost range.

The overall cost of construction HVAC commissioning is approximately 80% of that for comprehensive commissioning because commissioning work is concentrated in the construction and acceptance phases. The cost of the commissioning planning and organizational work carried out during the pre-design and design phases in comprehensive commissioning is minimal compared to the value added.

The exact value placed on each of the foregoing benefits will vary from owner to owner, and from building to building. Generally, however, the value of benefits will be greater for larger, more complex buildings—more than compensating for the higher commissioning costs in these buildings. Most commissioning benefits continue for the life of the building, whereas implementing the commissioning process is a one-time cost. Therefore, any realistic analysis of the initial and ongoing benefits of commissioning, compared to its modest cost, will demonstrate that commissioning can be justified in virtually every building.

CHAPTER 3 Selecting a Commissioning Provider

Selecting the commissioning provider represents one of the most important commissioning decisions that a building owner makes. The provider should be certified by a nationally recognized organization and have the requisite qualifications for the project that is being commissioned.

3.1 Request for Qualifications and Proposals

Request for Qualifications (RFQ) documents ask for details concerning previous relevant commissioning experience. The selection process warrants a thorough interview and verification of past performance. The RFQ will help narrow the list of commissioning providers that receive a Request for Proposal (RFP), thus reducing the number of RFP reviews required of the owner and consultants. An interview process, a Request for Proposal (RFP) process, and contract negotiations for the selected respondent typically follows the RFQ process.

The RFQ should include as much information about the project as possible. As a minimum, the RFQ should contain the following information:

- Date of Issuance
- RFQ Due Date
- Owner/Program Manager Contact Information
- Project/Program Description
- Project/Program Schedule
- Small Business/Minority Business Participation Goals
- Characterization of the Request
- Qualification Requirements
- RFQ and Selection Process Description
- Selection Criteria
- Notification of Selection/Unsuccessful Respondent Protocol

Request for Proposal (RFP) requirements typically involve greater characterization of commissioning services provided by the respondent, with particular emphasis on the procedures and application of these services to the specific project. The RFP should also include as much information about the project as possible, and usually provides details of schematic design for the systems to be commissioned. Proposed cost for services will be requested for review. As a minimum, the RFP should contain the following information:

The commissioning RFP should include as much information about the project as possible.

- Date of Issuance
- RFP due date
- Owner/program manager contact information
- Project name and location
- Project/program description
- Project/program schedule
- Small Business/Minority Business participation goals
- Characterization of the request
- Qualification requirements
- RFQ and selection process description
- Selection criteria
- Notification of selection/unsuccessful respondent protocol
- Approximate size, use and occupancy of the facility
- Types of systems to be commissioned
- Special project considerations
- Design team identification
- Design and construction document development and distribution process
- Submittal requirements
- Request for scope of proposed services
- Request for cost of services
- Detailed break-out of services costs
- Hourly charge-out rates for services applying to duly authorized extra work
- Interview or pre-proposal conference schedules
- Restrictions on communications with selection team members
- Rules of withdrawal
- Non-collusion affidavit
- Insurance requirements
- Contract requirements

3.2 Commissioning Authority

The commissioning authority is the leader of the commissioning team and is responsible for planning, organizing, and facilitating the commissioning process on behalf of the owner. In addition to having good technical knowledge of the systems being commissioned, the commissioning authority must also have a complete understanding of the commissioning process. The commissioning authority must possess organizational, documentation, communications, and team-building skills to effectively lead and coordinate the commissioning team.

3.2.1 Independent Third Party Under Contract to the Owner

A third party professional brings objectivity and practical experience to the project to provide a consistent level of assurance that the owner's best interests will be served.

Independent certified commissioning authority under direct contract to the owner represents the preferred delivery model for commissioning services advocated by ACG. A third party professional brings objectivity and practical experience to the project to provide a consistent level of assurance that the owner's best interests will be served.

Although many contractors possess the knowledge and capability to test the equipment they install, they may not be skilled at testing, documenting, or diagnosing integration problems. It is difficult for contractors to objectively test and assess their own work, especially since repairing deficiencies found through commissioning may increase their costs. While it is essential that contractors verify and test their installations, this required practice does not result in formal commissioning without appropriate independent oversight. Similar discussions concerning designer/consutant roles in the construction, installation, and acceptance of building systems leads to the preferred model of independent third party commissioning services.

It is important to involve the independent commissioning authority as early in the project as possible. This allows the provider the opportunity to review the design intent for the project, begin scheduling commissioning activities, and begin writing specifications into bid documents for other contractors.

3.3 ACG Commissioning Certification

Since 2002, the Associated Air Balance Council (AABC) has administered a successful commissioning certification program for Test and Balance Engineers. The AABC Commissioning Group (ACG) was established in 2004 as a separate non-profit association dedicated to advancing professional, independent commissioning services through education, training, and certification of qualified providers.

Candidates for certification must be a registered architect (AIA), a licensed professional engineer (PE), or a certified Test and Balance Engineer (TBE). Through a detailed application and examination process, ACG awards the designation Certified commissioning authority (CxA) to successful candidates, providing a meaningful commissioning credential that owners can request when selecting a qualified provider.

3.3.1 HVAC Commissioning Qualifications

These qualifications are focused on HVAC and control systems. Additional technical qualifications will apply for commissioning of other systems, such as electrical. When commissioning authorities do not have the expertise on staff for specific systems, they will often team with other professionals to address all systems being commissioned.

- Experience in the testing, design, specification, or installation of commercial building mechanical and control systems and other systems being commissioned.
- Experience working with project teams, project management and conducting scoping meetings; good team-building skills; strong communication skills, especially documentation.
- Experience commissioning at least two projects of similar size and of similar equipment to the current project. This experience should include writing functional performance test plans and assembling a complete commissioning plan.
- Direct responsibility for project management of at least two commercial construction or installation projects with mechanical costs greater than or equal to current project costs.
- Experience in design installation and/or troubleshooting of direct digital controls and energy management systems, if applicable.
- Demonstrated familiarity with metering and monitoring procedures.
- Knowledge and familiarity with air and water testing and balancing.
- Experience in planning and delivering O&M training.

3.4 TAB and Functional Performance Testing

Testing and balancing (TAB) is an integral part of the commissioning process. It is therefore recommended that an independent third party be retained to perform testing and balancing services on commissioning projects. ACG advocates providing TAB as a direct to owner contractual service.

Functional performance testing (FPT) of equipment and systems is at the heart of the commissioning process. Equipment operation during FPT's is performed by the appropriate contractor or equipment manufacturer, but the responsibility for directing, witnessing, and documenting the tests rests with the commissioning authority. The CxA may utilize an independent third party with field experience in the testing and analysis of equipment and systems, who becomes part of the commissioning team. This arrangement is especially desirable when the commissioning authority does not have significant experience and expertise with field testing of the equipment and systems to be commissioned.

Functional performance testing is at the heart of the commissioning process.

AABC certified test and balance engineers (TBEs) are independent and they possess the technical expertise to carry out both HVAC functional performance testing and TAB services. The Associated Air Balance Council (AABC) was founded on the principle of independence, and has been certifying TBEs since 1965. Independence will continue to be the hallmark of both AABC and ACG.

CHAPTER 4 The HVAC Commissioning Team

4.1 The HVAC Commissioning Team

Commissioning is a team effort and requires communication, coordination and cooperation among all parties involved with the project. The commissioning authority is the leader of the team. Typically the members of an HVAC Commissioning Team from the construction phase until the end of the project may include representatives of the following:

- owner
- architect
- electrical engineer
- mechanical contractor
- controls contractor
- TAB agency
- general contractor (or construction manager)
- end-user
- mechanical engineer
- commissioning authority
- electrical contractor
- sheet metal contractor
- owner's O&M staff

Not all commissioning team members will be fully involved throughout the project. However, each does need to be active before and during the time their particular contractual responsibilities are being scheduled or carried out. The detailed descriptions of HVAC commissioning methodologies in Chapters 5, 6 and 7 of this Guideline identify the roles and responsibilities of all parties as they typically occur.

4.2 Comprehensive HVAC Commissioning–New Construction

The Guideline recommends the use of Comprehensive HVAC Commissioning in new construction. In this approach, commissioning starts at the inception of a building project during the pre-design phase, and continues through the post-acceptance phase. Participation of the commissioning authority from the earliest pre-design provides an opportunity to cultivate a quality management focus among all design and construction team members as they become involved with the project.

Table 4.1
Comprehensive HVAC Commissioning Summary

Phase	Key Commissioning Activities
Pre-design	■ Commissioning is established as an integral part of the project ■ The owner selects the commissioning authority ■ Develop the scope of commissioning ■ Commissioning authority reviews design intent document
Design	■ Review design to ensure it accommodates commissioning ■ Write commissioning specifications defining contractor responsibilities ■ Commissioning authority writes the commissioning plan ■ Establish the project schedule
Construction	■ Commissioning authority reviews contractor submittals ■ Commissioning authority updates commissioning plan ■ Commissioning process is coordinated—through project schedule, commissioning plan and commissioning plan and commissioning meetings ■ Carry out and document system verification checks ■ Carry out the document equipment and system start-ups ■ TAB agency completes and documents test and balance work
Acceptance	■ Carry out functional performance tests on all HVAC systems ■ Train the O&M staff for effective, ongoing operations and maintenance of all systems ■ Provide full documentation
Post-Acceptance	■ Correct any deficiencies, and carry out any required re-testing ■ Carry out any required "off-season" tests ■ Update documentation as required

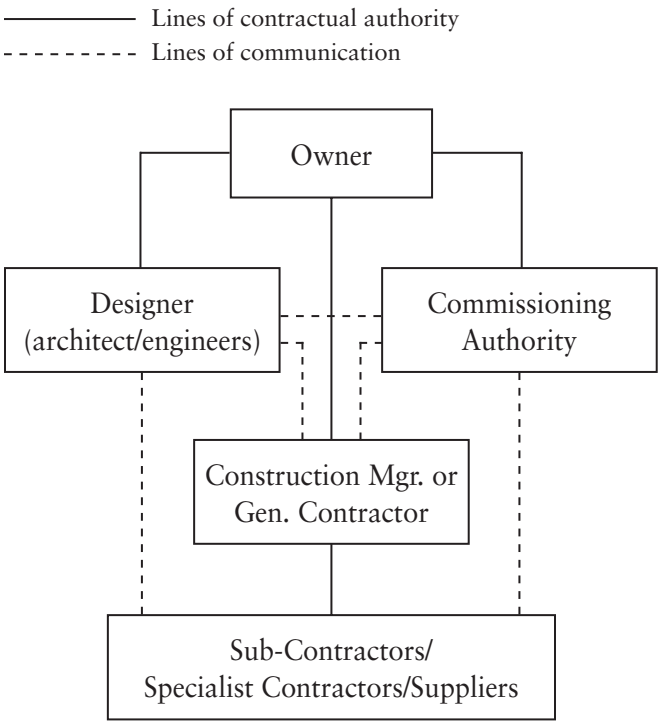

Figure 4.1 Organizational Structure for Comprehensive HVAC Commissioning—Plan and Spec

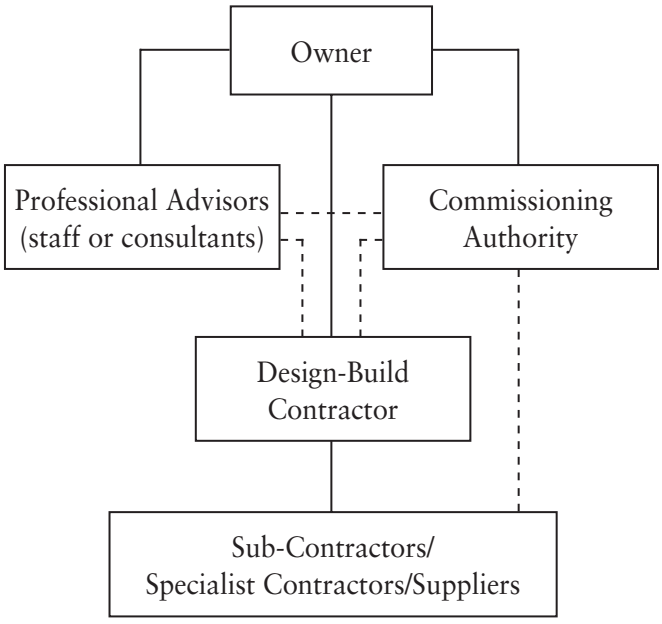

Figure 4.2 Organizational Structure for Comprehensive HVAC Commissioning—Design-Build

Table 4.1 gives a summary of the key commissioning activities undertaken during each phase of the comprehensive commissioning process for HVAC systems.

Chapter 5 of the ACG Commissioning Guideline contains a detailed methodology for carrying out Comprehensive HVAC Commissioning. It provides a complete list of commissioning activities, lists responsibilities for each, and indicates how each activity relates to the others.

The owner, or the owner's representative, selects the commissioning authority directly. The authority leads the commissioning process, and works cooperatively with the designers and contractors, but always in the owner's interest. In particular, the commissioning authority facilitates communication and coordination among designers, contractors and suppliers. Commissioning can be carried out within any contractual arrangement.

If the project uses the traditional plan and spec process, the commissioning authority will typically report directly to the owner, or the owner's representative. Figure 4.1 shows the recommended formal organizational structure for Comprehensive HVAC Commissioning with plan and spec. The methodology in Chapter 5 assumes this structure.

Table 4.2
Construction HVAC Commissioning Summary

Phase	Key Commissioning Activities
Construction	■ Identify commissioning scope; develop commissioning test details ■ Commissioning authority reviews contractor submittals ■ Coordinate commissioning process—through commissioning plan, commissioning meeting and schedule ■ Carry out and document system verification checks ■ Observe and document equipment and system start-ups ■ TAB agency completes and documents test and balance work
Acceptance	■ Carry out and document functional performance tests ■ Verify reported TAB results ■ Train O&M staff ■ Submit final commissioning report
Post-Acceptance	■ Carry out and document any required "off season" functional performance tests ■ Revise and submit final commissioning report, if required

Commissioning also applies to design- build projects, where a single entity (or joint venture) is responsible for both the detailed design and construction. However, the owner must develop a functional program and performance requirements upon which the design-build contractors' bids or proposals are based. Professional advisors or the owner's own staff will prepare these documents. These advisors will also monitor the design- build contractor's work and usually accept the final project on the owner's behalf. Figure 4.2 shows the formal organizational structure for Comprehensive HVAC Commissioning with design-build.

4.3 Construction HVAC Commissioning—New Construction

Construction HVAC Commissioning takes place during the construction, acceptance and post-acceptance phases of the project. Delaying the start of the commissioning process until the construction phase eliminates the pre-design and design phase planning and preparation included in Comprehensive HVAC Commissioning. This has a negative impact on commissioning effectiveness, and produces very little cost savings. The contractor has little or no advance warning that commissioning will occur. The commissioning authority has minimal time to plan and coordinate the commissioning process before system start-ups are scheduled.

Construction HVAC Commissioning severely limits the lead time the commissioning authority has to establish a commissioning "culture" on the jobsite that emphasizes doing the installation correctly the first time, finding and correcting any problems early so delays and extra costs are minimized, and finally, testing systems performance to confirm specified functionality. The later commissioning starts, the greater the risk of a confrontational—instead of a cooperative—relationship developing between the commissioning authority and the contractor. Construction commissioning can still achieve its primary benefit—systems that function as they should—but may not do so with the comprehensiveness and efficiency that comes with early planning and preparation through the pre-design and design phases.

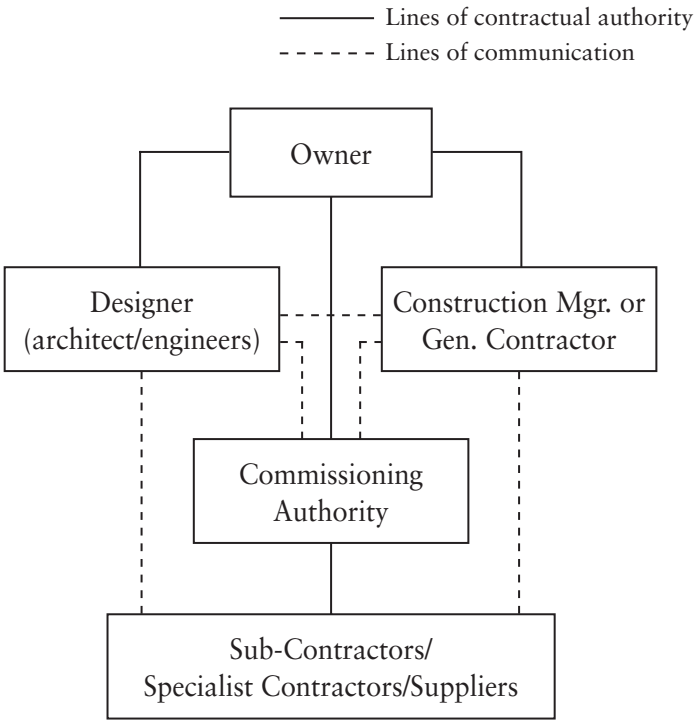

Figure 4.3 Organizational Structure for Comprehensive HVAC Commissioning—Plan and Spec. Project

Construction HVAC Commissioning can come about in two basic ways. First, at some time during design phase, the owner is convinced to include commissioning in the project. In this case, specification sections describing the contractor's commissioning responsibilities can be included in the contract documents. Second, the issue of commissioning does not arise until the project is in construction. The commissioning authority will be retained, and will typically work with the designer and contractor to plan and implement commissioning. The commissioning authority will write and distribute a commissioning plan that covers as much of the commissioning process as the available lead time permits. Contractor commissioning resposibilities will not be in the original contract documents, so these must be detailed in specification addendums issued to allow the contractors an opportunity to quote on the costs of extra work.

Table 4.2 provides a summary of key Construction HVAC Commissioning activities. Chapter 6 of the ACG Commissioning Guideline contains a detailed methodology for carrying out Construction HVAC Commissioning.

Table 4.3
HVAC Commissioning or Retrocommissioning in Existing Buiding

Phase	Key Commissioning Activities
Planning	■ The owner selects the commissioning authority ■ The scope of commissioning is identified ■ Review existing documentation, if available ■ Carry out a survey to gather and document needed information, if existing documentation does not exist or is inaccurate ■ Review system operation and control sequences in detail ■ Prepare commissioning plan
Implementation	■ Balance systems, document and verify the results, if that is part of the commissioning scope ■ Carry out functional performance tests on all HVAC systems included in scope to confirm and verify that they meet expected requirements; document results ■ Review O&M staff training; provide additional training or retraining as needed ■ Complete commissioning report

In construction commissioning, the commissioning authority is often included within the general contractor's scope of work, reporting to the general contractor as well as to the designer and owner. Figure 4-3 illustrates this Construction HVAC Commissioning organizational structure.

4.4 HVAC Commissioning in Existing Buildings

HVAC commissioning in existing buildings can take place for a number of reasons, including:

- Periodic re-commissioning—Periodically, the HVAC systems in a building that were commissioned when new are re-commissioned. The purpose of re-commissioning could be to diagnose the cause of ongoing, unresolved problems, or as part of a planned preventive maintenance program that includes formal re-commissioning elements. Recommissioning may be limited to the systems exhibiting problems, or may be carried out on all HVAC systems in the building.

- **Retro-commissioning—**Retro-commissioning methodology is identical to that for re-commissioning, except that it occurs when the HVAC systems in a building were not commissioned when new, and are being commissioned for the first time.
- HVAC system modifications—As occupancy or operational requirements change over time, HVAC system modifications will be undertaken to meet the new requirements. As with new construction, commissioning will ensure that the modification work has been carried out in accordance with the contract documents and design intent, and that new work has been properly integrated with existing systems.

Table 4.3 shows key commissioning activities in situations where recommissioning or retro-commissioning is being carried out as part of an evaluation of the performance of existing HVAC systems, without any simultaneous renovations or modifications. The commissioning phases have been adjusted to reflect the fact that there isn't any directly related construction work. It is important to note, however, that the results of the recommissioning or retro-commissioning may well result in identifying needed system modifications.

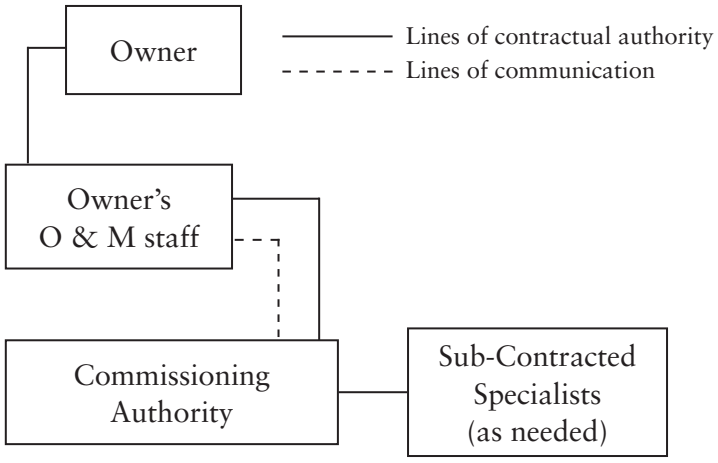

Figure 4.4 Organizational structure for re-commissioning or retrocommissioning in existing buildings

Chapter 7 of the ACG Commissioning Guideline contains a detailed description of the typical activities involved in commissioning HVAC systems in existing buildings.

The organization of a re-commissioning or retro-commissioning project, as just described is typically between the owner, the owner's O&M staff, and the commissioning authority. Figure 4.4 illustrates the typical contractual structure for such work.

If HVAC commissioning is being carried out as part of a building renovation project, then the key commissioning activities shown in Table 4.1 for Comprehensive HVAC Commissioning will generally apply. The organizational structure for commissioning in a building renovation project will typically be as shown in Figures 4.1 or 4.2, depending on whether the work is being done on a plan and spec or a design- build basis. The scope of commissioning will typically

be limited to the systems (or portions of systems) being modified or replaced. Existing systems that interface with the new work will be included in the commissioning scope to ensure correct systems and control integration has been achieved.

CHAPTER 5 Comprehensive HVAC Commissioning

5.1 Overview

ACG recommends comprehensive commissioning, which starts at the pre-design phase of a project, as the ideal approach to HVAC Commissioning. Commissioning, with its quality management focus, should be part of the project from its inception because an early start provides maximum benefits.

This chapter presents a detailed methodology for carrying out comprehensive HVAC commissioning, organized by project phase. For each phase, the required commissioning activities are listed. A detailed description of each activity and assignment of responsibility is given. Where applicable, references to sample specifications, forms or other material in the Appendices to this Guideline are provided.

The commissioning process methodology contained in this chapter is based on a traditional plan-and-spec organizational structure, as shown in Figure 4.1.

5.2 Pre-Design Phase

Commissioning activities during the pre-design phase are intended to establish commissioning as an integral part of the overall design, documentation and construction of the building.

5.2.1 Determine Commissioning Scope

After deciding to include HVAC commissioning on a project, the owner must determine the scope of commissioning – both in terms of what equipment and systems will be commissioned, and the general process to be used. These factors will determine the commissioning authority's scope of work.

Owners with established in-house commissioning programs typically have a commissioning protocol and generic forms for equipment and systems to be commissioned. Owners without such a program may need prospective commissioning authorities or other advisors to present them with information on the commissioning process, its benefits and costs, and the extent to which systems on a particular project should be commissioned.

5.2.2 Contract Commissioning Services

The owner initiates the commissioning process by deciding to retain a commissioning authority. Typically the owner will have information concerning the size and usage for the proposed building, and perhaps some design concepts, but generally little else.

Regardless of its form, the commissioning proposal should be specific concerning the scope of services provided. If the owner does not include details in the proposal request, then the commissioning authority must propose a suitable scope of work. ACG recommends clearly defining the responsibilities of the commissioning authority and the owner from the outset. A sample Request for Proposal (RFP) document giving information the owner should provide is included in Appendix 'A'.

The commissioning authority provides a fixed cost for the pre-design and design phase involvement, and an adjustable, estimated not-to-exceed cost for the remaining phases.

Along with the proposed scope of work, an experienced commissioning authority will be able to provide a preliminary commissioning services budget. The commissioning authority provides a fixed cost for the pre-design and design phase involvement, and an adjustable, estimated not-to-exceed cost for the remaining phases. That estimate can later be defined more precisely during the design phase, as details emerge on the type, number, capacity and zoning of HVAC systems in the project. At that time, the owner and commissioning authority can agree on a firm commissioning services fee for the construction, acceptance and post-acceptance phases. This scheme enables the commissioning authority to participate in the pre-design phase without having to commit to a firm price quotation for the entire project when there is insufficient information to do so.

5.2.3 Design Intent Document (DID)

The designer is responsible for the design intent document (DID), which defines the technical design criteria required to satisfy the building's intended use and occupancy needs. The DID continues to evolve throughout the design and construction phases to reflect changes and modifications arising from input by the owner, designers, suppliers and contractors as approved by the designer of record. Use and occupancy information comes from the owner. The commissioning authority reviews the DID and may provide information useful for establishing commissioning test criteria.

Typical design intent information includes the following:

- Overall building and specific space usage and requirements
- Design indoor environmental conditions including:
  - —Temperature
  - —Relative humidity
  - —Maximum air velocity (drafts) within the occupied area

—Outdoor ventilation air requirements

—Air changes per hour

—Space pressure – relative to adjacent spaces

—Acceptable tolerances for all of the above

—Barrier issues between adjacent spaces

—Occupancy assumptions

- Applicable codes, standards and regulations. These must include legal requirements such as building codes, fire and life-safety regulations, and specialized equipment or system codes, but may also include owner-mandated requirements and other standards
- Energy considerations—consumption and cost goals
- Building envelope characteristics
- Service shaft and mechanical room leakage characteristics, if these are used as plenums or for airflow
- Criteria for Leadership in Energy and Environmental Design (LEED) certification of green buildings
- Documentation requirements—identifies the owner's expectations, and who will be responsible for the various types of documents.
- Facility management—information about how the building and its systems will be operated and maintained, and by whom.

The pre-design commissioning outline is prepared by the commissioning authority.

5.2.4 Pre-Design Outline

The pre-design commissioning outline, prepared by the commissioning authority, typically contains the following information:

- Description of the commissioning process
- Identification of commissioning team structure, with a summary of the roles and responsibilities of each team member.
- Preliminary commissioning time requirements for each project phase.
- Commissioning cost estimates.
- Identification of the systems to be commissioned. At the pre-design phase, details of the types and number of systems may not be available, so the descriptions might have to be generic.

The commissioning outline is submitted to the owner for approval.

5.2.5 Approve Commissioning Outline

The owner and his design consultants review the commissioning outline. Once approved, it is distributed to all members of the design team, and guides design phase commissioning activities, particularly commissioning specifications and the commissioning plan.

5.3 Design Phase

Although the designer is responsible for the entire design, projects often benefit from independent design reviews.

The design phase is a time to ensure that both the construction documents and the design phase commissioning plan include the information required to guide successful commissioning during bidding and during the construction, acceptance, and post-acceptance phases. The following activities typically occur in the design phase.

5.3.1 Identify HVAC Systems

The designer works from the concepts identified during the pre-design phase to develop a schematic design. When the schematic design is approved, the owner, designer, and commissioning authority identify all HVAC systems to be commissioned using the commissioning outline as a guide.

5.3.2 Design reviews

Although the designer is responsible for the entire design, projects often benefit from independent design reviews when they produce constructive suggestions for the designer's consideration.

The commissioning authority carries out a review of design documents (drawings and specifications) as they are produced, particularly from the valuable and practical perspective of extensive field experience. Some of the review issues are:

- Balancing dampers, pressure ports, and access as needed for TAB or for observing physical responses of components during commissioning tests.
- Access for equipment maintenance and replacement.
- Barrier and inter-connection issues between buildings or spaces.
- Equipment locations and capabilities vs. occupancy needs.
- Description of each system, and its intended use.
- Flow and schematic diagrams to assist in describing more complex systems and how systems interact with one another.
- Building Automation Systems (BAS) layout; provide access to BAS data when and where required to support TAB and commissioning
- Complete and unambiguous control sequence descriptions.

- Equipment labeling requirements
- Inclusion of design criteria and assumptions.

5.3.3 Commissioning Specifications

The designer has sole responsibility for the specifications. The commissioning authority should review the specifications to ensure inclusion of material describing the contractor's responsibilities related to commissioning. Comments and suggestions should be forwarded to the designer for consideration.

The commissioning specification should include:

- Identification of the commissioning authority, and its role and responsibilities.
- A summary of the roles and responsibilities of all other team members.
- A list of all equipment, systems, and interfaces to be commissioned.
- System Verification Checklists (SVCs) for each type of equipment and system being commissioned.
- Functional Performance Test (FPT) checklists for each different system being commissioned.
- Detailed commissioning responsibilities of the general contractor (or construction manager).
- Detailed commissioning responsibilities of the mechanical contractor, noting that they apply to all mechanical sub-trades and suppliers associated with work on equipment and systems being commissioned.
- Detailed commissioning responsibilities of the TAB agency.
- Detailed commissioning responsibilities of the controls contractor.
- Detailed commissioning responsibilities of the electrical contractor.
- Detailed commissioning responsibilities of any other contractors whose scope of work includes systems being commissioned by the commissioning authority.
- Requirements for training the owner's O&M staff. These may include instruction sessions, with input from equipment manufacturers' representatives, and site demonstrations by applicable contractors. Videotaped training sessions may be required.
- Documentation requirements, such as copies of submittal data, manufacturers' operations and maintenance data, and contact information for all relevant contractors and suppliers
- Emphasis on cooperation necessary to maintain construction schedule with commissioning activities incorporated. Detail commissioning meeting requirements.

- Cross-references included in other sections of the specification where contractor or trade-specific commissioning requirements are applicable.
- Language assigning financial responsibilities for failed tests or tests aborted due to incomplete installation to the appropriate parties.

A sample specification illustrating typical commissioning responsibilities for all contractors is included in this Guideline as Appendix 'B'.

5.3.4 Design-Phase Plan

The commissioning plan typically includes the scope of commissioning, describing the overall commissioning process and listing all equipment, systems, and interfaces to be commissioned.

Expanding on the pre-design outline, the commissioning authority prepares the commissioning plan based on the final design information. The commissioning plan, submitted to the owner and designer for their review, typically includes the following:

- **The scope of commissioning—**This section describes the overall commissioning process, and lists all equipment, systems, and interfaces to be commissioned.
- **The commissioning team—**The plan lists all members of the commissioning team, identified by individual name and corporate identity (if known) or by functional identity (e.g. general contractor, mechanical contractor, etc.) and describes their roles and responsibilities.
- **Reference documents—**These will include the drawings and specifications for the project. In addition, published standards or guidelines relevant to commissioning requirements will be referenced.
- **Commissioning meetings—**Describe the purpose and number of commissioning meetings.
- **System-specific details—**For each system to be commissioned, the commissioning plan will include the details listed below. The plan should also identify the required testing sequence, progressing logically from equipment, to sub-systems, to systems, to interactions between systems.
  - **—Equipment readiness –**Describe the system verification checks to be carried out prior to start-up, and include specific checklists. Sample system verification checklists are in Appendix 'C'.
  - **—Equipment and system start-ups –**Describe the step-by-step start-up procedure for each system and piece of equipment. Often this information is contained in the same checklist as the system verification (or pre-start) checks. If the specification requires that the manufacturer's authorized technician perform the start-up, then the plan should require that a copy of the completed and signed manufacturer start-up form be included with the start-up checklist in the final documentation. Sample start-up checklists are in Appendix 'C'.

—**Functional performance tests** (**FPTs**)—Detail the tests needed to demonstrate correct operation under all modes of operation, and include the applicable pass/fail criteria. Sample functional performance test checklists are in Appendix 'D'. The commissioning authority must witness all FPTs to verify results.

—**Acceptance**—List the criteria for completion of the commissioning process. Typically these will include verification of functional performance for all systems, submission of TAB reports and O&M manuals, as well as other project-specific criteria. The designer bears responsibility for acceptance based on review of commissioning documentation and other relevant factors.

The criteria for completion of the commissioning process will typically include verification of functional performance for all systems, and submission of TAB reports and O&M manuals.

- **O&M staff orientation and training**—Describe the intended program for O&M staff orientation, training and demonstration. Training sessions should be videotaped.
- **Documentation requirements**—List all documentation required for the final commissioning report. The commissioning plan itself will form the basis of this documentation, which will typically include:

  —A document reference list

  —Descriptions of each system, including a sequence of operations

  —Completed and signed system verification, start-up and functional performance test checklists documenting, on a system-by-system basis, all checks and tests carried out, and the results.

  —Retests of all unacceptable results

  —Training documentation, including an agenda for each scheduled session, a list of attendees, and videotape requirements.

  —Comprehensive O&M data.

- **Schedule**—It consists of a sequence of events, with an elapsed time allowance for each activity. Typical schedules include:

  —Site inspections

  —Site meetings

  —Resolution Tracking Forms (RTFs)

  —System Verification Checklists (SVCs)

  —System Start-ups

  —Functional Performance Tests (FPTs)

  —Operations staff orientation, training and demonstration.

The owner and designer review, modify and approve the design phase commissioning plan.

5.4 Construction Phase

The commissioning plan is implemented during the construction phase. Direct interaction between the construction team and the commissioning authority and communication with the design team represents the cornerstone of successful HVAC commissioning.

5.4.1 Support for Commissioning

Each commissioning team member shares a responsibility to support the commissioning process and achieve a quality installation.

The commissioning authority provides leadership by communicating goals for the commissioning process, including identification of roles and responsibilities of team members, and clearly defining and documenting pass/fail criteria. Each commissioning team member shares a responsibility to support the commissioning process and achieve a quality installation.

5.4.2 Coordinate Planning

The sequence and timing of commissioning activities must be incorporated into the overall project schedule. The commissioning authority identifies the required commissioning activities. Coordination requires input from the owner, designer, and contractors. Cooperation among the parties facilitates integration of commissioning into the total construction program.

5.4.3 Review TAB Procedures

Before executing their work, the TAB agency submits to the design team and commissioning authority a report detailing the TAB procedures and instruments planned for use on the project. This report includes the formats in which results will be reported, including a preliminary TAB report representing the project's equipment design parameters on approved data sheets. The TAB agency also describes the operational conditions required before HVAC systems will be ready for balancing. During early construction the TAB agency provides comments from their review of contract documents pertaining to provisions for testing air and water flows, temperatures and pressures. The TAB agency submits a tentative schedule for their scope of work. The schedule includes site visits to evaluate the impacts of as-built conditions on the planned procedures and schedule, and to determine when the installation will be ready for on-site TAB work. The commissioning authority reviews this information and forwards any comments to the designer. The designer specifies TAB procedures, and makes all final decisions regarding a system's TAB status.

5.4.4 Review HVAC Submittals

The commissioning authority obtains and reviews HVAC submittal data, including complete HVAC controls submittals, and consults with the designers and contractors regarding conformance with the design intent. The designer provides final approval of all submittals.

5.4.5 Update Commissioning Plan

The commissioning authority updates the design phase commissioning plan to incorporate information contained in the submittal data, such as data on the specific equipment being installed, adjustments to controls sequences, and any revisions to check or test procedures. Changes in the DID resulting from change orders or usage alterations must be assimilated into the revised commissioning plan. Revisions to the initial commissioning and construction schedules, in accordance with contract documents and construction meeting minutes, should be included in plan updates.

The contractor is responsible for the overall construction process, but the commissioning authority maintains an issues tracking system to help keep the process on schedule.

The owner and the design team review the updated commissioning plan. The approved document is distributed to all commissioning team members for their information and action.

5.4.6 Observe Site Installation

The commissioning authority observes the installation periodically to assess construction compliance with the DID, specification requirements and prevailing industry standards. Observed deficiencies are discussed with the appropriate contractor representatives. The commissioning authority also reports findings to the design team and the owner.

5.4.7 Update Project Schedule

The owner, designer, contractors, and commissioning authority periodically review the updated project schedule to ensure that all required commissioning activities are incorporated, time allowances are adequate, and installation sequences are logical and properly coordinated with other construction activities.

5.4.8 Track Construction Issues

The contractor is responsible for the overall construction process, including the necessary scheduling and coordination. To keep the process on schedule, the commissioning authority will maintain an issues tracking system to ensure that issues raised during commissioning are documented, addressed, followed up, and kept visible until resolved.

Some commissioning authorities structure the commissioning meeting minutes to provide the necessary tracking and follow-up documentation. Others use resolution tracking forms (RTFs) specifically designed for this purpose.

5.4.9 Commissioning Meetings

The commissioning authority should work with the general contractor to schedule commissioning meetings in conjunction with regular progress meetings, because many participants will attend both. The commissioning authority keeps meeting minutes and distributes them to all team members. RTFs are updated through input from these working sessions.

The commissioning authority's on-site presence during construction provides an additional avenue for communicating design intent concerns.

Dates, times and prerequisites for upcoming commissioning checks, start-ups, or tests are established. Issues are raised and problems are identified with required action decided, and a date for completion determined.

All commissioning team members are responsible for attending commissioning meetings and for completing assigned action items by the agreed dates. Cooperation by all parties contributes to successful commissioning.

5.4.10 Monitor Installation

All contractors, sub-contractors, and suppliers are responsible to supply materials and install work in accordance with the design documents and the project schedule. The commissioning authority's on-site presence during construction provides owners, contractors and designers an additional avenue for communicating design intent concerns.

Many of the early planning and scheduling activities in the construction phase of commissioning are intended to create a coordinated and realistic schedule, and thus avoid delays. System verification checklists (SVCs) in the commissioning plan are particularly valuable. As scheduled HVAC start-up approaches, the checklists prioritize items for the contractor's attention. Checklists for upcoming start-ups are often reviewed at commissioning meetings to confirm readiness, and incomplete items will become issues for tracking and resolution.

5.4.11 System Verification Checks (SVCs)

SVCs ensure that systems have been installed properly, conform to the specifications and are ready for safe start-up. The responsibility for carrying out these checks, as well as any corrective action, lies with the contractor. Documentation of these checks depends on project specifications. The commissioning authority prepares SVCs as part of the commissioning plan.

5.4.12 Controls Point-to-Point Checks

The automatic temperature controls (ATC) contractor carries out point-to-point control checks, and documents the results on checkout sheets.

These checks confirm that all control-point wiring has been correctly installed and terminated, sensors have been calibrated, and field devices operate correctly. This involves physical observation of device responses by the ATC contractor to ensure they match control system displays. The commissioning authority verifies the results reported by the ATC contractor, and includes this information in the commissioning report. Commissioning authorities frequently employ sampling techniques to document verification of point-to-point checkouts. Direct monitoring of the ATC checkout process facilitates conformance with the DID.

The mechanical contractor is responsible for starting HVAC equipment and systems in accordance with the specifications. Problems or incomplete work must be corrected by the responsible contractors and re-tested to produce satisfactory results.

5.4.13 HVAC Start-ups

The mechanical contractor is responsible for starting HVAC equipment and systems in accordance with the specifications. Owner representatives should be invited to all equipment start-ups. No equipment should be started until appropriate commissioning plan documentation has been completed and the start-up time and date has been scheduled and approved by all parties in advance.

Before starting equipment or systems contractors must complete the relevant system verification checks. When required by the specification, the manufacturer's certified technician, using the manufacturer's formal start-up procedure and documentation, must perform the start-up. The commissioning authority should observe all major start-ups. Any abnormalities occurring or corrective actions taken during start-up of equipment or systems should be noted in the commissioning start-up documentation. Conditions not in compliance with project specifications or manufacturer's recommendations should preclude operation of affected systems until such conditions are corrected. The design team makes all formal decisions regarding a system's readiness for operation.

The commissioning authority witnesses start-ups, and documents the results using the start-up checklists and other provisions in the commissioning plan. When the manufacturer's technician does the start-up, the commissioning authority notes this fact on the start-up checklist and attaches a copy of the manufacturer's start-up report.

5.4.14 Correct Problems and Re-test

Problems or incomplete work discovered in any of the SVCs, HVAC controls point-to-point checkouts, or equipment and system start-ups, must be corrected by the responsible contractors and re-tested to produce satisfactory results before proceeding to the next stage of the commissioning process. The commissioning plan and the project specifications should include language delineating financial

responsibilities for re-tests. A common practice involves the parties responsible for the failing results undertaking the necessary corrections and incurring the additional costs associated with retests.

5.4.15 TAB services

The TAB agency is responsible for checking that all pre-requisites for the start of TAB services have been completed prior to initiating their field work.

The TAB agency performs TAB services in accordance with the project specifications and the procedures submitted and approved at the beginning of the construction phase.

Where controls need to be calibrated against measured air or water flows, the ATC contractor must work together with the TAB agency.

Where controls need to be calibrated against measured air or water flows, the ATC contractor must work together with the TAB agency so that the related measurements and calibrations are coordinated, and the results documented to the commissioning authority's satisfaction. This language should be included in the project specifications and in the commissioning plan, along with arrangements for providing the TAB agency with appropriate ATC interface devices.

5.4.16 O&M Documentation and Training

The mechanical contractor is responsible for preparing the O&M documentation and training program in accordance with specification requirements. In most cases, the commissioning authority is responsible for coordinating and videotaping O&M training, with the contractor providing O&M literature and training personnel.

The O&M training program should include:

- Design intent
- System limitations
- Start-up and shut-down procedures
- Modes of control and operation sequences
- Detailed review of the information and organization of the O&M manual
- Complete listing of contractors and manufacturer contact information
- Detailed instructions on the control system
- Recommended procedures for effective operational monitoring including trending and graphics features for direct digital control (DDC) systems
- Routine preventative maintenance procedures as specified by the designer or recommended by the manufacturer
- Provisions for safety shutdowns, emergency conditions, and interfaces with building automation systems (BAS) and life-safety systems (such as fire protection)

The commissioning authority, designer, owner and O&M staff should review and revise the training program summary to meet the facility's needs. The contractor, assisted by the commissioning authority, prepares detailed written or electronic O&M documents and training materials to supplement verbal presentations and demonstrations, thus providing a permanent resource for O&M personnel.

5.4.17 Preparing for FPTs

The mechanical contractor is responsible for preparing HVAC systems for Functional Performance Tests (FPTs). The mechanical contractor, the ATC contractor and other applicable sub-contractors carry out functional performance checks prior to the formal tests, using the functional performance test checklists as a guide. When trial tests demonstrate that systems are installed and function according to the contract documents and the DID, the contractor informs the commissioning authority that a system is ready for functional performance tests.

The commissioning authority, designer, owner and O&M staff should review and revise the training program summary to meet the facility's needs.

5.5 Acceptance Phase

The acceptance phase immediately follows the construction phase, and involves functional performance tests of specified systems after the completion and documentation of HVAC controls installation and TAB services. During the acceptance phase the owner's O&M staff receives the documentation and training necessary for effective operations and maintenance of all HVAC systems. Upon completion of the events described below, the designer and the owner evaluate new systems relative to the DID and suitability for occupancy. Acceptance of HVAC systems by the owner initiates warranties required by project specifications. Commissioning clarifies requirements by all parties for acceptance and initiation of the warranty period. These issues require careful consideration during composition of the commissioning specification and the commissioning plan.

5.5.1 Document HVAC Controls Installation

The ATC contractor is responsible for documenting all aspects of the controls installation. At a minimum, the following as-built information should be included:

- Data on all components included with the controls installation, including general description, technical and applications data, and installation, calibration and maintenance information.
- Schematic diagrams of the entire controls system, in the form of laminated or framed drawings, computer graphics, or other specified formats.
- A complete points list, with records of point-to-point wiring and field device tests.

- Complete written sequences of controls for all systems, with details of final values for all parameters and set-points.
- Clearly labeled control panels and devices per specifications.
- For DDC systems, a complete set of system discs.

5.5.2 TAB Report

The TAB agency completes and submits the preliminary TAB report to the designer. The designer requests TAB report verification based on the commissioning specifications and conducted by the commissioning authority with TAB agency equipment and personnel assistance. The TAB agency performs services to address inconsistencies identified during verification or designer comments and resubmits the final TAB report to the designer for approval.

5.5.3 Functional Performance Tests (FPTs)

The commissioning authority directs, witnesses and documents the results of the functional performance tests of all HVAC systems commissioned. The mechanical contractor operates the systems as directed by the commissioning authority so that FPTs, as documented in the commissioning plan, can be completed. The ATC contractor and applicable Division 15 & 16 sub-contractors will participate, along with other relevant commissioning team members.

The ATC contractor may have to override normal control operation or parameters to simulate specific test conditions, and set up trend-logs to provide a record of system responses to test actions.

FPTs should progress from individual items of equipment and sub-systems, to complete systems, to interfaces between HVAC systems, and finally to interfaces between HVAC systems and non-HVAC systems, depending on the scope of the commissioning plan. This test progression helps to isolate the cause of problems while confirming correct operation of smaller portions of the installation, before moving on to tests involving larger systems or interfaces between systems.

5.5.4 Correct Problems and Re-test

If problems or incomplete work are discovered during functional performance tests, the responsible contractors must correct or complete the work, and have it re-tested with satisfactory results before proceeding to the next stage of commissioning.

The commissioning authority will stop the process if numerous problems indicate that the installation is not ready for FPTs. The commissioning specifica-

tion and the commissioning plan should clearly indicate the financial responsibilities in the event of failed or aborted FPTs.

5.5.5 O&M Training

The commissioning authority coordinates and schedules O&M training with the contractor, the owner and the design team. The contractor notifies sub-contractors, suppliers and manufacturer's representatives, and plans the training program according to project specifications.

The owner is responsible for scheduling their O&M personnel for planned orientation, training and demonstration sessions.

The commissioning specification and the commissioning plan should clearly indicate the financial responsibilities in the event of failed or aborted FPTs.

Responsibility for the actual training program is shared by the commissioning authority, the HVAC designer, the contractors and major equipment suppliers. Responsibilities for O&M training are detailed in the commissioning specification, which should include provisions for expenses incurred by all parties in the event that required individuals do not attend scheduled training sessions.

The commissioning authority is responsible for the videotaping and documentation of O&M training and demonstration sessions, according to the specification.

Videotape permits existing O&M staff to review training material, and new staff to receive the same information provided at the original sessions, including questions posed and answers given. Video offers consistency in training and represents a key value-added component of the HVAC commissioning process.

5.6 Post-Acceptance Phase

The commissioning process does not end until HVAC issues are resolved to the satisfaction of the owner, and full documentation of the systems is provided. Some activities may occur after substantial completion.

5.6.1 "Off-season" FPTs

Some commissioning tests check performance at maximum heating or cooling loads. If the project is being completed in summer, peak heating loads will be difficult to simulate; likewise for peak cooling loads in winter. Therefore, it may be necessary to defer some tests until outside weather conditions are more suitable for achieving useful results.

The commissioning authority works with the commissioning team to schedule tests when weather conditions are suitable. System verification checks, start-ups of equipment and systems, O&M provisions, and most FPTs should occur prior to substantial completion, leaving the weather-dependent items to be performed later.

5.6.2 Correct Problems and Re-test

As with earlier tests, the contractor is responsible for correcting problems, and carrying out follow-up checks necessary to confirm correct operation. The commissioning authority is responsible for witnessing re-tests for satisfactory results. Contract documents should assign financial responsibilities for the costs associated with failed or aborted tests.

5.6.3 Final Commissioning Report

The final commissioning report should contain an executive summary addressing design intent conformance for all commissioned equipment and systems.

The commissioning authority is responsible for preparing and submitting the final commissioning report to the owner and the design team.

This report uses the final commissioning plan as its template. The report includes all system verification and start-up checklists, and all functional performance test checklists, completed with all test observations, problems encountered, corrective actions taken, and re-test results dated and signed by those carrying out and witnessing the tests.

Where the checklists make reference to other test reports, copies of those reports must be appended.

The final commissioning report should contain an executive summary addressing design intent conformance for all commissioned equipment and systems. The report should include references to all relevant HVAC system documentation, and should be organized and tabulated to facilitate access to specific information. The owner and the design team review the final commissioning report to determine completion of the commissioning plan.

CHAPTER 6 Construction HVAC Commissioning

6.1 Overview

The ACG Commissioning Guideline recommends comprehensive commissioning, which starts at the pre-design phase of a project, as the ideal approach to HVAC commissioning. Comprehensive HVAC commissioning methodology is described in detail in Chapter 5.

In many cases, however, commissioning is an activity that occurs only during the construction and acceptance phases of a project. Sometimes the designer includes HVAC commissioning requirements in the specifications. In other cases, the issue of commissioning does not arise until the project is already under construction.

ACG recognizes this reality and includes construction HVAC commissioning as an alternative approach. The main difference between comprehensive and construction commissioning is the starting point. Once underway however, commissioning activities should be similar for both.

ACG recommends that the commissioning authority be retained directly by the owner; however, specifications frequently assign the commissioning authority as a sub-contractor to the general contractor, but reporting to the designer and owner as well as to the contractor. Regardless of the contractual details, construction HVAC commissioning will be most effective when it has been recognized during design, and the specifications contain reasonably detailed information concerning the contractor's commissioning responsibilities.

However, even when commissioning is not considered until the building is under construction, ACG recommends that steps be taken to incorporate it into both the construction and acceptance phases. This requires retaining a commissioning authority, preparing a commissioning plan, and issuing specification sections covering the contractor's commissioning responsibilities to the affected contractors so they can bid the work as an extra cost.

This chapter of the Guideline contains a detailed methodology for construction HVAC commissioning, organized by project phase. A detailed description of each activity and typical assignment of responsibility is given. Where applicable, references to sample specifications, forms or other material in the Appendices to this Guideline are provided.

The HVAC commissioning process description contained in this chapter is based on a traditional plan-and-spec organizational structure, with the commissioning authority retained directly by the owner, as shown in Figure 4-1. However, it is adaptable to a structure where the commissioning authority is a sub-contractor to the general contractor, or to the design build model.

The commissioning plan contains the specific system verification and start-up checklists for all equipment and systems included in the commissioning scope.

6.2 Construction Phase

The construction phase activities listed in this section mirror the construction phase activities listed for comprehensive commissioning in Section 5.4.

6.2.1 Prepare Commissioning Plan

The commissioning authority prepares a commissioning plan to guide the activities of all parties to the commissioning process. The contents of the plan will be similar to those listed for the design-phase commissioning plan in Section 5.3.4. However, it will include updated construction information obtained from:

- Reviews of HVAC submittal data, including complete HVAC controls submittals.
- Incorporation of data on the specific equipment being installed.
- Incorporation of complete controls sequences of operation.
- Change order work to date
- Any agreed as-built modifications

The commissioning plan contains the specific system verification and start-up checklists for all equipment and systems included in the commissioning scope. Sample systems verification and start-up checklists for many pieces of equipment are contained in Appendix C.

The plan also includes a functional performance test (FPT) checklist for each system that details the tests to be undertaken to demonstrate correct operation under all modes of control, all specified sequences of operation, and the applicable pass/fail criteria. Sample FPT checklists for many typical systems are in Appendix D.

Elapsed time schedule allowances are developed by the commissioning authority for system verification checks, start-ups, and FPTs, and these are integrated into the overall project schedule by the owner, the design team and the contractor.

The commissioning authority submits the plan to the owner and design team for review and approval.

6.2.2 Review Commissioning Plan

The owner and designer review the commissioning plan. The approved document will be distributed to all commissioning team members for their information, and action.

6.2.3 Support for Commissioning

The commissioning authority provides leadership by communicating goals for the commissioning process, including verification of roles and responsibilities of team members, and clearly defining and documenting pass/fail criteria. Each commissioning team member shares a responsibility to support the commissioning process and achieve a quality installation.

The sequence and timing of commissioning activities must be incorporated into the overall project schedule.

6.2.4 Coordinate Planning

The sequence and timing of commissioning activities must be incorporated into the overall project schedule. The commissioning authority identifies the required commissioning activities. Coordination requires input from the owner, designer, and contractors. Cooperation among the parties facilitates integration of commissioning into the total construction program.

6.2.5 Review TAB Procedures

Before executing their work, the TAB agency submits to the design team and commissioning authority a report detailing the TAB procedures and instruments planned for use on the project. This report includes the formats in which results will be reported, including a preliminary TAB report representing the project's equipment design parameters on approved data sheets. The TAB agency also describes the operational conditions required before HVAC systems will be ready for balancing. During early construction the TAB agency provides comments from their review of contract documents pertaining to provisions for testing air and water flows, temperatures and pressures. The TAB agency submits a tentative schedule for their scope of work. The schedule includes site visits to evaluate the impacts of as-built conditions on the planned procedures and schedule, and to determine when the installation will be ready for on-site TAB work. The commissioning authority reviews this information and forwards any comments to the designer. The designer specifies TAB procedures, and makes all final decisions regarding a system's TAB status.

6.2.6 Observe Site Installation

The commissioning authority observes the installation periodically to assess construction compliance with the DID, specification requirements and prevailing industry standards. Observed deficiencies are discussed with the appropriate contractor representatives. The commissioning authority also reports findings to the design team and the owner.

6.2.7 Update Project Schedule

The commissioning authority should work with the general contractor to schedule commissioning meetings in conjunction with regular progress meetings.

The owner, designer, contractors and commissioning authority periodically review the updated project schedule to ensure that all required commissioning activities are incorporated, time allowances are adequate, and installation sequences are logical and properly coordinated with other construction activities.

6.2.8 Track Construction Issues

The contractor is responsible for the overall construction process, including the necessary scheduling and coordination. To keep the process on schedule, the commissioning authority will maintain an issues tracking system to ensure that issues raised during commissioning are documented, addressed, followed up, and kept visible until resolved.

Some commissioning authorities structure the commissioning meeting minutes to provide the necessary tracking and follow-up documentation. Others use resolution tracking forms (RTFs) specifically designed for this purpose.

6.2.9 Commissioning Meetings

The commissioning authority should work with the general contractor to schedule commissioning meetings in conjunction with regular progress meetings, because many participants will attend both. The commissioning authority keeps meeting minutes and distributes them to all team members. RTFs are updated through input from these working sessions.

Dates, times and prerequisites for upcoming commissioning checks, start-ups, or tests are established. Issues are raised and problems are identified with required action decided, and a date for completion determined.

All commissioning team members are responsible for attending commissioning meetings and for completing assigned action items by the agreed dates. Cooperation by all parties contributes to successful commissioning.

6.2.10 Monitor Installation

All contractors, sub-contractors, and suppliers are responsible to supply materials and install work in accordance with the design documents, and the project schedule. The commissioning authority's on-site presence during construction provides owners, contractors and designers an additional avenue for communicating design intent concerns.

Many of the early planning and scheduling activities in the construction phase of the commissioning process are intended to create a coordinated and realistic schedule, and thus avoid delays. System verification checklists (SVCs) in the commissioning plan are particularly valuable – but under construction commissioning, this opportunity will be bypassed if construction proceeds to start-up stage before the commissioning process is fully underway. As scheduled HVAC start-up time approaches, the checklists prioritize items for the contractor's attention. Checklists for upcoming start-ups are often reviewed at commissioning meetings to confirm readiness, and incomplete items will become issues for tracking and resolution.

SVCs ensure that systems have been installed properly, conform to the specifications and are ready for safe start-up.

6.2.11 System Verification Checklists (SVCs)

System Verification Checklists (SVCs) ensure that systems have been installed properly, conform to the specifications and are ready for safe start-up. The responsibility for carrying out these checks, as well as any corrective action, lies with the contractor. Documentation of these checks depends on project specifications. The commissioning authority prepares SVCs as part of the commissioning plan.

6.2.12 Controls Point-to-Point Checks

The automatic temperature controls (ATC) contractor carries out point-to-point control checks, and documents the results on checkout sheets.

These checks confirm that all control-point wiring has been correctly installed and terminated, sensors have been calibrated, and field devices operate correctly. This involves physical observation of device responses by the ATC contractor to ensure they match control system displays. The commissioning authority verifies the results reported by the ATC contractor, and includes this information in the commissioning report. Commissioning authorities frequently employ sampling techniques to document verification of point-to-point checkouts. Direct monitoring of the ATC checkout process facilitates conformance with the DID.

6.2.13 HVAC System Start-ups

The mechanical contractor is responsible for starting HVAC equipment and systems in accordance with the project specifications. Owner representatives should be invited to all equipment start-ups. No equipment should be started until appropriate commissioning plan documentation has been completed and the start-up time and date has been scheduled and approved in advance by all parties.

Before starting equipment or systems contractors must complete the relevant system verification checks. When required by the specification, the manufacturer's certified technician, using the manufacturer's formal start-up procedure and documentation, must perform the start-up. The commissioning authority should observe all major start-ups. Any abnormalities occurring or corrective actions taken during start-up of equipment or systems should be noted in the commissioning start-up documentation. Conditions not in compliance with project specifications or manufacturer's recommendations should preclude operation of affected systems until such conditions are corrected. The design team makes all formal decisions regarding a system's readiness for operation.

Before starting equipment or systems contractors must complete the relevant system verification checks. The commissioning authority should observe all major start-ups.

The commissioning authority witnesses start-ups, and documents the results using the start-up checklists and other provisions in the commissioning plan. When the manufacturer's technician does the start-up, the commissioning authority notes this fact on the start-up checklist and attaches a copy of the manufacturer's start-up report.

6.2.14 Correct Problems and Re-test

Problems or incomplete work discovered in any of the SVCs, HVAC controls point-to-point checks, or equipment and system start-ups must be corrected by the responsible contractors and re-tested to produce satisfactory results before proceeding to the next stage of the commissioning process. The commissioning plan and the project specifications should include language delineating financial responsibilities for re-tests. A common practice involves parties responsible for the failing results undertaking the necessary corrections and incurring the additional costs associated with retests.

6.2.15 TAB Services

The TAB agency is responsible for checking that all prerequisites for the start of TAB services have been completed prior to initiating their field work.

The TAB agency performs TAB services in accordance with the project specifications and the procedures submitted and approved at the beginning of the construction phase.

Where controls need to be calibrated against measured air or water flows, the ATC contractor must work together with the TAB agency so that the related measurements and calibrations are coordinated, and the results documented to the commissioning authority's satisfaction. This language should be included in the project specifications and in the commissioning plan, along with arrangements for providing the TAB agency with appropriate ATC interface devices.

6.2.16 O&M Documentation and Training

The mechanical contractor is responsible for preparing the O&M documentation and training program in accordance with specification requirements. In most cases, the commissioning authority will be responsible for coordinating and videotaping O&M training, with the contractor providing O&M literature and training personnel. The O&M training program should include:

- Design intent
- System limitations
- Start-up and shut-down procedures
- Modes of control and operation sequences
- Detailed review of the information and organization of the O&M manual
- Complete listing of contractors and manufacturers' contact information
- Detailed instructions on the control system.
- Recommended procedures for effective operational monitoring trending and graphics features for DDC systems
- Routine preventative maintenance procedures as specified by the designer or recommended by the manufacturer.
- Provisions for safety shutdowns, emergency conditions, and interfaces with building automation systems (BAS) and life-safety systems (such as fire protection).

The commissioning authority, designer, owner and O&M staff should all review and revise the training program summary to meet the facility's needs. The contractor, assisted by the commissioning authority, prepares detailed written or electronic O&M documents and training materials to supplement verbal presentations and demonstrations, thus providing a permanent resource for O&M personnel.

6.2.17 Preparing for FPTs

The mechanical contractor is responsible for preparing HVAC systems for Functional Performance Tests (FPTs). The mechanical contractor, the ATC contractor and other applicable sub-contractors carry out functional performance checks prior to the formal tests, using the functional performance test checklists as a guide. When trial tests demonstrate that systems are installed and function according to the contract documents and the DID, the contractor informs the commissioning authority that a system is ready for functional performance tests.

Functional performance tests begin upon receipt of all prerequisite materials and with approval from the owner and the design team.

6.3 Acceptance Phase

The acceptance phase immediately follows the construction phase, and begins with the completion and submission of O&M documentation, HVAC controls point-to-point checkout forms and system documentation, and the TAB report. Functional performance tests begin upon receipt of these prerequisite materials and with approval from the owner and the design team. During the acceptance phase the owner's O&M staff receives the documentation and training necessary for effective operations and maintenance of all HVAC systems. Acceptance phase commissioning documentation offers the design team and the owner detailed information for evaluating the performance of new systems relative to contract requirements, warranty initiation and occupancy. Acceptance of HVAC systems by the owner initiates warranties required by the project specifications. Commissioning can clarify requirements of all parties for acceptance and initiation of the warranty period through careful consideration during composition of the commissioning specification and the commissioning plan.

6.3.1 Document HVAC Controls Installation

The ATC contractor is responsible for documenting all aspects of the controls installation. At a minimum, the following as-built information should be included:

- Data on all components included with the controls installation, including general description, parts lists, technical and applications data, and installation, calibration and maintenance information.
- Schematic diagrams of the entire controls system, in the form of laminated or framed drawings, computer graphics, or other specified formats.
- A complete points list, with records of point-to-point wiring and field device tests.
- Complete written sequences of controls for all systems, with details of final values for all parameters and set-points.
- Clearly labeled control panels and devices per specifications.
- For DDC systems, a complete set of system discs.

6.3.2 TAB Report

The TAB agency completes and submits the preliminary TAB report to the designer. The designer requests TAB report verification based on the commissioning specifications and conducted by the commissioning authority with TAB agency equipment and personnel assistance. The TAB agency performs services to address inconsistencies identified during verification or designer comments and resubmits the final TAB report to the designer for approval.

6.3.3 Functional Performance Tests

The commissioning authority directs, witnesses and documents the results of the functional performance tests.

The commissioning authority directs, witnesses and documents the results of the functional performance tests of all HVAC systems being commissioned. The mechanical contractor is responsible for operating the systems as directed by the commissioning authority so that FPTs, as documented in the commissioning plan can be completed. The ATC contractor and applicable Division 15 & 16 sub-contractors will participate, along with other relevant commissioning team members.

The ATC contractor may have to override normal control operation or parameters to simulate specific test conditions, and set up trend-logs to provide a record of system responses to test actions.

FPTs should progress from individual items of equipment and sub-systems, to complete systems, to interfaces between HVAC systems, and finally to interfaces between HVAC systems and non-HVAC systems, depending on the scope of the commissioning plan. This test progression helps to isolate the cause of any problems as it confirms correct operation of smaller portions of the installation, before moving on to tests involving larger systems or interfaces between systems.

6.3.4 Correct Problems and Retest

If problems or incomplete work are discovered during functional performance tests, the responsible contractors must correct or complete the work, and have it re-tested with satisfactory results before proceeding to the next stage of commissioning.

The commissioning authority will stop the process if numerous problems indicate that the installation is not ready for FPTs. The commissioning specification and the commissioning plan should clearly indicate the financial responsibilities in the event of failed or aborted FPTs.

6.3.5 O&M Training Sessions

The commissioning authority coordinates and schedules O&M training with the contractor, the owner and the design team. The contractor notifies sub-contractors, suppliers and manufacturer's representatives, and plans the training program according to project specifications.

The owner is responsible for scheduling that their O&M personnel for planned orientation, training and demonstration sessions.

Responsibility for the actual training program is shared by the commissioning authority, the HVAC designer, the contractors and major equipment suppliers. Responsibilities for O&M training are detailed in the commissioning specification, which should include provisions for expenses incurred by all parties in the event that required individuals do not attend scheduled training sessions. The commissioning authority is responsible for the videotaping and documentation of O&M training and demonstration sessions, according to the specifications.

It may be necessary to defer some tests until outside weather conditions are more suitable for achieving useful results.

Videotape permits existing O&M staff to review training material, and new staff to receive the same information provided at the original sessions, including questions posed and answers given. Video offers consistency in training and represents a key value-added component of the HVAC commissioning process.

6.4 Post-Acceptance Phase

The commissioning process does not end until HVAC issues are resolved to the satisfaction of the owner, and full documentation of the systems is provided. Some activities may occur after substantial completion.

6.4.1 Off-season FPTs

Some commissioning tests check performance at maximum heating or cooling loads. If the project is being completed in summer, peak heating loads will be difficult to simulate; likewise for peak cooling loads in winter. Therefore, it may be necessary to defer some tests until outside weather conditions are more suitable for achieving useful results.

The commissioning authority works with the commissioning team and others to schedule these tests when weather conditions are suitable. System verification checks, start-ups of equipment and systems, O&M provisions, and most FPTs should occur prior to substantial completion, leaving only the weather-related FPTs to be performed later.

6.4.2 Correct Problems and Re-test

As with earlier tests, the contractor is responsible for correcting any problems, and carrying out follow-up checks necessary to confirm correct operation. The commissioning authority is responsible for witnessing re-tests for satisfactory results. Contract documents should assign financial responsibilities for cost associated with failed or aborted tests.

6.4.3 Final Commissioning Report

The commissioning authority is responsible for preparing and submitting the final commissioning report to the owner and the design team.

The final commissioning report uses the commissioning plan as its template.

This report uses the commissioning plan as its template. The report includes all system verification and start-up checklists, and all functional performance test checklists, completed with all test observations, problems encountered, corrective actions taken, and re-test results, dated and signed by those carrying out and witnessing the tests.

Where checklists make reference to other test reports, copies of those reports must be appended.

The final commissioning report should contain an executive summary addressing design intent conformance for all commissioned equipment and systems. The report should include references to all relevant HVAC system documentation, and should be organized and tabulated to facilitate access to specific information. The owner and the design team review the final commissioning report to determine completion of the commissioning plan.

CHAPTER 7 HVAC Commissioning in Existing Buildings

7.1 Overview

The process of commissioning HVAC systems applies to existing buildings as well as to new construction. Commissioning methodology is used to solve persistent problems in existing buildings, as a component of a comprehensive preventive maintenance program, or to commission post-occupancy facility modifications. Regardless of the motivation, adapting the commissioning process presented in this guideline to existing facilities represents a major market for those who offer commissioning services.

Two different terms are frequently applied to commissioning work in existing buildings. The term "recommissioning" is used when commissioning is carried out in a building whose HVAC systems have been commissioned previously, either during construction or at some time after initial occupancy. The term "retrocommissioning" is used when commissioning is carried out in a building whose systems have never been commissioned. Regardless of the term used, the methodology for both recommissioning and retrocommissioning is identical. It is described in Section 7.2.

Renovation (retrofit) projects also benefit from commissioning. Commissioning of HVAC system modifications is described in Section 7.3.

7.2 Recommissioning and Retrocommissioning

Throughout this section, the term recommissioning will be used. However, Section 7.2 applies to either recommissioning or retrocommissioning projects, as defined in Section 7.1.

HVAC commissioning carried out after building occupancy involves special issues outside the new construction model. The phases and typical activities involved in recommissioning are listed below. All activities are the responsibility of the commissioning authority, working in conjunction with the building owner, or the owner's O&M staff unless stated otherwise.

7.2.1 Planning Phase:

7.2.1.1 HVAC Commissioning Goals

Recommissioning arises from the building owner's need to resolve ongoing problems or to ensure functionality continues to meet facility needs even after HVAC system modifications. Some typical reasons for recommissioning are:

- HVAC equipment and systems are outdated or at the end of their useful life—recommissioning will identify specific problems and provide information needed to make upgrade or replacement decisions
- HVAC equipment and systems do not perform according to their design intent—recommissioning will identify substandard performance and guide corrective action.
- HVAC equipment and system performance has been degraded by maintenance and calibration problems—recommissioning will identify deficient performance and guide corrective action.
- A comprehensive HVAC preventive maintenance program can incorporate recommissioning components that periodically confirm HVAC systems operation and maintenance compliance with codes, regulations, and design intent—recommissioning can detect minor problems and facilitate their correction before performance becomes compromised.
- Operation and maintenance documentation deficiencies adversely impact performance—recommissioning will obtain or recreate the necessary documentation, including design intent data, needed to evaluate system performance versus design intent requirements.
- Occupant discomfort, or IAQ problems may be related to poor HVAC performance—recommissioning can investigate occupancy, usage, and HVAC systems performance issues that may contribute to such problems.

Before deciding on a complete redesign and renovation, an owner may elect to implement recommissioning, which might solve problems with less expense than replacement.

Instead of ad-hoc efforts to mitigate recurring HVAC problems, a building owner may decide to devise a systematic approach to identify and resolve existing adverse conditions. Often, an owner may elect to implement recommissioning before deciding on a complete redesign and renovation of HVAC systems, in case recalibration, reconditioning or reprogramming of existing installations might solve problems with less expense than replacement. The owner may retain a design professional who includes a commissioning authority on his design team, or the owner may decide to contract directly with a commissioning authority that includes a design professional as part of the recommissioning team.

7.2.1.2 Select a Commissioning Team

Typically the owner solicits proposals for commissioning services from several commissioning authorities. The owner should have information concerning the reasons for carrying out HVAC commissioning in the building, and the systems to be included in the commissioning scope. The commissioning authority may have to propose a suitable scope of work to the owner, based on the information gathered from an initial interview.

ACG recommends that the responsibilities of the commissioning authority and the owner be defined clearly from the outset. A sample Request for Proposal (RFP) document is included in Appendix 'A'. RFPs are customized to the specific project requirements, and include a definition of the scope of work (see activity 7.2.1.3 following).

The commissioning authority works with the owner to determine necessary parties for the recommissioning team.

The commissioning authority works with the owner to determine necessary parties for the recommissioning team, and these members may be contractually attached to the owner, the commissioning authority or a contractor entity depending on the owner's preference and the goals of the project. Potential recommissioning team members include:

- The owner and the owner's maintenance personnel
- The commissioning authority
- Design consultants
- Mechanical contractor
- Test and balance (TAB) contractor
- Automatic temperature controls (ATC) contractor
- Specialty systems vendors

7.2.1.3 Finalize the Recommissioning Scope

The recommissioning effort begins with detailed meetings between the owner and his recommissioning team, and includes input from the owner's O&M staff and the building's occupants. The scope of recommissioning is determined based on the objectives revealed through these discussions.

The scope of the recommissioning work should be finalized as soon as possible, using input based on the expertise of the various members of the recommissioning team. This information can be developed through an initial recommissioning team meeting. The final scope should include roles and responsibilities of team members, the sequence and coordination of actions to be performed by team members, required manufacturer literature and an initial schedule. This scope should be incorporated into a recommissioning plan prepared by the commissioning authority.

The owner has the responsibility for approving the final scope of HVAC recommissioning.

7.2.1.4 Documentation and Site Reviews

Review existing documentation, and inspect the physical installation with all recommissioning team members. This review and inspection can occur as part of the initial recommissioning team meeting. This step gathers the same information as that obtained from reviews of design documents and contractor submittals in new construction commissioning (see 5.3.2 and 5.4.4).

Existing information is often unavailable, incomplete, or inaccurate. In this case, information must be obtained so complete and accurate documentation is available as a database from which to plan and implement the recommissioning process. Sometimes data can be located in the design consultant's records, or in manufacturer's or supplier's data. Design basis information may have to be obtained directly from a site survey (see Section 7.2.1.5).

Design basis information may have to be obtained directly from a site survey.

7.2.1.5 Site Survey

Where information concerning the existing installation is missing or inaccurate, and cannot be located from designers, contractors or suppliers, it will have to be recreated from a survey of the existing installation. This can include:

- Data on equipment, such as models, service, air or water flows, heating or cooling capacities, motor sizes, electrical requirements, and control sequences.
- Test and balance work to produce data on current air and water flows
- Functional performance tests to produce comprehensive data on how systems are currently operating
- ATC point to point checkouts and sequences of operation

The level of effort required to carry out a properly documented survey can be substantial. Every effort should be made to locate existing information before trying to recreate it. Site surveys must be included in the recommissioning scope.

7.2.1.6 Preparation of Recommissioning Plan

Once the necessary data about the existing installation is available, the commissioning authority prepares a recommissioning plan whose content will resemble a comprehensive HVAC commissioning plan in new construction (see 5.3.4 and 5.4.5). The plan will contain functional performance test checklists detailing the test procedures to be used, with clear delineation of pass/fail criteria. Recommissioning plans should include special considerations for dealing with occupied building conditions. For example, scheduling of recommissioning work must accommodate occupancy schedules. Sample functional performance test checklists for many typical systems are in Appendix 'D'. Recommissioning plans should be submitted for owner approval prior to execution.

7.2.2 Implementation Phase

7.2.2.1 TAB Services

A TAB agency balances systems to ensure air and water flows within tolerances established by the recommissioning plan.

7.2.2.2 Document and Verify TAB Results

The TAB agency documents their work on approved data sheets and drawings as required by the recommissioning plan. The commissioning authority may employ sampling methods to verify TAB report data (similar to 5.5.2 in new construction commissioning).

7.2.2.3 Functional Performance Tests

The commissioning authority conducts functional performance tests for HVAC systems included within the recommissioning scope, and documents the results. The building O&M staff or an ATC contractor will work with the commissioning authority and operate the systems as required for testing in accordance with the recommissioning plan.

This work resembles comprehensive HVAC commissioning discussed in 5.5.3 and 5.5.4.

7.2.2.4 Analyze Results

The commissioning authority, the owner, and the owner's consultants analyze the results of the functional performance tests to determine if the systems are operating according to current requirements. If operational deficiencies are uncovered, the discrepancies must be identified, and corrective measures planned through discussions with the owner and the owner's consultants.

7.2.2.5 Review O&M Practices

The commissioning authority evaluates O&M staff practices throughout the planning and implementation phases of the recommissioning process. The O&M staff must understand how HVAC systems are intended to operate, including all modes and sequences of control. Operators occasionally modify important controls or equipment operations in attempts to address complaints, compromising overall system performance. Based on this review, the commissioning authority develops a training or re-training program for the O&M staff.

7.2.2.6 O&M Instruction and Documentation

The commissioning authority assists the owner's personnel to assemble existing and newly acquired O&M documentation into concise, indexed manuals, and uses this resource to prepare written and demonstrative O&M training sessions. Other recommissioning team members may be required by the recommissioning plan to deliver hands-on instruction for systems within their fields of expertise. The owner may choose to videotape training sessions for permanent record and for use in orienting new staff. The commissioning authority will provide videotape services if they are within their scope of work.

Emphasis in O&M training sessions should be placed on interactive demonstrations using the actual equipment and systems, along with system documentation.

Training sessions focus on practical aspects of the HVAC systems based on best practices for O&M excellence. Emphasis should be placed on interactive demonstrations using the actual equipment and systems, along with system documentation, and should encourage dialogue with the owner's O&M staff to ensure the training is meeting the specific needs of the recipients. Laboratory fume hoods or other specialized equipment requiring user interaction during normal operation, may warrant providing instructions for the owner's user staff.

7.2.2.7 Commissioning Report Completed

The commissioning authority prepares and submits a final recommissioning report. Its content will be similar to that for a new construction commissioning report. Refer to 5.6.3.

7.3 Commissioning of HVAC System Modifications

Building renovations will range from minor modifications of a portion of an HVAC system, to the complete reconstruction of all or part of a building with new HVAC and other systems. Regardless of scale or complexity, the HVAC commissioning process provides benefits. The commissioning of HVAC system modifications follows the methodology detailed in Chapter 5 for comprehensive HVAC commissioning, adapted to suit the scope of the specific renovation, modification or retrofit project.

One of the most significant differences between new construction and renovations can be the lack of accurate and complete documentation available for an existing building. Such documentation must be found or recreated before the renovation design can proceed. The designer will usually have this work included within his scope of work, but in some cases the owner may retain a commissioning authority to do this work as part of a preliminary study. Such preliminary work follows the recommissioning model outlined in sec-

tion 7.2. In fact, successful recommissioning projects frequently lead directly to renovation projects.

Commissioning of system modifications must address the mechanical, electrical, TAB and ATC interface issues between new and existing HVAC systems and equipment. In addition, the entire project, including commissioning, must account for building use and occupancy considerations. Thus a key to success is close coordination and scoping meetings with the owner and his commissioning team and design consultants. Because of these factors, pre-design and design phase commissioning work is critically important in HVAC system modification projects.

The owner may choose to carry out modification projects using any of the standard construction models, such as plan and spec, or design-build. As with new construction, the commissioning process for modification projects is adaptable to any of these models.

CHAPTER 8 Commissioning of Non-HVAC Building Systems

8.1 Overview

In the previous chapters, the ACG Commissioning Guideline has presented a detailed methodology showing how commissioning should be carried out for HVAC systems.

The commissioning methodology presented in this Guideline can apply to any building system. The basic planning, organizing, systems verification, functional performance testing, and documenting tasks of the commissioning process benefits all systems. The differences between systems are the details of who will be involved, the system-specific items to be checked and tested (before, during, and after start-up), the applicable documentation, and sometimes a requirement for regulatory agency presence during testing. If there are interactions with other systems, these must also be included within the overall commissioning protocols.

O&M training and documentation, two hallmarks of successful commissioning, provide owner benefits for all types of building systems. The U.S. Green Building Council LEED certification program, which advocates commissioning the installation of all building components, represents an example of the potential value of whole building commissioning.

8.2 Commissioning Authority Requirements

Section 3.3.1 outlines commissioning authority requirements for HVAC systems commissioning. Technical knowledge, organizational skills and communications skills, along with considerable experience are all necessary. The organizational and communications skills and experience as listed in Section 3.3.1 are equally applicable for commissioning non-HVAC systems.

When commissioning non-HVAC systems, the commissioning authority must have technical knowledge of, and experience with, the specific systems to be commissioned. If there are different types of systems included in the commissioning scope of a project, the commissioning authority may have to employ or team with the necessary expertise for all systems being commissioned.

Systems that are health or safety related will be governed by regulations or codes that mandate specific, formal, test procedures, which in some cases must be carried out or witnessed by personnel certified by a regulatory agency. If this work is included within the commissioning authority's scope of work, then the commissioning plan must include provisions to fulfill these requirements.

8.3 Non-HVAC Systems

There are many non-HVAC systems which benefit from commissioning. Some of these systems are related to HVAC in that they include mechanical or ventilation components or controls interactions, but their function is primarily oriented to process requirements or safety, not occupant comfort. Other systems are in completely different disciplines.

Systems that are health or safety related will be governed by regulations or codes that mandate specific, formal, test procedures.

Among the systems that are frequently commissioned are the following:

- Lighting
- Electrical supply
- Fire protection
- Fire alarm
- Smoke control
- Security
- Elevator control
- Space pressurization (e.g. in laboratories, hospitals, or clean room manufacturing)
- Fume hood or biological safety cabinet exhaust or ventilation
- Medical gases

APPENDIX A Sample Request for Proposal for Commissioning Services

Notes to Appendix A

This appendix contains a sample Request for Proposal (RFP) for Commissioning Services as would be issued by an Owner, or a representative of the Owner, to selected independent commissioning authorities inviting them to submit a proposal to act as the commissioning agent for a specific project.

This sample RFP is included solely as an example. ACG assumes no responsibility for how the material in this appendix may be utilized by users of the Guideline; the users assume full responsibility for any and all liability that may arise from any reference to, or use of, this material.

This sample RFP includes all the items considered important to include in such a document.

The wording of this sample RFP is generic. Therefore, it contains no project specific information. Such information is required in many locations, which are indicated as follows: ***[square brackets containing text in italics—with the text describing the project specific information required at that location]***

A. Solicitation of Proposals

1. ***[Insert the name of the owner, company, organization, etc. soliciting the proposals]*** hereinafter referred to as "the Owner", invites qualified, independent commissioning authorities to submit sealed proposals for Commissioning Services for ***[Insert the name of the project]*** in accordance with the requirements and instructions set forth in this Request for Proposal.

2. Project description and applicable information is as follows: ***[Include here a description of the project; as much information as is known concerning use and occupancy, floor area, number of floors, configuration, types of HVAC systems, and other applicable information; conceptual or schematic drawings, if available; and any issues of particular importance to the owner. Also include names and contact information for:***

   - ***Architect***
   - ***Mechanical engineer***
   - ***Electrical engineer***
   - ***Construction manager (if applicable)***
   - ***Contractor (if known)]***

B. Submittal of Proposal

1. All proposals shall be delivered to ***[Insert the name of the company, organization and/or person who is to receive the proposal]*** at the following address: ***[Provide address here]***
2. Proposals will be accepted at this address until ***[Insert date and time]***. Proposals received after this time will be returned to the sender unopened. The Owner will not be responsible for mail delivery delays.
3. Proposals shall be submitted in a sealed envelope, bearing the proponent's company name, and plainly marked: "Proposal for Commissioning Services for ***[Insert the name of the project]***."
4. Proposals shall be subject to acceptance by the Owner as submitted within sixty (60) days from the deadline for receipt of proposals.

C. Taxes

1. ***[Indicate which federal, state or local taxes are applicable to the work. If the owner is exempt from some or all taxes, so indicate. Indicate how applicable taxes are to be accounted for in the proposal.]***

D. Compliance with RFP Requirements

1. Unless the proposal clearly states otherwise, the Owner will assume that all conditions and requirements listed in this RFP will be met by the proposal. The proponent shall clearly list every specific condition or requirement that will not be met by the proposal, and either declare an exception or describe how the proponent will meet the intent of the RFP by other means.

E. Mandatory Pre-Bid Meeting

1. Commissioning authorities wishing to submit a proposal in response to this RFP are required to attend a mandatory pre-bid meeting that will take place ***[insert date, time and place of meeting]***. It is the responsibility of all proponents to register their attendance with the Owner's representative at the tour site. Proposals from companies that do not attend, and register at, the pre-bid meeting will have their proposals returned unopened.

F. Proposal Evaluation and Award

1. In reaching a decision on awarding a contract for the subject commissioning services, the Owner will consider and evaluate, for each proponent, the following:
   a. experience and qualifications
   b. the proposal quality
   c. the references submitted
   d. the proposed fee
   e. any other applicable factors
2. The Owner reserves the right to negotiate and accept any proposal, to reject any or all proposals, and to offer to accept any proposal subject to the deletion of any item or group of items of work from the scope of work. However, in such a case, the scope of work and fees proposed by the Owner are subject to the agreement of the proponent.
3. The proponent shall be prepared to attend an interview as part of the Owner's evaluation of the proposals submitted. The Owner may request a presentation identifying company qualifications, key staff, relevant experience, and the suggested approach to undertaking this project. In addition, the proponent shall be prepared to provide a sample of documentation created for previous commissioning services projects including commissioning reports and systems manuals.

The proponent shall bear all costs associated with preparing for and attending such an interview and presentation. Failure to attend when requested will disqualify the company from being selected to provide commissioning services for this project.

The owner shall issue a Notice to Proceed, with its attachments, to the successful company. When received by the company, this Notice, the RFP, the company's proposal, and documentation of all agreed variations from either the RFP or the proposal shall constitute the entire contract, and is to be interpreted, construed, and given effect in all respects according to the laws of ***[Insert the name of the appropriate jurisdiction]***.

G. Invoices and Payment

1. Invoices shall be submitted in duplicate to the Owner at the address in Article B.1.
2. Invoices shall be submitted on a monthly basis by the ***[Insert the appropriate day]*** of the month, covering work carried out since the previous invoice.
3. The owner shall pay all invoices in full within 30 days of the invoice date.

H. Compliance with Laws

1. The equipment or services furnished or used on this project shall comply with all applicable federal, state, and local laws, codes and regulations.
2. All items provided shall have proper labeling, and material safety data sheets shall be submitted to the Owner at the address in Article B.1, as required by ***[Insert a reference to the applicable law or regulation]***.

   [When required for security reasons, the following item should be included]
3. The successful proponent shall obtain employee background checks for all employees who will work on the project according to ***[Insert a reference to the applicable law or regulation]***, and ensure these are on file with the Owner prior to starting work on-site.

I. Default

1. In the event that any equipment or service provided by the successful proponent under a contract or purchase order should not conform to the requirements or specifications in the contract, the Owner may reject such equipment or service. In such an event, the Owner shall instruct the company to remove any rejected equipment without expense to the Owner, and to replace it with such equipment as conforms to contractual requirements, and/or to provide additional or alternative services that conform to contractual requirements.

J. Qualifications and Experience

1. At a minimum, the proponent company's qualifications and experience shall include the following:
   (a) Membership in the AABC Commissioning Group (ACG) and commissioning certification from that organization.
   (b) At least 10 years of experience with the types of building, HVAC and control systems included in this project.

(c) Knowledge of operations and maintenance requirements.

(d) A thorough knowledge of testing, adjusting, and balancing (TAB) procedures and methods.

(e) Knowledge and experience with applicable life safety codes, regulations, and procedures.

(f) Successful experience working with multi-disciplinary teams,

(g) Excellent oral and written communications skills.

K. Submittal Requirements

1. The proposal shall include the following:
   - A statement of qualifications and experience, as detailed in Article J.
   - Resumes of all key staff to be employed on the project.
   - Identification of the following staff to be assigned to this project:
     (a) Project manager - having overall project management authority, and
     (b) Field supervisor - having supervisory authority on-site.
   - An outline of your company's general approach to undertaking this project, demonstrating an understanding of the scope of work and a capability to carry it out successfully
   - References for projects similar in nature and scope to this one completed within the last five (5) years. For each referenced project, identify the project, include name and contact information for the Owner or his representative, and describe the scope of work undertaken by your company.
   - A firm fixed fee quotation to perform the commissioning services required for the pre-design and design phases of the project.
   - A budget, not-to-exceed, fee estimate to perform the commissioning services required for the construction, acceptance, and post-acceptance phases of the project, with negotiation of a firm fixed fee for these phases to be concluded with the successful company before the end of the design phase.

     [It is suggested to proponents that they state the basis for this estimate in the proposal]

   - Hourly charge-out rates for key staff to be assigned to the project that will apply to any extra work authorized by the Owner.
   - Technical information on the test, and any other, equipment and instrumentation proposed to be used by the commissioning authority in providing the required services.

2. The proposal shall be signed by an authorized officer, whose name and title shall be printed below the signature along with the date of signing.
3. The proponent's company name shall be clearly visible on every page of the proposal by stamp, label, printed header/footer, or some other satisfactory means.

L. Required Scope of Commissioning Services

1. Commissioning services are to be provided in five (5) phases: pre-design, design, construction, acceptance, and post-acceptance, in accordance with the ACG Commissioning Guideline.
2. During the pre-design phase, the commissioning authority shall carry out the following scope of work:
   - Provide input to the Owner's requirements for the mechanical systems.
   - Review the Design Intent Document and verify the initial design intent with the Owner and engineer.
   - Prepare the pre-design commissioning outline.

     [If the owner is implementing "construction HVAC commissioning" instead of "comprehensive HVAC commissioning, then the preceding item will not be relevant]
3. During the design phase the commissioning authority shall carry out the following scope of work:
   - Review the design documents (drawings and specifications) as they are prepared to ensure inclusion of material covering the contractor's responsibilities for commissioning; provide comments and suggestions for designer consideration.
   - Prepare the design-phase commissioning plan.

     [If the owner is implementing "construction HVAC commissioning", instead of "comprehensive HVAC commissioning, then the preceding item will not be relevant]
4. During the construction phase the commissioning authority shall carry out the following scope of work:
   - Organize and lead the commissioning team.
   - Review shop drawings and equipment submittals for information affecting the commissioning process.
   - Update the commissioning plan to reflect equipment and controls data from the submittals, and provide commissioning schedule information that the contractor can integrate into the project schedule.
   - Schedule and lead commissioning meetings.

- Establish and maintain a system for tracking issues needing resolution.
- Review the project schedule periodically to ensure commissioning activities are properly incorporated; provide feedback to the designer as needed.
- Perform on-site observations during construction.
- Monitor correct component and equipment installation; including controls point-to-point checkouts. Document all observations.
- Witness equipment and system start-ups as deemed necessary. Ensure complete documentation of same.
- Other related work.

5. During the acceptance phase the commissioning authority shall carry out the following scope of work:
   - Review and inspect, on a sample basis, the testing, adjusting and balancing work that has been carried out by another agency.
   - Conduct functional performance testing of sub-systems, systems, and interactions between systems, leading to acceptance of the completed work. Document results of all tests witnessed.
   - Organize and direct the training of O&M personnel.
   - Videotape O&M staff training sessions.
6. During the post-acceptance phase the commissioning authority shall carry out the following scope of work:
   - Conduct functional performance testing of sub-systems, systems, and interactions between systems that could not be carried out prior to acceptance due to unsuitable weather conditions.
   - Prepare and submit a final commissioning report.
   - Provide follow-up for quality performance during the guarantee period.
7. The scope of work as described in Articles L.2 through L.6 shall be provided for the following base building systems:
   - Supply air.
   - Return air.
   - Exhaust air.
   - Chilled water.
   - Condenser water.
   - Hot water.
   - HVAC control system.

8. In addition to the HVAC systems listed in Article L.7, include in the proposal a fee quotation to carry out the scope of work in Articles L.2 through L.6 as applicable for each of the following systems as an "add-on" alternate:

   [The preceding item 8 will not be applicable if the owner limits the RFP to commissioning of HVAC systems. However, if the owner is considering extending commissioning to non-HVAC system, then this item will be applicable, and it will need to include a list of these systems. The following is a partial list of possible systems. It will have to be edited and possibly extended as applicable to a specific project.]

   - Domestic water heating and distribution systems
   - Domestic water treatment
   - Electrical power distribution systems
   - Lighting control systems
   - Fire alarm system
   - Security and intrusion detection systems
   - Sprinkler system
   - Telephone and intercommunications systems
   - Cable TV and CCTV systems

M. Schedule

1. ***[Include here information on schedule milestones]***
2. A copy of the preliminary project schedule is attached.

APPENDIX B Sample Specification Covering Contractor Responsibilities for HVAC Commissioning

Notes to Appendix B

An inter-disciplinary team carries out commissioning. The commissioning authority is the leader of the team, and has overall responsibility for its organization, coordination and successful completion. But this responsibility cannot be achieved without all other team members carrying out their responsibilities.

The General Contractor (or Construction Manager), Mechanical Contractor and the various sub-contrators within Division 15, and the Electrical (Division 16) Contractor all have responsibilities with respect to HVAC systems commissioning. These responsibilities must be set out in the contract specifications defining their work.

The material in this appendix assumes the use of Comprehensive HVAC Commissioning as described in Chapter 5 of this Guideline. It contains a sample set of specification sections that describe the comprehensive commissioning process, and define the contractor's responsibilities with respect to commissioning.

This sample specification will also apply to construction HVAC commissioning. If a decision to include commissioning is made before the contract documents are completed, there is an opportunity to include commissioning requirements in the specifications issued for bid. If construction has started before commissioning is decided on, then the sample specification could be used as a guide to preparing the commissioning specification that contractors will use to identify their commissioning costs on a change order basis.

The sample specification sections are as follows:

- **Section 01660: Commissioning of HVAC Systems—**This section is in the General Contractor's part of the specifications. It contains the detailed requirements with respect to commissioning applicable to all Divisions of the work. As such, it includes requirements normally considered within the scope of both the mechanical and electrical contractors. However, it is in this location for two reasons. First, it allows all requirements, covering all Divisions of the work, to be stated in one place. Second, if specified responsibilities apply to more than one Division of work, or to several sub-contractors within Division 15, appropriate specification references can be placed in those Divisions pointing to the definitive requirements in Section 01660.
- **Section 15995: HVAC Systems Commissioning—**References to Section 01660, with a suitable indication of scope, will be included here.
- **Section 16XXX: Electrical Systems Commissioning—**References to Section 01660, with a suitable indication of scope, will be included here.

These sample specifications are included solely as an example. ACG assumes no responsibility for how the material in this Appendix may be utilized by users of the Guideline; the users assume full responsibility for any and all liability that may arise from any reference to, or use of, this material.

A. Specification 01660–Commissioning of HVAC Systems

Part 1 – GENERAL

1.1 Commissioning Authority

The owner shall procure an ACG-certified, independent third-party commissioning authority (CxA). The CA has overall responsibility for planning and coordinating the commissioning process. However commissioning involves all parties to the design and construction process, including the contractor.

1.2 Contractor Responsibility

This Section of the specifications defines the contractor's responsibilities with respect to the commissioning process. Each contractor and sub-contractor shall review this Section, and shall include in their bids for carrying out the work described, as it applies to each Division and Section of these specifications, individually and collectively.

1.3 Description of Work

The purpose of the commissioning authority is to provide the owner/operator of the facility with assurance that the mechanical systems have been installed according to the contract documents, and operate within the performance guidelines set out in the design intent documents (D.I.D.) and these specifications. The CA will provide the owner with an unbiased, objective view of the system's installation, operation, and performance. The commissioning process does not take away or reduce the responsibility of the installing contractors to provide a finished product, installed and fully functional in accordance with the contract documents.

Commissioning is intended to enhance the quality of system start-up and aid in the orderly completion and transfer of systems for beneficial use by the owner. The CA will be the leader of the commissioning team, planning and coordinating all commissioning activities in conjunction with the design professionals, construction manager, subcontractors, manufacturers and equipment suppliers.

The General Contractor, Mechanical Contractor, all Division 15 sub-contractors, and the Electrical Contractor shall be responsible for cooperating, and coordinating their work, with the CA. They shall also be responsible for carrying out all the physical activities required for installation of components and systems, and operating them during the commissioning process as required in this Section.

1.4 Related Documents

Drawings and general provisions of the contract, including general and supplementary conditions, general mechanical provisions and applicable Divisions 15 and 16 Specification sections, apply to work of this section.

1.5 References

ACG Commissioning Guideline

Part 2 – PRODUCTS

2.1 HVAC Systems to be Commissioned

HVAC systems installed under this contract are to be inspected, tested, signed off as complete and operational, and operated for commissioning authority verification as described in Part 3 of this Section. This includes, but is not necessarily limited to the work listed for each system. The foregoing includes all the following:

[Insert a list of components, equipment, and systems that must be commissioned. The following list is generic and should be edited and extended as appropriate for the specific project, or users may provide their own lists. It is the user's responsibility to create and include in 2.2 of the commissioning specification a Systems Verification Checklist (SVC) for each type of component and system to be commissioned in order to more clearly define the contractor's responsibilities with respect to pre-start and start-up of components and equipment. The SVCs will be obtained from the commissioning plan developed for the project.]

[It is the user's responsibility to create and include in 2.3 of the commissioning specification, a Functional Performance Test (FPT) checklist for every system to be commissioned in order to more clearly define the contractor's responsibilities with respect to carrying out performance checks for confirming correct system functionality, and operating the system as directed by the Commissioning Agent for formal functional performance tests. The FPTs will be obtained from the commissioning plan developed for the project.]

1. **Hot water, glycol solution, chilled water, and condenser water piping systems—**work includes installation inspections and checks; pressure tests and documentation; expansion tanks; confirmation of flow balancing completion; seismic restraints installation certification.
2. **Duct and air-handling systems—**work includes installation inspections and checks; confirmation of flow balancing completion; leak testing as applicable; seismic restraints installation certification.
3. **Chiller(s)—**work includes installation inspections and checks (including seismic restraints installation certification); checkout and startup by manufacturer's representative; documented performance measurements including capacity, evaporator and condenser flows, motor amperage, controls operation, and sound levels.
4. **Cooling Tower(s)—**work includes installation inspection and checks (including seismic restraints installation certification); checkout and startup by manufacturer's representative in conjunction with chiller; documented performance measurements including sound, capacity, motor amperage, pan heater operation, makeup water, overflow, and capacity controls.

5. **Closed-circuit heat rejector(s) or evaporative condenser(s)—*[list similar to that for cooling tower.]***
6. **Refrigeration Compressor/Condensing Unit(s)—**Work includes installation inspection and checks (including seismic restraints installation certification); checkout and startup by manufacturer's representative as specified; documented performance measurements including capacity, evaporator and condenser pressures, motor current draw, and controls operation.
7. **Boiler(s)—**Work includes installation inspections and checks (including seismic restraints installation certification); boil out and chemical treatment; checkout and startup by manufacturer's representative; documented performance measurements including combustion efficiency, capacity test, burner and controls operation.
8. **Pumps—**Work includes documented checks on alignment, rotation, motor current draw, flows and pressures.
9. **Supply, Return, Relief and Exhaust Fans—**Work includes checks on installation (including seismic restraints, dampers and other accessories), rotation, sound levels, motor current draw, and airflows and pressures.
10. **Air Handling Units (both packaged and built-up)—**Work includes installation inspections and checks (including seismic restraints installation certification); checkout and startup by manufacturer's representative as specified; documented capacity tests, for heating, cooling, air flow and static pressures; operation of all controls; sound level.
11. **Air Terminal Devices—**Work includes installation inspections and checks; for VAV units, flow adjustments and calibration coordinated with controls and air balancing; controls operation including flow modulation, reheat, controls responses.
12. **Fan-coil Units—**Work includes installation inspections and checks; performance and controls checks.
13. **Water-source Heat Pumps—**Work includes installation inspections and checks; documented seismic installation certification; performance and controls checks.
14. **Controls Air Compressor—**Work includes installation inspections and checks; documented seismic installation certification; operational checks.
15. **Direct digital controls system –** Work includes inspections and checks of installation and operation of all devices; complete operation of all controls sequences, in coordination with commissioning of all controlled systems.

The contractor shall be responsible for carrying out all work required for commissioning these systems that is defined as a contractor responsibility in Part 3 of this Section.

2.2 System Verification Checklist

This specification contains the system verification checklists as listed below:

SVC#1, Boiler
SVC#2, Chiller
SVC#3, Cooling tower
SVC#4, Pumps
SVC#5, Supply fan
SVC#6, Return fan
SVC#7, Exhaust fan
SVC#8, Coils
SVC#9, Air-handling unit, liquid heat/cool
SVC#10, Rooftop packaged air-handling unit, gas heat/DX cool
SVC#11, VAV terminal units
SVC#12, Fan-powered VAV terminal units
SVC#13, Unitary water-source heat pump
SVC#14, Controls air compressor

[It is important that the specification include a System Verification Checklist (SVC) for each different type of equipment and system to be commissioned. The SVCs define the checks that must be carried out by the contractor prior to start-up. Appendix 'C' contains sample SVCs for several different types of equipment. Project specific SVCs must be developed, and included in the commissioning specification. Each SVC will take at least an entire page.]

[The layout of this section of a commissioning specification should be: A listing of the SVCs included in the specification, covering all equipment and systems to be commissioned. The list above is just an example—it must be revised to suit the specific project. The listing will be followed by a separate, clearly identified SVC for each type of equipment and system, customized for the project, in the same order as presented in the listing.]

2.3 Functional Performance Test Checklist

This specification contains functional performance test checklists as listed below:

FPT#1, Hot water boiler and hydronic distribution system

FPT#2, Chilled water system, including heat rejection and hydronic distribution

FPT#3, VAV system, liquid heat/cool air-handling unit

FPT#4, Constant volume system, packaged rooftop gas heat/DX cool air-handling unit

FPT#5, Waterloop heat pump system

FPT#6, Air make-up and exhaust system

[It is important that the specification include a Functional Performance Test (FPT) checklist for each different type of system to be commissioned. The FPTs define the functional performance test protocols that must be performed by the contractor for commissioning authority verification. Appendix 'D' contains sample FPTs for several different systems. Project specific FPTs must be developed, and included in the commissioning specification. Each FPT may take up several pages.]

[The layout of this section of a commissioning specification should be: A listing of the FPTs included in the specification, covering all systems to be commissioned. The list above is just an example—it must be revised to suit the specific project. The listing will be followed by a separate, clearly identified FPT for each type of equipment and system, customized for the project, in the same order as presented in the listing.]

2.4 Members of the Commissioning Team

[Insert a list of commissioning team members applicable to the project. The following list is typical, but should be edited or extended as appropriate to the specific project.]

The commissioning team will consist of representatives of the following:

1. owner
2. end user *[if applicable]*
3. architect
4. mechanical design engineer
5. electrical design engineer
6. commissioning authority (CA)
7. general contractor **[or construction manager]**
8. mechanical (Div. 15) contractor (M)
9. electrical (Div. 16) contractor (E)
10. controls contractor (ATC)
11. sheet metal contractor
12. testing, adjusting, and balancing agency (TAB)
13. owner's O&M staff

During the commissioning process, participation of team members will generally be required as noted in the following table (with abbreviations as noted in brackets in the preceding list of team members). The mechanical contractor, indicated by "M", includes all mechanical sub-contractors or suppliers whose participation is required for commissioning a particular system or piece of equipment.

	Team Members				
Equipment/System Description	CA	M	TAB	ATC	E
Broiler	X	X	X	X	X
Chiller	X	X	X	X	X
Cooling tower	X	X	X	X	X
Closed-circut heat rejector	X	X	X	X	X
Pumps	X	X	X	X	X
Supply fan	X	X	X	X	X
Return Fan	X	X	X	X	X
Exhaust fan	X	X	X	X	X
Refrigerant compressor/condensing unit	X	X		X	X
Air-handling unit	X	X	X	X	X
Coil (hot water or chilled water)	X	X	X	X	
VAC terminal unit	X	X	X	X	
Fan-coil unit	X	X	X	X	X
Water-source heat pump	X	X	X	X	X

Part 3 – EXECUTION

3.1 Commissioning Responsibilities— Non-Contractor Team Members

3.1.1 Introduction

As noted in 2.2, a multi-disciplinary team carries out commissioning. The commissioning responsibilities of some non-contractor team members during the construction and acceptance phases of the project are provided here for information, and to provide some context for the overall process.

3.1.2 Commissioning Authority Responsibilities

The commissioning authority will:

- plan, organize and implement the commissioning process as specified herein,
- prepare the commissioning plan, and ensure its distribution for review and comment,
- revise the commissioning plan as required during construction,
- chair commissioning meetings, and prepare and distribute minutes to all commissioning team members, whether or not they attended the meeting,
- in conjunction with the General Contractor, coordinate commissioning activities among all contractors, sub-trades and suppliers,
- monitor system verification checks, and ensure the results are documented as the checks are done,
- monitor controls point-to-point checks done by the controls contractor, and ensure the results documented as the checks are done,
- observe all start-ups and initial system operations tests and checks,
- direct the contractors to operate equipment and systems as required to ensure that all required functional performance tests are carried out for verification purposes,
- witness all functional performance tests and document the results,
- prepare and submit a Commissioning Report which documents all checks and tests done throughout the commissioning process, and the results obtained from each, and
- ensure all required O&M manuals, instructions and demonstrations are provided to the owner's designated operating staff.

3.1.3 Mechanical Engineer Responsibilities

The Mechanical Engineer will review the Commissioning Plan, and will participate, as appropriate, in on-site commissioning meetings.

During the acceptance phase of the commissioning process, the Mechanical Engineer may be on site to review commissioning documentation, to witness functional performance tests, and to analyze the installation and its performance.

3.1.4 Owner's Responsibilities

The Owner will ensure the availability of operating staff for all scheduled instruction and demonstration sessions. This staff will possess sufficient skills and knowledge to operate and maintain the installation following attendance at these sessions.

The Owner will also ensure the appropriate involvement of the Electrical Engineer, Architect, and any other consultants as required, in the commissioning process.

3.2 Commissioning Responsibilities— General Contractor [or construction manager]

The General Contractor has responsibility to ensure the overall completion of the Work. In this regard, he shall:

1. participate as required in the HVAC commissioning process,
2. ensure the Mechanical Contractor performs all assigned HVAC commissioning responsibilities as specified in 3.3,
3. ensure the testing, adjusting and balancing agency performs HVAC commissioning responsibilities as listed in 3.4,
4. ensure the Electrical Contractor performs all assigned HVAC commissioning responsibilities as specified in 3.6,
5. ensure the cooperation and participation in the HVAC commissioning process of all other sub-contractors as applicable.

The General Contractor shall assign a representative to the commissioning team, and submit the person's name to the commissioning authority, within one (1) month of the award of the contract. The representative shall have the

authority to make decisions on behalf of the general contractor as they relate to the organization and scheduling of HVAC commissioning. The representative shall facilitate communications among all contractors and suppliers and other commissioning team members, and shall foster the necessary cooperative action. One specific responsibility shall be to attend commissioning meetings, and ensure action items arising from them are attended to as required to allow the commissioning process to proceed on schedule.

In the event that any scheduled equipment or system start-ups or functional performance tests are terminated because the CA or the mechanical engineer discover deficient or incomplete work, or due to the non-attendance of required contractor or supplier personnel, the contractor or subcontractor responsible for the termination shall also be responsible for paying reasonable costs of time and travel expenses of any or all of the following representatives who were physically present for the purpose of witnessing the start-up or the FPT: the CA, the mechanical engineer, the electrical engineer, and the owner. The owner may provide a statement to the General Contractor identifying the specific activity that was terminated, the scheduled date, and a list of those in attendance, along with their reasonable time and travel expense costs.

[NOTE: The reference to the TAB agency in item 3 assumes that TAB is a sub-contract directly to the general contractor. For other arrangements, refer to the note at 3.4.]

3.3 Commissioning Responsibilities—Division 15 (Mechanical) Contractor

The mechanical contractor, and all the sub-contractors and suppliers within Division 15, shall cooperate with the commissioning authority (CA), and other commissioning team members, to facilitate the successful completion of the commissioning process.

The contractor shall assign a representative to the commissioning team, and submit the person's name to the commissioning authority, within one (1) month of the award of the contract. The representative shall have the authority to make decisions on behalf of the mechanical contractor as they relate to the organization and scheduling of HVAC commissioning. The representative shall ensure communications between Division 15 contractors and suppliers and all other commissioning team members, and shall foster the necessary cooperative action. One specific responsibility shall be to attend commissioning meetings, and ensure action items arising from them are attended to as required to allow the commissioning process to proceed on schedule.

The Mechanical Contractor, and all mechanical sub-contractors and suppliers, shall cooperate with the commissioning authority in carrying out the HVAC commissioning process. In this context, the Mechanical Contractor shall:

1. Each contractor and sub-contractor in this division shall include in their quotes the cost of participating in the commissioning process as specified herein.
2. Ensure the automatic temperature controls (ATC) contractor performs HVAC commissioning responsibilities as listed in 3.5.
3. Provide instruction and demonstrations for the Owner's designated operating staff, in conjunction with the commissioning authority and mechanical engineer, and with the participation of qualified technicians from major equipment suppliers and the controls contractor.
4. Include requirements for submittal data, O&M data, and training information in each purchase order or sub-contract written.
5. Ensure cooperation and participation of specialty sub-contractors such as sheet metal, piping, refrigeration, and water treatment as applicable.
6. Ensure participation of major equipment manufacturing in appropriate start-up, testing and training activities.
7. Attend HVAC commissioning meetings scheduled by the CA.
8. Notify the CA a minimum of two weeks in advance of scheduled equipment and system start-ups, so that the CA may witness system verifications, and equipment and system start-ups.
9. Provide sufficient personnel to assist the CA as required during system verification and functional performance testing.
10. Prior to start-up, inspect, check and confirm the correct and complete installation of all equipment and systems for which system verification checklists are included in the commissioning plan. Document the results of all inspections and checks on the checklists and sign them. If deficient or incomplete work is discovered, ensure corrective action is taken and re-check until the results are satisfactory and the system is ready for safe start-up.
11. Notify the CA a minimum of two weeks in advance, of the time for start of the TAB work. Attend the initial TAB meeting for review of the TAB procedures.

12. Provide equipment and systems start-up resources as specified and required. If during an attempted equipment or system start-up, deficient or incomplete work is discovered that would preclude safe operation, the start-up shall be aborted until corrective action has been taken. Ensure such action is taken and verified before re-scheduling a new start-up. Those responsible for deficient or incomplete work will be responsible for costs in accordance with 3.2 in this Section.
13. Carry out performance checks to ensure that all equipment and systems fully functional and ready for the CA to witness formal functional performance tests (FPTs).
14. Operate equipment and systems for FPTs in accordance with the commissioning plan and as directed by the commissioning authority. If improper functionality, incomplete work, or other deficiencies affecting system performance are discovered, the FPTs will be stopped by the CA. Those responsible for deficient or incomplete work will be responsible for costs in accordance with 3.2 in this Section. Ensure that all corrections necessary for full and complete system operation as specified are completed; then with the ATC contractor and other applicable sub-contractors, carry out functional performance checks to confirm correct operation before applying to the CA to reschedule the FPTs for the system in question.
15. Prepare preliminary schedule for mechanical system orientation and inspections. O&M manual submission, training sessions, pipe and duct system testing, flushing and cleaning, equipment start-up TAB, and task completion for use by the CA. Update schedule as appropriate throughout the construction period.
16. Attend initial O&M staff training session.
17. Conduct mechanical system orientation and inspection at the equipment placement completion stage.
18. Update drawings to as-built condition and review with the CA.
19. Gather O&M data on all equipment, and assemble in binders as required by the commissioning specification. Submit to CA prior to the completion of construction.
20. Participate in, and schedule vendors and contractors to participate in the

O&M staff training sessions as set up by the CA.

21. Provide written notification to the general contractor *[or construction manager]* and CA that the following work has been completed in accordance with the contract documents and the equipment, systems and sub-systems are operating as required.
    - HVAC equipment including all fans, air handling units, dehumidification units, ductwork, dampers, terminals and all Division 15 equipment.
    - Refrigeration equipment, pumping systems and heat rejection equipment.
    - Fire stopping in the fire rated construction, including fire and smoke damper installation, caulking, gasketing and sealing of smoke barriers.
    - Seismic restraints installed to specification; a certification from the seismic restraint engineer meets this requirement.
    - Dedicated smoke control systems including stairway pressurization and atrium systems.
    - Non-dedicated systems using the air-handling units for smoke control.
    - Fire detection and smoke detection devices furnished under other divisions of this specification as they affect the operation of the smoke control systems.
    - That the building control system is functioning to control mechanical equipment and smoke control systems as specified.
22. Provide a complete set of as-built drawings and O&M manuals to the CA.

3.4 Commissioning Responsibilities–TAB Agency

[If the TAB agency is contracted directly by the owner, this material would be included in 3.1 above and the reference to TAB in 3.2 would be deleted. If the TAB agency is a sub-contractor within Division 15, the reference to TAB in 3.2 would be relocated to 3.3 as a mechanical contractor responsibility.]

With respect to HVAC commissioning, the TAB agency shall:

1. Include costs for HVAC commissioning requirements in the quoted price.
2. Attend commissioning meetings scheduled by the CA prior to, and during, on-site TAB work being done.
3. Submit proposed TAB procedures to the CA and mechanical engineer for review and acceptance.

4. Attend the TAB planning meeting scheduled by the CA. Be prepared to discuss the procedures that shall be followed in testing, adjusting and balancing the HVAC system.
5. At the completion of the TAB work, submit the final TAB report to the general contractor *[or construction manager]*, with copies to the Owner, CA and mechanical engineer. ***[If the TAB work is contracted directly by the owner, submittal will be to the owner, CA and mechanical engineer; if contracted directly by the mechanical contractor, submittal will be to the mechanical contractor, with general contractor, CA, and mechanical engineer notified.]***
6. Participate in verification of the TAB report by the CA for verification or diagnostic purposes. This will consist of repeating a sample (normally 10% to 20%) of the measurements contained in the TAB report as directed by the CA.
7. Participate in O&M personnel training sessions as scheduled by the CA.

3.5 Commissioning Responsibilities–Controls Contractor

With respect to HVAC commissioning, the controls contractor shall:

1. Include cost for commissioning requirements in the quoted price.
2. Review design for controllability with respect to equipment selected for the project;
   - Review and confirm in writing that a proper hardware specification exists to permit functional performance testing as required by specification and sequence of operation.
   - Review and confirm in writing that proper safeties and interlocks are included in design.
   - Ensure the proper sizing of control valves and actuators, based on design pressure drops.
   - Ensure that control valve authority will result in capacity control as specified. Include valve sizing and authority information in submittal to mechanical engineer.
   - Ensure the proper sizing of control dampers. Ensure damper authority to control air flows as specified. Review and confirm in writing proper damper positioning for mixing to prevent stratification. Ensure correct actuator vs. damper movement for smooth operation. Include damper sizing, control authority and actuator selection data in submittal to mechanical engineer.
   - Ensure the proper selection of sensor ranges, and include data with submittal to mechanical engineer.

- Clarify all questions concerning sequences of operation with the mechanical engineer.

3. Attend commissioning meetings scheduled by the CA.
4. Provide the following submittals to the CA for review:
   - Hardware and software submittals.
   - Control panel construction shop drawings.
   - Diagrams showing all control points, sensor locations, point names, actuators, controllers and where necessary, points of access, all superimposed on diagrams of the physical equipment.
   - Narrative description of all control sequences for each piece of equipment controlled.
   - Logic diagrams showing the logic flow of all control sequences.
   - A list of all control points, including analog inputs, analog outputs, digital inputs and digital outputs. Include the values of all parameters for each system point. Provide a separate list for each stand-alone control unit.
   - A complete control language program listing including all software routines employed in operating the control system. Also provide a program write-up, organized in the same manner as the control software. This narrative shall describe the logic flow of the software and the functions of each routine and sub-routine. It should also explain individual math or logic operations that are not clear from reading the software listing.
   - Hardware operation and maintenance manuals.
   - Application software and project applications code manuals.
5. Inspect, check, and confirm the proper installation and performance of controls/BAS hardware and software provided by others.
6. Integrate installation and programming scheduling with construction and commissioning schedules.
7. Inspect, check and confirm the correct installation and operation of input and output field points and devices through documented and signed off point-to-point checkouts.
8. Provide thorough training to operating personnel on hardware operations and programming, and the application program for the system, in accordance with the O&M staff training program in the commissioning plan.
9. In conjunction with the mechanical contractor, demonstrate system perfor-

mance to the CA including all modes of system operation (e.g. occupied, unoccupied, emergency) during the functional performance tests (FPTs). If improper functionality, incomplete work, or other deficiencies affecting system performance are discovered, the FPTs will be stopped by the CA. Those responsible for deficient or incomplete work will be responsible for costs in accordance with 3.2 in this Section.

10. Provide control system technician to assist during system verification and functional performance testing.
11. Provide support and coordination with TAB contractor on all interfaces between controls and TAB scopes of work. Provide, at no additional cost to the TAB and commissioning agencies, all devices, such as portable operator's terminals and all software for the TAB agency to use in completing TAB procedures.

3.6 Commissioning Responsibilities– Electrical (Division 16) Contractor

With respect to HVAC commissioning, the electrical contractor shall:

1. Include cost for HVAC commissioning requirements in the quoted price.
2. Review design with respect to providing power to the HVAC equipment;
   - Verify that proper hardware specifications exist for functional performance and sequence of operation required by specification.
   - Verify that proper safeties and interlocks are included in the design of electrical connections for HVAC equipment.
3. Attend commissioning meetings scheduled by the CA.
4. Schedule work so that required electrical installations are completed, and systems verification checks and functional performance tests can be carried out on schedule.
5. Inspect, check and confirm in writing the proper installation and performance of all electrical services provided.
6. Provide electrical system technicians to assist during system verification and functional performance testing as required by the CA.

B. Specification 15995–Commissioning of HVAC Systems

1.1 Commissioning Authority

The commissioning authority (CA) has been contracted directly with the owner for this project. The CA has overall responsibility for planning and coordinating the commissioning process. However commissioning involves all parties to the design and construction process, including the mechanical (Division 15) contractor, and all specialty sub-contractors within Division 15, such as sheet metal, piping, refrigeration, water treatment, and controls, plus major equipment suppliers as required.

1.2 Contractor Responsibility

The mechanical (Division 15) contractor's responsibilities are defined in Section 01660 of the specifications. These responsibilities apply to all specialty sub-contractors and major equipment suppliers within Division 15. Each contractor and supplier shall review Section 01660, and their bids shall include for carrying out the work described, as it applies to each Section within the Division 15 specifications, individually and collectively.

C. Specification 16995–Commissioning of HVAC Systems

1.1 Commissioning Authority

The commissioning authority (CA) has been contracted directly with the owner for this project. The CA has overall responsibility for planning and coordinating the HVAC commissioning process. However commissioning involves all parties to the design and construction process, including the electrical (Division 16) contractor, as many HVAC system components require electrical power and controls in order to operate as specified.

1.2 Contractor Responsibility

The electrical (Division 16) contractor's responsibilities are defined in Section 01660 of the specifications. Each contractor and supplier within Division 16 shall review Section 01660, and their bids shall include for carrying out the work described, as it applies to each Section within the Division 16 specifications, individually and collectively.

APPENDIX C

Sample Format for System Verification and Start-up Checklists

Notes to Appendix C

This appendix contains sample systems verification and start-up checklists for a selection of equipment used frequently in typical HVAC systems.

There is no intention in the appendix to provide sample checklists for all possible equipment included in any design. These checklists are intended to illustrate a level of detail that is appropriate in good commissioning practice, and to suggest a practical format. As such, they contain typical items that are often required to be included in the inspections and checks carried out, and documented, prior to and during equipment start-up.

The sample checklists are generic; thus they do not apply to any specific project, and so the list of check items is generic, not specific. Commissioning authorities must develop systems verification and start-up checklists for every piece of equipment within the scope of any commissioning project, and those checklists must include all items included in the specific design that require checking.

ACG assumes no responsibility for how the material in this Appendix may be utilized by users of the Guideline; the users assume full responsibility for any and all liability that may arise from any reference to, or use of, this material.

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
AIR HANDLING UNIT

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenums clean and free of loose material		
Temporary start-up filters		
Fire & balance dampers positioned		
Duct system tested and cleaned		
Access doors, Insulation and interior lights		
Local valving/piping (HWS, CHWS, steam, condensate, drains)		
Drain pans		
Heating and cooling coils		
Failed position of heating coil valve-open to coil		
Failed position of cooling coil valve-closed to coil		
Outside air, return air and mixed air dampers		
Humidifier		
Building & fan room cleanliness		
Filter bank, DP switch gauge and photohelics		
Electrical wiring complete		
Motor rated for VSD service		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Instrumentation (temperature, volume, pressure & humidity)		
Control system - point to point checks complete		
START-UP		
VSD Start-up by manufacturer's representative		
Direction of rotation		
Electrical interlocks - stop/start		
Freeze protection operational		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :__ Actual :_____		
Final operating filters installed		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
CONTROLS AIR COMPRESSOR

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Local valving/piping (air, condensate, drains)		
Bypass piping around dryer and filter		
Intake air filter		
Inlet and outlet air silencers		
High pressure relief valve		
Status indicators- local/remote.		
Pressure gauges.		
Air receiver with automatic and manual drains		
Duplex oil and particle separators.		
Duplex Micron discharge filters		
Flexible air connection		
Refrigerated air dryer.		
Pressure reducing valve		
Isolation valve on each high pressure line.		
Electrical wiring complete		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Local starters		
Control system - point to point checks complete		
START-UP		
Start-up by manufacturer's rep. (report attached)		
Direction of rotation		
Electrical interlocks - stop/start		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :__ Actual :_____		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
HOT WATER BOILER

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Boiler certificate / registration (copy attached)		
Mounting/support system		
Seismic restraints		
Maintenance clearance		
Local valving/piping correct (including expansion tanks and make-up water).		
Chemical cleaning and treatment (report attached)		
Temperature and pressure gauges		
Pressure relief valve		
Pressurization and leak tests		
Blowdown system		
Safety interlocks- low water and high temperature		
Combustion air supply and ventilation		
Insulation/lagging		
Stack and breaching		
Combustion chamber inspection		
Fuel system (including emergency shutdown and gas inspection certificate)		
Electrical wiring		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Control system - point to point checks complete		
START-UP		
Start HWS pumps to create load.		
Start boiler circulation pumps.		
Boiler startup by supplier		
Supplier certificate or log provided for start-up and all specified and regulatory tests.		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____
print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
CHILLER

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system		
Seismic restraints		
Maintenance clearance		
Local valving/piping correct (including expansion tanks, make-up water and identification).		
Pressurization and leak tests		
Supplier pre-start (including charging the system) (report attached)		
Chemical cleaning and treatment (report attached)		
Insulation/lagging		
Refrigerant relief valve		
Temperature and pressure gauges		
Flow switches - safety interlocks		
Temperature sensors - safety interlocks		
UL and ASME approvals		
Control/diagnostic/programmable module		
DDC interface with specified points e.g. chilled water setpoint and demand limiter analogue inputs, and % load, run status and alarm outputs		
Electrical wiring		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Control system - point to point checks complete		
START-UP		
Start condenser water system		
Start chilled water system to create load		
Chiller startup by supplier		
Modulation through specified range		
Safety interlocks		
Supplier certificate or log provided for start-up and all specified and regulatory tests		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
HEATING AND COOLING COILS

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Mounting/support system		
Seismic restraints		
Building & fan room cleanliness		
Plenums clean and free of loose material		
Duct system tested and cleaned		
Fire & balance dampers positioned		
Local valving/piping (HWS, CHWS, steam, condensate, drains)		
Drain pans		
Coils clean, fins straight and not damaged or corroded.		
Water system cleaned & treated (report attached)		
Strainers - construction screens removed.		
Failed position of heating coil valve-open to coil		
Failed position of cooling coil valve-closed to coil		
Control system - point to point checks complete		
START-UP		
Freeze protection operational		
Use Point-to-Point Checklist to record:		
Water inlet temperature: _____°F		
Water discharge temperature: _____°F		
Air inlet temperature: _____°F		
Air discharge temperature: _____°F		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
COOLING TOWER

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system/vibration isolation		
Seismic restraints		
Maintenance clearance and access panels		
Local valving/piping correct (including make-up water, meter, back flow preventer and identification).		
Cooling tower leak test		
Sump clean and free of loose material		
Blowdown, drain and overflow system		
Chemical cleaning & treatment (report attached)		
Temperature gauges		
Temperature sensors		
Vibration sensor		
Sump heater aquastat.		
Sump heater, low water and high temp. cutout.		
Lubrication		
Vanes or dampers		
High and low speed motors (or VSD)		
Motor guards.		
Sheaves and belts, alignment and tension		
Freedom of rotation		
Electrical wiring (complete)		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Local control panel with DDC interface		
Control system - point to point checks complete		
START-UP		
Start cooling tower fans		
Direction of rotation		
Motor Amps - Rated:__ Actual :_____		
Motor Volts - Rated:_____Actual :_		
Start condenser water pumps		
Modulate or stage cooling tower fans and/or vanes		
Vibration & noise level acceptable		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION /START-UP CHECKLIST
EXHAUST FAN

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Flexible connections		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenum/volute clean and free of loose material		
Duct system tested and cleaned		
Fire & balance dampers positioned		
Exhaust louvers tested (gravity or motorized)		
Building & fan room cleanliness		
Electrical wiring		
Motor rated for VSD service		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Control system - point to point checks complete		
START-UP		
Start-up by manufacturer's rep. (report attached)		
Direction of rotation		
Electrical interlocks - stop/start		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :_ Actual :_____		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION /START-UP CHECKLIST
FAN POWERED VARIABLE AIR VOLUME BOXES

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

PRE-START-UP INSPECTION					
Check the following equipment for:	VAV 1	VAV 2	VAV 3	VAV 4	VAV 5
Local valving and piping					
Local ductwork					
Mounting support and seismic system					
Maintenance access, access doors and insulation					
Valve operation (reheat coil)					
Damper operation					
Sensor location and operation					
Fan freedom of rotation					
Electrical wiring complete					
Overload protection (sized correctly)					
Disconnect switch (tested)					
Control system - point to point checks complete					
Building cleanliness					
START-UP					
Start air handling system (see separate checklist)					
Local fan direction of rotation					
Electrical interlocks - stop/start					
Speed selector switch					
Local air leakage acceptable					
Vibration & noise level acceptable					
Motor Amps - Rated: Actual:					
Motor Volts - Rated : Actual :					
Final operating filters installed					

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
UNITARY HEAT PUMP - WATER SOURCE

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Seismic restraints		
Lubrication		
Temporary start-up filter		
Access doors and insulation		
Duct system completed and cleaned		
Fire & balance dampers positioned		
D/X coil, water/refrigerant heat exchanger, reversing valve, compressor		
Water supply piping		
Strainer, isolation and balance valve(s)		
Drain piping		
Drain pan		
Fan freedom of rotation		
Building cleanliness		
Electrical wiring complete		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Local heating/cooling thermostat		
START-UP		
Start-up by manufacturer's representative and certificate or log provided		
Direction of rotation		
Electrical interlocks - stop/start		
Fan speed selector switch		
No water or condensate leakage		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :_ Actual :_____		
Final operating filters installed		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
PRE-START/START-UP CHECKLIST
PUMPS

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Piping and valving		
Seismic restraints		
Mounting/support system and vibration isolation		
Freedom of rotation		
Lubrication		
Electrical wiring		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Control system - point to point checks complete		
START-UP		
HWS or CHWS available		
Direction of rotation		
Electrical interlocks - stop/start		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :_ Actual :_____		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION /START-UP CHECKLIST
RETURN FAN

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Flexible connections		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenums clean and free of loose material		
Duct system tested and cleaned		
Fire & balance dampers positioned		
Building & fan room cleanliness		
Electrical wiring		
Motor rated for VSD service		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Control system - point to point checks complete		
START-UP		
Start-up by manufacturer's rep. (report attached)		
Direction of rotation		
Electrical interlocks - stop/start		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :__ Actual :_____		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
ROOF TOP UNIT - GAS HEAT/DX COOLING

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Mounting/support system and vibration isolation		
Seismic restraints		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenums clean and free of loose material		
Temporary start-up filters		
Fire & balance dampers positioned		
Access doors, Insulation and interior lights		
Filter bank, DP switch gauge and photohelics		
Local valving/piping (gas, condensate, pans, drains)		
Motorized dampers		
D/X expansion (cooling) coil and compressor		
D/X condensing coil and fans		
Gas piping and valving complete		
Gas inspection certificate		
Regulatory authority approved installation and burner control (certificate available)		
Building cleanliness		
Electrical wiring complete		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Local control module with DDC interface		
Control system - point to point checks complete		
START-UP		
Start-up by manufacturer's representative with report and certificate or log provided		
Direction of rotation		
Electrical interlocks - stop/start		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :__ Actual :_____		
Final operating filters installed		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION/START-UP CHECKLIST
SUPPLY FAN

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

ITEM	√	COMMENTS
PRE-START-UP INSPECTION		
Commissioning lock-out procedures reviewed		
Operation and maintenance information		
Electrical wiring		
Motor rated for VSD service		
Overload protection (sized correctly)		
Disconnect switch (tested)		
Mounting/support system and vibration isolation		
Seismic restraints		
Flexible connections		
Equipment guards		
Alignment & V-belt tension		
Freedom of rotation		
Lubrication		
Plenums clean and free of loose material		
Temporary start-up filters		
Fire & balance dampers positioned		
Inlet louvers tested (gravity or motorized)		
Duct system tested and cleaned		
Access doors, Insulation and interior lights		
Building & fan room cleanliness		
Filter bank, DP switch gauge and photohelics		
Instrumentation (temperature, volume, pressure & humidity)		
Control system - point to point checks complete		
START-UP		
VSD Start-up by manufacturer's rep. (report attached)		
Direction of rotation		
Electrical interlocks - stop/start		
Freeze protection operational		
Local air leakage acceptable		
Vibration & noise level acceptable		
Motor Amps - Rated :_ Actual :_____		
Motor Volts - Rated :__ Actual :_____		
Final operating filters installed		

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

HVAC COMMISSIONING
SYSTEM VERIFICATION /START-UP CHECKLIST
VARIABLE AIR VOLUME BOXES

PROJECT:_____

Equipment Name/Tag:_____ Location:_____

System/Area Served:_____ Related Equipment:_____

PRE-START-UP INSPECTION
Check the following equipment for:
local valving and piping
local ductwork
mounting support and seismic system
maintenance access
valve operation
damper operation
sensor location and operation
Control system - point to point checks complete
Building cleanliness
START-UP
Start air handling system (see separate checklist)
Local air leakage acceptable

Unit ID	Room	Reheat	Ducting	Valving & Piping	Mounting Support Seismic	Maint. access	Valve operation	Damper operation	Airflow Sensor	Temp. Sensor

Pre-start checks by:_____ _____ Date:_____

Start-up checks by:_____ _____ Date:_____

print name signature

acg AABC Commissioning Group

HVAC COMMISSIONING
SYSTEM VERIFICATION /START-UP CHECKLIST
CONTROLS POINT-TO-POINT CHECKS

PROJECT:_____

Equipment/System:_____ Location:_____

Point		Output				Input		Accept	Comment
Description	Name	DO	AI 0%	AI 50%	AI 100%	DI	AI	Y/N	

Checked by:_____ _____ Date:_____

Verified by:_____ _____ Date:_____

print name signature

APPENDIX D

Sample Functional Performance Test Checklists

Notes to Appendix D

This appendix contains sample functional performance test checklists for a number of commonly used HVAC systems. The information for each system includes the following:

1. Description of the system, including its major components
2. Table showing all modes of operation with the status or position of key equipment in each mode
3. A sequence of operations
4. The functional performance test checklist that corresponds to the preceding information

There is no intention in the appendix to provide sample checklists for all possible systems included in any design. These checklists are intended to provide basic information about each system, so that the functional performance test checklists will logically follow from it, and they will illustrate a level of detail that is appropriate in good commissioning practice, and to suggest a practical format.

The sample functional performance test checklists are generic; thus they do not apply to any specific project, and so the list of test items is generic, not specific. Commissioning agencies must develop functional performance test checklists for every system included within the scope of any commissioning project, and those checklists must include every mode of operation and sequence of operation, covering normal, abnormal and emergency conditions that could occur in the specific design.

ACG assumes no responsibility for how the material in this appendix might be utilized by users of the Guideline; the users assume full responsibility for any and all liability that may arise from any reference to, or use of, this material.

Chilled Water System

System Description

The chilled water system is typical of one that may be installed in a large office building.

The system consists of:

- 3 chillers, CH-1 through CH-3. Chiller CH-1 is smaller than CH-2 and CH-3.
- 1 plate heat exchanger HE-1. It is located between the condenser water system (CWS) and the chilled water system (CHWS) in order that condenser water from the cooling towers may be used to directly cool the chilled water without the chiller(s).
- 2 cross-flow cooling towers CT-1 and CT-2. Each has a high speed and low speed motor driving common shaft mount fans.
- A modulating condenser water bypass valve allows the condenser water to bypass the cooling towers in order to maintain flow without going below the temperature set point.
- 5 chilled water pumps: 2 for the plate heat exchanger P-1 & P-2 and 1 for each chiller P-3, P-4 and P-5
- 5 condenser pumps: 1 for the plate heat exchanger P-6, 1 for the filter P-7 and 1 for each chiller P-8, P-9 & P-10
- A modulating chilled water bypass valve controls the differential pressure across the supply and return piping.

The chilled water distribution system serves cooling coils in air handling units. The system has the following modes of operation:

- Shutdown
- Off
- Start-up
- Free cooling (occupied or override)
- Chiller (override)
- Chiller (occupied)

CHILLED WATER SYSTEM

Modes of Operation

	Shutdown	Off	Start-up	Free Cooling	Chiller (override)	Chiller (occupied)
P-1 (HE-1 chilled water)	Off	Off	Off	Modulating	Off	Off
P-2 (HE-1 chilled water)	Off	Off	Off	Off/On	Off	Off
P-6 (HE-1 condenser water)	Off	Off	Off	On	Off	Off
P-3 (CH-1 chilled water)	Off	Off	Off	Off	On (with CH-1)	Off (except in high load conditions)
P-4 (CH-2 chilled water)	Off	Off	Off	Off	Off	On (with CH-2)
P-5 (CH-3 chilled water)	Off	Off	Off	Off	Off	On (with CH-3)
P-8 (CH-1 condenser water)	Off	Off	Off	Off	On (with CH-1)	Off (except in high load conditions)
P-9 (CH-2 condenser water)	Off	Off	Off	Off	Off	On (with CH-2)
P-10 (CH-3 condenser water)	Off	Off	Off	Off	Off	On (with CH-3)
CH-1 (Chiller)	Off	Off	Off	Off	Modulating (after free cooling)	Off (except in high load conditions)
CH-2 (Chiller)	Off	Off	Off	Off	Off	Modulating (lead/lag with CH-3)
CH-3 (Chiller)	Off	Off	Off	Off	Off	Modulating (lead/lag with CH-2)
CT-1, CT-2 (low and high speed fans)	Off	Off	Off	Cycles	Cycles	Cycles
P-7 (Filter)	Off	Off	Off	Cycles (with P-6, 8, 9 & 10)	Cycles (with P-6, 8, 9 & 10)	Cycles (with P-6, 8, 9 & 10)
Condenser Water Bypass Valve	Open	Open	Open	Modulating	Modulating	Modulating
Chilled Water Bypass Valve	Open	Open	Open	Closed	Modulating	Modulating
Condenser Water Make-up Valve	Closed	Cycle open/closed	Cycle open/closed	Cycle open/closed	Cycle open/closed	Cycle open/closed
Chilled Water Make-up Valve	Cycle open/closed	Cycle open/closed	Cycle open/closed	Cycle open/closed	Cycle open/closed	Cycle open/closed

Sequence of Operations

1. This sequence to be read in conjunction with the control drawings and points list.
2. The DDC system shall determine when the chillers are to operate based on a building demand program by monitoring the various space temperatures as well as the outdoor air temperature.
3. Heat exchanger HE-1 shall be initiated as the source of chilled water when the outdoor air is cold enough to permit this. The DDC system shall start the respective chilled water pump and cycle the condenser water pumps and the cooling tower fans in stages in order to maintain the chilled water supply temperature setpoint of 44°F. (adjustable).
4. Modulate the tower bypass valve in order to maintain condenser water temperature if the outdoor air temperature is low and the cooling tower fans are off .
5. Switchover from HE-1 to the chillers if the condenser water temperature is above 44°F. (confirm with chiller manufacturer for exact conditions).
6. Chiller CH-1 shall be enabled if the demand for cooling is during the unoccupied mode (e.g. one Floor on override mode). Chillers CH-2 and CH-3 shall operate during the occupied mode based on a lead/lag arrangement with the changeover duration being no less than 1 day.
7. The DDC system shall enable the selected chiller for operation and the chiller shall start its respective chilled water and condenser water pumps.
8. The water flow switches are wired to the chiller control panel.
9. The DDC system shall monitor the status of the chiller through a dry contact provided by the chiller manufacturer and shall annunciate an alarm if this contact indicates the chiller is malfunctioning, switch over to an alternate chiller shall be automatically done via the DDC system.
10. The DDC system shall monitor the status of each purge and annunciate an alarm on a pump failure. The selected chiller shall immediately be shut down and the alternate chiller selected.
11. The DDC system shall provide an analog signal (4-20 mA, 2-10 VDC) to the chiller control panel which shall be used to reset the chilled water supply temperature set point based on the building cooling load, as represented by AHU cooling coil control valve positions. As the CHWR temperature rises above 52°F the CHWS temperature set point shall be decreased as required If any space temperature is above the acceptable limit the CHWS set point shall be reduced accordingly, The minimum allowable CHWS temperature shall be 42°F.

12. The second chiller shall be enabled if the CHWR temperature continues to rise above 54°F and the lead chiller has been operating at full capacity for at least 20 minutes. If the building occupied mode is nearly over the DDC system shall determine if the lag chiller may be kept off while still maintaining reasonable space conditions. These limits shall be confirmed with the consultant.
13. Operate all three chillers simultaneously when the cooling load is very high. This shall only be done if it is earlier than 4:00 P.M. (adjustable) and the CHWS temperature is more than 1.0°F above setpoint.
14. The DDC system shall modulate the pressure bypass valve between the CHWS line and the CHWR line based on the difference between the two as sensed by a differential pressure transducer in order to maintain water flow through the chillers and HE-1 at all times. The differential pressure setpoint shall be changed to suit the chilled water pump operating at the time.
15. The DDC system shall cycle the cooling tower fans in sequence as required to maintain the condenser water supply temperature set point. This set point is to be initially set at 80°F but shall be confirmed with the chiller manufacturer to ensure maximum chiller efficiency is maintained and no surging takes place.
16. The DDC system shall monitor the cooling tower fan's current draw and shall annunciate an alarm upon a fan failure.
17. DDC system shall provide a 15 second time delay before the low speed is energized when switching from high speed to low speed fan operation.
18. The DDC system shall monitor a sump water level switch in each cooling tower. The DDC system shall open the two way water make up valve located in the Basement Mechanical Room when the water level is below normal. The valve shall close when the desired water level is reached.
19. The DDC system shall monitor the current draw of the cooling tower filtration pump and annunciate an alarm upon pump failure.

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Shutdown mode: (heating only season)		
– Place the system into a seasonal "shutdown mode" by manual command.		
– Confirm that all 10 pumps (P-1 thru P-10) are commanded OFF by DDC – pump on/off DO points.		
– Confirm that CT-1 and CT-2 fans, both high & low speed, are commanded OFF by DDC – CT fan on/off DO points.		
– Confirm that chilled water & condenser water bypass valves are commanded to 100% bypass – valve AO points = 0.		
– Confirm that cooling tower water make-up solenoid valve is closed, regardless of tower basin water level – solenoid valve open/close DO point.		
Off mode: (cooling season)		
– This mode applies when the system is active (i.e. has been taken out of shutdown mode), but the chilled water sequence is disabled.		
– Confirm that all 10 pumps (P-1 thru P-10) are commanded OFF by DDC – pump on/off DO points.		
– Confirm that CT-1 and CT-2 fans, both high & low speed, are commanded OFF by DDC – CT fan on/off DO points.		
– Confirm that chilled water & condenser water bypass valves are commanded to 100% bypass – valve AO points = 0.		
– Simulate low water level in CT-1 basin. Confirm that cooling tower water make-up solenoid valve opens. Simulate normal water level in CT-1; confirm the solenoid valve closes.		
– Repeat for CT-2.		
NOTES:		
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Start-up mode:		
– This mode applies when the building is occupied (on time schedule, or when OFF time override is in effect) and a cooling demand exists.		
– Test 1 – Confirm that OA temp > ___ºF (or simulate this condition).		
– Test 2 – place building in "occupied status" by time-of-day (TOD) schedule.		
– Test 3 – Ensure a cooling demand exists, or is simulated, based on AHU cooling coil control valve positions. Confirm that chilled water sequence is enabled.		
– Repeat, but with Test 2 placing building in occupied status by manual override. Confirm that chilled water sequence is enabled.		
– Simulate low water level in CT-1 basin. Confirm that cooling tower water make-up solenoid valve opens. Simulate normal water level in CT-1; confirm the solenoid valve closes.		
Cooling tower operation:		
– Check condenser water supply (CWS) temp setpoint – AI point. Record it: ____ºF		
– Starting condition – CWS temp is more than 2ºF below setpoint, with condensing water bypass valve at least partly open. During the following tests, simulate CWS temps as needed to test total load range. The actual break points for each stage will depend on the specific DDC settings.		
Increasing Load:		
– When CWS temp > (setpoint – 1.5ºF); confirm that condenser water bypass valve modulates to fully closed to tower – AO point.		
– When CWS temp > (setpoint – 0.5ºF); confirm that CT-1fan starts on low speed.		
– When CWS temp > (setpoint + 0.5ºF); confirm that CT-2fan starts on low speed.		
– When CWS temp > (setpoint + 1.5ºF); confirm that CT-1fan switches from low-speed to high-speed.		
– When CWS temp > (setpoint + 2.5ºF); confirm that CT-2fan switches from low-speed to high-speed.		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued	PASS FAIL	NOTE
Decreasing Load:		
– When CWS temp < (setpoint + 2.0ºF); confirm that CT-2 fan switches from high-speed to low-speed, with a 15 sec delay between deactivating high-speed and activating low-speed.		
– When CWS temp < (setpoint + 1.0ºF); confirm that CT-1 fan switches from high-speed to low-speed, with a 15 sec delay between deactivating high-speed and activating low-speed.		
– When CWS temp < setpoint; confirm that CT-2 fan shuts OFF.		
– When CWS temp < (setpoint – 1.0ºF); confirm that CT-1 fan shuts OFF.		
– When CWS temp < (setpoint – 2.0ºF); confirm that condenser water bypass valve starts to modulate open to tower.		
Check operation of:		
– Test fan failure alarms on CT-1, low and high speed – based on fan current draws and commanded state.		
– Test CT-2 fan failure alarms as above.		
– Enable any of pumps P-6, P-8, P-9 or P-10; confirm that cooling tower filtration pump P-7 is activated by DDC. Test several combinations of P-6, P-8, P-9 and P-10.		
– Test P-7 failure alarm – low or no current draw when pump is commanded ON.		
– Test cooling tower filter backwash sequence timer and operation.		
– Test operation of chemical treatment feed pumps – 1 for corrosion control, 2 for biocides.		
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued	PASS FAIL	NOTE
Free cooling mode – thru heat exchanger: (occupied or override modes) (once per day)		
– When OA temp (AI) < 45ºF (adjustable), confirm that pumps P-2(DO) and P-6(DO) start.		
– When OA temp (AI) > 50ºF (adjustable), confirm that pumps P-2(DO) and P-6(DO) stop.		
Chilled water operation:		
– As cooling load increases, so does chilled water flow, thus reducing chilled water system supply pressure.		
– When supply pressure drops below setpoint, confirm that pump P-1 starts (DO) and modulates (AO) to maintain CHW supply pressure.		
– When supply pressure rises above setpoint, confirm that after a time delay pump P-1 stops (DO).		
Condensing water operation – increasing cooling load:		
– When CHWS temp > (setpoint – 1.0ºF); confirm that condenser water bypass valve modulates to fully open to tower – AO point.		
– When CHWS temp > (setpoint – 0.5ºF); confirm that CT-1fan starts on low speed.		
– When CHWS temp > (setpoint); confirm that CT-2 fan starts on low speed.		
– When CHWS temp > (setpoint + 0.5ºF); confirm that CT-1fan switches from low-speed to high-speed.		
– When CHWS temp > (setpoint + 1.0ºF); confirm that CT-2 fan switches from low-speed to high-speed.		
– When CHWS temp > (setpoint + 1.5ºF), free cooling cannot meet cooling load; confirm that chiller sequence is enabled.		
– When lead chiller has started; confirm that pumps P-1, P-2 and P-6 stop.		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued	PASS FAIL	NOTE
Condensing water operation – decreasing cooling load:		
– Relevant when CHWS temp stays below setpoint + 1.5ºF		
– When CHWS temp < (setpoint + 0.75ºF); confirm that CT-2 fan switches from high-speed to low-speed, with a 15 sec delay between deactivating high-speed and activating low-speed.		
– When CHWS temp < (setpoint + 0.25ºF); confirm that CT-1 fan switches from high-speed to low-speed, with a 15 sec delay between deactivating high-speed and activating low-speed.		
– When CHWS temp < (setpoint – 0.25ºF); confirm that CT-2 fan shuts OFF.		
– When CHWS temp < (setpoint – 0.75ºF); confirm that CT-1 fan shuts OFF.		
– When CHWS temp < (setpoint – 1.25 ºF); confirm that condenser water bypass valve starts to modulate open to bypass.		
Check operation of:		
– P-1 status alarm (DI)(aux. contact)		
– P-2 status alarm (DI)(aux. contact)		
– P-6 status alarm (DI)(aux. contact)		
– P-7 status alarm (DI)(aux. contact)		
Chiller mode:(override mode:)		
– Confirm that activating manual override enables chiller operation in override mode.		
– CH-1 (DO) enabled when CWS (AI) > 10 C.		
– Pumps P-3 & P-8 hardwire start from CH-1.		
– Chilled water bypass valve (AO) DDC modulates to maintain system differential pressure (AI) setpoint		
– CH-1 (AO) CHWS setpoint (AI) is reset from demand based on the AHU ** CHW control valve (AO) position and the CHWR (AI) temperature.		
NOTES:		
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued	PASS FAIL	NOTE
Chiller mode (occupied mode)		
– Sequence written with CH-2 as lead chiller, CH-3 as lag chiller		
– Temper (warm) CWS to >50ºF (adjustable) if needed, using HE-1		
– When CWS > 50ºF; confirm CH-2 (DO) is enabled when CHWR (AI) > 52ºF for > 20* min. and TOD < 16:00 and CHWS temperature > 44ºF.		
– Confirm pumps P-4 & P-9 hardwire start from CH-2		
Operation – increasing cooling load:		
– Chilled water bypass valve (AO) DDC modulates to maintain system differential pressure (AI) setpoint		
– CH-2 (AO) CHWS setpoint is reset from demand based on the AHU ** CHW control valve (AO) position and the CHWR (AI) temperature.		
– CHWS minimum limit is 42ºF (adjustable); CHWR maximum limit is 52ºF (adjustable).		
– Confirm that CH-3 (DO) is enabled when CHWR (AI) > 54ºF (adjustable) for > 20 min. and TOD < 16:00.		
– Confirm pumps P-5 & P-10 hardwire start from CH-3.		
– CH-3 (AO) CHWS setpoint is reset from demand based on the CHWS bypass valve (AO) position and the CHWR (AI) temperature.		
– Confirm that CH-1 (DO) is enabled when CHWR (AI) > 54ºF (adjustable) for > 20 min. and TOD < 16:00.		
– Confirm pumps P-3 & P-8 hardwire start from CH-1.		
Operation – decreasing cooling load:		
– Confirm that CH-1 is disabled, and pumps P-3 & P-8 stopped when CHWS temp is < (setpoint – 1.0ºF) for > 10 min. or TOD > 16:00.		
– Confirm that CH-3 is disabled, and pumps P-5 & P-10 stopped when CHWS temp is < (setpoint – 1.0ºF) for > 10 min. or TOD > 16:00.		
– Confirm that CH-2 is disabled, and pumps P-4 and P-9 stopped, when CHWS temp < (setpoint – 1.0ºF) for > 10 min and AHU** CHW control valve positions indicate less than minimum load.		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
CHILLED WATER SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued	PASS FAIL	NOTE
Check operation of:		
– Daily DDC alternation of lead/lag CH-2,3(DO)		
– P-3 or P-8 failure as sensed by CHWS(DI) and CWS(I) flow switches status(alarm) stops CH-1(DO) and enables CH-3(DO).		
– P-5 or P-10 failure as sensed by CHWS(DI) and CWS(I) flow switches status(alarm) stops CH-3(DO) and enables CH-1(DO).		
– P-4 or P-9 failure as sensed by CHWS(DI) and CWS(I) flow switches status(alarm) stops CH-2(DO) and enables the lead chiller.		
– CHWS(AI) and CHWR(AI) common header temperatures		
NOTES:		
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Water Loop Heat Pump System

System Description

The water loop heat pump system is typical of one that may be installed in retail, commercial, or office buildings. Each ceiling-space mounted heat pump serves a specific zone of the building.

The system consists of water loop piping throughout the building with:

- water loop temperature control panel (probably DDC) with return water temperature sensor and flow switch
- single stage gas fired hot water boiler (B-1) on a branch circuit with a circulation pump (P-1)
- heat rejecter (HR-1) with packaged controls (external reset), cooling coil, isolation damper, fan, spray pump, sump heater and drain
- 2 parallel main loop circulation pumps (P-2 & P-3)
- a heat pump for each zone (HP-1, HP-2, etc.) with local heating/cooling thermostat.

The ceiling space is provided with a separate source of outside air. The outside air ventilation system is not included in this sample system.

The system has the following modes of operation:

- Off (Shutdown)
- Start-up
- No load demand - mixed heating/cooling
- Heating
- Cooling

Modes of Operation

	Off (Shutdown)	Start-up	No Load	Heating	Cooling
B-1 (boiler)	Off	Off	Off	On	Off
P-1 (boiler pump)	Off	Off	Off	On	Off
HR-1 Damper (Heat rejecter)	Closed	Closed	Closed	Closed	Open
HR-1 Fan (Heat rejecter)	Off	Off	Off	Off	Cycles (Off/On)
HR-1 Spray Pump (Heat rejecter)	Off	Off	Off	Off	Cycles (Off/On)
P-2 (main water loop)	Off	On (lead/lag)	On (lead/lag)	On (lead/lag)	On (lead/lag)
P-3 (main water loop)	Off	Off (lead/lag)	Off (lead/lag)	Off (lead/lag)	Off (lead/lag)

Heat Pumps

	Off (Shutdown)	Start-up	No Load	Heating	Cooling
Fan	Off	On	On	On	On
Compressor	Off	Off	Off	On	On
Reversing Valve	–	–	–	Heat	Cool

Sequence of Operation

1.1 Main Water Loop

1. The main water loop circulates water 24/7.
2. The main water loop circulation pumps operate on a lead/lag/backup basis.
3. The packaged heat rejecter shall be enabled from the main water loop controller based on the loop heat rejection demand as sensed by the main water loop return water temperature sensor. The local packaged heat rejecter controls shall operate the damper, fan and spray pump to maintain setpoint as determined (enabled/ disabled) by the main water loop controller.
4. The main water loop controller shall cycle the boiler off and on to maintain the water loop return water temperature setpoint. The boiler circulation pump shall be switched by the boiler and an inline flow switch in the boiler branch line shall allow the boiler to fire.

1.2 Heat Pumps

1. Local heating/cooling thermostats shall control the heat pumps. These shall allow 4 time-of-day setpoints (programs) and auto/manual fan control.

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
WATER LOOP HEAT PUMP SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
MAIN WATER LOOP		
Start up mode:		
– Initiate water-loop circulation DDC start-up sequence, with P-2 as lead pump.		
– Confirm that P-2 starts and runs.		
– Confirm that water-loop flow switch confirms flow (P-2 status = ON)		
– Simulate failure of P-2; confirm (1) that water-loop flow switch indicates no flow, (2) that P-2 no-flow alarm is generated, and (3) that lag pump P-3 starts and runs.		
No load mode:		
– Applies when water-loop return water temp. is between minimum and maximum setpoints of 40ºF and 90ºF.		
– Confirm that either P-2 or P-3 are ON.		
– Confirm that P-1 and B-1 are OFF; i.e. water loop does not require any supplementary heat.		
– Confirm that HR-1 is OFF; i.e. water loop does not require any heat rejection.		
Heating mode:		
– Applies when water loop return temp. (WLRT) is at or below minimum setpoint.		
– On decreasing WLRT, if WLRT < (min. setpoint – 1.0ºF), confirm that B-1 is enabled. Confirm sequence of P-1 start, boiler loop flow switch indicating flow, and that B-1 then fires.		
– On increasing WLRT, if WLRT > (min setpoint + 1.0ºF), confirm that B-1 is disabled and that B-1 stops, and P-1 stops after a time delay of ____ sec..		
NOTES:		
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
WATER LOOP HEAT PUMP SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
MAIN WATER LOOP (cont'd)		
Cooling mode:		
– Applies when water loop return temp. (WLRT) is at or below minimum setpoint.		
On increasing WLRT:		
– If WLRT > (max setpoint), confirm that HR-1 damper is enabled, and it OPENS.		
– If WLRT > (max setpoint + 2.0°F), confirm that HR-1 fan is enabled, and it STARTS & RUNS.		
– If WLRT > (max setpoint + 4.0°F), confirm that HR-1 spray pump is enabled, and it STARTS & RUNS.		
On decreasing WLRT:		
– If WLRT < (max setpoint + 1.0°F), confirm that HR-1 spray pump is disabled, and STOPS.		
– If WLRT < (max setpoint - 1.0°F), confirm that HR-1 fan is disabled, and STOPS.		
– If WLRT < (max setpoint - 3.0°F), confirm that HR-1 damper is disabled, and it CLOSES.		
Check operation of:		
– HR-1 sump level control, water makeup (local HR control)		
– HR-1 sump heater (local HR control) – confirm heater is locked out when OA temp > 40°F		
HEAT PUMPS		
Check operation of individual heat pumps using the local heating and cooling thermostats:		
– off/on switch – entire heat pump is either OFF or ON (ready for operation upon thermostat signal.		
– fan on/auto switch – ON = fans operates constantly; AUTO = fan operates only when compressor operates.		
– time-of-day programs		
Check air and water, inlet and outlet temperatures		
NOTES:		
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
WATER LOOP HEAT PUMP SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued

Heat Pumps: (continued)

Heat Pump ID	Location	HP On/Off	Fan Auto/ON	TOD Program	Heating				Cooling			
					Water-side		Air-side		Water-side		Air-side	
					Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet

Comments:

Checks performed by:_____ _____ Date:_____

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Make-up Air and Exhaust System

System Description

This make-up air and exhaust system is typical of one that may be installed in a commercial/industrial building serving a specific area of the building where there is a need to supply 100% outside air to balance a significant exhaust air requirement. Examples of this are industrial shops, kitchens, boiler rooms, etc.

The system consists of:

- ceiling mounted supply fan (SF) ducted to the outside air with:
  —motorized inlet (supply) open/closed damper (OAD)
  —hot water heating coil and control valve (HCV)
- roof mounted exhaust fan (EF) with barometric back-draft damper.
- controls
  —by a central DDC system
  —space and supply air temperature sensors
  —fan motor current relays
  —freezestat
- air distribution ductwork with supply and exhaust grilles (constant volume)

Modes of Operation

	Off		Unoccupied (System Off)	Occupied
Equipment	Shutdown	Freezestat (activated)		
OAD (dampers)	Closed	Closed	Closed	Open
SF (fan)	Off	Off	Off	On
EF (fan)	Off	Off	Off	On
HCV (valve)	Closed	Open	Closed	Modulating

System Description

1.1 OCCUPIED MODE

1. Occupied mode shall be determined by the time-of-day (TOD) programming.
2. The supply fan (SF) shall start/stop from a hard-wired connection to the outside air damper (OAD) limit switch. The outside air damper shall be open/closed by the DDC system.
3. The supply fan shall run continuously.
4. The exhaust fan shall be started by the DDC system once the supply fan status is proved on.
5. The heating control valve (HCV) shall modulate to maintain the supply air temperature setpoint.

1.2 UNOCCUPIED MODE

1. Unoccupied mode shall be determined by the time-of-day (TOD) programming.
2. Outside air damper closed, supply fan off, heating control valve closed, unless outside air temperature is less than 30°F, and exhaust fan off.

1.3 FREEZE PROTECTION

1. A hard-wired freezestat shall stop the supply fan, close the outside air damper and open the heating control valve 100%.
2. The exhaust fan shall be stopped by the DDC system.
3. The heating control valve shall be opened prior to running the supply fan in cold weather.

1.4 ALARMS

1. The DDC system shall annunciate an alarm when:
   —the freezestat is actuated
   —the supply fan fails to start (indicated by motor amps)
   —the exhaust fan fails to start (indicated by motor amps)
   —the supply air temperature is lower than ___°F.

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
MAKE-UP AIR AND EXHAUST SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Start-up:		
– If OA temp < ___ ºF, confirm that heating coil valve (HCV) opens 100% for ___ seconds prior to opening OA damper and starting supply fan.		
– Confirm that OA damper opens.		
– Confirm that when OA damper is open, as sensed by limit switch, that supply fan (SF) starts.		
– When supply airflow is proven, confirm that exhaust fan (EF) starts.		
Heating:		
Occupied mode:		
– Confirm that HCV modulates to maintain the supply air temperature (SAT) setpoint of ___ ºF		
Unoccupied mode:		
– As the makeup air system does not provide primary space heating, confirm that SF and EF stay OFF, and HCV stays closed unless freezestat has been triggered (see below).		
Freeze Protection:		
Trip the freezestat (manually, or with an ice pack). Confirm that the following actions occur:		
– SF stops		
– OA damper closes tightly		
– HCV opens 100% to heat		
– EF stops		
– Freezestat alarm is generated		
Alarms and status indications:		
– Simulate SF failure; confirm SF failure alarm is generated		
– Simulate EF failure; confirm EF failure alarm is generated		
– When supply fan is ON, simulate SAT < (setpoint – 3.0ºF); confirm low SAT alarm is generated.		
– When SF is OFF, simulate SAT < (setpoint – 3.0ºF); confirm low SAT alarm is NOT generated.		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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Packaged Rooftop Gas Heat/DX Cool System

System Description

The roof top unit is typical of one that may be installed in a commercial/ industrial/office building serving a specific area of the building.

The system consists of:

- packaged roof top unit (RTU) with:
  —supply fan (SF)
  —modulating outside-air, return-air and relief dampers (MAD) operated by a single motor
  —gas heating with a single stage burner (GB)
  —D/X cooling (DX) with single stage compressor, 2 coils and fan
- local unit controller (usually supplied by unit manufacturer or other dedicated controller) c/w:
  —outside and supply air temperature sensors
  —heating/cooling thermostat
- air distribution ductwork with supply and return grilles (constant volume)

Modes of Operation

	Off (Shutdown)	Unoccupied		Occupied		
Equipment		Off	Heating	Free Cooling	Heating	Cooling
MAD (dampers)	Closed (to O/A)	Closed (to O/A)	Closed (to O/A)	Modulating	Minimum (O/A)	Minimum (O/A)
SF (fan)	Off	Off	On	On	On	On
GB (burner)	Off	Off	On	Off	On	Off
DX (comp. and cond. fan)	Off	Off	Off	Off	Off	On

Sequence of Operations

1.1 OCCUPIED MODE

1. Occupied mode shall be determined by the time-of-day (TOD) programming.
2. The supply fan shall run continuously.
3. The mixed air dampers shall modulate to provide free cooling (economizer operation) as determined by the supply air temperature (SAT) and the outside air temperature (OAT).
4. The mixed air dampers shall be positioned to provide minimum outside air when the unit is in either gas heating or D/X cooling modes.
5. The gas burner shall cycle on/off to maintain the space temperature heating setpoint.
6. The D/X cooling shall cycle on/off to maintain the space temperature cooling setpoint when the economizer operation is unable to maintain the cooling setpoint.

1.2 UNOCCUPIED MODE

1. Unoccupied mode shall be determined by the time-of-day (TOD) programming.
2. The supply fan and gas burner shall cycle on/off as required to meet the set-back heating setpoint.
3. The mixed air dampers shall be closed to the outside air.

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
PACKAGED ROOFTOP GAS HEAT/DX COOL SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Occupied mode:		
– Confirm that SF is ON		
When heating is required, confirm that:		
– MAD is positioned to minimum OA setpoint (value set by TAB agency).		
– DX cooling if OFF		
– GB cycles ON/OFF to maintain space heating temp. setpoint.		
Record the following data:		
– OA temp. ____ ºF		
– Max. space temp., when GB stops ____ ºF; Min. space temp., when GB starts ____ ºF		
– Max. supply air temp. (SAT) ____ ºF; Min. SAT ____ ºF		
When heating is not required, and free cooling can maintain space temp below cooling setpoint, confirm that:		
– GB and DX cooling are both OFF.		
– MAD modulates from min. OA position to 100% open to OA, to maintain space cooling setpoint ____ ºF		
When cooling is required, confirm that:		
– MAD is positioned to minimum OA setpoint (value set by TAB agency).		
– DX cooling cycles ON/OFF to maintain space cooling temp. setpoint.		
Record the following data:		
– OA temp. ____ ºF		
– Max. space temp., when DX starts ____ ºF; Min. space temp., when DX stops ____ ºF		
– Max. supply air temp. (SAT) ____ ºF; Min. SAT ____ ºF		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
PACKAGED ROOFTOP GAS HEAT/DX COOL SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Unoccupied mode:		
When space temp. > night setback heating setpoint, confirm that:		
– MAD is tightly closed to OA.		
– Heating and cooling are both OFF		
– Supply fan (SF) is OFF.		
When space temp. < night setback heating, confirm than:		
– MAD stays tightly closed to OA and cooling stays OFF.		
– SF is started		
– Gas heating (GB) fires		
– When space temp. rises to > night setback heating setpoint, confirm GB and SF turn OFF.		
NOTES:		
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Variable Air Volume System

System Description

The air handling system is typical of one that may be installed in a commercial/ industrial building serving a specific area or floor of the building.

The system consists of:

- air handling unit (AHU) with:
  - —supply fan with variable speed drive (VSD) motor control
  - —modulating outside-air, return-air and relief dampers
  - —heating and cooling coils
  - —steam humidification
  - —air filters
- coil circulation pumps
- modulating heating coil control valve (HCV) and cooling coil control valve (CCV)
- return fan
- variable air volume (VAV) boxes with DDC controllers
- direct digital control (DDC) system

The AHU has ducted access to untempered outside air.

The supporting steam, heating and cooling water systems are outside the scope of this example.

The system has various modes of operation:

- Off (Shutdown)
- Start-up
- Warm-up
- Normal
- Economizer
- Fire
- Freeze

VARIABLE AIR VOLUME SYSTEM

Modes of Operation

Equipment	Shutdown			Normal Operation			
	Normal	Fire	Freeze	Free Cooling	Heating	Cooling	Night Heating
Outdoor Air Damper	Closed	Open	Closed	Modulating	Minimum	Modulating	
Return Air Damper	Open	Closed	Open	Modulating	Modulating	Modulating	Modulating
Relief Air Damper	Closed	Open	Closed	Modulating	Modulating	Modulating	Modulating
Heating Coil Pump	Off	On	On	Off	On	Off	On
Heating Coil control valve	Closed	Modulating	Open	Closed	Modulating	Closed	Modulating
SF-1	Off	On	Off	On	On	On	On
Humidifier enable	Closed	Closed	Closed	Open	Open	Closed	Open
HU-1 control valve	Closed	Closed	Closed	Modulating	Modulating	Closed	Modulating
Cooling coil control valve	Closed	Modulating	Closed	Closed	Closed	Modulating	Closed
RF-1	Off	On	Off	On	On	On	On

Sequence of Operations

1.1 GENERAL

1. On a signal to start the supply and return fans, open the return air dampers and crack the outdoor air damper (5% open).
2. Start the supply and return (AHU-1 only) fans on a minimum speed.
3. After fan status is proven, modulate the dampers in a normal manner.
4. Modulate the speed of the supply fans to maintain the required duct static pressure.
5. Modulate the speed of the return fan to maintain the required building pressurization. Use the volume probes to determine the appropriate return volume (i.e. return volume = supply volume + building pressurization volume; where the building pressurization volume is to be determined on site).
6. On a signal to start an exhaust fan, open its motorized damper. When the damper end switch is made, start the fan.
7. When no heating is required, the mixing dampers shall modulate to provide the amount of free cooling (up to 100% outdoor air) required to maintain the supply air temperature (SAT) setpoint.
8. When the dampers are at the minimum outdoor air position, heating shall be allowed. When the dampers are at the 100% outdoor air position, cooling shall be allowed.
9. When the outdoor air temperature (OAT) is below 40°F, start the heating coil circulating pump whether the fan is running or not.
10. When cooling is required, modulate the cooling coil valve, start pump P-2 to maintain the required SAT setpoint.
11. The SAT shall be reset from the system's associated room temperature sensors.
12. A return air humidity sensor and a supply air high limit humidity sensor shall control the humidifiers. On a call for humidification, the humidifier isolation valve shall open. After unit heat up has been proven by an internal temperature switch, the humidifier control valves shall modulate to maintain the required humidity, subject to the supply air high limit. The humidifiers shall only operate if the associated supply fan is on.
13. Install a low temperature sensor on the discharge side of the heating coil, (set for approx. 40°F). On a low temperature alarm, shut off the fans, enable the heating coil pump, and open the heating coil valve.

1.2 VAV BOXES

1. Modulate the control damper to maintain the required room temperature.
2. (For those boxes with reheat coils) If heating is required, modulate the 2-way reheat control valve to maintain the required room temperature with the control damper set at minimum airflow position.
3. Switch the box mode between "day" and "night" modes based on time-of-day or operator command.

HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
VARIABLE AIR VOLUME SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Unoccupied mode:		
Confirm that:		
– Supply fan (SF) is OFF and its VFD speed = 0%		
– Return fan (RF) is OFF and its VFD speed = 0%		
– MAD is tightly closed to OA.		
– Humidifier control valve is fully closed (AO = 0%)		
– VAV boxes are in unoccupied "night" mode.		
If OAT ≥ 41 ºF then confirm that:		
– HWH coil pump is OFF		
– Heating coil control valve (HCV) is closed to 0%		
If OAT < 40ºF, then confirm that:		
– HWH coil pump starts and runs		
– HCV moves to 10% open position.		
Start up mode:		
– Simulate time of day (TOD) to start of occupied hours.		
Confirm that fan start-up sequence occurs as follows:		
– If avg. space temp (from VAV box sensors) < (occupied heating setpoint – 2.0ºF), then MAD stays closed to OA, otherwise MAD opens to 5% OA.		
– SF and RF start at minimum VFD speed		
– When SF operating status is proven, modulate fan speed to maintain supply duct static pressure at setpoint ____ " WG		
– When RF operating status is proven, modulate fan speed to maintain building pressure at setpoint ____ " WG		
– HU-1 humidifier isolation valve opens when return air relative humidity < 35%		
– VAV boxes move from unoccupied mode to occupied "day" mode		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
VARIABLE AIR VOLUME SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Warm-up:		
– MAD stays closed to OA until avg. space temp > occupied heating setpoint.		
– When avg. space temp > occupied setpoint, then MAD moves to min. OA position, ____ % OA		
Occupied "normal" mode:		
Confirm supply air temp. (SAT) setpoint reset logic.		
– Min. SAT setpoint = ____ ºF; max. SAT setpoint = ____ ºF		
– When avg. space temp. > (cooling setpoint + 1.0ºF), confirm that SAT setpoint = min.		
– When avg. space temp. < (heating setpoint – 1.0ºF), confirm that SAT setpoint = max.		
SAT control:		
If SAT < (setpoint – 1.0ºF), confirm that:		
– MAD is at min. OA position		
– Cooling coil pump of OFF and CCV is closed.		
– HCV modulates to maintain SAT = (setpoint – 1.0ºF).		
– Heating coil pump starts when HCV > 10% open; stops when HCV < 5% open.		
– Except if OA temp < 40ºF, then heating coil pump is ON at all times.		
If SAT > setpoint, and < (setpoint + 1.0ºF), confirm that:		
– Heating coil pump is OFF, and HCV is closed.		
– Cooling coil pump is OFF and CCV is closed.		
– MAD modulates between min. position and 100% OA to maintain SAT = setpoint.		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
VARIABLE AIR VOLUME SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Occupied (normal) mode(continued):		
If SAT > (setpoint + 1.0ºF), confirm that:		
– MAD is at 100% OA position if return air temp. (RAT) ≥ OA temp.; or at min. position if RAT < OA temp.		
– Heating coil pump is OFF, and HCV is closed.		
– CCV modulates to maintain SAT + (setpoint + 1.0ºF)		
– Cooling coil pump starts when CCV > 10% open; stops when CCV < 5% open.		
Humidity:		
– Confirm that humidifier is OFF when HCV < 5% open.		
– When humidifier is enabled, confirm that HU-1 control valve modulates to maintain return air RH = setpoint.		
– Confirm that the humidity control valve action is delayed 10 minutes after the isolation valve opens.		
Fire mode:		
– Hardwire stop SF from fire alarm system wired to SF speed controller		
Confirm that:		
– SF stops – DO = OFF, SF VFD = 0%		
– RF stops – DO = OFF, RF VFD = 0%		
– MAD moves to 0% OA position		
– Humidifier stops – control valve = 0% open, and isolation valve closed.		
– VAV boxes go to unoccupied "night" mode.		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
VARIABLE AIR VOLUME SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION:	PASS FAIL	NOTE
Freeze mode:		
– On low temperature freezestat(DI) (auto reset type) ≤ 40°F for 10 seconds.:		
Confirm that:		
– SF hardwire stopped while freezestat activated as above.		
– SF stops – DO = OFF, SF VFD = 0%		
– RF stops – DO = OFF, RF VFD = 0%		
– MAD moves to 0% OA position		
– Humidifier stops – control valve = 0% open, and isolation valve closed.		
– Heating coil pump starts and HCV goes to 10% open position.		
Confirm that freeze mode can be reset by operator toggling DDC "freeze reset point".		
Alarms and status checks:		
– SAT (AI)		
– RAT (AI)		
– Filter high DP (AI).		
– HWH coil pump status(AI)		
– CHW coil pump status(AI)		
– SF status (AI)		
NOTES:		
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Checks performed by:_____ _____ Date:_____
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HVAC COMMISSIONING
FUNCTIONAL PERFORMANCE TEST CHECKLIST
VARIABLE AIR VOLUME SYSTEM

PROJECT:_____

System:_____ Location:_____

Area Served:_____ Equipment:_____

SEQUENCE OF OPERATION: Continued						√
VAV Boxes:						
The VAV boxes shall modulate the damper and Reheat HCV to maintain the DDC room setpoint during "day mode" and "night mode" (different setpoints in each VAV box controller).						
Simulate heating and cooling conditions.						
VAV ID	Location	Day Mode	Night Mode	Heating	Cooling	
Comments:						

Checks performed by:_____ _____ Date:_____
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APPENDIX E Glossary of Acronyms

AABC Associated Air Balance Council

ACG AABC Commissioning Group

AI analog input

AO analog output

ATC automatic temperature controls

BAS building automation system

CA commissioning authority

CxA ACG Certified Commissioning Authority

CT cooling tower

CHWR chilled water return

CHWS chilled water supply

CWR condenser water return

CWS condenser water supply

DDC direct digital controls

DI digital input

DID design intent document

DO digital output

FPT functional performance tests

HVAC heating, ventilating and air conditioning

IAQ indoor air quality

LEED Leadership in Energy and Environmental Design, USGBC trademarked "Green Building Rating System"

O&M operation and maintenance

OA outside air

PM preventative maintenance

RFP request for proposal

RTF resolution tracking form

SVC system verification check

TAB testing, adjusting, and balancing or test and balance

TBE test and balance engineer

USGBC United States Green Building Council

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