



ASHRAE Guideline 1.6P

Public Review Draft

Guideline 1.6P, Application of the Commissioning Process to Data Centers

**First Public Review (October 2026)
(Complete Draft for Full Review)**

This draft has been recommended for public review by the responsible project committee. To submit a comment on this proposed standard, go to the ASHRAE website at <https://www.ashrae.org/technical-resources/standards-and-guidelines/public-review-drafts> and access the online comment database. The draft is subject to modification until it is approved for publication by the Board of Directors and ANSI. Until this time, the current edition of the standard (as modified by any published addenda on the ASHRAE website) remains in effect. The current edition of any standard may be purchased from the ASHRAE Online Store at www.ashrae.org/bookstore or by calling 404-636-8400 or 1-800-727-4723 (for orders in the U.S. or Canada).

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FOREWORD

(This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

Large scale aggregation of electronic data is a major industrial process associated with Internet Technology (IT) and telecommunications (telecom). Data centers serve IT applications, distinguishing them from telecom applications by both higher energy consumption density and the preponderance of Uninterruptable Power Supply (UPS) loads due to the Mission Critical 8760 (24/7/365) operational demands. Data center design, commissioning, and operation intent provides primary consideration for technology system conditions as distinguished from other market sectors primarily concerned with human occupant well-being.

Human life safety is the first consideration for data centers. Many spaces in data centers are not intended for human occupancy and have demanding performance requirements for technology cooling systems (TCS), technology space conditioning (TSC), aisle air distribution, liquid cooling systems, battery storage, alternative fuel options, reliability, resilience, and resource efficiency.

MEP equipment selection for data center infrastructure has different priorities than human occupant-dominated environments. Energy consumption density and power reliability goals lead to site energy storage, alternate fuel sources, and renewable energy sources onsite. Infrastructure uptime, resilience, reliability, energy use density, and resource consumption efficiency dominate the data center mission. ANSI/ASHRAE Standard 90.4, Energy Standard for Data Centers, which utilizes Power Use Effectiveness (PUE), as well as Energy Use Intensity (EUI), augments ANSI/ASHRAE/IES Standard 90.1, Energy Standard for Sites and Buildings Except Low-Rise Residential Buildings.

While the data center construction industry commissions building systems in a business-as-usual model, the industry seeks commissioning best practices. Standards represent minimum acceptable requirements, making production of a guideline for data center commissioning process the predominant need. Driving factors for development of this ASHRAE Guideline include:

- *Need for accepted framework for building infrastructure systems commissioning to unify the process for stakeholders*
- *Inconsistent terminology creates confusion and is counterproductive.*
- *Inconsistent capitalization/acronyms/abbreviations confuse process stakeholders.*
- *Codes and standards for data center commissioning are unique to jurisdictions.*
- *Energy management metrics, sustainability criteria, and community environmental, social, corporate governance prerogatives impact data center commissioning.*
- *Data center building systems commissioning boundaries should be clearly defined.*
- *Data center commissioning providers collaborate across system boundaries.*

The data center commissioning process (Cx) is a quality-based method that is directed by an Owner to achieve successful construction and renovation projects. It is not an additional layer of construction or project management. Its purpose is to integrate installation with management, commissioning with quality control to streamline delivery efficiency to achieve on time turnover to mission critical clients.

The Cx detailed in the ASHRAE SSPC 300 family of standards and guidelines is the result of experience gained on projects by professionals. Guideline 1.6 represents ASHRAE's first building-type specific commissioning guideline. It is based on experience by building sciences professionals with projects that met the requirements of data center owner-developers, end users, occupants, and facility operating maintenance organizations at a high level of satisfaction at reduced cost of project delivery.

This supplementary technical guideline has been developed to provide specific and detailed information on how to implement Cx for data center systems, power chain lineups, and building systems and assemblies making up data center infrastructure, up to the server racks and IT equipment for various stages of facility development and operation. The scope and budget for the Cx is set by the Owner for each project at the beginning of the development process.

1. PURPOSE

This guideline provides technical support for the application of the commissioning process (Cx) to data centers.

2. SCOPE

This guideline:

- 2.1 Provides assistance in the application of ASHRAE Guideline 0, *The Commissioning Process for New Buildings and New Systems* and ANSI/ASHRAE/IES Standard 202, *The Commissioning Process Requirements for New Buildings and New Systems* to data centers.
- 2.2 Addresses commissioning process (Cx) issues that are particular to data centers.
- 2.3 Provides technical support for the commissioning of data centers.
- 2.4 Is intended for use with new and existing buildings.
- 2.5 Applies to data center support infrastructure, not to data equipment networks.

3. DEFINITIONS

3.1 Defined Terms

Definitions for general Commissioning Process (Cx) terms can be found in ASHRAE Guideline 0, ANSI/ASHRAE/IES Standard 202, ANSI/ASHRAE Standard 230, and ASHRAE Guideline 0.2. Additional terms are defined as follows.

commissionability: condition of a design or installation such that associated Cx activities can be implemented without requirements for additional provisions or considerations.

operational readiness: equipment, system, or component installation conditions and status at which Owner beneficial use in accordance with design intent and Owner's Project Requirements (OPR) can be delivered to the client as verified system performance at load under normal, maintenance, and failure modes with automatic recovery enabled.

receiving checklists: a structured, itemized document used during the Cx to verify that delivered equipment, materials, and supplies meet specified requirements before they are accepted, stored, tracked, or installed. It ensures correct quantity, condition, documentation, labeling, handling requirements, and readiness for subsequent installation/commissioning activities. Their purpose is to prevent acceptance of damaged, incorrect, or incomplete shipments, to ensure compliance with procurement specs, warranty, and manufacturer requirements, to provide documented chain-of custody and inventory for commissioning and operations teams, and to capture nonconformances and trigger corrective actions.

tamper seal: a physical security device applied to equipment, enclosures, containers, or access points to provide visible evidence of unauthorized access, interference, or removal during transport, storage, installation, or operation. Tamper seals protect assets help maintain chain-of-custody and accountability until formal handover or transfer of custody. Attributes include visible evidence clearly indicating if seal integrity is compromised, unique identification: serial numbers, barcodes, or uniquely printed text to prevent unnoticed replacement, designed for one-time use to be destroyed or visibly changed when opened, durable for anticipated environmental temperature, humidity, vibration, and UV exposure, non-reusable design, and traceable.

torque verification: the process of measuring and confirming that fasteners, electrical connections, busbar joints, grounding points, and other torque-sensitive components have been tightened to the specified torque values and assembly procedures. It ensures mechanical integrity, electrical continuity, thermal performance, and safety during and after installation. The purposes are to prevent loose connections that cause overheating, arcing, or failure, ensure mechanical stability for racks and cabinet mounting hardware, power distribution equipment, HVAC and structural elements, maintain warranty and manufacturer compliance, and provide documentary evidence for commissioning acceptance and maintenance.

3.2 Abbreviations, Acronyms, and Initialisms

AHJ	Authority Having Jurisdiction
EPMS	Electrical Power and Monitoring System
FAT	Factory Acceptance Testing
FOD	Foreign Object or Debris

FOK	First of Kind
FT	Factory Test
FWT	Factory Witnessed Test
HMI	Human Machine Interface
I&D	Installation & Documentation
IST	Integrated Systems Test
MOP	Method of Procedure
OFCl	Owner Furnished Contractor Installed
OFE	Owner Furnished Equipment
OPR	Owner's Project Requirements
PEI	Pre Energization Inspection
PQM	Power Quality Monitor/Monitoring
PUE	Power Usage Effectiveness
SCADA	Supervisory Control and Data Acquisition
SIP	Set In Place
SOO	Sequence of Operation
WUE	Water Usage Efficiency

4. UTILIZATION

4.1 Introduction. This guideline can be applied to the implementation of the Cx on all or some selected systems and assemblies within a data center's support infrastructure, up to, but not including, the information technology equipment. As with any commissioning project, the scope should be defined in the Owner's Project Requirements (OPR), contract documents, and the Cx Plan. The commissioning effort should align with the scope outlined in these documents and as procured under the specific contract. This guideline serves as a supplementary technical document, detailing the specific requirements for implementing the Cx in a data center. It is applicable to both new construction and renovation projects.

4.2 Purpose and Organization

4.2.1 The intent is to use this guideline to:

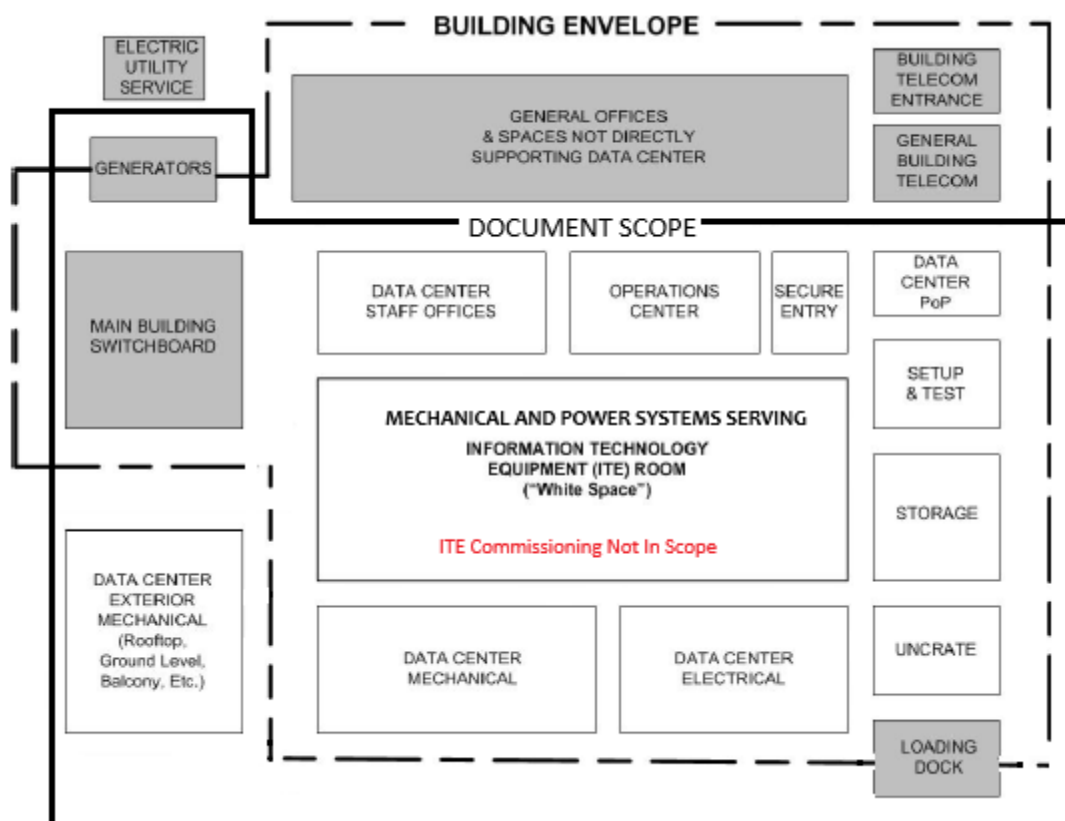
- Define detailed OPR requirements for data center projects and develop thorough contract documents.
- Evaluate a BoD with respect to addressing data center specifics of the OPR.
- Prevent common data center operational issues and promote best practices.
- Create and implement a sustainable training plan for data center owners, operators, and emergency response personnel.
- Establish and execute a comprehensive commissioning plan to confirm operational performance requirements, such as uptime, are met.
- Compile all deliverables and documentation into a structured systems manual suitable for critical operations.

4.2.2 In addition to direction provided herein, refer to ANSI/ASHRAE/IES Standard 202, ANSI/ASHRAE Standard 230, ASHRAE Guideline 0, and/or ASHRAE Guideline 0.2 for general Cx details for new or existing buildings and systems. This guideline is intended to supplement these documents and other associated commissioning guidelines, focusing on data center applications. Since it serves as a supplement, this guideline does not include general Cx information that is applicable to all commissioning projects.

4.2.3 ANSI/ASHRAE/IES Standard 202, Table 4-1, "Cx Activities and Deliverables," outlines Cx activities and deliverables common to all commissioning projects. This guideline references those activities while providing additional considerations specific to data centers.

4.3 Boundary

- 4.3.1** This guideline applies to data center support infrastructure, including building envelope where specific to data centers, from the service point with utility up to, but not including, the information technology equipment (ITE), which includes computers, data storage, servers, and network/communication equipment. Service point is applied here as the point of common connection between the components of the serving utility and the premise components of the facility.
- 4.3.2** The boundary of this guideline is similar to that used for ANSI/ASHRAE Standard 90.4, *Energy Standard for Data Centers*. The main deviations are:
- Generators and main building switchboard efficiency are excluded from the electrical loss component (ELC) in ANSI/ASHRAE Standard 90.4, but the commissioning of these systems is included in this guideline.
 - ITE energy consumption is an integral component of calculating the mechanical load component (MLC) and ELC in ANSI/ASHRAE Standard 90.4, but the commissioning of ITE is not part of this guideline.



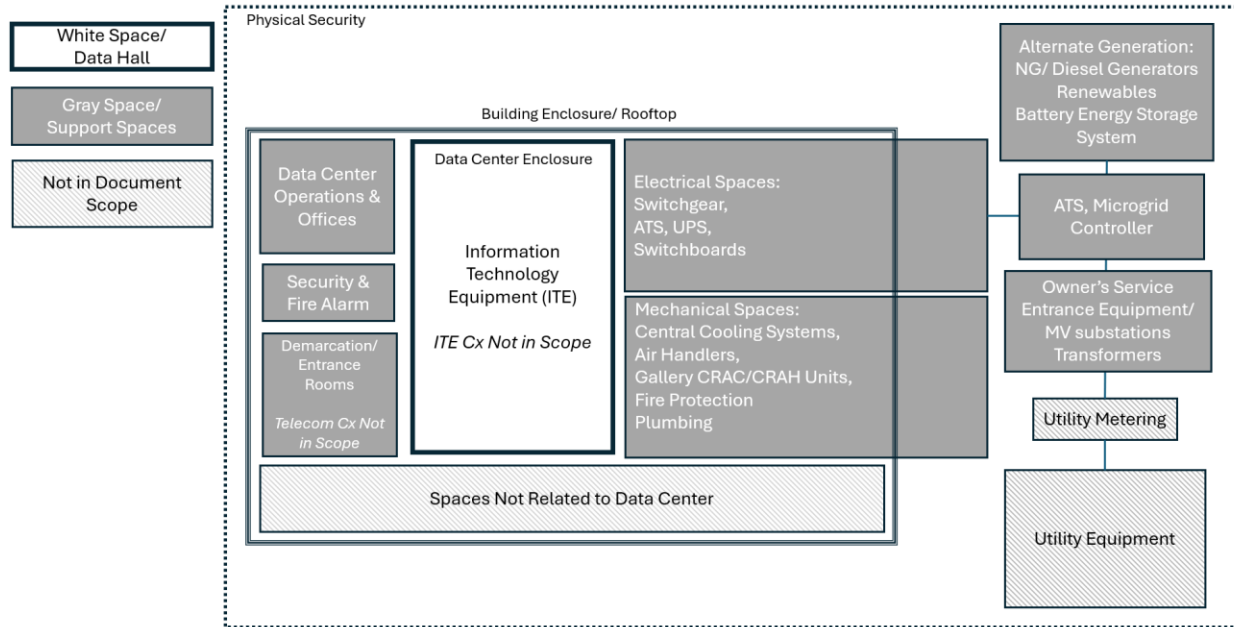


Figure 4-1 Demarcation of systems and building areas within the scope of this guideline.

5. INITATING THE CX

5.1 General

- 5.1.1** At the initiation of the project, the Owner is responsible for determining the Cx Scope, selecting the Cx Provider (CxP), incorporating Cx requirements in all contract documents, establishing Cx budget, establishing Cx schedules, and developing the Owner's Project Requirements (OPR).
- 5.1.2** The Owner is responsible for selecting qualified Project Team members. The CxP is assigned to act as the Owner's representative for the Cx and should be an objective advocate of the Owner. Advocacy should include design review, oversight of the Level 1 to Level 3 Cx, and direction of Level 4 and Level 5 Cx. The CxP should possess experience in executing the Cx steps as defined in this guideline. The CxP should supply a team of individuals with the technical experience required for the systems being commissioned. Technical experience should be relevant in providing the content of the following as described in the Request for Proposal (RFP) scope:
- Design Commissionability Review
 - Cx Specifications (or acknowledgement of and comment on Cx specifications provided by the Owner)
 - Cx Plan and Cx schedule development and continuous review
 - Critical MEP Submittal Reviews
 - SOO Reviews
 - Inspection and Testing Procedure Reviews (Level 1 to Level 3 Cx)
 - Targeted Sample Observations of Level 1 to Level 3 Cx Activities
 - Construction Observations and Issues and Resolution Log (IRL) Management
 - Level 4 and Level 5 Cx Observations and Test Scripts Development
 - Execution of Level 4 and Level 5 Observations and Tests
 - Evaluation of Observation and Test Reports
- 5.1.3 Cx Specifications.** It is recommended that the Owner maintain their own set of Cx standards and specification requirements which outline expectations for Cx roles and responsibilities, inspection and testing protocols, load testing durations and acceptance processes, as well as additional Owner defined Cx requirements, as detailed in Section 10. These requirements primarily define the expected scope of works for the contractor, supplier, and manufacturer.

- 5.1.4 Providing Direction and Acceptance.** The Owner should provide direction, reviews, and acceptance as required throughout the project and the Cx.

5.2 Cx Requirements

- 5.2.1 Roles and Responsibilities.** The Owner should provide direction, reviews, and acceptance as required throughout the project and the Cx.
- 5.2.2 Owner's Project Requirements.** For new construction or major renovations, the Owner should develop the OPR in accordance with Section 7. The Owner should require a final updated and approved OPR at substantial completion.
- 5.2.3 Cx Design Reviews.** The Owner should require the CxP to perform a Cx Design Review and for the Design Team to review, respond to, and participate in issues and resolution activities to resolve issues identified during the Cx Design Review as defined in Section 11. The Owner or their designated representative should review the Cx Design Review comments, participate in issues and resolution activities, and provide direction to the Design Team when necessary to meet the OPR.
- 5.2.4 Basis of Design Documentation.** The Owner should require, by agreement, the development and updating of the Basis of Design (BoD) by the Design Team, as described in Section 9.
- 5.2.5 Cx Plan.** The Owner should require the development of the Cx Plan as described in Section 8. The Cx Plan should provide guidance for the participants involved, their roles and responsibilities, and direction for scheduling, implementation, testing, reporting, and documentation of the various stages of the Cx. The Cx Plan outlines all process activities required to meet the project requirements and Cx specifications. The Cx Plan will evolve throughout the Cx and be expanded with more detail as the design/construction of the facility evolves. Subsequent issues of the Cx Plan will be released at the appropriate stages of the Cx.

Although the Cx Plan is designed to cover the rules and roles for the Cx, it is intended to primarily govern activities from project conception through final construction documents. The specific requirements of the contractors are to be delineated within the Cx specifications to minimize the need for the contractor to consult the Cx Plan.

- 5.2.6 Commissioning Submittal Review.** The Owner should require that the construction submittals for systems and assemblies being commissioned be reviewed by the CxP in accordance with Section 12. At a minimum, the construction submittals to be reviewed should include sequence of operations (SOO), inspection and testing procedures, protection and coordination studies, BAS graphics, and BAS/control points lists.
- 5.2.7 Cx Schedule.** The Owner should require that the Project Team (including the CxP and construction service providers) develop a detailed Cx schedule which includes as Cx Activities within the project construction schedule. At a minimum, the following Cx Activities and documents should be detailed in the schedule:

- a. Cx Activities
 - 1. Level 1 FWTs
 - 2. Installation completion and verification
 - 3. Pre-energization tests
 - 4. Level 2 tags per equipment
 - 5. Power On
 - 6. IT/BMS/Security Network Available
 - 7. Testing, adjusting, and balancing (TAB)
 - 8. Energized electrical testing
 - 9. Level 3 startup and preliminary functional testing per equipment/system
 - 10. Level 3 tags per equipment/system
 - 11. Training
 - 12. Level 4 functional testing per test scripts
 - 13. Level 4 tags per equipment/system
 - 14. Level 5 IST
- b. Documentation Activities

1. Level 1 test scripts
 2. Level 2 and Level 3 installation and testing procedure submittals
 3. Training plans
 4. Protection, coordination, and arc flash studies
 5. Level 4 test scripts
 6. Level 5 test scripts
- 5.2.8 Observation and Testing.** The Owner should require that project observation and testing be performed and documented as required in contract documents and the Cx Plan. See Section 14 for observation and testing requirements.
- 5.2.9 Issues and Resolution Log.** The Owner should require the development and use of issues and resolution logs as required in the OPR and Section 15. The Owner should review the Cx issues and resolution logs, participate in collaborative team resolution, and provide direction when needed.
- 5.2.10 Cx Progress Reports.** The Owner should require the development and use of Cx progress reports as required in the OPR and Section 19. The Owner should review the progress reports and provide direction when needed.
- 5.2.11 Systems Manual.** The Owner should require, by agreement, the development and delivery of a project Systems Manual, and that deliverables be provided for the Systems Manual in accordance with Section 16. The Owner should confirm that specific entities are designated for the development and assembly of the Systems Manual and the Facility Guide.
- 5.2.12 Training.** The Owner should require, by agreement, that the Project Team (including the Design Team and Construction Team, as applicable) perform training defined in the OPR, contract documents, and/or Cx Plan. See Section 17 for training requirements.
- 5.2.13 Initial Occupancy and Operations.** The Owner should require, by agreement, that the Cx Activities described in Section 18 be performed. This includes provisions ensuring adequate training with provisions noted for seasonal variations. Additional training after occupancy, seasonal tests, warranty site visits, unresolved issues, and drawing updates post turnover typically are not practical for 8,760 hours operating mission critical facilities. The OPR and Occupancy and Operations Phase deliverables should account for turning over systems, equipment, and components that are operationally ready and resilient to operational condition variations whether seasonal, emergency, or maintenance based.
- 5.2.14 Warranty Period Cx.** The Owner should require, by agreement:
- a. CxP performance of Cx during the warranty period
 - b. Update of the Systems Manual based on modifications to operations to meet the OPR
 - c. Update of the OPR to meet changes in the Owner's objectives and criteria
- 5.2.15 Preliminary Cx Report and Final Cx Report.** The Owner should require, by agreement, the development and delivery of a Preliminary Cx Report and Final Cx Report, and that deliverables be provided in accordance with Section 19. The Owner should confirm that specific entities are designated for the development and assembly of these reports.

6. LEVELS OF COMMISSIONING

- 6.1** Data center Cx Activities are classified into five levels, progressing from factory testing of equipment to full facility integrated systems testing. The definitions of these levels provide a framework for the organization, tracking, and execution of Cx Activities. These levels are summarized as follows:
- a. Level 1: Factory Testing
 - b. Level 2: Installation Verification and Pre-Energization Testing
 - c. Level 3: Start Up and Preliminary Functional Testing
 - d. Level 4: Functional Performance Testing
 - e. Level 5: Integrated Systems Testing

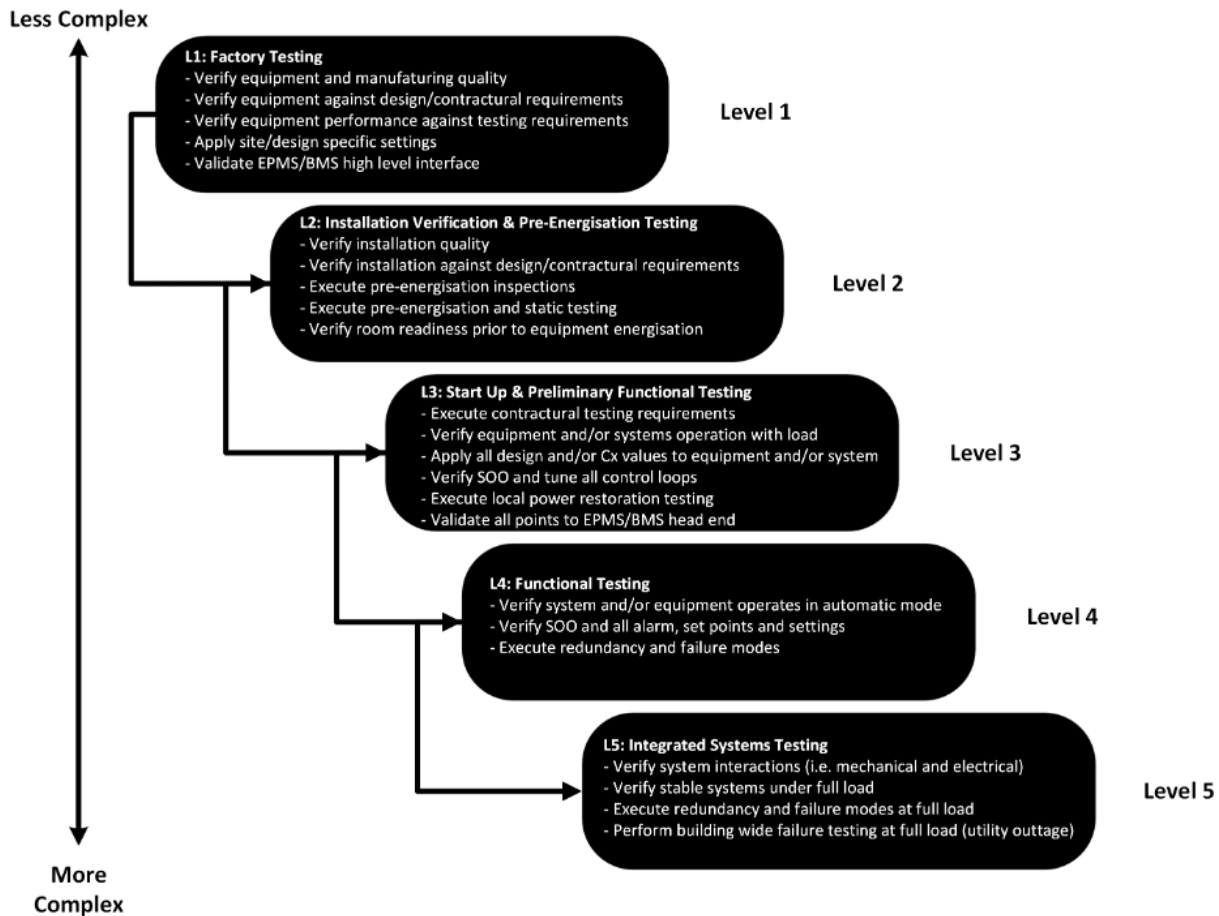


Figure 6-1 Levels of Commissioning.

6.1.1 Level 1: Factory Testing

Factory testing refers to the testing of equipment prior to it leaving its place of manufacture. The scope can range from end-of-line quality manufacturing checks to complex test sequences. Factory testing is intended to verify that components, materials, control logic, and equipment are manufactured and function in accordance with design, Owner, and legislative requirements. This may be a manufacturer’s standard test protocol, or it may include project specific enhanced testing.

Subcategories of factory testing may include:

- Factory Acceptance Testing (FAT): a quality and testing process conducted by the manufacturer and signed off on by factory quality control personnel prior to shipping the product.
- Factory Witness Testing (FWT): based on the same process that the factory goes through during FAT, but it should be observed approved by the CxP, Engineer of Record, and Owner prior to shipment.
- Control Bench Logic Testing: a simulation testing process to verify critical control functions prior to the implementation within equipment or a system. Although this is primarily simulation-based testing, it may also involve hardware integration to verify specific interfaces or critical functions (sometimes referred to as “hardwire-in-the-loop testing”).

The contractor, supplier, or manufacturer is responsible for execution at Level 1. The CxP should review and approve the test procedures in accordance with contract documents. See Section 13 for more details on factory testing.

6.1.2 Level 2: Installation Verification and Pre-Energization Testing

Level 2 commissioning is an enhanced Quality Control and Quality Assurance (QA/QC) process of static inspections to verify that installation is in accordance with the OPR, manufacturers' recommendations, design drawings, contract specifications, and local regulations. It also includes testing which is required before safe energization of systems, equipment, and components.

Level 2 Cx begins when equipment arrives on-site. Inspections are first conducted by receiving contractors upon delivery to confirm equipment condition, verify compliance with approved submittals, and ensure no damage or contamination is present. Receiving checklists prepared by the CxP are completed by the contractor for each piece of equipment. Adequate and appropriate on-site transportation and storage should be in place to confirm that the equipment is secure and protected until ready for installation. The CxP conducts targeted sampling of the on-site equipment receiving process and documentation. Delivery inspections include:

- a. Inspect each component upon delivery to the site, recording delivery date and relevant details of the equipment (e.g., serial/part number, general description).
- b. Record observations, noting any damage to the equipment and its protective covering using Cx Plan receiving checklists.
- c. For sensitive items or storage conditions, record evidence of water ingress, foreign object debris (FOB), or other contamination.

Set In Place (SIP) inspections are conducted after the contractor completes receiving checklists. The CxP creates SIP inspection documentation and performs SIP inspections on First of Kind (FOK) for each equipment type, while the contractor performs SIP inspections for each piece of equipment.

Installation & Documentation (I&D) is completed by the installing contractors for each piece of equipment in accordance with specifications and the Cx Plan for each piece of equipment after SIP inspections are completed. Some equipment requires multiple I&D reports from different trades and vendors associated with the installation. I&D records are compiled and stored by the CxP for inclusion in the Cx Report and/or Systems Manual.

Clean walks are conducted by the General Contractor or Project Manager as determined by contracts and specifications. After I&D is completed by the installers, the GC or PM inspects the installation and associated conditions to verify cleanliness, absence of housekeeping concerns, and that no FOD is present. The CxP uses targeted sample clean walks to confirm clean walk efficacy.

Torque verification follows clean walks. The CxP conducts a statistical sampling of each type of equipment to observe the installing contractor or vendor verify torque settings for field connections. Torque verification may occur during the electrical contractor's sequence of installation at the time of Pre-Energization Inspections (PEIs) prior to energization or anytime in between.

Pre-Energization Inspection (PEI) may be a 2-fold process if utility power delivery is delayed. First, the equipment vendor or vendor representative inspects their equipment and signs off on readiness for energization. This would typically be the normal pre-power checks in a Level 3 start-up process when utility power is delivered in sequence with installation progress. Secondly, if utility power delivery is delayed, the CxP performs inspections of equipment. Torque verification is confirmed at this time, if not completed prior. Upon CxP PEI completion, the CxP installs tamper seals to ensure no unauthorized access to equipment until energized start-up procedures begin. The CxP utilizes a tamper seal protocol such that when a vendor or contractor requires access to equipment, CxP notification triggers a process to remove the tamper seal, confirm PEI status, and re-tamper seal the equipment. Tamper seals are intended to remain in place until energized start-up, but tamper seal protocol provisions should be in place for extraordinary circumstances. Torque seal checklists are completed by the CxP upon request if access is required to equipment after torque verification and tamper seal.

Pre-Energization Inspections (PEIs) include:

- a. Workmanship and material compliance to approved submittals
- b. Provision of access and clearance to allow for maintenance, service, repair, removal, and replacement without the need to disassemble or remove other equipment or building elements
- c. Interconnections between components

- d. Product and installation compliance to design documents
- e. Product and installation compliance to local codes and regulations
- f. Installation compliance to manufacturer's guidelines, requirements, and recommendations
- g. Internal and external cleanliness
- h. Equipment labelling per design documents

Level 2 commissioning also covers testing procedures which are required prior to energization of equipment and/or systems, such as electrical testing, building envelope testing, pipework hydraulic testing, and duct air leakage. The contractor, supplier, or manufacturer is responsible for execution at Level 2. The CxP should review and approve the QA/QC protocols and test procedures in accordance with contract documents, and perform targeted sampling and verification in accordance with contract provisions, project specifications, and the Cx Plan.

6.1.3 Level 3: Start-Up and Preliminary Functional Testing

Level 3 commissioning is primarily a testing phase for the contractor, supplier, or manufacturer to verify that equipment and systems are started up safely and function as per design, manufacturers' guidance, and local codes and regulations.

The Level 3 process begins with start-up procedures, covering the initial energization of equipment, followed by preliminary functional testing. This testing should verify the sequence of operations, confirm proper component-to-component interfacing, and validate monitoring and control systems such as the BAS. Once basic functionality is confirmed, testing, adjusting, and balancing (TAB) is carried out to establish the correct airflow, water flow, and system pressures, demonstrating that the systems operate in line with design expectations. Electrical testing should be performed; the testing effort should be rigorous enough to demonstrate that each piece of equipment can operate at its rated design capacity, that systems perform their intended functions in a resilient manner with the required redundancy, and that they respond appropriately under failure conditions.

This phase of commissioning should allow the contractor, supplier, or manufacturer to observe system performance, identify deficiencies, recommend modifications and complete control loop tuning to determine the optimal control parameters for stable operation over a range of load and failure response and recovery scenarios. All control loop settings and set points should be documented and included within the Cx Plan and as-built SOO for inclusion within the Systems Manual.

The contractor, supplier, or manufacturer is responsible for execution at Level 3. The CxP should review and approve the QA/QC protocols and test procedures in accordance with contract documents.

6.1.4 Level 4: Functional Performance Testing

Level 4 commissioning is a testing phase that is led by the CxP on behalf of the Owner. The objective is to independently validate that equipment and systems are functioning as per the OPR, manufacturers' guidance, Sequence of Operation, and design intent. This is the Owner's acceptance phase to confirm that the contractor, supplier and manufacturer have completed their contract scope and that systems are operating in accordance with the design intent and OPR.

The Level 4 process begins upon successful documented completion of the associated Level 3 testing. Functional testing is driven by the sequence of operation, design requirements, and manufacturers' operating recommendations. This testing should verify the sequence of operation, confirm proper component-to-component interfacing, and validate monitoring and control systems such as the BAS. The functional testing should be rigorous enough to demonstrate that equipment and system capacity block can operate at its rated design capacity, that systems perform their intended functions with the required redundancy, and that they respond and recover appropriately under failure conditions.

The objective of Level 4 Functional Tests is to demonstrate that related components, equipment, and ancillary systems that make up a defined system, operate and function to their rated and specified performance criteria. The testing dynamically verifies that the equipment and systems perform under all modes of operation, which include normal modes, maintenance modes, and failure modes.

Typically, the CxP is responsible for writing and directing the Functional Tests and the CxP Team reviews the test scripts, with execution and coordination performed by the contractor, supplier, and manufacturer observed by the CxP and Owner's representatives.

6.1.5 Level 5: Integrated Systems Testing (IST)

Level 5 commissioning is the final testing phase that is led by the CxP with support from the full project team. This is to verify that the facility and systems are functioning according to the OPR and design intent. This is carried out by performing Integrated Systems Testing (IST) on the facility systems, equipment, and components. The objective of the IST is to provide a final validation that systems and equipment correctly deliver performance under varying load and failure scenarios in line with the design requirements.

During this phase, as multiple systems are tested simultaneously, they typically require significant staffing to execute them and monitor the results. As such, these tests should be supported by the entire project team. IST is intended to be the last set of tests which are conducted on the systems and equipment prior to substantial completion. It should conclude with all systems and equipment left in a state of fully automatic and enabled with final settings. IST is driven by the sequences of operation, design requirements and are focused on building wide failures and integrated system responses (i.e. utility outage simulation).

IST should commence once the prerequisites have been completed. This can be evaluated during an IST Readiness Assessment (Go/No Go), which would generally require:

- a. IST scripts fully reviewed and approved.
- b. All associated Level 4 Functional Testing has been completed and substantially passed. No IST should commence unless all Level 4 testing is complete and documented.
- c. All systems are configured automatically and enabled with all alarms and enunciations active.
- d. Equipment and/or system are alarm-free at the equipment and/or sub-component and at the BAS.
- e. Confirmation of previous inspection and testing documentation is complete, signed off, and available.
- f. No functional or substantial issues are open.
- g. Approval has been obtained from the CxP and Owner.

The CxP is responsible for writing and directing the IST and the CxP Team reviews the test scripts, with execution and coordination by the contractor, supplier, and manufacturer.

6.2 Cx Tagging. In data center developments (particularly when there are substantial quantities of equipment assets), Cx tagging may be utilized to monitor commissioning completion.

Cx tagging is a quality control process used to track and record equipment and system completion status throughout the levels of commissioning. This process employs a color-coded equipment tagging system that correlates to the commissioning levels, providing a progressive and transparent indication that each inspection and/or testing procedure has been successfully verified and complete. Cx tagging provides a comprehensive audit trail and confirms that Level 5 testing can commence with a high degree of confidence in success.

Tags are awarded upon the completion of a set of equipment/system checks that are agreed upon between the CxP and contractor in the early stages of the project, as detailed in the Cx Plan and checklists. They are awarded sequentially and serve as a progress marker in the Cx. Should a tag not be achieved, this will result in a hold-point, preventing advancement to subsequent tagging activities for the respective system, equipment, or component. Color identification and tagging are attached to system, equipment, and component assets in the Cx or construction management software platform for tracking and documenting.

An example of a color-coded tagging system could be as follows:

- Level 2A Red Tag – Equipment Delivered and Set in Place
- Level 2B Yellow Tag – Installation Verification and Pre-Energization Testing Complete
- Level 3 Green Tag – Startup and Preliminary Functional Testing Complete
- Level 4 Blue Tag – Functional Testing Complete

7. OWNER'S PROJECT REQUIREMENTS

7.1 Requirements. The impact of downtime associated with data centers once operating justifies robust new construction and existing building Cx. In addition to the OPR considerations in the ASHRAE commissioning documents (such as facility objectives, size, location, elevation, floor space, and user requirements), the data center OPR document should include the specific elements for the commissioned systems detailed in Sections 7.2 through 7.8.

- 7.2 Data center mission critical operations are frequently realized through construction and major renovation projects delivering at large scale and high tempo that should be tracked by the CxP in a strict asset management framework utilizing equipment and system being commissioned with a tagging process using a cyber secure database and appropriate software to deliver real time evaluation of Operational Readiness from project initiation through acceptance and operations. Reentry to data center facilities after acceptance and turnover is not realistic, necessitating that “readiness for tests” as defined in SSPC 300 Informative Annex 10, “Testing and Reporting,” is not an adequate condition for mission critical environments. Final acceptance observations and tests should be conducted at operational readiness to verify that passing results are persistent during operation.
- 7.3 Boundary definitions for both systems to be commissioned and vendor/supplier commissioning activities require detailed specification. Specifications should clearly define interfaces between the commissioning provider and quality control processes performed by contractors, manufacturers, suppliers, or others to leverage common deliverables through collaboration. This is intended to streamline logistics and observation scheduling through interactive construction tools including deadlines and methods shared on a platform available to quality control processes and the commissioning plan activities.
- 7.4 Although data center commissioning scope boundary is defined in this guideline as support infrastructure up to information technology equipment (ITE), what happens at the server racks impacts commissioning and should be accounted for in the Cx Plan where commissioned systems interact or integrate directly or indirectly with systems being commissioned. Similarly, utilities and resources used for data center operation should be accounted for in the Cx Plan where they impact commissioned systems directly or indirectly. Uptime, meaning full operational duration, represents the key goal of successful data center commissioning. Effects on commissioned systems from both inside and outside the scope of commissioning boundary should be considered and tested and observed for compliance with the OPR.
- 7.5 Levels of commissioning and clear prerequisites for successful advancement of commissioned systems within level criteria and for advancing to the next level should be specified in explicit detail to include required cooperation between quality control personnel and commissioning providers through integrated platforms that eliminate duplication of activities and project data transfer.
- 7.6 Factory testing provisions for systems, equipment, and components should be detailed in the OPR. The distinction between contractor-furnished and owner-furnished equipment (OFE) should be clarified, and factory-testing responsibilities should be assigned.
- 7.7 Data centers built at scale are successful when developers engage consistently and transparently with the site community and local government. Siting, permitting, electrical-transmission investments, and water-use and reuse infrastructure require cooperation between Project Teams and local entities, including, but not limited to, authorities having jurisdiction (AHJs). Data center electrical-load growth and electrical-power-demand forecasting represent substantial mutual interests between local communities, their governments, and data center Project Teams. Sustainability, reliability, and efficiency goals and benchmarks should be considered in the OPR for systems being commissioned, including the following metrics and requirements.
- a. Resource utilization efficiencies
 1. Power Usage Effectiveness (PUE) or Data Center Infrastructure Efficiency (DCIE)
 2. Total-Power Usage Effectiveness (TUE)
 3. Water Usage Effectiveness (WUE)
 4. Carbon Usage Effectiveness (CUE), including grid and onsite (microgrid) with IT equipment included in ratio
 5. Water tables
 6. Power consumption (BYOP, BYONP)
 7. Emissions levels scope 1, 2, 3 accounting and reduction targets
 8. Greenhouse gas (GHG) protocols
 - b. Physical plant operational efficiencies
 1. Generator emissions
 2. Refrigerant management

3. EPMS and SCADA philosophy, structure, and methodology
4. BAS control philosophy, structure, and methodology
5. Submetering strategy
6. Redundant and/or scalable building systems
7. Thermal energy storage and rejection
8. Monitoring, control, and alarm strategy
9. Fuel systems
10. Exterior enclosure requirements
11. Backup power generation and distribution
12. Fire protection
- c. Environmental responsibilities
 1. Heat island effect
 2. Fuel storage spill prevention, control, and counter measure plan
- d. Property boundary public restrictions
- e. Sound escaping/noise pollution/acoustical emissions/public decibel level restrictions
- f. Indoor environment requirements, including temperature, humidity, ventilation, building and spaces relative pressures, sound pressure levels, temperature, relative humidity, relative pressure space differentials.
- g. Thermal guidelines, x-factor, ASHRAE thermal envelope defined by T, P, RH, and rates of change of T, P, RH (refer to ASHRAE TC 9.9 Datacom Encyclopedia online resources)
- h. Equipment, systems, and assemblies' directives
 1. Water cooled vs. air cooled chilled water system
 2. Coolant distribution units
 3. Raised floor or no raised floor
 4. Aisle containment strategy
- i. Special project requirements
 1. Transmission load connections (69 kV nominal 100 kV)
 2. Communication technology infrastructure (fiber testing, pinging IP/MAC addresses)
 3. Onsite load bank testing strategy
 4. Runtime requirements for emergency or alternate systems
 5. Distributed energy resources
 6. Interconnection testing requirements for electric utility
 7. Data floor critical power distribution
 8. Computational Fluid Dynamics (CFD) modeling
 9. Building classification based on the risk to human life, health, and well-being
 - Blast requirements
 - Seismic
 - Anti-terrorism/force protection (AT/FP)
 - Electromagnetic pulse (EMP) shielding
 10. Modular construction elements incorporation
 - Third party integration
 - Ready for testing criteria
 11. Physical and cyber security
 - Access controls
 - Change management
 - Monitoring
 12. Fire protection and alarm systems

- Emergency Power Off (EPO)
- Pre-action system
- Clean agent system
- Early warning aspirating smoke detection systems
- j. Owner's design standards
- k. Applicable standards, codes, and guidelines in addition to local building codes
- l. Owner's project delivery requirements
- m. Maintainability
 - 1. Access
 - 2. Operational performance requirements
 - 3. Redundancy strategy
 - 4. Third-party rating criteria
 - 5. Component Hot Swap Capability
 - 6. Supply chain critical components and materials inventory
- n. Testing requirements
 - 1. Factory Testing
 - 2. Sampling strategy
 - 3. Test Risk Assessments
 - 4. Test tag levels
 - 5. Testing at integrator
 - 6. Bench Testing
 - 7. Functional Performance Testing
 - 8. Integrated System Testing
 - 9. Full site/facility power loss testing
 - 10. Data Center specific benchmark and/or modeling validation
- o. Cx Plan Owner required CxP and/or testing agency certifications and qualifications

7.8 Cx Sequence. The sequence for placing systems into service should be delineated in the OPR, project specifications, and the Cx Plan

7.8.1 Critical Electrical Distribution Systems

- a. Checklists are filled out to confirm construction is complete and the equipment is ready for the testing and commissioning program to begin.
- b. Acceptance testing is performed on the electrical distribution equipment, such as circuit breakers, transformers, power cables, automatic transfer switches, switchgear, switchboards, motor control centers, and power distribution units.
- c. The electrical contractor energizes the electrical distribution system based on the agreed upon method of procedure (MOP) so that power is available for equipment startup.
- d. Equipment vendors (generators, UPS modules, ATS, STS, etc.) start up their equipment and make sure it is operational. Burn-in tests, in which the equipment is operated at rated load for an extended period of time (such as 4 h, 8 h, 12 h, or 24 h), are also performed.
- e. Commissioning tests are performed on the major components, such as generators, UPS modules, and STS using resistive load (and reactive load for some applications).
- f. Commissioning tests are performed on the major systems, such as the transfer from utility power to generator power and on the UPS systems.
- g. Load banks are installed on the secondary of the PDUs to provide the rated load for the UPS system design. The heat rejected from the load banks in the data center rooms is used for the mechanical cooling systems commissioning
- h. Once the mechanical systems are commissioned, an integrated systems test (IST) is performed with both

the critical electrical distribution and critical mechanical cooling system operating at rated load in accordance with the designs.

7.8.2 Critical Mechanical Cooling Systems

- a. Checklists are filled out to confirm construction is complete and the equipment is ready for the testing and commissioning program to begin.
- b. Contractor for the BMS verifies the inputs and outputs for all of the controls are properly connected and the sequences are programmed in accordance with the specifications and design documents.
- c. Once the electrical contractor has energized the electrical distribution system so that power is available for equipment start up, the mechanical contractor flushes the major piping and confirms the proper water treatment has been provided.
- d. Equipment vendors (chillers, cooling towers, etc.) start up their equipment and make sure it is operational.
- e. The test and balance contractor adjusts all of the valves, dampers, etc. as needed to set the required water and air balance for the mechanical cooling systems.
- f. Commissioning tests are performed on the major components, such as chillers, pumps, cooling towers, and computer room air handling (CRAH) units.
- g. Commissioning tests are performed on major systems.
- h. Load banks are installed on the secondary of the PDUs to provide the rated heat load in the data center rooms for the mechanical cooling systems commissioning.
- i. IST is performed with both the critical electrical distribution and critical mechanical cooling system operating at rated load in accordance with the designs.

7.8.3 High-level project specific performance requirements for initial and future build-out are included in the OPR.

- a. Infrastructure resiliency, redundancy, reliability, availability, expandability
- b. Basic strategy of acceptance testing is to identify issues and problems as early as possible, so they can be resolved with the least impact on project quality, schedule, and cost. In general, commissioning relies on identifying faulty components prior to shipping and identifying damaged deliveries prior to installation.

7.8.4 Identify installation errors prior to startup

- a. Identifying system level issues prior to integrated systems testing
- b. Identifying facility performance and reliability issues prior to beginning critical operations
- c. Delivering proven performance with trained operators and accurate as-builts

7.8.5 Prescribe Commissioning Levels

- a. Level 1: Factory Testing (FT)
- b. Level 2: Site Acceptance and Installation Checks
- c. Level 3: Startup and Pre-functional Testing
- d. Level 4: Functional Performance Testing (FPT)
- e. Level 5: Integrated Systems Testing (IST)

7.9 Acceptance. The OPR should be reviewed by the CXP Team and approved by the Owner during project initiation. Updates to the OPR made during subsequent project activities should also be formally accepted by the Owner.

8. CX PLAN

8.1 General. The Cx Plan is a written document intended to provide organization, documentation requirements, and tools to evaluate and document that the design, construction, and operation of the project or facility, systems, and assemblies comply with the OPR.

8.2 Requirements

8.2.1 The Cx Provider (CxP) should, with input from the Owner's Project Team, develop the initial Cx Plan at the initiation of the project. The Cx Plan should be updated and expanded during design and construction as the project evolves. Given the complexity, scale, and mission critical nature of data center infrastructure, a rigorous commissioning approach is required. The data center Cx Plan could include the following specific elements.

8.2.2 The Cx Plan should include the following information:

- a. A description of the five levels of commissioning (Levels 1 through 5)
- b. Key milestone dates and reference to the Cx schedule
- c. List of agreed Factory Witness Testing (FWT) events for the project
- d. Strategy for tracking the Cx across the five levels of commissioning, including the use of commissioning software tools
- e. Commissioning tagging list per equipment/systems (Levels 2 through 4), where applicable
- f. Required inspection procedures, test methodologies, and test scripts for each commissioning level
- g. List of expected inspection and testing procedures to be submitted for approval by discipline/vendor
- h. A list of any specific testing equipment required through the Cx by each equipment type, vendor, and test
- i. Details of manufacturers' site acceptance requirements to confirm storage conditions/warranty provisions are maintained upon equipment delivery
- j. Control loop tuning strategy, identifying all control loops and settings requiring field adjustment, including the methodology and any temporary load requirements
- k. Method of validating power quality and power quality meter (PQM) placement strategy
- l. Load testing strategy inclusive of load bank layout, selection, temporary (mock-up) hot aisle containment (HAC) requirements and CFD comparison for pass/fail criteria. This can be an appendix document to the Cx Plan or a reference document.
- m. Details of live infrastructure interfaces (where applicable), outlining processes and specific details which may impact live operational infrastructure
- n. Commissioning meetings schedule, outlining key meetings throughout the project life cycle
- o. Management of commissioning records and document storage

8.2.3 Key Milestone Dates. Key project milestone dates which are important to include in the Cx Plan and to monitor throughout the Cx are as follows:

- a. Project start date/break ground (when construction activities commence)
- b. First energization (when the first energization to the building has been completed, signaling the commencement of Level 3 testing activities)
- c. ICT Room Ready (when the ICT Rooms and associated fiber backbone pathways have been completed. This is to allow for the IT hardware infrastructure installation and tune up process to begin to bring the IT/BMS/security network live)
- d. Network Live (when the IT/BMS/EPMS/security network is live, associated servers/switches are provisioned and communication has been established with the associated workstation. The pre-requisite of Level 3 completion is that all points to graphics on the BMS/EPMS systems have been performed.)
- e. Commencement of Level 2, Level 3, Level 4, and Level 5 testing activities
- f. Project Handover/Facility Acceptance (typically, when all defect issues have been resolved, all documentation has been provided, IST successfully completed and turnover procedure performed and accepted by the Owner)

8.2.4 Commissioning Tracking

The Cx Plan should define a clear strategy for tracking all quality, testing, and Cx Activities in accordance with the project's commissioning schedule. This includes the use of a live Cx tracker, sometimes referred to as the Cx Levels 1-4 Tracking Matrix, that monitors the Cx status for all systems and equipment. The

tracker should be structured around the equipment assets and Cx Levels or Cx Tag requirements (where implemented) and provide real-time visibility into progress against the commissioning schedule for planned versus actual completion status. The use of an online software tool is encouraged to facilitate transparency, coordination and accessibility for project stakeholders. The tracking tool should serve as the single source of truth for the Cx and enable consistent reporting whilst identifying delays or performance issues early in the process.

8.2.5 Equipment Storage Requirements

The Cx Plan should include manufacturers' environmental storage requirements for each asset, including temperature, humidity, and cleanliness to confirm these conditions are maintained prior to delivery and installation. Where multiple pieces of equipment are located within a room, the strictest environmental requirements should apply.

To maintain the manufacturers' requirements, any additional measures required to preserve these conditions should be detailed within the Cx Plan. This may include items such as temporary protection, power, heating, cooling, humidity control, and/or ventilation requirements.

- 8.3 Acceptance.** The Cx Plan should be approved by the Owner and include a process for approval of the subsequent revisions.

9. BASIS OF DESIGN (BOD)

- 9.1 General.** The Basis of Design (BoD) is a written document that should provide detailed information on the Design Team's approach to meeting the OPR to provide the Owner with a better understanding of design intent and secure the Owner's approval of critical design decisions. The BoD is a living document updated for technical advancements and project specific conditions. The BoD is a narrative that explains the translation of OPR requirements into project drawings and specifications.

9.2 Requirements

- 9.2.1** The BoD should be developed by the Design Team in accordance with the OPR or CFR. The data center BoD should address the following for the commissioned systems:

- a. Building systems, assemblies, and technical approach of the BoD should address all OPR requirements listed in this guideline.
- b. Provide a reference platform for the review of the detailed design and changes as the project progresses.
- c. Track approved design approach changes and justification.

- 9.2.2** The Design Team should submit the BoD to the Owner, Owner's representatives, and CxP for review and Owner approval upon necessary changes being made and at each milestone defined by the OPR and Cx Plan.

- 9.2.3** The Owner, Owner's representatives, and CxP should evaluate data center specific BoD content.

9.2.4 Electrical Systems

- a. Comprehensive power infrastructure design to include redundancy, resiliency, voltage requirements backup power systems, and UPS generation.
- b. Provide detailed electrical load calculations.
- c. Provide redundant power paths.
- d. Detail uninterruptible power supply (UPS) specifications.
- e. Specify voltage and amperage requirements to size utility services and equipment.

9.2.5 Mechanical Systems

- a. Comprehensive IT heating and cooling infrastructure to include thermal management, airflow distribution and aisle containment, cooling efficiencies, redundant cooling paths, and rapid system loss recovery characteristics.
- b. Thermal management strategies should be determined.
- c. Cold and hot aisle containment configuration, cold plate, or direct to chip cooling strategies are specified.
- d. IT conditioning humidity, temperature, and airflow distribution strategies are specified.

- e. Cable and fiber management strategies are determined.

9.2.6 IT Infrastructure

- a. Network and computing infrastructure layout is provided with rack density, cable management, IT cooling systems, and future expansion capabilities are designed.
- b. Provide network topology.
- c. Provide equipment heat load predictions.
- d. Design future scalability provisions.

9.2.7 Structure Considerations

- a. Building design should include allowable enclosure air leakage, moisture infiltration/exfiltration control provisions, seismic safety requirements, floor and wall load capacities, and environmental protection provisions.
- b. Fire suppression systems compatible with IT equipment environment as designed.
- c. Physical security infrastructure is designed.

9.2.8 Facility Efficiencies and Sustainability

- a. Sustainable design parameters may be required for OPR compliance.
- b. Renewable energy integration or microgrids may be design components.
- c. Demonstrate thermal optimization and resource utilization efficiencies.
- d. Provide power usage effectiveness (PUE) calculations.
- e. Include heat recapture and reuse strategies.

9.3 Acceptance

- 9.3.1** Each submission of the BoD should be formally reviewed and accepted by the Owner, Owner's representatives, and CxP to facilitate the next steps in the design process.
- 9.3.2** Comparison of construction documents with the BoD should continue through the end of the construction phase. The BoD should account for limited seasonal, delayed, and incomplete testing and training of facility systems and assemblies that will be difficult or impossible to complete after occupancy.

10. DATA CENTER CX SPECIFICATIONS

10.1 General

- 10.1.1** ANSI/ASHRAE/IES Standard 202 includes fundamental generalized requirements for Cx specifications to be included in project contract documents. ASHRAE Guideline 0 provides a recommended organization of the Cx specifications within the project manual, and includes content to be included for commissioning any type of facility. This section expands on the recommended content to be included in the Cx specifications as it relates to data centers.
- 10.1.2** The Cx specification establishes the minimum quality, testing, verification, and documentation requirements necessary to ensure that all systems are commissioned in accordance with the OPR, design intent, and applicable standards. The Cx specification forms a foundational contractual document defining how commissioning is to be planned, executed, witnessed, recorded, and accepted.

10.2 Requirements. It is recommended that the Owner maintain their own set of Cx specification requirements. If the Owner does not have these, a CxP should be engaged to develop the requirements. The content of the Cx specifications may include the following:

- a. Acronyms and definitions used within the specification.
- b. Roles and responsibilities of the stakeholders and CxP Team.
- c. The scope of the Cx, listing all of the equipment and systems covered by the requirements.
- d. Expected testing equipment and any temporary works (e.g., load banks, temporary hot aisle containment where required by the OPR).
- e. A description of the levels of Cx with the requirements of each stakeholder clearly defined; requirements

may also be set out within a RACI table.

- f. Documentation requirements. For pre-execution and planning, define expected structure, format, and approval processes for inspection templates and testing methodologies. For post-execution, define how inspection and testing records should be presented, recorded, and stored.
- g. Where a Cx software tool is being implemented, provide setup, usage, and data quality requirements for each stakeholder.
- h. Details on issue management and resolution processes, including categorization, corrective action plans, and close-out verification.
- i. Training requirements for Owner's operations team and associated acceptance criteria.
- j. Turnover processes, including "as left" documentation and required turnover forms.
- k. Cx schedule requirements, including key Cx milestones and activities that should be included in the master project schedule.
- l. General and system-specific inspection and testing requirements (e.g., electrical cable testing or hydraulic pressure testing of pipework systems).
- m. Asset-based Cx requirements, including load testing requirements, through the levels of Cx for each commissionable asset on the project. For example, the inspection and testing requirements of a chiller at Cx Levels 1 through 5.

It is recommended that the Cx specifications are included within the contract documentation for the contractor, supplier, and manufacturer.

10.3 Testing. Several construction and acceptance phase activities that are typically included in a data center project should be addressed to assign participation and responsibility in the contract documents. These include Integrated Systems Testing, First of Kind Testing, Factory Acceptance Testing, and Software Acceptance Testing.

10.3.1 Integrated Systems Testing. Since IST is the pinnacle of the Cx and the performance of these activities demonstrates the performance of the facility as a whole against the OPR, it is critical to include IST in the commissioning specifications. The test requirements at various loads and system operating modes should be provided for complete demonstration of fully automatic operation and proper response to equipment failures and utility problems. Ultimately, these tests should be defined adequately to confirm that the data center performs in accordance with the requirements and provides a more reliable, available environment for the Owner. The CxP Team as well as equipment vendors of the support system equipment (UPS, generators) should participate in the testing.

The testing plan should include the necessary equipment required to run the test (e.g., load banks) and should detail how the testing will be conducted if the facility is in the process of a partial buildout. The assumed duration of the test and availability of equipment throughout should be included, as well as procedures in place if the test does not pass, under what circumstances additional compensation will be required, and the responsible party. Since the IST requires the participation of several disciplines, including vendors, outlining the process in the general Cx section will provide the contractor with the necessary information to allocate subcontractor and manufacturer participation and to avoid ambiguity.

10.3.2 First of Kind Testing. Testing for first of kind (FOK) should be carried out on any major piece of equipment for a project, to serve as proof of concept. Discrepancies between submittals and the manufactured product are most common in this scenario; this can be due to the equipment being a new product for the manufacturer or the customer not being familiar with the product. The CxP Team as well as members of the facility operations team should participate in the testing.

The following are examples of equipment where first of kind testing is typically required:

- a. Mechanical Equipment
 - 1. Chillers
 - 2. Computer Room Air Handling (CRAH)/Computer Room Air Conditioning (CRAC) Units
 - 3. Custom/packaged air handling units and DOAS units
 - 4. Fuel oil control systems

- b. Electrical Equipment
 - 1. Engine generators
 - 2. UPS modules
 - 3. Battery strings
 - 4. Motor Control Center
 - 5. Intelligent Switchgear that includes PLC-based automation
 - 6. Transfer equipment (automatic/ATS, static/STS)
 - 7. Rectifiers (48V DC plants)

Requirements for FOK testing should be included in the applicable technical sections for commissioning.

10.3.3 Factory Testing. Since the intent of factory testing is to provide assurance that the purchased equipment has been tested and verified for build quality and performance, the specifications should include a complete list of the required equipment to be tested. The sampling rate of similar equipment should be stated and any details of equipment-specific testing included. If the factory testing is customized to include a mixture of manufacturer-prescribed standard tests with specific client or designer requirements, the test conditions should be explicitly defined. Additionally, details of the approval process and minimum acceptable levels of access to manufacturer facilities should be addressed. Participation in factory testing should include the EoR, contractor(s), subcontractor(s), CxP Team, and Owner's Representative.

The testing plan should include the in-person expectations from the Project Team and the estimated time for completion. Any necessary provisions in project schedule for issue correction as a result of factory testing and additional costs associated with retests should also be included.

Requirements for factory testing should be included in the applicable technical sections for commissioning (i.e., chiller FAT in Division 23 Cx Section).

10.3.4 Software Acceptance Testing. Often referred to as BMS testing, verification of correct applications and current versions of software, along with detailed testing of the routines, safeties, alarms, trending, and archiving represents a crucial element of data center commissioning. BMS verification is embedded in all levels of commissioning. Software acceptance testing proves the programming matches the design intent and OPR. From Level 3 through Level 5, Cx checks and tests various software applications and platforms residing on the BMS, as well as those contained in equipment and components. Specifications must be clear as to the parties responsible for programming, troubleshooting, demonstrating, and correcting software operation and functionalities for individual equipment and components and BMS sequences of operation. Software acceptance testing verifies all modes of operation, safeties, alarms, notifications, and integrations with other equipment and components and with enterprise platforms.

Software and BMS issues can dominate logging and tracking activities on Cx projects. Communication of issues and timely resolutions are key to successful software testing. Direct collaboration between the CxP Team and software vendors should be established early and utilized with regularity to address issues as they arise to prevent adverse impact on project delivery.

10.4 Acceptance. The Owner should approve Cx specifications when developed by the CxP before inclusion in the tender package. Where the Owner provides their own Cx specification standard, they should approve any proposed deviations in coordination with the CxP.

11. COMMISSIONING DESIGN REVIEW

11.1 General. A Cx Design Review should be performed to evaluate compliance with the OPR. This can also cover aspects such as building phased handover requirements, connecting to live infrastructure, and any power restrictions which may be in place by the utility provider.

11.2 Requirements

11.2.1 The CxP should be engaged to perform a review of the commissioned systems and assemblies in the design documents to evaluate compliance with the OPR. This may also include attending page turn events with the Project Team and Owner. A Cx Design Review should be completed, and issues resolved, prior to the issuing of contract documents for systems being commissioned. The OPR and the Cx Plan should define any sampling strategies for Cx Design Review.

11.2.2 The review should focus on and verify that there is sufficient detail at each design stage for the following:

- a. Compliance with the OPR
- b. Mechanical, electrical, fire protection/alarm, and controls single line diagrams and layouts
- c. System functional descriptions and sequence of operation
- d. Potential commissioning coordination issues
- e. Selection and placement of balancing devices, isolation points, flushing bypasses, and measuring points
- f. Single point of failures in accordance with redundancy requirements set out in the OPR
- g. Project phasing and operational impact to live infrastructure, where applicable
- h. Protection and coordination Study
- i. Operational and maintainability access requirements
- j. Evaluation and coordination of the availability of the utility supply and its capacity, where applicable

11.2.3 The CxP should conduct Cx Design Reviews, as detailed in the Cx scope, and develop corresponding reports with comments, suggestions, clarifying questions, and observations in a Cx Design Review Report to the Owner and Design Teams evaluating compliance with the OPR. This Cx Design Review should not be considered a peer design review or a code or regulatory design review. The report should include (at a minimum):

- a. Introduction and summary
- b. Project phasing and constructability review
- c. Highlighting and influencing design on any shared services across phases
- d. Advising on commissioning strategies to facilitate a phased delivery
- e. Where temporary power is applicable, establishing capacity needs to facilitate testing and commissioning (i.e., load testing)
- f. Cx Design Review log to track observations and resolutions

11.2.4 The Design Team, Owner, and/or other responsible part should respond to the Cx Design Review report with necessary responses and agreed to revisions to the project design documents. Revised documents should be backchecked by the CxP. Any unresolved issues should be reported to the Owner for direction to the Design and Project Teams on final disposition and direction.

11.2.5 A copy of the Cx Design Review reports and responses should be included in the Final Cx Report.

11.3 Acceptance. The Owner should approve the Cx Design Review report and the Design Team's response before the start of construction.

12. COMMISSIONING SUBMITTAL REVIEW

12.1 General. For construction or renovation projects requiring contractor or supplier submittals, a submittals document review for commissioned systems and assemblies should be performed to evaluate compliance with the OPR. The commissioning submittal review should not replace the designer of record submittal review.

12.2 Requirements. The Commissioning Submittal Review begins in the Project Initiation Phase and is ongoing through the end of the Construction Phase of commissioning projects. Submittals are reviewed for comprehensiveness, detailed technical content, and critical data center systems compliance. Submittals should provide clear performance criteria related to project performance expectations for data center infrastructure and support systems. Submittals should indicate compliance verification with the OPR and design intent requirements, and ensure alignment with relevant industry standards, such as ASHRAE and BICSI guidelines.

12.3 Commissioning Submittal Review Criteria

- a. Precise technical manufacturer specifications
- b. Comprehensive system integration plans
- c. Function Performance Test requirements
- d. Compliance with industry standards
- e. Independent third-party review

- f. Repeatable evaluation process utilizing checklists

12.4 Commissioning Submittal Reviews

12.4.1 The Project Initiation Phase includes initial Cx scope and Cx Activities review.

12.4.2 The Design Phase includes OPR and BoD reviews, as well as project systems and equipment performance evaluations.

12.4.3 The Construction Phase is the busiest period for commissioning submittal reviews conducted by the CxP in parallel with the Design Team submittal reviews. Detailed technical compliance should be demonstrated to achieve Design Team approval. The CxP provides advisory reviews to the Owner and Design Team in a timely manner to be considered in conjunction with the Design Team to approve or reject decisions. Manufacturer startup and testing protocols and measurable benchmarks are reviewed for OPR compliance.

12.4.4 The Occupancy and Operations Phase involves QA/QC documentation reviews for adherence to industry standards and regulations, as well as OPR compliance.

12.4.4.1 Mechanical Systems Commissioning Review Evaluations

- a. IT heating and cooling equipment requirements
- b. Redundant and recovery cooling system details
- c. Air distribution equipment performance parameters
- d. Heat transfer equipment performance parameters
- e. Redundancy, reliability, and resiliency provisions

12.4.4.2 Electrical Systems Commissioning Review Evaluations

- a. Power Distribution Unit (PDU) specifications
- b. Uninterruptible Power Supply (UPS) specifications
- c. Emergency generator specifications
- d. Electrical load calculations

12.4.4.3 IT Infrastructure

- a. Server rack and cabinet specifications
- b. Conductor, cable, and fiber management systems
- c. Network equipment details
- d. Server cooling and airflow designs

12.5 Acceptance. The CxP should maintain a record of all Cx submittal reviews and should submit a written report to the Owner and design authority. If it is determined that any reviewed submittals do not comply with the OPR, that submittal should be provided to the Owner and design authority to determine whether the system or equipment should be accepted or rejected.

13. FACTORY TESTING

13.1 Description. Factory testing, for the purposes of this section, covers testing at the factory where the equipment is manufactured. It also applies to testing of packaged equipment at an equipment integration facility. It is not intended to cover testing by the manufacturer or equipment integrator at project site. Factory testing may also be referred to as Factory Acceptance Testing (FAT) or Factory Witness Testing (FWT).

Some form of factory testing is expected and common to all major equipment manufactured for use in a data center. Factory testing is generally an aspect of the manufacturer's internal QA/QC program and can span from visual inspection to verification of published performance ratings, through to more intensive performance and integration testing. Examples include factory pressure testing of chillers and vibration testing of pumps. Data center Project Teams may require additional project specific factory testing in the project specifications, including testing equipment prior to shipment at non-standard design conditions, under various load profiles, and to prove project specific SOOs.

While factory testing may be a critical task in the Cx for a data center, it is not always a requirement. Factory testing can add significant time to the project schedule, as well as a noticeable premium to the equipment cost.

It is best to define factory testing requirements in the OPR. The extra cost can be quantified by requesting the factory testing effort as an optional cash allowance in the proposed pricing documents. Each project should weigh the impact to the budget and schedule against the perceived benefits. The OPR should establish which type of equipment will require factory testing. How many of each type will need to be tested should be reviewed with the Project Team and clearly identified in the BoD and construction documents.

Factory testing requirements should be defined in the equipment specifications. This should include who and how many people will attend, requirements for review and approval of proposed factory testing procedures, how factory testing costs are managed, and who is responsible for factory testing acceptance and reporting.

Major equipment suppliers may manage travel and accommodation associated with factory testing and include the associated costs in their equipment pricing, as a separate line item or the inclusion of a cash allowance. If not explicitly included in the equipment purchase contract, the Owner will be responsible for these costs separately.

Manufacturers should submit their proposed factory testing processes and procedures for Project Team review. The Engineer of Record (EoR) and the CxP should review and comment as needed on the proposed processes and procedures. The agreed upon processes and procedures should then be discussed with the Project Team prior to responding to the submittal.

Attendance and participation at factory testing should include (at a minimum) the EoR, CxP, and installing contractor. Attendance by the monitoring and controls contractor, facilities management representative, general contractor, and Owner should also be considered.

13.2 Purpose. Factory testing provides reassurance that the purchased equipment has been tested and verified for build quality and performance under agreed standard or customized testing regimes. The primary intent is to identify any manufacturing errors or deficiencies prior to shipment so that they can be resolved at the factory, including factory testing procedures. This may include operation in unexpected conditions, such as overloads and failure modes, that cannot easily be recreated onsite or tested on critical equipment once in service.

Factory testing typically expands on manufacturers' standard testing, including project specific requirements. The factory testing can be customized to include a mixture of manufacturer prescribed tests, combined with specific client or designer requirements, selected to demonstrate and verify the functionality and capacity of the equipment is as per approved shop drawings. Finding discrepancies early in the procurement process provides the best chance to avoid impacting the schedule, cost, or causing other unforeseen aspects of the project. Factory testing assists the Owner in receiving equipment that complies with project specifications and site requirements. Factory testing also allows multiple parties of the Project Team to get an early look at equipment; for custom equipment, this can have a positive impact on making timely decisions in the project approach. Other benefits include:

- a. Having the receiving contractor understand the rigging requirements for large and/or heavy equipment, and optimum sequence for transporting and reassembly of equipment transported in sections.
- b. Allowing for the controls contractor to verify communication interfaces between the equipment integral controls and the facility monitoring and controls systems.
- c. Allowing the Project Team, and especially the Owner's and Owner's facilities management staff, to understand at an early stage any equipment specific maintenance requirements.
- d. Allowing the Project Team to have access to factory experts.

13.3 Roles and Responsibilities

13.3.1 Owner or Owner's Representative. With consultation from the EoR, the Owner should determine what level of factory testing is appropriate for the project, as well as which equipment, if any, is to undergo factory testing. This should be captured within the OPR and/or BoD, as well as the construction documents.

13.3.2 Equipment Manufacturer

- a. The manufacturer and/or local sales representative should provide standard factory testing procedures in advance of the test(s) for review and approval by the EoR, and for use by the CxP in developing any project specific factory testing scripts.
- b. Once at the factory, the manufacturer should provide a designated work area for the team to review the day's agenda, as well as a place to regroup throughout the day, away from the factory floor.

- c. Manufacturers should provide full access to the equipment, calibrated instrumentation, and necessary personnel as required to accommodate factor testing, as prescribed by the test scripts.

13.3.3 Integrator. The integrator has the same responsibilities as the equipment manufacturer with respect to the integrated equipment package.

13.3.4 CxP

- a. The CxP, in collaboration with the EoR, should be responsible for reviewing and commenting on the manufacturer's proposed factory testing procedures and advising on any areas of improvement of project specific testing procedures. Any modifications should be reviewed and accepted by the manufacturer in advance of scheduling the tests. In accordance with the manufacturer's safety regulations and based on the Owner's requirements, the EoR or CxP may facilitate the testing effort at the factory.
- b. The CxP should advise the Owner if the testing has been successfully completed, or if corrective action is required before being released for shipment. The CxP should base the acceptance or rejection of the factory testing result based on the acceptance criteria established by the EoR.
- c. If corrective action is required, the Owner's factory test facilitator (EoR, CxP, or other) should consult with the Project Team's representatives to determine which course of action is appropriate with final approval by the Owner. Options may include:
 - 1. All corrective work takes place at the factory, and a new factory test is performed prior to release for delivery.
 - 2. All corrective work takes place at the factory, but equipment can be released upon completion; no additional testing is required, although a further visual inspection may be undertaken prior to delivery to the project site.
 - 3. Some or all corrective work takes place in the field. Additional field inspections and testing may be required to verify all field corrections. This could include additional performance testing under load conditions, additional metering to efficiencies, etc.
 - 4. Corrective work is minor and can be performed on site by the local authorized factory technician. The equipment can be released for shipment.

13.3.5 Attendance. The CxP and EoR should attend the factory testing, along with the general contractor or trade contractor responsible for installing the equipment. The Owner's representative, monitoring and controls contractor, general contractor (if not the installing contractor), and local sales representative should be encouraged to attend/participate, but should not be required to do so.

13.4 Project Schedule Impact. Factory testing can impact the project schedule if customized for the project or required to be observed by the Project Team. Proper project planning can make a positive impact. Factory testing typically adds time to a project schedule upfront as the manufacturer is required to pull equipment out of the production flow and store in the test bay(s), ready for the factory testing effort. Time should also be allowed to make corrective actions as needed. Additional time for factory testing should be allotted in initial project scheduling and specifically discussed with the manufacturer during the equipment selection process.

If issues are identified, the Project Team can decide whether it is better to remedy the issues before the equipment leaves the factory, or if applying a solution in the field will best meet project requirements, including schedule. Without factory testing, issues may not be found until the equipment is installed or even operational, resulting in downtime and rework that could have been avoided.

13.5 Factory Testing Recommendations/Quantities

13.5.1 First of Kind (FOK). Factory testing for first of kind should be carried out on any major piece of equipment for a project to serve as a proof of concept. Discrepancies between submittals and the manufactured product are most common in this scenario; this can be due to the equipment being a new product for the manufacturer or the customer not being familiar with the product.

13.5.2 One per Type (Sampling). On projects that require many units of the same configuration, it may not be practical to perform factory testing on each unit. Instead, a sample size relative to the total number required should be determined to go through a factory test. The results of testing on these units will determine the likelihood that the remaining units are acceptable or identify issues of concern that need to be checked on all units.

13.5.3 All Critical Equipment. Data centers have many types of equipment that, despite redundancy, are deemed too critical to fail, especially due to avoidable issues. This type of equipment often has failure modes that leave it operational, sometimes at a reduced capacity. Due to the criticality of such equipment, testing each individual piece of equipment verifies that the operation of each one can be relied upon when in service, and they are not a single point of failure.

13.5.4 Factory Site Visit Only. Project budget may not allow, or equipment criticality may not warrant, the time and costs associated with factory testing. However, if the equipment or manufacturer is new to the industry or the Project Team, at a minimum, a visit to the factory to view conditions and sample product quality is recommended. This is often the first procurement step for critical equipment during the RFP process, but can also be a cost-effective alternative to full factory testing where appropriate.

13.6 Equipment Integrators. For large data center projects, the use of prefabricated equipment skids or subsystem assemblies is often utilized to accelerate the project schedule and improve quality control. Individual components still go through the normal submittal review process and can also be required to go through factory testing at the manufacturer's facility. Rather than shipping this equipment to the project site, it may be shipped to an equipment integrator facility where equipment is assembled for testing.

The equipment integrator facility is responsible for installing the various equipment, components, piping, and even controls. This assembly is configured with shipping splits in mind, such that it requires only minimal disassembly at the factory and reassembly once on site. Factory testing requirements for integrated equipment can represent any of the methods identified above, but typically requires a factory site visit (at a minimum) to observe the "installation" prior to shipment. In addition, construction progress inspections, as well as equipment energization and startup/checkout processes, can be employed and performed at the integrator's facility prior to shipping to the construction site.

13.7 Examples of Equipment to be Considered for Factory Testing

13.7.1 Mechanical Equipment

- a. Chillers
- b. Pumps
- c. Computer Room Air Handling (CRAHs)/Computer Room Air Conditioning (CRAC) units
- d. Custom/package air handling units (AHUs) and Dedicated Outdoor Air System (DOAS) units
- e. Fuel oil control system

13.7.2 Electrical Equipment

- a. Generator sets
- b. Uninterruptible Power Supply (UPS) systems
- c. Battery strings
- d. Energy storage systems
- e. Motor control center (MCC)
- f. Switchgear with Programmable Logic Control (PLC)
- g. Automatic transfer (ATS), static transfer (STS) equipment
- h. Power distribution units (PDUs)
- i. Rectifiers (48 V VC plants)

13.7.3 Integrated Equipment

- a. Chiller Skids: Often includes pumps, isolation and control valves, piping, and accessories, such as expansion tanks, air separators, water-side economizer heat exchangers, and plant cooling, if mounted within a container). At a minimum, conduit and wire between equipment and control devices is included. For larger assemblies, however, a motor control center (MCC) can be provided, complete with feeder distribution to the various equipment and components.
- b. UPS and Battery Containers: Many large data centers utilize critical power distribution containers, installed onsite adjacent to the building's perimeter. Not only does this reduce the overall building envelope, but it can also improve project schedule and quality control. In addition to the UPS modules and battery cabinets, the containers typically include distribution panels, conduit and wire, hydrogen

detection and exhaust, and environmental control (heating and cooling).

- c. Paralleling Gear and Generator Sets: Large or complex systems that have diverse manufacturers and/or will be installed in diverse locations at the project site can benefit from being shipped to a common equipment integrator facility for testing before being shipped to the site for installation.

13.8 Control Logic Bench Testing

- a. The initial checking of the control application and user interface software, such as the building automation or building management system (BAS/BMS), is commonly referred to as bench testing. The primary objective of bench testing is to confirm that the control code operates as intended according to the SOO. Such testing is much easier in an off-site office or factory environment. The hectic environment of a construction site is not conducive to the testing and verification of what can be very complex control strategies.
- b. Manual testing of the control logic can be complemented by the use of emulators, logic checking software and test rigs to confirm the correct logic of control strategies in a suitable off-site environment. The off-site testing and verification of application and user interface software may also aid in the reduction of on-site testing work. The application software should be checked, and quality control certified by the control system contractor at the end of the off-site test.
- c. The Design Team may wish to witness some or all of these checks at this time depending on the contractual/specification requirements. Specific routines that may be tested off-site could include set points, time schedules, interlocks, control loops, sequencing, start-up and shutdown procedures, equipment change-over, alarm functionality, and the user interface graphics.
- d. Where possible, hardware components (e.g. external field devices, sensor integration, switches, etc.) should form part of the bench test to improve the simulation method and validation process. This step verify that these interfaces function correctly and that the programming can accurately interact with the physical hardware.

13.9 Software Acceptance Testing

- a. Requirements for software acceptance testing should utilize a similar approach to FAT. The testing method should be defined, including the level of simulation required to observe the control/management/monitoring systems' response to events.
- b. The CxP Team and Owner's representative should participate in the testing.
- c. Considerations for software acceptance testing should include a description of the test that includes the level of system architecture necessary to demonstrate control performance. Controls contractors may be required to set up representative hardware with programming uploaded at field and area level controllers to demonstrate field controller performance, as well as area controller performance networked to downstream controllers. Requirements should include direction on expected simulation of equipment to evaluate control loop performance and graphical interface functionality.
- d. Requirements should be stated in the Division 26 commissioning section.

14. CONSTRUCTION OBSERVATION AND TESTING

14.1 General. Construction observation and testing is a process that verifies the proper installation, coordination, testing, and interaction among commissioned systems and assemblies. The systems and assemblies to be commissioned are identified in the OPR, Cx specifications, and Cx Plan and are confirmed to comply with the OPR and with the contract documents.

Checklists and test procedures with necessary report forms are developed after submittal approval and used as guidance during equipment installation and testing.

14.2 Requirements

- 14.2.1** Installation checklists can be used to verify that appropriate materials, equipment, and components are on site, ready for installation, correctly installed, and in compliance with manufacturers' requirements, design, and contract documents as part of Level 2 QA/QC. These should be developed for each piece of equipment and each connected system. The contents of installation checklists should consider the manufacturers' requirements, design requirements, maintenance access, and best practices. Installation checklists should be

reviewed and approved by the CxP prior to field execution.

- 14.2.2** Testing procedures are written protocols that define the methods, test equipment, personnel, and expectations with pass/fail criteria for tests conducted on equipment, components, assemblies, systems, and interfaces among systems to verify compliance with contract requirements and local regulations. Testing procedures should contain the following content:

- a. A unique project specific identification
- b. Details of the equipment or system to be tested
- c. Schematic drawings
- d. Prerequisites
- e. Test equipment and/or instruments required with serial number and date of calibration
- f. Reason and method of testing
- g. Design parameters
- h. Pass/fail criteria
- i. Test records sheet (where applicable, these should be prepopulated with design data)
- j. Sign-off sheet
- k. Estimated duration of test
- l. Qualifications and experience of testing personnel

Testing procedures should be reviewed and approved by the CxP prior to field execution.

- 14.2.3** Site visits are a required method used during the Construction Phase to verify that the installed systems and assemblies comply with the contract documents. A clear, concise, and consistent procedure is developed as part of the Cx Plan and followed for each site visit to properly identify Construction Phase process problems and issues.

- 14.2.4 Executing Checklists and Test Procedures.** Once construction checklists and test procedures are established and approved, the responsible entities execute relevant inspections and tests and repeat testing as necessary until equipment, systems, or assemblies being tested pass all tests.

- a. The CxP witness a sampling of inspections and tests conducted during Level 2 and Level 3 commissioning as defined by the Cx Plan and Cx specifications.
- b. Completed test reports are submitted to the Project Team for review and to the CxP for evaluation and approval.
- c. Any commissioned system or assembly that fails to meet requirements and that cannot be resolved in a timely manner is listed in an issues and resolution log for follow-up.

- 14.2.4.1 Verification.** This is a process to document Cx testing of commissioned equipment, systems, and assemblies. Evaluation of the systems and assemblies by the Project Team should include the following:

- a. Vital information on the equipment or materials being supplied. Information describing what equipment/material was specified and submitted vs. what was actually delivered on site.
- b. The condition of the equipment at the time it is delivered to the site and prior to its installation.
- c. Proper installation of the systems and assemblies.
- d. Successful testing results of systems and assemblies.

- 14.2.4.2** The following should be included in the Final Cx Report:

- a. Project specific construction checklists and testing procedures
- b. Test procedures listing the entities responsible for executing each test
- c. Required test data for a specific system or assembly, included as an item in the associated construction checklist for the test data to be submitted to the CxP.
- d. Sampling procedures used and defined in the Cx specifications (if required)

- 14.3 Acceptance.** Construction checklists and testing procedures should be approved by the CxP. The Cx Plan should be approved by the Owner and include a process for approval of subsequent revisions. A summary of testing

should be submitted to the Owner in a written report following the completion of testing. Review of summary reports should have a response of concurrence or acceptance by the Owner.

15. ISSUES AND RESOLUTION DOCUMENTATION

15.1 General. Issues identified during the Cx should be documented and any open or continuing items listed in an issues and resolution log.

15.2 Requirements

15.2.1 The CxP should facilitate regular issues and resolution log review meetings with the CxP Team to support appropriate assignment of responsibilities and support resolutions of open issues.

15.2.2 The CxP should maintain a digital platform for storing, tracking, and updating critical path commissioning issues as contained in the issues and resolution log. CxP Team members should have access to review and comment on issues. The CxP with documented CxP Team buy-in closes open issues on the issues and resolution log.

15.2.3 Parties responsible for issues and resolution logs for data center Cx should include OFE vendors, OFCI subcontractors, Owner personnel, third-party integrators, container and skid assembly manufacturers, and independent testing agencies in addition to onsite Project Team members.

15.3 Acceptance. The Owner should review and accept the final issues and resolution log; upon acceptance, the issues and resolution log should be included in the Final Cx Report.

16. SYSTEMS MANUAL

16.1 The documentation requirements for data center and other high-reliability critical facility construction projects are similar to the general requirements for commercial office and other non-critical facilities, but involve a far greater amount of information and documentation due to the inherent complexities and large quantity of infrastructure typical of data centers.

The purview of the CxP is to fully document the construction project by ensuring the requisite documentation is defined, assigned, developed/collected, organized, compiled, and delivered as a comprehensive Systems Manual, also referred to as a Systems Operations and Maintenance Manual (SOMM).

16.2 Similar to how this guideline is considered a supplemental document to ASHRAE Guideline 0 and it is intended for the two documents to be used in conjunction with each other, ASHRAE Guideline 1.4 should be considered a supplemental document and used in conjunction with this guideline.

16.3 An example of data center related construction documentation that is not typical of commercial office buildings and other non-critical facilities are load test reports that establish baseline performance data at various load profiles including block-loading of UPS and generators.

16.4 Construction project documentation requirements are typically established in the CSI specifications listed below. The best practice is for each of these specifications to refer to the 017823 *Operations & Maintenance Data* where the SOMM structure, organization, and content requirements for collection, compilation, and delivery of the required documentation is clearly described in accordance with the client's standards and/or ASHRAE Guideline 1.4:

- 01 33 00 – Submittal Procedures
- 01 77 00 – Closeout Procedures
- 01 78 23 – Operations & Maintenance Data
- 01 78 30 – Warranties
- 01 78 39 – Project Record Documents
- 01 79 00 – Demonstration & Training
- 01 91 13 – General Commissioning Requirements

16.5 Data centers are typically built for pre-planned, expansion, upgrades, and refreshes over the life of the facility. As such, the record and site-specific documentation is expected to change over time as the facility evolves. In order to maintain the SOMM is up to date, there should be a formal document management and control program

that defines a process to document and capture new documents as they are generated, placed under document control, and obsolete or superseded documents are deleted and/or archived.

17. TRAINING

- 17.1** The contractor should plan, coordinate, and track all activities related to training, including training plan submittal approval process and execution of training events.
- 17.2** The contractor, vendor, and/or manufacturer should conduct comprehensive training of the commissioned systems and equipment.
- 17.3** The contractor should develop and submit a training schedule at least 90 days prior to commencing the first training module. The training schedule should include all training modules being conducted, including the associated dates, times, durations, instructor's name, and tracking of the approval of the associated training plan. The training schedule should be approved by the CxP and/or Owner.
- 17.4** The contractor, vendor, and/or manufacturer should develop and submit a training plan per each training module being conducted for approval by the CxP and/or Owner. The training plan should be submitted at least 60 days prior to commencing the related training session. Training modules should not be conducted unless the associated training plan has been approved.
- 17.5** Each training plan should include:
- a. Title page
 - b. Table of contents
 - c. Facilitator/instructor name(s) and qualifications
 - d. Summary of topics covered and location (i.e., classroom or in the field)
 - e. Learning objectives
 - f. Training agenda with expected durations
 - g. Training material (e.g., presentation slides, drawings, manufacturers' operator instructions)
 - h. Evaluation process that learning objectives are achieved
 - i. Signoff sheet for each trainee, as well as the trainer
- 17.6** Within the training plan, the contractor, vendor, and/or manufacturer should provide guides and presentation notes describing key elements of the installation, normal and emergency modes, and critical maintenance. Principles of plant operation and adjacent dependencies should also be presented. All as-installed drawings and operating manuals should be available prior to the associated training module.
- 17.7** The training content and subject matters should include, at a minimum:
- a. Documentation: an overview of operating and maintenance manual documentation should be carried out in detail
 1. Emergency manuals
 2. Operations manuals
 3. Maintenance manuals
 4. Project record documents
 5. Identification systems
 6. Warranties and bonds
 7. Maintenance service agreements and similar continuing commitments
 - b. Operation: instructions should be provided for the safe and efficient operation of each system and/or equipment, under normal and emergency conditions
 1. System and equipment descriptions
 - Equipment function
 - General operating mode
 - Operating characteristics
 - Limiting conditions

- Performance curves
 - Performance and design criteria
 - 2. The recommended strategy for operation and control
 - 3. Regulatory requirements
 - 4. Standard operating and emergency operating procedures, and sequences for startup, operation, and shutdown, under normal and emergency conditions
 - 5. Interlocks between plant items
 - 6. Operating procedures for standby plant
 - c. Emergencies: instructions should be provided for emergency situations, as applicable
 - 1. Instructions on meaning of warnings, trouble indications, and error messages
 - 2. Instructions on stopping
 - 3. Shutdown instructions for each type of emergency
 - 4. Operating instructions for conditions outside of normal operating limits
 - 5. Sequences for electric or electronic systems
 - 6. Special operating instructions and procedures
 - d. Safety: Instruction concerning hazards and safety precautions of which operations and maintainers need to be aware, including:
 - 1. Any known hazards against which protection can be provided
 - 2. Any mandatory requirements relating to safety
 - 3. Any other safety precautions which must be observed
 - 4. Use of any safety equipment installed
 - 5. Safe access to equipment that is not provided with a fixed access platform
 - 6. Any other relevant warning
 - e. Maintenance: Outline all of the maintenance requirements, including:
 - 1. Overview of the maintenance program including manufacturers' recommendations, statutory and mandatory requirements for both preventative and routine maintenance
 - 2. Isolation and return to service of plant and equipment
 - 3. Dismantling and reassembly
 - 4. Cleaning
 - Types of cleaning agents to be used and methods of cleaning
 - List of cleaning agents and methods of cleaning detrimental to product
 - Procedures for routine cleaning
 - Details of any specialist service expertise or qualifications required
 - Special tools, test equipment, and ancillary services required
 - 5. Fault find procedures for the logical diagnosis and correction of faults
 - 6. Spare parts held onsite
- 17.8** Training modules should include “hands on” instruction to provide familiarity with the equipment and components, as well as “classroom” type instruction to cover system overviews, drawings, SOOs, and relevant operations and maintenance procedures. Both site and classroom training sessions should be arranged around operations shift patterns. There should be a minimum of two training sessions per module.
- 17.9** Training should be facilitated by specialists in their respective fields knowledgeable about the installations. All nominated instructor’s qualifications are to be issued to CxP and/or Owner for review and approval prior to commencement of training. The contractor may appoint a qualified videographer to video and audio record demonstrations and trainings. Each training module should be recorded separately and include classroom instructions and field demonstrations, board diagrams, and other visual aids, but not student practice. Sign off registers for each training module and training quality reviews should be required from all training attendees.
- 17.10** On projects with repeatable phases and/or campus buildouts, where the systems, equipment, and components

are the same, the training requirements can be reduced for the follow-on phases with agreement and coordination with the Owner. The strategy for this should be raised and agreed upon during the tender process.

18. POSTOCCUPANCY OPERATION

In addition to the information provided herein, refer to ANSI/ASHRAE/IES Standard 202, ANSI/ASHRAE Standard 230, ASHRAE Guideline 0, and ASHRAE Guideline 0.2 (as applicable), for details of the postoccupancy operation Cx for new buildings and systems and/or existing buildings and systems. This guideline is intended to supplement these documents and other related commissioning guidance by addressing considerations specific to data center applications; accordingly, it does not include general Cx information that is applicable to commissioning projects in all building types.

19. CX REPORTS

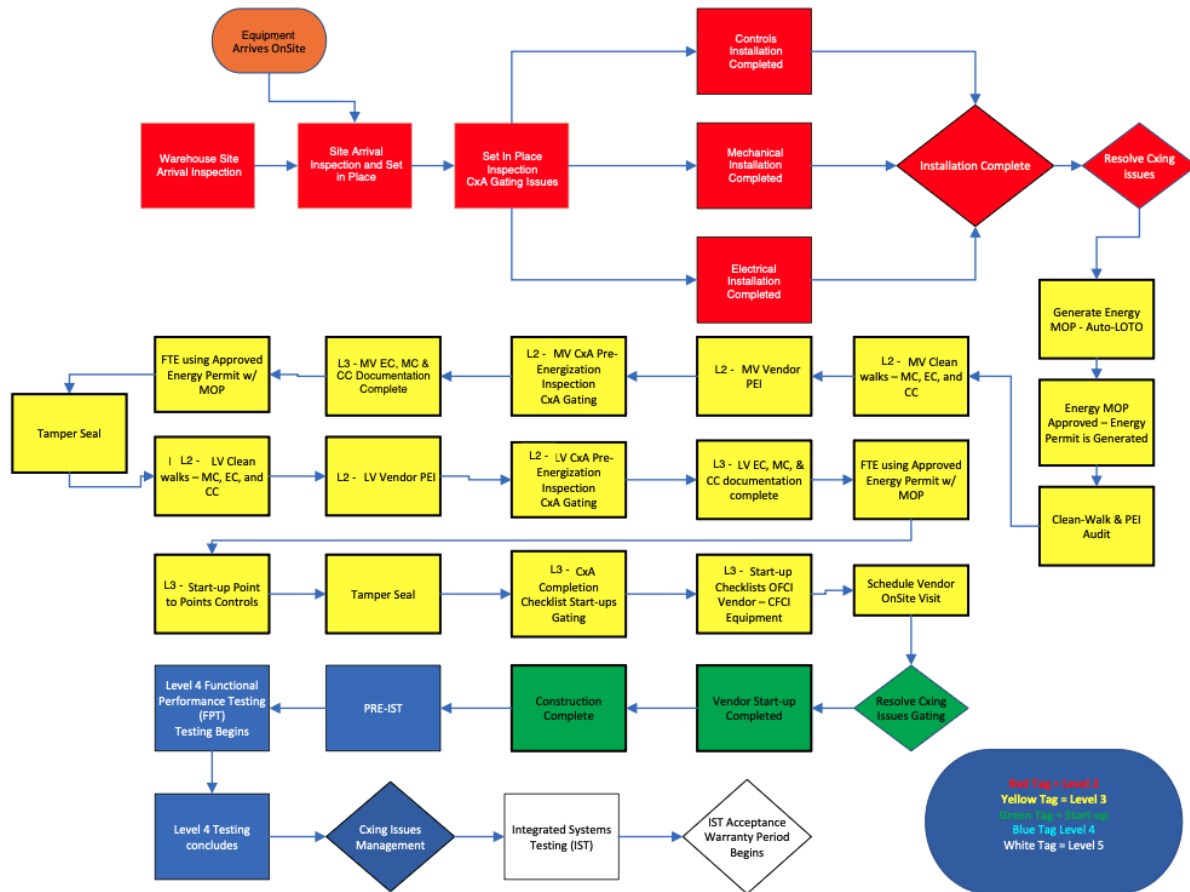
- 19.1** In addition to the information provided herein, refer to ANSI/ASHRAE/IES Standard 202, ANSI/ASHRAE Standard 230, ASHRAE Guideline 0, and ASHRAE Guideline 0.2 (as applicable), for details of the Cx report process for new buildings and systems and/or existing buildings and systems. This guideline is intended to supplement these documents and other related commissioning guidance by addressing considerations specific to data center applications; accordingly, it does not include general Cx information that is applicable to commissioning projects in all building types.
- 19.2** Satisfactory completion and documentation of the Cx Activities requires a Cx report approved by the Owner for system acceptance.
- 19.3** At no time should acceptance be made for individual pieces of equipment. The Final Cx Report should only be issued for complete systems that operate as intended per the BoD and OPR.

20. REFERENCES

- 1. ASHRAE. 2019. ASHRAE Guideline 0, *The Commissioning Process for New Buildings and New Systems*. Peachtree Corners, GA: ASHRAE.
- 2. ASHRAE. 2015. ASHRAE Guideline 0.2, *The Commissioning Process for Existing Systems and Assemblies*. Peachtree Corners, GA: ASHRAE.
- 3. ASHRAE. 2019. ASHRAE Guideline 1.4, *Preparing Systems Manuals for Facilities*. Peachtree Corners, GA: ASHRAE.
- 4. ASHRAE. 2025. ANSI/ASHRAE Standard 90.4, *Energy Standard for Data Centers*. Peachtree Corners, GA: ASHRAE.
- 5. ASHRAE. 2024. ANSI/ASHRAE/IES Standard 202, *The Commissioning Process for New Buildings and New Systems*. Peachtree Corners, GA: ASHRAE.
- 6. ASHRAE. 2022. ANSI/ASHRAE Standard 230, *The Commissioning Process for Existing Buildings and Systems*. Peachtree Corners, GA: ASHRAE.

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX A—DATA CENTER CX FLOWCHART



(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX B—DATA CENTER CX ARTIFACTS (Reserved for Future Use)

(This appendix is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.)

INFORMATIVE APPENDIX C—LOAD BANK PLAN

C1 General

Load banks are most commonly temporary devices (but may also be permanent) that can be used to provide very stable, precise, and controllable loads for testing and validating the capabilities of both the power (electrical) and cooling (mechanical equipment) and systems in a data center. The purpose of a Load Bank Test Plan is to document the anticipated load bank quantity, sizes, locations, installations, and safety requirements necessary to validate the OPR for capacity, redundancy, and resiliency of the power and cooling systems. The Load Bank Plan is a comprehensive document that is developed by the CxP with input from various members and stakeholders of the Design and Construction Teams.

The Load Bank Test Plan is developed in conjunction with the associated project-specific Functional Performance Tests (FPTs) and Integrated Systems Tests (ISTs) with a focus on verifying and demonstrating the following:

- a. Individual equipment and system capacities
- b. Equipment and system redundancies
- c. Control system stability
- d. Power quality
- e. Voltage drop under part and full load conditions
- f. Baseline equipment and system performance (temperatures, flows, etc.) and energy consumption
- g. Measurement and verification calculations and targeted energy efficiency goals such as PUE, EUI, and WUE

A Load Bank Plan typically has two parts; one developed for Level 4 FPTs and the second for Level 5 ISTs. Each part consists of a narrative component and accompanying floor plans/schematics and single line drawings, indicating:

- a. Points of connection for load banks
- b. Connection requirement types
- c. Load bank quantity, size, and settings
- d. Power quality meter locations and quantities

C2 Requirements

C2.1 Level 4 FPT. A Load Bank Test Plan section for Level 4 FPT focuses on the specific load requirements necessary for each type and piece of equipment to be load tested. Level 4 FPT is the stage of commissioning where comprehensive FPT of individual components and systems takes place. This level focuses on evaluating the performance and capabilities of each component and system according to predefined criteria and specifications. The Load Bank Test Plan supports the equipment specific FPTs with detailed load bank testing information. The following types of equipment generally require load testing.

- a. Electrical
 1. Utility high voltage substations
 2. Utility interconnection
 3. Utility protection systems
 4. High voltage switchgear
 5. Generator paralleling gear
 6. Standby/emergency generators
 7. Low voltage switchgear and switchboards
 8. Distribution panels
 9. Automatic and manual transfer switches
 10. Power Distribution Units (PDUs)

11. Transformers
- b. Mechanical
 1. Chillers, cooling towers, and pumps
 2. Heat exchangers
 3. Chilled water and blended chilled water systems
 4. Air handling units
 5. Computer Room Air Handling (CRAH) units
 6. Computer Room Air Conditioner (CRAC) units
 7. Blower coil and fan coil units
 8. Water cooled IT racks

For each type of equipment to be load tested, a load and capacity analysis for each should be provided, addressing the following:

- Capacity analysis based on equipment nameplate capacity
- Analysis of required testing level (nominal capacity, design capacity, day one capacity)
- Part and full load testing requirements and durations
 - Block loading/transient load testing
 - Continuous load testing
- Power factor requirement
- Overload testing (if applicable, UPS, Gens, ATS)
- Infrared testing requirements
- Load bank type/size

The load and capacity analysis is supported with schematic drawings indicating the load bank type, quantity, size, settings, and points of connection in the system, and any specific connection requirements for cables and/or water piping and manifold connections. Any Power Quality Meters (PQMs) required for validating performance of the electrical system and responses should be quantified for each system and indicated schematically. Additionally, PQMs are utilized to verify the performance and integration of electrical meters used for control and monitoring by comparing them against the independent PQM.

C2.2 Level 5 IPT. A Load Bank Test Plan section for Level 5 IPT focuses on the specific load configurations required to verify the performance and operation of an integrated system (electrical and mechanical) operating under either N capacity and/or design load (or Day 1 conditions). The systems are in fully automatic operation with no alarms or system overrides in place. The goal of this testing is to verify the operation, proper interdependencies, redundancies, and fail-safe operation of all critical systems under load. There may be multiple ISTs for a facility, each with a specific load profile which should be addressed in the Level 5 Load Bank Test Plan section.

Each progressive level of IST typically includes prior systems (chiller plant, data halls, generator plant), culminating in a complete facility integrated systems test (Black Start). During this testing, various operational and failure modes testing is completed. Normal Level 5 IST testing would be to simulate a power failure (blackout test) and see how the backup systems react; for example, if the UPS systems can handle the load and if the generators start up as intended. The Load Bank Testing Plan supports each specific IST with detailed load bank testing information.

C3 Application

Load banks are modular load devices that allow the CxP Team to fully test the capabilities of the electrical and mechanical infrastructure systems from part load to full load across all operational (normal and failure) modes. Utilizing load banks allows for the precise control of the applied load and power factor for the duration of testing. Load bank testing is commonly undertaken at different levels of the Cx for a data center. Emergency/standby generators, UPS, and PDUs typically undergo load bank testing during vendor startup (Level 3 Cx) and again during Level 4 FPTs and Level 5 ISTs. In testing of the emergency generators, the load

banks are used to create a current with the temporary diesel generators that simulate the electrical grid. These external generators can be disconnected through various methods to simulate a blackout or other out-of-tolerance grid conditions. In some cases, reactive load banks are used to simulate power factor conditions anticipated on the grid.

C4 Types of Load Banks. The most common load banks are resistive air-cooled load banks and convert electrical energy to heat; this heat can be used to verify the performance of the airside data center HVAC systems, as well as providing an electrical load to test the electrical distribution and control systems. Load banks can be categorized based on their function into three main groups:

- Resistive load banks are used to simulate the operational load at unity power factor that a power source will see in actual use; these can be air- or water-cooled type load banks.
- Reactive load banks are used to accurately simulate systems that are affected by electric motors or other electromagnetic devices on an electric distribution system. Devices that require reactive power compensation are typically motor driven devices, transformers, and capacitors. They can simulate either an inductive or capacitive load, depending on the type of load expected on the power system.
- DC load banks are used to test DC generating systems, such as power converters, transformers, battery systems, and controls.

C5 Load Bank Testing in Data Centers

C5.1 Bulk Room Testing. Many data centers are tested and commissioned using bulk room power and thermal load simulation. Typically, 75 to 100 kW load banks (sometimes referred to as “suitcase load banks”) are dispersed throughout the room to simulate the power and heat generated by computer equipment. This method generally provides straightforward setup and execution.

C5.2 Discrete Zone Testing. This method uses small rack-mounted load banks installed in the racks of the computer room. The setup of rack-mounted load banks is more time-consuming, but provides more precise simulation of rack-level architecture. Actual rack-level equipment can be reconfigured if rack-mounted load bank testing reveals extreme temperature gradients on the intake and/or exhaust sides of the rack.

C6 Other Equipment

C6.1 Remote Controls. Remote controls of load banks allow the simultaneous control of multiple load banks.

C6.2 Data Capture. Monitoring equipment that can be used to capture data during a test that can be analyzed for interconnection compliance or power quality performance.

INFORMATIVE APPENDIX D—RENEWABLE INTEGRATION: MICROGRIDS

Renewable integration into commercial and industrial facilities is at forefront of decarbonization and fighting climate change. Data Centers, with high electricity demand and redundant backup power systems, have the opportunity to be at the forefront of innovations in this area. The electric power industry is working hard to allow facilities to quickly integrate renewable resources while maintaining reliability and resilience.

The most probable way that this renewable integration would occur in data centers would be integration of renewable energy sources (RES), such as solar PV or wind with energy storage, within the facility. This means that the equipment would be placed behind the main circuit breaker with interconnection controls. The above-mentioned RES produce DC electricity and are commonly integrated with facilities through an inverter that converts the AC to DC. There are inverters within many UPS systems, but integrating renewable sources into these systems may compromise facility availability. The inverters dedicated to renewable integration would most likely provide active power feeding the UPS system input.

Solar and wind RES are highly dependent on weather conditions and provide variable and intermittent electrical energy output. To integrate more RES, there is a higher need for flexibility grid services; energy storage technologies play an important role in mitigating these issues. Technological advances are also being made in low/no carbon fuel resources, such carbon-free fuels, which can provide a base for future mainstream technology.

Inverters are solid-state electronic power conversion systems, consisting of a matrix of power electronic switches. They have no inherent storage elements (rotating inertia), no significant stored energy (capacitors and inductors are not used as storage devices), nor do they possess typical dynamic characteristics associated with rotating masses and machine windings, including damping types, of synchronous machines.

The initial growth in renewable energy sources (RES), in the area of solar photovoltaic (PV) systems, was concurrent with the increasing deployment of distributed energy resources (DER). The early deployments of DER were in the form of synchronous generators (SGs), typically driven by diesel or natural gas engines. This was concurrent with the deployment of DER associated with RES, including wind and solar generators and, more recently, with battery energy storage systems. Most applications of inverters during this transition were grid-following (GFL) inverters. The use of GFL inverters was possible due to their lower initial penetration (as a percentage of total resources) and allowed the use of conventional utility protection systems, since the grid reference was setting the performance requirements of the inverters. As RES gradually displaced the rotating generators in DER applications, issues such as the behavior of low-inertia grids, local needs for voltage support, and ride-through requirements to handle the impact on the grid led to some of the first interconnection requirements.

The initial DER standards, IEEE Std 929-2000, for solar systems, and IEEE Std 1547-2003, for DER, served the industry well for many years. The DER standard was revised to take into account new developments, and the latest version is IEEE Std 1547-2018. The requirements of these standards state clearly the technical requirements for interconnection to the utility electric distribution system. During commissioning, care should be taken to determine that the out-of-tolerance voltage or frequency conditions are not produced by any internal RES functioning, such as transient disconnect/reconnect or rate of change in voltage and frequency. The requirements apply to the entire DER system within the data center facility.