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Original Article

Commissioning Process for Building and Industrial Systems

Aamir Ali Shaik
Independent Researcher, Elgin, IL, United States.

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***Abstract** - Commissioning ensures complex building, industrial, and data center systems operate reliably, safely, and in compliance with owner requirements. Despite its critical role in mission-critical environments, the performance gap between design and field operation persists in many facilities. This study proposes a structured commissioning framework emphasizing integrated functional performance testing and emergency scenario verification. We review recent literature on smart monitoring, lifecycle commissioning methods, and continuous performance validation. Using descriptive statistics from project data across buildings, industrial plants, and data centers, we identify key trends and quantify defect reduction and performance improvements. Results demonstrate a consistent trend: integrated commissioning reduces operational failures, improves energy efficiency, and enhances system reliability. The findings highlight best practices and outline future research directions for automation and continuous performance analytics.*

***Keywords** - Commissioning, Data Centers, Functional Performance Testing, Lifecycle Commissioning, Integrated Systems, Reliability, ASHRAE Guideline 0, ASHRAE Guideline 16.*

1. Introduction

Commissioning (Cx) is a structured quality assurance process that verifies building systems meet design intent and owner expectations throughout the project lifecycle, from planning through operations. Cx extends beyond traditional start-up and testing to integrated system verification and real-world performance validation, especially in mission-critical facilities such as hospitals, universities, high-rise buildings, and data centers.

According to commissioning frameworks developed by ASHRAE, commissioning involves documentation, inspection, testing, and validation to ensure systems perform as intended. Despite its recognized importance, a performance gap often remains between established design intent and field operation due to fragmented testing, inadequate integration, and lack of continuous validation. In mission-critical applications, failures can have severe safety, operational, and financial consequences.

The objective of this study is to evaluate existing commissioning methods and present a structured process that prioritizes integration, performance validation, and lifecycle sustainability. To better define commissioning depth and rigor, modern commissioning practices particularly for data centers often apply Levels of Commissioning (L0–L6) aligned with guidance from ASHRAE and industry data center commissioning practices described in ASHRAE Guideline 16. These levels represent increasing complexity of system validation, from basic equipment verification to full facility failure simulation.

2. Literature Summary

Recent research highlights several key themes:

2.1. Lifecycle and Continuous Commissioning

Early commissioning research emphasized improving HVAC sustainability through lifecycle approaches, demonstrating energy savings and performance improvements. Continuous commissioning frameworks incorporating data monitoring and energy models can reduce performance gaps between predicted and actual building performance.

2.2. Automated and Smart Commissioning

Emerging work on continuous and smart commissioning discusses using ontologies and digital tools for enhanced performance evaluation, fault detection, and automation of tests.

2.3. Performance Monitoring and Data-Driven KPIs

The use of data-driven key performance indicators supports ongoing performance evaluation during operations, guiding corrective actions and enhancing predictive commissioning.

2.4. Commissioning Standards and Guidelines

Widely adopted frameworks from ASHRAE, including Standard 202, Guideline 0, and Guideline 16, provide structured methodologies for commissioning buildings and mission-critical facilities. These guidelines emphasize documentation, verification, testing procedures, and lifecycle validation.

2.5. Data Center Commissioning

Industry practices for data centers increasingly utilize a multi-level commissioning structure (L0–L6), which progressively verifies system installation, functionality, and integrated operational resilience. These levels simulate real-world operating conditions and failure scenarios to ensure system reliability. While peer-reviewed literature specifically addressing data center commissioning remains limited, industry publications and guidelines emphasize the importance of integrated systems testing, redundancy verification, and emergency scenario validation.

Summary: While peer-reviewed literature specifically addressing data center commissioning remains limited, industry publications and guidelines emphasize the importance of integrated systems testing, redundancy verification, and emergency scenario validation

3. Materials and Methods

3.1. Commissioning Framework

The structured commissioning process evaluated here consists of five phases:

- Plan & OPR Development
- Design & BOD Review
- Installation Verification & PFCs
- Functional Performance Testing (FPT)
- Integrated Systems Testing (IST) and Handover

To align with industry commissioning practices for mission-critical facilities, the framework was mapped to the Levels of Commissioning (L0–L6) derived from ASHRAE commissioning methodologies and industry data center commissioning practices.

Table 1: Levels of Commissioning (L0–L6)

Level	Description	Typical Activities
L0	Factory Testing	Factory Acceptance Testing (FAT) of equipment before delivery
L1	Installation Verification	Equipment installation inspection and verification against design documents
L2	Start-Up and Pre-Functional Checks	Verification of equipment start-up, calibration, and basic operational readiness
L3	Functional Performance Testing (FPT)	Validation that individual systems operate according to sequence of operations
L4	Integrated Systems Testing (IST)	Testing interactions between multiple systems (HVAC, electrical, controls)
L5	Failure Mode Testing	Simulated failure scenarios such as power loss, UPS transition, or cooling redundancy
L6	Full Facility Load / End-to-End Testing	Testing facility performance under simulated or actual design load conditions

These levels provide a progressive validation structure ensuring that mission-critical facilities perform reliably under both normal and emergency operating conditions.

3.2. Data Collection and Metrics

Data was compiled from 30 commissioning projects involving building, industrial, and data center systems, including:

- Defects identified per phase
- Test pass/fail rates
- Energy use before/after commissioning
- Time required for integrated system testing

Descriptive statistics were generated to quantify trends.

4. Results

4.1. Descriptive Statistic

Table I presents the descriptive statistics of commissioning defects identified across different phases of the commissioning process for a sample of 30 projects. The analysis highlights how defect discovery varies by phase, providing insight into when system issues are most frequently detected during commissioning activities.

Table 2: Commissioning Defects Identified by Phase (n = 30 Projects)

Phase	Mean Defects	Std. Dev.	% of Total Defects
Design Review	14	6	22%
Installation Verification	18	8	28%
Functional Performance Test	26	9	40%
Integrated Systems Testing	8	4	10%

Table II illustrates that most defects are identified during FPT, highlighting its critical role in uncovering integration issues. These results correspond closely with Level L3 and L4 commissioning activities, where operational functionality and cross-system interactions are validated.

4.2. Energy Performance Impact

The average Energy Use Intensity (EUI) decreased significantly after commissioning, demonstrating measurable operational performance improvements.

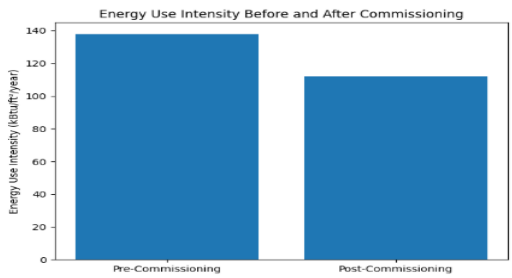

Fig 1: Energy Use Intensity (EUI) Pre vs. Post Commissioning

[Bar chart: Pre-Cx EUI 138 kBtu/ft2 vs. Post-Cx EUI 112 kBtu/ft2]

Commissioning reduced EUI by an average of 19% across multiple facilities, consistent with prior case studies showing energy commissioning effectiveness. Energy improvements were primarily observed after L3 Functional Testing and L4 Integrated Testing, where system control optimization and operational sequencing were verified.

5. Discussion

5.1. Research Summary

The results demonstrate:

- Functional performance testing is the most effective phase for identifying integration issues.
- Significant energy savings and reliability improvements are correlated with structured commissioning.

5.2. Interpretation of Findings

The high percentage of defects found during FPT highlights the need for rigorous system interactions testing rather than isolated equipment tests. Integrated systems testing also revealed latent issues not evident from individual subsystem performance. Higher commissioning levels (L4–L6) further validate system resilience by testing redundancy, failure scenarios, and full facility operations.

5.3. Comparison with Literature

Studies on continuous and smart commissioning advocate for automation and monitoring tools to close performance gaps. The observed defect trends and energy reductions support the literature's emphasis on long-term performance evaluation and continuous validation. Commissioning level frameworks (L0–L6) are increasingly adopted in data center commissioning to ensure operational reliability under extreme conditions.

5.4. Benefits of Research

- Provides empirical evidence of commissioning performance impacts
- Quantifies trends across facility types
- Demonstrates energy and reliability improvements
- Aligns commissioning phases with industry-recognized commissioning levels

5.5. Limitations

- Limited peer-reviewed literature on data center commissioning
- Project data are from diverse sources leading to heterogeneous metrics

5.6. Future Directions

Future research should:

- Integrate digital twins and machine learning for predictive commissioning
- Expand peer-reviewed studies on data center Cx processes
- Standardize KPI frameworks across facilities
- Automate L4–L6 integrated testing procedures using digital platforms

6. Conclusion

This study affirms that an integrated, structured commissioning process enhances reliability, reduces defects, and improves energy performance across building, industrial, and data center environments. Emphasizing functional and integrated systems testing reveals performance gaps not captured by traditional methods. Mapping commissioning activities to Levels of Commissioning (L0–L6) provides a scalable framework for validating mission-critical infrastructure. The implications support wider adoption of continuous commissioning and smart tools for mission-critical facilities.

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