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Architectural Commissioning: An Overview

The purposes of architectural commissioning are manifold, including reducing the likelihood, extent, and cost of failures by ensuring the Owner's intent has been met, regulatory requirements are satisfied, the architect and engineer's design and specifications have been faithfully executed, and the manufacturer's installation and warranty requirements and any other applicable criteria have been adhered to in the work as constructed. Successful commissioning results in lower costs and effort to operate and maintain a facility and assurance that the Owner receives a building that meets their expectations for aesthetics, durability, and occupant comfort. Architectural commissioning, like the more traditional engineering systems commissioning, can be applied to any architectural system, most frequently including the exterior envelope systems (e.g., roofing, curtain walls, exterior doors/windows, etc.) and critical interior systems (e.g., stairwells, interior doors/hardware, high performance coating systems, etc.). Architectural commissioning is most frequently utilized for new construction, but it may come in various overall forms to encompass large or complex renovations or refurbishment of in-service architectural systems.

Architectural Commissioning (Cx): Cx should be initiated during the project planning phase and extend through turnover and occupancy. The specific Cx workflow may vary, but generally consists of the following:

- **Planning Phase:** The project management team initiates the process for engaging third party architectural Cx Agent (CxA) services. The CxA supports the inclusion of design qualification (a specialized design phase review to ensure all the Owner's Project Requirements are consistent with applicable regulations and reasonably achieved by the proposed design).
- **Design Phase:** The CxA develops Cx specifications, functional performance tests, an architectural systems manual, and training requirements; executes the design qualification review in parallel with typical design review processes; tracks to resolution all design review comments; and reviews all design/Basis Of Design submissions and variance requests.
- **Construction Phase:** The CxA holds a Cx kickoff meeting with the project's Integrated Project Team, including subcontractors and key manufacturers; reviews all construction phase submittals, shop drawings, and coordination drawings; inspects all mockups; executes, oversees, and documents all work described in the Cx specification; executes all functional performance tests and other tests; assists in troubleshooting and accommodation of varying site conditions and latent defects discovered during the course of demolition and construction activities; assists in adjusting/optimizing active architectural systems; executes verification checks; oversees factory/manufacturer's acceptance tests and site acceptance tests; oversees the execution of all training; and tracks all open punch list items to closure.
- **Turnover Phase:** The CxA collates and organizes all Cx and training documentation into a Cx report and architectural systems manual; reviews the contractor's Operations and Maintenance (O&M) binders to assure all documents are complete, in order, and legible, with all signatures and dates affixed; confirms all warranty and guarantee information is complete and filed; and holds the Cx closeout meeting.
- **Operations & Maintenance Phase:** The CxA returns as required to perform/oversee the execution of seasonal and deferred testing; performs near warranty-end review of architectural materials and systems; reviews all maintenance orders, change directives, and similar documents generated since turnover; and provides recommended changes to the system manual, as appropriate.

Several specialized types of architectural Cx exist that are appropriate for certain applications, including:

Retro-Commissioning (RCx): The model of Cx generally used for existing buildings that have not been previously commissioned, or for which considerable time has passed or changes have occurred, making prior Cx documentation unreliable. RCx involves detailed investigation and documentation of existing conditions to improve the performance of the system(s) being commissioned through changes to O&M procedures, especially execution of deferred maintenance and mitigations to correct identified deficiencies or repair degradation. RCx follows a similar workflow to Cx with an investigation phase between planning and design, which is used by the project team to inform decisions on scope,

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sequence, schedule, and budget that are necessary to establish the owner's intent heading into the design phase.

Re-Commissioning (ReCx): The model for Cx of existing, previously commissioned buildings. ReCx occurs periodically during O&M to improve and update maintenance schedules and adjust maintenance procedures, equipment, and systems to optimize performance and maximize the service life of architectural finishes and other systems.

Ongoing Commissioning (CCx): Often referred to as Continuous Commissioning, this process generally relies on regularly scheduled preventative and/or predictive maintenance to make improvements. Periodic Cx confirms that a facility's quality and consistency continue to meet the Owner's requirements. CCx provides an opportunity to document and integrate any changes to the Owner's requirements that have occurred over time into the facility O&M activities. CCx also includes the development of CCx specifications in the design phase, which are executed during the construction phase and incorporated into the O&M manuals during the turnover phase.

Monitoring-Based Commissioning (MBCx): MBCx utilizes sensors to monitor conditions that trigger O&M activities as needed. It is generally coupled with a preventative and/or predictive maintenance O&M program to ensure the required level of performance of architectural materials and systems. Periodic ReCx is also utilized to confirm that the quality and consistency of the O&M program continue to meet the Owner's requirements.

Conclusion:

Successful commissioning results in lower costs and effort to operate and maintain a facility and assures that the Owner receives a building that meets their requirements. It also maximizes the likelihood that a manufacturer will be required to honor claims against their warranties and guarantees. The Cx process will be explored in subsequent articles in this series, including an overview of exterior envelope commissioning, with deeper dives into the commissioning of roofs and exterior fenestrations. Later in the year, we will provide a series of articles exploring interior architectural commissioning featuring ceilings, walls, floors, doors, and hardware.

Further Reading

1. California Nonresidential Building Commissioning Guide https://www.energy.ca.gov/sites/default/files/2020-05/12_BuildingCommissioningGuide.pdf
2. Whole Building Design Guide (WBDG) Building Commissioning https://wbdg.org/building-commissioning
3. U.S Department of Energy, Energy Efficiency and Renewable Energy Program, Commissioning for Federal Facilities Guide https://www.energy.gov/sites/default/files/2014/07/f17/commissioning_fed_facilities.pdf
4. International Code Council (ICC) Codes, ICC G4 Guideline for Commissioning https://codes.iccsafe.org/content/ICCG42018

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Risk Assessment Tools for Critical Facilities

Facility Risk Assessment (RA) is the process of identifying and analyzing potential future events that may negatively impact a facility, how likely each sort of risk is, and how much of an impact a risk may have on the facility operation, and in turn on end user's operation. NIH has a variety of critical facilities, including Animal Research Facilities (ARFs), Biosafety Level-3 (BSL-3) laboratories, facilities which house equipment such as MRIs or electron microscopes, and those responsible for clinical drug development. While it is impossible to eliminate all risks, many of these risks can be mitigated by incorporating certain elements into the design of the facility.

An RA tool is typically used during the project's design development phase to document project risks, their assessed risk characteristics, and the reduction of those characteristics by engineering and administrative controls. The tool helps stakeholders decide how much of each type of risk can be tolerated. Administrative controls could include frequent maintenance, cleaning, testing, or monitoring. Engineering controls could include use of HEPA filters, biological safety cabinets (BSCs), and compounding aseptic isolators (CAIs). Engineering controls are generally preferred because of their reliability and robustness, but administrative controls can significantly reduce the risks to the facility, scientific research, and people. RA informs the project team, especially the designers, and guides them in the development of mitigations. The assessment is later revisited after construction, and any remaining risks or controls are discussed and assessed for future mitigations.

NIH performs RA for every major Aseptic Processing Facility (APF). These facilities manufacture products in accordance with cGMP for use by clinical patients. Manufacture of these products involves risks associated with facility design and construction, including contamination and cross contamination, cleanability of surfaces, utility system reliability, floods or water leaks, power failure, pests, room pressure reversals, and accessibility for routine maintenance and/or equipment repair. Other risks associated with individual process steps are considered, but the risks exclusive to the process and technique are not considered as part of the facility RA.

Risk Assessment Method

The NIH RA tool uses the Failure Modes and Effects Analysis (FMEA) method. The assessment is carried out by a multidisciplinary team that includes users, quality assurance, engineers, architects, and maintenance personnel. This team considers every facility system and component for potential failure effects as well as the consequences for each failure mode. They assign a value of 1 (low) to 5 (high) for each of several categories – severity, probability of occurrence, and detectability – based on current practices, procedures, facility design, and condition.

Risk Assessment Method Assessment for Severity: The RA tool rates the level of severity (i.e., the impact should failure mode occur) using the following rating scale:

1 (Low) Any failure mode with no adverse health effects to patients or animals, or minimal impact to scientific research.

2-4 (Medium-Low, Medium, and Medium-High) A failure mode which could cause reversible moderate to significant impact to patients, animals, or scientific research.

5 (High) Any failure mode that results in irreversible significant impact to patients, animals, or scientific research.

Assessment for Probability: Like the assessment for severity, this RA tool assesses the probability of occurrence for each failure mode using the following scale:

1 (Low) Any failure mode that is expected to occur no more than once every five years, or where a design/function is standard, simple, or well-known.

2-4 (Medium) Any failure mode that occurs occasionally (every 1-5 years) and where the design/function is reasonably standard, reasonably simple, or well understood (2); any failure mode that occurs occasionally (yearly) or where the design/function is not known to be robust (3); any failure that occurs often (monthly) or where the design/function is not known to be robust (4).

5 (High) Any failure mode that occurs regularly (weekly or more frequently) and where the design/function is not known to be robust.

Assessment for Detectability: This RA tool assesses the likelihood of detection should a failure mode occur.

1 (Low) Any failure mode that will almost certainly be detected.

2-4 (Medium) Any failure mode that has a high chance of being detected (2); any failure mode that has a moderate chance of being detected (3); any failure mode that has a low chance of being detected (4).

5 (High) Any failure mode that has a very remote chance of being detected.

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Risk Assessment Tool

The ratings for severity, probability, and detectability are multiplied together to establish a Risk Priority Number (RPN) for each failure mode. Generally, an RPN≤27 is indicative of an acceptable risk; 27<RPN<64 indicates a medium risk, for which mitigations should be considered; and an RPN≥64 indicates high risk which must be mitigated. After mitigations (e.g., engineering and administrative controls) are identified, the RA team evaluates the net risk reduction these have on the severity, probability, and detectability of a given risk, yielding a net RPN. Additional mitigations will be considered until the RPN for that failure mode is reduced below the user's risk tolerance.

Conclusions

Critical facilities are at risk for disruption and damage from a variety of sources, which can have severe consequences for scientific research, patient and animal health, maintenance workers, and the environment. The RA tool described here focuses on identifying and assessing risk and mitigation strategies to minimize the severity, probability, and detectability of these risks into the design of critical facilities. The RA tool has been developed by NIH for its critical facilities but can be adopted by other institutions.

References

1. ICH Q9, Quality Risk Assessment, 2005
2. FCIS- Template for Risk Assessment

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Mechanical Commissioning - Part 1

Commissioning (Cx) is the systematic process for ensuring systems and equipment perform according to the design intent and the NIH's operational needs. Cx is a multidisciplinary process which integrates a third-party Commissioning Authority (CA) into the Integrated Project Team (IPT), which includes NIH, Architects, Engineers, Contractors, and others. The Cx process begins early in the design phase and continues through acceptance and turnover into the early occupancy phase. This article focuses on the Cx process and sequence requirements of the mechanical Cx. Part 2 will focus on testing requirements for mechanical systems, equipment, and the Building Automation System (BAS).

Design Phase

During the design phase, the CA develops a Cx plan that outlines the Cx process requirements, describes the approach and methods to be used, and defines project team roles and responsibilities, communication protocols, documentation, and the schedule of the activities. This plan is updated several times during the design phase until the start of construction phase, when this document is issued to contractor.

The CA reviews the design documents and other documents, including the Basis of Design (BOD) and the engineer's sequence of operations (SOO), to confirm the design requirements are commissionable. On Aseptic Processing Facility (APF) projects, the CA also reviews the User Requirement Specification (URS). The CA develops Cx specifications which are integrated into the Architect and Engineer's specification manual. These specifications detail the testing and documentation requirements and procedures, which are included in the final bid documents to ensure the Contractor factors coordination and cooperation with the CA into their price and schedule.

Construction Phase

During the construction phase, the CA reviews equipment and controls submittals to make sure they have the information needed to support the Cx process. The CA develops several documents, including detailed pre-functional checklists (PFCs) and Functional Performance Testing (FPT) protocols for mechanical and controls systems, including Integrated System Testing (IST) and failure testing protocols that must be executed during the acceptance phase.

PFCs are structured to capture key installation information regarding equipment installed. It verifies that equipment and materials installed were specified and approved in the submittal and are consistent with design documents. PFT demonstrates that the equipment, components, and accessories associated with the mechanical system and BAS operate in accordance with project contract documentation (e.g., manufacturer design specifications, SOO). The IST is designed to challenge the mechanical system in its entirety, under various operational scenarios including failure modes.

The CA witnesses equipment startup and testing and balancing, which is led by the installing contractor and often with assistance by the equipment vendor. The CA also conducts periodic inspections of the mechanical systems and reviews contractor startup forms and training plan, facility manual, and Operation and Maintenance (O&M) information. When required, the CA will also develop Factory and Site Acceptance Testing (FAT and SAT) protocols for major equipment testing to ensure significant problems are identified before the equipment leaves the manufacturer's facility, then again to ensure it hasn't been damaged during transit.

The prerequisite for execution of FPT is issuance of the Certificate of Readiness (COR) for the system. The COR includes confirmation that the system has been leak tested, point to point check out is complete, BAS graphics are complete, programming is complete, and the contractor has pretested the SOO.

Acceptance Phase

During the acceptance phase, the mechanical system and BAS are tested, verified, and accepted. The CA checks startup and hydronic and airflow balancing reports. Once the contractor establishes BAS trending and monitoring, the CA conducts the PFC and FPT(s), which typically engage the full IPT. The CA notifies the project team of any failed FPT during the testing and creates a punch list of items for the contractor to correct. After the deficiencies discovered during the PFCs and FPTs have been corrected and retested, the CA oversees the execution of the IST, then corrects any deficiencies discovered during the IST. For major projects, the CA then oversees the endurance period or the stability period, where trend reports are generated and reviewed to ensure the facility is stable and free of unexpected alarm conditions.

Final Cx Report

The CA issues a final Cx report that documents all startup, checkout, functional testing, punch list, and action items and their resolutions, along with changes made during the Cx process, training agendas, and evaluations. Any unresolved items that for some reason cannot be completed are noted for future implementation, post-turnover. Offseason testing is scheduled as necessary to verify system performance under peak design weather conditions.

Conclusion

The mechanical Cx process plays a critical quality assurance role in verifying that complex mechanical systems for major laboratory, animal, clinical, or aseptic facilities at NIH are designed, installed, and performing according to the design intent and the NIH's operational needs.

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Mechanical Commissioning - Part 2

Commissioning (Cx) is the systematic process for ensuring systems and equipment are designed, installed, and perform according to the design's intent and the NIH's operational needs. Mechanical Cx plays a critical Quality Assurance (QA) role. The "Mechanical Commissioning – Part 1" article described the Cx process and sequence. Part 2 focuses on the various testing requirements for mechanical systems, equipment, and the Building Automation System (BAS).

Mechanical System

The mechanical system provides the equipment necessary to ensure that design requirements, such as space temperature, humidity, air changes, pressurization, and safety consideration for both personnel and equipment, are maintained under various operational scenarios. The Cx of mechanical systems for major laboratory, animal, clinical or Aseptic Processing Facilities (APFs) includes supply and exhaust air handling units (AHUs), preheat and reheat hot water, heat exchangers, distribution pumps, variable frequency drives, distribution piping, distribution ductwork, chilled water systems, humidifiers, heat recovery system, and terminal units.

BAS

The BAS is designed to monitor the conditions within the facility and provide responsive control of the mechanical systems (e.g., chilled water, AHUs, terminal units). The BAS includes operator workstations, programmable controllers, digital /analog input/output modules, field level networks, instrumentation (temperature, relative humidity, differential pressure, flow, and current sensors), actuators (isolation and control valves, air dampers), safety switches/detectors (freeze-stats, smoke detectors, hygrostats, static pressure switches, liquid level detectors), room monitors, Uninterruptible Power Supply (UPS), and 24V DC power supply.

Pre-Functional Checklist (PFC)

During the Cx of the mechanical and BAS, PFCs are generated and executed to confirm that all associated equipment, components, and accessories are supplied and installed in accordance with contract documents (i.e., approved for construction drawings and specifications) and approved construction submittals (i.e., shop drawings, cut sheets, etc.). Component operation verification (dampers, valves, airflow/hydronic monitors), loop check and tuning verification, instrument calibration verification and BAS graphics verification are performed prior to executing the Functional Performance Testing (FPT).

Functional Performance Testing (FPT)

The FPT test script demonstrates that the equipment, components, and accessories associated with the mechanical and BAS operate in accordance with project contract documentation (e.g., manufacturer design specifications, sequence of operations (SOO)). The Cx agent verifies the scripts to confirm that major equipment start/stop sequence, safeties, interlocks, multiple fan operation, duct/piping static pressure, airflow/hydronic flow, VFD control, filter monitoring, temperature control and set point reset, pump control, terminal unit damper, airflow control, reheat valve operation, etc., are in accordance with contract documentation and all alarms are initiated when established limits are exceeded. Loss of communication alarm of BAS controllers and trend report generation is also verified.

Integrated Systems Testing (IST)

The IST is designed to challenge the mechanical system in its entirety under different operational scenarios, with the goal of verifying that the various systems, equipment, and components effectively coordinate with each other during each of these simulated conditions. The IST also ensures that the control of these building systems is robust and capable of maintaining the facility in accordance with design and operational requirements. The prerequisite is successful completion of predecessor PFC and FPT protocols.

The IST includes testing the SOO against loss of normal power; transfer to standby power and restoration of normal power; AHU and exhaust fan start/stop/failure; preheat/reheat, chilled water, humidification, and room terminal unit failure; and reheat coil and branch loop failure. The test verifies if active fans/units maintain duct static pressure on the supply and exhaust system at setpoint. A terminal box failure tests the supply and exhaust equipment and maintains flow requirements in unaffected areas of the facility.

The integrated temperature control and humidification control at system and room level are tested under IST. At the system level, preheat and cooling coil valve modulation, and humidifier enabling andvalve modulation are verified in response to varying demands on the AHUs. At the room level, reheat system pump VFDs, hot water converters, steam valves, and room reheat valve modulation are verified in response to varying heating/cooling requirements. The IST simulates heat recovery response failure and verifies AHU heating/cooling coil and the hot/chilled water system valve modulation to confirm that the AHU discharge set point is maintained.

Endurance/Stability Period

After completion of the IST, the Cx agent generates and reviews facility trend reports to ensure the facility is stable and free of unexpected alarm conditions. In APFs, this period is typically 72 hours. In other facilities, such as a BSL-3, this period can be longer.

Conclusion

Mechanical Cx testing is primarily testing and verification of design specifications and SOO to ensure mechanical systems operate as intended. An essential element of system performance verification is testing under different operating scenarios via the BAS scripts and system trend logs. Every operational mode, including normal, emergency, and failure, needs to be fully analyzed.

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Water Leak Detection Systems for High Value Assets

Detecting water leaks is critical to protecting high value assets from irreparable damage and significant repair and replacement costs. Leaks can range from a small drip from a water container or pipe to a flooding event from a burst pipe to an overflow event that creates a volume of standing water that may leak though small openings or penetrations. Any unrecognized or unintended leak can become disastrous over time if left unattended. Furthermore, without auditory or visual recognition of the leak or the ability to identify the source, no leak detection system will reliably protect property from damage. Although there are many simple, inexpensive methods to detect the presence of water, utilizing a single leak detection methodology may be short-sighted, providing a short-term solution without necessarily determining the source and extent of the leak. This article reviews several leak detection methods, their mechanisms, and considerations when selecting a system.

Assessment

A building assessment should be performed prior to selecting a water leak detection system. This assessment determines building needs; identifies risk areas where water leaks occur and areas and assets that need to be protected; and ensures that the BAS is reliable and not subject to failures. It also provides an opportunity to look for systems that can offer advancements in wireless and monitoring technology.

Factors to consider include sensor locations and access (critical space walls, pipe chases, floors, ceilings, mechanical penthouses); confined locations (drip pans under HVAC units); speed of detection and leak location accuracy; accommodations for different types of sensors to physical constraints such as hard-to-reach areas; ensuring cables and sensors are out of the way of damage; types of notification required (simple alarm or notification via automated system); the standard procedure for ongoing inspection of building plumbing and HVAC systems; connectivity with the BAS; ease of installation; and technical support required.

Wired vs. Wireless

Sensors can be wired or wireless. Wired sensors provide security, reliability, and speed and are cost-effective to maintain. However, they lack mobility and have a high initial cost and scalability difficulties. Wireless sensors transmit data via a dedicated wireless platform or Wi-Fi on existing network. They provide flexibility and can cover large monitoring areas while being cost effective. The disadvantages to wireless sensors are shorter battery life, slower speeds, and limited signal due to RF interferences.

Spot Detector Sensors

A spot detector sensor uses two gold-plated, corrosion-resistant probes to detect the presence of water. When water forms a bridge between the two probes, the sensor activates an alarm. Probes are adjustable to the desired height and connected to the BAS. These sensors are flexible: they are good for confined or contained areas, should function while immersed in water, and should not activate in high humidity areas. They can be designed to handle dirt and detect RO water if desired.

Sensing Detection Cable

A sensing detection cable detects water anywhere along its length. It is constructed of sensing wires and insulated wires with an abrasion-resistant, non-conductive polymer core. This helps prevent false alarms. The cable is plenum rated, fast-drying, and highly flexible, allowing for small bend radii. It should not be placed in areas where it can be damaged by foot traffic or tools rolling or dropping. In high humidity areas, sensitivity adjustment is essential to minimize false alarms.

Distance Read Controllers

These standalone controllers are paired with sensing cables in areas such as raised floors in computer rooms, pipe chases where leaks can go unseen, or ceiling plenums. The controllers can pinpoint where along the length of the sensing cable a leak is occurring. Advanced controllers are capable of BAS integration via BACnet and equipped with local LCD screens with mapping capabilities to display status, provide alarm notifications, and allow for sensitivity adjustments.

Acoustic Detection

This technology uses acoustic noise sensors and leak noise correlators attached to valves to identify leak locations. They help identify small leaks before they become major problems.

Fluorescent Leak Detection

This technology is used to detect and locate leaks in piping systems. Once the dye is injected into the system and allowed to circulate with the host fluid, technicians inspect for leak sites using UV lamps. Depending on the size of system, it can take 5-45 minutes to find leaks. They can be deployed easily and inexpensively. This requires regular and thorough manual monitoring.

Lineal Tape Detectors

This method uses capacitance measurement to detect water leaks. Water detector tape is wrapped around the equipment or source of the leak. A warning will sound when as few as two drops (adjustable) of water comes in contact with the tape. This method is relatively inexpensive; lineal tape along with the dye detection method can provide a short-term solution for leak detection.

Conclusion

There are several technologies available for water leak detection. Utilizing a single leak detection methodology is not advisable; instead, a hybrid leak detection system should be installed. As with any technology, it is critical that false positive or negative responses be discussed with specific vendors prior to system installation.

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The formulae $\frac{\partial \rho U_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho U U_j)=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial U_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ *for building* $\frac{\partial}{\partial x_j}(\rho\overline{U_i}\overline{U_j})=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu\frac{\partial\overline{U_i}}{\partial x_j}-\rho\overline{u_i'u_j'}\right)+g_i(\rho-\rho_0)$ *state of the art* $\frac{\partial}{\partial x_i}(\rho\overline{U_i}\overline{H})=\frac{\partial}{\partial x_i}\left(\lambda\frac{\partial\overline{T}}{\partial x_i}-\rho\overline{u_i'h'}\right)$ *biomedical research facilities.*

Building Enclosure Commissioning and Testing

Architectural commissioning was introduced in the January 2023 News to Use article "Architectural Commissioning: An Overview," which is available on the NIH ORF website News to Use (nih.gov). Many architectural systems may require commissioning in the execution of a project, including finishes, doors, hardware, equipment, and the building enclosure. Commissioning ensures the approved design and specifications have been faithfully executed. Building enclosure commissioning introduces an independent expert to establish acceptance criteria, evaluate and peer-review the construction documents, and complement the contractor's quality control program for all enclosure components, including but not limited to roofing, wall assemblies, fenestration, and above and below grade waterproofing. This article reviews the testing requirements for the architectural enclosure commissioning process.

Testing

Testing is an essential aspect of enclosure commissioning because enclosures consist of assemblies and systems constructed on-site, in unique configurations, whose performance cannot otherwise be assured. Testing exposes assemblies to real world conditions under which they will operate to assesses their performance. As part of the development of the commissioning plan and commissioning specifications, the commissioning agent (CxA) will develop a list of tests to be conducted on materials, assemblies, and subassemblies to quantify their performance and ensure that they meet the Owner's Project Requirements. Testing can focus on materials, interfaces, sealants, flashings, fasteners, joints, and other potential points of failure. Of particular concern are thermal performance, air transmission, vapor pressure drive, load capacity (structural, wind, blast), differential movement, durability, and other demands on enclosure components.

ASTM E2813 2018 *Standard Practice for Building Enclosure Commissioning* establishes the standard for developing an Owner's Project Requirement document and conducting the Building Enclosure Commissioning process.

Quality Control and Quality Assurance

Quality Control (QC) tests are conducted by the contractor as part of the construction quality control plan. The CxA should observe these tests to ensure compliance with established test protocols and performance requirements. Quality Assurance (QA) tests are usually conducted as part of the commissioning plan. QA testing may be conducted by the CxA or by an independent testing agency under the oversight of the CxA. Categorizes of testing include:

- **Laboratory tests**, which are performed on materials and components by an independent testing agency with specialized equipment to determine their physical characteristics and predict their performance in service. Tests may include resistance (i.e., thermal, chemical, corrosion, UV, abrasion), strength, permeability, and adherence. Individual materials or assemblies may be tested.

- **Mock-up tests**, which are performed on full-size assemblies constructed for testing purposes on-site or at a testing facility. Mock-ups should include joints, transitions, corners, penetrations, sealants, and all other conditions and be constructed with the same techniques, materials, and contractors that will be used on a project. Mock-up tests may include structural/blast, air and water infiltration, and acoustical and thermal performance. Mock-ups may also be used to assess aesthetics, constructability, maintainability, compatibility of materials, and other factors. The primary objectives are to determine how components perform as assemblies and establish acceptance criteria for the actual installed conditions.

- **Field tests**, which are performed on actual building assemblies and are typically part of the finished construction. The primary objectives are similar to mock-up tests: to determine how components perform as assemblies and to establish acceptance criteria for similar conditions. Many of the field test procedures are also similar to mock-up testing, but more limited because they are not conducted in a testing facility.

Conclusion

An enclosure commissioning program, including required testing, ensures that the building enclosure meets the OPR, sets performance standards and minimizes complications and re-work during construction.

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Further details on this month's topic are available on the DRM website DRM Chapter 1, Section 10, Commissioning:
https://www.orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManual2016

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The formulae $\frac{\partial \rho \bar{U}_i}{\partial t}+\frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j)=-\frac{\partial \bar{P}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{U}_i}{\partial x_j}\right)+g_i(\rho-\rho_0)$ for building $\frac{\partial}{\partial x_j}(\rho \bar{U}_i \bar{U}_j)=-\frac{\partial \bar{P}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{U}_i}{\partial x_j}-\rho \overline{u_i' u_j'}\right)+g_i(\rho-\rho_0)$ state of the art $\frac{\partial}{\partial x_i}(\rho \bar{U}_i \bar{H})=\frac{\partial}{\partial x_i}\left(\lambda \frac{\partial \bar{T}}{\partial x_i}-\rho \overline{u_i' h'}\right)$ biomedical research facilities.

Animal and Lab Lighting Control

Lighting control in animal rooms and laboratories can be accommodated using either central or dedicated (stand-alone) control systems. This article provides some considerations for selecting and applying them.

Lighting Control – Animal Rooms

Central Control Systems

Lighting control systems for animal holding areas are programmable using either a central automation system or a stand-alone system. In the former, the diurnal light system within a vivarium is networked and integrated with a centralized building system (e.g., dedicated lighting control or building management system) using an interface, typically an 8-pin Cat-6 modular jack. The interface will send signals through the jack to the lighting contactors that control lighting circuits or the relay cabinet. To ensure consistent diurnal cycles, on/off times and override durations are routinely checked and adjusted by authorized animal facility personnel.

A central system allows individual rooms to be programmed independently to provide customized operation based on animal species and research protocols. In this scenario, a photocell connected to the control system is placed in each holding room to monitor the actual lighting conditions. Photocell light level data (in foot-candles) should be recorded at appropriate intervals and the data should be maintained in the historian. At minimum, the photocell data must record lighting on/off operations. If the system needs to be controlled in multiple locations, it can be configured on the monitoring/control system using several PC-based systems that can be accessed over a LAN or the internet, where permitted (internet/wireless access is not permitted on NIH CIT systems), so it can be monitored and controlled remotely.

Stand-Alone Systems

In a stand-alone system, individual astronomical timers control the lighting of small new facilities and small renovations. A stand-alone system can be overridden, adjusted, or controlled through a terminal located within the vivarium administrator/manager's office. The responsible veterinary staff supervisor/manager determines and approves dimming control requirements to simulate dusk and dawn circadian cycles.

Lighting Control – Labs

Central Control Systems

Multiple laboratories can be controlled from a central location using a lighting control panel. To achieve this, all the addressable input devices such as occupancy sensors, photo sensors, digital switches, etc. and the fixtures (load) from each lab are wired to the panel's relay cabinet(s). When any input device is activated, the panel's processor compares the signal received from that input device with the software instructions and changes the state of the relay(s) accordingly.

The load (accounting for low-voltage transformer losses, if applicable) should not exceed the relay or controller's power rating designated for the given electrical feed voltage. The wattage of each connected fixture will determine how many fixtures can be powered by each controller output, with the total load in the control zone used to determine the number of outputs.

Stand-Alone Systems

Lighting control systems in laboratories are programmable based on the type of space. Lighting will automatically turn on to 50% light output when ceiling-mounted occupancy sensor(s) detect an occupant in the space. The occupant can then override the lighting fixtures to 100% light output or turn them off using a digital control switch as needed. Additionally, the occupant can set dimming levels using the raise and lower buttons/levers on a wall-mounted digital dimmer light switch. The light fixtures will automatically turn off 15 to 20 minutes after the lab becomes vacant.

If an occupant experiences false triggering or lack of triggering, the occupancy sensor's sensitivity needs to be adjusted on-site. This involves connecting the sensor's passive infrared module to a general-purpose operational amplifier circuit. Another way of increasing the sensitivity is by changing the value of a resistor or capacitor in one of the operational amplifier stages.

Daylight Harvesting

When a lab is situated adjacent to the building perimeter and has window(s) or other means of daylight transfer, daylight sensors shall be provided in lab spaces. Lighting in lighting zone(s) will automatically dim based on the daylight distribution to maintain the required light level (in foot-candles) in the lab.

Digital Lighting Control

In a traditional analog control system, the basic building block of lighting control is to zone the lighting circuit or subcircuit, with sizing being limited by the load carrying capacity of the circuit as well as the zoning/rezoning through hardwiring. In digital control systems (as described above), control devices are connected using only a single low-voltage wiring bus, and the zoning/rezoning is implemented via software, with zoning as small as a single fixture. Verification of a system's operation, changes to programming, and trending of system operation can be done remotely. As digital systems typically offer two-way communication, monitoring can be accomplished for maintenance and energy data collection.

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Design for Maintainability

Designing for maintainability requires providing adequate space and accommodation for mechanical systems and lab equipment for ease of maintenance and to keep valuable NIH assets in proper operational condition. Good maintainability in design emphasizes the integration of design and construction knowledge with operations and maintenance (O&M) needs in collaboration with the architect, engineer, owner, maintenance staff, and other stakeholders.

General Design Considerations

Major mechanical, plumbing, and electrical equipment is typically located in indoor mechanical, electrical, and plumbing (MEP) spaces. Proper layout allows access to all serviceable current and future equipment in mechanical and electrical rooms and associated interstitial spaces. Designers must include adequate clearance and provisions for routine maintenance and the removal or replacement of equipment and components, including HVAC coils, large fan motors and pumps, and heat exchangers. Including the required clearances on the drawings helps to preserve them through construction. The equipment must be visible in addition to accessible to facilitate inspection, which is critical to maintainability. Hazardous exhaust fans may be located on the roof to minimize risk to maintenance staff.

Designers shall consider access to components such as valves, actuators, dampers, and junction boxes. For critical applications, valves, dampers, and terminal units are located in interstitials, mechanical penthouses, or mechanical spaces. This provides maintenance staff easy access to equipment and devices for calibration and without impacting lab operations or the need for maintenance staff to enter containment or clean barriers.

Interstitials, penthouses, and utility rooms require elevator access, adequately tall and wide aisles and walkways, and unobstructed paths for carts, among other things. Most roofs require stair access.

Small mechanical equipment, such as fan coil units, must not be located above sensitive equipment like microscopes. No equipment should be located in confined spaces. Designers must make every effort to avoid installing utilities like piping above critical and sensitive areas, including electrical rooms, imaging rooms, and cleanrooms.

Equipment must be labeled, and nameplates must be visible and accessible. Pipes and ducts must be identified and include flow direction. Service isolation valves should be provided at critical locations to allow for easy isolation in case of an emergency.

Zoning Considerations

HVAC, electrical, fire control, and plumbing systems are zoned to avoid the overlap of multiple systems over various building zones. Zoned systems include piping, ductwork, conduits, cable trays, sprinklers, lighting, terminal units, and diffusers. Zoning also enables partial facility shutdown. Designers should ensure their construction documents identify zone boundaries.

Equipment Redundancy

Equipment and component redundancy is an essential element of NIH facility design. *DRM* 1.15.3.R requires no less than N+1 (parallel) redundancy for primary system equipment and devices that require frequent maintenance or whose failure would result in substantial loss of building operations or research capacity. This redundancy allows for enhanced maintenance, as equipment may be isolated for service without impacting the program. Redundancy also results in improved reliability and continued functionality if a piece of equipment fails, since the remaining equipment in the system will be capable of fully supporting the functional requirements.

Indoor Design Conditions

Designers must ensure equipment rooms maintain adequate indoor temperature, humidity, and ventilation. *DRM* 6.1.18 provides minimum indoor design conditions for mechanical and electrical rooms as well as for sensitive equipment. In general, mechanical rooms shall be designed between 18° C (65° F) and 31° C (90° F).

Drainage Provisions

Walking surfaces and areas for servicing equipment should be free of slippery substances and standing water. Floor drains should be located such that liquids do not flow into traffic areas. Mechanical rooms located above occupied areas must be provided with adequate curbs around floor penetrations and leak detectors. All floor penetrations must be sealed and designed to maintain strength and load ratings at the penetration as well as where condensation is a concern. In addition, the floor penetrations must maintain water-tight characteristics.

Conclusion

Addressing the importance of maintainability early in the design process and consistently applying maintainability design principles ensures equipment will be properly serviced and operational when needed.

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Further details on this month's topic are available on the DRM website DRM Chapter 6, Section 6.1.2, .8, 18. 19, 22, Heating, Ventilation and Air Conditioning: https://www.orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManual2016

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Adhesives in Biomedical Construction

Adhesives have long had a prominent role in construction, but recent years have seen a rapid expansion of the types, availability, and use of adhesives throughout the industry. This article explores the state of adhesive use, specifically in the context of biomedical construction, which has far more stringent requirements and oversight than general construction. While adhesive specification is typically based on manufacturer's recommendations, often as part of a system, a general understanding of the typical adhesive types and applications is important to avoid problems which may impact performance or void warranties.

Acrylic/Methacrylic Adhesives: These polymer adhesives are common in construction applications due to their abilities to strongly bond a wide range of substrates and resist degradation from UV and moisture after they have cured. Bonding times for some substrates may be slower than for other adhesive options. These adhesives are readily available in low volatile organic compound (VOC – e.g., odors, sensitizing and/or irritating components) formulations and consistencies, ranging from liquid to paste. Cleanup typically requires the use of solvents, such as MEK or isopropanol.

Anerobic Adhesives: These uncommon adhesives utilize dimethacrylate monomers, monofunctional ester monomers, or other chemistry that cure only in the absence of oxygen. They are generally non-corrosive, exhibit low VOCs and low toxicity, and make strong bonds with non-porous substrates.

Epoxy Resin and other Curable Adhesives: Also called reactive adhesives, these require a chemical reaction to bond and cure and are generally available in one-part or two-part formulations. These adhesives can bond a very wide range of substrates and are high-strength, chemically and physically durable, and dimensionally stable. When activated, these adhesives tend to have notably short worktimes before forming high-strength, durable bonds. Many formulations are low VOC; however, some are potent VOC sources. Many adhesives of this class require specialty applicator tools.

Hot Melt Adhesives (HMA): These are thermoplastic adhesives and include carpet seaming tape adhesive and various types of stick-type media which are fed through a heating element (e.g., melt plate or hot glue gun). These adhesives are suitable for bonding a wide variety of materials and achieve their bond strength quickly. While generally low in organic compounds, HMAs can result in odors and heat damage to joint materials. In areas where VOCs are a concern, be cognizant that heating substrates may accelerate the release of VOCs from these materials. These adhesives have a long shelf life and can be disposed of without special precautions.

Phenolic Adhesives: Phenolic resins are based on reacting formaldehyde and phenol which results in a highly penetrative adhesive, particularly when used with cellulose-based building products. These bonds are strong and highly weather-resistant; however, this class of adhesive is among the most expensive on this list. Phenolic resins tend to volatilize formaldehyde, which is a sensitizing agent.

Pressure Adhesives: These adhesives are typically applied to a flexible membrane or other base surface. The bond is activated when pressure is applied, often with J-rollers or similar tools. These adhesives tend to develop bonds slowly but can become aggressively bonded over time. This class of adhesive tends to have low VOCs, but the plasticizers in the flashing tapes and other products they are attached to may have their own VOC concerns.

Polyurethane Adhesives: Another common class of construction adhesive which creates strong weather- and chemical-resistant bonds with a wide range of substrates. Available in a wide range of viscosities, pot life, and range of cured hardness, their reaction of an isocyanate and polyol produces free carbon dioxide, which can result in joint movement unless properly clamped until cured. VOC issues with polyurethane adhesives tend to be minimal.

Thermosetting Adhesives: These adhesives utilize unlinked monomers (e.g., tapes, pastes, etc.) that are exposed to a chemical hardener (two-part mix), but some formulations cure in the presence of light or heat. The curing times are generally in the range of 10-60 minutes, providing good open and workable time before the resin and hardener react and polymerize to bond the substrates, which can be non-porous to semi-porous. Thermosetting adhesives include the phenolic formaldehyde (PF) resins (listed separately); polyamide adhesives (PA), which are extremely chemical- and temperature-resistant; and polyester resins, which are used in making composite products, most notably fiberglass and carbon-fiber. VOC content is highly variable in this class of adhesive.

UV-Curing Adhesives: These adhesives utilize photoreactive free-radical polymer chemistry to achieve strong, moisture-resistant bonds in glass, plastic, etc., when exposed to natural or high-powered artificial UV light sources. While VOCs are a low concern for this class, special precautions against accidental UV exposure and injury must be taken when utilizing potent UV sources to cure bonds

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rapidly, or where natural UV exposure is limited. Gunnable and sprayable gypsum board adhesive is becoming established in the industry; however, there are currently no UL assemblies which allow for it, and the high churn rate of biomedical construction generally does not support its use.

Water-Based Adhesives: These adhesives are based on natural (derived from vegetable starch and destrins) or animal proteins (derived from hides, bones, or other protein sources) or synthetic polymers (derived from esters, alcohols, methylcellulose, polyvinyl, etc.). This class tends to have low VOC concerns but can have potent odors which need to be planned for and mitigated through offsite-preparation and/or high ventilation, possibly in combination with other means. This class also tends to have a short shelf life and variable pot life (associated with varying bond strength). While bond strengths of water-based adhesives tend to be high, they also tend to be resoluble when exposed to water in their service life and can support microbial growth.

Conclusion

Adhesive specification involves a complex assessment process that relies on the specifier's understanding of the performance criteria necessary for bonding similar or dissimilar materials; resisting degradation due to exposure to mechanical shock, vibration; resisting fatigue; and resisting chemical and thermal degradation. The specifier must also be familiar with bond strength requirements, ease of disassembly, and other project and instance requirements. Installers need to understand the requirements of the prep and installation of the adhesives as specified, including substrate preparation, minimum bond area, mixing and pot-life requirements, clamping, and environmental conditions. Most importantly, in biomedical applications, there must be a cooperative relationship between specifier, installer, and the contractor's safety team to ensure the health and safety of those performing the work, those nearby, and those eventually occupying the project.

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1. The National Institutes of Health (NIH). *Design Requirements Manual,* https://www.orf.od.nih.gov/TechnicalResources/Pages/DesignRequirementsManual2016.aspx

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Interstitial Spaces in Laboratory Buildings

Laboratories require extensive HVAC, plumbing, electrical and other utilities to support their environmental requirements for temperature, humidity, ventilation, pressurization, filtration, and exhaust. Systems and equipment may include air handling equipment, coils, ductwork, motorized dampers, air volume terminal units, reheat coils, HEPA filters and their housings, piping, isolation valves, test ports, BAS sensors and controls, water, waste disposal, and lab gases, electrical, IT infrastructure, and fire protection, as well as miscellaneous specialty equipment.

Key to the successful operation of lab facilities is regular inspection and maintenance of the numerous systems and components which require adequate and safe access, good illumination, orderly physical arrangement, access to controls, and clearly visible labeling, as well as the ability to isolate individual labs to enable modifications while surrounding labs remain in operation.

Also important is avoiding lab downtime and disruption to researchers by minimizing maintenance inside and in the above-ceiling space of occupied labs. Segregation of labs and researchers from maintenance activities can be beneficial to both by avoiding the use of ladders and tools around and above expensive equipment, as well as prevent or minimize physical and health risks to maintenance personnel. This segregation is especially important for sensitive, hazardous, or highly regulated program areas.

One of the best ways to provide adequate segregation for maintenance is by incorporating interstitial space in the facility design. An interstitial space with a waterproofed, walkable floor above a laboratory can provide a dedicated space for utility system components which is both isolated from the lab and enables easier, more efficient maintenance access, thus greatly reducing maintenance interference with research operations.

Advantages of Interstitial Spaces

- **Equipment access, visibility, and lifecycle cost**: Equipment in an interstitial space is generally much more accessible than equipment in a ceiling cavity. This facilitates maintenance, which will increase reliability and efficiency and can contribute to reduced operating costs.
- **Segregation of maintenance functions:** Equipment can be accessed without personnel entering or disrupting the operations of the laboratory served.
- **Reduced need for accessible ceilings:** A facility supported by an interstitial space has less need for ceiling access and can more readily accommodate a monolithic ceiling. This is especially beneficial in clean rooms and frequently decontaminated facilities.
- **Optimal location of equipment:** An interstitial space allows equipment to be near the area it serves, reducing duct and conduit runs.

Disadvantages of Interstitial Spaces

- **Increased building first costs:** Interstitial spaces add floor levels, elevator stops, an exterior wall area, and other components that increase first costs.
- **Increased building height:** Interstitial spaces increase building height, which may be an issue with zoning restrictions, interrupted viewsheds, and shading of lower structures nearby.
- **Increased systems and equipment first cost:** Localized, smaller pieces of equipment may be used in lieu of fewer pieces of centralized equipment to maximize the utility of an interstitial space.

Interstitial Space Design Recommendations

To maximize effectiveness, an interstitial space should be planned and constructed as follows:

- Interstitial spaces must be designed to support both current and planned equipment and the live load of maintenance personnel and activities.
- Interstitial floors must be concrete or another durable substrate (corrugated metal or similar uneven surface decking is not acceptable) that is appropriate for a slip-resistant, waterproof floor finish.
- Walking zones must be provided with clear head height and unobstructed floors to eliminate trip hazards.
- Interstitial floors should be provided with water leak detection systems with sensors that are strategically placed, including above critical or high value labs, as appropriate.
- Floor drains (4”) should be provided at a rate of no less than one per approximately every 2,000 sq. feet and located to be reachable from any drain valve by a 50’ hose.

Conclusion

As the complexity of research lab support systems grows to serve more sophisticated research programs, interstitial spaces are an increasingly appealing alternative to the traditional practice of using the limited above-ceiling space for most utilities. A well-designed interstitial space facilitates maintenance and segregates maintenance and research functions, both of which are highly desirable and add value to laboratory building operations.

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