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Project Testing and Commissioning Guideline

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1.0 PURPOSE

The main purpose of this document is to highlight the importance of the Testing and Commissioning in the process of assuring by documentation and testing, from the design to occupancy phase that all project facilities and systems are:

- Designed
- Installed
- Operational
- Maintained
- Performed interactively

…in accordance with the design documentation and intent and in accordance with the Owner's Project Requirements.

Many project owners experienced problems regarding the operation of the Building Services and Fire/Life Safety Systems after the handover where the project was certified to be complete, operational, and had undergone a comprehensive and rigorous Testing and Commissioning process. Such problems could be avoided if the Owner Project Requirements was clear, device selection had been correctly made, the requirements of the code and standards were implemented, Commissioning process and activities properly implemented…etc.

In the end, it is always the primary responsibility of the owner to ensure that the building is safe and properly functioning prior to any occupancy. The owner and his representatives will always be responsible for incidents and accidents that can happen inside his premises due to failure of Building Services and Life Safety System.

Most projects could suffer from delays when the project reaches the Testing and Commissioning (T&C) stage. One of the main reasons is the weak understanding by the Owners, Designers, Consultants, Project Managements, and Contractors of the complexity of the T&C Work and the stages that follow every testing activity. An example of the weak understanding product is an unrealistic T&C schedule and not synchronized to the General Construction Schedule. This failure results to a project delay and overcast most of the cases.

This document intends to concentrate in Building Services and Fire/Life Safety System Testing and Commissioning, but it also covers the requirements for most of the systems for infrastructures. The document does not intend to cover Specialty System T&C not related to Building Services Systems.

The document uses the ''Commissioning Authority'' term –the nominated company by the international standards to oversee, advice and lead Testing and Commissioning activities. In proposed EXPRO organization model, its role is taken over by the Entity Project Management Organization who is hired by the project's Owner/Entity and is independent against Contracting and Engineering companies.

2.0 SCOPE

This document is prepared for the following scopes:

- For the Client to differentiate the Conventional T&C work procedure from that of NFPA, ASHRAE, and LEED Commissioning Processes and to employ the service of a Commissioning Authority as early as the project inception; to understand the risk involved in the conventional T&C and the benefits of the new approach conforming to the requirements of the Codes and Standards.
- For the Project Owner to understand the importance of employing a Commissioning Authority and incorporate provisions for the requirement in the Project Contract.
- For the user to be familiar with the testing requirements, documentation and procedures that are required to ensure an efficient, safe, reliable and functional building.
- For the user to be familiar with the sequence of testing required to assess duration for each activity and prepare the T&C work schedule and manpower loading in coordination with the General Construction Schedule, as applicable to project type.

- To define all necessary steps in the T&C work and explain the purpose of each required test.
- To develop a proposed Scope of Work (SOW) for the Commissioning Authority, Designer, and Consultants/Project Manager/Construction Manager for the Client to incorporate into their contracts. The proposed SOW clarifies the responsibilities of all parties during the Commissioning Process in order to have a successfully Commissioned Project.
- To develop a proposed Scope of Work for the Main Contractor Testing and Commissioning Agent and to include the SOW into the Project Specification and to define a clear understanding of the responsibilities of the T&C Agent.

This procedure does not intend to include commissioning process for the building envelope or for industrial process piping but concentrate in Building Services System commissioning. The document applies to works performed under all Government construction projects executed throughout the Kingdom of Saudi Arabia.

3.0 DEFINITIONS

Abbreviations	Description
ACH	Air Change per Hour
AHJ	Authority Having Jurisdiction
AHU	Air Handling Unit
A/E	Architect/Engineer
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BACNet	Building Automation Network
BEP	Best Efficiency Point
BMS	Building Management System
BOD	Basis of Design
BSRIA	Building Service Research and Information and Association
CAV	Constant Air Volume
CCTV	Closed Circuit Television
CFD	Computational Fluid Dynamics
CIM	Control Interface Module
C&EM	Cause and Effect Matrix
DDC	Direct Digital Controller
ELV	Extra Low Voltage
FACP	Fire Alarm Control Panel
FAT	Factory Acceptance Test
FDAS	Fire Detection and Alarm System
FLS	Fire and Life Safety System
HCIS	High Commission for Industrial Security
HVAC&R	Heating, Ventilating, and Air Conditioning and Refrigeration
ICCB	Insulated Case Circuit Breaker
IEC	International Electro-technical Commission
IPC	International Plumbing Code
I/O Point	Input / Output Point
LAN/ VLAN	Local Area Network / Virtual Local Area Network
LEED	Leadership in Energy and Efficiency
MIM	Monitor Interface Module
NC/RC	Noise Criteria / Room Criteria
NEBB	National Environmental Balancing Bureau
NETA	international Electrical Testing Association
NFPA	National Fire Protection Association
OCPD	Over Current Protective Device
OPR	Owner Project Requirement
OSI	Open System Interconnection

Abbreviations	Description
O&M	Operation and Maintenance
PABX	Private Automatic Branch Exchange
PAVA	Public Annunciation and Voice Alarm
PCB	Power Circuit Breaker
PICV	Pressure Independent Control Valve
PM/CM	Project Manager / Construction Manager
PRV	Pressure Reducing Valve
P&ID	Process and Instrumentation Diagram (for BMS)
RCBO	Residual Current Circuit Breaker with Overload
RCD	Residual Current Device
RFI	Request for Information
RFP	Request For Proposal
RH	Relative Humidity
RMU	Ring Main Unit
RODI	Reverse Osmosis De-ionize Water
SLD	Single Line Diagram
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
SOO	Sequence of Operation (for BMS)
SOW	Scope of Work
TAB	Testing and Balancing
TCP/IP	Tele Communications Protocol over Internet Protocol
TIA	Telecommunications Industry Association
TTC	Type Testing Certificate
T&C	Testing and Commissioning
UPC	Uniform Plumbing Code
UPS	Uninterruptible Power Supply
UTP/STP	Unshielded Twisted Pair /Shielded Twisted Pair
VAV	Variable Air Volume
VFD	Variable Frequency Drive
VOIP	Voice Over Internet Protocol
ZSCS	Zoned Smoke Control System

3.1 Definition of Terms

3.1.1 Owner Project Requirements (OPR)

The OPR start as a preliminary document during the initial planning stage and is updated continually up to the completion of the commissioning phase. Its importance is to satisfy the owner and end-user need of the project

The OPR is an owner generated mandatory pre-design document by ASHRAE, LEED, and NFPA which is the basis for the Basis of Design (BOD) preparation, construction, acceptance, and operational requirements. The document contains the specific and detailed functional requirement of the project and expectations how the project will be used and operate.

The document form part of the System Manual and is the basis of the Commissioning Authority validation/verification work for the project and addresses the following requirements:

Owner and User Requirements

- Infrastructure
- Project purpose & Functional Use
- Building size, height, and orientation
- Building façade and external wall requirements

- Area of use and space allocation requirements
- Building hours of operation
- Applicable Codes, Standards, and version to be used
- Optional systems to be included in the project
- Any other specific maintenance and end-user requirements

Environmental and Sustainability Goals

- LEED or Non-LEED project
- Platinum, gold, silver, or accredited
- Energy efficiency goals

Lifecycle of the proposed development
Indoor Environmental Quality Requirements

- ISO classification for clean rooms, as required re

System and Equipment Expectations

- System detailed requirements (e.g., BMS Data Points, C&E Matrix)
- Minimum efficiencies
- Limit of system integration
- Specific performance criteria
- Tolerable arc-flash levels

Building Occupants and O&M Requirements

- O&M Training requirements
- O&M Training Plans
- Preferred Method of operation
- Owner's Assets Management System
- Adaptability for future facility changes and expansion
- Security and Access
- Asset coding
- Asset Tagging Requirements
- Asset classification methodology
- Building Information Modeling (BIM) if applicable.
- Warranty and maintenance requirements

Cost Consideration

- Project budget limitation

Commissioning process budget and scop

Performance Criteria

General

- Quality requirements for materials and construction
- Acoustical requirements
- Vibration requirements
- Aesthetics requirements
- Constructability requirements

Economic

- Benchmarking goals

- Energy efficiency goals

3.1.2 Basis of Design (BOD)

The BOD is a designer generated mandatory pre-construction document by ASHRAE, LEED, and NFPA which is the basis of preparation for the Systems Manual, Commissioning Plan, and Construction Documents. The BOD covers the OPR in a more detailed, specific, and technical manner. The document along with the OPR, is the basis of the T&C Authority verification work for the project and addresses the following requirements.

System Narrative Description

- Building Services System types and required Integration
- Design and Performance Criteria
- Life Safety System Design Criteria
- Sustainability Target and Requirements
- Constructability and Hazard reviews
- Maintenance and end-user requirements

Primary Design Assumptions

- Diversity Factors
- Redundancy

Design Development Guidelines

Codes, Standards, and Sections to be used

Owner Representative Directives – instructions not covered in the OPR

3.1.3 Validation and Verification

For the purpose of this document and to identify and differentiate the Conventional T&C work to the ASHRAE, LEED, and NFPA revised Commissioning Process, the terms are defined as follows:

Validation

- The process conducted by the Commissioning Authority to confirm that the Basis of Design (BOD) prepared by the designer complies with the criteria described in the Owner's Project Requirements (OPR).

Verification

- The process conducted by the Commissioning Authority to confirm that what the site team installed, tested, and approved, conforms to the Basis of Design (BOD) and Specification.

Note that as stated above, ASHRAE/LEED, and NFPA define both terms synonymously as follows:

"*The process by which specific documents, components, equipment, systems, and interfaces among systems are confirmed to comply with the criteria described in the Owner's Project Requirements*".

3.1.4 Commissioning Authority and Fire Commissioning Agent

The Commissioning Authority is defined by ASHRAE, LEED, and NFPA as an Independent Specialized Third Party directly reporting to the Owner which is not part of the design and construction team. The Commissioning Authority is separate from the Contractor's In-house T&C Agent or Specialized Third Party who will conduct the actual and rigorous site testing and commissioning. The Commissioning Authority is required to be independent to eliminate any possible influence from the Design Team, Project Management and Contractor in order that an impartial reporting of the project status can be made. For specific and detailed proposed Commissioning Authority scope of work during the pre-design, design development, bidding, construction, and occupancy phases, refer to Section 5.1.5 of this Guideline.

The Commissioning Authority is the lead in the Commissioning Process and requires extensive hands-on experience in the design, installation, operation, and maintenance of the Building Services Systems and equipment. The Commissioning Authority must also be experienced in system controls and must be familiar with communication protocols use in Building Automation System (such as BACNet, LON, SCADA DNP3, etc.). The Commissioning Authority must be certified by a recognized approved association such as the Building Commissioning Association in the United States.

NFPA 3 defines the Fire Commissioning Agent as having the same responsibility and scope as the Commissioning Authority with the exception that its concern is confined only to Fire Protection and Life Safety System. The Commissioning Authority serve as a coordinator between the Fire Commissioning Agent and the rest of the T&C Team, ***when applicable*** (this is the excerpt that appears in NFPA 3 section 5.2.2.5). For practical application and for the purpose of this document, it is considered that both will be the same entity and will be annotated as the Commissioning Authority since almost all Specialized T&C Entities are capable to handle both HVAC, Public Health, and Fire/Life Safety Systems. Only if the AHJ (Authority Having Jurisdiction) requires a separate entity for the Fire and Life Safety System T&C that it is required to have a dedicated Fire Commissioning Agent.

3.1.5 T&C Agent

The T&C Agent, for the purpose of this document, is the party that conducts, performs, and witnesses the actual and rigorous system testing and commissioning process. The T&C Agent can be a Main Contractor in-house specialized body who works directly under the umbrella of the Main Contractor and whose primary responsibility is to complete the project as per the contractual project duration. The T&C Agent can also be a Specialized Third-Party contractor, providing services to the Main Contractor as appointed by the T&C Authority or the Client, if the Main Contractor's in-house agent is deemed unexperienced or unfit to conduct T&C works for the project. The T&C Agent will directly supervise, lead, and coordinate all T&C activities including integration of Building Services Systems. For the T&C Agent detailed scope of work, refer to Section 5.3.5 of this report.

3.1.6 T&C Third Party Test Entity – Trade Contractor and Equipment Supplier

The Third-Party Test Entity as defined by NFPA 3 and for the purpose of this document, is the party that conducts the actual and rigorous testing for a specialized system or equipment. The T&C Third Party Test Entity is a division of the Trade Contractor which supply and install the specialized system and equipment. (e.g., Honeywell for BMS, Setra for Fire Alarm System, etc.). The Third-Party Test Entity reports directly to the Contractor T&C Agent (In-house T&C Team or Specialized Third Party).

3.1.7 Owner Representative

The Owner Representatives are individuals or firms hired to represent the Owner. Whenever the term is used, this pertains to Consultants and Project Managers, PM, where the Main Contractor's contract is directly under the Client, or Construction Managers, CM, where the Main Contractor's contract is under the Consultant.

3.1.8 Architect / Engineer

The Client appointed Project Design Firm

3.1.9 Owner Operation and Maintenance Staff

The Owner Representative who will maintain the operation of the building services and equipment.

3.1.10 Owner or Client

Whenever the term is used in this guideline, it pertains to the entity, authority, ministry, project direct engineering management staff, and end-users (security, IT, maintenance, medical representatives, etc.) representing the government interest which main responsibility is to develop the OPR prior to the design development stage.

3.1.11 Authority Having Jurisdiction (AHJ)

In case of the Middle East this is the "The Civil Defense" or the HCIS for Industrial Facilities.

3.2 Definition and Purpose of Commissioning Process

3.2.1 The Commissioning Process

ASHRAE, LEED and NFPA currently define Commissioning as a quality focused PROCESS for enhancing the delivery of a project. The process focuses upon verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the Owner Project Requirements (OPR). The Commissioning Process ensures that the building will function as per the owner requirements, the system and equipment will be reliable, operation of the system and equipment will be efficient, the occupants and properties will be safe and protected during any event of fire and evacuation is strategically planned in-case of any emergency event. The Commissioning Process also ensures that the end-users clearly understand the intent of the design as well as the operation and maintenance requirement of the equipment.

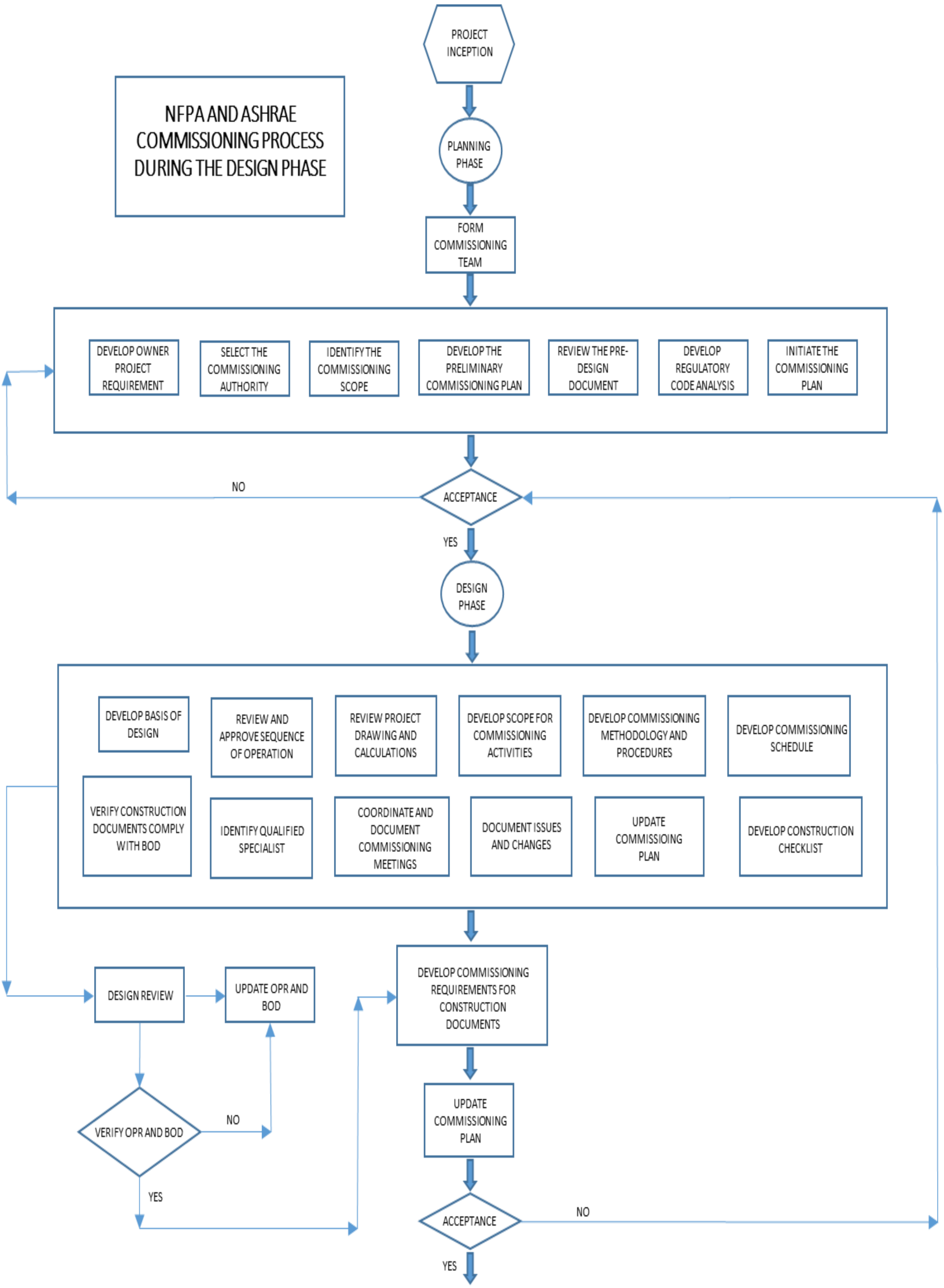
Testing is not Commissioning but is part of it. Whenever this document uses the word "Commissioning Process", it pertains to ASHRAE, LEED and NFPA definition while the term "Testing and Commissioning Work" abbreviated as T&C work pertains to the conventional process which is done at the later stage of the construction phase.

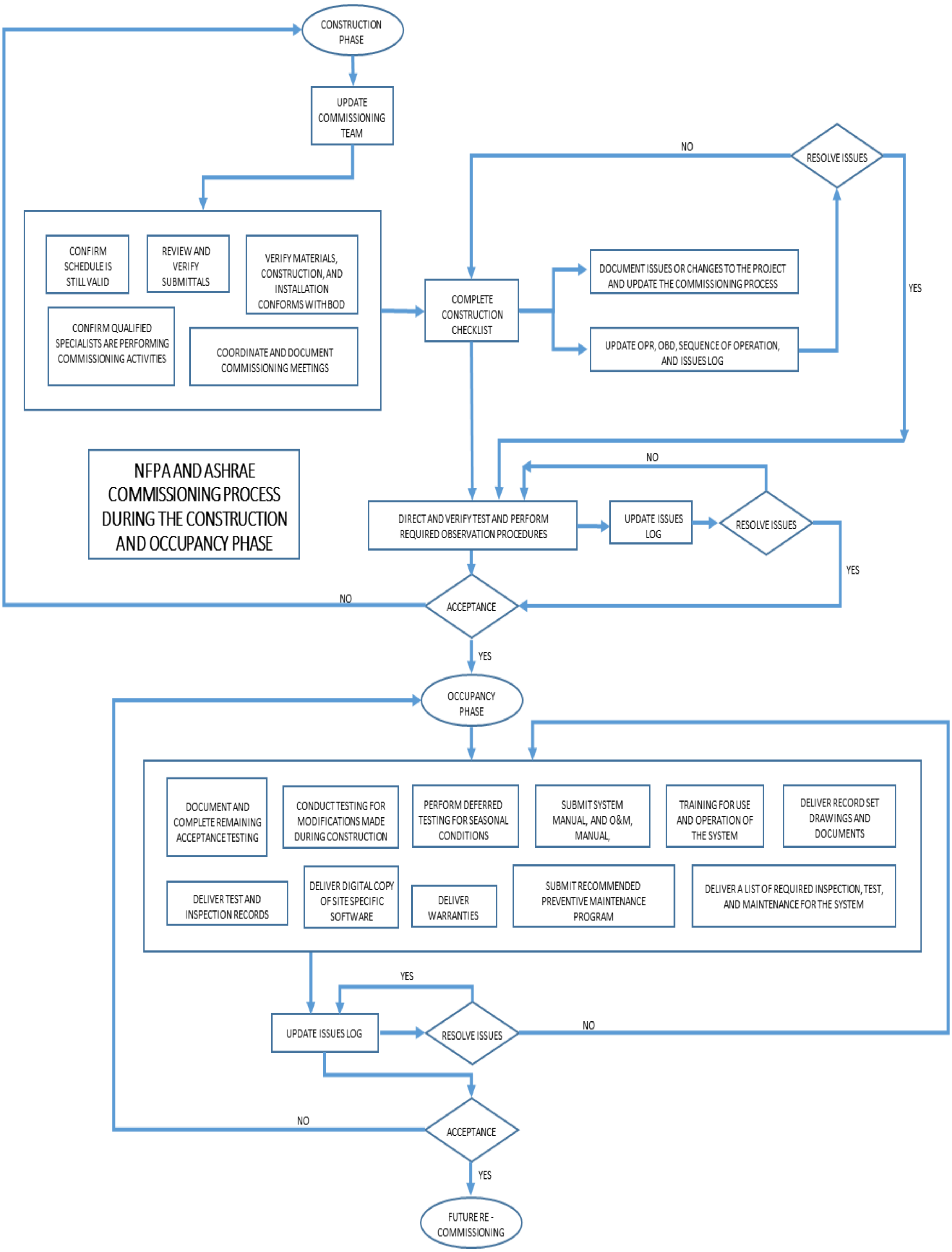
3.2.2 Conventional T&C Work

Prior to the introduction of the revised definition of Commissioning Process, the Conventional T&C work was defined as the PROCESS of inspection and documentation to ensure that the actual installed and tested systems comply to the design intents. There was no Commissioning Authority requirement, and the T&C Agent started the process at the latter part of the construction stage under the shadow and influence of the Main Contractor. T&C work verification was not covered, so there was no requirement to review the BOD and Specification. It was very rare that a project had the OPR, and it was always assumed that the designer completely covered the requirement of the owner and end-users. It was also assumed that the design was produced based on proper engineering practice, compliant with the relevant Codes and Standards and that the project team followed the Specification and correctly made the selection for the equipment, system field devices, and piping accessories. If an error in the selection process for the long lead devices and system accessories was determined during the T&C work stage, compromise and remedies were resorted to since the usual aim of the project team was to beat the handover deadline. This conventional approach is inclined to compromise resulting in end-user complaints and dissatisfaction, reduced performance of the Building Services Systems, unreliability of the system and equipment leading to premature failure and increased risk to the safety of the building occupants and the property itself.

There are many cases in large scale and complex projects that the Contractor In-house T&C Agent were inexperienced, resulting in hiring the service of a Specialized Third Party. Contractors are focused on cost savings and benefits so that the scope of work of the third party is compressed and limited to the extent that even the verification scope is intentionally neglected.

It was because of these reasons that ASHRAE, LEED and NFPA have improved the conventional process and a new and more effective approach has been created.


NFPA AND ASHRAE COMMISSIONING PROCESS DURING THE DESIGN PHASE
PROJECT INCEPTION
PLANNING PHASE
FORM COMMISSIONING TEAM
DEVELOP OWNER PROJECT REQUIREMENT
SELECT THE COMMISSIONING AUTHORITY
IDENTIFY THE COMMISSIONING SCOPE
DEVELOP THE PRELIMINARY COMMISSIONING PLAN
REVIEW THE PRE-DESIGN DOCUMENT
DEVELOP REGULATORY CODE ANALYSIS
INITIATE THE COMMISSIONING PLAN
NO
ACCEPTANCE
YES
DESIGN PHASE
DEVELOP BASIS OF DESIGN
REVIEW AND APPROVE SEQUENCE OF OPERATION
REVIEW PROJECT DRAWING AND CALCULATIONS
DEVELOP SCOPE FOR COMMISSIONING ACTIVITIES
DEVELOP COMMISSIONING METHODOLOGY AND PROCEDURES
DEVELOP COMMISSIONING SCHEDULE
VERIFY CONSTRUCTION DOCUMENTS COMPLY WITH BOD
IDENTIFY QUALIFIED SPECIALIST
COORDINATE AND DOCUMENT COMMISSIONING MEETINGS
DOCUMENT ISSUES AND CHANGES
UPDATE COMMISSIOING PLAN
DEVELOP CONSTRUCTION CHECKLIST
DESIGN REVIEW
UPDATE OPR AND BOD
VERIFY OPR AND BOD
NO
YES
DEVELOP COMMISSIONING REQUIREMENTS FOR CONSTRUCTION DOCUMENTS
UPDATE COMMISSIONING PLAN
ACCEPTANCE
NO
YES


CONSTRUCTION PHASE
UPDATE COMMISSIONING TEAM
CONFIRM SCHEDULE IS STILL VALID
REVIEW AND VERIFY SUBMITTALS
VERIFY MATERIALS, CONSTRUCTION, AND INSTALLATION CONFORMS WITH BOD
CONFIRM QUALIFIED SPECIALISTS ARE PERFORMING COMMISSIONING ACTIVITIES
COORDINATE AND DOCUMENT COMMISSIONING MEETINGS
COMPLETE CONSTRUCTION CHECKLIST
DOCUMENT ISSUES OR CHANGES TO THE PROJECT AND UPDATE THE COMMISSIONING PROCESS
UPDATE OPR, OBD, SEQUENCE OF OPERATION, AND ISSUES LOG
RESOLVE ISSUES
NO
YES
NFPA AND ASHRAE COMMISSIONING PROCESS DURING THE CONSTRUCTION AND OCCUPANCY PHASE
DIRECT AND VERIFY TEST AND PERFORM REQUIRED OBSERVATION PROCEDURES
UPDATE ISSUES LOG
RESOLVE ISSUES
NO
YES
ACCEPTANCE
NO
YES
OCCUPANCY PHASE
DOCUMENT AND COMPLETE REMAINING ACCEPTANCE TESTING
CONDUCT TESTING FOR MODIFICATIONS MADE DURING CONSTRUCTION
PERFORM DEFERRED TESTING FOR SEASONAL CONDITIONS
SUBMIT SYSTEM MANUAL, AND O&M, MANUAL,
TRAINING FOR USE AND OPERATION OF THE SYSTEM
DELIVER RECORD SET DRAWINGS AND DOCUMENTS
DELIVER TEST AND INSPECTION RECORDS
DELIVER DIGITAL COPY OF SITE SPECIFIC SOFTWARE
DELIVER WARRANTIES
SUBMIT RECOMMENDED PREVENTIVE MAINTENANCE PROGRAM
DELIVER A LIST OF REQUIRED INSPECTION, TEST, AND MAINTENANCE FOR THE SYSTEM
UPDATE ISSUES LOG
RESOLVE ISSUES
YES
NO
ACCEPTANCE
NO
YES
FUTURE RE - COMMISSIONING

4.0 REFERENCES

Codes, Standards, Guidelines and Recommended Practice

Engineering Codes and Standards are minimum design requirements that must be implemented without compromise. It is a "Prescriptive Approach" which mandates specific minimum construction practices. Guidelines are "best practice" and synonymous to "Recommended Practice" which is both an optional approach and not prescriptive. ASHRAE usually uses the term "Guidelines" while NFPA uses the term "Recommended Practice".

LEED v4 is a USGBC Certification Program and not a Prescriptive nor a Performance Based Approach. It is a credit point certification based on cumulative points that can be achieved by the project by complying to the requirements of each pre-requisite and credit.

The Code also allows "Performance Based Approach" criteria for designing above that of the "Prescriptive Approach". This approach uses Engineering Analysis and Computer Software to analyze strategy that will be suitable for a certain scenario. A good example is the car parking Jet Fan System which uses "Computational Fluid Dynamics" software to analyze smoke generation and movement. It is a well-accepted fact that this analysis is sufficient and no further "System Performance Test" is required above that of the "Equipment Operational Testing".

It should also be noted that NFPA deals with Commissioning Process for Fire/ Life Safety Systems and do not deal with other Building Services Systems (HVAC, Plumbing, etc.), while ASHRAE and LEED deal with HVAC and other Building Services equipment and systems not related with Fire/Life Safety Systems. ASHRAE and LEED focus on the incorporation of the Commissioning Authority in the Commissioning Process and do not refer to entities such as the T&C Agent (as termed in this report) and Third-Party Test Entity. NFPA 3 and 4 do not put emphasis on the Commissioning Authority but rather incorporate several entities such as Fire Commissioning Agent, Integrated Testing Agency, and Third-Party Test Entity. The SOW of the Commissioning Authority (as defined by ASHRAE and LEED) is limited only to coordination when it comes to NFPA 3 and 4, and the Fire Commissioning Agent is the highest authority when it comes to Fire and Life Safety System Commissioning. NFPA also tends to concentrate only on the scope of the Fire Commissioning Agent, the Third-Party Test Entity, and the Integrated Testing Agency since all the Fire and Life Safety Systems are specialized systems, installed, tested, integrated, and commissioned by Specialized Trade Contractors; unlike HVAC, Domestic Water, and Drainage System which are installed, tested, integrated, and commissioned by the Main Contractor and his T&C Agent. In many cases, the T&C Agent of the Main Contractor is also his installation group. In actual practice, the T&C Agent is the entity which is in direct contact with the PM/CM and Client during the T&C Work, and not the Third-Party Test Entity. The Third-Party Test Entity reports directly to the T&C Agent. The T&C Agent is also the Integrated Testing Agency who is leading, coordinating, and supervising the integration works for non-Fire and Life Safety System (FLS). It is therefore the intention of this Guideline to reconcile and simplify the process by combining entity's' SOW (such as the Commissioning Authority and Fire Commissioning Agent) and introducing a T&C Agent, who acts as the Integrated Testing Agency for all Building Services System (related or not to FLS) and Third-Party Testing Entity for Building Services not related to Fire and Life Safety, as applied in actual construction practice.

Below is the list of Codes, Standards, Guidelines, and Recommended Practice dominantly used for the T&C Process.

- NFPA 3 – Recommended Practice for Commissioning of Fire Protection and Life Safety Systems.
- NFPA 4 – Standard for Integrated Fire Protection and Life Safety System
- ASHRAE Standard 202 – Commissioning Process for Buildings and Systems
- ASHRAE Guidelines 0 – The Commissioning Process
- ASHRAE Guideline 1.1 – HVAC&R Technical Requirements for the Commissioning Process
- ASHRAE Guideline 1.5 – The Commissioning Process for Smoke Control Systems
- NETA Testing Standards and Specification

- IEC and TIA Standards

- BSRIA- Building Services Research and Information Association
- CIBSE - Chartered Institution of Building Services Engineers
- NEBB – National, Environment Balancing, Bureau for HVAC Testing, Balancing & Adjusting
- CSA – Commissioning Specialist Association
- SBC – Saudi Building Code

5.0 RESPONSIBILITIES

5.1 REQUIREMENT FOR THE COMMISSIONING AUTHORITY - SPECIALIZED INDEPENDENT THIRD PARTY

5.1.1 When and why does the Commissioning Authority Need to be "Independent"?

As required by ASHRAE 202, NFPA 3 & 4 and the LEED; the Commissioning Authority needs to be "Independent" from the Design and Construction Team and must report directly to the Client for the following reasons:

- To oversee the T&C work progress and report back to the Client, the true condition of the T&C work against the project time schedule.
- To check and verify that the Contractor T&C Team and Project Management Team are following the approved method statements and T&C Plan.
- To check and verify that all T&C work results are within the allowable limit.
- To check and verify that the Construction Team has followed the Project Specification for the selection of materials and equipment.
- To confirm that the equipment and system are operating as per the OPR and design intent.

Having an independent Commissioning Authority will reassure the Client that impartial reporting by the Construction Team will be avoided.

For small projects with a total area of less than 50,000 $ft^{2,}$ LEED has allowed the Commissioning Authority to be an employee of the Owner, Design Team, or Construction Firm. However, when deciding for the service of the Commissioning Authority for small projects, the complexity of the project Building Services Systems must always be considered, although LEED has generalized small projects based solely on floor area. For instance, Data Centers are normally less in footprint area but the Building Services Systems, especially the Low Current (or ELV in British Standards) are very complex and therefore it is always advised to have an Independent Commissioning Authority.

5.1.2 Project Type Requirement for Commissioning Authority

5.1.2.1 Sustainable LEED Projects

For projects requiring LEED Certification and pursuing "Energy and Atmosphere" credit points, EA Prerequisite 1 (Fundamental Commissioning) and EA Credit 3 (Enhanced Commissioning) requires the mandatory employment by the Client of a Commissioning Authority. Specific SOW (Scope of Work) for each section that is required to be complied with by the Commissioning Authority to attain credit points is as follows:

Task	Responsibility	
	To meet EA Prerequisite 1	To meet EA Prerequisite 1 and EA Credit 3
Designate a Commissioning Authority	Owner	Owner

Task	Responsibility	
	To meet EA Prerequisite 1	To meet EA Prerequisite 1 and EA Credit 3
Document Owner Project Requirement	Owner	Owner
Develop Basis of Design	Design Team	Design Team
Incorporate commissioning requirement into the construction documents	Project Team or Commissioning Authority	Project Team or Commissioning Authority
Conduct commissioning review prior to mid-construction documents	n/a	Commissioning Authority
Develop and implement a commissioning plan	Project Team or Commissioning Authority	Project Team or Commissioning Authority
Review contractor submittal applicable to the system to be commissioned	n/a	Commissioning Authority
Verify the installation and performance of commissioned system	Commissioning Authority	Commissioning Authority
Develop a system manual for the commissioned system	n/a	Project Team and Commissioning Authority
Verify that the requirements for training are complete	n/a	Project Team and Commissioning Authority
Complete a summary commissioning report	Commissioning Authority	Commissioning Authority
Review building operation within 10 months after substantial completion	n/a	Commissioning Authority

5.1.2.2 Non-Sustainable Projects

ASHRAE and NFPA both require a Commissioning Authority to be involved in any project be it small (except for 50,000 ft^2 footprint), medium, or large-scale projects. Commissioning Authority staffing can vary from a single person to handle a small project, to a group of individuals for large and complex projects.

Although cost is a common issue in employing the services of the Commissioning Authority, the Client should consider the benefits of properly commissioned Building Services Systems, which enhance performance and considerably reduce the operational and maintenance cost. Properly commissioned buildings also assure the Client of safely occupied buildings.

5.1.3 Commissioning Authority Scope of Work

The details below list the proposed Scope of Work (SOW) of the Commissioning Authority:

5.1.3.1.1 Initial Planning Stage

- Provide support to develop the OPR and validate it with the client/project sponsor
- Provide support to develop the initial handover plan
- Provide support to develop the project execution strategy

5.1.3.1.2 Tender for Design Stage

- Aid in the selection of an Architect/Engineer for the design work

- Develop a draft commissioning plan
- Review the OPR for clarity and completeness and recommend improvements
- Ensure the scope of work include the requirement of commissioning and handover during the design stage such as check for commissionability, development of TOP and handover plan.

5.1.3.1.3 Design Stage

- Coordinate the commissioning work during design stage
- Assist in developing a Proper Scope of Work and Request for Proposal (RFP) with the Client and Designer.
- Perform reviews of the design, drawings, and specifications at various stages of development (during schematic design, design development, and contract document phases) to incorporate requirements for T&C work.
- Assist, review and approve the development and updating of the Design Record documentation by design team members (Design Intent, Design Narrative, Design Basis)
- Develop full commissioning specifications for all equipment and systems to be commissioned. Coordinate with and integrate into the specifications of the Architect/Engineer. The commissioning specification will include:
    - detailed description of the responsibilities of all parties
    - details of the commissioning process,
    - reporting and documentation requirements including formats,
    - alerts to coordination issues,
    - deficiency resolution,
    - construction checklist and start up requirements.
    - the functional testing process and specific functional test requirements, including testing conditions and acceptance criteria for each piece of equipment to be commissioned
- Coordinate a commissioning meeting where the engineering design team and the Commissioning Authority discuss integration issues between equipment, systems, and controls to ensure that all responsibilities are clearly described in the specifications.
- Review the handover plan and TOPs in alignment with the OPR.

5.1.3.1.4 Tender for Construction Stage

- Attend pre-bid meetings to answer commissioning related questions.
- Aid the Client and his representatives to evaluate capability of the bidding contractor to conduct the T&C work and decide if a Specialized Third-Party T&C Agent is required.

5.1.3.1.5 Construction Stage

- Review and comment the T&C Methodology with the Client Representative and approve the T&C Plan.
- Coordinate and direct the commissioning activities in a logical, sequential, and efficient manner using consistent protocols and forms, centralized documentation, clear and regular communications, and consultations with all necessary parties, frequently review the updated timelines and schedules.
- Plan and conduct commissioning meetings as needed and distribute minutes to the commissioning team
- The Commissioning Authority, through the accountable people, ensures that the construction works are in conjunction to coordinate all testing, inspecting and site-specific activities pertaining to commissioning. The Commissioning Authority must also ensure that all commissioning activities are incorporated into the construction schedule prior to starting the testing and commissioning activities.

- Assist in the development of Scope of Work and Request for Proposal for items not covered in the contract but required to complete the commissioning work
- Review requests for information and change orders for impact on commissioning and owner's objectives
- Review coordination drawings to ensure that trades are making a reasonable effort to coordinate
- Perform site visits, as necessary, to observe component and system installations. Attend selected planning and job-site meetings to obtain information on construction progress. Review construction meeting minutes for revisions/substitutions relating to the commissioning process. Assist in resolving any discrepancies regarding the commissioning of any system or single piece of equipment
- Write and distribute commissioning checklists for all applicable equipment prior contractor start-up. These checklists shall include static inspections, pre-functional tests, functional tests and set point adjustments
- Document systems start up by reviewing start-up reports and by selected site observations
- Maintain a master deficiency log and a separate record of functional testing. Report all issues as they occur directly to the Architect/Engineer Consultant (A/E). Provide directly to the A/E written weekly reports and test results with recommended actions and deficiency updates
- A commissioning report summary which includes a list of participants and roles, brief building description, overview of commissioning and testing scope, and a general description of testing and verification methods to be provided to the commissioning authority for the review. For each piece of commissioned equipment, the report should contain the disposition of the Commissioning Authority regarding the adequacy of the equipment, documentation, and training, meeting the requirements of the contract documents in the following areas: 1) Equipment meeting the specifications 2) Equipment installation 3) Functional performance and efficiency 4) Equipment documentation 5) Operator training
- Review equipment warranties to ensure that the building owner's responsibilities are clearly defined

5.1.3.1.6 Testing and Commissioning Stage

- Request and review additional information required to perform commissioning tasks, including O&M materials, contractor start-up and checkout procedures. Before start up, gather and review the current control sequences and interlocks and work with contractors and design engineers until sufficient clarity has been obtained, in writing, to be able to write detailed testing procedures
- Review normal contractor submittals applicable to systems being commissioned for compliance with commissioning needs and design documents, in conjunction with the Owner Representative review
- Selective witnessing piping pressure test and flushing, sufficient to be confident that proper procedures were followed. Include testing documentation in the Commissioning Record
- Selective witnessing any ductwork testing and cleaning sufficient to be confident that proper procedures were followed. Include documentation in the Commissioning Record
- Validate the completeness of commissioning checklists for both the static and pre-functional testing unless otherwise specified (as this can be undertaken by the T&C Agent). Inspect 100% of the equipment unless otherwise specified
- Validate the approval air and water systems balancing (for non-pressure independent systems) by spot testing and by reviewing completed reports
- With necessary assistance from the specifications and submittals, write the functional performance test procedures for equipment and systems. This will include manual functional testing, energy management control system trending and may include stand-alone data-log monitoring. Submit to the Owner Representative for review and approval if required
- Analyze functional performance trend logs and monitoring data to verify performance.
- Validate the functional performance tests performed by installing contractors. Coordinate retesting as necessary until satisfactory performance is achieved. The functional testing shall include operating the system and components through each of the written sequences of operation, and other

significant modes and sequences, including start up, shutdown, unoccupied mode, manual mode, staging, miscellaneous alarms, power failure, security/fire alarm when impacted and interlocks with other systems or equipment. Sensors and actuators shall be calibrated during construction check listing by the installing contractors and spot-checked by the Commissioning Authority during functional testing. Tests on respective HVAC equipment shall be executed, if possible, during both the heating and cooling season. However, some overwriting of control values to simulate conditions shall be allowed. Functional testing shall be done using conventional manual methods, control system trend logs, and read-outs or stand-alone data loggers, to provide a high level of confidence in proper system function.

- Validate the possibility to perform the training of the building owner's operating personnel and end-users.
- Validate the compilation of a Commissioning Report, which shall include:
    - All outstanding non-compliance items shall be specifically listed. Recommendations for improvement to equipment or operations, future actions, commissioning process changes, etc., shall also be listed. Each non-compliance issue shall be referenced to the specific functional test, inspection, trend log, etc. where the deficiency is documented.
    - Also included in the Commissioning Record shall be the issues log, commissioning plan, progress reports, submittal and O&M manual reviews, training record, test schedules, construction checklists, start-up reports, functional tests, and trend log analysis
    - the Operations and Maintenance (O&M) Manual submitted by the T&C Agent with the Client Representatives prior to submission to Client and his end-user.

5.1.3.1.7 Handover and Closeout Stage

- Coordinate and supervise required seasonal or deferred testing and deficiency corrections and provide the final testing documentation for the Commissioning Report and O&M Manuals
- Return to the site at the 10th month after the preliminary handover and lead a satisfaction review with facility staff of the current building operation and the condition of outstanding issues related to the original and seasonal commissioning. Also, interview facility staff and identify problems or concerns that they may have with operating the building as originally intended. Make suggestions for improvements and for recording these changes in the O&M Manuals. Identify areas that may come under warranty or under the original construction contract. Assist facility staff in developing reports and documents and requests for services to remedy outstanding problems.

5.2 Requirement of contractor T&C agent/third party

A T&C Agent can be a Contractor in-house specialized entity or a Third-Party providing service to the Contractor as appointed by the Client, his representative, or the T&C Authority. The sections below explain the factors affecting these variations in actual projects. As explained in the previous section of this Guideline, the codes and standards do not use any language to force the Contractor to hire a Specialized Third Party.

5.2.1 Factors Affecting Variations in T&C Agent (In-House or Third Party) Scope of Work

5.2.1.1 Project Scale and Complexity

Small projects that contain relatively simple electro-mechanical systems are normally handled by the Main Contractor In-house T&C Agent. As LEED does not require an Independent T&C Authority for building with total area below 50,000 $ft.^2$, it is safe to conclude that a Specialized Third-Party Agent will not be required for the same footprint. An exemption to this rule is when the small-scale project contains complex electro-mechanical systems such as in the case of Data Centers, which require precise control of room temperature and humidity as well as redundancy for both mechanical and electrical systems. Data Centers contain thousands of cables for IP Based Low Current Systems and Data Infrastructures, which require thorough testing for the cables alone. Considering the extent of mechanical, electrical, and Low Current infrastructure and required reliability, the service of a Third-Party T&C Agent is highly recommended.

In the case of a high-rise healthcare project that was recently completed in Riyadh containing state-of-the art electro-mechanical systems, each patient floor contains around 700 to 900 Ethernet cables for structured data cabling alone (this does not include non-data cabling such as Fire Alarm System, Security and Access Control System, etc.) which requires testing for continuity, insulation resistance, insertion losses, polarity, etc. The cable testing needs to be 100% witnessed by the Owner Representative (CM or PM) as required by the Standards, to ensure cable integrity and correct termination to cable jacks. This condition will require eight (8) Low Current Engineers just to witness the cable test for three (3) months of work. Considering quality control procedures that the test must be done internally by the Main Contractor prior to offering for inspection to the Owner Representatives, this will again extend the project duration from six (6) to eight (8) months. Many tests will need to be completed (see Section 6.4 of the Guideline for all test required for Low Current System) and considering the tests that are required for all electro-mechanical systems for healthcare by using the procedure used for small scale projects using contractor in-house T&C Agent, it will require longer period to complete the T&C work. The standard practice to overcome this problem is to include in the contract specification the requirements for a reputable Specialized Third-Party T&C Agent to be appointed by the Client, his representative, or the T&C Authority to work under the umbrella of the Main Contractor. In this manner, the Third-Party Agent will witness and validate the test result directly with the Main Contractor, and the Owner Representative and the T&C Authority will only have to witness and validate 10% of the cable quantity to be tested. It is a standard practice that if a reputable Third-Party T&C Agent is employed, all tests to be witnessed by the Owner Representative and T&C Authority shall be reduced to 10% and randomly selected. The Third-Party acts as an independent entity to ensure quality control.

5.2.1.2 Contract Condition

Projects vary regarding the SOW of the T&C Agent because of the conditions stipulated in the Contract Specification. Designers are mostly inexperienced in regard to the Commissioning Process and are not aware of the requirements for Specialized Third-Party Entity particularly in large and complex projects. This results in the Main Contractor undertaking the T&C using his own in-house staff and then subsequently discovering that he is incapable of conducting the T&C works. Specifications are prepared typically from project to project by Designers not differentiating the complexity of the electro-mechanical systems from small, medium, large, and complex projects.

Many Specifications have been prepared inconsistently requiring Specialized Third Party for some discipline and not for the others. Consider the KFSH Project Specification where a clause was included to hire a Specialized Third Party to conduct the Mechanical and Electrical Systems T&C but nothing was indicated for the Low Current Systems. The clause that was used to require the Third Party was vague and did not specify the SOW which lead to confusion, arguments, and endless discussion. To resolve the argument and confusion, it was decided to limit the Specialized Third-Party Agent scope to supervision and verification only and the T&C work itself to be conducted by the Main Contractor (e.g., TAB works, flushing, cable testing, etc.).

To prove the resiliency and reliability of the building, it was necessary to verify the Low Current Systems, including the integration of all the Building Services and Life/Safety Systems, by a Specialized Third Party. However, this requirement was not included in the Specification and BOQ. Hence, the most critical of all work was not included in the contract, which was a vital mistake on the part of the Designer. This is one of the reasons why the code and standards require the Commissioning Authority and Designer to prepare the T&C Specification separately from the General Specification. It is the responsibility of the T&C Authority to aid the Client and his representatives during the bidding stage to assess the capability of the Main Contractor to conduct the T&C work and decide if the Specialized Third-Party Agent will be required, particularly for medium size projects.

5.2.1.3 General / Main Contractor Qualification

There is a common saying in the construction industry that “not all contractors are the same”. Qualifications of Main Contractors with regards to T&C work varies, but most do not possess the required expertise and reputation to conduct the T&C works especially for large and complex projects. During the bidding process, it is the duty of the Commissioning Authority to evaluate the bidder's capability and expertise to determine if a Specialized T&C Third Party Agent is required. The qualifications usually rely on the following information.

- Records of completed projects
- Awarded Extension of Time for each project
- Client satisfaction report
- T&C team structure which includes qualifications, certifications, employment history, and completed projects.
- Rating of T&C Team staff based on technical interviews
- T&C documentation and Quality Control
- Categorical level for electro-mechanical works as determined by local authorities
- Trade Contractor report – specialty trade contractors involved in BMS and Fire Alarm Systems

SOW of the Third Party can vary from supervision, verification/validation, and doing the actual rigorous work based on the evaluation of the T&C Authority. For instance, several Main Contractors have technicians qualified to do TAB works, air and hydronic flushing, and cable testing; therefore, the scope of the Specialized Third Party can be reduced to perhaps supervision, coordination, and verification/validation.

5.2.1.4 Client Financial Budget

It is a well-known fact that Specialized T&C Third Parties are very expensive and add considerable burden to the over-all project cost. It is always desirable to reduce the SOW of the Third Party to the minimum and avoid any work overlapping/redundancy with the Commissioning Authority to reduce the overall project cost. Refer to the succeeding sections of this Guideline for the proposed SOW of the T&C Agent.

5.2.2 T&C Agent Division and Scope of Work (SOW)

This section discusses the division and SOW of the T&C Agent as it is applied to the in-house contractor T&C Team or a Specialized Third Party, which is mobilized during the Pre-commissioning phase or T&C Work phase. The T&C Agent is divided into the Management Level and Site-Based T&C Group with the following Scope of Work (SOW);

5.2.2.1 T&C Management

Consists of an experienced and qualified T&C Manager with the following SOW;

- Verification/validation
  - To check and report any deviation from the OPR to the BOD and actual installation.
- High level assessment of shop drawings for commissionability
  - To check and report any anticipated technical problem that will hinder progress in the T&C Process such as issues with accessibility, missing dampers, uncoordinated protective breakers, undersize feeders/breakers/ducts/pipes, etc.)
- Preparation of T&C report to Client Representatives
  - The report includes Site Observation and Defects, T&C Progress, T&C Coordination Meeting Minutes, and T&C Activity Sheets
- Coordination and reporting to the Commissioning Authority
- Management of T&C work activity and progress monitoring which includes coordination meetings with Trade Contractors and T&C staff.
- Review and finalization of T&C Plan and Methodology
- Lead, manage, coordinate, and accept Trade Contractor electro-mechanical system as stand-alone.
- Lead, manage, coordinate, and accept integration activities with Trade Contractors

- Lead the compilation, review, and preparation of the O&M Manual, As-built drawings, and Systems Manual.
- Lead the preparation of training and site demonstration for all Building Services.
- Lead and supervise site-based T&C Group
- Return to site after 10 to 12 months from Preliminary Handover and lead final satisfaction review with the Client, Commissioning Authority, PM/CM, end users, and Facility/ Maintenance staffs.

5.2.2.2 Site Based T&C Group

Consists of T&C Supervisor/Lead and Technicians with the following SOW;

- Scope of Work and Responsibilities (General)
    - Inspection of installation to determine deviation to shop drawings
    - Inspection of the actual installation location for accessibility
    - Site observation and defects reporting to the T&C Manager
    - Lead, supervise, and witness Building Services stand-alone Testing and Commissioning
    - Lead, supervise and witness Building Services and Fire/Life Safety integration
    - Lead, supervised and witness Power Failure Testing
    - Lead the preparation of Site Observation/Defects Report and Progress Report to the T&C Manager
    - Lead the filling up of all testing package /templates with the PM/CM, and Commissioning Authority.
- Scope of Work – Mechanical
    - Lead/Supervise hydronic and air flushing
    - Conduct or supervise Testing and Air/Hydronic Balancing (TAB)
    - Conduct or witness acoustic and vibration testing
- Scope of Work – Electrical
    - Conduct or witness thermal scanning of equipment, cables, bus bars, and bus ducts.
    - Conduct or witness cable testing
    - Conduct or witness electrical cold and live testing
- Assisting and Witnessing of T&C works
    - Equipment Pre-Start up and Operational/Functional Testing
    - Equipment Performance Testing
    - Electrical system energization
    - Witnessing for water treatment or any bacteriological testing

5.3 DIVISION OF WORK AND RESPONSIBILITIES

To have a successfully commissioned project, it is essential to have good collaboration between project team members and each member must have a good understanding of his responsibilities. The project team members comprise of the Client, Commissioning Authority, Designers (Architect/Engineer), Client Representative (Consultant/CM or PM), Construction Contractor, T&C Agent, and Owner Operation & Maintenance Personnel. The following sections summarized the proposed responsibilities of each project team member.

5.3.1 Client

5.3.1.1 Planning Stage

- Lead in identifying the Commissioning Team.

- Lead in the provision of contract for Commissioning Authority services.
- Lead in the development of the preliminary OPR document.
- Lead in the development of preliminary commissioning scope and plan
- Establish budget for all commissioning work and integrate cost into the project budget.
- Ensure that proper commissioning schedule is included in the initial project schedule.
- Include commissioning responsibilities in the designer and CM/PM scope of service.

5.3.1.2 Design Stage

- Participate in the design stage of commissioning meetings.
- Responsible for identifying project-specific responsibilities.
- Responsible in identifying limit of contract and scope between Main Contractor and Client supplied specialty contractors.
- Responsible for identifying Owner supply equipment and furniture.
- Support and provide assistance in the review of the OPR for completeness and clarity with the Designer and Commissioning Authority. Review and Accept changes in the OPR based on design review with the Commissioning Authority, Owner Technical Support (Facility and Operation as well as end-user) and Designer.
- Acceptance of the developed BOD.
- Participate in the review of focus based commissioning review of design drawings and Specifications and other constructability reviews.
- Lead in the acceptance of appropriate changes to construction documents based upon design reviews.
- Participate in the initial preparation of the Commissioning Specification and testing protocols.
- Review and accept integration of Commissioning activity/schedule into the general project schedule.
- Review and accept building services integration proposals and responsibilities between equipment, systems, and disciplines.
- Review and accept revised Commissioning Plan.
- Incorporate Commissioning requirements into the Main Contractor scope of work.

5.3.1.3 Construction Stage

- Accept any revision in the Commissioning Plan as required.
- Participate in the technical review of submittals for critical equipment to check compliance to Specification and Project Contract.
- Responsible for mobilization of specialty contractor as per the general project schedule and delivery of Client supply equipment and furniture.
- Accept functional test procedures and documentation format for all equipment and system to be commissioned.
- Review and accept request for information and changes for impact on Commissioning.
- Maintain record of drawings and equipment list as detailed in the construction documents.
- Perform occasional quality control inspections.
- Review, comment, and accept commissioning progress reports and records.
- Review, comment, and accept hand-over package deliverables.
- Participate in commissioning meetings.
- Review and provide assessment for all outstanding issues prior to handover.
- Address concerns with facility management and end-user.

5.3.1.4 Testing and Commissioning Stage

- Review, comment, and accept commissioning progress reports and records.
- Review, comment, and accept hand-over package deliverables.
- Participate in commissioning meetings.
- Address concerns with facility management and end-user.
- Acceptance of the Preliminary Handover with the following attached documents:
    - Preliminary Completion Letter/Certificate from the PM/CM with the Preliminary Completion Notice signed and certified by the Main Contractor and his T&C Agent (or Third Party as applicable), and the Commissioning Authority.
    - Installation deficiency report (punch list).
    - Deferred and seasonal testing report.
    - Certificate of Completion for all electro-mechanical services from Third Party T&C Agent (as applicable), Trade Contractors and Suppliers.
- Acceptance of the O&M Manual reviewed and attested by the PM/CM and the Commissioning Authority.
- Acceptance of the As-Built drawings signed and attested by the PM/CM and Main Contractor.
- Participate in implementing training program for end-users.
- Review and accept request for information and changes for impact on Commissioning.

5.3.1.5 Handover and Closeout Stage

- Acceptance of the Final Handover Notice from the Contractor with the following attached documents;
    - Installation deficiency completion report signed and attested by the end-user and facility management.
    - Deferred and seasonal testing completion report signed and attested by the Contractor and his T&C Agent, and the Commissioning Authority.
- Acceptance of final satisfaction review with the Commissioning Authority 10 month after the Preliminary Handover (For LEED Projects) or as included in the Main Contractor Contract.

5.3.2 Commissioning Authority

- Refer to Section 5.1.3 of this Guideline for the T&C Authority responsibilities

5.3.3 Project Designer (Architect/Engineer)

5.3.3.1 Design Stage

- Participate in design stage commissioning meetings.
- Participate in identification of project-specific responsibilities.
- Review the OPR for completeness and clarity and raise any concerns for improvements.
- Responsible for developing the BOD.
- Provide assistance in focus commissioning review of design drawings, Specifications, and constructability reviews and lead in incorporating appropriate changes to the construction documents upon review completion.
- Provide assistance in refining the OPR requirements based upon design stage decisions.
- Provide assistance in creating Commissioning Specification including testing protocols for all equipment and systems to be commissioned.

- Update all parties in writing regarding the Commissioning activities integrated into the general project schedule.
- Lead and coordinate integration issues and responsibilities between equipment, system, and discipline.
- Lead the development and coordination of the BMS Data Point Schedule, Process and Instrumentation Diagram, and Sequence of Operation.
- Lead the development and coordination of the Fire Alarm System Cause and Effect Matrix.
- Update all parties in writing regarding updates of Commissioning Plan.
- Provide assistance in incorporating the Commissioning requirements into the construction contractor scope of work.

5.3.3.2 Construction Stage

- Review and provide comments in the revision of Commissioning Plan as required.
- Assist in the review of submittals applicable to the equipment and systems to be commissioned and confirm the accuracy and completeness of the project submittals for construction quality control and specification conformance.
- Review and comment in the development of the functional / performance test procedures and documentation formats for all equipment and system to be commissioned.
- Confirm the accuracy and completeness of the commissioning requirements and activities in each purchase order and subcontracts.
- Lead in the development of construction and commissioning checklist for equipment and systems to be commissioned.
- Confirm the completeness of installed components and systems.
- Confirm the accuracy of the RFI (Request for Information) and changes for impacts on commissioning.
- Confirm the accuracy and completeness of the demonstrated operation of the system.
- Accept the completed construction checklist as the work is accomplished.
- Confirm the accuracy and completeness of the maintained record construction drawings against the submitted documents.
- Lead and accept functional testing for all commissioned system and equipment.
- Participate in quality control inspections.
- Review and provide comment in the commissioning progress report.
- Participate commissioning meetings if required.
- Lead in reviewing equipment warranties to ensure owner responsibilities are clearly defined.
- Provide assistance and confirm completeness of the delivered hand-over package.

Testing and Commissioning Stage

- Confirm the accuracy and completeness of the demonstrated operation of the system.
- Participate commissioning meetings if required.
- Lead in reviewing equipment warranties to ensure owner responsibilities are clearly defined.
- Provide assistance and confirm completeness of the delivered hand-over package.
- Confirm completeness in the delivery of Commissioning Records.

Handover and Closeout Stage

- Provide assessment and review of deficiency correction report, deferred seasonal testing report, and other outstanding issues.
- Provide assistance regarding concerns of operating facility as required.

5.3.4 Client Representative - Consultant/Project Managers or Construction Managers

5.3.4.1 Design Stage

- Participate in design stage commissioning meetings.
- Advise, recommend, and participate in identifying project specific responsibilities.
- Advise, recommend, and participate in the review of the OPR and BOD for completeness and clarity.
- Provide assistance in the focus review of design drawings and Specifications.
- Lead in the project constructability reviews.
- Check update of construction documents based on design reviews.
- Check update of OPR based upon design stage decisions.
- Provide assistance in the preparation of Commissioning Specification including testing protocols for all equipment and systems to be commissioned.
- Provide assistance in the update of Commissioning Plan.
- Lead in incorporating all the Commissioning requirements into the construction contractor scope of work.

5.3.4.2 Construction Stage

- Review and accept submittals applicable to equipment and systems to be commissioned for quality control and compliance to Specifications.
- Provide assistance in the development of functional/performance test procedures and documentation format for all equipment and systems to be commissioned.
- Ensure to keep updated construction checklist for equipment and systems to be commissioned.
- Inspect and accept installed components, equipment, and system.
- Provide assistance in the review of “Request for Information” and changes for the impact on Commissioning.
- Witness and accept all construction testing and other pre-commissioning testing for equipment, components, assembly, and system and maintain records for completed items.
- Lead in maintenance of commissioning progress records.
- Lead all commissioning meetings.

5.3.4.3 Testing and Commissioning Stage

- Lead in maintaining master issues log.
- Provide assistance in the compilation and delivery of hand-over package, commissioning records, and system manuals.
- Lead in implementing training for end-user and facility personnel.
- Lead in maintenance of commissioning progress records.

5.3.4.4 Handover and Closeout Stage

- Provide assessment, review, and acceptance of deficiency correction report, deferred seasonal testing report, and other outstanding construction issues.

- Provide assistance regarding concerns of operating facility as required.

5.3.5 T&C Agent

- Refer to Section 5.2.2 of this Guideline for the T&C Agent responsibilities

5.3.6 Owner Operation and Maintenance Personnel

5.3.6.1 Planning Stage

- Provide assistance in identifying the Commissioning Team, developing the Preliminary OPR, Preliminary Commissioning scope and Preliminary Commissioning Plan.
- Provide assistance in establishing budget for all Commissioning Work and integrating cost to the project budget.

5.3.6.2 Design Stage

- With the Client, lead and identify project specific requirements for maintenance.
- Participate in design stage commissioning meetings.
- Review updates to the OPR documents for completeness and clarity.
- Participate in the review and provide comments in the developed BOD.
- Participate in the focus review of design drawings and specifications and oversee to incorporate appropriate changes to the construction documents.
- Review and provide comment in the completed Commissioning Specification and testing protocols.

5.3.6.3 Construction Stage

- Provide assistance in the development of functional/performance test procedures and documentation format for all equipment and systems to be commissioned.
- Participate in commissioning meetings.
- Participate in implementing training program for facility personnel.
- Review and accept handover package (composed of O&M Manual, As-built drawings, and System Manual).

5.3.6.4 Testing and Commissioning Stage

- Participate in commissioning meetings.
- Participate in implementing training program for facility personnel.
- Review and accept handover package (composed of O&M Manual, As-built drawings, and System Manual).

5.3.6.5 Handover and Closeout Stage

- Provide assistance in the assessment, review, and acceptance of deficiency correction report, deferred seasonal testing report, and other outstanding construction issues.
- Provide assistance for the final satisfaction review after 10 (ten) months of occupancy.

6.0 PROCESS

6.1 T&C Work Program during the Construction Stage

6.1.1 Definition of Terms

6.1.1.1 First Fix

- Refers to the installation of piping and ducting, supports, and cable conduits.

6.1.1.2 Second Fix

- Refers to the installation of insulation for piping and ducting, piping, and ducting accessories, above ceiling equipment and devices, cable installation, equipment installation, and painting works.

6.1.1.3 Third Fix

- Refers to the installation of ceiling, wall, and floor fixtures and devices such sprinkler head, diffusers, Access Points, smoke detectors, light fixtures, speakers, manual pull stations, convenience outlets, water closets, floor drains, clean out, etc.

6.1.1.4 Pressure Independent System

- Refers to HVAC air and water distribution system in which pressure fluctuations resulting from the movement of the terminal control device or terminal equipment, because of the changes in the demand, does not affect or minimally effect the distribution downstream of the control device or equipment. The terminal equipment or device is not affected by the upstream pressure fluctuation as long as the minimum operating upstream pressure is satisfied. Example is the use of Pressure Independent VAV System in air distribution or PICV valve in the chilled water system.

6.1.1.5 Pressure Dependent System

- Refers to the system opposite of the Pressure Independent System. The distribution of air or water downstream of the control valve or equipment is greatly affected by the fluctuation of pressure in the upstream of the control valve or equipment due to changes in demand.

6.1.1.6 Dedicated Smoke Control System

- A smoke control system designed and arranged to run only during a fire condition. It is a dedicated system, which is intended and specifically listed for smoke-control purposes only.

6.1.1.7 Non-dedicated Smoke Control System

- A smoke control system designed and arranged to be used in HVAC System in normal conditions and smoke control in emergency fire condition. Non-dedicated smoke control shares components with other Building Services System such as HVAC.

6.1.1.8 Compensated Staircase Pressurization System (SPS)

- An SPS System that maintains the required pressure differential with minor fluctuations either by variable speed control, relief damper, variable pitch fans, etc. A non-compensated system operates in a differential pressure within tolerable range, say from 25 pa to 50 pa.

6.1.1.9 Structured Cabling

- Composed of horizontal cabling (UTP or STP cables) and cable management (trays, basket, and trucking) system, telecommunication outlets (RJ45 plugs and pins), patch panels, switches and routers, signal boosters (or repeaters) and backbone cabling (riser type UTP cables and Fiber Optics). Structured cabling is used for voice and data transmission.

6.1.1.10 Auxiliary Power

- Pertains to the power supplied to equipment controllers and field controllers separate from the normal power source.

6.1.1.11 Load Shedding

- An electrical power feature that removes or delays power supply to equipment of secondary importance because of the unavailability of the emergency power system to support the full building equipment and systems power supply.

6.1.2 T&C Plan and Methodology

The first step prior to conducting the rigorous conventional T&C work is for the Commissioning Authority to prepare the final T&C Plan in coordination with the T&C Team. In a conventional set-up where the Commissioning Authority service is not available, the T&C Plan is prepared by the T&C Agent in the later stage of the project construction phase prior to the T&C work mobilization. The T&C Plan is systematic and project tailored documentation on how to complete the T&C for a given scope of work in a given project time duration. It outlines the scope and extent of the work, organization, schedule, allocation of resources, and coordination planning.

The T&C Plan consists of the following:

- General Project Information
  - Contains project overview emphasizing key project information and delivery method characteristics, including the OPR and the Project BOD.
- Scope and list of systems and equipment covered under the T&C Program
  - This section lists all the systems and equipment covered under the T&C Program and indicates their location and quantity. It also provides a list of the system and equipment not covered in the SOW of the Third-Party T&C Agent, if employed.
- System Descriptions
  - This section provides a narrative for the Building Services Systems on how it was designed. For instance, Centralized VAV All Air System using centralized chilled water, Double-ended Substation with Emergency Generator, Up-feed constant pressure variable speed drive booster pumping system, combined soil and waste stack system, Integrated Building Management System, Combined or separate sprinkler and hose risers, etc.
- Overview of the T&C Strategy
  - This section provides narrative on the strategy of how to prove the verification/validation works and that the contractor complies with the Specification rigorously. It also includes the strategy on how to carry the T&C Process from the Pre-design phase to the post-acceptance phase (e.g., Commissionability study, method statement production, O&M Template and contents, installation monitoring, etc.)
- T&C Milestone Schedule
  - A chart representation of the overall T&C Schedule in-coordination to the General Project Construction Schedule. This provides information about individual equipment/system T&C timing and manpower loading.
- T&C Organizational Chart

    - Provides list of individuals, which will form the T&C Team and provides schematic details who reports to whom. Designation of each individual is also indicated as well as their contact information.
- Reporting procedure for progress, defects, and corrections
    - Provides information to whom the reports will be submitted and from whom copies will be furnished. The document discusses timings of report submission and expected duration of defects correction in coordination with the contractor.
- Division of Responsibility – refer to Section 5.3 of this Guideline for explanation
- T&C Templates and checklist

The T&C Methodology is a written protocol which defines procedures and expectations for testing conducted on equipment, assemblies, systems, and interfaces (or integration). The document includes test prerequisites, test conditions, limitation and tolerance, tools and instruments to be used, schematics, and safety risk assessment. The T&C Methodology is prepared by the entity who is responsible for the work. For instance, equipment suppliers prepare method statements for their equipment functional testing and performance testing, followed by the review and preliminary approval of the T&C Agent prior to submission to the Client Representative and Commissioning Authority for final approval. Specialty Trade Contractors (e.g., Honeywell) prepare the methodology for his specialized system (BMS) T&C prior to the review and preliminary approval of the T&C Agent. Methodology for Integration between specialized systems is prepared by the T&C Agent in coordination with Specialty Trade Contractors. Some methodology for specialized work needs to be prepared by the T&C Agent himself such as the TAB (Testing and Air Balancing). Below is the common list of T&C Methodology that is normally prepared in a complex high-rise healthcare project.

- T&C Methodologies prepared by the T&C Agent:
    - Hydronic and air flushing
    - T&C of chilled water system
    - T&C of the Air Distribution System
    - T&C of domestic water system
    - T&C of the Sprinkler and Hose System
    - T&C of the Drainage System
    - Testing for Electrical System – To include Cold and Live Testing, Earth Electrodes, Distribution Boards, Switchgears/Switchboards, Transformer, RMU, Motor Control Centers, UPS, ATS, Auxiliary Power, and Lightning Protection System
    - T&C of Emergency Power System
- T&C Methodology prepared by the Specialty Trade Contractors to be reviewed and preliminarily approved by the T&C Agent:
    - T&C of Specialized Fire Suppression System - Clean Agents (NOVEC, FM-200, Carbon Dioxide, etc.) and Pre-action System
    - T&C of Pneumatic Transfer System
    - T&C of Building Management System
    - T&C of Fire Detection and Alarm System (FDAS)
    - T&C of Access Control and CCTV (or a separate methodology for IP CCTV)
    - T&C of Data Network System
    - T&C of Public Address System
    - T&C of Nurse Call System
    - T&C of Telephone Network System (and/or VOIP –Voice over IP)
    - T&C of Door Entry and Intercom System
    - T&C of Master Clock System
    - T&C of Real Time Location System
    - T&C of Wireless Network System
    - T&C of Audio-Visual System

    - T&C of Digital Signage System
    - T&C of Car Parking Management System
- T&C Methodologies prepared by the T&C Agent in coordination with Trade Contractors:
    - T&C of FDAS and Fire/Life Safety Integration
    - T&C of the Mechanical System Integration
    - T&C of the Low Current System Integration
- T&C Methodology prepared by the Equipment Suppliers to be reviewed and preliminary approved by the T&C Agent:
    - Functional Testing of Mechanical and Electrical Equipment (see Functional Testing Section 6.1.4.4 for the list of equipment)
    - Performance Testing of Mechanical and Electrical Equipment (see Performance Testing Section 6.1.4.5 for the list of equipment)

6.1.3 Pre-Requisites Prior to T&C Mobilization

Before the start of the T&C work mobilization, certain documents need to be in place and preparations need to be completed for the T&C work to go smoothly and unhampered. Specialized Third Party T&C Agents are very expensive and are usually under a man-days type of contract. Third Party costs can consume the contract budget even they are idle and unproductive due to unfinished work and unavailable resources which is under the scope of the Main Contractor.

The following documents and resources must be available, and this requirement must be complied by the Main Contractor and forwarded to his T&C Agent.

Certificates that are required:

6.1.3.1 Equipment Factory Acceptance Test Certificate (FAT)

The FAT is provided by the manufacturer and certifies that the equipment was built and tested in compliance with the requirement of the Standards for equipment testing. The FAT contains data gathered during testing to prove the ratings have been achieved. It is signed and certified by accredited witnessing Third Party Agency separately from the Client Representative who witnesses the test as required or not by the contract. Certain equipment such as chillers where performance can only be proven in the factory must always be witnessed by the Client Representative since site performance testing is not possible (ambient temperature is not possible to control unless in factory setting). FAT certificates form part of the handover document and System Manual.

6.1.3.2 Type Testing Certificate (TTC)

TTC is provided by the manufacturer which is applicable to Switchgear, Switchboard, panel board, bus bar and other static electrical equipment. The Type Tested Assemblies (TTA) or Partially Type Tested Assemblies (PTTA) Certificates confirm that the equipment complies with the requirement of IEC regarding safety, reliability, and maintainability. The Certificate is signed by an accredited witnessing Third Party Agency and will form part of the handover document and System Manual.

6.1.3.3 System Installation Acceptance and Sign-Off Certificate

All Building Services System installation to include second fix (insulation for piping, above ceiling equipment and devices, etc.) must be inspected and accepted by the Client Representatives. All preliminary construction testing such as gravity testing for drainage, pressure testing for piping, and cable testing (except structured cabling) must be completed. Third fix (ceiling installed fixture such as air diffusers, sprinklers, smoke detectors, speakers, etc.) must be available and terminated. All approved RFI (Request for Inspection) and MIR (Material Inspection Request) to prove completed installation and testing will form part of the handover document and System Manual.

Documents that are required for preparation to T&C:

6.1.3.4 Fire Alarm System Cause and Effect Matrix (C&EM)

This is a table format representation of how the Fire/Life Safety System is expected to respond at each floor level or zone upon activation of an initiating device (smoke and heat detector, manual pull station, and flow switch). The table also shows time delays upon activation of Notification Appliances (speakers and strobes) and electro-mechanical Fire/Life Safety Systems. The C&EM is used by programmers to provide equations to the Fire Alarm Panels. This document is prepared by the Specialist Trade Contractor in coordination with the Designer and form part of the System Manual.

6.1.3.5 BMS Data Point Schedule, PID and Sequence of Operation

Refer to Section 6.2.2 of this Guideline for information.

6.1.3.6 Evacuation Plan

The document will be significant for high-rise building application where elevators are planned to be used for immediate evacuation of patients in upper floors as allowed by Codes. The Evacuation Plan will also aid the Commissioning Authority and Project Team in fire drill evacuation to identify priority levels, programming of Fire Alarm Panels for notifications, and identification of assembly sites. This document is prepared by the Designer in coordination with the Authority Having Jurisdiction (AHJ).

6.1.3.7 Equipment Cut Sheets/ Catalogue

Equipment performance characteristics provided by manufacturers are required to assess data obtained from the equipment during the testing phase.

Resources that must be available prior to commencing T&C:

6.1.3.8 Availability of As-Built Drawings

As-built information is critical for T&C Agent initial work to identify errors in the installation, which requires modification or missing accessories (such as dampers for TAB) which can hinder progress in T&C work. As built is extremely important for structured cabling for the cable Wire Map Testing (WMP) and other testing to proceed. Labelling on both ends of the data cabling must coincide with the As-built drawing for ease of cable testing.

6.1.3.9 Availability of Permanent Stable Power

The use of generators as a source of power can damage electronic equipment and control due to power fluctuations and is not recommended to be used during T&C work. It is recommended to use permanent electric power to ensure source stability.

6.1.3.10 Availability of Potable Water for Flushing

For the effectiveness and to reduce time duration for flushing, it is always recommended to use potable water to ensure that TDS and bacteria are within acceptable limit.

6.1.3.11 Availability of Drainage System

Flushing activities consumes a lot of potable or clean water which discharges to the drainage system so that the permanent drainage system is required to be complete prior to the commencement of the flushing activities. For flushing of systems containing harmful chemicals, it is required to coordinate with local authorities prior to discharge since most of building wastewater goes to local wastewater treatment plant. Chemicals can kill aerobic bacteria, which are the microorganisms that decompose organic (or biodegradable) waste materials.

6.1.4 Preliminary Phase – Pre-commissioning

This section discusses work preparations that are required during the construction stage prior to the mobilization of the T&C Agent. In the conventional method, this is the work required to be completed after the second fix. As an acceptable practice, Conventional T&C work starts after the third fix has been completed. All testing that is conducted during the first and second fix is called pre-commissioning or construction stage testing.

6.1.4.1 Electrical System

- Distribution boards must be provided with labels to indicate incoming feeds and outgoing circuits.
- All Electrical equipment must be labelled. Incoming and outgoing feeders must be labelled to indicate where it is fed from and where it is feeding.
- Above ceiling conduit must be labelled to indicate where it is fed from and where it is feeding.
- Continuity testing for conductors must be completed especially for protective conductors, bus ducts, and switchgears/switch board buses.
- Insulation resistance testing must be completed for cables, bus ducts, switchgears/switch boards buses, and other electrical equipment and devices. Below are the required Insulation Resistance values using IEE Wiring Regulations:

Industrial and commercial wiring- IEE Wiring Regulation 17th Edition

System	Test Voltage	Min. Test Value
Extra Low Voltage	250 volts DC	0.5 M-Ohms
Low voltage up to 500 volts	500 volts DC	0.5 M-Ohms
Over 500 V to 1kV	1000 volts DC	1.0 M-Ohms

HV Test for new XLPE Cable - ETSA

Application	Test Voltage	Min. Test Value
New Cable - sheath	1 kV DC	100 M-Ohms
New Cable- insulation	10 kV DC	1000 M-Ohms
After Repair - sheath	1 kV DC	10 M-Ohms
After Repair - insulation	5 kV DC	1000 M-Ohms

11KV and 33KV Cables between Cores and Earth - ETSA

Application	Test Voltage	Min. Test Value
11 kV New Cable - sheath	5 kV DC	1000 M-Ohms
11 kV After repair - sheath	5 kV DC	100 M-Ohms
33 kV- no TF connected	5 kV DC	1000 M-Ohms
After Repair - insulation	5 kV DC	15 M-Ohms

IR Values for Motor – NETA ATS 2007

Motor Nameplate	Test Voltage	Min. Test Value
250 volts	500 volts DC	25 M-Ohms
600 volts	1000 volts DC	100 M-Ohms

1000 volts	1000 volts DC	100 M-Ohms
2500 volts	1000 volts DC	500 M-Ohms
5000 volts	2500 volts DC	1000 M-Ohms
8000 volts	2500 volts DC	2000 M-Ohms
15000 volts	2500 volts DC	5000 M-Ohms
25000 volts	5000 volts DC	20000 M-Ohms
34500 volts	15000 volts DC	100000 M-Ohms

IR Values for Rotating Machine with Low Voltage Rating– IEEE 43

IR Value	(Rated Voltage (volts)/1000) + 1 M-Ohms

IR Values for Motors in well with cable– IEEE 43

IR Value	2 M-Ohms

IR Values for Transformer – IEEE Standard

Equipment	Test Voltage-LV Side	Test Voltage-HV Side	Min. Test Value
Up to 415 volts	500 volts DC	2.5 kV	100 M-Ohms
Up to 6.6 kV	500 volts DC	2.5 kV	200 M-Ohms
6.6 kV to 11 kV	500 volts DC	2.5 kV	400 M-Ohms
11 kV to 33 kV	1000 volts DC	5 kV	500 M-Ohms
33 kV to 66 kV	1000 volts DC	5 kV	600 M-Ohms
66 kV to 132 kV	1000 volts DC	5 kV	600 M-Ohms
132 kV to 220 kV	1000 volts DC	5 kV	650 M-Ohms

For Cables, manufacturer recommends correction factor for cable temperature above or below 20°C. The factory measured insulation resistance reading can be adjusted by halving the factor measured value every 10°C above the base temperature of 20°C, and doubling the factory measured value for every 10°C below 20°C.

It should be noted that Standards differ with regards to test voltage requirements and required test values. The above data are for reference only, the Specification should be consulted. In common project situation, if the Specification requires site testing, the manufacturer recommendation is always followed. Equipment is mandated to be tested and proved in a factory setting to comply with Standards. The procedure of factory testing is only repeated at site, if the Specification and Contract requires.

- Electrical installation is signed-off and confirmed by the construction team to be in compliance with the approved shop drawing. It is assumed at this time that the OCPD for electrical system is selected and in compliance to the IEE Standard for Total System Earth Fault Loop Impedance (External Ze and Supply Zs Earth Fault Loop Impedance) by preliminary calculations.
- Equipment Grounding (equipotential bonding of all exposed conductive parts of the installation) and System Grounding (transformer neutral grounding) tested and accepted by the PM/CM.
- Lightning Protection System shall conform to the approved shop drawings as per the requirement of NFPA 780 for air terminals, conductors, and grounding electrode class, or earth electrodes for lighting protection must be tested for resistance and each should not exceed 5 Ohms and the combined total resistance to earth should not exceed 10 Ohms as required by BS 7430.

- Voltage drop calculation has already proven that voltage drop for each feed do not exceed 3% for lighting circuits and 5% for other type of circuits as required by IEE Wiring Regulation 17th edition.
- Lock-out/tag-out procedure must be in place and approved by the Team HSE Manager.

6.1.4.2 Mechanical System

- All hydronic piping pressure test should be completed and passed. Below are the pressure testing requirements from a variety of Standards.
  - For Plumbing and HVAC System as per ASHRAE, IPC and UPC

    Test Pressure = *1.5 x Operating pressure but not lower than 8.5bar for 2 hrs. minimum without noticeable drop in pressure*

  - For Sprinkler and Hose System as per NFPA 13

    Test Pressure = *not lower than 200 psig for working pressure up to150 psig, for working pressure above 150 psig - plus 50 psig for 2 hrs. minimum without drop in pressure*

  - For LPG Gas piping – NFPA 54

    Test Pressure = *1.5 times the maximum working pressure but not less than 3 psig for a duration of ½ hr. for each 14m3. of volume and not exceeding 24 hrs. with no noticeable drop in pressure.*

- Gravity or Air Leakage Testing for Drainage System must all be completed and passed. Below is the different testing requirement from a variety of Standards.
  - By Uniform Plumbing Code and International Plumbing Code

    Gravity Test = *Stack should extend 10 ft. above the floor level it serves and shall have no noticeable drop in water level for at least 15 mins.*

    Air Test = *10 inches of mercury using manometer for 15 mins. with no noticeable drop in air pressure*

  - By BSEN 1610 Standard

    Air Testing = *120 mm. of water using a manometer for 5 minutes. Allowable air pressure is up to 75mm. after the 5 mins. period*

- Flow Testing for drainage system must be completed and accepted by Client Representative-

  Prior to the installation of Plumbing System Third Fix (water closets, lavatory or washbasins, floor drains, and clean out), drainage is flow tested to check for any possible clogs during construction. A creative way of conducting the flow test is to drop numbered ping-pong balls in clean-outs followed by continuous pouring of water to check clogs in main lines, then water is poured in branch floor/wall stub-outs to visible see any clog through back flowing water, and overflowing water in-case of floor trap use. All numbered Ping-Pong balls are recovered in the main street discharge manholes. Unrecovered balls indicate clogs in marked inlets lines.

- All air ducts have been tested for leakage and accepted by the Client Representative

  Air ducts are tested according to pressure class and has the following allowable leakage limits as per DW 143.

Duct Pressure Class	Static Pressure Limit		Allowable Air Leakage (% of total air flow)
	Positive	Negative	

Class A – Low Pressure	500 Pa	500 Pa	6%
Class B – Medium Pressure	1000 Pa	750 Pa	3%
Class C – High Pressure	2000 Pa	Above 750 Pa	2%

Duct leakage testing uses leakage testing machine especially for medium and high-pressure class. It should be noted that the smoke or light testing is only applicable for low-pressure (Class A) ducting as per site practice, but Codes and Standards do not mention such testing. Class A ducting does not require any testing - testing is only required if the quality of ducting installation (especially of the duct joints) is in question or if the Specification call for smoke or light type of testing.

- System Flushing must be completed and accepted by Client Representative-
    - Hydronic flushing – clean or potable water is used to remove welding slags, dirt, and other impurities internal of the piping during construction. The following are required to be complied for mild steel piping.
        - The use of correct flushing velocity to (1) keep insoluble materials in suspension, (2) help speed up deposit dissolution, (3) to produce scrubbing velocity to avoid development of bio-films in pipe surfaces which protects corrosion causing bacteria, (4) gases produced by the cleaning chemicals are immediately carried to venting system thus avoiding oxidation, (5) uniform water condition can exist all over the system which can avoid variations in water sampling results. For flushing velocity, refer to the table below from BSRIA. It should be noted that NFPA limit for flushing velocity for any pipe size is 3 m/s and this velocity is proven sufficient for effective flushing.
    - Use of multiple type of chemicals for the following reasons.
        - Use of degreaser/detergents for pipe cleaning.
        - Use of chelants or inhibited acid to remove unwanted oxides, scales, and speed up deposit dissolution followed immediately by neutralization.
        - Use of passivation chemical to passivate active metal surface to avoid oxidation even in the presence of dissolved oxygen.
        - Use of corrosion inhibitor and biocides as final protecting agent.

For system composed of copper piping, only weak acid is used to remove the product of oxidation. Refer to the table below for the required flushing velocity for different pipe sizes (as per BSRIA AG 1/2001.1):

Nominal Pipe Size (mm)	Flushing Velocity (m/s)
15 ø	0.96
20 ø	1.0
25 ø	1.03
32 ø	1.06
40 ø	1.08
50 ø	1.11
65 ø	1.15
80 ø	1.17
100 ø	1.21
125 ø	1.24
150 ø	1.26

A proper flushed hydronic piping system will take from two (2) months for medium size installation to four (4) months for large installation using mild steel piping (BI Piping). Copper piping will take around ¼ of this time duration.

- Air Flushing – the procedure is to use air as medium to removed dust in the ducting system by running the AHU or FCU continuously at design flowrate until no visible dust is present. Air blowing is also used traditionally in large steam piping (power plants) using large air compressors. Procedure for air blow is typical to steam blow.
- Steam Flushing – the method for flushing is solely used in large steam piping and equipment (in power plants) by steam blowing using the medium momentum during each blow. Usual number of blows are ranging from 10 to 20 per cleaning leg until no impurities can be seen in the collection strainer. Pressure ranges from 300 psig to 500 psig and the residual pressure of 100 psig to close the blow valve and recharge the boiler. Start-up flushing starts at lower pressure (appx. 50 psig) and then gradually increases. Large steam equipment requires more blows (appx. 100 blows). Normal flushing duration is from three (3) to four (4) weeks for Power Plants. Client should refer to steam piping cleaning companies for specific cleaning method/procedures.
- Commercial steam piping system uses a continuous supply of steam by activating all available boilers and opening all relay drain points and extending all terminals to the atmosphere for flushing until no visible impurities are noticeable in all outlets and condensates are clear.

6.1.4.3 Low Current System

- All Low Current cable (except data cabling) insulation resistance tests must be completed. Test voltage and minimum test values are as follows:

IEE Wiring Regulation

System	Test Voltage	Min. Test Value
Extra Low Voltage	250 volts DC	0.25 M-Ohms

NFPA 72.27.7.1.2.7- National Fire Alarm Code

System	Test Voltage	Min. Test Value
Metallic Cables	250 volts DC	200 M-Ohms per mile between conductors, the sheath, and ground

- Continuity testing must be completed and accepted for all non-data cabling.
- Data cable testing must be completed and accepted by Client Representative. Registered jack modular plugs must be patched to the patch panel as per the approved patching plan. Cable testing for data cable comprises.
    - Wire Mapping – check for proper pin-to-pin termination, and for each of the eight (8) wire conductors, wire-mapping check for (1) continuity, (2) short between conductors, (3) split pairs, (4) transposed pair, and (5) reverse pair.
    - Length verification – the allowable actual length of the cable depending on the cable type.
    - Insertion Loss, IL (dB) – loss of signal when the cable is inserted between the transmitter and receiver.
    - Near End Cross Talk, NEXT (dB) – is the unwanted coupling of a signal from one pair to another when a signal is induced by the transmitter at the near end.
    - Power Sum Near End Cross Talk, PSNEXT (dB) – is the combined NEXT from all disturber pair operating at the same time.
    - Far End Cross Talk, FEXT (dB) – is the unwanted coupling of a signal induced by a transmitter at the near end, measured on the disturbed pair at the far end.

  - Equal Level Far End Cross Talk, ELFEXT (dB) – is the measurement of unwanted coupling of a signal injected at the far end into adjacent pair at the near end. ELFEXT is FEXT less Insertion Loss.
  - Power Sum ELFEXT, (dB) – is the statistical calculation of the sum of all far end disturber on the near end pair.
- Fiber Optic cables testing has been completed and accepted by Client Representative.

6.1.4.4 Equipment Site Pre-Startup Check and Operational Testing

Pre-Startup Check - After the equipment is installed, and before providing power and running any equipment, it is required do a pre-startup check. Dynamic package equipment such as centrifugal fans are delivered with transport block, which needs to be removed to avoid damaging the fan. Supply voltage must be same as the nameplate voltage of the equipment and phases must be check for reversal through color-coding. Vibration isolators must be correctly designed, selected, and in place to avoid damaging the equipment. Bus connections of Switchgear/switchboard are torqued to check for any loose connection. Impedance is checked between phases of transformers to ensure proper termination. Power Circuit Breakers (PCB) for Switchgears are rack-in and rack-out tested (same for ICCB for switchboards) for mechanical interlock check. Pre start-up check therefore is conducted by the manufacturers/suppliers to ensure that the static and dynamic equipment will be safe and will be running properly once the power is turn-on.

Operational Testing - sometimes termed as “functional testing”, is required for the purpose of determining that all static and dynamic equipment is running or operating in its normal condition when power is turned on. Equipment manufactures/suppliers conduct the site test to determine abnormal condition such as excessive noise and vibration due to misaligned shafts for motor and pump/fan assemblies. Excessive temperature of the equipment is verified to be within the limit to avoid premature failure of the windings. Current drawn is checked to ensure that abnormalities do not exist which can burn the motor. Switchgears and switchboards PCB and ICCB are trip tested during the operational test.

Below is the list of equipment. The reader is referred to Section 8 (reference to document EPM-KT0-RG-000007) of this Guideline for the checklist and operational testing.

- Mechanical Equipment - refer to document ref. EPM-KT0-RG-000007
  - Pumps ref. EPM-KT0-TP-000001
  - Fire Pumps ref. EPM-KT0-TP-000002
  - Fans ref. EPM-KT0-TP-000003
  - Air Handling Unit ref. EPM-KT0-TP-000004
  - Variable Air Volume (VAV) ref. EPM-KT0-TP-000005 and EPM-KT0-TP-000056
  - Fan Coil Unit ref. EPM-KT0-TP-000006
  - Precision Unit ref. EPM-KT0-TP-000007
  - Chillers ref. EPM-KT0-TP-000008
  - Cooling Tower ref. EPM-KT0-TP-000009
  - Heat Exchanger and Steam Calorifier ref. EPM-KT0-TP-000010
  - Boilers ref. EPM-KT0-TP-000011
  - Condensate Recovery Unit (CRU) ref. EPM-KT0-TP-000012
  - Water Treatment Plant ref. EPM-KT0-TP-000013
  - Waste Water Treatment Plant ref. EPM-KT0-TP-000014
- Electrical Equipment - refer to report ref. EPM-KT0-RG-000007
  - HV and MV Switchgears ref. EPM-KT0-TP-000019
  - Switchboards ref. EPM-KT0-TP-000020
  - Transformer ref. EPM-KT0-TP-000021
  - Ring Main Unit ref. EPM-KT0-TP-000022
  - Capacitor Banks ref. EPM-KT0-TP-000023 and EPM-KT0-TP-000043

  - Generator Set ref. EPM-KT0-TP-000018
  - Automatic Transfer Switch (ATS) ref. EPM-KT0-TP-000024
  - Uninterruptible Power Supply (UPS) ref. EPM-KT0-TP-000025 and EPM-KT0-TP-000044
- Transport and Lifting Equipment - refer to report ref. EPM-KT0-RG-000007
  - Elevator ref. EPM-KT0-TP-000015 and EPM-KT0-TP-000040
  - Escalators and Moving Walks ref. EPM-KT0-TP-000016 and EPM-KT0-TP-000041
  - Building Management Unit (BMU) ref. EPM-KT0-TP-000017 and EPM-KT0-TP-000042

6.1.4.5 Equipment Site Performance Testing

Equipment Site Performance Test - is conducted to prove that the dynamic mechanical equipment and electrical power supplying equipment performs to the capacity, rating and efficiency at the condition specified during the design and manufacturing. For pumps and fans, the test proves that the equipment capacity (flowrate) and pressure head (in meters, psig, bar, or kPa) lies within the performance curve and the electrical power drawn shall not exceed the rating as indicated in the nameplate or catalogue. Performance testing for some equipment cannot be done on site, as it is only possible to be conducted in a factory setting. Chiller is one good example since the environment condition (e.g., ambient temperature and wind) cannot be simulated and controlled in site conditions to prove the cooling capacity, hence the Specification always requires Client Representative witnessing during the factory testing.

When to perform the Equipment Performance Testing on site varies from equipment to equipment. Some equipment like pump and fans do not require complete second and third fix installation but require only certain part of the installation (such as looping the discharge to the suction or returning to tank for pumps). Indoor transformers require complete installation including loads or providing temporary loads such as resistor or load banks. Capacitor banks requires complete installation to include end-user loads.

Codes and Standards do not require Equipment Performance Testing to be repeated on site but is a requirement for the Client Representative satisfaction when required by the specification. The test is also conducted when equipment has noticeable damage caused during transport and haulage, which requires replacement of parts. Requirements for site performance testing varies from project to project based on what is required in the Project Specification. Where the contract stipulates retest of equipment for performance, it is necessary to use the typical methodology that was used during the factory testing. Systems that are assembled at site such as wastewater treatment and water treatment systems will require performance testing.

For equipment that does not require connection to other systems and can function by itself (such as elevators can directly proceed with capacity testing), site operational and performance testing is usually combined.

Below is the list of equipment and site assembled system for which Performance Testing is normally conducted onsite:

- Mechanical Equipment - refer to report ref. EPM-KT0-RG-000007
  - Fire Pump ref. EPM-KT0-TP-000029 and EPM-KT0-TP-000045
  - Other Pumping System ref. EPM-KT0-TP-000030
  - Fans ref. EPM-KT0-TP-000031
  - Air Handling Unit ref. EPM-KT0-TP-000032
  - Precision Unit ref. EPM-KT0-TP-000033
  - Fan Coil Unit ref. EPM-KT0-TP-000034
  - Cooling Tower ref. EPM-KT0-TP-000035
  - Boilers ref. EPM-KT0-TP-000036
  - Water Treatment Plant ref. EPM-KT0-TP-000037
  - Waste Water Treatment Plant ref. EPM-KT0-TP-000038
  - CRU (Condensate Recovery Unit) ref. EPM-KT0-TP-000039

It should be noted that projects differ on how to conduct the pre-startup, functional, and equipment performance testing. Some projects will conduct pre-startup tests followed later by combined equipment functional and performance testing. Some projects prefer combined pre-startup and functional testing while the equipment performance test if required follows after. There is no rule when such tests will be conducted and it depends primarily on the agreed method for testing between the T&C Agent, the PM or CM, and the Commissioning Authority.

6.2 Mechanical System Standalone T&C

This section discusses different electro-mechanical building services system and all the corresponding testing required by the Code for equipment, systems, components, and assemblies as standalone.

6.2.1 Heating, Ventilating and Air Conditioning

"Testing and Balancing" for Pressure Dependent System

Both air and water Pressure Dependent Systems use "Proportional Method" for Balancing. This is a technique which does not use definitive values during the process but maintains a constant ratio between the actual measured value and design value, referenced to the index point. All other branches are adjusted to have a common ratio. An index is the branch which has the greatest resistance of all branches, therefore has the lowest ratio during the initial reading. TAB Groups require a minimum of three (3) visits for a system to balance such as (1) initial reading, (2) proportional balancing and (3) verification of actual reading. Balancing for air distribution of one central clinical AHU in a healthcare may take about one (1) month minimum to complete. Fresh air distribution for a large hotel usually takes about a month or two depending on the network of duct distribution. Chilled water systems using conventional control valves for medium to large system takes about one (1) to three (3) months to complete. Leakage for air distribution systems shall be determined by comparing the traverse reading in the main duct against the summation of all air fixtures air flowrate. Leakage shall not exceed as given in the allowable leakage table (refer to the mechanical preliminary stage section 6.1.4).

Pressure Independent Systems do not require balancing. Chilled water system using Pressure Independent Control Valves (PICV) only require simple setting of the valve to work and an air distribution using Pressure Independent Variable Air Volume (PI-VAV) Box requires the BMS to manually or automatically command the VAV to operate at any flow requirements from a central station.

Unbalanced hydronic and air distribution systems result in fan/pumps excessive power consumption since the equipment operates away from the Best Efficiency Point. It is therefore necessary to ensure that the air and water distribution are balanced prior to handover.

Fire Damper Drop Testing - Accordion Type FD

This is a simple manual test to ensure that the accordion curtain will drop to the bottom of the damper to seal any air passage by removing the fusible link. During installation, Fire Dampers can be misaligned due to duct misalignment especially for large fire dampers, therefore the accordion curtain will not totally reach the bottom of the damper creating a path for fire and compromising the fire containment. NFPA 80 requires 100% drop testing for all installed fire dampers prior to handover. Dynamic fire dampers are required to be drop tested under the design airflow while static fire dampers are not. Accordion Type Static FD can be installed in the vertical and horizontal position while the Dynamic Type is only for vertical installation. Dynamic Type FD is used for continuous fire and smoke control systems during the fire condition while the static type is used for system that requires shutdown during fire condition.

Re-inspection/re-certification for eachand every damper shall be one (1) year after the inspection/ certification prior to handover, and then every four (4) years interval with exception for hospitals with six (6) years frequency for re-inspection/re-certification.

Motorized Smoke and Fire Damper (MSFD) and Motorized Smoke Damper (MSD) Testing

This test requires opening and closing of the dampers to (1) check for any misalignment that will avoid full closing of the blades and (2) check if the actuator is correctly selected and has the right torque to close the damper especially for dynamic type dampers. Large ducting is prone to misalignment, which may affect the alignment of large multi-blade dampers, therefore compromising fire compartmentation. NFPA 105 requires 100% operational testing for all type of smoke/dampers used for Life Safety Systems. NFPA 105 requires all smoke dampers to be re-inspected and re-certified every six (6) months for dedicated smoke control systems and every year for non-dedicated smoke control systems after the first certification prior to handover. All MSFD and MSD are required to be fail-safe closed. Combination smoke and fire damper (MSFD) must comply both to NFPA 80 and 105 requirements.

6.2.2 Building Management System (BMS)

The Building Management System purpose is to centralize and simplify monitoring, operation and management of a building or buildings electro-mechanical systems. It is composed of a collection of hierarchy of controllers, sensors, and actuators communicating and controlled from a Central Station. The benefit of having BMS are as follows:

- Achieves more efficient building operation by ensuring that equipment only supplies the required demand therefore reducing energy cost.
- Reduces labor for maintenance needed to monitor operation of the equipment and system.
- Provides a safe and comfortable working environment for the building occupants.

The BMS function is for the control and monitoring of the HVAC System, whereas it is used only for monitoring for other building services. To have a successful BMS, collaboration between the mechanical systems, electrical systems, and low current systems providers must take place. The succeeding part discusses the scope of each discipline, as well as the testing procedures that need to be completed in a sequential manner.

Mechanical Scope of Work

This section discusses the responsibilities of the Mechanical Designer/ Project Engineer in the development of the BMS from the design up to implementation. An example is shown in the succeeding sections for the reader to understand the requirement for Data Point Schedule, a BMS PID, and the Sequence of Operation.

- Data Point Schedule

  Is a representation of points to be controlled and monitored in table format. Functions such as control and monitoring (especially that of the HVAC) are listed and represented in I/O Points (Input and Output Point to and from the controller). I/O Points are categorized into Digital I/O and Analogue I/O. Digital inputs are inputs to the controller representing on/off condition (contact or non-contact). Digital Outputs are output from the controller representing on/off command to field controllers. Analogue Inputs are analogue values to the controller representing change in condition in the field sensors in terms of voltage and current signals (either 0-10 volts, 2 to 10 volts, 0 to 5 volts, or 4 to 20 mA signal). Analogue Outputs are analogue values from the controller to command field device actuators to respond corresponding to the analogue input received by the controller. Current signaling is used for long cabling since the resistance of the wire (or degradation of wire resistance due to age and thermal effect) does not affect current signals. Universal I/O Points can be either Digital or Analogue depending on object configuration. Below is an example of data point schedule.

Function	Digital		Analogue		Field Device	Comments
	DI	DO	AI	AO		
ON/OFF Status of AHU	X				DPS-model XXX	DI Represent ON Status
AHU Discharge Air Temp.			X		Temp. Sensor Model XXX	

Chilled Water Control Valve				X	Actuator Model XXX	
AHU Shutdown		X				
Total	**1**	**1**	**1**	**1**		

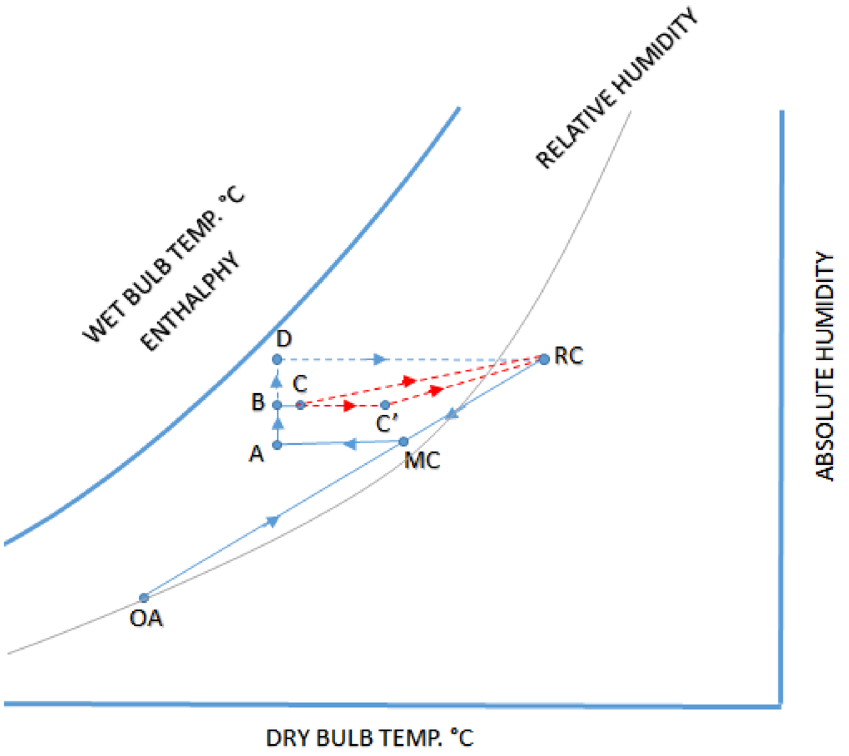
The total of the Data Point Schedule influences the selection and quantity of the DDC required in the DDC panel.

Almost all projects suffer from delays in the completion and commissioning of the BMS since it is normal practice to develop the Data Point Schedule during the mid-stage of the project. Instead of the Designer providing the Data Point Schedule, it is always the BMS Trade Contractor who initializes the proposal which results in compressing and limiting the ability of the BMS. During any tender, it is a common practice to provide an incomplete Specification for BMS which is the basis of the contractor for pricing. These Specifications are normally copied from project to project without considering the functions of HVAC systems for some projects are very complicated.

- Process and Instrumentation Diagram (PID) and Sequence of Operation (SOO)

The PID is a schematic presentation showing the equipment, field devices, and input/output to the DDC for the purpose of simplifying the functional description of the equipment and system. The SOO is a written explanation of how the HVAC system is intended to work and form part of the System Manual. SOO varies from simple to complex function. For instance, where an HVAC system incorporates a complex function for healthcare AHU serving four (4) Operating Rooms which requires the use of laser for treatment, the OPR is required to maintain the room condition at 21°C and 50% RH even if the laser is in use and not used. In this condition, the laser contributes about 80% of the total cooling load in the form of sensible heat. To control the humidity, steam is used in the AHU but the OPR requires a back-up electric resistance humidifier in the OR in case the AHU humidifier fails. Fresh air is required to be 20% of the total supply air as per ASHRAE for Operating Theatre and the system must work both in the summer and winter seasons. The AHU is required to shut down in the case of smoke detection as per NFPA 99- 2012 edition. ASHRAE and LEED requires energy to be conserved by supply air temperature set-back as well as demand control ventilation technique. The Standards require OR Rooms supply airflow rate to be maintained at 20 ACH as minimum. The above conditions are only few of the requirements for an OR function, but for the purpose of developing and describing the PID and SOO, the following analysis must be completed:

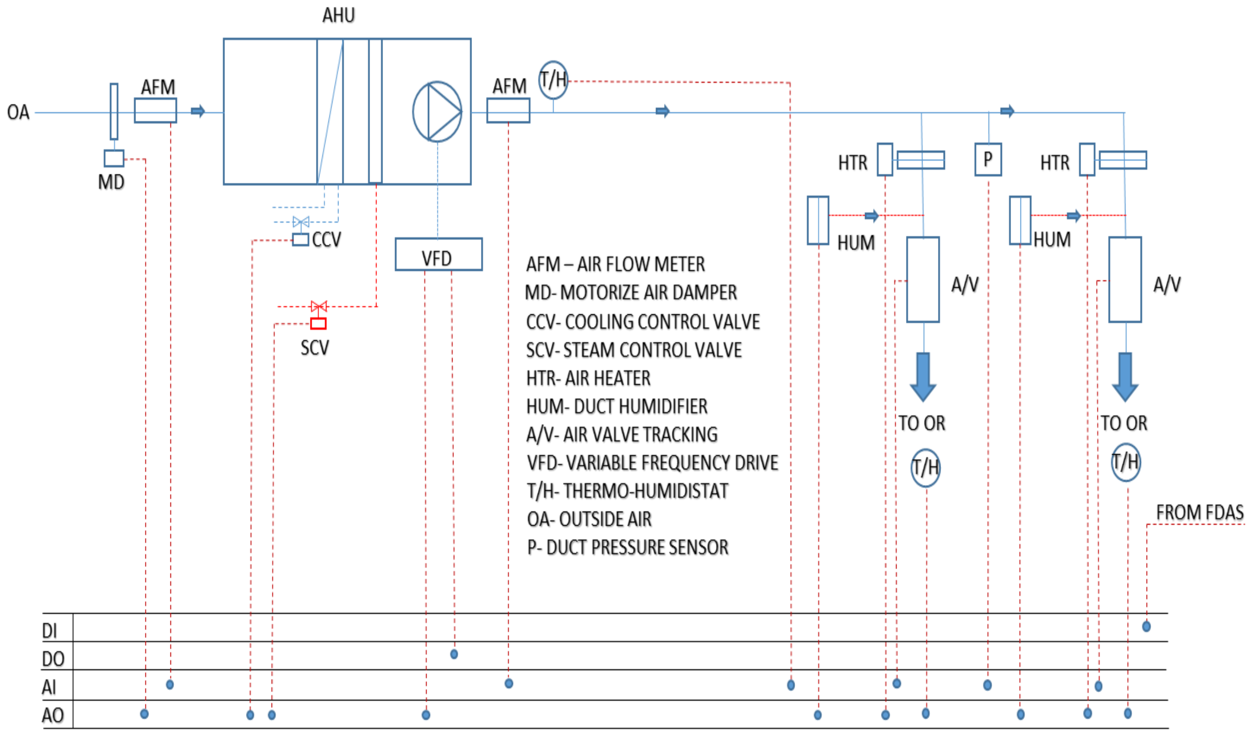
Below is the Psychrometric Analysis of the system:



From above, it can be concluded that for the winter condition (only winter is discussed to simplify the SOO).

- For 21°C and 50%RH, the dew point is 10°C and is the lower limit of supply air to avoid condensation. Since the AHU is serving multiple OR, then the off coil of 10°C must be maintained.
- Chilled water will be used, and a control valve is required in the AHU.
- Energy saving can be done by reducing the airflow required when the laser is not in use by using VFD driven fan and Air Valve Tracking System. Air Valve Tracking System is a NIST traceable calibrated flow measuring and control air valve.
- An air flowmeter is required in the supply ducting and fresh-air ducting as well as motorize damper in the fresh air ducting to maintain the 30% ratio of the fresh air to the supply air.
- Reheat is required to match the minimum ACH required in the OR when the laser is operating or not (point B-C and B-C'). The reheat must be located in the supply ducting serving the OR. Point D-RC represent high sensible heat ratio since most of the OR load is sensible due to the laser large sensible heat dissipation. Point C'-RC represent RSHR (Room Sensible Heat Ratio) of 0.75 when the laser is off. C-RC represent variation in room load due to presence of medical staffing.
- While the AHU off-coil temperature is maintained, humidification is required after the cooling coil in the AHU (point A-B) to attain the required humidity when the laser is on or off.
- When the laser is operating, humidification is required (point B-D) in the supply ducting serving each OR.
- 20 ACH as per room volume is equivalent to 1300 L/s but the required airflow when the laser is working is 2600 L/s as per cooling load calculation.
- The room thermos-humidistat is a PI (Proportional/Integral) algorithm type set to 0.2°C control point.
- A motion sensor or a button in the OR control panel is required to lower down the airflow to 50% of the minimum ACH required by the Code during un-occupied mode by change in set-point.

The PID is drawn as follows:



The Sequence of Operation will be as follows:

1. The AHU off-coil temperature shall be maintained at 10°C dry bulb by the chilled water control valve and the relative humidity in the supply air shall be maintained at 95% RH by the steam humidifier through the steam control valve.
2. The airflow supplied within the room shall not go below 1300 L/s. When the room temperature drops below the set point of 21°C, the heater shall be activated to maintain the space temperature. The room humidity shall be maintained at 50%RH by activating the room humidifier in case the relative humidity falls below 50%RH. Control point for humidifier deviation from the set point is 0.5%RH.
3. The speed of the fan shall be controlled by the pressure sensor installed at 3/4 of the supply duct run and shall be set at 350 pascals.
4. The fresh air requirement shall not fall below 20% of the measured supply air quantity. This will be accomplished through the DDC calculating 30% of the measured airflows in the supply through the flowmeter. The motorized damper in the fresh air ducting shall modulate to maintain the required ratio.
5. When the motion sensor inside an OR does not detect any movement, the 1300 L/s set point to the air valve controller shall be reduced to 650 L/s and the room temperature shall be raised to 28°C. When all motion sensors within the ORs detect no movement and that, all air valve controllers are set to 50% of the minimum airflow, the AHU off coil set point shall be raised to 15°C.
6. If a signal from the Fire Detection and Alarm System is received by the DDC, the AHU shall be immediately shutdown.

The Sequence of Operation and PID shall be established by the Designer for the whole HVAC System, from the air side distribution to the water side distribution as early as the design stage for the contractor to study and provide the required site cabling, select and set-up the DDC Panel, and the programmer to prepare the program and graphics as early as the mid-construction stage. Many large and complex projects suffer from delays and failures since no one in the project really knows how the HVAC System really works, even the Designers.

- Selection of Field Devices (Sensors, Valves and Actuators**)**

  Functionality of the BMS relies on the HVAC design so that the selection of field devices concerning functions are under the responsibility of the Mechanical Discipline. Electrical scope in the selection is compliance to the provided auxiliary power supply, control signal type, and its construction reference to the Electrical Specifications. For instance, pressure and differential range is confirmed by the mechanical engineer for pressure and differential sensors while the power supply (either 24 volts AC/DC or 220 volts AC) and signal type (0-10 volts, 2-10 volts, 0-5 volts, or 4-20 mA) is confirmed by the electrical engineer. Mechanical engineers confirm the speed of actuators (fast acting or slow acting) while the signal type and power supply are by the electrical engineer. For devices attached to the piping in which condensation can occur, the mechanical discipline usually influences use of 24 volts AC or DC for safety purposes.

- Selection of Direct Digital Controller (DDC)

  The scope of Mechanical Discipline in the DDC selection is only limited to number and type of available Data Points (or Object). Since the Mechanical Discipline defines the functions, it is the responsibility of the Mechanical Discipline to confirm the total number and type of DDC Objects (how many are DI, DO, AI, and AO based on the HVAC functions). Electrical Discipline has to confirm the signal type and auxiliary power provisions.

Electrical Scope of Work

- Data Point Schedule

  Electrical scope in the development of the Data Point Schedule is only limited to monitoring of electrical equipment. The electrical discipline defines what and how many electrical equipment need to be monitored.

- Auxiliary Power Supply

  Auxiliary Power Supply is the power supply to the controllers, and this is decided by the Electrical Discipline based on design provisions (either 24 AC/DC or 220 volts AC).

Procedure and Test Requirements for BMS

This section discusses the step-by-step testing required to complete the BMS System testing.

- Cable Testing

  See Preliminaries in Section 6.1.4 of this Guideline.

- DDC and Network Controller Programming and Configuration

  Direct Digital Controllers for BMS comes un-programmed and un-configured and selection is based on the number of Data Points to be provided to comply with the functions required for a certain HVAC service. The total number of data points determines the quantity of DDCs inside a DDC Panel. Programmers uploads software's to the DDC as the first step for activating the DDC after the power is turn on. Un-configured DDC contains only object types in the form of AI, AO, DI, and DO to which BACNet properties type needs to be assigned (e.g., temperature data, pressure data, and other measurable data). Signal type (voltage or current) shall also be assigned and the corresponding analogue value for the signal. Response type shall also be assigned (such as linear, equal percentage, etc.) for the output value against the received signal, and many more. This procedure is called configuration. DDCs are always in the Link Layer, which is the third layer in the BACNet (Building Automation and Control Network) communications protocol.

  Application Specific Controllers/Actuators such as those used in VAV which is supplied together with the equipment are always pre-configured and can work on its own when power and control wirings are provided. It only requires connection to the devices and sensors to function and a network connection to communicate with other controllers.

  Network Controllers (Building Controllers, or Plant Controllers) are controllers connecting to the Network (LAN) where DDCs are communicating through Master/Slave Token Protocol (MSTP). All data from the configured DDC shall be transferred to the Network Controller by uploading the .ede file (or other file transfer software certified to BACNet) from the DDC and downloading to the Network Controller. BACNet protocol has an auto-discovery feature in that if a laptop with BACNet discovery software is installed (like BQT) anywhere in the BACNet Network, all BACNet devices can be found. Each device has a unique vendor ID, instance number, and IP address assigned by ASHRAE unique to any BACNet device. Any DDC information must be transferred to the Network Controller and then to the Workstation Controller (which is in the Central Station where the user can interface with the BMS System). For BMS network controllers connected via TCP/IP Network, it is required that network controllers are configured to have the correct subnet masking address (for routing within the LAN in-case the lop top is not connected to the same subnet during configuration) and default gateway address (for routing outside the LAN for web-based control and monitoring in-case the laptop is not connected to the same LAN during configuration).

- Point to Point Testing

  A test conducted to confirm that the DDC is responding to any of the field devices' inputs and the DDC is providing an output signal by:

  - Shorting the terminal of the field device for DI ports.
  - Commanding from the test laptop to close the field actuators/device and see closing/opening of actuators for DO ports.
  - Providing a temporary signal source from AI field device ports and see response in the test laptop.
  - Commanding from the test laptop to provide control signal to the AO device and see step-by-step response.

  At any time during the test, the DDC indicating green LED shall continue to blink to confirm that the DDC is working properly. The test also validates that there is no communication problem between the field devices and controller. For large systems, it is advisable to ask for Trend Log prints rather than witnessing 100% of the test. The print will be compiled and will become part of the Commissioning Record documentation.

- Loop Testing

  A test conducted to confirm the response from each of the DDC loops from a changed set point manually from the test laptop. For an analogue loop, the test shall show the loop response to a change in set point, which represents a change of actuator position of at least 25% of the full range.

  An example of a control loop is a thermostat installed in the supply ducting to control the action of the chilled water control valve through the actuator. If the supply air is set at 13°C, the set point can be changed to 10°C from a test laptop for the controller to command the actuator to open further or the set point can be raised to 15°C to command the actuator to close further. The change in the measured value against the set point can be checked if the sensor is properly working.

  For large systems, it is advisable to ask for Trend Log prints rather than witnessing 100% of the test. The print will be compiled and will become part of the Commissioning Record documentation.

- Field Device Calibration

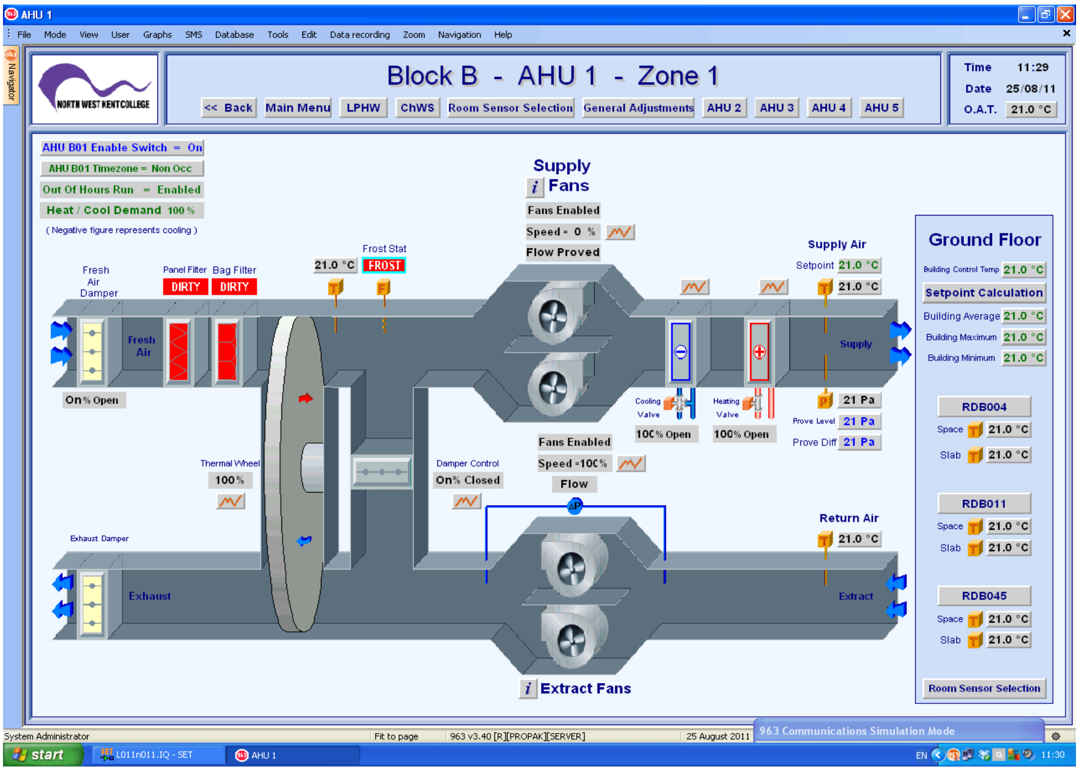
  NIST Traceable calibrated sensors and actuators are normally certified for a 12-24-month period, depending on the required contract accuracy, from the date of last test or from the date of first use or installation, which requires recalibration afterwards. Most field devices are delivered to site with only a few months remaining to recalibration or already with expired calibration certificates. Almost all projects T&C are always delayed for several reasons and these delays are compounded by the problem of recalibration. In many cases, recalibration in the factory is not practical and this is resolved by the approved and accepted methods of proving the accuracy of the field devices. Methods of proving the accuracy of field devices are always reviewed and approved by the Commissioning Authority and PM/CM.

  Close coordination between engineering, procurement, and construction is required to resolve the issue of calibration. It is ideally required that upon delivery and installation of all field devices that the T&C Work should immediately commence. Material receiving engineers should ensure that calibration dates stated in the certificates are recent and are not close to expiration (for field devices the recalibration is based upon the last date of testing).

  The problem regarding expired calibration of field devices always creates operational errors during the T&C work, which results in the extensive delays in the project completion.

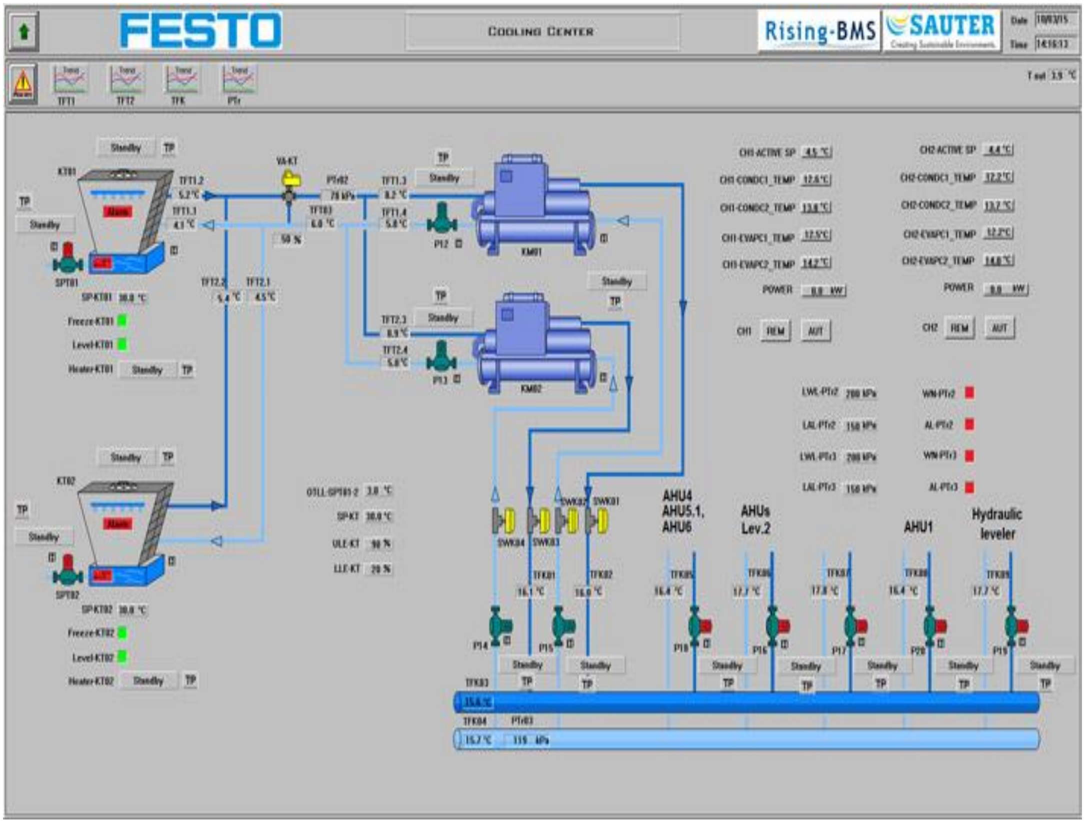
- BMS Graphics

  A BMS Graphics is a screen artistic representation of how the system and equipment will look on the computer monitor. This is where a user can interface with the system to do editing of the set points and control points. The graphics include measured and control parameters, alarms and notifications, calendars, reporting, etc. Below is an example of the graphics of a Centralized AHU with heat recovery wheel, complete with field accessories as well as chilled water system network.



Ideally, the graphics should be completed as early as possible during the construction phase. The common problem in any project is that the Data Point Schedule is developed during the latter stages of the construction phase as well as the PID and Sequence of Operation, resulting in the late development of the BMS Graphics. It is therefore advised that the designer develop all the above-mentioned requirements during the design stage with the Commissioning Authority and Trade Contractors to avoid delays in the development of the BMS Graphics.

The BMS Graphics requires approval from end-users prior to development especially if there is an existing facility, which needs system interaction.



- Functional Test /System Performance Test, System Tuning, and Optimization

  Once all graphics are completed, all testing for equipment and system functionality can be proven by adjusting the settings to see the response of the system. From time to time, verification requires a real time view of the actual performance of a piece of equipment in response to a change in sensor setting.

  System Performance Testing pertains to the testing required in order to prove the performance of the HVAC System as a whole or as part of the system. The HVAC system is composed of multiple systems such as the cooling system, heating system, air distribution system, humidification system and controls, which must act together as one system in order to be able to perform the designed purpose (occupant comfort, efficiency, and reliability). Each system design varies, and performance is based on the designed programmed control algorithm such as proportional, integral (reset) and differential (rate of change) which needs to be proven during the T&C phase. Chilled water distribution is generally classified into primary system or primary/secondary system and is further diversified into dedicated pumping or combined pumping when pertaining to chiller and pump relationship. Chiller arrangement is also classified into parallel and series arrangement depending on the purpose of the design. Air distribution can be a simple fixed speed fan or a variable frequency drive fan where the control algorithm can be set to constant pressure variable flow or an algorithm of variable head and variable flow. In relationship to the return or exhaust system, the air supply distribution can be designed as control demand ventilation, maintaining constant room pressure, or can be based on flow. Depending on the intent of the design, each system must be proven after the completion of the BMS. System Performance Testing incudes testing for all functions of the equipment, field devices, measuring devices, and controllers, to work as an integrated system. Refer to centralized AHU and pump performance checklists EPM-KT0-TP-000030 and EPM-KT0-TP-000032 contained in the Testing and Commissioning Checklist and Templates document, as samples.

  System tuning is a term used to adjust set points, gains, timings, and other control parameter during the operation of the HVAC System to correct or improve the performance of the system. Initial calculation provides the basis for set points and control points, but performance may not be as expected during the actual operation, thus requiring some adjustments. As an example, a chilled water index point as the reference of control set-point for secondary pump operation, was calculated at 0.8 bar based on calculated pressure drop of the coil, control valve, and accessories. However, during operation, it was noticed that the actual flow was lower than designed and created a problem with the cooling capacity. The set-point is adjusted to 0.85 bar (or higher) to increase the flow. Optimization in HVAC System pertains to the method of operating the system and equipment in the most energy efficient manner and must be develop during the design stage as part of the SOO with the assistance from the Commissioning Authority.

It must be noted that most of the problems encountered in the BMS regarding operation is the use of wrong signal matching (or unmatched signal) and type. Zero (0) to ten (10) volts field device must match the controller signal, 2 to 10 volts device must match to 2 to 10 volts controller, etc. Voltage signals must not be used for long distance wiring communication since degradation of the wire resistance due to temperature changes will largely affect the BMS performance. In this case, current signal (4 to 20mA) is more appropriate.

6.2.3 Mechanical Life Safety Systems

The following section deals with all mechanical systems related to Fire and Life Safety. For all systems discussed under smoke management system, the required differential pressure across doors by NFPA 101-2012 edition are as follows:

“Minimum 12.5 pascal door differential for fully sprinkler buildings and 25 pascal for non-sprinkler or partially sprinkler buildings and the force to open the door leaf shall not exceed 133 N (30 lbf) when the system is operating.”

For smoke barriers, the required minimum pressure differential by NFPA 101 are as follows:

Building Type	Ceiling Height, mtrs.	Design Pressure Difference, pascal
Sprinklered	Any	12.5
Non-sprinklered	9	25
Non-sprinklered	15	35
Non-sprinklered	21	45

It is also worth noting that sprinklers have a great affect in reducing the plume temperature therefore reducing the required volume of extracted smoke as well as the make-up air requirements. Selection of smoke extract fan temperature rating is highly influenced by the sprinklers since the smoke layer will not exceed 185° in a sprinkler-controlled fire. Smoke layer can reach more than 500°C in a non-sprinklered fire even there is a proper smoke extraction system. The resulting plume temperature greatly depends upon the rate of heat release of the fuel considered. Extract fans must then be selected according to the published temperature ratings.

Temperature rating tests for fire rated fans can only be conducted at factory setting, as well as thrust testing for jet fans used for enclosed car parking structure. It is advisable that a Client representative should always be present to witness the factory testing for fire rated fans.

Staircase Pressurization System (SPS)

SPS and other smoke control systems (e.g., vestibule smoke control) is required for a staircasein order for it to be considered as an NFPA defined smoke proof enclosure. For any building, the staircase is considered as the safe point of exit and Travel Distances are terminated at the entry to the staircase. Travel distances extend to the staircase that is not considered a smoke proof enclosure. Travel distances can increase if the building is fully covered by sprinkler system complying to the requirements of NFPA 13. This section only discusses the SPS since it is always preferred to other types of smoke control systems for staircase.

SPS design varies from building to building. The design can be any of the following.

- A variable frequency (or speed) drive pressurization fan with differential pressure sensors installed inside and outside the floor door.
- A constant speed pressurization fan with relief damper at the top of the shaft.
- A constant speed pressurization fan with relief damper in the supply ducting (relieving air to the atmosphere).
- A constant speed pressurization fan with variable pitch (varofoil)

For a SPS to work effectively, an exhaust shall be needed in the adjacent corridor to remove the air from the unpressurized area, in order to maintain the required differential pressure.

The resulting air flowrate for pressurization varies from code to code due to the required open doors and air velocity across the open doors to maintain a required differential pressure. British Standard BS5588 requirements result in the lowest air flow since the standard only requires two (2) open doors and 0.75 m/s velocity (for 50 pa to 60 pa) while the Australian and Singapore Standard AS1668 and CP13 requires 1 m/s (for 50 to 110 pa for non-compensated system) and four (4) open doors. NFPA do not define the number of required open doors.

Standalone tests as per NFPA 92A 2012 edition, is simply running the pressurization and exhaust fan when all doors are closed and measuring the pressure differential across the door by an inclined manometer. Doors are opened one by one (based on the design number of open doors) by a door pressure gauge and ensures that the maximum door leaf opening pressure of 133 Newton will not be exceeded at any time and that the minimum pressure will not be violated for sprinkler and non-sprinkler building.

Atrium Smoke Extraction System (ASES)

Two or more floors interconnected through a large, enclosed space is called an Atrium and smoke extraction is required by Codes and Standards. Smoke extraction is not required for two (2) floors when the lower floor is the ground floor. Extract air flowrate primarily depends in the (1) heat release rate of the fuel considered, (2) the design depth of the smoke clearance and (3) temperature of the plume reference to the space for sprinkler or non-sprinkler. As explained in Section 4 of this Guideline, the technique for identifying the required exhaust volume is by using the “Performance Based Criteria” through Computational Fluid Dynamics (CFD). System performance testing will not be required above that of the equipment (fan) performance testing.

Since the volume of air that needs to be extracted is huge for an Atrium, make-up air from the AHU cooling the space is always insufficient, requiring other means of make-up air source. Since most Atriums are located with its lower floor in the ground floor level, the entrance doors are normally used to provide make-up air by opening the doors prior to the running of the exhaust fans. Using the entrance doors for make-up air will require integration testing between the Atrium Smoke Extraction System and the Access Control System.

Testing procedure is similar to that of the Staircase Pressurization System.

Engineered Zoned Smoke Control System

Is a non-dedicated smoke control technique where the HVAC system is designed and arranged to be utilized during normal condition with the same system used for smoke extraction during any fire condition. For multiple floors, each floor is composed of multiple smoke zones and the zone where the smoke is detected is immediately subjected into negative pressure, while all other adjacent zones (including above and below floors) are pressurized. Motorized dampers are usually utilized to attain the desired function as well as increasing/reducing the speed of the supply/exhaust fans. This system requires a large amount of exhaust air (such as Atrium Smoke Extraction System) and therefore requires large volume of make-up air, which poses difficulties during the HVAC design.

Because of the complexity of controls and required sophisticated programming, the BMS is always the prime mover of this system instead of Fire Alarm Panels. Extensive integration (in terms of programming and testing) between the BMS and FDAS is required to ensure that the correct information is received by the BMS regarding the address of the smoke detectors to provide smoke protection in the correct zone.

Connectivity between BMS and FDAS is always through software using this system. To complete the T&C Work for this system is extremely complex especially for healthcare because of the difficulties in programming and testing since there are many zones involved. Testing requires each and every smoke zone to be proven for correct programming of field devices and to ensure relevant pressurization.

Maintenance of the system is normally neglected since most facility personnel are not aware of the system functionality. The stated problems are some of the reasons why Codes such as NFPA have moved away from such requirements. Other reasons for removing such requirements are (1) improvements of anesthesia with regards to fire hazards for healthcare, (2) improvements to fire resistivity and smoke generation characteristics of building components, (3) improvement of smoke detection systems and (4) improvements in fire suppression systems such as sprinklers. For instance, NFPA 99 editions prior to 2012 required zone smoke control for windowless anesthetizing locations of healthcare was already removed in the 2012 edition.

As explained in Section 4 of this Guideline, the technique for identifying the required exhaust volume is by using the “Performance Based Criteria” through Computational Fluid Dynamics (CFD).System performance testing will not be required above that of the equipment (fan) performance testing. Testing procedures are similar to those of the Staircase Pressurization System.

Lift Lobby Smoke Management System (LSMS)

The purpose of the system is to avoid any risk of smoke penetration into a Lift Lobby, which could then go through the opening of the elevator car doors and to the other Lift Lobbies through the elevator shaft. Several mechanical techniques are allowed by the Code to avoid such risks, are as follows:

- Lift Lobby Pressurization System

  A technique used to pressurize all Lift Lobbies.
- Lift Shaft Pressurization System

  A technique used to pressurize all Lift Shafts.

Unlike other smoke management systems, this system is designed to prevent ingress of smoke into the lift lobbies, therefore the design for air flow only considers air leakage at the doors and lift shafts and to overcome the pressure created in the adjacent area due to increase in temperature during fire condition.

Test methods for testing pressure differential across doors are similar to that of the Staircase Pressurization System.

Car Parking Smoke Management System (CSMS)

Car parking facilities are classified as open or enclosed car parking structures. To be classified as open car park, NFPA 88A and SBC requires the following conditions to be met for a non-combustible construction (NFPA Type I and II construction);

- Each parking level shall have wall openings open to the atmosphere, for an area not less than 0.4 m2 for each linear meter of exterior perimeter.
- Such openings shall be distributed over 40% of the building perimeter or uniformly between two opposing sides.
- Interior wall lines and column lines shall be at least 20% open, with openings distributed to provide ventilation.

Open Car Parking structures do not require smoke extraction and sprinkler system. Enclosed Car Parking requires smoke management system, and the code allows two (2) kind of approach, namely.

1. Use of fire rated smoke extraction fan and fire rated ducting system.
2. Use of fire rated smoke extraction fan and fire rated impulse fan (or jet fans).

Both systems require testing only for extract fan performance testing, system performance testing is not required. Extract air quantity for smoke extract fans is dictated by Codes while Jet Fans are designed using s “Performance Base Approach” by Computational Fluid Dynamics. Jet fan thrust is witnessed and certified during factory testing.

6.2.4 Fire Sprinkler, Stand Pipe, Hydrants and Hose System

Fire Sprinkler System complying to NFPA 13 installation requires the following:

Flushing of Sprinkler Piping and Stand Pipes

Requirements for flushing velocity of NFPA 24 is 3 m/s for any pipe size. Flushing starts from the main lines (feed-main and cross-mains) and risers until no visible welding slags and burrs are noticeable, then at every sprinkler head outlet points at the end of each branch. Use of fire pump is the usual method of flushing for fire sprinkler and standpipe system.

Setting of Pressure Reducing Valves

Standard available sprinklers used for fire protection has a maximum rating of 175 psig while fire hoses maximum residual pressure is limited by NFPA 14 to the following.

40mm. ø fire hose (including 25mm. hose reel) – 100 psig.

65mm. ø fire hose – 175 psig.

For medium and high-rise building applications where the static and residual pressure (especially when the fire pump is activated by a single sprinkler where it operates close to the shut-off head) can exceed the pressure limitation, it is mandatory to use UL/FM listed Pilot Operated Pressure Reducing Valves. Setting the PRV simply requires rotating the knob of the PRV pilot valve until the discharge pressure gauge indicates the pressure requirement to limit the most extreme fire hose and sprinkler heads to the pressure as stated above.

Setting of Fire Hose Valves

Some local codes and jurisdiction requires 40mm.ø fire hose valves to be set at exactly 65 psig and the 65mm. ø hose valve at 100 psig. They do not allow the maximum pressure as per NFPA 14 for safety reasons. Some jurisdictions even allow 65mm.ø fire hose valves to be set at 65 psig. UL/FM pressure limiting type hose valves are delivered with a graph, which indicates a corresponding number based on upstream static pressure and target downstream residual pressure. The limiter can then be rotated and set to obtain the required level, which will reduce the downstream residual pressure. A hydro test box is temporarily connected to verify the pressure.

Hose Stream Flow and Residual Pressure Test

NFPA 14 requires to prove the flow and residual pressure of the most remote fire hose. The most remote fire hose shall be flow/throw tested to prove the following:

Hose Valve Size, mm.	Flow Requirement, gpm	Residual Pressure, psig.
40 ø	100	65
65 ø	250	65 or 100 (depends on AHJ)

Testing is done by providing a test manifold with pressure gauge in between the most remote hose valve and the fire hose. The hose valve is fully open, and the flowrate is determined through the obtained head of the fire pump plotted against the pump performance curve to obtain the flow. Residual pressure is directly read from the pressure gauge.

Sprinkler Bursting

To burst a sprinkler which is normally done at the most remote location (or other chosen location) is not a Code or Standard requirements, but an AHJ requirement to prove the coverage of sprinkler, proper operation of the fire pumps, and Fire Alarm System.

Supervisory Switch and Flow Switch Test

Flow Switch testing is conducted to confirm the flowing:

- That the flow switch can be activated by opening the inspector test valve which simulates bursting of one sprinkler head. The inspector test manifold contains an orifice equal to the orifice of the sprinkler head.
- To confirm that the system is clean and no slags, burrs or other dirt are present which can clog the sprinkler heads.

Supervisory switch testing is a simple test to confirm that the valve (a build-in supervisory for UL/FM butterfly valve or an installed supervisory switch in an OS&Y gate valve) is working. The test is done by rotating the valve handle for two (2) full turns from the fully open position when the switch should be activated prior to the completion of the full two (2) turns for normally open position. For normally close function, the valve shall be in fully closed position and the switch should activate prior to the completion of the two (2) full turns. Activation of the switch shall be determined by a continuity or resistance meter.

Fire Hydrant Testing

Fire hydrants are used by the Fire Fighters for three (3) reasons, namely.

- For direct use as a supply of pressurized water for firefighting in low rise and medium rise building application, where the 65mm.ø connection is used.
- For supply of water to supplement the fire truck in case of a high-rise building application, where the 100mm. ø connection is used.
- For supply of water to supplement the building fire tank, where the 65mm. ø connection is used. In this type of design, a 65mm.ø fire tank connection is required in the Fire Department Connection.

Tests for fire hydrants are similar to that of hose stream flow and residual pressure testing except that a flow-metering device is needed since hydrants are always installed in remote locations. The test manifold shall comprise of pressure gauge and a flow-metering device with straight pipe lengths (usually from 5 to 10 pipe lengths depending on the type of flow meter).

6.2.5 Domestic Water System

Upon completion of the Domestic Water System network, the following activities shall follow:

System Chlorination and Disinfection

The water tank is first chlorinated by hypochlorite or pure chlorine with concentration of 50 parts per million and shall maintain the concentration for 60 minutes (as per BS 8558:2011 and IPC). All surfaces that are un-wetted such as the portion above the water table and the tank soffit shall be applied with 1000 ppm solution. AWWA requirements is to chlorinate the tank with a solution between 50ppm to 150ppm and the concentration shall not fall below 25ppm after 24 hrs. After the chlorination time has elapsed for the tank, the chlorinated water is pumped to the piping network to disinfect the domestic cold and hot water systems for the required disinfection time. Water is flushed out continuously until chlorine concentration drops below 2.5 ppm. All strainers as well as all metallic parts of the system that can corrode during the process shall be removed.

The chlorination process is required to be conducted by a certified and approved water specialist. Refer to Section 7 of this Guideline for safe handling of chemicals HSSE risk assessment.

System Flushing

Flushing for domestic water system is done by ensuring that flushing velocity is attained anywhere in the network. For flushing velocity, refer to mechanical system preliminaries section 6.1.4

For large projects with large domestic water network, it is required to subdivide the building into flushing zones since the booster pump is always sized to have a diversity factor, therefore one time flushing for the whole network is not possible.

Pressure Reducing Valve Setting

Plumbing fixtures operate at a maximum pressure of 5.5 bar or less (as required by IPC and UPC). Healthcare normally limits the maximum pressure to 3.0 bar especially for showers and bidet in order to have a comfortable water jet. PRVs are required especially for high-rise building applications to limit the downstream pressure as indicated above.

Plumbing Fixture and Drainage Functional Testing

After system pressure is confirmed to be within the required limits within the network and third fix for plumbing system is completed, functional test immediately follows. The test is simply filling all fixtures with water and then draining them. Water filling and draining requires only visual inspection and any clog in the system will show slow fill or slow draining. A vortex formed during draining indicates a good drainage system. Hot water temperature of 50°C for normal application and 60°C for commercial kitchens, should come out from the faucet no later than 10 secs after activation of the faucet. Water closets and other fixtures with flush valves and tanks are flushed and visually inspected for effective flushing.

Hydronic Balancing for Hot Water Circulation System

For hot water systems employing the use of conventional balancing valves (low flow double regulating valve), balancing is done using the “Proportional Balancing Technique” (see section 6.2.1.1- mechanical preliminaries for hydronic balancing). All fixtures are required to be closed during the balancing process.

Proportional balancing for medium size to large hot water domestic network takes about two (2) weeks to a month. Use of temperature balance valves or automatic balancing valves resolve the issues of proportional balancing lead-time.

6.2.6 Irrigation System

The Irrigation System is divided into the conventional wired system and wireless system. The conventional type uses hard wire for communication and the wireless system uses transmitter and receiver for communication. Communication between the main controllers and solenoids or receivers is required for zoning of the distribution. Both systems follow the test procedures detailed below.

System Flushing

All ends of the main lines and branch lines (after the PRV and control valves) require flushing valves as a requirement of good design. Sprinkler heads such as impact heads, spray heads, shrub heads and drippers will not operate correctly if the piping system is not properly flushed. The principle of flushing velocities is only applicable in main lines. For branch lines (after the control valve and PRV, as required), flushing is simply done by fully opening the flush valve for 5-10 mins. Timing varies on irrigation specialist situations. Prior to the branch flushing, the PRV is set to the design pressure and the control valve is set open. After the flush, branch strainers are removed for cleaning and later reinstallation.

Flushing for all heads will only be required upon visual inspection if the device is not working properly. In such case, the head is removed, and the port is flushed until no dirt is found.

PRV Setting

Each irrigation sprinkler head is design for different pressures. Spray heads such as pop-up heads are normally design for a maximum 2.5 bar operating pressure, impact heads such as rotor type have a maximum operating pressure of 6 bar, shrub heads and dripper are designed for 2 bar maximum operating pressure. Due to these different pressure requirements, it is necessary to group the head types and provide Pressure Regulating Valves (PRV). Setting of the PRVs is simply by rotating the knob until the downstream pressure is set to the desired value.

System Zoning Test

Softscapes contain different kinds of trees, plants, shrubs, and grass that require different types of soil and water demand. Due to the large water requirements, designers divide the softscaping into zones to reduce demands. This also resolves problems in areas that are occupied during the day, so irrigation can be done during the nighttime.

Zoning is achieved by in the conventional wired irrigation system by programming the main controller with the timing of each solenoid valve serving a particular area. For wireless irrigation system with solenoid valve equipped with receivers, programming is done through the main controller. For wireless irrigation system with intelligent solenoid equipped with microprocessor, programming is done through the solenoid valve itself.

Zone Testing is done by observing the operation of the system against the design and programmed zoning.

6.2.7 Steam System

The pressure head of boilers heavily depends upon the type of utilization. If the requirement is for heat exchange utilization such as in heating with no specific temperature requirements above 120°C, 1 bar is sufficient as supply pressure corresponding to 120°C at the point of use. At this condition, there is no such difference between 1 bar and higher pressure since total heat will be same. For temperature utilization with specific requirements above 120°C, higher pressures are required at the point of use. For process utilization, such as in power plants, higher pressure and steam quality are necessary to run steam turbines, avoid blade erosion, avoid corrosion fatigue, sticking valve stem and plugging seals.

Commercial use of steam demands pressure up to 12 bar at the point of use such as in a centralized state-of-the-art laundry system. This will require 14 bar boiler head pressure to include pressure drop in piping. Process steam such as in power plants demands pressure head from 65 bar to 165 bar depending on the type of steam turbine to generate the required power output.

Commercial steam equipment cost is proportional to the pressure rating and exemplary savings can be obtained by lowering down pressure ratings. This is another reason why PRV Stations are used.

Steam discussed in this section is steam that comes from a boiler and not through natural (or geothermal) source. Steam piping system testing follows the procedure detailed below (refer to mechanical preliminaries for steam equipment operational and performance testing section 6.1.4).

System Flushing

Refer to Mechanical Preliminaries section 6.1.4. for flushing method using steam or air. Flushing requires removal of PRV in steam piping, station relief valves and extending steam piping to the external of the building.

PRV Station Setting

As explained above, pressure requirements vary from equipment to equipment and pressure ratings are normally limited to 1 bar to reduce equipment cost. Setting of PRV are typical to that of domestic water system.

Steam Quality Testing

Steam used in Pharmaceutical and healthcare equipment (CSSD autoclave, etc.) and Power Plants require steam quality testing. Boiler used for healthcare and pharmaceuticals are made of stainless steel and the water used comes from an RODI Water Treatment Plant to obtain the following steam quality as required by EN 285:2015 and ISO 17665:

Steam Parameter	Quality
Dryness	>0.95 w/w

Non-condensable Gases	≤3.5% v/v
Superheat	≤25°K

Test for steam quality uses Steam Test Kit to validate the above information.

Steam used in turbines for power generation is required to have the following quality by most of the turbine manufacturers:

Steam Parameter	Quality
Sodium Content	5 - 10 ppb
Silica Content	10 - 20 ppb
Chloride and Sulfide	3 - 15 ppb
Cation Conductivity	0.1 - 0.3 mS/cm

Testing for steam quality shall be based on ASTM D1016 sampling manifold for isokinetic flow.

6.2.8 Liquefied Petroleum Gas (LPG)

LPG is classified as Butane or Propane or a mixture of the two. For LPG piping network, NFPA 54 and 58 limit the pressure for LPG to 20 psig for welded indoor piping. PE piping is only limited to outdoor and buried piping with service pressure not exceeding 30 psig. Corrugated stainless steel is limited to 5 psig service pressure only for indoor installation. Outdoor piping using mild steel has no service pressure limitation. Because of these limitations, it is necessary to provide first and second stage pressure regulation. First Stage regulation is required prior to the piping entry to the building while the second stage regulation is required prior to the equipment connection that prevalently requires 4kPag. Selection of second stage regulator depends upon the equipment required pressure and capacity. First and second stage pressure regulators are not pressure adjustable.

Butane has a higher service pressure compared to propane (at 50°C ambient, propane has 17 bar vapor pressure while butane has only 4 bar vapor pressure). Butane has a higher heating value of 121.3 kJ/m3 after vaporization compare to that of 92.4 kJ/m3 for propane. Engineers and installers should be careful in selecting the first stage regulator because of the difference in developed pressure between butane and propane.

For cold regions where the ambient temperature is low, vaporization will be less for LPG gases therefore the user cannot rely only on natural vaporization. In this case, a vaporizer is required to satisfy LPG demand.

The following test procedures are required for proper system operation.

Pipe Flushing

Flushing for LPG Piping using water requires 3 m/s velocity for all pipe sizes until no burrs, welding slags or other dirt is noticeable. After water flushing, the piping is blown by air to remove any trapped water residue.

Leak Detection System (LDS) Testing

Due to the nature of LPG where it is heavier than air, leak detection is required by AHJ especially when kitchens or other LPG appliance is located below the ground floor level, where the gas can accumulate and pose danger to occupants. Leak detectors for LPG are always installed at the lowest point of the floor. The following tests are conducted to prove the resiliency of the detection system.

- Cable Continuity Testing – refer to electrical preliminaries section 6.1.4.1
- Cable Insulation Resistance Testing – refer to electrical preliminaries section 6.1.4.1
- Controller Configuration – pertains to the activity where each detector is assigned an address and group base on service location. Isolation solenoid valve is then assigned according to the group of

detectors. LPG isolation during detection varies from project to project but it is acceptable to have one central solenoid to cut-off the main supply line once a leak is detected. Other designs have one solenoid for each group of equipment located in a room or served by a common exhaust hood, so that other gas equipment continues to operate while isolating the group of equipment where the leak is detected.

- LDS Functional Testing – the test is conducted by opening LPG supply of an equipment until gas is detected. Solenoid valve should be closed correspondingly to the location of leak detected for multiple isolation or close the central solenoid for central isolation design.

Kitchen Equipment Functional Testing

The test is conducted by operating all gas equipment (as per the design assumption for diversity) by the suppliers and end-user to prove that the LPG design capacity satisfies the requirement during the lowest ambient temperature anticipated during the design.

6.2.9 Medical Gas System

The testing procedure discussed in this section is based on HTM 02-01 Standard and applicable for all types and mixtures of medical gases. Procedures for testing are as follows:

Leakage Testing

Prior to T&C Work commencement, the standard requires pressure leak testing for the whole medical gas system. A temporary piping test manifold to connect gas piping can be used in the plant room for testing purposes. Test methods for medical gases are as follows:

Gas System	Test Pressure	Pressure Loss (max)	Duration of Test
Vacuum and WAGD	5 bar (copper pipe)	0.2 kPa	2 hrs.
Surgical Air, MA7	18 bar	0.5 kPa	2 hrs.
Medical Air, MA4	10 bar	0.2 kPa	2 hrs.
Oxygen and other medical gases	10 bar	0.2 kPa	2 hrs.

For vacuum and WAGD total system leakage test, pressure loss shall not exceed 1 kPa for 1-hour period.

Pressure changes due to room temperature variation when using air as a test medium shall always be considered. It is always advisable to use nitrogen for leak testing of pressurized piping since it is not affected by temperature change.

Leakage Testing is done with all AVSU (Area Valve Service Units), LVU (Line Valve Unit) with accessories installed and fully open.

Cross Connection Testing

This is testing required by the Standard to check and ensure that there are no cross connections between medical gases. Pressurized air (MA7) is applied into each system one at a time where others are under atmospheric pressure. Gas terminals are checked one by one for pressurized airflow.

Functional Test of Manifolds and Pressure Reducing/Flow Control Stations

Each medical gas control station contains pressure regulation, flow control and redundancy control. Two (2) manifolds are always provided where one serves as stand-by and for emergency use in case the other manifold fails for any reason.

The test is conducted by closing the service valve of one manifold (service) and validating that the stand-by/emergency manifold comes on line maintaining the flow and pressure.

AVSU, LVU Closure and Zoning Test

The test in conducted to validate the terminals that are covered and controlled by the AVSU and LVU against the as-built drawings. It is extremely important to have a correct identification of terminals served by AVSU and LVU to avoid closure of medical gases during use, which can lead to serious circumstances or fatality.

Functional Test of Terminal Units

This test can be conducted along with the cross-connection testing. The purpose of the test is to (1) confirm that the pressure drop does not exceed that given in the table below for the required test flow, (2) that the special NIST connector fits only to the specific gas terminal, (3) that the NIST connector for a specific gas terminal does not fit to any other gas terminal, (4) that the NIST probe sealing device fits properly and does not leak.

Gas System	Test Flow	Pressure Loss (max)
Oxygen	100 L/min for OR and Anesthesia Rooms (AR)	20 kPa
	10 L/min for all other terminal unit	20 kPa
Nitrous Oxide	15 L/min	20 kPa
MA4	80 L/min for Critical Care Areas, OR, AR	20 kPa
	20 L/min for all other Terminal Unit	20 kPa
MA7	350 L/min at 700 kPa	
Oxygen & N_2O	275 L/min for LRDP Rooms (inhalation gasps)	90 kPa at 5 sec.
	20 L/min for all other terminal unit	20 kPa
He/O_2	80 L/min for critical care only	20 kPa
Vacuum	40 L/min for all terminal unit	100 mm. Hg

Functional Test of Pipeline System

This test is conducted to prove that the piping distribution has been sized sufficiently and that the required capacity of all gas terminal units can be satisfied under the system design flow or diversified flow of HTM 02-01.

Validation of Pressure Safety Valves

Safety valves are not required to be site tested under HTM 02-01 and are only required to have valid certification to conform to BS EN ISO 4126-1:2004 manufacturing and testing method.

Warning System Testing

Warning System testing is required to prove (1) that all systems operate within the specified tolerance limits at all operating parameters and fault conditions and can be seen and heard as specified in HTM 02-01, (2) that systems react accordingly following return to normal status, (3) that all indicator panels and switches are correctly marked, (4) that all functions on all indicator panels operate correctly, (5) that the system will operate from the essential power supply, (6) that all indicator panels are labelled to show the areas and locations they serve.

The test is conducted by varying the pressure (closing each AVSU one by one to test for low pressure and then increasing the system pressure through the gas manifold control stations and opening the AVSU one by one to test for high pressure) and monitoring the audible and visual alarms. Silence and reset switch are tested during each course of the testing.

Filling with Medical Air (MA4)

If undue delays may occur in completion of the project, prior to the use of the medical gases, it is necessary to fill all medical gas piping with MA4. Prior to filing with the permanent gas, each system is tested for particulate contamination and odor testing.

Purging and Filling with Medical Gas

Once installation of the medical gas network is complete including gas terminals and all required test are successfully completed, the system is filled with medical gas. All AVSU and LVU shall be fully open, and each gas terminal is purged open equal at least to the volume of the pipeline being purged.

Vacuum and WAGD are not needed to be purged and can be directly put in use.

Gas Identity and Quality Testing

After the system is filled with the specific medical gas, identity and quality tests follow. This is the last testing to be conducted by the end user to check the identity and quality of the gas prior to system acceptance. Oil, water, CO, CO_2, NO_2, SO_2 particulates are determined as well as the gas odor. Parameters shall comply with the requirement of HTM-02-01.

6.2.10 Clean Agent System

Clean agent pertains to fire extinguishing agents that do not leave any residue when discharged during fire propagation. They are classified into different types with their own advantages and disadvantages. FM-200 and NOVEC are halocarbons, which operate by smothering and cooling. Halocarbon has the disadvantage of ozone depletion and contribution to global warming. It is not advisable for use in quick propagating fires with high release rate as well as electrical rooms containing oil equipment since it can decompose into dangerous compounds. Electrical arcing easily decomposes halocarbon into toxic compounds. Carbon dioxide also operates by cooling and smothering but has issues with gas expansion and nozzle freezing. CO_2 is also not so effective in controlling class A fires.

The following testing requirements have to be complied with by the manufacturer/installer prior to acceptance.

Flushing of Piping

Since clean agent piping is short and confined locally, air is a common acceptable method for flushing. An air compressor of sufficient capacity is used to blown any burrs and dirt inside the piping.

Functionality Testing

After completing the installation, the following test follows to prove the functionality of the system and controller. A portable smoke generator is provided to activate smoke detectors (or the design can employ a combination of heat and smoke detectors).

Solenoid Activation

In practice, solenoids are detached from the tank-actuating valve since clean agents are very expensive to discharge. Codes and Standards do not require discharge of the agent during test. A common site method to prove solenoid functionality is to insert a metal rod into the solenoid slot and see if it is magnetized.

Damper Closure (as applicable) and HVAC Equipment Shutdown

When ducts penetrate the room served by clean agent, it is required to provide motorized dampers. Upon cross-zone (double knock) detection, the motorized dampers are closed to seal the room and ensure integrity. Shutdown of HVAC equipment (AHU or FCU) is usually employed to avoid pressurizing the room, which can cause the clean agent to escape. In some conditions however, HVAC equipment needs to run continuously such in the case of Healthcare Data Rooms since excessive heat generated by the IT equipment can disable all data infrastructure causing the operation of the hospital to stop.

Audible and Visual Alarm Test

Upon the first detection, “visual” lamp illuminates in the control panel and the audible/visual alarm are energized. After the second detection (double knock), the pre-discharge lamp illuminates in the control panel and pre-discharge audible/visual alarm sounds.

Abort Testing

Upon the second detection, the time delay sequence starts as well as the abort sequence. Once the abort button is pressed or activated, all visual and audible alarms (in the panel and pre-discharge alarm) will stop as well as the time delay sequence.

Emergency/ Manual Release

Once emergency or manual release is pulled or activated, the solenoid shall immediately energize (by confirming the magnetization of test metal rod in the solenoid slot). Alarm shall start and will continue until the panel is re-set.

Re-Set Testing

In the event of detection either for single or double knock which activates visual and audible alarms, the controller shall silence all alarms upon activation of reset button in the controller.

Panel Circuit Supervision

Supervisory is the term used in low current systems which pertains to the continuous monitoring of any “trouble” within the system such in the case of cut-cables, removed detectors, low battery status, etc. Test shall be conducted by removing cable termination, detectors, and battery to see if the control panel will respond by indicating “trouble and alarm signal” and sending the signal to the Fire Alarm Panel.

Battery Autonomy Testing

This test is required to test the capacity and ability of the battery to support the system to remain fully operational in design functionality for a minimum of 24hrs without normal power supply.

Room Integrity Testing

NFPA 2001 requires all room protected by a clean agent system to pass the Room Integrity Testing (RIT) for the clean agent to function properly. The test is to determine the air leakage in the room due to improper wall and slab soffit termination, improper door specification and installation (such as to much undercut and without seals), improper sealing of electro-mechanical penetration and to ensure that the leakage will not exceed the requirements of the Code.

6.2.11 Acoustic and Vibration Testing

Contract Specification should specify the method of noise measurement. The majority of projects require overall noise criteria in terms of Average dB and some projects require verification of noise emissions from mechanical and electrical equipment and fixtures in terms of NC level or RC level. The overall noise criteria in dBA is composed of intrusive noise, noise coming from building services equipment, transmitted noise from ducting, noise from plumbing pipes, noise from internal equipment, etc. The dBA criteria is always the concern of the architect and not the mechanical engineers. Different noise criteria such as dBA, NC, and RC have different ways of considering peak frequencies within the audible frequency range and have different applications where it will be applicable. Every noise criteria is a logarithmic summation of all frequencies within the audible range.

The focus of this Guideline is in the equipment-generated noise and noise transmitted through the ducting and emitted in the diffusers, which is expressed in terms of NC levels or RC levels.

NEBB measurement for noise emission based on NC or RC is as follows (using an NC or RC acoustic meter):

- Noise level is taken 1.2 mtrs. above the floor and 1.5 mtrs. away from the ceiling or wall diffuser.
- For rooms adjacent, above, or under a mechanical room, noise level is taken 1.2 mtrs. above the floors and at least 0.9 mtrs. away from the wall or any reflective surfaces. Several points shall be considered for the test for long wall or reflective surfaces.
- For HVAC equipment above ceiling, radiative noise shall be taken 1.2 mtrs. above the floor and directly below the equipment.

Below is the ASHRAE Noise Criteria for NC/RC:

Room Types	NC or RC
Residences, Apartments, and Condominiums	25 to 35
Hotels and Motels	
Individual room or suit	25 to 35
Meeting/banquet Rooms	25 to 35
Corridors, lobbies	35 to 45
Service, support areas	35 to 45
Office Buildings	
Executive and private offices	25 to 35
Conference Rooms	25 to 35
Teleconference Rooms	≤ 25
Open plan offices w/out sound masking	≤ 40
Open plan offices with sound masking	≤ 35
Corridors and lobbies	40 to 45
Hospitals and Clinics	
Private Rooms	25 to 35
Wards	30 to 40
Operating Rooms	25 to 35
Corridors and Public Areas	30 to 40
Court Rooms	
Unamplified Speech	25 to 35
Amplified Speech	30 to 40
Performing Art Spaces	
Drama Theatres, concert, and recital halls	25
Music teaching Studios	25
Music practice rooms	30 to 35
Laboratories with fume hoods	
Testing/research, minimal speech communications	45 to 55
Research, extensive telephone use, speech communication	40 to 50
Group teaching	35 to 45
Church, Mosque, Synagogue	25 to 35
Schools	
Classrooms	25 to 30
Large lecture rooms	25 to 30
Large lecture rooms w/out speech amplification	≤ 25
Libraries	30 to 40
Indoor stadiums, gymnasiums	
Gymnasiums and natatoriums	40 to 50
Large seating capacity spaces with speech amplification	45 to 55

When taking noise measurements using NC or RC criteria, all other sources of noise shall be at a minimum. It is therefore necessary that the tests and readings should take place during the night when all other source of noise is at the minimum. Unlike dBA criteria where it is required to take readings or measurement during the day when all sources of noise are evident (with the exception of speech-generated noise).

Requirements for vibration limits of rotating equipment should be clearly specified in the contract as well as the vibration criteria for occupied spaces for human comfort. In general, vibration criteria are specified based on three (3) areas namely, (1) relative to perceived human response to vibration, (2) vibration levels that have potential disruption to sensitive equipment such as MRI and PET-CT for healthcare, (3) vibration severity of an operating machine. Although not commonly specified, it is a normal practice that rotating equipment greater than 7.5 hp should be included in the vibration measurement.

Below is ASHRAE requirement for vibration limits:

	Time of Day	rms velocity 8 to 80Hz curve, mm/s
Human Comfort		
Workshops	All	0.813
Office Areas	All	0.406
Residential (good environmental standards)	0700- 2200	0.203
Hospital Operating Rooms and Critical works areas	All	0.102
Sensitive Equipment Requirements		
Adequate for computer equipment, probe test equipment, and microscope less than 40X	n/a	0.203
Bench microscope up to 100X magnification, laboratory robots	n/a	0.102
Bench microscope up to 400X magnification, optical and other precision balance, coordinate measuring machines, metrology laboratories, optical comparators, microelectronics manufacturing equipment, proximity, and projection aligners	n/a	0.025
Electron microscope up to 30000X magnification, microtomes, magnetic resonance imager, microelectronic manufacturing equipment such as lithography and inspection equipment to 1mm. detail size.	n/a	0.013
Electron microscope at magnification greater than 30000X, mass spectrometer, cell implant equipment, microelectronic manufacturing equipment such as aligner, steppers, and other critical equipment for photolithography with line widths of 1/2 µm which includes electron beam system.	n/a	0.0054
Un-isolated laser and optical research system, microelectronics manufacturing equipment such as aligners, steppers, and other critical equipment for photolithography with line widths of 1/4 µm which includes electron beam system.	n/a	0.0032
Building Equipment Requirements		
Pumps	n/a	3.3
Centrifugal compressor	n/a	3.3
Fans (vent sets, centrifugal, axial)	n/a	2.3

The above vibration velocity is measured by an accelerometer placed in building structures near the vibrating equipment or in areas containing occupants or sensitive equipment.

As a rule, vibration isolation for building equipment is effective if the ratio of the disturbing frequency of the equipment to the natural frequency of the structure where the equipment is fixed is equal to or greater than 3.5. For instance, a pump running at 3600 rpm (natural frequency of 60 Hz) is placed on a ground slab with natural frequency of 4 (ground slab has lower natural frequency since it is thinner than a suspended slab and has less reinforcement). In this case since the ratio is 15 (60 /4), vibration isolation is already efficient and further installation of isolators will have no further effect. This is the main reason why equipment installed in ground slab have less problems concerning vibration.

For building equipment installed on suspended slabs which create large vibratory forces (such as large generators), a Specialist should always be consulted since the equipment rotational speed is usually low and the slab natural frequency is high (due to thicker and stiff structure, deep beams, and high reinforcements). Vibration transmission to the structure is high in this scenario, therefore other measures of vibration isolation are required (such as inertia bases and special isolators). It should be noted that a Specialist should always be consulted for vibration isolation of sensitive equipment as noted above.

6.3 Electrical System Standalone T&C

6.3.1 Power System Study

Prior to the approval of the electrical Single Line Diagram (SLD) shop drawing, it is a mandatory requirement that a power system study must be provided. The electrical power study is composed of the following:

Short Circuit Study

A short circuit study is the first analysis of an electrical system that determines the magnitude of the currents that flow during an electrical fault (line-to-earth, line-to- line, and three-phase fault). Comparing these calculated values against the OCPD (Over Current Protective Device) ratings is the first step for ensuring that the electrical power system is safely protected. Fault currents are calculated based on the overall impedance of the loop downstream of the fault. Overall loop impedance includes three major contributions such as (1) impedance through the power source (source transformer and neutral grounding in the case of earth fault for TT Earthing System) via transmission and distribution lines, (2) Generators in the power network and (3) Rotating plant such as motors which convert mechanical inertia into electrical energy. Once the expected short circuit currents are known, a protection coordination study is performed to determine the optimum characteristics, ratings, and settings of the power system protective devices.

Protective Device Coordination Study

In a properly coordinated protective device, any short circuit fault downstream of the protective device will open the device as fast as possible to isolate the fault circuit while leaving the remainder of the system undisturbed, maintaining continuity of service. Coordination of OCPD is done under the time-current curve within the 0.1 sec as normally interpreted through the Codes (some projects specify 0.01 sec coordination) by adjusting the settings (increasing and decreasing delays and pick-ups) of OCPD. Once the coordination study is completed, arc flash study can then commence.

Coordination study follows the short circuit study. Selective coordination which is the usual term used in T&C Works means that not only the coordination due to earth and phase fault should be included but the study shall also include overload coordination.

The Specification should clearly indicate the requirement of the owner and the AHJ regarding the extent of OCPD coordination study based on the interpretation of the Code.

ARC Flash Study

Arc flash study is the analysis of the incident energy that is rapidly produced due to an arcing fault such as phase faults, ionization of air between phase buses, and switching. Arc flash study during OCPD coordination is concerned more on arc produced during switching. The incident energy produced during switching, decreases if the interrupting time of the OCPD is shortened while the incident energy increases if the interrupting time of the OCPD is increased. NFPA 70E defines four (4) levels of hazard risk categories based on arc flash incident energies. The HSSE hazard risk categories determine the type of PPE required for electrical maintenance within the arc flash boundary.

Completion of the arc flash study yields labelling output for each maintainable and semi-maintainable OCPD (Power Breakers and Insulation-Case Breakers in Switchgears and Switchboards) with two (2) important pieces of information namely, (1) amount of incident energy which determines the PPE requirements and (2) the arc flash boundary. It is important that the allowable level of hazard risk category be stablished in the design specification since this will govern the selection of the OCPD.

Hazard Risk Categories (HRC)

HRC	Clothing	Incident Energy, Cal/cm2
0	Non-melting, flammable materials (untreated cotton, wool, rayon, silk, or blends of this materials) with a fabric weight of at least 4.5 oz/yd^2	n/a
1	FR shirt and FR pants of FR coverall	4
2	Cotton underwear, conventional short sleeve ad brief/shorts, plus FR shirts and FR pants	8
3	Cotton underwear plus FR shirt and FR pants plus FR overall, or cotton underwear plus two (2) FR coverall	25
4	Cotton underwear plus FR shirt and FR pants plus multi-layer flash suit	40
Extreme Danger	No PPE Available	>40

Completion of the above three (3) studies is a pre-requisite prior to the approval of the SLD shop drawing. The electrical single line diagram (SLD) should include information regarding the brand, model of each OCPD, distance of transmission and distribution cables, size, transformer impedance for phase-to-phase, phase-to-earth, and phase to earth fault (to include impedance of the source neutral grounding). The commissioning report shall include manufacturer supplied time-current curve for all selected OCPD as well as the coordination and arc-flash study for the whole electrical power network OCPD.

The contractor is advised to be proactive in completion of the above three (3) studies since it is always the common source of problems for the electrical T&C Work completion. The above studies usually take from three (3) to six (6) months for medium size to large-scale projects, upon substantial completion of electrical shop drawings for all building floors.

Phase Balancing - Single Phase Load

Phase balancing for all single-phase circuits is a requirement prior to the approval of distribution boards as well as the SLD. While lighting circuit does not pose any difficulties in phase balancing, the opposite is true for convenience outlets since actual loads cannot be accurately identified during the construction phase. Phase balancing can only commence for convenience outlets during the occupancy phase when single-phase loads are fixed, therefore balancing during the construction phase only serves as a preliminary study. Since phase imbalance up to 10% of the current is acceptable for the three (3) phases (between phase with the highest and lowest current), medium to large project do not suffer from phase imbalance problems because single-phase loads are only a small fraction of the total electrical load.

Harmonic Study

Harmonic study is the analysis of the phase waveform in regard to pure sinusoidal distortion due to non-linearity of the current flowing in the load to the applied voltage. Odd harmonics which are odd integer multiples of the fundamental harmonic, cause; (1) voltage distortion, (2) zero crossing noise, (3) overloading of neutrals, (4) overheating of transformers and induction motors, (5) nuisance tripping of circuit breakers, (6) over stressing of power factor correction capacitors, and (7) skin effect. Common source of harmonics within the building premise are as follows: (1) Switch mode power supplies, (2) electronic fluorescent lighting ballast, (3) variable speed drives, (4) Uninterruptable power supplies and (5) magnetic core devices such as transformers.

Harmonic study follows the completion of phase balancing activity and should be conducted by a Specialist. Close coordination between designer and the Specialist needs to take place to arrive at a possible solution. Common solutions involve the use of the following methods, (1) Active harmonic filters, (2) Passive harmonic filters, (3) Isolation transformers.

Since variable speed drives contribute large amounts of harmonics in a modern building, selecting a 12-pulse bridge VFD controller helps eliminate the third up to the ninth harmonics.

Other Power System Studies which are required during the design stage such as (1) Power Flow Study which deals with the behavior of the flow of power from multiple simultaneous sources and (2) Power Factor corrections are not discussed in this document.

6.3.2 Electrical System Testing

This section discusses electrical power system testing based on the British Standard IEE Wiring Regulations.

Cold Testing

Cold Testing is the term used for all inspection and testing required in low voltage electrical installations (main, sub-main, distribution boards and Motor Control Centers) prior to energization. Cold Testing is part of the construction testing or preliminary T&C Work. The test is witnessed and accepted by Project Managers/Construction Managers in normal construction set-up prior to energization and offering of the work to the T&C Agent for Live Testing. Cold Testing is composed of the following activities.

- Visual inspection and recording of the details of electrical equipment and electrical distribution boards.
- Visual inspection and recording of actual circuit details and cable sizes against the schedule.
- Checking for tightness of all cable connections including bus bars by torque testing. Manufacturer provided information of torque requirements shall be the basis of inspection and verification.
- Carrying out continuity tests on board and outgoing circuits using an Ohmmeter. Phase to neutral, phase to phase, and phase to earth resistance values are recorded.
- For panel bus bar or distribution bus bar, continuity resistance is measured of every joint by the use of a micro-ohm meter (ductor tester) during construction.
- Insulation testing on board and outgoing circuits are carried out. For MCC, insulation resistance on bus bars and outgoing circuits are measured and recorded as follows:
    - Between phases.
    - Between phase and earth.
    - Between phase and neutral.
    - CPC (Circuit Protective Conductor) and neutral.
    - Motor insulation resistance.

  Insulation test at 500V DC to each joint and section during construction and re-test at completion of installation is carried out. For medium voltage, refer to the preliminaries section 6.1.4.1 for test voltage on different MV cables.
- Polarity check is conducted afterwards (for single phase). This test is conducted to ensure that fuses and single pole switches are in the phase conductor. For projects which strictly follow cable color coding, this test is normally overridden.
- Setting of OCPD delays and pick-up for coordination is carried out.
- All warning stickers for Hazard Risk Categories are put in place for all OCPD panels. Electrical technicians involved in switching are required to wear the mandatory PPE. All other personnel are expected to respect the arc flash boundaries.

Note that testing for electrical equipment such as transformers, switchgear, switchboards, UPS, ATS, etc. come under the Supplier/Manufacturer responsibilities and are discussed under the electrical preliminaries (see equipment re-start up check and Operational Testing in section 6.1.4.4). Only cables connected to this equipment are the responsibility of the T&C Agent for continuity and insulation resistance testing.

Electrical System Energization

Upon completion of the Cold Testing and inspections as well as the testing required for the electrical equipment by the Suppliers/Manufacturers, electrical system energization takes place. Energization is always carried out by the Main Contractor electrical installation team in coordination with all electrical equipment suppliers and supervision of the Main Contractor's Safety Department Team, T&C Agent, PM/CM, and Commissioning Authority. Lock-out and tag-out procedures must be in place starting at the upstream and downstream of any feeder. Warning labels and a means of security (locks) must be provided to restrict / prevent entry to electrical rooms and inform construction workers and staff regarding the activity. Energization starts one-by-one from the main equipment source and down to the last distribution board.

Live Testing

Live Testing pertains to all testing required by IEE Wiring Regulation to prove the electrical installation safety and functionality. Once each electrical board is energized, live testing takes place at the downstream panel incomer while the main earth conductor is detached from the downstream panel earth bar.

- Earth Fault Loop Impedance Testing (EFLI) and Prospective Earth Fault Current (PEFC) Testing

  EFLI and PEFC are tests required by IEE Wiring Regulation edition 17 to check and verify that a sufficient fault current will be available during an earth fault to trip the OCPD upstream of the fault as fast as possible. The test is conducted from the first OCPD downstream of the transformer as the upstream circuit is energized. This procedure is continued up to the last downstream distribution board. Test is from the incomer of any board back to the source using an earth fault loop impedance tester (by megger or others) to obtain Ze (external impedance) and Zs (total impedance) and the prospective earth fault current between phases-to-earth. Value of the PEFC in amps is plotted in the time OCPD time-current curve to obtain value of the disconnection time. For distribution board branch OCPD containing MCB (Miniature CB) an MCCB (Molded Case CB), the testing is conducted by momentarily creating an earth fault at the end of the circuits.

- Phase-To-Phase Prospective Fault Current (PPFC)

  PPFC is required by IEE Wiring Regulation edition 17 to check and verify that the phase-to-phase short circuit current will not exceed the interrupting current capacity of the OCPD to avoid damage in the device during the fault. The value can be taken directly by conducting the test between phases by a PFC tester or multiplying the highest PEFC between the three phases by two (if the tester is not capable to obtain phase-to-phase PFC) and comparing it to the KAIC rating of the OCPD. The measured or calculated PPFC should not exceed the OCPD KAIC rating. For distribution board branch OCPD containing MCB (Miniature CB) an MCCB (Molded Case CB), testing is conducted by momentarily creating an earth fault (or shorting phases) at the beginning of the circuits immediately downstream of the MCB o MCCB.

  For any fault to exist, disconnection time should not exceed the values below as per IEE Wiring Regulation 17th edition. For OCPD which exceeds the disconnection time, replacement of CB type is required.

Disconnection Time

Circuit Type	TN System	TT System
230/400 volts for final circuit not exceeding 32 A	0.4 sec.	0.2 sec.
230/400 volts for final circuit exceeding 32 A, distribution circuits and street lighting circuits	5 sec.	1 sec.

- Phase Rotation or Phase Sequence Test

Phase sequence tests are conducted for three (3)-phase circuits to ensure that the phase arrangements (L1, L2, and L3) are in the correct order reference to the source phases through a PST tester. For installation that follow strict cable color-coding, this test is normally overridden.

- Random Test for OCPD Coordination

  Testing for actual OCPD coordination for completed installation differs from project to project and depends on the requirement of the Specification. Standards require that all electrical components and assemblies must pass Type Testing in a testing facility witnessed by certified third parties. This will guarantee performance against manufacturer published data, safety, and reliability therefore actual testing for coordination is not required. Some projects require 10% of the CB quantity for actual coordination testing and some require actual coordination testing according to model type only per DB. If required by the contract, testing shall include phase to earth and phase to phase faulting.

- RCD Functional Testing (Applicable to RCBO and other Residual Current Device)

  This section pertains to the functional testing of Residual Current Device (RCD) required by IEE Wiring Regulation, which are used for supplementary protection from receiving a direct and indirect shock by touching live exposed parts of the electrical installation. RCD operates on the principle of unbalance current passing through a solenoid, which serves as a sensor to activate a tripping mechanism. Tests conducted by using an RCD Tester to determine the tripping time of the device are based on the applied test current. The tripping time should conform to BS EN 61008 and BS EN 61009, which are as follows:

RCD Type	**Rated Current IRC, Amps.**	**Rated Residual Current IRRC, Amps.**	**Standard Values of Break Time(s) and Non-Actuating Time(s) at test values multiple of IRRC (secs)**			
			IRRC	**2 x IRRC**	**5 x IRRC**	
General	Any value	Any value	0.3	0.15	0.04	Maximum break time
S (Time Delay Type)	≥ 25	> 0.030	0.5	0.2	0.15	Maximum break time
			0.13	0.06	0.05	Maximum non-actuating time

  British Standard BS 7671 requires any TT and TN earthing installation (with the exception of mineral insulated cable and bus bar trunking system) to provide RCD having a tripping current not exceeding 300 mA for protection against fire.

- MCB and MCCB Testing for Overload

  Similar to OCPD actual testing for coordination and testing for overload is not required to be conducted at site since all boards should pass the Type Testing in factory setting witnessed by certified third party. Only if the Specification requires then overload testing shall be conducted. Testing will require a megger overload tester which will inject test current and the time to trip the OCPD shall be within the published rating (between the hot and cold state region of the Time-Current Curve).

6.3.3 Electrical Power Management System (EPMS)

EPMS function is similar to the Building Management System (BMS), only that it is dedicated for the electrical power systems. Communications protocol and platform that is widely used is SCADA (Supervisory, Control and Data Acquisition) and SCADA DNP3 (Distributed Network Protocol) or Modbus compared to that of BACNet for BMS (although SCADA were originally created as a propriety protocol, each created by a manufacturers for a proprietary system to meet a specific need, DNP3 and Modbus are open protocols created for controller inter-operability). System communication architecture is divided into three (3) collapsed OSI models instead of four (4) layers for BACNet. Terminology used for controller hierarchy is slightly different such as DDC (for BMS) is called RTU (Remote Terminal Units) in EPMS.

Since EPMS is solely dedicated to the electrical power system, its architecture is much more simple compared to BMS. Functions of EPMS is limited to (1) electrical equipment monitoring and/or control, (2) power consumption management and (3) load shedding. Load shedding is a control scheme to remove electrical loads of secondary importance when the source is not sufficient to cater for all the electrical loads. This can happen in cases when (1) emergency power system capacity is designed to have a diversity compared to the total normal power requirements or (2) electrical power system design is a double-ended substation where each transformer on both ends of the substation is diversified compared to the total substation load.

Testing procedure is similar to BMS (for point-to-point, loop, and field devices calibration) and the user is referred to the BMS testing procedure. Final system functional testing in a load-shedding scheme requires shutting down of normal power or shutting off the incomer from one side of the double-ended substation and to verify that the secondary loads are removed.

6.3.4 Emergency Power Supply System (EPSS) - Generator Set

It is always desirable that the Project Specification should contain clauses that the EPSS (which included the power generating equipment, paralleling switchgear, ATS, and other accessories such as NGR) **MUST BE** manufactured and factory tested through a common manufacturer. Complication in completing the system testing arises when each component of the EPSS are manufactured and supplied by different manufacturers, which often leads to unavailability of appurtenances such as sensors, actuators, and other instrumentation. Factory testing of the EPSS should prove the individual and combined capacity of the equipment through load bank testing. Other features such as insulation resistance, metering, synchronization and bus closing, exhaust emission, vibration, noise emission, cooling system, protective functions, etc. shall also be tested and verified during factory testing. Protective functions to check are (1) low lube oil pressure/high engine temperature, (2) fail to start/fail to crank, (3) engine over speed, (4) low coolant level, (5) not in auto, (6) overload warning and shutdown, (7) short circuit warning and shut-down, (8) over current warning and shutdown, (9) over and under voltage protection, (10) reverse reactive power/loss of field protection, (11) under and over frequency warning and shutdown, (12) reverse power warning and shutdown, (13) phase sequence voltage monitoring, (14) bus voltage and frequency out of range, (15) out of phase paralleling protection, (16) permissive paralleling monitoring, (17) earth fault warning/monitoring, (18) surge protection device monitoring, (19) breaker mis-operation monitoring, (20) paralleling breaker fail to close monitoring, (21) auxiliary contact failure, (22) paralleling breaker fail to open monitoring.

For Pre-startup Inspection and Operational Testing of the emergency power generator set system as one single system, refer to T&C preliminaries section 6.1.4.

Black Start Testing

Black Start Testing is designed to demonstrate that the entire on-site emergency power system has been properly installed and the system support equipment which includes fuel transfer pumps, day tanks, main fuel tank and ventilation systems are designed, installed correctly, and properly functioning. NFPA 110 section 7.13.2 requires every EPSS to perform site acceptance testing prior to handover. For generator sets, all testing done in the factory is not required to be repeated except those tests required by NFPA 110 section 7.13.4.1.3 which are as follows:

- Testing to prove combined rated kW capacity of the emergency power system with the actual building load or through the assistance of a load bank if the building load is not sufficient.
- All equipment shall be verified to be running in normal condition (pertaining to frequency, voltage, current drawn, oil pressure and cooling water temperature). Data shall be repeatedly taken every 15 minutes until the time duration of two (2) hours is completed.
- Automatic re-transfer to normal power shall not exceed five (5) minutes when normal power is restored.

In common project set-up, Black Start Testing is conducted when all building services, including all low current systems integration, are completed, and accepted. Test procedures are discussed under the “Power Failure Testing” at the end of this Guideline. It should be noted that EPSS using generator sets (especially multiple generator sets) falls under NFPA110 Type 60 power restoration, which means it will require a minimum of 60 secs. for the emergency power to restore the utility power in case of normal power outage. Sixty (60) secs. is the minimum time requirement for start signal reception, engine cranking, pre-heat, stabilization (of voltage, frequency, and phase), synchronization, paralleling bus closing and ATS transfer for generator sets. Type 10 (10 sec. restoration as required by NFPA for healthcare) can only be achieved by redundant normal power source such in the case of double-ended substation.

6.3.5 Lightning Protection System (LPS)

After thorough inspection of the installation to ensure that there is no visual damage, corroded parts, defective installation, and test links are available in each down conductor, testing for LPS shall proceed in the following manner using a resistance tester based on BS 7430 Standard.

- Removal of any bonding to other services, such as mechanical plant or electrical services, from the electrode to be tested.
- With the test links removed, testing of the earth electrodes is carried out and the resistance of each earth electrode should not exceed 5 Ohms.
- With the test links reinstalled, the resistance to earth of the complete lightning protection system is measured and the combined total resistance to earth should not exceed 10 Ohms.
- Bonding to the equipment is re-installed after the test.

6.3.6 Automatic Lighting Control System (ALCS)

With the advent of LEED and other sustainability standards and guidelines, lighting control systems have changed from simple to complex. Since lighting systems contribute considerably to the overall power consumption, it is required to provide means of controlling, dimming and time scheduling for power savings especially for LEED projects.

ALCS functional testing is as follows (as applicable to project requirements):

Daylight Power Savings

This is a feature where lighting fixtures in areas with external glazing or light wells are reduced or dimmed during the day to reduce the power consumption (lighting and cooling load) but does not affect the required luminance or lighting levels. The system requires photoelectric sensors placed within the area with glazing or light wells (not from direct sunlight) to trigger change in output from the controller to operate switches. Testing is conducted by varying the luminance level setting and then to verify the reaction of the system (by dimming or turning off lighting circuits). Room luminance level is cross-checked by Lux Level Meter.

Occupancy Sensing

This is a feature where the lighting system is turned off in areas during unoccupied time. The system requires motion (Infrared or Ultrasonic) sensors to monitor presence of occupants. The system requires override switches located close to the entrance in case that the system fails to automatically turn-on during occupancy. Time delay is also incorporated in the sensor to avoid on-off cycling. Testing is conducted by occupying and un-occupying the room and then verifying the response of the system, including the set time delay.

Time Scheduling or Sweep-Off Feature

This is a lighting control feature to turn-off the lighting system as per the scheduled or programmed timing. In this type of system, control overrides are normally provided and placed within an accessible area (close to the entrance door) to override control once occupants require lighting system during the scheduled time-off. Testing is conducted by changing the time schedule setting and verifying the response of the system.

Manual Dimming

This feature is usually applied in auditoriums and bedrooms where dimmers are placed close to the lighting switches for lighting level or luminance control. Control can also be through a human-machine interface (such in case of auditoriums). Testing is done by gradually setting from the higher limit to the lower lighting limit as per the design without lamp flickering.

As with any lighting system, lighting levels are always confirmed and verified by using a Lux Level Meter, taking several readings across the room. Pre-requisites prior to the testing of automatic lighting control system are as follows:

- Finishes and furniture must be in place.
- Windows and skylights are clean.
- Lamps have reached 100 hrs. of burn-in before testing as per National Building Institute Standard.
- Motion sensors shall not be located close to air diffusers for occupancy sensing.

The table below lists the recommended lighting levels for various applications as per US National Optical Astronomy Observatory (NOAO) and National Science Foundation (NSF):

Activity Based:

Activity	Illumination, lux
Public areas with dark surroundings	20 - 50
Simple Orientation for short visits	50 - 100
Working Areas where visual tasks are only occasionally performed	100 - 150
Warehouses, homes, theatres, archives	150
Easy office work, classes	250
Normal office work, PC work, study library, groceries, show rooms, laboratories	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshop, Operation Theatre	1,000
Detailed drawing work, very detailed mechanical work	1,500 – 2,000
Performance of visual task of low contrast and very small size for prolonged periodof time	2,000 – 5,000
Performance of very prolonged and exacting visual task	5,000 – 10,000
Performance of very special visual tasks of extremely low contrast and small size	10,000 to 20,000

Application Based:

Spaces	Illumination, lux
Normal work station space, open, or close offices	500
ADP Areas	500
Conference Rooms	300
Training Rooms	500
Internal Corridors	200
Auditoria	150 - 200
Entrance Lobbies, Atria, Elevator Lobbies, Public Corridors	200
Pedestrian Tunnels and Bridges, Stairwells	200
Toilets, Staff Locker Rooms, Storage Rooms, Janitor Closets	200

Spaces	Illumination, lux
Electrical Rooms, Generator Rooms. Mechanical Rooms	200
Communication Rooms, Maintenance Shops, Loading Docks	200
Dining Areas	150 - 200
Kitchens, Out-leased Spaces, Physical Fitness Space	500
Child Care Centers	500
Structured Parking, General Spaces	50
Structured Parking, Intersections	100
Structured Parking, Entrances	500

Roadways and Sidewalks:

Road and Pedestrian Conflict Area		Illumination based on Pavement Classification, lux		
Road	**Pedestrian Conflict**	**R1**	**R2 & R3**	**R4**
Freeway Class A	n/a	6	9	8
Freeway Class B	n/a	4	6	5
Expressway	High	10	14	13
	Medium	8	12	10
	Low	6	9	8
Major	High	12	17	15
	Medium	9	13	11
	Low	6	9	8
Collector	High	8	12	10
	Medium	6	9	8
	Low	4	6	5
Local	High	6	9	8
	Medium	5	7	6
	Low	3	4	4

Intersection of Continuously Lighted Urban Streets:

Functional Classification	Illumination at Pavement, lux		
Road	**High**	**Medium**	**Low**
Major / Major	34	26	18
Major / Collector	29	22	15
Major / Local	26	20	13
Collector / Collector	24	18	12

Functional Classification	Illumination at Pavement, lux		
Road	High	Medium	Low
Collector / Local	21	16	10
Local / Local	18	14	8

6.4 Low Current System Standalone T&C (ELV in British Standard)

This section covers the step-by-step and systematic procedures to complete the required testing for all the Low Current Systems.

6.4.1 Fire Detection and Alarm System (FDAS) - Addressable Type

Testing work discussed under this section is limited only to the common scope of work of the FDAS Trade Contractor, which includes Initiating Appliance, Notification Appliance, and Interface Appliance (such as Control Interface Modules (CIM) and Monitoring Interface Module (MIM)) and their circuits. Secondary circuit of all Interface Appliances are tested by other Specialized Trade Contractors. Interface between the FDAS and all other systems shall be discussed separately under the “Fire and Life Safety System Integration” section. FDAS is categorized into two major groups namely, (1) the Addressable Type and (2) the Conventional Class A and B circuiting. The Addressable System is the common type used from small to large projects since the system can specifically identify the location of detection and its condition unlike the Conventional Type. The Testing process for the Addressable System is first discussed followed by the Conventional Type.

Field Device Labelling and Addressing

After the completion of cable testing and installation of field device base plates, labelling for the base and device head follows. Upon completion of the labelling for each field device, assigning addresses then follows for each detector head through built-in DIP Switches or by pre-assigned card attached to the bases, depending on how the detector was manufactured. The test technician lists down the assigned addresses, labels and location served to ensure that there will be no redundancy to other devices. Each initiating and notification device is set for a unique address, which will be programmed to the FACP (Fire Alarm Control Panel) so they can communicate.

Initial Programming

After the completion of addressing for all of the field devices, initial programming follows. The programmer will need to program to the FACP the assigned address for each device including the label, location or room served and zoning as per the smoke control strategy.

Field Device Interface Testing

Once initial programming is completed for the whole floor or zone, interface testing follows. The test is to prove the accuracy of the initial programming by planning the sequence of activating all field devices. All field devices shall be activated one by one as per the sequence by the following means.

- Smoke detectors by portable smoke generators
- Manual Pull Stations (MPS) by manual activation
- Monitoring Interface Module (MIM) by shorting the secondary side circuit terminals in the case where the secondary circuit is not yet completed.

It is required to reset the FACP each time an initiating device is tested, including the Manual Pull Station (since it will not automatically reset). Once completed, the Alarm Trend Log will be printed and compared to the activation sequence and they should tally. Any discrepancy should be subject to investigation, correction, and retest. The Trend Log and test sequence record shall be documented to form part of the Commissioning Records.

Cause and Effect Programming and Testing (Floor or Zone Wise)

After the completion of the field device interface testing, Cause and Effect (C&E) Programming follows. Based on the approved C&E Matrix, the Fire Alarm Control Panel is programmed for functional purposes. The C&E Matrix describes the action of the FDAS when an initiating device is activated, and this matrix is converted to equations and fed to the control panel by the programmer.

Once the C&E Programming is done, testing for each floor or zone is conducted based on the scenarios developed to prove the functionality of the system. During this testing, it is ideal that all secondary circuits of the interface modules are already tested and accepted so it can be included in the testing. In the real-world scenario, many systems that need interfacing are not ready by this time. Since the FDAS Trade Contractor is not responsible for other systems completion, then this testing can be included in the interface testing and will usually proceed as availability allows, so the contract completion will not be delayed. For the reader to understand, a sample of scenarios are listed below in a high-rise healthcare project to prove the functionality of the FDAS.

<u>Scenario #1</u>: Detection of a single smoke detector (SD) except SD in elevator lobbies, elevator shafts, elevator machine rooms, and HVAC ducting.

The system responses are as follows:

- Activation of audible and visual alarms after the agreed delay time (normally 10 to 30 secs as agreed with Client and Fire Specialist) on the floor of the incident and at above and below the floor of the incident.
- Closure of all smoke zone duct dampers.
- Deactivation of all electro-magnetic door holders for cross-corridor doors to close and seal the smoke zone.
- Activation of staircase pressurization and lift lobby pressurization.
- Release of security and access control doors (as agree with the Client security manager) except exit staircase doors.
- Notification to the Annunciator Panel located in Nurse Call Station for the floor of incident.
- General Building Notification after elapsed time without reset in Nurse Station Annunciator Panel or Nurse Station (usually 3 minutes)
- Closure of LPG solenoid (as applicable in floor where kitchen is located).

<u>Scenario #2</u>: Detection of single SD in elevator lobby, elevator shaft, and elevator machine room.

The system responses are as follows:

- Recall of elevator group within the lobby where detection occurs (phase I recall).
- All system actions as in Scenario #1.

<u>Scenario #3</u>: Detection of single SD in HVAC ducting return and supply.

The system responses are as follows:

- Shutdown of dedicated Air Handling Unit.
- All system actions as in Scenario #1.

<u>Scenario #4</u>: Detection of second smoke detector (or double knocking)

The system responses are as follows:

- All system actions as in Scenario #1.
- Unlocking of exit staircase security doors.
- Signal to Central Fire Stations.

- General Building Notification after elapsed time without reset in Nurse Station Annunciator Panel or Nurse Station (usually immediate)
- Roll-up door/roller shutter activated to close.

Scenario #5: Detection of sprinkler flow switch

The system response are as follows:

- All system actions as in Scenario #1.

Scenario #6: Activation of clean agent system

- All system actions as in Scenario #1.

Scenario #7: Activation of Manual Pull Station

- Activation of audible and visual alarms after the agreed delay time (normally 10 to 30 seconds as agree with Client and Fire Specialist) on the floor of the incident and above and below the floor of the incident.
- Activation of Fire and Life Safety System common to the building such as Stair Pressurization System.

Scenario #8: Discharge of Kitchen Hood Suppression System

- All system actions as in Scenario #1.

It must be understood that it is ideal that all systems be interfaced or integrated with the FDAS, must be ready during the test. The common problem that will arise if many systems are not ready for testing is that the FDAS Trade Contractor will require additional charges for retest when all other systems are eventually ready. After that all floors or zones testing are completed, the FDAS is now ready for "Building-wise Cause and Effect Testing". Refer to integration for Fire and Life Safety Systems section of this Guideline.

Cause and Effect programming and floor wise testing always takes time. This requires two (2) to six (6) months for medium to large and complex (high-rise healthcare) projects.

Notification Appliance Sound Level Testing

All notification appliances such as speakers, sounders and strobes are required to be set at a certain loudness. Refer to the table below for NFPA 72 requirements:

Mode of Application	Required loudness
Generally provided minimum sound level	65 dBA
With background noise which will likely to persist for more than 30 secs.	5 dBA above of the background noise
Area for sleeping such as in hotels and in-patient rooms for hospitals	75 dBA as minimum in bedhead with all doors shut

Since the requirement is dBA, it is required that all sources of noise, including intrusive noise, are present so that sound level testing occurs during the period of highest noise generation.

Paging System Testing

A test to prove functionality of the FACP Paging System by zones and group of zones. A microphone is located close to the FACP located in the Fire Command Centre and zone or group of zones are selected to test for manual annunciation/paging. Site staff to verify result.

Annunciator Panel Testing

This is a simple test to verify functionality of the Annunciator Panel (or repeater panel in BS Standard). Display is checked and verified for the indication of type and location of detection, zone, date, time. Silencing feature, reset, and re-alarm are tested if working properly.

Battery Autonomy Testing

Batteries used in FACP for standby power in case of mains failure are required to be tested by NFPA 72 for 24 hrs. under normal load with normal power supply with charger disconnected to allow the battery to discharge and 30-minutes load testing for fully completed FDAS or with artificial load equivalent to the fire alarm system load under emergency condition as per manufacturer's recommendation for incomplete FDAS installation. Voltage shall not drop below the specified voltage for type of battery used. Allowable voltage drop is 10% of the nominal voltage or the FACP installation guide recommended voltage drop.

Fireman's Telephone Testing

NFPA 72 requires that Fireman communication system be tested to ensure functionality and connectivity. The test required is to demonstrate the following.

- Communication ability of the "talk line" depending on the project Specification regarding how many active lines can communicate simultaneously.
- Transfer of talk line priority.
- Test of remote phone or jacks for incoming calls and communication to the master phone (remote phone with back LED should blink to indicate incoming calls and should turn off once successful communication with the master phone is stablished). Once a remote phone is picked-up or a phone is attached to the remote jack, the master phone system visual and audible indication must start to indicate location of the call.

With the advent of all Low Current Systems turning in IP Based System, FDAS is also in the process of using such systems for backbone, which means that the conventional non-plenum FPLR and MICC are now being replaced by UTP, STP and Fiber Optic cables for TCP/IP LAN. In the near future, all Building Services will only have a common backbone under the TCP/IP Protocol working under a common LAN.

6.4.2 Fire Detection and Alarm System (FDAS) - Conventional Type

The conventional FDAS System is a wired Class A (4-wire) or Class B (2-wire) initiating and notification System. Class A provides supervision of the circuit and continues to work even if there is broken wire within the system, unlike Class B circuit where a broken wire will provide a supervisory signal for "trouble" but all field device downstream of the open wire will not function unless the "trouble" is resolved. Conventional System operates on the principle of over-current to trigger initiation and notification with the use of end-of-line resistors. Conventional Systems are unpopular nowadays because of their limitations in accurately identifying the location of the detection and is often used for small warehouses and complexes.

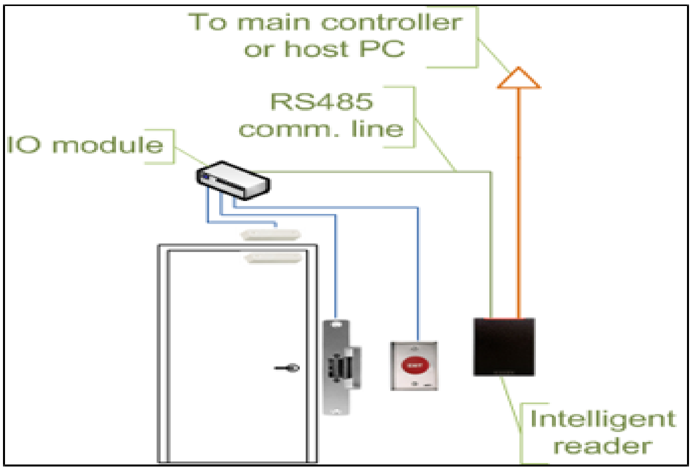
The method of testing is very similar to the addressable type with the exclusion of addressing, programming, and field device interface testing. Cause and Effect function for this type of system is very simple and complex system interface is not possible. Initiating and notification zones are composed of field devices with common labels and circuitry.

6.4.3 Security and Access Control System (SACS)

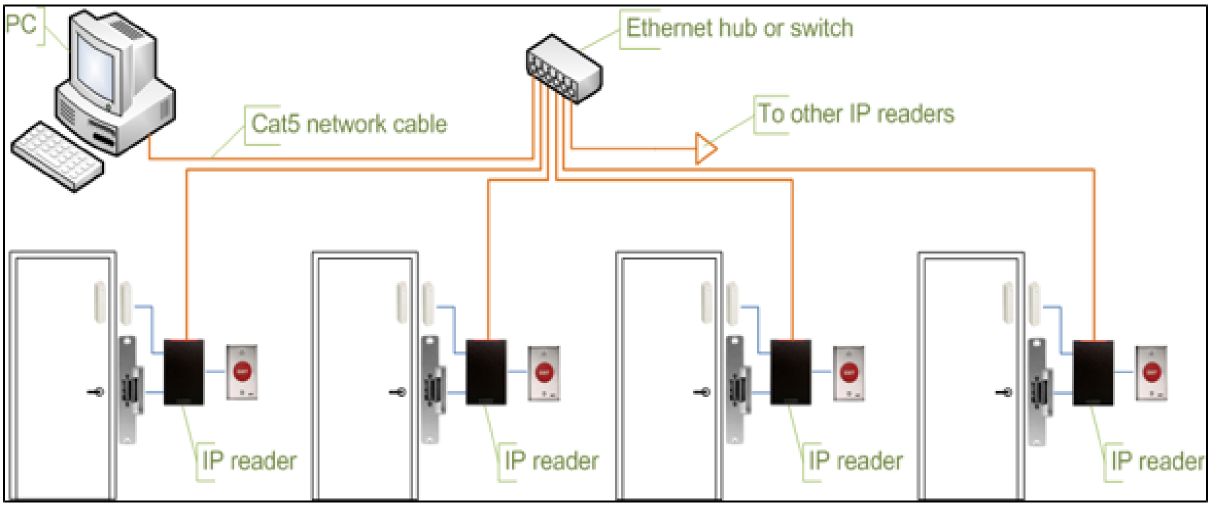
SACS historically are used to restrict access to an area or to premises, for unauthorized persons only, but functions can be extended to time management and monitoring (attendance management and monitoring). Loss Prevention Council (LPC) defines SACS as "an interconnected arrangement of various types of equipment intended to control entry into a location". SACS architecture varies from application to application depending upon the Client requirements. System architecture and configuration can be anything from the following.

- Use of I/O modules and intelligent IP based reader connected to the network switches/routers (for older IP-Based system) - System Architecture 1
- Use of an intelligent IP based reader (without I/O modules) connected to the network switches/routers (for older IP-Based systems) - System Architecture 2
- Use of IP based controller (where readers, strikes, maglocks, door contacts, exit button are directly controlled) connected to network switches/routers. *This is one of the most common system nowadays for IP Based ACS* - System Architecture 3
- Use of serial controllers and terminal servers (Gateways) connected to network switches/routers - System Architecture 4
- Use of serial controllers and IP Based controller connected to network switches/routers. *This is one of the most common system nowadays for IP Based ACS.* - System Architecture 5
- Use of master controller, serial main, serial sub-main controller under MS/TP Topology. *This is one of the most common system nowadays for non-IP Based ACS* - System Architecture 6
- Use of serial controller connected to master controller under MS/TP (or RS485) Topology. *This is the most common system nowadays for small non-IP Based ACS* - System Architecture 7
- Use of serial controller for standalone access control without master controller (no external means human control) - System Architecture 8

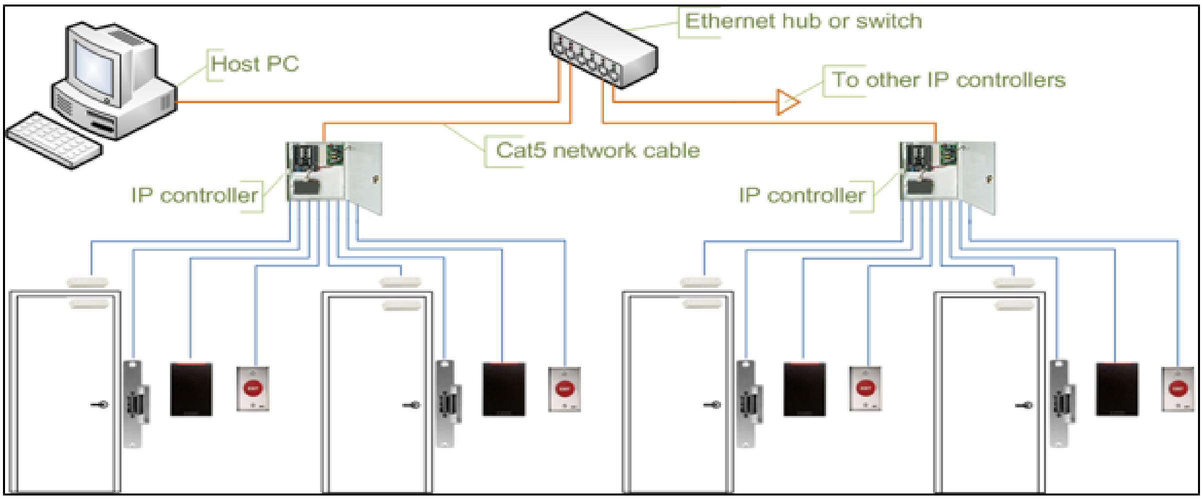
All SACS has the following components namely (1) Device reader, (2) Door locking and unlocking device (magnetic locks and strikes), (3) Door contacts for door status monitoring, (4) request to exit such as push button and push bar, (5) controller, (6) proximity cards/tags, Smart Cards, RFID, and biometrics (face recognition, finger prints, palm prints, retinal recognition, and voice recognition), (7) SACS software and (8) central control and monitoring station. For centralized ACS, classification falls under IP Based System (item 1 to 5) and non-IP Based (MS/TP) network (item 6 & 7). The following step-by-step procedures and testing are required to prove the functionality of the ACS:



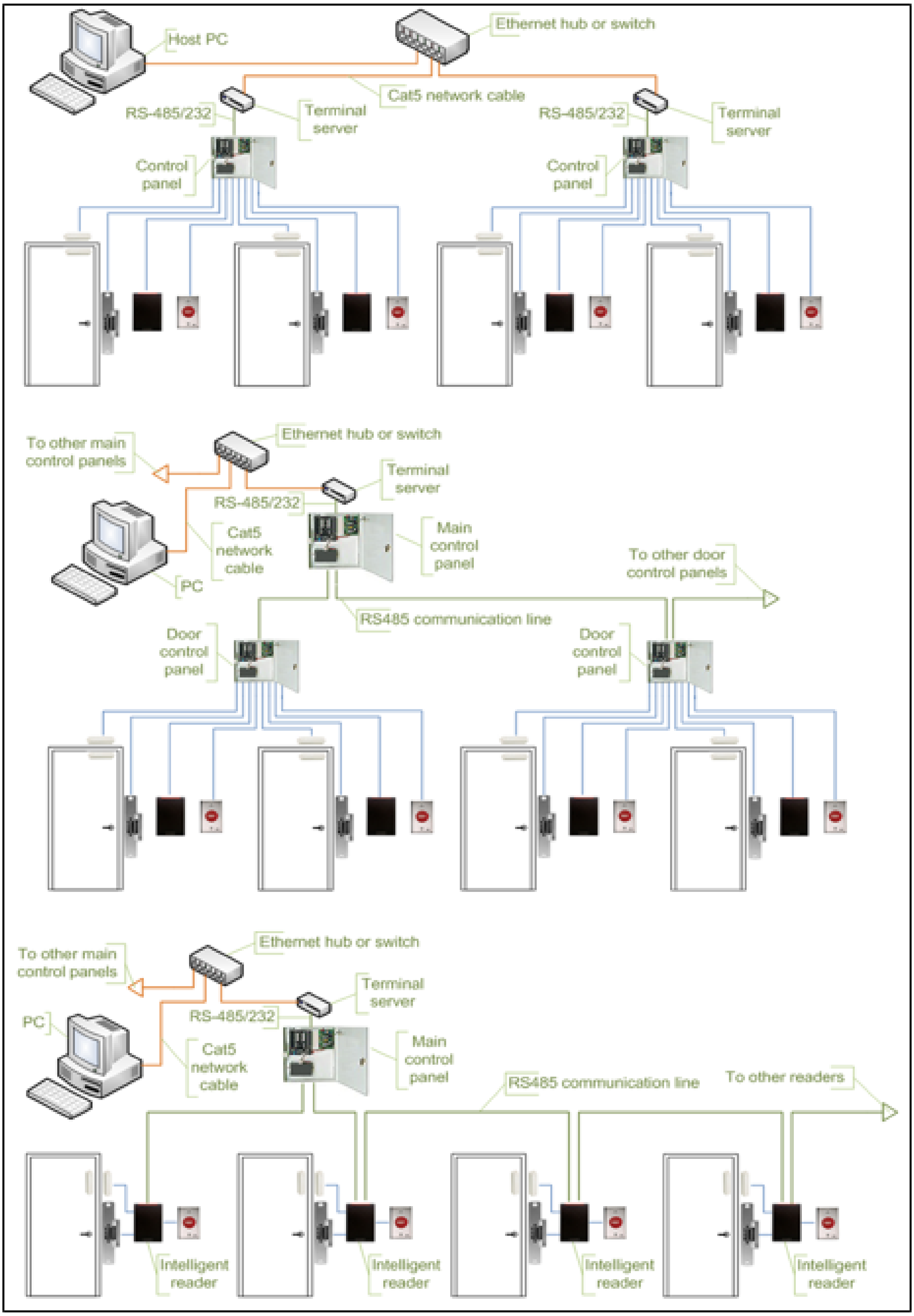
SYSTEM ARCHITECTURE 1



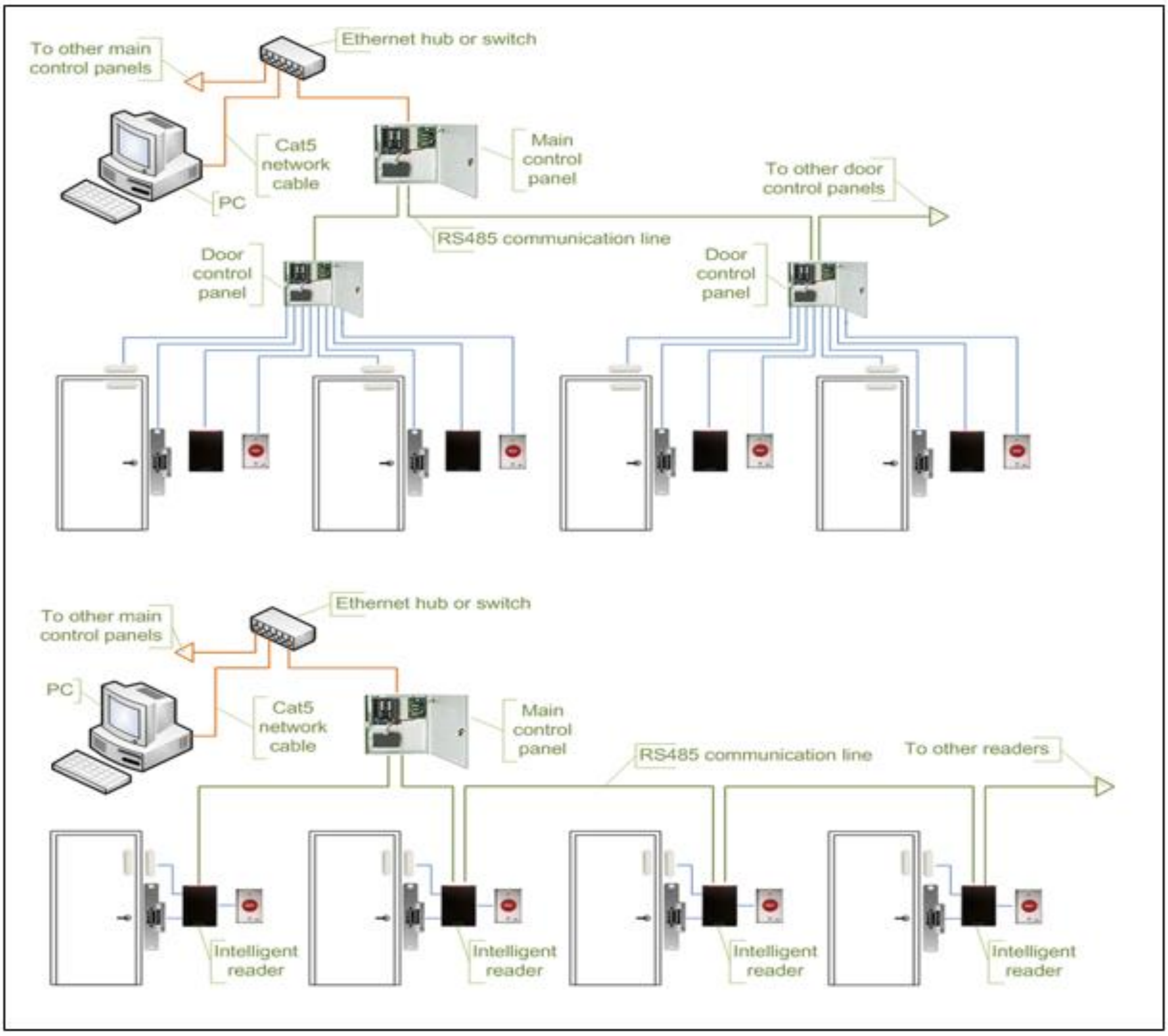
SYSTEM ARCHITECTURE 2



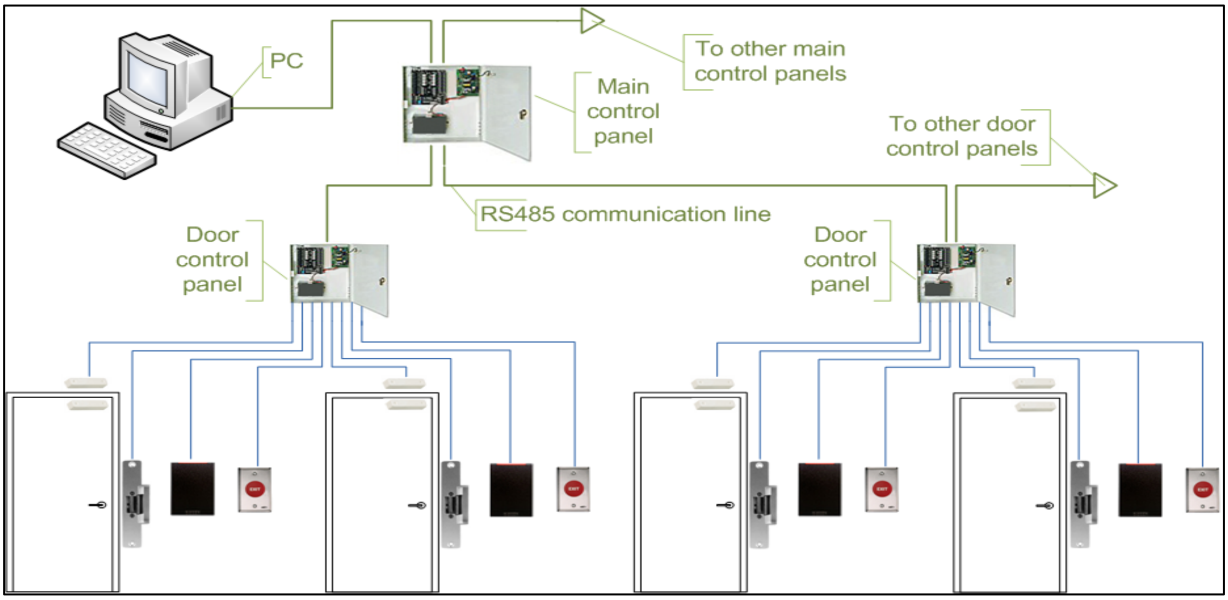
SYSTEM ARCHITECTURE 3



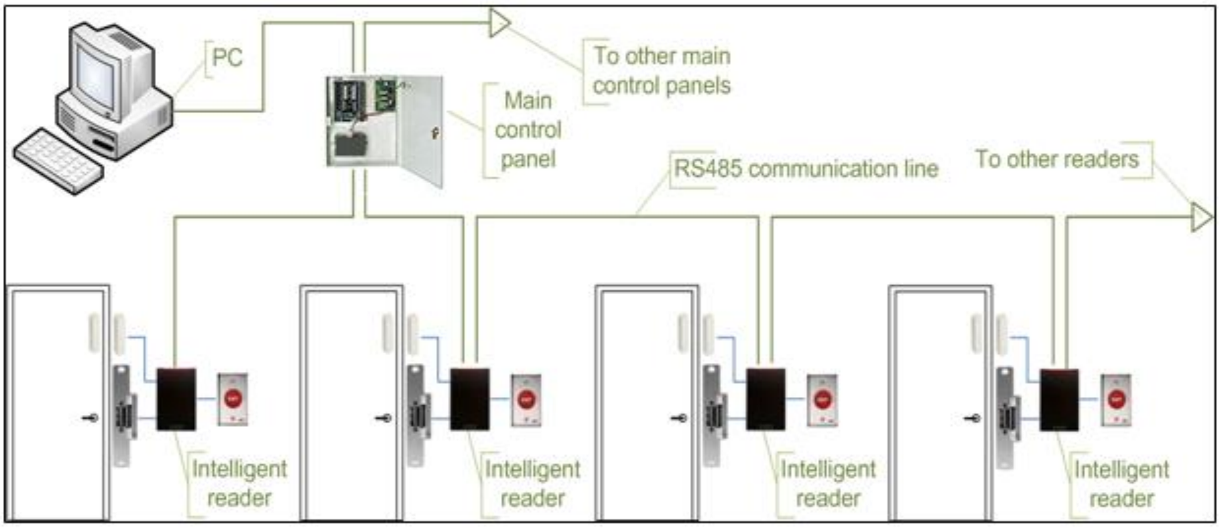
SYSTEM ARCHITECTURE 4



SYSTEM ARCHITECTURE 5



SYSTEM ARCHITECTURE 6



SYSTEM ARCHITECTURE 7

Configuration and Addressing (Applicable for IP Based System)

Similar to the BMS field controllers, IP Based ACS uses I/O controllers which require configuration (see BMS for explanation of configuration) and addressing. Unlike the BMS where all devices have a unique BACNet IP address, vendor ID and instance number which can be discovered automatically using BACNet discovery software, SACS does not have the same feature for now (except auto-discovery) since there is still no unification between manufacturers. SACS field devices are assigned with default IP address and requires re-addressing (static and permanent IP addressing) for device identification within the network. For SACS network controllers communicating via TCP/IP, it is required that the controllers are configured with the correct subnet masking address (for routing within the subnet, in-case that the laptop is not connected to the same subnet during configuration) and default gateway address (for routing outside the LAN in-case of web-based notification, when the laptop is not connected in the same LAN during configuration).

Programming

Serial or IP Based controllers for SACS require software programming to provide restrictions and levels of security access to authorized persons, schedule of allowable access and user notification for web-based SACS through mobile phones. Programming of network controllers are very similar to BMS using certified transfer software (refer to BMS section 6.5.1 for point-to-point and loop response testing).

Functional Testing

SACS required functional testing are broken as follows (as applicable to the requirement of the contract);

- Authorized and Unauthorized Access
    - Test for authorized entry using proximity/smart cards, biometric, RFID and the doors should open while doors shall remain closed for unauthorized entry.
- Level of Access Authorization (for doors with level of authorization)
    - Test for authorized entry using proximity/smart cards, biometric, RFID and the doors should open corresponding to the level of authorization while doors shall remain closed for levels below authorization.
- Time Schedule for Authorized Access
    - Test for authorized entry within the time schedule and the doors should open and remain closed during off time schedule testing.
- Attendance Log and Monitoring
    - Test for authorized entry and verifying staff attendance log and monitoring for time duration within the HRD time attendance system.
- Door Status and Monitoring through Door Contacts
    - Test to verify status of door in the central control station display when doors are open and closed.
- Request to Exit Testing
    - Test to verify unlocking of doors when exit button or panic bar is pressed.
- Fault and Trouble Monitoring
    - Test to verify fault and “trouble” supervisory signal to the central control and monitoring system.
- Alarm Testing for Force Entry
    - Test for alarm in case of forced entry. Requires temporary removal of door magnetic contacts without activation of the card/RFID/biometric reader.
- Response Time to Open Doors
    - Test for time to open doors and should be within the product specification.
- Head End and Graphic Testing
    - Test to open and close doors from the central control station.
- Anti-Pass Back for Proximity Cards Type of Access
    - Test to verify that doors or parking booms will not open or raise during double “in” or set time has not elapse for “in” and “out” sequence.
- Web Based Notification through Mobile Phones
    - Test for verification of notification in case of entry in restricted or limited entry space, or double authentication as means of access in restricted/limited spaces.
- Trend Monitoring and File Storage/Back-Up Capacity Testing
    - Test for all events that happen during access, or attempt to access, alarms, faults, and other notifications.
- Power Failure and Battery Discharge Testing

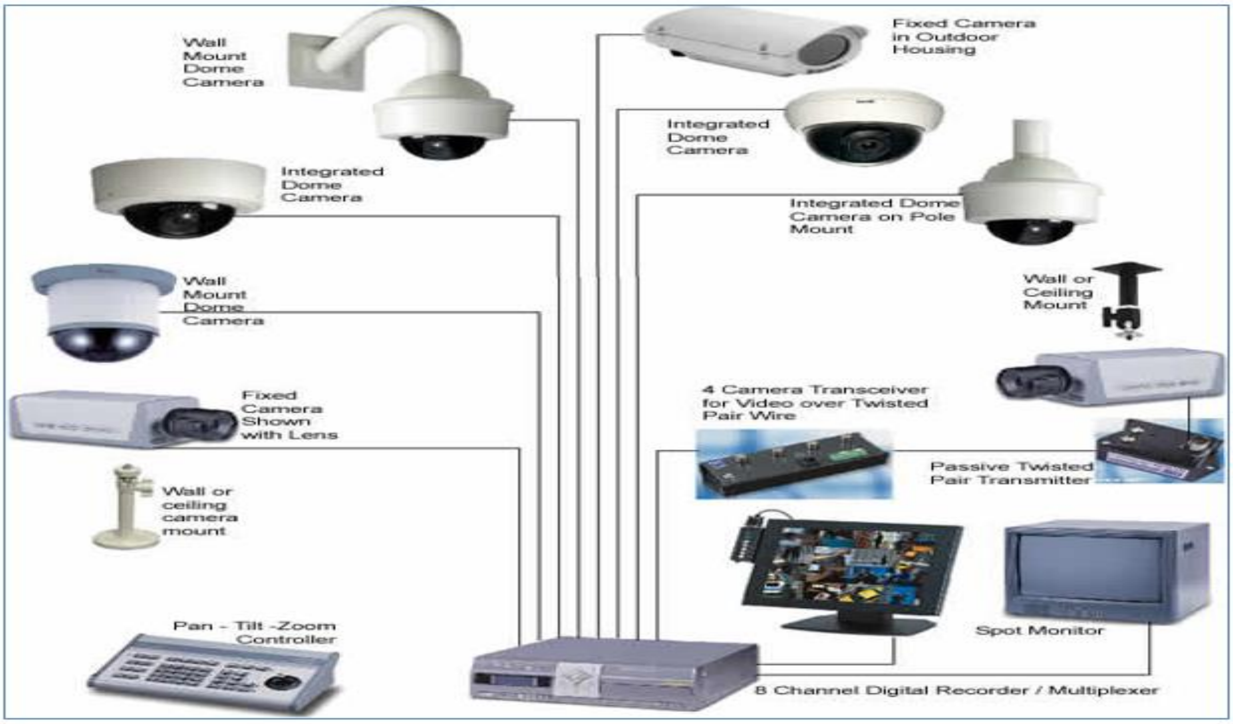
- Test to prove system will continue to function during loss of normal power. Battery is disconnected to charger and allowed to discharge. Final voltage shall not fall below 10% or as per manufacturer's installation and testing manual information.

6.4.4 Closed Circuit Television System (CCTV)

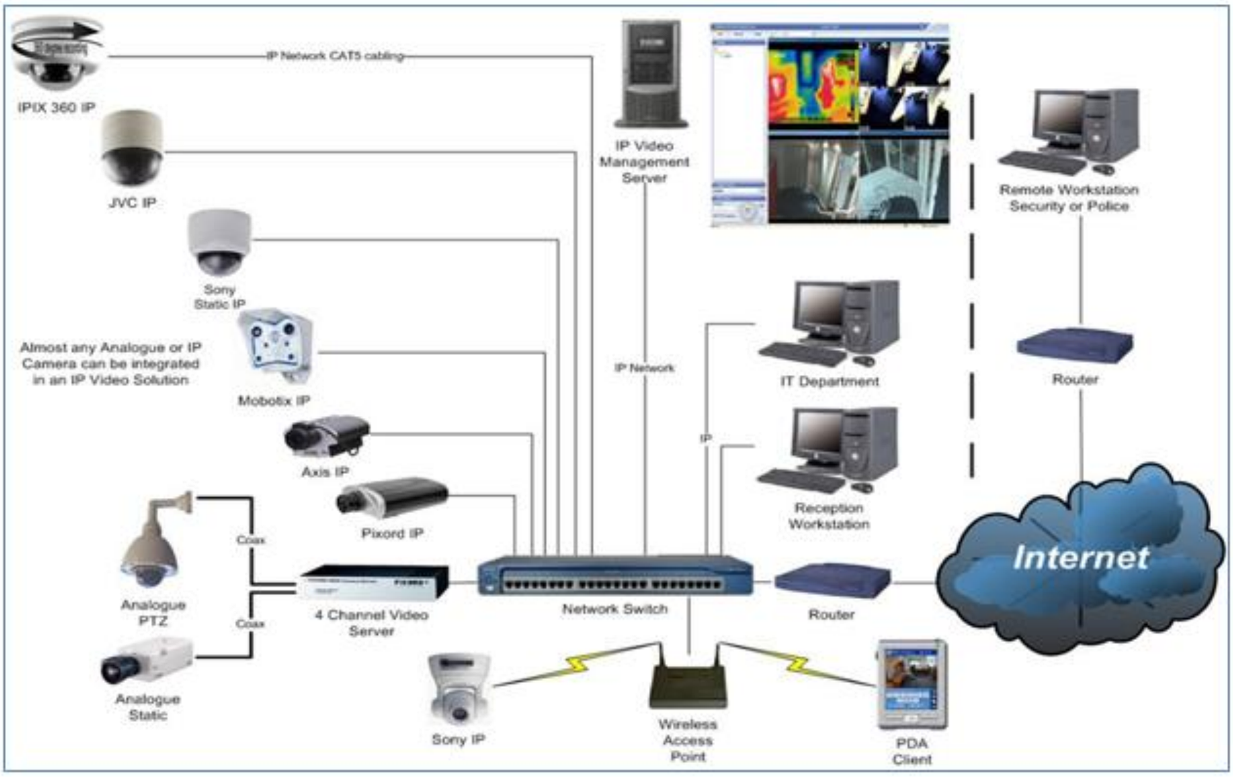
CCTV is a method of providing remote surveillance of selected location using remote television cameras, transceivers, multiplexers, recorders, monitors, and human-machine interface. With the development of building communication data network, low current systems such as CCTV are turning into IP Based Systems, from the conventional systems using coaxial A/V cables to the use of UTP cables (such as CAT 5e and 6).

System architecture and configuration varies from small to large projects for the following conventional system.

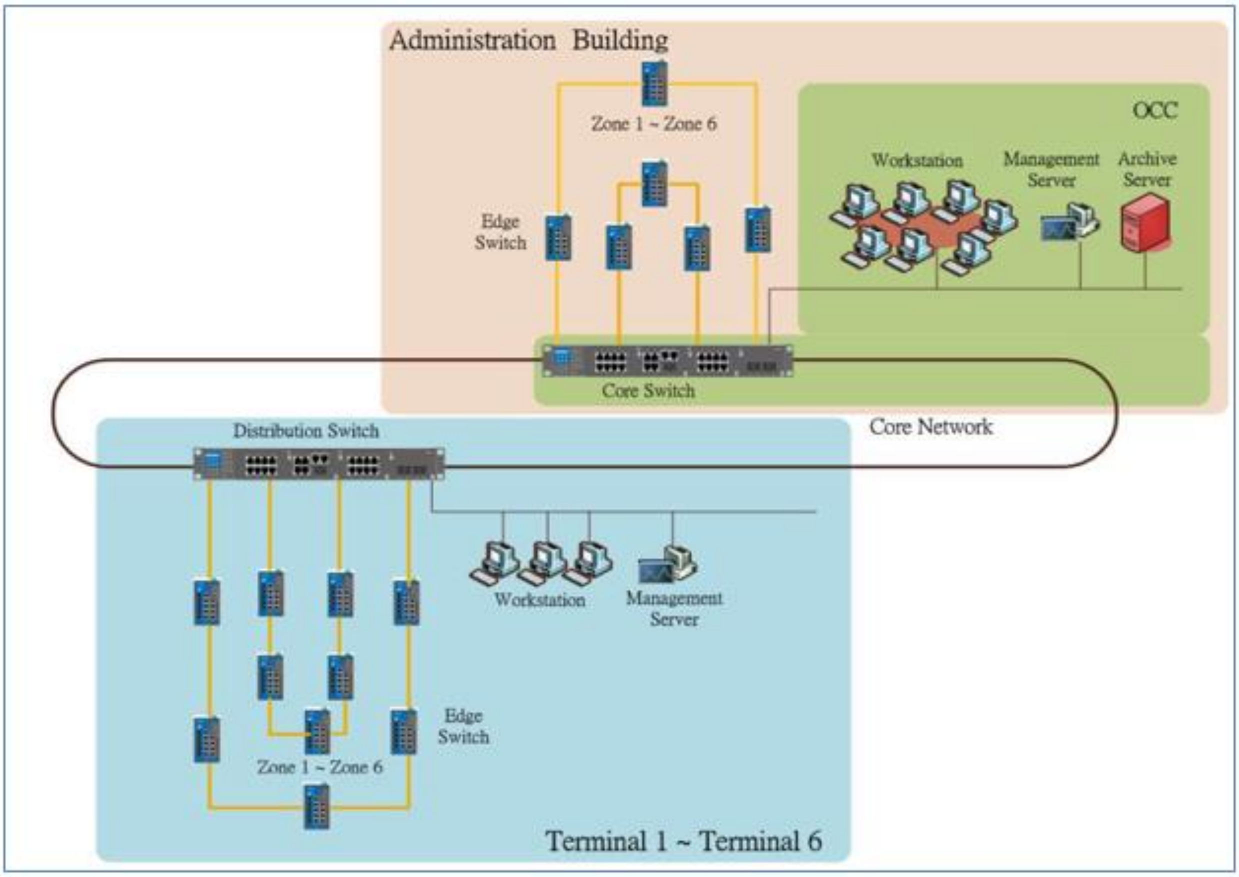
- Use of coaxial cable connecting the camera, multiplexer, recorder/decoder, and CCTV monitor for small to medium CCTV System Network.
- Use of IP Based cameras with direct connection to the data network. Components include NVR (Network Video Recorders), System Server and Data Storage Servers
- Use of network core switches, distribution switches, edge switches (connected to camera through coaxial cables), management servers, storage servers and workstations for large CCTV System Network.



SYSTEM ARCHITECTURE 1



SYSTEM ARCHITECTURE 2



SYSTEM ARCHITECTURE 3

Addressing and Local Viewing (Applicable for IP Based Camera)

IP Based CCTV cameras are provided with default IP address and require re-addressing (static and permanent IP addressing) for camera identification within the network. For CCTV network controllers communicating via TCP/IP, it is required that the controllers are configured with the correct subnet masking address (for routing within the subnet, in-case that the laptop is not within the same subnet during configuration) and default gateway address (for routing outside the LAN in case of web-based notification and monitoring, in-case the laptop is not connected in the same LAN during configuration). Once re-addressing is complete, each camera is tested locally for viewing, focusing, and tilting (as applicable).

Functional Testing for IP and Analogue CCTV

Once it is proven that each camera is properly functioning during the local viewing and the system installation is complete, the CCTV system requires the following functional testing.

- Head End Viewing
  - Test to conduct functionality of each camera in the Central Monitoring and Control Station display based on level and zoning.
- CCTV Camera Resolution Test
  - Test to confirm resolution of the camera based on EIA Standard resolution testing pattern placed in front of the camera being tested. The limiting resolution shall be measured by observing the vertical wedges of the pattern on the monitor and noting the reading at the point where the lines are no longer discernible.
- CCTV Camera Sequence Test (as applicable)
  - Test to prove automatic sequencing of camera as programmed for limited viewing.

- Keyboard Control Test
  - Test to demonstrate pan, tilt, and zoom functions for all cameras. Camera viewing shall include entire zoom focal length for all areas.
- Recording and Back-Up Storage Testing
  - Test to demonstrate that recorders (VCR, DVR, NVR) are recording images as seen in the monitor and back up storage can attain what was specified in the product catalogue.
- Low Light Level Test for Exterior CCTV
  - Test to demonstrate exterior camera coverage during diminishing daylight to verify scene illumination and clarity until midnight. Test is demonstrated by a person walking through field of view and must be of quality to identify the individual.

6.4.5 Public Address and Voice Alarm (PAVA)

PAVA is a system composed of microphones, speakers, and amplifiers for the purpose of public annunciation and providing immediate information during normal building operation and emergency cases such as during fire condition and evacuation. PAVA is sometimes referred to as PA-BGM (Public Annunciation and Background Music) System. Some PAVA manufacturers have already incorporated CCTV Systems in their product to increase effectiveness of directing people during normal and emergency conditions.

It is a common project set-up nowadays that PAVA speakers are used by FDAS (Fire Detection and Alarm System) for fire alarm and evacuation notification to reduce first cost, but some jurisdictions require dedicated notification (local codes are not yet updated since during the past days, system integration was a real problem). In the case where both systems have speakers, PAVA speakers should be silenced, or loudness shall be automatically reduced during annunciation from the FDAS speakers during fire condition.

Functional Testing for PAVA

- Sound Level Testing for Single Speaker

  The test is to prove that each speaker is properly working, and the minimum loudness required by codes can be attained by the amplifier and speaker (see FDAS section 6.4.1.5 for speaker loudness required for fire notification).

- Zone Testing for Group of Speakers

  The test is to prove that a group of speakers within each and every PAVA zone is working properly. Temporary speaker is usually provided attached to the zone amplifier and channels are activated. Inspection team conduct actual verification of speakers.

- Zone Testing for Fire Alarm

  The test is to prove that annunciation for each and every fire zone is working properly. Note that fire zoning can be equal or greater than PAVA zoning depending in the design of the systems. Most of the large and complex projects have fire zoning greater than the PAVA zone. For instance, high-rise building PAVA zone is usually per floor but the minimum fire annunciation zone is three (3) floors. Test is normally conducted by providing a temporary signal to the controller/amplifier to imitate FDAS signal to see if multiple PAVA zone (comprising a single fire zone) annunciations are activated. Speaker loudness is also proved to automatically adjust for fire annunciation purposes. Fire priority shall also be tested by overriding any manual or automatic annunciation.

- Zone Testing for BGM (Background Music)

  The test is to prove BGM is initiated upon selection of music mode for selected areas (based on design intent) and the speaker loudness automatically adjusted.

- Zone Test for Manual and Emergency Manual Paging

  Once the PAVA System is completed and all speaker zones are proven to be working properly, manual paging is conducted through the Master PA station and verified by the site inspection team for each and every zone. Emergency manual paging priority shall also be tested for overriding any automatic (normal) and fire automatic annunciation. All volume controls shall also be overridden during the emergency manual paging testing.

- Zone Test for Automatic Paging

  The test is to prove any pre-set automatic paging or annunciation based on the requirement of the Specification. For instance, automatic paging can be set to provide paging for all passengers during boarding for air flight.

- Capacity Testing for Amplifiers

  The test is to prove the capacity of all amplifiers during fire annunciation or paging. Amplifier shall be capable to handle increased power requirements for all speakers during general evacuation annunciation.

- Trouble Supervisory Signal Testing

  A test to prove that each PAVA circuit “trouble” is monitored and will provide audible and visual indication in the PA Master Station display when a circuit is open. Test is conducted by temporary removing connections to and from the amplifiers to check for supervision alarms.

IP Based PAVA

Almost all low current systems nowadays are converting from the conventional systems to IP Based Systems with the exception of FDAS FACP to device connection (which is required to use fire rated cables such as MICC cables or FPL Plenum and Non-plenum type). PAVA is not exempted in turning into IP Bases System. Test as indicated above are typical for non-IP and IP Based System. Configuration and addressing for IP Based devices are typical including their architecture (such as use of UTP Cables, patch panels, router/switches, process servers, and storage servers).

6.4.6 Enterprise Telephone and VoIP (Voice over IP)

Enterprise telephone system uses PABX (Private Automated Building Exchange) since trunk lines from providers are limited compared to the number of telephone lines (or stations) required inside the building. Local extensions are provided to channel incoming calls, while outgoing calls from local extension is channeled by the PABX to any of the available trunk lines. PABX also functions as local intercom, which connects local extensions to other local extensions. PABX connects analogue and digital stations. Components of enterprise telephone systems are composed of distribution frames, PABX (w/ modem) and phone/fax units (or stations). Interface to PABX range from PAVA, Paging System (especially for healthcare), and Intercoms. Interface or integration is separately discussed in the Low Current Integration part of this document. Auto-attendant is one feature for enterprise telephone systems that uses voice mail servers which are located separately or within the console of the PABX. Voice mail servers store and process all enterprise phone system features with regards to voice recording and attending.

With the advent of VoIP, phone system has been digitalized to run over IP Protocol through SIP (Session Initiation Protocol) above the TCP/IP Protocol which is used as the backbone for almost all building services LAN nowadays. VoIP advantage over the enterprise phone is that the communication cost is very cheap and local call accounting or billing is possible. VoIP Servers (equivalent to PABX of enterprise telephone) can also accommodate analogue and digital stations above that of the IP phones, including capability for interface to other systems as found in enterprise telephone system. Components for VoIP are similar to other IP Based Systems using patch panels, switches/routers, VoIP Servers, IP hard phones/fax machines and soft phones (such as computers and mobile phones).

Configuration and Addressing

Typical to other IP Based systems, configuration of IP addresses needs to be done for the IP phones and the VoIP Server. Manufacturer provides default IP address for the phone which can be modified by accessing the IP address of the product through the web server and assign a static IP address. All other addresses such as VLAN, subnet masking, and default gateway shall be assigned in the device for large networking if the laptop is not connected to the same subnet and LAN during configuration. The VoIP Server is then assigned the extension number, user account and password for each IP phone line and is repeated for the Client IP Phone for them to communicate.

Enterprise phone system configuration for the user account, local extension number and password are all done in the PABX.

Functional Testing for Analogue Phone and VoIP phone

- Dial Tone Test

  This is a simple test done by lifting the phone ear/mouth piece and listening for any dial tone.

- Auto attendant and Call Recording Testing (as applicable)

  Test to check auto attendant and call recording feature by calling a local extension without answering and see if auto attendant and call recording will function for phone extensions (or stations) equipped with such feature.

- Outside and Incoming calls Test

  A simple test by simultaneously calling all trunk lines and connections to local extensions and vice versa. For Enterprise Telephone System equipped with group call hunting, a call shall be made in one available line that is in use and confirm that the call will be transferred to other trunk lines automatically. Any problem with group call hunting shall be coordinated with the telephone service provider. Call Transfer, Call Forward Test, and Call Billing Test are also conducted, refer to checklist EPM-KT0-TP-000057 and EPM-KT0-TP-000058 under document EPM-KT0-RG-000007 (T&C Checklist and Templates) for VoIP Pre-start Up and Functional/Performance Testing.

6.4.7 Wireless Network (WLAN), Access Points and RTLS (Real Time Location System)

Wireless network is similar to wired network or LAN (Local Area Network) except the Access Points (AP) are used instead of hardwire connectors (such as registered jacks and plugs). Access Points are devices that can receive and transmit signals wirelessly from and to a Client (a computing device) and transmit and receive the signals to the LAN switch/router by hard wire (or wireless for a mesh network). Wireless networks were designed purposely for data and voice transmission but the coverage of the wireless network in this section includes the use of RTLS.

Real-Time Location System (RTLS) is a system used to provide real-time tracking and management of equipment, staff, and patients (in Healthcare Environment) within the building. It is a type of indoor GPS which can easily integrate with other IT Systems (especially for healthcare) to enable facilities to improve workflow, reduce clinic operational costs, increase clinical process, and improve staff security. RTLS solutions comprise of (1) tags, wrist bands, and badges; (2) technology platforms such as Wi-Fi, Infrared, Bluetooth Low Energy and Radio Frequency; (3) hardware infrastructure such as APs, AP controllers, readers, exciters, RTLS server and end-user interface; (4) Local Area Network and (5) system provider software. RTLS solutions typically include location sensors that are attached to various assets be it a patient, a staff member, or a piece of equipment. Utilizing a unique ID, the system can locate the tags and gives real-time information about its positioning within the facility.

Configuration of Access Points (AP)

Prior to fixing the AP to its base in the ceiling, APs are required to be configured. Configuration of AP is more complex compared to other IP field devices since in addition to the IP address, subnet mask and default gateway that needs to be changed; SSID identifier, device name, SNMP (as applicable), radio settings and others needs to be set-up. Contact AP supplier for all configuration requirements for proper operation of AP.

Site Surveys and Heat Maps

Site Surveys are software tools used during the design stage to assess quantity and location of required AP based on the selected AP model, attenuation due to walls and finishes and interference with other IT devices (such as cellphones, wireless laptops) and electronic equipment for an optimum wireless network performance. It is also used during the construction T&C Stage to assess the performance of the system based on actual site condition and to provide fine tuning, AP adjustment (in setting, placement, and quantity) and trouble shooting. An on-site site survey is conducted during the T&C Stage to provide preliminary assessment of the wireless network using a test laptop roam around the vicinity of APs covering the wireless network for an active and passive survey (or hybrid survey). Passive surveys measure signal strength and signal-to-noise ratio, while active survey prove end-to-end connection. The result of a Site Survey is a heat map showing signal strength variations in colored spectrum visualization.

A final Site Survey is conducted during the occupancy stage when all electronic equipment is fully operational, and tenants are having their full range of BYOD (Bring Your Own Device). During this stage where all interference is active and attenuation is at maximum, that the final performance of the wireless network can be proven.

Head End / Graphic Testing

This test is to confirm the functionality of the RTLS from the end-user interface display. Each badge, tag, wrist band shall be tentatively carried by building staff after programming the unique identifier and walked through several locations in the building, monitored and called to report to the nurse station (see integration with Nurse Call System). Movement of each device shall be seen in the RTLS display screen with accuracy as stated in the RTLS manufacturer catalogue (usually within three (3) mtrs. accuracy). Real time shall also be indicated in every change in location based on recording intervals set.

Head End tests also include security testing for staff tags and badges equipped with security features such as un-located staff during time of scheduled (based on programmed days of absence) and security breach beacon. For other testing requirements, refer to checklist EPM-KT0-TP-000059 and EPM-KT0-TP-000060 under document EPM-KT0-RG-000007 (T&C Checklist and Templates) for WLAN Pre-start Up and Functional/Performance Testing

6.4.8 Audio/Video System

A/V System is a system for audio and visual aiding of end-user during conference, meetings, concert halls, symposiums, or any form of presentation. It is classified into two (2) systems such as the stand-alone A/V system (local A/V System) and Video/Audio Conference System. A local A/V System is composed of a projector and screen (such as in meeting rooms) or an electronic projection screen (such as in concerts) and sound system (amplifiers, speakers, microphones, etc.). Video/Audio Conference System is a system that connects end-users audibly and visually from different remote locations. V/A Conference System is composed of the same equipment such as the local A/V with the addition of Local Area Networking and Internet using the SIP Protocol over TCP/IP.

Testing of the A/V System is as follows:

Test for Audio

Testing is required to verify the clarity and stability of audio system. Clarity of audio systems are dependent on many factors such as room Relative Humidity, room finishes which affects attenuation and reverberation, quality of LAN installation and testing, Codecs and transmission bandwidth and total harmonics distortion (THD). Lower RH absorbs audio pressure, and the test should be done when the air conditioning System is already commissioned and working. Finishes such as wall and ceiling must be completed including all required attenuation. THD is very prevalent in high volumes and maximum amplification should be tested to ensure quality of sound and absence of substantial THD. For IP based V/A Conference Systems, clarity for audio can be poor, caused by multiple reasons such as poor terminal connections of UTP cables, poor quality of cables, excessive cable run, poor signal reception, etc. The end-user is strongly advised that the LAN Provider and the Trade Contractor, which install and provides the structured cabling network and LAN backbone, should provide supporting documents to prove integrity and compliance of the LAN to TIA Standards.

The method of acoustic testing usually employed by the suppliers, is the Average Weighing Scale (dBA) or the 468 Weighing. Acoustic test should measure and provide information about the following information.

- Frequency Response – range of sound spectrum the audio system produced to be life like (or as human sound as possible).
- THD (Total Harmonic Distortion) – measure of total sine wave distortion resulting in squeaking and spurious tones.
- Acoustic Noise – measure of unwanted noise made by the system itself or mixing from external source of noise.

- IMD (Intermodulation Distortion), cross talk, CMRR (Common Mode Rejection Ratio), SNR (Signal to Noise Ration), Transient Response, Dampening Factor and Output Power.

Test for audio is not only limited to the A/V System but requires close coordination for all requirements as explained above to have a successfully commissioned A/V System.

Test for Video

Manual testing to see the clarity and stability of video system. For IP based A/V Conference System, clarity for video is dependent from multiple reasons such as poor terminal connections of UTP cables, poor quality of cables, excessive cable run, poor signal reception, Codecs, and transmission bandwidth, etc. The end-user is strongly advised that the LAN Provider and the Trade Contractor, which install and provides the structured cabling network and LAN backbone, should provide supporting documents to prove integrity and compliance of the LAN to TIA Standards.

Test for Audio and Video Synchronization

A test to verify that the A/V is synchronized, and sound system is not lagging compared to the video system.

Configuration for Video/Audio Conference System

Typical to any IP Based Building Services System using the TCP/IP Protocol, each A/V Receiver shall be configured for a new IP Address from its default address. Other information such as subnet masking and default gateway shall also be configured (as required).

6.4.9 Door Intercom and Access System (DIAS)

Door Intercom and Access Control System is a stand-alone system independent to any Building Services System, which only requires mains power to the main controller to operate. The DIAS is used to provide security to areas with limited access. It is also used to restrict exit or escape of individuals from certain locations such as in infectious isolation rooms. The system is made up of the following components.

- A Master Door Controller (with the capability to provide notification through a bell or chime, two-way communication and to open doors through the Security and Access Control System controller)
- A panel with chime/bell button/switch, microphone, video (optional) and speaker at the requesting end
- A panel with bell/chime, ear/mouth piece, and video (optional) in the responding end
- A switch/button at the responding end (normally located at the soffit of the table of the controlling personnel) to unlock and automatically open (optional) access doors
- A motorized assembly to automatically open door (optional based on SACS contract)
- A request to exit (such as an exit button or panic bar). This feature is not available for infectious isolation rooms. During any fire condition where general evacuation is required, FDAS system should automatically unlock isolation room doors.

Testing required to prove the functionality of the DIAS is as follows:

Bell and Chime Testing

The button or switch is pressed in the requesting end to alert staff of the request to entry.

Audio and Visual Testing

The requesting end shall press the button of speaker panel to activate the speaker. Video display is working continuously.

Door Release and Opening Test

The attending staff shall press the switch or button to unlock and automatically open (optional) the door.

Request to Exit Testing

The exiting staff shall press the exit button or press the panic bar to automatically unlock the door.

For interlock of the door to the Access Control System and FDAS, refer to the low current integration section 6.6.7 of this Guideline.

6.4.10 Nurse Call System (NCS)

NCS is a healthcare patient assistance system to alert and summon nurses for immediate response especially during cases of emergency (such as cardiac arrest). The system is composed of; (1) wired or wireless bed hand piece (or hand set) readily available within patient reach, (2) bedhead call station panel for nurse use during emergency, (3) bathroom disabled call station located close to the water closet within patient reach, (4) over door lamps for visual indication of nurse call request, (5) Nurse Station MSDU (Master Station and Display Unit) for call volume monitoring, patient call recording, nurse response time recording, other data log recording, phone system interlink and attendant call button and (6) nurse room audible and visual call unit or nurse paging unit. Integration to other building services system such as RTLS, Lighting System, Security Panic Alarm System, Telephone System and Wireless Networking (paging) shall be discussed separately under the integration section of this Guideline.

Like any other building services systems, NCS is also moving towards to become IP based system using SIP over TCP/IP.

Configuration for IP Based NCS System

Similar to any IP Based Building Services System using VoIP over the TCP/IP Protocol, each NCS component shall be configured for a new IP Address from its default address. Other information such as subnet masking and default gateway shall also be configured (as required).

Functional Testing Required for NCS

- Patient Bed Hand Piece (Handset) Testing

  Test to prove functionality of the patient bed handset by pressing nurse call button, or emergency button which will activate; (1) distinct alert tone and visual indicator (white or yellow for routine call, or blue for emergency patient need) in the nurse station MSDU including indication of patient and room information, (2) bedhead nurse call reset button lighting and (3) over door (yellow) lamps. Once the bedhead reset button is pushed, the system will silence and reset. Microphone and Nurse Station speaker shall also activate once the nurse call button is pressed.

- Bathroom Disable Call Station testing

  Test to prove functionality of the patient disabled call station by pulling the station string or call button, which will activate; (1) distinct alert tone and visual indicator (white or yellow) in the nurse station MSDU including indication of patient and room information, (2) bedhead nurse call panel reset button lighting and (3) over door (white or yellow) lamps. Once the bedhead reset button is pushed, the system will silence and reset.

- Bedhead Call Station Panel testing

  Test to prove functionality of the bedhead call station panel by pressing the emergency button, which will activate; (1) distinct emergency tone and visual indicator (green) in the nurse station MSDU including indication of patient and room information, (2) bedhead nurse call panel emergency button lighting and (3) over door (green) lamps. Once the bedhead emergency button is pushed, the system will silence and reset.

  Test to prove functionality of the bedhead call station panel by pressing the cardiac arrest button, which will activate; (1) distinct cardiac arrest tone and visual indicator (blue) in the nurse station MSDU including indication of patient and room information, (2) bedhead nurse call panel cardiac arrest button lighting and (3) over door (blue) lamps. Once the bedhead cardiac arrest button is pushed, the system will silence and reset.

- Attendant Call Testing

Test to prove the functionality of the attendant call during receipt of patient by pressing the attendant call button in the Nurse Station MSDU and verify if the visual and audible notification in the nurse waiting room is activated.

Note that the above feature and procedure have slight variation from manufacturer to manufacturer as well as the color-coding for lamps since different healthcare codes has different color-coding.

6.4.11 Enterprise IPTV (Internet Protocol TV) and CATV (Cable TV)

Enterprise IPTV or Cable TV both require pre-configured set-top boxes, which are supplied by the multimedia provider. IPTV runs over TCP/IP protocol that it can use the LAN backbone used by other Building Services Systems. Router for the LAN using TCP/IP requires capability for multicast broadcasting. CATV requires dedicated infrastructure using coaxial cables, splitters, and signal booster. Once the analogue/digital TV (for CATV) or a SMART TV (for IPTV) is plugged-in to the preconfigured set-top box, the TV will automatically function.

6.4.12 Parking Management and Assistance System (PMAS)

The Parking Management System consists of automated access control system, parking guidance display and parking statistical information so that motorist can find available parking slot quickly. The system is composed of (1) Parking Management Software that ties in all the components of the Parking management system, (2) automated access control system such as automatic gates, barrier controls and anti-pass back (optional), (3) automated or manual parking fee systems depending on the duration, or exclude payment of fee based on management issued passes, (4) statistical and financial reporting software which generate daily, weekly, monthly & yearly reports, (5) parking statistical digital display located at the entrance of the parking and each and every level entrance, (6) parking slots availability indicator and directional display (red and green signage), (7) car sensors/detector, (8) controllers and (9) end-user interface and display.

Integration to SAC (Security and Access Control) and Fire Detection and Alarm System (FDAS) shall be discussed separately under the Fire and Life Safety System Integration section 6.5.3 of this Guideline.

- Functional Testing Required for PMAS
    - Car sensor/detector (mostly ultrasonic type installed) and statistical display/signage testing

      Test to check for the functionality of the sensor/detector by placing a temporary block (hard surface) directly below (for ceiling mounted sensor) or above (for floor mounted sensor) the limitation of the sensor (usually 1.5 mtrs. for ceiling sensors and 0.5 mtrs. for floor sensors). Indicator LED light should change from green to red and total number of available slots in the main statistical display/signage and entry signage should reduce. Upon removal of the temporary block, the LED light should return to green and the available slot in the main display and entry display should return to the previous count. Test shall be repeated in all parking slots.
    - Directional Display testing

      For large parking areas, it is not possible or practical to provide temporary block for all parking slots and it will require actual use of the parking area to verify accuracy of the directional display. Based on the parking architectural design, full parking bays (for floor segregated into parking bays) shall turn the LED light red to indicate full parking.
    - Car Park Access Control System testing

      For enterprise car parking system, each motorist possesses a proximity card, which is enrolled or subscribed in the Parking Management System. Test is conducted by placing the card close to the entrance sensor to automatically raise the entrance boom. For enterprise parking access with anti-pass back feature (optional), test is conducted by the following procedure.
        - Placing the proximity card to the first (entrance) sensor for the second time (without detection from the second sensor after the boom) and the boom should not raise, and

  - Placing the proximity card to the first sensor (before the boom) and then to the second sensor (after the boom) and back to the first sensor. The boom should not raise if the time elapse between the repeated first detection is within the allowable (or programmed) timing.

    For automated paid car parking system, pay parking station or kiosk are located close to the parking exits which accepts credit cards, debit cards, coins, monetary denominations, pre-paid cards, and proximity sensors for management staff (depending on the strategy of the design) which raise the exit boom. Entry of cars are automatic in this kind of control scheme by placing a ticketing kiosk before the access boom to record entry time. Manual paid parking system is similar to the automated paid parking except that it has a 24 hrs. attendant who accepts payment and issues receipts.

- Test for statistical and financial reporting for daily, weekly, and monthly durations.

6.4.13 Q-Matic System

Q-Matic is a standalone system for regulating costumer queuing physically or virtually. Physical (or linear), virtual and mobile queuing provides effective management and control of costumers volume and waiting experience to avoid annoyance both for customers and employees. Basic Q-matic architecture involves physical ticketing kiosk (or web ticketing as an option) which provides costumer number, numbering display for public notification, counter digital signage, and counter button for queue progression. Added features such as mobile queueing provides interface to individual smart phone for queuing update. Q-matic features and capabilities as explained above varies from project to project depending on contract requirements.

6.4.14 Master Clock System

As the name implies, Master Clock System governs time management for all the Building Services Systems with indicated time. The system is composed of analogue or digital clock installed in multiple locations within the building, which can be a wired distribution or wireless system. There must be one (1) common time appearing for all interfaced building systems lead by the Master Clock.

6.4.15 Voice and Data Infrastructure (VDI) - Local Area Network (LAN)

Voice and Data Infrastructure involves structured cabling systems, servers, protocols (for transmission, routing, and communication) and software. The VDI is used to transfer voice and data information from one location to another (a server and Client communication). Building Services Systems protocol used for transfer of information is the TCP/IP which is the standard Internet Protocol Suite. All Building Services nowadays are moving to IP Based using the TCP/IP for unification, which means that the same VDI will be used all throughout the building by all low current systems. This simplifies and reduces the required number and type of cabling used in the building for Low Current services backbone.

Although the physical infrastructure for all building services is unified through the TCP/IP, it should be noted that IP addressing, and subnet masking plays an important part in the success of the T&C for the VDI. All Low Current Systems Supplier/Manufacturer connected to the voice and data infrastructure should closely coordinate with the VDI Administrator the required IP address and subnet (as required) of every field device to avoid errors due to redundancy.

Testing required for the VDI cabling and terminations is explained in the preliminaries (see Section 6.1.4 of this Guideline). Servers, repeaters, switches, and routers are plug and play type. For other testing requirements, refer to checklist EPM-KT0-TP-000059 and EPM-KT0-TP-000060 under document EPM-KT0-RG-000007 (T&C Checklist and Templates) for LAN Pre-start Up and Functional/Performance Testing

6.5 Fire and Life Safety (FLS) System Integration – FDAS as Prime Mover

All building services systems that can be used for life and property preservation must be able to “talk” to each other to have an effective system, which can collectively function as one system. Fatalities are commonly related to smoke generation and propagation and it is therefore mandatory that the building life/safety system must act as quickly as possible to control or suppress smoke generation and propagation by means of the following methods.

- Early detection of fire and smoke and providing fast occupant and firefighting staff notification
- Fast fire suppression.
- Fire and smoke containment
- Effective ventilation and smoke evacuation
- Control or elimination of fuel and oxygen source

In real life, even in the presence of sophisticated fire protection and detection system, there are scenarios where fire and smoke will be uncontrolled for some reason. Failure can be due to poor maintenance of the system and improper or noncommissioned fire/life safety system. It is therefore required that system and procedure must be in place so that occupants can be evacuated as fast as possible to preserve life. Emergency evacuation requires clear occupant notification for direction, effective means and path of evacuation and effective monitoring of all locations within the building.

This section will discuss the function of each and every building services system as they act as a single and integrated system for firefighting, smoke detection and control and occupant evacuation as per the requirement of NFPA 4 and Best Construction Practices. The FDAS is the prime mover of all the electro-mechanical systems as integrated system, which provides the detection, notification, and activation of all other electro-mechanical systems. For other building services interface/integration to FDAS, it is done through the secondary loop of the Control Interface Modules (CIM) and Monitoring Interface Modules (MIM). The primary loop is the loop where smoke detectors, heat detectors, MPS, strobes and interface modules are connected to the FACP.

6.5.1 Building Management System (BMS)

When a Zone Smoke Control System (ZSC –refer to section 6.2.3 for explanation) is required by the Code, it is the BMS that takes control of the ZSC system and not the FDAS. This is mainly because of the limited capability of the Fire Alarm and Control Panel (FACP) for the required control and automation. ZSC is a complex system which requires control and modulation of fire/smoke dampers, measurement of airflows, fan speed adjustment and control, which the FACP is not capable to do. The FACP sends the signal to the BMS which indicates the specific location and zone of the smoke detection for the HVAC System (controlled by the BMS) to respond correspondingly. In a large healthcare project composed of multiple smoke zones in each floor, wrong programming of the FACP as well as the BMS will result in a catastrophic condition, where fire and smoke can quickly propagate throughout the building due to wrong zone pressurization.

Staircase Pressurization System employing variable speed control and differential pressure sensing across the stairwell doors is also controlled by the BMS because of the same reason as stated above. Only systems that have simple operation (such as on or off function through dry contacts) are controlled by the FACP.

Shutdown of AHU and fans for public response (collective shutdown of all AHU and fans within the building) is usually controlled by the BMS to avoid excessive wiring and field devices from FDAS CIM (Control Interface Module) to HVAC equipment control panel / starter. The usual set-up employing this strategy is by providing a signal (hard wired-analogue interface) from the FACP to the BMS main controller to shut down all AHUs and fans.

6.5.2 Mechanical Life Safety Systems

Staircase Pressurization System (SPS)

SPS employing simple on-off control for fans with the use of mechanical pressure relief damper installed at the top of the stairwell, to regulate pressure within the staircase is controlled by the FACP. During smoke detection, the pressurization fans activate to provide pressure differential across the stairwell and the adjacent area separated by the stairwell door.

Atrium Smoke Extraction System (ASES)

Operation of the ASES during smoke detection includes opening of main entry doors as the source of make-up air and then followed by the activation of fire rated exhaust fans. AHU as source of make-up air is seldom employed due to the large amount of air required. Control of ASES fans and main entrance doors (through the SACS - Security and Access Control System) is by the FACP.

Lift Lobby Smoke Management System (LSMS)

LSMS utilizing either Lift Lobby Pressurization or Lift Shaft Pressurization is directly controlled by the FACP since it only incorporates turning-on of fans (without speed control) during detection of smoke.

Carpark Smoke Management System (CSMS)

CSMS is a system dedicated for carpark and separate to the building smoke control system since carpark is always treated by the Code as different occupancy by providing firewall separation. CSMS is activated when there is a smoke or heat detection within the car parking area.

6.5.3 Security and Access Control System (SACS)

Unlocking and locking of doors always creates a major dispute between FLS consultant and the Client Security Management since there is no direct guidance from the Code. FLS consultants normally specify unlocking of all doors controlled by SACS during the first field device (smoke detector or sprinkler flow switch) detection while Security Consultants require unlocking during the second device detection. Majority of FLS strategy for healthcare (especially that of non-ambulatory type) requires doors controlled by the SACS to be unlocked during the second detection of field device (double knocking or cross zoning), and doors which can cause compromise of highly secured and controlled areas remains locked. For hotels, unlocking of doors controlled by SACS including stairwell doors usually happen during the first field device detection.

Main entrance doors located in the atrium requires full opening prior to the activation of atrium exhaust fans during the activation of a single beam smoke detector.

6.5.4 Public Address and Voice Alarm (PAVA)

During a single field device detection and based on the set time of delay, the FACP sends signal to PAVA to initiate programmed annunciation to make the occupant aware of the condition. Audible annunciation strategy happens in the floor of incident, floor above and below the incident floor, for hotels and other buildings with ambulatory occupants. Sample annunciation during the first detection is "*There is an emergency condition in level xxx, all occupants are requested to be alert and wait for further instructions*". Other annunciation strategy includes the whole building announcement using color coding to alert and summon fire wardens (used for healthcare) such as "*May I have your attention please, there is a code <u>red</u> in <u>xxxx</u> floor. All staff are requested to initiate response based on code red scenario".*

During the first field device detection and public annunciation where the FACP or the Annunciator Panel (or repeater) is not acknowledge and reset after a set elapsed time, or the second field device detection occurs without acknowledgement and reset, the system proceeds to the general evacuation scheme with the following announcement, "*All occupants are requested to evacuate the building. Please use the staircase and do not use the elevator*". Evacuation annunciation starts from the floor of incident, above and below floors, then shifted to the highest floor and downwards based on agreed time intervals. It may be required by the evacuation strategy a simultaneous or parallel annunciation to speed up the evacuation time especially for super high-rise buildings. For super high-rise building or healthcare-high rise projects which the use of staircase will extend evacuation time, jeopardize occupants due to panic and exhaustion, or occupants are unable to use the stairs, then elevators can be used for evacuation as allowed by the Code.

Annunciation during smoke detection and general evacuation depends heavily on the FLS and evacuation strategy. Capacity of the PAVA amplifiers and FACP voice card are related to the annunciation requirements.

6.5.5 CCTV System

CCTV System is very useful during fire condition and general evacuation to determine the actual fire scenario and watch the effectiveness of evacuation. With regards to interface to FDAS, cameras with tracking systems are rarely employed. This feature requires a moving camera to change from its normal position (e.g., corridor) to a new position (usually an exit door) for security reasons.

6.5.6 Elevators

Depending on the FLS strategy, elevators can be recalled during the first field device smoke detection anywhere in the building floor and staircase will be used for occupant evacuation. Ground Floor is the usual first recall level since it leads directly to the outside exit. Secondary recall level is the level above the Ground Floor where the elevator car would go in the case where the fire is on the Ground Floor and depends on the architectural and FLS design. Elevators are allowed by the Code to be used for general evacuation and should only be recall if smoke detection happens in the lift lobby, lift lobby shaft and elevator machine room.

Phase II recall is a condition where a certified fire fighter uses the elevator car for responding to emergencies. Firefighter's key switch is used to change status of the firefighter's switch located at the Ground Floor to Phase II recall for the control of the elevator car.

6.5.7 Sprinkler Flow Switch and Supervisory Switch

During an event of a fire and when the temperature rating of the sprinkler is reached, the sprinkler will burst open. The speed of bursting depends upon the RTI (Response Time Index) of the sprinkler. When a sprinkler is open and water is discharging, a flow is created in the piping, which will be detected by a flow switch installed in the sprinkler feed main. The flow switch as well as the supervisory switch is wired or looped to the MIM (Monitor Interface Module) which will send a signal to the FACP. The FACP will then respond based on the programmed C&E (Cause and Effect) equations (see Section 6.4.1 for response scenarios).

Supervisory switch purpose in the Floor Control Valve Assembly is to monitor that the sprinkler isolation valve is always open, and water is always available for firefighting. In any attempt of valve closure, (refer to Section 6.4.1) the MIM will send a signal to FACP to indicate that valve is closed or being closed.

6.5.8 Audio-Visual System

It is required that A/V System audio shall turn-off or be silenced during the event of fire so that all occupants inside the room (meeting or conference room) will hear the fire alarm annunciation. A/V System is connected to the secondary loop of the CIM.

6.5.9 Door Hold-Open Hardware

In buildings having long corridors, which exceeds the maximum allowed architectural zoning and travel distance, fire rated doors are installed to maintain the fire and smoke integrity of the fire/smoke zone. The fire door installed is kept open by hold-open hardware, which is an electro-magnetic device. During fire conditions, the hold-open hardware is de-energized and releases the door to seal the fire/smoke zones. Door hold-open hardware is mains powered through a controller, which is connected to the CIM. The FACP sends a signal to the CIM through the primary FDAS loop and the CIM sends a signal to the controller to de-energize the door hardware.

6.5.10 HVAC Duct Motorized Fire/Smoke Dampers

Duct motorized dampers (fire or combination fire/smoke dampers) are used to seal duct penetrations in walls within the fire and smoke zones. Motorized dampers (MD) require mains power to operate and are wired in parallel (in-group based on wall penetrations) controlled by a controller linked to CIM (or CIM nowadays has an integral controller in one unit). In the event of FDAS field device activation or detection, MD in the supply, return and exhaust ducting closes to seal the fire/smoke zone or modulates to increase or decrease flow if the Zone Smoke Control System is implemented for pressurization and smoke control.

6.5.11 LPG Solenoid Valve

During an event of fire, a signal (hard wire-analogue signal) is sent from the FACP to the LPG Control Panel to close the Main LPG Solenoid valve located externally to the building. Closing the solenoid cuts the supply of LPG to the building, which could otherwise aggregate the condition of the fire.

6.5.12 Clean Agent System (CAS)

Clean Agent System is a standalone system and only sends a signal from its own control panel to the FACP by means of MIM (Monitoring Interface Module) in the event of fire. Clean Agent control panel is activated through its own smoke or heat detector (Clean Agent detectors are separate from FDAS detectors). The signal to the FACP initiates activation of FDAS System based on the approved C&E Matrix.

6.5.13 Pre-Action System

Operation of the Pre-action System is similar to the Clean Agent System.

6.5.14 Kitchen Hood Fire Suppression System (KHFSS)

KHFSS is a wet chemical fire suppression system to protect the kitchen equipment below the hood in the event of fire. The system is linked to the BMS to shut down the exhaust fan and the make-up air AHU serving the kitchen in case of fire, which will melt the fusible link installed in the hood. Turning-off the hood exhaust fan is required to avoid sucking and disposing the chemical externally through the ducting. Turning-off the make-up air AHU is required to avoid excessive positive pressure in the kitchen and increase in oxygen, which can aggravate the fire growth. Signal to the FACP can be through the BMS or through a contact in the hood wired to a MIM.

6.5.15 Roll-Up Doors

External roll-up doors located normally in back-of-house areas drops during the event of fire for security reasons since all building occupants and staff are required to evacuate. Internal roll-up doors are required to drop to seal up fire and smoke zones for corridors with large openings or to seal up fire/smoke zones between communicating spaces (e.g., large open space from a floor connecting to an atrium). Mains power for the roll-up door motors are connected through a controller connected to a CIM (Control Interface Module) or a CIM with integral controller. Roll-up doors can automatically return to open position during a FDAS system reset or can be manually open through an operating switch.

6.5.16 Drop Curtains (Fire Rated)

Fire rated drop curtains have the same function as the internal roll-up doors and can usually be found in large malls where atriums and communicating spaces are common. Fire curtains drop during an event of fire to seal up fire and smoke zones. Mains power for the drop curtain motors are connected through a controller connected to a CIM (Control Interface Module) or a CIM with integral controller. Drop curtains can automatically return to the raised position during a FDAS system reset or can be manually raised through an operating switch.

6.5.17 Oxygen Solenoid Valve for Healthcare

Oxygen supply must be prevented during an event of fire since it can greatly aggravate the growth of fire. Oxidizing agents such as peroxides and dry-chemical powders react with high concentrations of oxygen and will cause explosion. Oxygen main supply solenoid or main branch supply solenoid, depending on the FLS strategy and Medical Gas design, must be closed during a single knock (single detection) or double knock (double device detection or cross-zoning).

6.5.18 Car Parking Entrance and Exit Booms

Fire always creates a panic, which makes occupants do improper things to save their lives. It is common that people and motorists rush to get out from the building or an enclosed parking area during a fire event, which results in motorist ramming-off entrance and exit booms to escape. Because of this main reason that it is good practice to automatically raise booms during fire condition.

6.5.19 2-Way Emergency Communication System

As required by NFPA and other Safety Codes, 2-way emergency communication system must be provided within the building for emergency purposes. 2-way communication can be a dedicated system or can be an existing system such as an Enterprise Telephone System or Enterprise VoIP integrated with the elevator emergency communication system. 2-way Communication System must be provided in (1) Main Plant Rooms, (2) Main Electrical Rooms, (3) Elevator Machine Rooms, (4) Elevator Car, (5) Elevator Lobbies, (6) Area of Refuge, (7) MDF Room, (8) Data Centers, (9) Nurse Stations, (10) Maintenance Department Office and (11) Fire Command Centre.

In the event of a fire emergency, the FDAS sends a signal to the PABX or IP VoIP Server to activate two-way communication (talk line) between the above-mentioned locations automatically to the Master Phone Station located in the Fire Command Center without dialing any local number, if the phone system is used as 2-way emergency communication system.

6.5.20 Cause and Effect Testing - Building Wise

After the completion of all the above-mentioned systems, the FDAS is now ready for building wise Cause and Effect Testing. Procedure for this test varies and should be agreed and established between the Client, the Project Management (or Construction Management) and the Contractor during the preparation of the methodology. Questions of how many sets of single and double knocking is required to prove the Fire and Life Safety System for the whole building should be resolved. During the test, it is advised that sets of single and double knocking should happen on the floors last served by the FACP. For instance, a twelve (12) floor project is composed of three (3) FACP serving four (4) floors each. C&E testing should happen in levels 4, 5, 8, and level 9. The purpose of the test is to verify that FACPs and PAVA are communicating properly by confirming that the annunciation of the PAVA speakers on the floor of the incident and the above and below floors are happening. Test per floor should include a set of single and double smoke detector (SD) test, a set of flow switch and SD test, and a MPS (Manual Pull Station) activation test.

6.6 Low Current System Integration

When each Low Current System (LCS) is completed and has passed all the required testing as standalone, it will require integration with other LCS to fulfil the desired functionality as required by the Specification. Low Current Integration is independent to the integration required for Fire and Life Safety Systems.

6.6.1 BMS (Building Management System) to EPMS (Electrical Power Management System)

Information between systems such as electrical system status (on or off, fault, measurements, and readings) can be shared through software integration or the BMS can have a separate hardwire connection to an auxiliary dry-contact integral to the electrical equipment for monitoring purposes.

6.6.2 NCS Integration to Lighting, RTLS, Security Panic Alarm, Enterprise Telephone or VoIP and Wireless Network

The below explains the integration of the Nurse Call System (NCS) to other electrical and Low Current Systems.

Nurse Call System to Room Lighting System

Bed Hand piece (or handset) serves as the remote for controlling the room lighting system either by on-off or by dimming feature.

Nurse Call System to RTLS and vice versa

When the patient summons a duty nurse or an attendant nurse summons another duty nurse in case of emergency, the RTLS shall record the location and time of the nurse to respond the need of the patient or attendant nurse.

For wandering patient or patient with intensions to elope from their confined locations, the RTLS which provide patient real-time location can be programmed or configured to alert nurses when patients are out of their designated confined area.

Nurse Call System to Wireless Network, Security Panic Alarm and RTLS

Attacks on nurses and doctors are common in healthcare set-up. The paging unit that is owned and carried by nurses are configured to have a unique code representing the nurse identity and a feature to send emergency signal to the Nurse Station Nurse Call MSDU through the Wireless Network, which will send signal to RTLS station and Security Panic Alarm System (display shall be in flashing black color).

Nurse Call System to Enterprise Telephone or VoIP and Wireless Network

Nurse Call MSDU (Master Station and Display Unit) varies from manufacturer to manufacturer and units can include or exclude phone station. For MSDU having integral phone unit, the designer must be aware of compatibility to the telephone system especially for VoIP. VoIP providers such as CISCO and AVAYA have their own propriety software for SIP (Session Initiation Protocol). MSDU that comes from different manufacturer will require a gateway for the unit to work with AVAYA or CISCO VoIP system. The MSDU phone station connects to the telephone system or network and serves as an intercom.

Using VoIP and Wireless Network, the mobile paging units which are currently utilizing android phone technology can be used by every nurse for voice communication.

6.6.3 ADT (Admission, Discharge and Transfer) Integration to NCS and Data Infrastructure

Each time a patient is admitted, discharged, or transferred, it is required for nurses to provide records (electronically) or update the records of the patient, record the patient's physical condition assessment, record the hour of admission/discharge/ and transfer, record who accompanied the patient and record the means of patient's arrival (e.g., ambulance, wheelchair, etc.) through the ADT. Presence of an attending nurse is important so that during a patient admission, discharge or transfer, the ADT Administrator will send request to the Nurse Call System for the immediate summoning of nurse to provide real-time patient records or update of patient's record through the ADT.

When a patient presses the handheld device (handset) of the NCS, the ADT monitor in the Nurse Station should automatically display the real-time information about the patient inclusive of the recent medication that was provided, and routine treatment required.

6.6.4 Master Clock Integration to BMS, FDAS, SACS, CCTV, VDI, NCS, RTLS, Q-Matic, PAVA and PMAS

As the name implies, Master Clock System governs time management for all the Building Services Systems with indicated time. Integration to BMS, FDAS, SACS, CCTV, VDI, NCS, RTLS, Q-MATIC, PAVA and PMAS is required to have a common time across all interfaced building systems.

6.6.5 PAVA Integration to IPTV or Analogue TV and Digital Signage

Some projects like airports will require integration of the PAVA (Public Address and Voice Alarm) to the Digital Signage System for the purpose of public notification and information. Since the information on all

Digital Signage will be typical, multiple set-top boxes (or decoders) will not be required in IP based PAVA. Only IP addressing will be required and subnet masking (depending on what subnet the Digital Signage was configured, not required if in the same subnet). PAVA is also integrated to the IPTV or Analogue TV System to interrupt entertainment (both visual and audio, or audio only) during public annunciation.

For the conventional PAVA with its own backbone and utilizing Analogue TV public addressing for flight schedule and timing, communication is by PTP (Point-to-Point) protocol data transmission from the main server and user interface to DAC (Digital to Analogue Converters) Boxes using signal boosters and splitters.

6.6.6 SACS Integration to CCTV

For doors that are equipped with Security and Access Control, CCTV Tracking is sometimes required by the Specification during unauthorized access. Functionality will be required that allows CCTV to change its position and focus on the door, which initiates an alarm due to forced entry. In the event of forced entry or repeated attempt for unauthorized entry, the SACS sends a signal to the CCTV System to initiate camera tracking in the pre-set position and focus.

6.6.7 DIAS Integration to SACS

Door Intercom and Access Control (DIAS) is integrated to Security and Access Control System (SACS) to avoid an intrusion alarm for doors equipped with both systems, such as in hospital VIP in-patient main elevator lobby door entrance to Nurse Stations. The DIAS controller will send a signal to the SACS controller through hard wire connection during the request to unlock or automatically open doors.

6.6.8 BMS Integration to Security and Access Control System

Security and Access Control System can be integrated into the Building Management System to provide information during unauthorized access or failure of the access control system. An alarm notification appears in the graphics of the BMS indicating the location of the incident. Interface of the systems is through the software integration.

6.6.9 Building Services Integration to Wireless Network

Due to the technological development and unification of all building services systems by using a common Voice and Data Infrastructure and LAN through TCP/IP protocol, enterprise integration of Low Current Systems is becoming more and more flexible, and software based. This means that enterprise integration using a common backbone is greatly dependent on the software integration at the OSI Application layer. Low Current Systems can easily be integrated into the Wireless Network to inform maintenance personnel in case of equipment and system breakdown through mobile phones. Q-Matic Systems can be integrated to wireless network to avoid physical queuing and give freedom for people to roam around or to be productive instead of wasting time in queuing. FDAS can send emergency messages in case of fire and smoke detection to firefighting team to provide better and quicker response. Security and Access Control System can notify security personnel in case of unauthorized or forced entry. PAVA can be integrated to the wireless network for notification of passengers for flight schedule changes and timing.

There may come a time when all Low Current Systems controllers and smart devices can inter-operate openly and be unified under one truly open communication protocol, which will assign unique IP addressing and instance numbering to all field devices as well as unique manufacturer ID. This will greatly simplify the T&C of the building services.

6.7 Mechanical System Interface and other Integration

There is no known integration concerning the mechanical system except that of the interface of the Infectious Isolation Room exhaust fan to the shutdown of AHU supplying conditioned air to the room for healthcare. Infectious Isolation Rooms are kept at negative pressure to avoid contaminated air spreading outside the room. If the AHU does not immediately shutdown when the exhaust fan is turned-off for any reason, the room pressure will become positive and infected air will spread throughout the building. Control configuration can be either by (1) a flow sensor/switch, a pressure sensor or a differential pressure switch installed in the exhaust ducting which wiring runs in the nearest BMS DDC. The DDC sends a signal to the DDC controlling the AHU, serving the isolation room to turn-off in case the contact from the switch or sensor is lost which indicates that the exhaust fan is off or (2) a direct hardwire connection from the flow sensor/switch (or pressure sensor, or differential pressure switch) to an auxiliary relay/contactor of motor control panel of the AHU.

Lighting System can be integrated to the BMS to obtain functions such as (1) switching of lighting zones in accordance with zone occupation time as set in the BMS, (2) switching off lighting zones in accordance with occupancy sensing and light level sensing and (3) monitoring of lighting zone for lamp run hours and raising an alert/alarm if the specified maximum usable hours are exceeded.

For complex projects such as healthcare Operating Rooms and laboratories, interface of the specialty equipment to the Building Services should be considered and develop during the design phase. Close coordination between the specialty equipment manufacturers, the Building Services Designers, the Commissioning Authority, the end-users, and O&M Staff must take place and all interface connection must be stablished in the OPR including all T&C requirements and expectations.

6.8 Power Failure Testing (Doomsday Testing or Full Load Testing) for 100% Generator Set Emergency Power System

After the integration for all electro-mechanical systems and all connections to specialty equipment (such as laundry equipment, medical equipment, operating theatres, radiology equipment, etc.) are completed and the emergency power system has passed the required preliminary testing, the building is now ready for Power Failure Testing. Power Failure Testing requires extensive planning and coordination, and the objective of the test is to; (1) conduct an actual emergency scenario where the normal power mains will be turned-off (to simulate loss of normal power) to allow the essential (or emergency) power to come in during a full building load condition, (2) to simulate a fire condition to activate all fire and life safety systems when the building is in normal peak operation. The test is conducted through the following methodology.

- All Building Services Systems and equipment shall be activated during the test including elevators, escalators, medical equipment, radiology equipment, laundry, kitchen equipment and all transient loads such as fire pumps. It is required that all elevators, escalators, etc., are in operation during the test. Fire pumps shall be activated by bursting a sprinkler head (usually in the parking area) and activating fire hose streams (usually on the roof).
- All Low Current and Electrical Systems shall be in operation during the test. Smoke detectors shall be activated to initiate the Fire and Life Safety Systems (alarms, notifications, elevator recall, staircase pressurization, atrium smoke extraction, etc.).
- Incoming electrical mains upstream of the source of auxiliary contact power supply to the Automatic Transfer Switch (ATS) shall be turn-off to cut normal power to the building. The emergency power system shall receive a signal from the Paralleling Switchgear Master Control Panel (PSMCP) to start and stabilize. Once the emergency power system is stabilized and synchronized, the PSMCP will send a signal to the ATS to transfer from normal to essential to provide power to the building.
- The testing shall be coordinated with the Fire Department Authority to test fire trucks road access going to the building and connections of their fire hose to the Siamese twin (or fire department connections).
- To allow the FDAS to reach general evacuation stage by allowing notification time to expire or by setting the system for general evacuation.

Note that the above scenario can vary from project to project based on the design of the emergency genset power. Some projects that require close to Type 10 (10 secs. to provide essential power) emergency power system requires the lead genset to come on line and provide power to the building while the other equipment will be synchronized based on the lead generator set frequency, voltage, and phase angle before coming on line. This type of arrangement for emergency power system will require load-shedding scheme.

- Once the Power Failure Testing is completed, the normal mains shall be turned-on to provide signal to the ATS to return to normal power.
- Depending on the design scheme of the emergency power system, the gensets can be manually turned-off or gradually and automatically turned-off.

The reasons for conducting the testing are as follows:

- Train maintenance and clinical personnel how to deal with the loss of utility power during the power system transfers.

  It is common to any project that the first Power Failure Testing will fail for several reasons such as (1) ATS will not transfer to emergency position, (2) several breakers will trip due to simultaneous coming on of loads which will require adjustment in OCPD delays and pick-ups, (3) high transformer inrush current which will require further adjustment of inrush current protection and (4) incomplete system installation such as missing provisions for auxiliary power and field controller and devices low voltage power. It is at this stage that maintenance shall be trained by the T&C Agent on how to handle these problems.
- Test the functionality of all equipment and building services systems related to generation and distribution of emergency power

  During the test, problems regarding power supply will be discovered especially for low voltage power supplies for field controllers and field devices. Design drawings do not always indicate from where the low voltage power will be taken and most of the time it is unfortunately left to the contractor. Most of the low voltage power required for the mechanical equipment and Low Current System controllers is required to be from the essential power.
- Test Clinical and Radiology Equipment response to power system transfers

  Clinical, Radiology and other critical equipment are required to be provided with Uninterruptible Power Supplies (UPS) and no discontinuity or flickering of power supply is allowed. All suppliers for critical equipment must be present during the test to verify performance of the power system transfer and UPS during the test.
- To test the Power System load shedding scheme as applicable

  Projects with load shedding requirements for electrical power system, secondary priority equipment shall be removed from the system and will be monitored through the EPMS and BMS. Trend logs shall be submitted by the contractor to prove that secondary loads are shed during the test.
- To prove the required time of Emergency Power Transfer

  Codes such as NFPA defines Type 10 and Type 60 for emergency power systems to provide stable power to equipment and systems during normal power failure. During the test, the time during the start of the power loss shall be recorded. The systems and equipment should restore at 10 secs. for Type 10 and 60 secs. for Type 60 depending on the requirement of the contract specification.
- To test Fire Department fire truck access to the building and to ensure proper truck parking distance from the Fire Department Connections (or Siamese Twins).
- To test and prove compliance of the occupant evacuation time to the requirement of the AHJ and Fire/ Life Safety System Strategy.
- Avoid any conditions that compromise occupants' safety.

The vast majority of problems would have been resolved during each system testing; however, there will undoubtedly be a number of issues that will arise during the Power Failure Testing that can then be rectified. T&C reports will be compiled upon completion of the testing for inclusion in the handover documentation.

6.8.1 Importance of BMS and EPMS during the Power Failure Test

During the Power Failure Test, it will require many workers just to monitor all the mechanical and electrical equipment as well as all Low Current Systems controllers and field devices without the BMS and EPMS, which can result in inaccurate reporting of Building Service Systems and equipment status. It is always preferable that the BMS and EPMS are 100% operational during the test to simplify and provide accurate monitoring specially for large projects. After the test, Trend Logs are required to be submitted not only for the BMS and EPMS, but also for all Low Current Systems especially the FDAS, PAVA and Security and Access Control System.

6.9 Handover Requirements

Once the Power Failure Testing is completed and accepted by the Client Representative, the Main Contractor will raise a “Project Substantial Completion Notice” (or Preliminary Completion Notice as how it is defined in the contract terms) in form of a formal letter to the Client Representative (PM or CM). Attached to the Notice of Substantial Completion letter will be a punch list (or snag list) and a balance of work (outstanding works) both to be completed during the maintenance period (defects liability period). Prior to the submission of the Notice of Substantial Completion letter; the System Manual, O&M Manual, and As-built Drawings are also submitted by the Contractor to the Client Representative for review and approval. The contents of the O&M Manual are as follows:

- System Description
- Equipment Manuals (Operational and Maintenance Manuals)
- Factory Acceptance Testing (FAT) and Type Testing Certificates
- Testing and Commissioning Report
- Testing and Commissioning Results
- Testing and Commissioning Certificates
- Completion Certificates from all Trade Contractors
- Warranty (or Extended Warranty) Certificates
- Recommended Spare Parts List
- Instructions for energy savings operations and descriptions of the energy savings strategies in the facility
- Recommendations for retro-commissioning frequency by equipment type
- Energy tracking recommendations
- Contractor and Supplier address and contact number
- Manufacturer Literature

(Note that NFPA 3 includes the As-Built drawings as part of the O&M Manual but for the purpose of this Guideline and as per ASHRAE and standard practice, the As-Built drawings shall be treated separately.)

Once the above-mentioned documents are completed and the Client Representative is satisfied with the work, the project is now ready to be offered to the AHJ (Authority Having Jurisdiction) for Occupancy or Building Permit application by the Consultant. Requirements for the application of the Building Permit is as follows:

- Application form for the Building Permit duly signed by the Consultant.
- Letter of Appointment of the Consultant and Contractual agreement with the Client.
- Consultant’s Engineer license copy
- Consultant letter for the confirmation of project completion.
- NOC from Water, Drainage, Electricity, Civil Aviation (for high-rise building and buildings with roof helipads) and Telecom Authorities and lease agreement.
- As-Built drawings for Civil (Architectural, Structural with calculations and Soil Investigation Report) Mechanical (HVAC and cooling load calculation), Fire Safety (Architectural FLS, Sprinkler and Hose System and FDAS) and EHS (Architectural, Health, and Safety)
- Land Ownership Documents or Lease Documents.
- Preliminary Design Drawings and FLS Drawings

Once all the above pertinent documents have been submitted to AHJ, the AHJ Representatives will schedule a site visit, where it is required to conduct a repeat of the Power Failure Testing with bursting of sprinkler heads and hose stream testing. Once this testing is deemed acceptable by the AHJ, the project is ready for Substantial Completion Handover. The Client Representative (PM or CM) shall provide to the Client a letter for Substantial Completion stating the acceptance of the AHJ and completion of all required documentation such as O&M and As-Built drawings. The Client in return shall provide a “Substantial Completion Certificate” to the Contractor duly signed by the Client, the Client Representative, the Commissioning Authority, and the Contractor. The date in the “Substantial Completion Certificate” is the date of commencement of the “Project Warranty Period”.

Training, system orientation and site visits for the end-users and Operation / Maintenance Staff shall be conducted during the last stage of the T&C phase and must be complete prior to substantial handover.

Final Project Completion shall commence once all ofthe following items below are completed:

- Punch list (snag list) items and balance (or outstanding work) listed during the Substantial Project Completion Notice are all complete and accepted by the Client and the Owner Operation/Maintenance Department.
- Post occupancy Testing and Commissioning are all completed and accepted by the Client, the Commissioning Authority, the Client Representative, and the Owner Operation/Maintenance Department.
- For LEED Projects, after the completion of comments based on the satisfaction review 10 months after the Substantial Completion handover date.

6.10 Post Occupancy Testing and Commissioning

There are testing activities that requires loading to be finalized during the post-occupancy phase and there are testing activities that follow the completion of the loading. The following tests are required to be completed after the occupancy phase.

6.10.1 Phase Balancing for Convenience Outlet Circuit

Design of electrical convenience outlets are based on assumptions of uniform loading per outlet. During occupancy, actual connections of appliances and equipment by the tenants greatly differs from the design assumptions, so it will require rearrangement of wiring connections in the distribution boards. Phase imbalance causes useless current to flow to the neutral wiring and to the phase wiring creating electrical losses and overheating of motors. For medium and large projects which are prevalently 3-phase loads (Industrial projects, healthcare, power plants, etc.), unbalance between phases of the 3-wire connection due to single-phase load imbalance is not of a big concern since up to 10% current imbalance between phases with the highest and lowest current readings is allowed. Projects such as residential hotels which is prevalently single-phase loads requires phase balancing for convenience outlet circuits.

6.10.2 Harmonic Correction

Harmonics can result in overloading the neutral due to excessive current flowing in it. After the single-phase loads are balanced and there is still excessive current flowing in the main neutral wiring, presence of harmonics is evident. Harmonics is a common problem nowadays for any building due to advancement of technology in electronic controllers, magnetic core devices such as transformers, UPS, lighting ballast, etc. Service of Specialists in harmonic correction must be employed to resolve such issues. Common solutions lie between the use of any of the following methods, (1) Active harmonic filters, (2) Passive harmonic filters, (3) Isolation transformers.

6.10.3 Thermal Scanning

Thermal scanning (or Thermographic Survey) is conducted in electrical power system distribution to verify overloading of cables, bus bars, equipment and overheating due to poor termination between cables/bus bars and connections. Thermal scanning should be conducted when the; (1) building load is at peak which is occurring during the peak summer season since about 60% to 70% of the building load is attributed to the HVAC System and (2) after the completion and acceptance of harmonic correction.

6.10.4 Final Site Survey for Wireless Network

Projects or areas within a project that are expected to have occupant congestion, are required to conduct a final site survey to verify effectivity of the Wireless Network. Individuals nowadays carry BYOD (Bring Your Own Devices) such as wireless laptop, mobile phones, iPad, etc. which create interference with the wireless network and reduce its effectivity especially when the system is used for RTLS.

6.10.5 Seasonal HVAC Testing and Commissioning

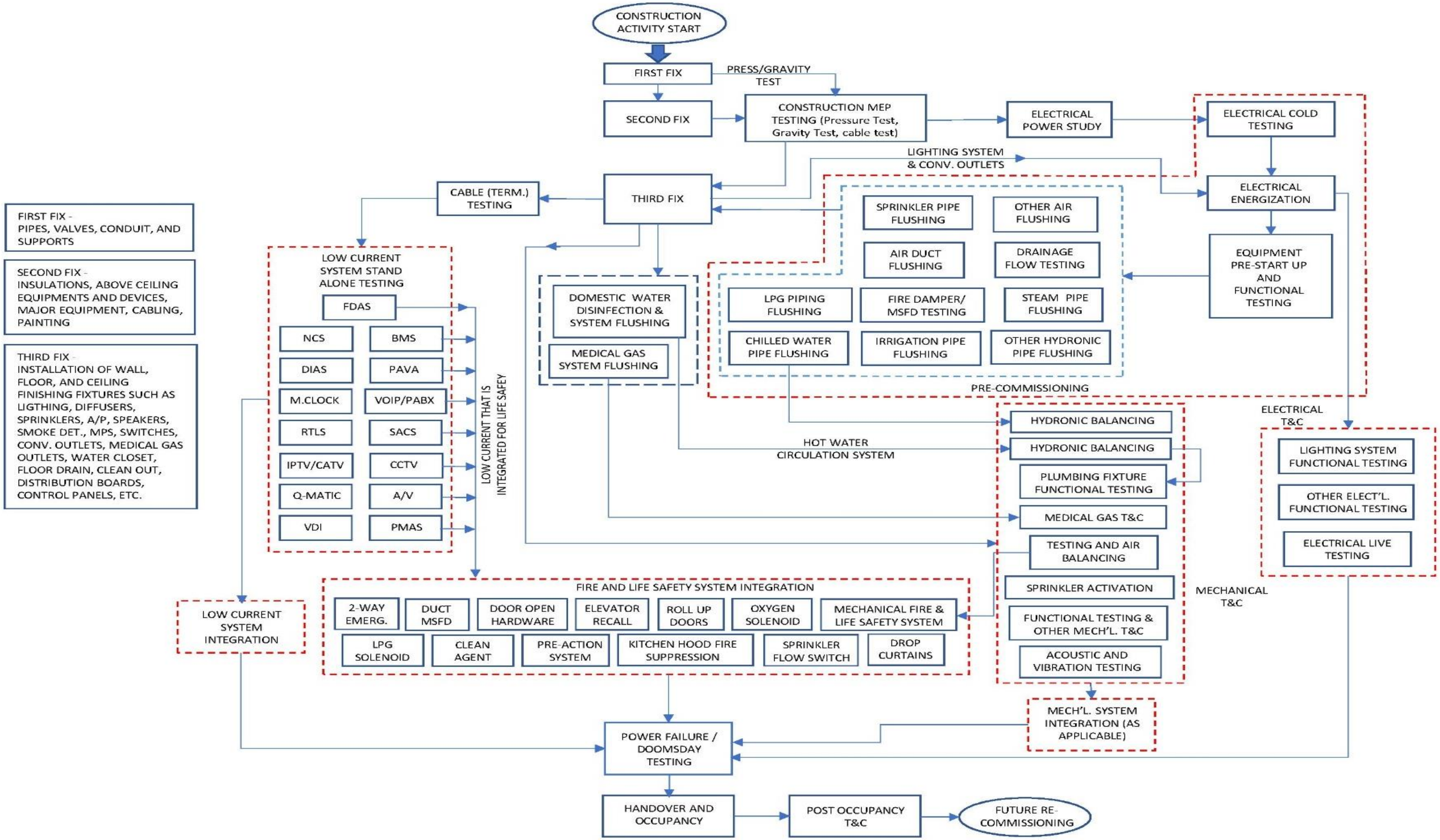
For projects located in areas where extreme ambient hot and cold is experienced, or great fluctuation in ambient %RH is expected and the indoor condition requires small window of fluctuations for space temperature and %RH, it is required to prove the system operation for the two (2) seasons. For example, in the Kingdom of Saudi Arabia, Riyadh, a hospital with Operating Theatres requires precise %RH control, temperature control and minimum Air Change per Hour for supply air (when the ACH is high compare to the actual cooling requirement air flowrate) and outdoor air. The HVAC system operation must be proven to (1) provide the cooling and terminal heating requirements during peak summer and when the ambient %RH is at peak, (2) cooling, humidification, and terminal heating at peak summer with low %RH and (3) cooling load (for mixed outdoor air and supply air system since Operating Theatre load is high especially when the laser is used), humidification and terminal heating during the winter season.

As explained above, the complexity of proving seasonal HVAC operation is expected for projects requiring lower room temperature and humidity such as medicine factories, paper factories, laboratories, etc. Projects requiring lower relative humidity requires dehumidification, which complicates seasonal T&C. For hotels and other projects (such as malls) that have wider tolerance in room temperature and %RH fluctuations, seasonal T&C is much simpler compared to healthcare and the like.

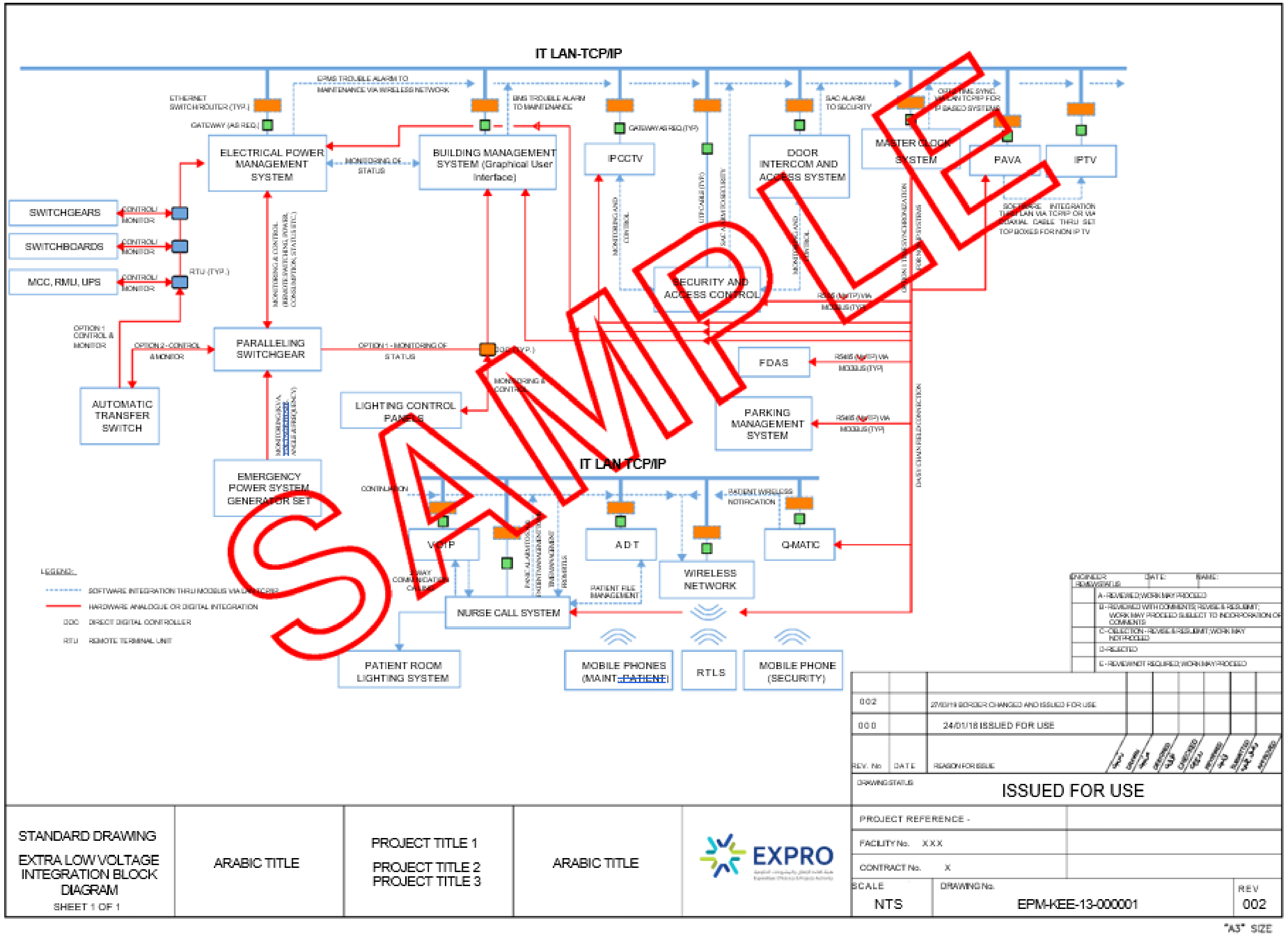
6.10.6 LEED Requirement - Building HVAC Systems Performance Assessment 10 Months after the Preliminary Handover

For projects requiring LEED Certification pursuing EA Credit 3 points (Enhanced Commissioning), the Main Contractor and the Commissioning Authority is required to conduct a Client and Operation/Maintenance Staff satisfaction interview and assessment of the HVAC System performance. All comments, defects and commissioning related issues must be resolved to attain the target credit. Client satisfaction report will be attached as a supporting document to attain EA Credit 3 points.

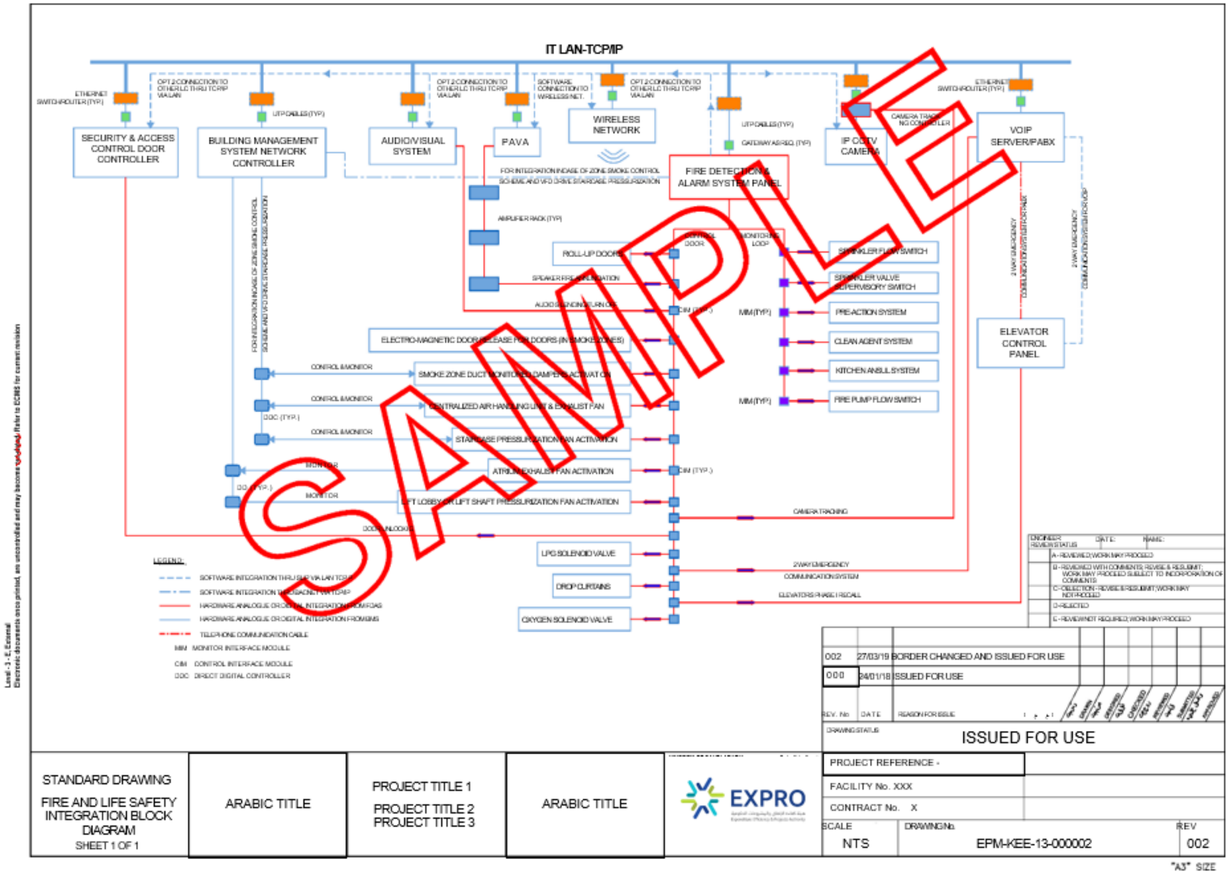
Testing and Commissioning Flow Chart



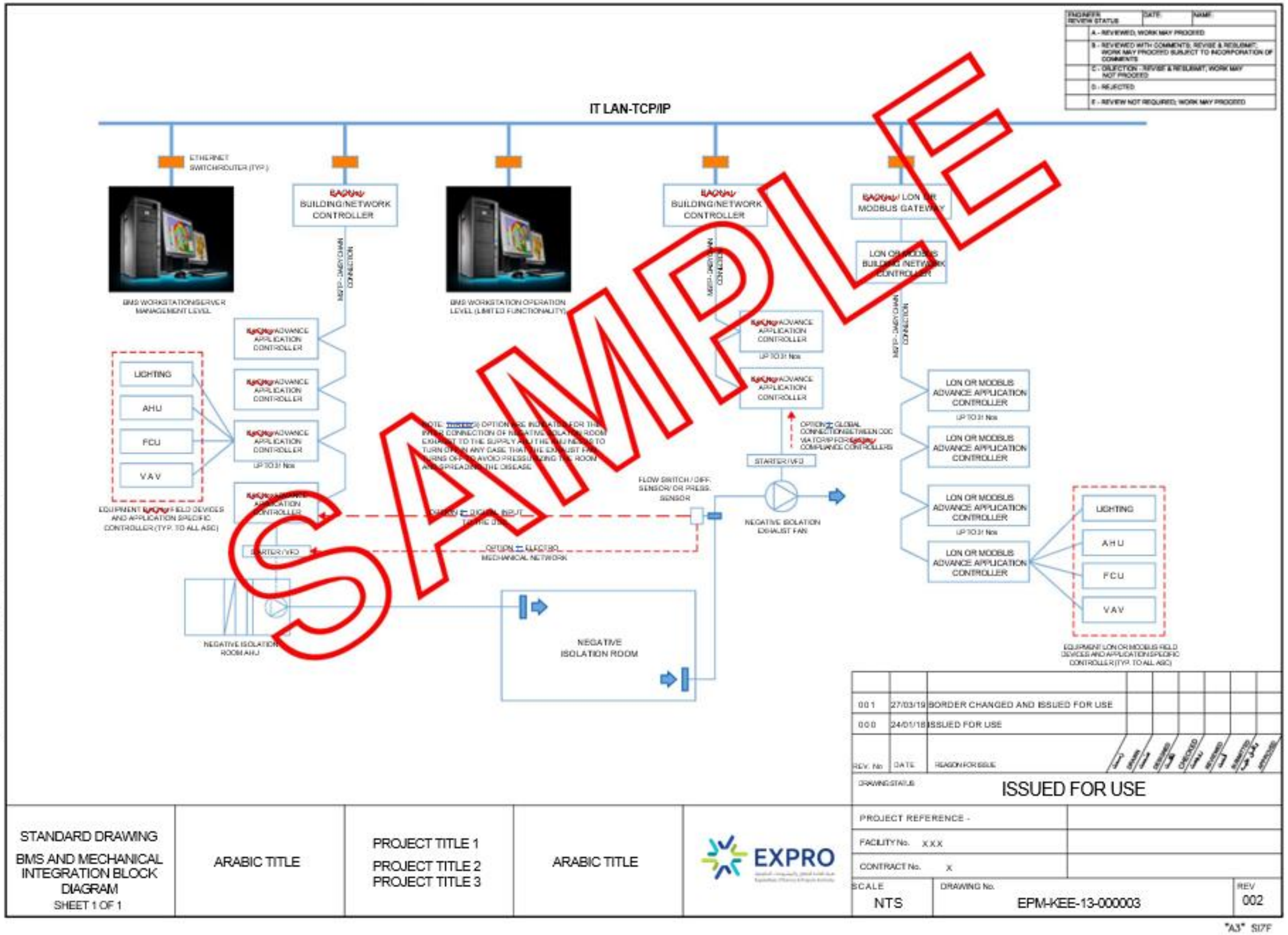
EPM-KEE-13-000001 - Low Current System Integration Schematics



EPM-KEE-13-000002 - Fire & Life Safety Integration Schematics



EPM-KEE-13-000003 -BMS and Mechanical System Integration



Critical T&C Activities Approximate Duration

T&C ACTIVITIES	PROJECT TYPE						
	Small Scale		Medium Scale	Large Scale	Health Care		
	General	Data Center			2 to 3 Floors	4 to 6 Floors	High Rise
Flushing of Chilled Water Network (Mild Steel)	1 week	2-4 weeks	6-10 weeks	12-16 weeks	2-4 weeks	6-8 weeks	12-16 weeks
Disinfection and Flushing of Domestic Water Network (Copper)	3-7 days		1-2 weeks	3-4 weeks	1 – 2 weeks	2-3 weeks	3-4 weeks
Flushing for Fire Sprinkler Piping	n/a		1-2 weeks	2-3 weeks	1-2 weeks	2-3 weeks	3-4 weeks
Air Balancing for each Centralized AHU/FAHU Air Distribution per 1 m^3/s Airflow	0.15 - 0.25 week/1m^3 of supply airflow						
Water Balancing for Chilled Water Piping	1-2 weeks	1-2 weeks	4-6 weeks	8-12 weeks	1-2 weeks	4-6 weeks	8-12 weeks
Water Balancing for Domestic Hot Water Return Piping	Less than a week		2-4 weeks	4-6 weeks	< week	2-4 weeks	4-6 weeks
Structured Cabling Testing	40 - 60 horizontal UTP Cables per Test Instrument per day						
	20 - 30 Fiber Optic Cables per Instrument per day						
Electrical Power Study (Short Circuit, OCPD Coordination, Arc Flash)	2-3 weeks	4-6 weeks	8-12 weeks	10-16 weeks	4-6 weeks	8-12 weeks	12-16 weeks
Electrical Live Testing	< week	1-2 weeks	2-3 weeks	3-4 weeks	1-2 weeks	2-3 weeks	3-4 weeks
BMS Standalone Testing (from PTP Test to Graphics Testing)	n/a	12-16 weeks	16-24 weeks	16-24 weeks	12-16 weeks	16-24 weeks	24–32 weeks
Fire Alarm System Standalone - Conventional Type	< week	n/a	n/a	n/a	n/a	n/a	n/a
Fire Alarm System Standalone - Addressable Type	n/a	2-4 weeks	6-8 weeks	8-10 weeks	4-6 weeks	6-8 weeks	10-12 weeks
Voice and Data Infrastructure Configuration, Programming & Testing (Low Current Systems are all IP Base)	2-6 weeks	12-16 weeks	8-12 weeks	12-16 weeks	12-16 weeks	16-20 weeks	20-24 weeks
Fire and Life Safety Integration to Cause & Effect Testing	n/a	2-4 weeks	6-8 weeks	8-10 weeks	4-6 weeks	6-8 weeks	10-12 weeks
Low Current System Integration and Testing	n/a	2-4 weeks	4-6 weeks	6-8 weeks	2-4 weeks	4-6 weeks	8-10 weeks
Power Failure or Doomsday Testing (inclusive of repeated testing due to failure and correction)	1-2 weeks	2-4 weeks	2-4 weeks	3-5 weeks	2-4 weeks	3-5 weeks	4-6 weeks

7.0 TESTING AND COMMISSIONING SAFETY RISK ASSESSMENT

Conducting the rigorous Testing and Commissioning activities poses hazardous threats, which can cause severe harm to the workers and damage to the building due to several reasons. Cause can vary from presence of high electrical voltages and high piping pressure for testing; harmful and combustible chemical for flushing; workers working in elevated locations during TAB; working on live high voltage equipment; excessive noise and vibration, etc. It is required that hazards be identified, and risk assessments shall be prepared to eliminate any possible exposure of people and the building to any form of harm. A risk assessment is simply a careful examination of anything that may cause harm during the course of the work and then providing all safety measures or appropriate actions to avoid or eliminate the harm. The aim is to prevent accident, illness, and property damage. The assessment is carried out by identifying risk and using appropriate control measures to minimize or eliminate it.

The Main Contractor and all trades working under him must follow and be aware of the Health and Safety Program/Procedures as outline in the following documents.

HSSE PROGRAM AND PROCEDURE	Document Number
General Safe Work Requirement Procedure	EPM-KSS-PR-000001
Housekeeping Requirements Procedure	EPM-KSS-PR-000002
Personal Protective Equipment Procedure	EPM-KSS-PR-000003
Fire Prevention and Protection Procedure	EPM-KSS-PR-000004
Fall Protection Procedure	EPM-KSS-PR-000005
Barricades and Signs Procedure	EPM-KSS-PR-000006
Confined Space Entry Procedure	EPM-KSS-PR-000007
Elevated Work Platform Procedure	EPM-KSS-PR-000008
Compressed Gas Cylinder Procedure	EPM-KSS-PR-000009
Night Work Procedure	EPM-KSS-PR-000010
Potable Ladders Inspection and Control Procedure	EPM-KSS-PR-000011
Drinking Water Procedure	EPM-KSS-PR-000012
Work On or Near Water Procedure	EPM-KSS-PR-000013
Emergency Preparedness Procedure	EPM-KSS-PR-000014
Suspended Personnel Platform Procedure	EPM-KSS-PR-000015
Hazardous Work Permit Procedure	EPM-KSS-PR-000016
Crane and Lifting Operation Procedure	EPM-KSS-PR-000018
Electrical Safety Procedure	EPM-KSS-PR-000021
Non-Destructive Examination Procedure	EPM-KSS-PR-000022
Hazard Communication Procedure	EPM-KSS-PR-000024
Manual Material Handling Procedure	EPM-KSS-PR-000027
Floor and Wall Openings Procedure	EPM-KSS-PR-000028
Safety Watches Procedure	EPM-KSS-PR-000030
Lock-out/Tag-out Procedure	EPM-KSS-PR-000031
Scaffolding Control Management Procedure	EPM-KSS-PR-000033
Respiratory Protective Equipment	EPM-KSH-PR-000004
Control of Hazardous Materials	EPM-KSH-PR-000007
Heat Stress Management	EPM-KSH-PR-000008
Hearing Conservation Program	EPM-KSH-PR-000010
Waste Management	EPM-KSE-PR-000002
Environmental Training and Awareness	EPM-KSE-PR-000003
Site Work Security	EPM-KCJ-PR-000001

All methodology produced for Testing &Commissioning must include hazard identification, safety risk assessment and safety measures to eliminate hazards and risk. The methodology and risk assessment must then be approved not only by the HSSE Manager of the Main Contractor but also by the Consultant (PM or CM) HSSE Representative. All members of the project team must rigorously do their best to implement all measures to eliminate the risk.