STANDARDS

a BICSI International Standard

ANSI/BICSI 002-2019

Data Center Design and Implementation Best Practices

BICSI®

ANSI/BICSI 002-2019

Data Center Design and Implementation Best Practices

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PREFACE

Revision History

June 18, 2010 First publication of this standard, titled BICSI 002-2010, *Data Center Design and Implementation Best Practices*

March 15, 2011 Revision of BICSI 002-2010 published as ANSI/BICSI 002-2011, *Data Center Design and Implementation Best Practices*

Major revisions include:

- Addition of Section 9, *Electrical*
- Addition of Section 14, *Telecommunications*

Minor revisions include: definitions, updating of graphics for printing and readability, other editorial corrections

December 9, 2014 Revision of ANSI/BICSI 002-2011 published as ANSI/BICSI 002-2014, *Data Center Design and Implementation Best Practices*

Major revisions include:

- Revision of Class F0 – F4 electrical infrastructure, including the removal of the requirement for a second power utility connection in Section 9, *Electrical*.
- Revised telecommunications Availability Classes C3 and C4 concerning the redundancy of main and horizontal distributors in Section 14, *Telecommunications*.
- Added, expanded and revised Availability Class structure to mechanical, telecommunications and network infrastructure (see Sections 9, 14, and 15 respectively).
- Addition of Appendix C, Alignment of Data Center Services Reliability with Application and System Architecture.
- Addition and revision of content for modular and containerized data centers in Section 6, *Space Planning* and Section 9, *Electrical*.
- Introduced content on DCIM and renamed Section 13 to *Data Center Management and Building Systems.*
- Expanded content regarding DC power and safety in Section 9, *Electrical.*
- Addition of hot and cold aisle containment in Section 6, *Space Planning* and Section 11, *Fire Protection*.
- Added and expanded content regarding designing for energy efficiency in multiple sections and added Appendix G, *Design for Energy Efficiency.*
- Addition of Appendix D, Data Center Services Outsourcing Models.
- Addition of Appendix E, Multi-Data Center Architecture.
- Updated cabinet door air flow and cable capacity calculations in Section 14, *Telecommunications.*

Minor revisions include:

- Moved former Section 5, *Space Planning* to directly after former Section 6, *Site Planning.*
- Restructuring of Section 5, *Site Planning*, Section 14, *Telecommunications*, and Section 16, *Commissioning.*
- Expansion of content to reflect both new and international design practices.
- Revisions to Appendix B, *Reliability and Availability*, to accommodate extension of availability classes.
- Update Section 8, *Structural*, to align with revisions to the *IBC* and related standards.

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- Updated Section 10, *Mechanical*, to reflect expanded ASHRAE guidelines for temperature and humidity.
- Updated Section 11, *Fire Protection* section to reflect changes in NFPA 75 and NFPA 76.
- Updated Section 14, *Telecommunications*, to reflect updates to ISO, TIA, and CENELEC data center cabling standards including cable types (removed OM1 and OM2, recommend OM4, added Category 8) and addition of intermediate distributor.
- Revised content regarding zinc whiskers and moved to Section 7, *Architectural*.
- Added content on testing equipment, system testing, acceptance testing, equipment operations and maintenance manuals, and system training to Section 16, *Commissioning*.
- Revised and moved system availability information to Appendix B, *Reliability and Availability*. (content formerly in Section 17, *Maintenance*).
- Added new content on maintenance plans and service contracts in Section 17, *Maintenance.*
- General content relocation and editorial corrections to improve readability and reduce ambiguity.

May 1, 2019 Revision of ANSI/BICSI 002-2014 published as ANSI/BICSI 002-2019, *Data Center Design and Implementation Best Practices*

Notable content relocation to BICSI 009-2019 includes:

- Operational security topics from Section 12*, Security*
- Operational maintenance topics from Section 17*, Data Center Maintenance*

Major revisions include:

- Revision and addition of content for, and related to, equipment cabinets and racks, including open racks and Open Compute Project® infrastructure within multiple sections
- Revision of computer room requirements and recommendations in Section 6, *Space Planning*
- Expansion of electrical busway content in multiple sections
- General restructure, including an update and expansion to heat rejection and cooling system technologies in Section 10, *Mechanical Systems*
- Restructure of Section 12, *Security*
- Title change of Section 13 to *Facility, Ancillary and IP-enabled Systems*, with addition of applicable content
- Revision and expansion of Section 16, *Commissioning*
- Addition of Appendix H, *Colocation Technical Planning*

Minor revisions include:

- Additions or revisions to airports volcanoes, and microgrids in Section 5, *Site Selection*
- Revision of access control and video surveillance systems within multiple sections
- Expansion of equipment access and pathway (e.g., ramps) requirements and recommendations within Section 6, *Space Planning* and Section 7, *Architectural*
- Update to access floors requirements for seismically active areas in Section 8, *Structural*
- Addition of lithium ion (Li-ion) batter information within multiple sections
- Alignment of telecommunications bonding and grounding terminology to international usage in Section 9, *Electrical Systems*
- Revision of equipment cabinet and rack bonding in Section 9, *Electrical Systems*
- Addition of oxygen deletion systems and fire alarm systems and an update to gaseous fire suppression systems in Section 11, *Fire Protection*
- Addition of time synchronization in Section 12, *Security*
- Expansion of content related to entrance facilities, entrance rooms, and meet-me rooms in multiple sections
- Addition of ICT infrastructure requirements for supporting and non-computer room systems
- Revision to permissible backbone and horizontal cabling media and addition of optical fiber connector cleaning in Section 14, *Telecommunications Cabling, Infrastructure, Pathways and Spaces*

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- Expansion of network topologies and fabrics in Section 15, *Information Technology*
- Addition of maintenance plan philosophies in Section 17, *Data Center Maintenance*
- Addition of existing facility assessments to *Appendix A, Design Process*
- General content relocation and editorial corrections to improve readability and reduce ambiguity

Document Format (Usability Features)

This standard has the following usability features as aids to the user:

- Additions and changes, other than those for editorial purposes, are indicated with a vertical rule within the left page margin.
- Deletion of one or more paragraphs is indicated with a bullet (•) between the content that remains

NOTE: The relocation of content within or between sections (e.g., Section 10, *Mechanical Systems*, Section 12, *Security*) related to structure, readability, or content alignment is not indicated.

Translation Notice

This standard may have one or more translations available as a reference for the convenience of its readers. As that act of translation may contain inconsistencies with the original text, if differences between the translation and the published English version exist, the English text shall be used as the official and authoritative version.

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1 Introduction

1.1 General

This standard is written with the expectation that the reader is familiar with the different facets of the design process (See Appendix A). The reader should understand from which role and point of view he or she intends to use this document (e.g., information technology, facilities, other corporate internal or external to the owner). Refer to Sections 1.2.1 – 1.2.3 below.

1.2 Purpose

This standard provides a reference of common terminology and design practice. It is not intended to be used by architects and engineers as their sole reference or as a step-by-step design guide, but may be used by such persons to determine design requirements in conjunction with the data center owner, occupant, or consultant.

This standard is intended primarily for:

- Data center owners and operators
- Telecommunications and information technology (IT) consultants and project managers
- Telecommunications and IT technology installers

Additionally, individuals in the following groups are also served by this standard.

1.2.1 Users Within IT

1.2.1.1 IT and Telecommunications Designers

IT and telecommunications designers and consultants may use BICSI 002 in conjunction with the appropriate local telecommunications infrastructure standard (e.g., ANSI/TIA-942-B, AS/NZS 2834-1995 Computer Accommodation, CENELEC EN 50173 Series, ISO/IEC 24764) to design the telecommunications pathways, spaces, and cabling system for the data center. The telecommunications designer/consultant should work with the data center architects and engineers to develop the IT and telecommunications equipment floor plan using guidelines specified in this standard.

1.2.1.2 IT and Telecommunications Management

IT and telecommunications management may use BICSI 002 as an aid in defining initial data center design requirements based on required levels of security, reliability, and availability. IT and telecommunications should work with information protection management, the business continuity group, and end user departments to determine the required levels of security, reliability, and availability.

1.2.1.3 IT Operations Management

Working with facilities groups, IT operations managers may use BICSI 002 to guide the requirements they specify to outsource suppliers who provide computing services and server room IT operations.

1.2.1.4 Information Security

Information security personnel may use BICSI 002 as a guide in defining and implementing information protection and security and assisting in the development of standard policies and operating procedures.

1.2.2 Users Within Facilities Group

1.2.2.1 Technical Representatives Within Facilities Group Capital Projects

Facilities group technical representatives may use BICSI 002 as a guide during the project planning phase as they estimate costs, prepare preliminary design and construction schedules, and prepare requests for professional services (RFPS) for the design and construction of new or renovated IT facilities. Thus, after the method of project delivery is determined, BICSI 002 becomes a referenced document in the RFPS that the facilities group prepares and issues to architecture and engineering (A/E) and design-build (D/B) firms. These companies, in turn, bid on the design and construction of the IT facilities.

1.2.2.2 Facilities Management Representatives Within Facilities Group

Facilities operations and management may use BICSI 002 as a guide in planning the operation and maintenance of corporate IT facilities so that these facilities maintain defined levels of reliability and availability. For example, BICSI 002 provides guidance in defining training needs and maintenance schedules of critical equipment for operations and maintenance personnel.

1.2.3 Staff Outside IT and Facilities Groups

1.2.3.1 Physical Security Management

Security staff responsible for physical security management may use BICSI 002 as a guide in determining physical security and fire protection system requirements for IT facilities.

1.2.3.2 External Resources

1.2.3.2.1 Telecommunications Consulting Firms

BICSI 002 is useful to telecommunications consulting firms or design/build installation firms by providing guidance in the design and construction of IT facilities for the corporation.

1.2.3.2.2 A/E and Construction Firms

BICSI 002 is useful to A/E and construction firms to guide them in the process of design and construction of IT facilities. It provides a reference of common terminology and reliability topologies. It is not intended to be used by A/E and construction firms as their sole reference, and it is not meant to provide a step-by-step design guide for the A/E or D/B firms; however, it may be used by such persons to guide design requirements in conjunction with the data center owner, occupant, or consultant.

1.3 Categories of Criteria

Two categories of criteria are specified — mandatory and advisory:

- Mandatory criteria generally apply to protection, performance, administration and compatibility; they specify the absolute minimum acceptable requirements.
- Advisory or desirable criteria are presented when their attainment will enhance the general performance of the data center infrastructure in all its contemplated applications.

Mandatory requirements are designated by the word *shall*; advisory recommendations are designated by the words *should*, *may*, or *desirable*, which are used interchangeably in this standard. Where possible, requirements and recommendations were separated to aid in clarity.

Notes, cautions and warnings found in the text, tables, or figures are used for emphasis or for offering informative suggestions.

2 Scope

This standard provides best practices and implementation methods that complement TIA, CENELEC, ISO/IEC and other published data center standards and documents. It is primarily a design standard, with installation requirements and guidelines related to implementing a design. The standard includes other installation requirements and guidelines for data centers where appropriate.

3 Required Standards and Documents

The following standards and documents contain provisions that constitute requirements listed within this standard. Unless otherwise indicated, all standards and documents listed are the latest published version prior to the initial publication of this standard. Parties to agreement based on this standard are encouraged to investigate the possibility of applying a more recent version as applicable.

Where equivalent local codes and standards exist, requirements from these local specifications shall apply. Where reference is made to a requirement that exceeds minimum code requirements, the specification requirement shall take precedence over any apparent conflict with applicable codes.

Alliance for Telecommunication Industry Solutions (ATIS)

- ATIS 0600336, *Engineering Requirements for a Universal Telecommunications Framework*

American Society of Civil Engineers (ASCE)

- ASCE/SEI 7, *Minimum Design Loads for Buildings and Other Structures*

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

- ANSI/ASHRAE 62.1, *Ventilation for Acceptable Indoor Air Quality*
- *Best Practices for Datacom Facility Energy Efficiency*
- *Datacom Equipment Power Trends and Cooling Applications*
- *Design Considerations for Datacom Equipment Centers*
- *Particulate and Gaseous Contamination in Datacom Environments*
- *Structural and Vibration Guidelines for Datacom Equipment Centers*
- *Thermal Guidelines for Data Processing Environments*

ASTM International

- ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*

BICSI

- ANSI/BICSI 005, *Electronic Safety and Security (ESS) System Design and Implementation Best Practices*
- ANSI/BICSI 006, *Distributed Antenna System (DAS) Design and Implementation Best Practices*
- ANSI/BICSI 007, *Information Communication Technology Design and Implementation Practices for Intelligent Buildings and Premises*
- ANSI/BICSI 008, *Wireless Local Area Network (WLAN) Systems Design and Implementation Best Practices*

Electronic Components Industry Association (ECIA)

- EIA/ECA-310-E, *Cabinets, Racks, Panels, and Associated Equipment*

European Committee for Electrotechnical Standardization (CENELEC)

- CENELEC EN 50173-1, *Information technology – Generic cabling systems – Part 1: General requirements*
- CENELEC EN 50173-5, *Information technology – Generic cabling systems – Part 5: Data centres*
- CENELEC EN 50174-2, *Information technology – Cabling installation – Installation planning and practices inside buildings*

European Telecommunications Standards Institute (ETSI)

- ETSI EN 300-019, *Equipment Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment*

International Code Council (ICC)

- *International Building Code (IBC)*
- *International Fuel Gas Code (IFGC)*
- *International Mechanical Code (IMC)*
- *International Plumbing Code (IPC)*

Institute of Electrical and Electronics Engineers (IEEE)

- IEEE 142 (The IEEE Green Book), *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*
- IEEE 450, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Application*
- IEEE 484, *IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications*
- IEEE 1100 (The IEEE Emerald Book), *IEEE Recommended Practice for Powering and Grounding Electronic Equipment*
- IEEE 1106, *IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications*
- IEEE 1115, *IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications*
- IEEE 1184, *IEEE Guide for Batteries for Uninterruptible Power Supply Systems*
- IEEE 1187, *IEEE Recommend Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Batteries for Stationary Applications*
- IEEE 1188, *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications*
- IEEE 1189, *IEEE Guide for the Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications*
- IEEE 1491, *IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications*
- IEEE 1578, *IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management*

International Electrotechnical Commission (IEC)

- IEC 61280-4-1, *Fibre-optic communication subsystem test procedures - Part 4-1: Installed cable plant - Multimode attenuation measurement*
- IEC 61280-4-2, *Fibre optic communication subsystem basic test procedures - Part 4-2: Fibre optic cable plant - Single-mode fibre optic cable plant attenuation*
- IEC 61300-3-35, *Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-35: Examinations and measurements - Fibre optic connector endface visual and automated inspection*
- IEC 61935-1, *Specification for the testing of balanced and coaxial information technology cabling - Part 1: Installed balanced cabling as specified in ISO/IEC 11801 and related standards*
- IEC 62305-3, *Protection against lightning - Part 3: Physical damage to structures and life hazard*

International Organization for Standardization (ISO)

- ISO 7240, *Fire detection and alarm systems*
- ISO/IEC 11801-1, *Generic cabling for customer premises – Part 1: General requirements*
- ISO/IEC 11801-5, *Generic cabling for customer premises – Part 1: Data centres*
- ISO/IEC 11801-6, *Generic cabling for customer premises – Part 6: Distributed building services*
- ISO 14520, *Gaseous fire-extinguishing systems – Physical properties and system design*
- ISO/IEC 14763-2, *Information technology – Implementation and operation of customer premises cabling – Part 2: Planning and installation*
- ISO/IEC 14763-3, *Information technology – Implementation and operation of customer premises cabling – Part 3: Testing of optical fibre cabling*

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- ISO/IEC 18598, *Information technology – Automated infrastructure management (AIM) systems – Requirements, data exchange and applications*
- ISO/IEC 24764, *Information technology – Generic cabling systems for data centres*
- ISO/IEC 30129, *Information Technology – Telecommunications bonding networks for buildings and other structures*

National Electrical Contractors Association (NECA)

- ANSI/NECA/BICSI 607, *Telecommunications Bonding and Grounding Planning and Installation Methods for Commercial Buildings*

National Fire Protection Association (NFPA)

- NFPA 12, *Carbon Dioxide Fire Extinguishing Systems*
- NFPA 12A, *Halon 1301 Fire Extinguishing Systems*
- NFPA 13, *Standard for the Installation of Sprinkler Systems*
- NFPA 20, *Installation of Stationary Pumps for Fire Protection*
- NFPA 70®, *National Electrical Code® (NEC®)*
- NFPA 70E, *Standard for Electrical Safety in the Workplace*
- NFPA 72®, *National Fire Alarm and Signaling Code*
- NFPA 75, *Standard for the Protection of Information Technology Equipment*
- NFPA 76, *Recommended Practice for the Fire Protection of Telecommunications Facilities*
- NFPA 1600, *Standard on Disaster/Emergency Management Business Continuity Programs*
- NFPA 2001, *Standard on Clean Agent Fire Extinguishing Systems*
- *NFPA Fire Protection Handbook*

Telcordia

- Telcordia GR-63-CORE, *NEBS Requirements: Physical Protection*
- Telcordia GR-139, *Generic Requirements for Central Office Coaxial Cable*
- Telcordia GR-3028-CORE, *Thermal Management in Telecommunications Central Offices*

Telecommunications Industry Association (TIA)

- ANSI/TIA-568.0-D, *Generic Telecommunications Cabling for Customer Premises*
- ANSI/TIA-568.2-D, *Balanced Twisted-Pair Telecommunications Cabling and Components Standard*
- ANSI/TIA-568.3-D, *Optical Fiber Cabling Components Standard*
- ANSI/TIA-569-D, *Telecommunications Pathways and Spaces*
- ANSI/TIA-606-C, *Administration Standard for Telecommunications Infrastructure*
- ANSI/TIA-607-C, *Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises*
- ANSI/TIA-862-B, *Structured Cabling Infrastructure Standard for Intelligent Building Systems*
- ANSI/TIA-942-B, *Telecommunications Infrastructure Standard for Data Centers*
- ANSI/TIA-1152-A, *Requirements for Field Test Instruments and Measurements for Balanced Twisted-Pair Cabling*
- TIA TSB-155-A, *Guidelines for the Assessment and Mitigation of Installed Category 6 Cabling to Support 10GBASE-T*

Underwriters Laboratories (UL)

- ANSI/UL 497, *Standard for Safety Protectors for Paired-Conductor Communications Circuits*
- UL 723, *Standard for Test for Surface Burning Characteristics of Building Materials*
- UL 1449, *Surge Protective Devices*
- UL 60950-1, *Information Technology Equipment - Safety - Part 1: General Requirements*

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4 Definitions, Acronyms, Abbreviations, and Units of Measurement

4.1 Definitions

For the purposes of this document, the following terms and definitions apply. Some terms and definitions may also be represented by an acronym as listed in Section 4.2.

A-C-rated fire-retardant plywood	Plywood treated with a fire-retardant that has a well-finished A grade side that typically faces outward and a less finished C grade side that typically faces the wall.
abandoned cable	Installed cables that are not terminated at both ends at a connector or other equipment and not identified 'For Future Use' with a tag.
access block	A single access switch or group of switches sharing one trunk/uplink or set of redundant uplinks to the distribution layer. Generally confined to one telecommunications room (TR). In a large TR, it is possible to have more than one access block.
access floor	A system consisting of completely removable and interchangeable floor panels (tiles) that are supported on adjustable pedestals or stringers (or both) to allow access to the area beneath the floor (also known as raised floor).
access layer	The point at which local end users are allowed into the network. In a LAN environment, this connection point is typically a switched Ethernet port that is assigned to a VLAN.
access provider	The operator of any facility that is used to convey telecommunications signals to and from a customer premises.
adapter	A device that converts attributes of one device or system to those of an otherwise incompatible device or system. The use of an adaptor may allow actions such as (a) the connection of different sizes or types of plugs (b) the rearrangement of leads or segmentation of cables with numerous conductors into smaller group (c) interconnection between cables (d) connection of systems with differing voltage, polarity or waveform.
administration	The method for labeling, identification, documentation and usage needed to implement moves, additions and changes of the telecommunications infrastructure
alarm	An electrical, electronic, or mechanical signal that serves to warn of danger or abnormal condition by means of an audible sound or visual signal.
alien crosstalk	Unwanted coupling of signals into a balanced twisted-pair in a given cable from one or more balanced twisted-pair(s) external to the given cable.
alien far-end crosstalk	The unwanted signal coupling from a disturbing pair of a 4-pair channel, permanent link, or component to a disturbed pair of another 4-pair channel, permanent link or component, measured at the far end.
alien near-end crosstalk	Unwanted signal coupling from a disturbing pair of a 4-pair channel, permanent link, or component to a disturbed pair of another 4-pair channel, permanent link, or component, measured at the near end.
asset	Anything tangible or intangible that has value.
attenuation	The decrease in magnitude of transmission signal strength between points, expressed in units of decibels (dB) from the ratio of output to input signal level. See also *insertion loss*.
attenuation to crosstalk	Crosstalk measured at the opposite end from which the disturbing signal is transmitted normalized by the attenuation contribution of the cable or cabling.

automatic transfer switch	See *transfer switch, automatic*.
availability	The probability that a component or system is in a condition to perform its intended function, which is calculated as the ratio of the total time a system or component is functional within a specified time interval divided by the length of the specified time interval.
backboard	A panel (e.g., wood or metal) used for mounting connecting hardware and equipment.
backbone	(1) A facility (e.g., pathway, cable, conductors) between any of the following spaces: telecommunications rooms (TRs), common TRs, floor-serving terminals, entrance facilities, equipment rooms, and common equipment rooms. (2) In a data center, a facility (e.g., pathway, cable, conductors) between any of the following spaces entrance rooms or spaces, main distribution areas, horizontal distribution areas, and TRs.
backbone bonding conductor	A telecommunication bonding connection which interconnects telecommunications bonding backbones. NOTE: Formerly known as the grounding equalizer (GE)
backbone cable	See *backbone*.
battery backup unit	An energy storage device connected to an AC to DC power supply unit (PSU) or power shelf that serves as an uninterruptible power supply (UPS). Battery backup units are typically used within open rack configurations.
blanking panel (or filler panel)	(1) A panel that may be plastic or finished metal and is not integral to any discrete electronic component or system. (2) A barrier installed in information technology equipment cabinets, racks, or enclosures for maximizing segregation for optimized cooling effectiveness.
bonding	The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed.
bonding conductor (jumper)	A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.
bonding network	A set of interconnected conductive elements that provide functional equipotential bonding for telecommunications equipment
building commissioning	In the broadest sense, a process for achieving, verifying, and documenting that the performance of a building and its various systems meet design intent and the owner and occupants' operational needs. The process ideally extends through all phases of a project, from concept to occupancy and operations.
building systems	The architectural, mechanical, electrical, and control system along with their respective subsystems, equipment, and components.
built-in-place	A traditional construction method that may be employed for the data center space or supporting infrastructure. It can be extrapolated to also indicate hand-configured cabinets, networks and information technology equipment and systems. It is synonymous with the phrase stick built.
bundled cable	An assembly consisting of two or more cables, of the same or different types of cable media, continuously bound together to form a single unit. Bundled cable may be created by the original cable manufacturer, a third-party facility, or during installation. See also *hybrid cable.*

bus topology (1) Networking topology where each communications device or network has a single connection to a shared medium that serves as the communications channel. Also called a point-to-multipoint topology. (2) A linear configuration where all network devices are connected using a single length of cable. It requires one backbone cable to which all network devices are connected.

cabinet A container with a hinged cover that may enclose telecommunications connection devices, terminations, apparatus, wiring, and equipment.

cable (1) An assembly of one or more insulated conductors or optical fibers within an enveloping sheath. (2) An assembly of one or more cable units of the same type and category in an overall sheath. It may include overall screen. (3) The act of installing cable.

cable management Physical structures attached to, within, or between cabinets and racks to provide horizontal and vertical pathways for guiding and managing cabling infrastructure.

cable plant Cable, raceways, vaults, junction/pull boxes, racks, equipment, patch bays/blocks, and other infrastructure required to provide physical, electrical, optical connectivity between buildings of the owner or between buildings on the owner's property.

cable sheath A covering over the optical fiber or conductor assembly that may include one or more metallic members, strength members, or jackets.

cable tray A support mechanism used to route and support telecommunications and other cable. Cable trays may be equipped with side walls or barriers to constrain a cable's horizontal placement or movement.

cable tray system A cable tray unit or assembly of cable tray units or sections and associated fittings forming a rigid structural system used to securely fasten or support cables and raceway.

cabling A combination of all cables, jumpers, cords, and connecting hardware.

campus (1) The buildings and grounds having legal contiguous interconnection (e.g., college, university, industrial park, military installation). (2) A premise containing one or more buildings.

central office A building that functions as a network or telecommunication service provider's switching center. A central office typical serves a defined geographical area and utilizes outside plant cabling infrastructure to connect the central office to one or more customers. A central office may also be termed a *telco exchange* or *public exchange.*

centralized cabling A cabling configuration from the work area to a centralized cross-connect using pull through cables and an interconnect or splice in the telecommunications room.

change of state A change from the normal operating stance of a system, whether required by maintenance or a failure, resulting from an automatic or a manual response to some form of system input or response.

channel The end-to-end transmission path between two points at which application-specific equipment is connected.

Class An abbreviation of Data Center Facility Availability Class—the characteristic uptime performance of one component of the critical IT infrastructure. A quantitative measure of the total uptime needed in a facility without regard to the level of quality required in the IT functions carried on during that uptime. As used in this standard, it applies to scheduled uptime. Class is expressed in terms of one of five Data Center Facility Availability Classes. This classification reflects the interaction between the level of criticality and the availability of operation time.

clean agent An electrically nonconductive, volatile, or gaseous fire extinguishant that does not leave a residue upon evaporation.

clean agent fire suppression	A fire extinguishing system using a total flooding clean agent.
clear zone	An area separating an outdoor barrier from buildings or any form of natural or fabricated concealment.
client	(1) An internal or external customer. (2) A hardware or software entity, as in "client/server."
closed transition	A change of state or transfer where the electrical circuit connection is maintained during the transfer. This is also known as "make before break".
colocation	A data center, managed by a vendor, that provides one or more services (e.g., space, power, network connectivity, cooling, physical security) for the server, storage, and networking equipment of one or more customers. A colocation data center is often called a colo.
command center	A location where network and IT systems are managed and monitored. A command center is commonly referred to as a network operations center (NOC).
commissioning authority	The qualified person, company, or agency that plans, coordinates, and oversees the entire commissioning process. The Commissioning Authority may also be known as the commissioning agent.
commissioning plan	The document prepared for each project that describes all aspects of the commissioning process, including schedules, responsibilities, documentation requirements, and functional performance test requirements.
commissioning test plan	The document that details the prefunctional performance test, functional performance test, and the necessary information for carrying out the testing process for each system, piece of equipment, or energy efficiency measure.
common bonding network	The principal means for effecting bonding and grounding inside a telecommunication building. It is the set of metallic components that are intentionally or incidentally interconnected to form the principal bonding network (BN) in a building. These components include structural steel or reinforcing rods, plumbing, alternating current (AC) power conduit, AC equipment grounding conductors (ACEGs), cable racks, and bonding conductors. The CBN always has a mesh topology and is connected to the grounding electrode system.
common equipment room (telecommunications)	An enclosed space used for equipment and backbone interconnections for more than one tenant in a building or campus.
common grounding electrode	(1) An electrode in or at a building structure that is used to ground an AC system as well as equipment and conductor enclosures. (2) A single electrode connected to separate services, feeders, or branch circuits supplying a building. (3) Two or more grounding electrodes that are bonded together.
compartmentalization	The segregation of components, programs, and information. This provides isolation and protection from compromise, contamination, or unauthorized access.
component redundancy	A configuration designed into a system to increase the likelihood of continuous function despite the failure of a component. Component redundancy is achieved by designing and deploying a secondary component so that it replaces an associated primary component when the primary component fails.
computer room	An architectural space with the primary function of accommodating information technology equipment (ITE).
concurrently maintainable and operable	A configuration where system components may be removed from service for maintenance or may fail in a manner transparent to the load. There will be some form of state change, and redundancy will be lost while a component or system is out of commission. This is a prime requirement for a Class 3 facility.

conduit (1) A raceway of circular cross section. (2) A structure containing one or more ducts.

connecting hardware A device providing mechanical cable terminations.

connectivity Patch panels, cabling, connectors, and cable management used to create and maintain electrical and optical circuits.

consolidation point A location for interconnection between horizontal cables extending from building pathways and horizontal cables extending into furniture pathways.

construction manager An organization or individual assigned to manage the construction team and various contractors to build and test the building systems for the project.

containerized An information technology equipment (ITE) or infrastructure solution offered in a cargo shipping container, typically 12 m long by 2.4 m wide by 2.4 m high (40 ft by 8 ft by 8 ft). A container solution may offer combined electrical, mechanical and data center space as part of the solution or may offer space for a singular service (e.g., electrical or mechanical solutions).

cord A length of cable with connectors on one or both ends used to join equipment with cabling infrastructure (i.e., patch panel or cross-connect), a component of cabling infrastructure to another component of cabling infrastructure, or active equipment directly to active equipment.

core layer The high-speed switching backbone of the network. Its primary purpose is to allow the distribution layer access to critical enterprise computing resources by switching packets as fast as possible.

countermeasures The procedures, technologies, devices or organisms (e.g., dogs, humans) put into place to deter, delay or detect damage from a threat.

critical distribution board A power distribution board that feeds critical loads.

criticality The relative importance of a function or process as measured by the consequences of its failure or inability to function.

cross-connect A facility enabling the termination of cable elements and their interconnection or cross-connection.

cross-connection A connection scheme between cabling runs, subsystems, and equipment using patch cords or jumpers that attach to connecting hardware on each end.

dark fiber Unused installed optical fiber cable. When optical fiber cable is carrying a light signal, it is referred to as lit fiber.

data center A building or portion of a building with the primary function to house a computer room and its support areas.

data center infrastructure efficiency Typically expressed as *DCiE*, data center infrastructure efficiency is a metric for an entire data center, calculated as the reciprocal of power usage effectiveness (PUE), where 1/PUE = IT equipment power/Total facility power x 100%.

delay skew The difference in propagation delay between the pair with the highest and the pair with the lowest propagation delay value within the same cable sheath.

demarc See *demarcation point.*

demarcation point A point where the operational control or ownership changes, typically between the service provider and the customer.

design document The record that details the design intent.

design intent Design intent is a detailed technical description of the ideas, concepts, and criteria defined by the building owner to be important.

designation strips A type of label designated for insertion into a termination frame, comprised of paper or plastic strips, which are usually contained in a clear or color-tinted plastic carrier. Designation strips are usually imprinted with the adjacent terminal number and are used to aid in locating a specific pair, group of pairs, or information outlet or for delineating a termination field.

detection, (fire protection) The means of detecting the occurrence of heat, smoke or other particles or products of combustion.

distribution layer Collection of switches between the core and access layer. Distribution switches may be a switch and external router combination or a multilayer switch.

domain A portion of the naming hierarchy tree that refers to general groupings of networks based on organization type or geography.

double ended A power distribution switchboard with two power source inputs with an interposing tiebreaker between the sources where either input source of the switchboard can supply 100% of the load. The double-ended system constitutes an N + 1 or 2N system. This type of system may be used for dual utility systems or a single utility system split into redundant feeds and may possess the circuit breaker transfer system with the generator.

earthing See *grounding.*

electromagnetic interference Radiated or conducted electromagnetic energy that has an undesirable effect on electronic equipment or signal transmissions.

emergency systems Those systems legally required and classed as emergency by municipal, state, federal, or other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life.

energy efficiency measure Any equipment, system, or control strategy installed in a building for the purpose of reducing energy consumption and enhancing building performance.

entrance conduit Conduit that connects the outside underground infrastructure with the building's entrance room.

entrance facility (telecommunications) (1) An entrance to a building for both public and private network service cables (including wireless), including the entrance point of the building and continuing to the entrance room or space. (2) A facility that provides all necessary mechanical and electrical services for the entry of telecommunications cables into a building and that complies with all relevant regulations.

entrance point (telecommunications) The point of emergence for telecommunications cabling through an exterior wall, a floor, or from a conduit.

entrance room or space (telecommunications) A space in which the joining of inter or intra building telecommunications backbone facilities takes place. Examples include computer rooms and server rooms.

equipment cord See *cord*.

equipment distribution area The computer room space occupied by equipment cabinets or racks.

equipment grounding conductor The conductive path installed to connect normally non-current carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor or both.

equipment room (telecommunications) An environmentally controlled centralized space for telecommunications and data processing equipment with supporting communications connectivity infrastructure.

equipotential bonding	Properly designed and installed electrical connections(s) putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential, especially during normal (non-transient) conditions.
event	Typically, a message generated by a device for informational or error purposes.
failure mode	A system state resulting from an unanticipated system outage and typically an automatic system response to that failure.
Faraday cage	A metallic enclosure that is designed to prevent the entry or escape of electromagnetic fields. An ideal Faraday cage consists of an unbroken perfectly conducting shell. This ideal cannot be achieved in practice but it can be approached.
fault tolerant	The attribute of a concurrently maintainable and operable system or facility where redundancy is not lost during failure or maintenance mode of operation.
fiber management	Hardware designed and manufactured for keeping optical fiber patch cords neat and orderly. Most termination frame manufacturers provide optical fiber management components designed to work in conjunction with their termination frames. Fiber management may also refer to other types of hardware for securing optical fiber cable to the building.
fiber optic	See *optical fiber.*
fire	The presence of a flame.
fire detection	The means of detecting the occurrence of heat, smoke or other particles or products of combustion.
fire protection	The active means of detecting and suppressing fires.
fire suppression	The means of extinguishing an active fire.
flexibility	A design's ability to anticipate future changes in space, communications, power density, or heat rejection and to respond to these changes without affecting the mission of the critical IT functions.
frame	A special purpose equipment mounting structure (e.g., IDC blocks, fiber termination hardware not meant to be mounted in standard 19 inch or 23-inch racks).
functional performance test	The full range of checks and tests carried out to determine whether all components, subsystems, systems, and interfaces between systems function in accordance with the design documents.
ground	A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or to some conducting body that serves in place of earth.
ground fault circuit interrupter	A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds the established value.
grounding	The act of creating a ground.
grounding conductor	A conductor used to connect the grounding electrode to the building's main grounding busbar.
grounding electrode	A conducting object through which a direct connection to earth is established.
grounding electrode conductor	The conductor used to connect the grounding electrode to the equipment grounding conductor or to the grounded conductor of the circuit at the service equipment or at the source of a separately derived system.
grounding electrode system	One or more grounding electrodes that are connected together.
hanging load	The weight that can be suspended from the underside of the floor or structure above.
hardening	Protection from physical forces, security breaches, and natural disasters.

heat (fire protection)	The existence of temperatures significantly above normal ambient temperatures.
high resistance/impedance grounding system	A type of impedance grounded neutral system in which a grounding impedance, usually a resistor, limits the ground-fault current.
higher Class	Within this standard, a higher Class data center is a data center that meets the requirements of either Class 3 or Class 4.
horizontal cabling	(1) The cabling between and including the telecommunications outlet/connector and the horizontal cross-connect. (2) The cabling between and including the building automation system outlet or the first mechanical termination of the horizontal connection point and the horizontal cross-connect. (3) Within a data center, horizontal cabling is the cabling from the horizontal cross-connect (in the main distribution area or horizontal distribution area) to the outlet in the equipment distribution area or zone distribution area.
horizontal cross-connect	A cross-connect of horizontal cabling to other cabling (e.g., horizontal, backbone, equipment).
horizontal distribution area	A space in a computer room where a horizontal cross-connect is located and may include LAN switches, SAN switches, and keyboard/video/mouse (KVM) switches for the equipment located in the equipment distribution areas.
hot spot	A temperature reading taken at the air intake point of equipment mounted in a cabinet or rack in excess of the design standard or equipment requirement.
human events	Man-made incidents, including economic, general strike, terrorism (e.g., ecological, cyber, nuclear, biological, chemical), sabotage, hostage situation, civil unrest, enemy attack, arson, mass hysteria, accidental and special events.
hybrid cable	A manufactured assembly of two or more cables of the same or differing types of media, categories designation, covered by one overall sheath. See also *bundled cable.*
identifier	An unique item of information that links a specific element of the telecommunications infrastructure with its corresponding record.
impact of downtime	One of three characteristics used to determine the performance requirements and associated redundancy of the critical systems within a data center. The impact of downtime characteristic integrates the multiple effects that a disruption in computer processing services has on an organization's ability to achieve its objectives. See also *operational level* and *operational availability*.
incipient	The early or beginning stage of a fire where combustion particulates may be emitted from materials developing inherently high heat, but no smoke is visible and are low in density and below the level of detection capabilities of conventional smoke detectors.
inductive/reactance-grounded power system	A method of grounding in which the system is grounded through impedance, the principle element of which is inductive reactance.
information technology equipment	Electronic equipment used for the creation, processing, storage, organization, manipulation and retrieval of electronic data.
information technology equipment power	The power consumed by ITE to manage, monitor, control, process, store, or route data within the data center, excluding all infrastructure equipment.
infrastructure (telecommunications)	A collection of those telecommunications components, excluding equipment, that together provides the basic support for the distribution of all information within a building or campus.
input source transfer	The function of and the location in the electrical system where the transfer occurs between two sources.

insertion loss The signal loss resulting from the insertion of a component or link between a transmitter and receiver. Insertion loss is often referred to as attenuation.

inside plant Communication systems inside a building (e.g., wire, optical fiber, coaxial cable, equipment racks, and information outlets). Telecommunications companies refer to this as inside wire or intrafacility cabling.

interconnection (1) A connection scheme that employs connecting hardware for the direct connection of a cable to another cable without a patch cord or jumper. (2) A type of connection in which single port equipment connections (e.g., 4-pair and optical fiber connectors) attach to horizontal or backbone cabling by means of patch cords or jumpers.

intermediate cross-connect A cross-connect between first level and second level backbone cabling. Also referred to as the horizontal cross-connect (HC).

intersystem bonding conductor A conductor used to connect grounding systems for diverse (e.g., electrical, telecommunications) or multiple electrical services to a common building grounding electrode system (e.g., building ground [electrode] ring).

isolated bonding network Typically expressed as IBN, an isolated bonding network is a bonding and grounding subsystem in which all associated equipment cabinets, frames, racks, cable trays, pathways and supplementary bonding grids designated to be within that IBN are bonded together at a single point of connection (SPC). The SPC is also bonded to either the common bonding network (CBN) or another IBN. All IBNs have a connection to ground through the SPC.

isolation A design strategy that mitigates the risk of concurrent damage to some components in a facility using physical, logical, or system separation.

jumper (1) An assembly of twisted pairs without connectors used to join telecommunications circuits/links at the cross-connect. (2) A length of optical fiber cable with a connector plug on each end. (3) A length of twisted-pair or coaxial cable with connectors attached to each end, also called a patch cord.

label A piece of paper or other material that is fastened to something and gives predefined information about it. Describes its identity, path, location, or other important information about the product or material.

ladder rack A cable tray with side stringers and cross members, resembling a ladder, which may support cable either horizontally or vertically.

layering In security, the use of many layers of barriers, other countermeasures, or a mixture of both used to provide the maximum level of deterrence and delay to intruders.

link A transmission path between two points, not including equipment and cords.

linkage A connection between a record and an identifier or between records in a database.

Listed Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction (AHJ), maintaining periodic inspection of production of listed equipment or materials or periodic evaluation of services and whose listing states either the equipment, material, or services meets appropriate standards or has been tested and found suitable for use in a specified manner

load bank A device to simulate actual equipment consisting of groups of resistive and reactive elements, fans, and controls. The load bank is an electrical load that is connected to power distribution unit (PDU) systems, uninterruptible power supply (UPS) systems or generators in load test situations.

local distribution point	A connection point within the zone distribution cabling subsystem between a zone distributor and an equipment outlet as described in CENELEC EN 50173-5 and ISO/IEC 24764. An LDP is equivalent to the consolidation point (CP) in a zone distribution area (ZDA) as described ANSI/TIA-942-B.
luminaire	An electric light and its components; an electrical lighting fixture.
M13 multiplexer	Consolidates T-1 and E-1 signals into a T-3 or E-3 circuit. A cost-effective device for combining independent T-1s, E-1s, or a combination of the two over the same T-3 or E-3 circuit.
main cross-connect	A cross-connect for first level backbone cables, entrance cables, and equipment cords.
main distribution area	The space in a computer room where the main cross-connect is located.
main distributor	A distributor used to make connections between the main distribution cabling subsystem, network access cabling subsystem, cabling subsystems and active equipment. Equivalent to the main cross-connect.
main electrical grounding busbar	The busbar within the building at which electrical service grounding electrode conductor(s) and other grounding and bonding conductors are interconnected to establish the main equipotential location for the building.
maintenance mode	A system state resulting from an anticipated system outage or routine maintenance activity and typically a manual system response to that activity.
management information base	Within the simple network management protocol (SNMP), defines objects and attributes to be managed.
manual transfer switch	See *transfer switch, non-automatic.*
mechanical room	An enclosed space, which serves the needs of mechanical building systems.
media (telecommunications)	Wire, cable, or conductors used for telecommunications.
medium voltage	Any electrical voltage above the normal utilized value and below transmission-level system voltages. The utilization voltage varies from country to country. In the United States, medium voltage is considered to be between 1001 V and 35,000 V, whereas in the European Union and other parts of the world, the utilization voltage level can be significantly higher than in the United States.
meet me room	A place within a colocation data center where telecommunications service providers can physically connect to each other and where customers in the data center can connect to the telecommunications service providers. The meet me rooms may be the same or different rooms as the telecommunications entrance rooms.
mesh bonding network	A non-insolated bonding network to which all associated equipment cabinets, frames racks, cable trays, and pathways are connected by using a bonding grid. This grid is connected at multiple points to the common bonding network.
mission critical	Any operation, activity, process, equipment, or facility that is essential to continuous operation for reasons of business continuity, personnel safety, security, or emergency management.
modular	As applied to a data center, a factory-built or pre-fabricated data center space, infrastructure or combination of data center space and infrastructure that is constructed away from the actual data center site and is delivered as a complete solution. A modular data center may utilize or require some final site assembly or fabrication.

modular jack The receptacle ("female") element of a telecommunications connector that may be keyed or unkeyed, typically has six or eight contact positions, of which not all the positions need to be equipped with contacts.

NOTE: The element inserted into a modular jack is named a modular plug.

module The incremental development size of a storage or computer node, electrical or mechanical system, or data center area.

multimode optical fiber An optical fiber that carries many paths (modes) of light.

natural barrier Any object of nature that impedes or prevents access, including mountains, bodies of water, deserts, and swamps.

natural events Natural disasters, including drought, fire, avalanche, snow/ice/hail, tsunami, windstorm/tropical storm, hurricane/typhoon/cyclone, biological, extreme heat/cold, flood/wind-driven water, earthquake/land shift, volcanic eruption, tornado, landslide/mudslide, dust/sand storm, and lightning storm.

near-end crosstalk (1) The unwanted signal coupling between pairs. It is measured at the end of a cable nearest the point of transmission. (Contrast with far-end crosstalk, which is measured at the end farthest from point of transmission). (2) The signal transfer between circuits at the same (near) end of the cable.

network operation center See *command center*.

normal mode The steady-state system configuration while under load.

open rack A rack that has the following characteristics: 1) two busbars in the rear of the rack that supply power to mounted equipment, 2) a width that allows the mounting of 528 mm (21 inch) wide equipment, 3) a larger vertical spacing of 48 mm (1.89 in) for equipment, termed an open rack unit or OU, and 4) cable connections are accessed from the front of the rack.

NOTE: Open racks typically do not conform to the specifications of EIA/ECA-310-E.

open transition A change of state or transfer where the electrical circuit connection is not maintained during the transfer. This is also known as "break before make".

operational availability One of three characteristics used to determine the performance requirements and associated redundancy of the critical systems within a data center. The operational availability integrates the multiple effects of an organization's expected uptime of the computer processing systems during normal operations. See also *operational level* and *impact of downtime*.

operational level One of three characteristics used to determine the performance requirements and associated redundancy of the critical systems within a data center. The operational level integrates the multiple effects of an organization's ability, or inability, to suspend all computer processing operations for planned maintenance. See also *impact of downtime* and *operational availability*.

optical fiber Any filament made of dielectric materials that guides light.

optical fiber cable An assembly consisting of one or more optical fibers.

outside plant Communications system outside of the buildings (typically underground conduit and vaults, exterior/underground, aerial, and buried rated wire and cable).

panelboard (electrical) A single panel, or groups of panel units, designed for assembly in the form of a single panel, including buses and automatic overcurrent devices such as fuses or molded-case circuit breakers, accessible only from the front.

passive damper An unpowered device that is utilized in structures to mitigate the effects of vibration due to seismic or wind loading.

patch cord See *cord*.

patch panel A connecting hardware system that facilitates cable termination and cabling administration using patch cords.

pathway A facility for the placement of telecommunications cable.

performance test A series of tests for specified equipment or systems, which determines that the systems are installed correctly, started and are prepared for the functional performance tests. Often these tests are in a checklist format.

performance verification The process of determining the ability of the system to function according to the design intent.

permanent link (1) The permanently installed portion of horizontal cabling, excluding cords (e.g., test, equipment, patch). (2) A test configuration for a link excluding test cords and patch cords.

plenum A compartment or chamber that forms part of the air distribution system.

power distribution unit Typically expressed as PDU, this is a floor- or rack-mounted enclosure for distributing branch circuit electrical power via cables, either overhead or under an access floor, to multiple racks or enclosures of information technology equipment (ITE). A PDU includes one or more distribution panelboards and can include a transformer, monitoring, and controls. PDUs may also be called a computer power center or a power distribution center.

power strip A device mounted onto or within an information technology equipment (ITE) rack or enclosure, supplied by a single branch circuit, and containing power receptacles into which multiple IT devices can be plugged. A power strip can include metering, controls, circuit protection, filtering, and surge suppression. A power strip is identified within IEEE 1100 as a power outlet unit or POU. A power strip may also be called a rack-mount PDU, rack power distribution unit, ITE-PDU, cabinet distribution unit, or plug strip.

power sum alien far-end crosstalk The power sum of the unwanted signal coupling from multiple disturbing pairs of one or more 4-pair channels, permanent links, or components to a disturbed pair of another 4-pair channel, permanent link, or component measured at the far end.

power sum alien near-end crosstalk The power sum of the unwanted signal coupling from multiple disturbing pairs of one or more 4-pair channels, permanent links, or components to a disturbed pair of another 4-pair channel, permanent link, or component measured at the near end.

power sum attenuation to alien crosstalk ratio at the far end The difference in dB between the power sum alien far-end crosstalk (PSAFEXT) from multiple disturbing pairs of one or more 4-pair channels, permanent links, or components and the insertion loss of a disturbed pair in another 4-pair channel, permanent link, or component.

power sum attenuation to crosstalk ratio, far-end A computation of the unwanted signal coupling from multiple transmitters at the near end into a pair measured at the far end and normalized to the received signal level.

power sum near-end crosstalk A computation of the unwanted signal coupling from multiple transmitters at the near end into a pair measured at the near end.

power usage effectiveness Typically expressed as PUE, power usage effectiveness is an efficiency metric for an entire data center calculated as the total facility power usage divided by the information technology equipment power usage. PUE is the reciprocal of data center infrastructure efficiency (DCiE).

primary bonding busbar A busbar placed in a convenient and accessible location and bonded by means of the telecommunications bonding conductor to the building service equipment (power) ground.

NOTE: Formerly known as a telecommunications main grounding busbar (PBB)

primary side	The high-voltage side of the electrical power service transformer (above 600V), the electrical power service line side of the UPS, and the electrical power service line side of the PDU transformer or the input side of the static switch.
private branch exchange	A private telecommunications switching system allowing private local voice (and other voice-related services) switching over a network.
propagation delay	The time required for a signal to travel from one end of the transmission path to the other end.
protected circuit	A communication circuit in which a second path automatically activates when the primary path fails.
psychological barrier	A device, obstacle or lack of obstacle that by its presence alone discourages unauthorized access or penetration.
pull box	A housing located in a closed raceway used to facilitate the placing of wire or cables.
quality control	One of the four major strategies for increasing reliability by ensuring that high quality is designed and implemented in the facility, thus reducing the risk of downtime because of new installation failures or premature wear.
raceway	An enclosed channel of metal or nonmetallic materials designed expressly for holding wires or cables. Raceways include, but are not limited to: rigid metal conduit, rigid nonmetallic conduit, rigid nonmetallic conduit, intermediate metal conduit, liquid tight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways. NOTE: Cable tray is not considered a type of raceway.
rack	An open structure for mounting electrical and electronic equipment.
rack unit	The modular unit on which panel heights are based. One rack unit is 45 mm (1.75 in) and is expressed in units of U or RU
radio frequency interference	Electromagnetic interference within the frequency band for radio transmission.
raised floor	See *access floor.*
record	A collection of detailed information related to a specific element of the infrastructure.
record drawing	A plan, on paper or electronically, that graphically documents and illustrates the installed infrastructure in a building or portion thereof. Also known as an as-built drawing.
redundancy	Providing secondary components that either become instantly operational or are continuously operational so that the failure of a primary component will not result in mission failure. See also *component redundancy*.
reliability	The probability that a component or system will perform as intended over a given time period.
remote power panel	A power distribution cabinet downstream from a PDU or UPS, typically containing circuits and breakers, without a transformer, located near the load. A remote power panel may be referred to as a RPP, power distribution panel, or PDP.
report	Presentation of a collection of information from various records.
resistively grounded power system	A method of grounding in which the system is grounded through impedance, the principle element of which is resistance.

return loss A ratio, expressed in dB, of the power of the outgoing signal to the power of the reflected signal. When the termination (load) impedance does not match (equal) the value of the characteristic impedance of the transmission line, some of the signal energy is reflected back toward the source and is not delivered to the load; this signal loss contributes to the insertion loss of the transmission path and is called return loss.

return on investment The ratio of money gained or lost on an investment relative to the amount of money invested.

ring topology A physical or logical network topology in which nodes are connected in a point-to-point serial fashion in an unbroken circular configuration. Each node receives and retransmits the signal to the next node.

riser (1) Vertical sections of cable (e.g., changing from underground or direct-buried plant to aerial plant). (2) The space used for cable access between floors.

riser cable Communications cable that is used to implement backbones located on the same or different floors.

risk The likelihood that a threat agent will exploit a vulnerability, creating physical or technological damage.

risk management The process of identifying risks and developing the strategy and tactics needed to eliminate, mitigate, or manage them.

scan Within local area networks, a nonintrusive analysis technique that identifies the open ports found on each live network device and collects the associated port banners found as each port is scanned. Each port banner is compared against a table of rules to identify the network device, its operating system, and all potential vulnerabilities.

screen A thin metallic wrapping (e.g., aluminum foil) used to isolate cable pairs from interference.

screened twisted-pair cable A balanced twisted-pair cable with one or more pairs of individual unscreened balanced twisted-pairs having an overall foil screen shield and may contain a drain wire. The entire assembly is covered with an insulating sheath (cable jacket). It may also be called *foil twisted-pair cable*.

secondary side The low-voltage side of the electrical power service transformer, the load side of the UPS, the load side of the PDU transformer, or the output side of the static switch.

seismic snubber Mechanical devices, when anchored to the building structure and placed around vibration-isolated equipment, are intended to limit motion by containing the supported equipment. Snubbers are designed for use in locations subject to earthquakes, high winds, or other external forces that could displace resiliently supported equipment.

separately derived system A premise wiring system in which power is derived from a source of electric energy or equipment other than a service. Such systems have no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

service gallery Space adjacent to a computer room where electrical and mechanical equipment that supports the computer room may be located.

service provider The operator of any service that furnishes telecommunications content (transmissions) delivered over access provider facilities.

sheath See *cable sheath*.

shield A metallic sheath (usually copper or aluminum) applied over the insulation of a conductor or conductors for the purpose of providing means for reducing electrostatic coupling between the conductors.

shielded twisted-pair cable Cable made up of balanced metallic conductor pairs, each pair with an individual shield. The entire structure is then covered with an overall shield or braid and an insulating sheath (cable jacket).

simplicity The application of irreducible functionality to achieve the intended goal with the corresponding understanding that complexity introduces additional risk.

single-mode optical fiber An optical fiber that carries only one path (mode) of light.

smoke Visible products of combustion prior to and concurrent with a fire.

solidly grounded Connected to ground without inserting any resistor or impedance device.

space (telecommunications) An area whose primary function is to house the installation and termination of telecommunications equipment and cable (e.g., MDA, IDA, HDA, TR, entrance room).

splice A joining of conductors, which is meant to be permanent.

star topology (telecommunications cabling) A topology in which telecommunications cables are distributed from a central point.

static switch See *transfer switch, static.*

storage area network A high-speed network of shared storage devices. A SAN permits storage devices attached to the SAN to be used by servers attached to the SAN.

structural barrier Defined as something that physically deters or prevents unauthorized access, movement, destruction, or removal of data center assets.

supervisory control and data acquisition system A control system composed of programmable logic controllers (PLCs), data input to the PLCs, custom software, and electrically operated circuit breakers in the distribution gear. All these combine to form a unique system that allows automatic operation and monitoring of the electrical system through control panel workstations.

supplementary bonding grid A set of conductors or conductive elements formed into a grid or provided as a conductive plate and becomes part of the bonding network to which it is intentionally attached.

• **surge protection device** A protective device for limiting transient voltages by diverting or limiting surge current. It has a nonlinear voltage-current characteristic that reduces voltages exceeding the normal safe system levels by a rapid increase in conducted current.

NOTE**:** A surge protection device may also be known as a voltage limiter, overvoltage protector, (surge) arrestor, or transient voltage surge suppressor (TVSS).

switch (device) (1) A device designed to close, open, or both one or more electrical circuits. (2) A mechanical device capable of opening and closing rated electrical current. (3) A device for making, breaking, or changing the connections in an electric circuit. (4) An electronic device connected between two data lines that can change state between open and closed based upon a digital variable.

NOTE**:** A switch may be operated by manual, mechanical, hydraulic, thermal, barometric, or gravitational means or by electromechanical means not falling with the definition of *relay*.

switch (equipment) A voice communications device that uses switching technology to establish and terminate calls.

switch (network) A network access device that provides a centralized point for LAN communications, media connections, and management activities where each switch port represents a separate communications channel.

switchboard A single-panel frame or assembly of panels, typically accessed from the front, containing electrical disconnects, fuses, and circuit breakers used to isolate electrical equipment. Switchboards are typically rated 400 A to 5,000 A and are characterized by fixed, group-mounted, molded case, or insulated case circuit breakers, but they may include draw-out circuit breakers and usually require work on de-energized equipment only.

switchgear An electrical enclosure, typically having both front and rear access, containing overcurrent protective devices, such as fuses and circuit breakers, used to isolate electrical equipment. Switchgear is typically rated 800 A to 5,000 A and is characterized by segregated, insulated-case, or low-voltage power circuit breakers, usually draw-out, and frequently contains monitoring and controls as well as features to permit addition or removal of switching devices on an energized bus.

switching (1) The action of opening or closing one or more electrical circuits. (2) The action of changing state between open and closed in data circuits. (3) A networking protocol in which a station sends a message to a hub switch, which then routes the message to the specified destination station.

system redundancy A strategy for increasing reliability by providing redundancy at the system level.

targeted availability A positive expression of allowable maximum annual downtime

technological events Technological incidents, including hazardous material release, explosion/fire, transportation accident, building/structural collapse, power/utility failure, extreme air pollution, radiological accident, dam/levee failure, fuel/resource shortage, strike, business interruption, financial collapse, and communication failure.

telecommunications Any transmission, emission, and reception of information (e.g., signs, signals, writings, images, sounds) by cable, radio, optical, or other electromagnetic systems.

telecommunications bonding backbone A conductor that interconnects the primary bonding busbar (PBB) to the secondary bonding busbar (SBB).

telecommunications bonding conductor A conductor that interconnects the telecommunications bonding infrastructure to the building's service equipment (power) ground.

NOTE: Formerly known as a bonding conductor for telecommunications (BCT)

telecommunications entrance point See *entrance point (telecommunications).*

telecommunications entrance room or space See *entrance room or space (telecommunications).*

telecommunications equipment room See *equipment room (telecommunications).*

telecommunications infrastructure See *infrastructure (telecommunications).*

telecommunications media See *media (telecommunications).*

telecommunications room A telecommunications space that differs from equipment rooms and entrance facilities in that this space is generally considered a floor-serving or tenant-serving (as opposed to building- or campus-serving) space that provides a connection point between backbone and horizontal cabling.

telecommunications space See *space (telecommunications).*

termination The physical connection of a conductor to connecting hardware.

test procedures The detailed, sequential steps to set the procedures and conditions necessary to test the system functionality.

threats — The agents by which damage, injury, loss, or death can occur. Threats are commonly classified as originating from temperature extremes, liquids, gases, projectiles, organisms, movement, or energy anomalies. See also vulnerability.

topology — The physical or logical arrangement of a system.

total facility power — The power dedicated solely to the data center, including all infrastructure equipment that supports the information technology equipment (ITE) such as power delivery components, cooling and environmental control system components, computer network and storage nodes, and miscellaneous other components necessary for the operation of the data center.

transfer switch, automatic — Self-acting equipment that transfers a load from one power source to an alternate power source through the use of electrically operated mechanical moving components, (e.g., switch, breaker).

NOTE: Automatic transfer switches with open transition transfer times exceeding 20 milliseconds will result in a reboot or restart cycle of any loads with electronics or controls utilizing switch-mode power supplies. Automatic transfer switches with open transition transfer times of 16 milliseconds or less will not result in a reboot or restart cycle of any loads with electronics or controls utilizing switch-mode power supplies.

transfer switch, non-automatic — Equipment that enables an operator to transfer a load from one power source to an alternate power source through the use of manually operated mechanical moving components (e.g., switch or breaker).

NOTE**:** The transfer time consists of an open transition greater than 20 milliseconds, which results in a reboot or restart cycle of any loads with electronics or controls (also commonly referred to as manual transfer switch).

transfer switch, static — Self-acting equipment that transfers a load from one power source to an alternate power source through the use of semiconductors devices (e.g., silicon controlled rectifiers).

NOTE**:** Because there are no mechanical moving components the transfer time is typically less than 6 milliseconds, which will not result in a reboot or restart cycle of any loads with electronics or controls that utilize switch-mode power supplies.

tree topology — A LAN topology that has only one route between any two nodes on the network. The pattern of connections resembles a tree or the letter “T”.

trunk cables — Cables bundled together to form a single unit.

trunk cabling assemblies — A type of bundled cable consisting of two or more preconnectorized cabling links of the same or different types cabling media, which may either be covered by one overall sheath or be continuously bound together to form a single unit.

trunking — (1) A combination of equipment, software and protocols that allows many clients to share relatively few telecommunications channels as opposed to each channel being dedicated to an individual client. In radio systems, the channels are frequencies and repeaters. In wireline systems, the channels are copper wire pairs or fiber optic strands. Trunking greatly expands the efficiency of resource usage, making limited resources (channels) available to many more clients. (2) In networking protocols, combining (multiplexing) frames from multiple VLANs across a single physical link (trunk) by using an encapsulation protocol such as IEEE 802.1Q. The protocol modifies the frame to identify the originating VLAN before the frame is placed on the trunk. The reverse process occurs at the receiving end of the trunk.

uninterruptible power supply — A system that provides a continuous supply of power to a load, utilizing stored energy when the normal source of energy is not available or is of unacceptable quality. A UPS will provide power until the stored energy of the system has been depleted or an alternative or the normal source of power of acceptable quality becomes available.

uninterruptible power supply, rotary — A UPS consisting of a prime mover (such as an electric motor), a rotating power source (such as an alternator), a stored energy source (such as a battery), associated controls and protective devices, and a means of replenishing the stored energy (such as a rectifier/charger).

uninterruptible power supply, static — A UPS consisting of nonmoving (solid state) components, usually consisting of a rectifier component, an inverter component, a stored energy component, associated controls and protective devices.

unshielded twisted-pair — A balanced transmission medium consisting of a pair of electrical conductors twisted to provide a level of immunity to outside electrical interference without the use of metallic shielding. Typical construction has four such pairs of conductors contained with a common outer sheath.

uplink — Referring to data processing, a connection between layers (switches) in a hierarchical network. Uplinks are usually optical fiber links configured on Gigabit Ethernet (GbE) ports. (Fast Ethernet uplinks can also be configured using optical fiber or balanced twisted-pair cabling). An uplink can be referred to as a trunk.

uptime — The period of time, usually expressed as a percentage of a year, in which the information technology equipment (ITE) is operational and able to fulfill its mission.

validation — The establishment of documented evidence that will provide a high degree of assurance the system will consistently perform according to the design intent.

verification — The implementation and review of the tests performed to determine if the systems and the interface between systems operates according to the design intent.

virtual local area network — A networking protocol that allows the overlay of logical topologies onto a separate physical topology. VLANs provide traffic separation and logical network partitioning. A VLAN forms a broadcast domain and, to communicate between VLANs, a routing function is required.

vulnerability — A physical, procedural, or technical weakness that creates an opportunity for injury, death, or loss of an asset. See also threats.

wire — An individual solid or stranded metallic conductor.

wire management — See *cable management.*

wireless — The use of radiated electromagnetic energy (e.g., radio frequency and microwave signals, light) traveling through free space to convey information.

X-O bond — The point in the electrical system where a separately derived ground is generated. This point generates a power carrying neutral conductor or 4th wire for the electrical power system. The X-O bond point is typically used as the ground reference for the downstream power system.

XaaS — A generic representation of services provided by external vendors and data centers. Examples of usages include Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

zero U space — A space for mounting accessories in cabinets that does not consume any rack mount spaces, typically between the side panel and the sides of equipment mounted in the rack unit mounting space.

zone distribution area — A space in a computer room where a zone outlet or a consolidation point is located.

zone distributor — Distributor used to make connections between the main distribution cabling subsystem, zone distribution cabling subsystem, network access cabling subsystem, and cabling subsystems specified in ISO/IEC 11801-5 or EN 50173-1 and active equipment (CENELEC EN 50173-5 and ISO/IEC 24764). Equivalent to the horizontal cross-connect (HC) in ANSI/TIA-942-B.

zone outlet A connecting device in the zone distribution area terminating the horizontal cable enabling equipment cord connections to the equipment distribution area.

4.2 Acronyms and Abbreviations

Abbreviations and acronyms, other than in common usage, are defined as follows:

24/7	twenty-four hours a day, seven days a week
A/E	architectural/engineering
AC	alternating current
ACEG	alternating current equipment grounding conductor
ACRF	attenuation to crosstalk ratio, far-end
ACS	access control system
ADA	Americans with Disability Act
AFEXT	alien far-end crosstalk
AHJ	authority having jurisdiction
AHU	air handling unit
AISS	automated information storage system
ANEXT	alien near-end crosstalk
APC	angle physical connector; angle polished connector
ASTS	automatic static transfer switch
ATM	asynchronous transfer mode
ATS	automatic transfer switch
AWG	American wire gauge
BAS	building automation system
BBU	battery backup unit
BMS	building management system
BN	bonding network
BNC	Bayonet Neill-Concelman
CATV	community antenna television
CBN	common bonding network
CBRNE	chemical, biological, radiological, nuclear, or explosive
CD	construction document
CFD	computational fluid dynamics
CM	construction management
CO	central office
CP	consolidation point; critical power
CPE	customer premises equipment
CPU	central processing unit
CPVC	chlorinated polyvinyl chloride
CRAC	computer room air conditioner; computer room air conditioning
CRAH	computer room air handler; computer room air handling
DC	direct current
DCEG	direct current equipment grounding conductor
DCiE	data center infrastructure efficiency
DCIM	data center infrastructure management
DP	data processing; distribution panel
DS-1	digital signal level 1
DS-3	digital signal level 3
DSX	digital signal cross-connect
DWDM	dense wave division multiplexer
E-1	European trunk level 1
E-3	European trunk level 3
EAC	electronic access control
EAP	electronic asset program
EDA	equipment distribution area
EGC	equipment grounding conductor
EGS	equipment grounding system
EMD	equilibrium mode distribution
EMI	electromagnetic interference
EMS	energy management system
EO	equipment outlet
EPMS	electrical power management system
EPO	emergency power off
ESCON	enterprise system connection
ESD	electrostatic discharge
ESS	electronic safety and security
EU	European Union
F/UTP	foil screened unshielded twisted-pair
FDDI	fiber distributed data interface
FE	Fast Ethernet
FICON	fiber connection
GbE	Gigabit Ethernet
GEC	grounding electrode conductor
GES	grounding electrode system
GFCI	ground fault circuit interrupter
GUI	graphical user interface
HC	horizontal cross-connect
HCP	horizontal connection point
HDA	horizontal distribution area
HEPA	high-efficiency particulate air

HMI	human machine interface
HR	human resources
HVAC	heating, ventilating, and air conditioning
IBN	isolated bonding network
IC	intermediate cross-connect
IDC	insulation displacement contact
IIM	intelligent infrastructure management
ISDN	integrated services digital network
ISP	inside plant
IT	information technology
ITE	information technology equipment
KVM	keyboard/video/mouse
LAN	local area network
LDP	local distribution point
LED	light-emitting diode
LPS	lightning protection system
LSZH	low smoke zero halogen
MC	main cross-connect
MD	main distributor
MDA	main distribution area
MDF	main distribution frame
MEGB	main electrical grounding busbar
MERV	minimum efficiency reporting value
mesh-BN	mesh-bonding network
MIB	management information base
MMR	meet me room
MPLS	multiprotocol label switching
MTBF	mean time between failures
MTTR	mean time to repair
NC	noise criterion
NEBS	network equipment building system
NEC®	*National Electrical Code®*
NEXT	near-end crosstalk
Ni-Cd	nickel-cadmium
NRTL	nationally recognized testing laboratory
O&M	operation and maintenance
OC	optical carrier
OCP	Open Compute Project

NOTE: OCP is a registered trademark of the Open Compute Project Foundation and is used with permission.

OLTS	optical loss test set
OSP	outside plant
OTDR	optical time domain reflectometer
PBB	primary bonding busbar
PBX	private branch exchange
PC	personal computer
PD	propagation delay
PDU	power distribution unit
PLC	programmable logic controller
PM	preventive maintenance
PoE	power over Ethernet
POU	power outlet unit
PPE	personnel protection equipment
PQM	power quality monitoring
PSAACRF	power sum attenuation to alien crosstalk ratio at the far end
PSACRF	power sum attenuation to crosstalk ratio, far-end
PSAFEXT	power sum alien far-end crosstalk
PSANEXT	power sum alien near-end crosstalk
PSNEXT	power sum near-end crosstalk
PSU	power supply unit
PUE	power usage effectiveness
PVC	polyvinyl chloride
QoS	quality of service
RAID	redundant array of independent (or inexpensive) disks
RC	room cooling
RCI	rack cooling index
RF	radio frequency
RFI	radio frequency interference
RFP	request for proposal
RH	relative humidity
RJ48X	registered jack with individual 8-position modular jacks with loopback
ROI	return on investment
RPP	remote power panel
RU	rack unit
SAN	storage area network
SBB	secondary bonding busbar
SBG	supplementary bonding grid
SC	supplemental cooling
SCADA	supervisory control and data acquisition
SCSI	small computer system interface
ScTP	screened twisted-pair
SD	schematic design
SDH	synchronous digital hierarchy
SNMP	simple network management protocol
SONET	synchronous optical network
SPC	single point of connection
SPD	surge protection device

SPG	single point ground
STM	synchronous transport module
STP	shielded twisted-pair
STS	static transfer switch
T-1	trunk level 1
T-3	trunk level 3
TBB	telecommunications bonding backbone
TBC	telecommunications bonding conductor
TLE	telecommunications load equipment
TR	telecommunications room
TVSS	transient voltage surge suppression
UPS	uninterruptible power supply
UTP	unshielded twisted-pair
VAV	variable air volume
VBIED	vehicle borne improvised explosive device
VCSEL	vertical cavity surface emitting laser
VFD	voltage and frequency dependent, variable frequency drive
VFI	voltage/frequency independent
VI	voltage independent
VLA	vented lead-acid
VLAN	virtual local area network
VoIP	voice over Internet protocol
VPN	virtual private network
VRLA	valve-regulated lead-acid
VSS	video surveillance system
WAN	wide area network
ZD	zone distributor
ZDA	zone distribution area

4.3 Units of Measurement

The units of measurement used in this standard are metric. Approximate conversions from metric to U.S. customary units are provided in parentheses; e.g., 100 millimeters (4 inches).

Units of measurement used in this standard are defined below:

°C	degree Celsius
°F	degree Fahrenheit
µm	micrometer
A	ampere
BTU	British thermal unit
dB	decibel
CFM	cubic foot per minute
fc	foot-candle
ft	foot, feet
ft^2	square foot
ft/min	foot per minute
ft^3/min	cubic foot per minute
ft/s	foot per second
Gbps	gigabit per second
GHz	gigahertz
gpd	gallons (U.S.) per day
gpm	gallons (U.S.) per minute
Hz	hertz
in	inch
in WC	inches of water column
K	kelvin
kb/s	kilobit per second
kg	kilogram
kg/m^2	kilogram per square meter
kHz	kilohertz
km	kilometer
kN	kilonewton
kPa	kilopascal
kVA	kilovolt-ampere
kW	kilowatt
lb	pound
lbf	pound-force
lbf/ft^2	pound force per square foot
lbf/in^2	pound force per square inch
lx	lux
m	meter
m/s	meter per second
m^2	square meter
m^3/min	cubic meter per minute
MCM	thousand circular mils
MHz	megahertz
MHz•km	megahertz kilometer
mm	millimeter
MPa	megapascal
mph	mile per hour
MW	megawatt
N	newton
nm	nanometer
OU	open rack unit

NOTE: 1 OU is equivalent to 48 mm (1.89 in).

Pa	pascal
psi	pound per square inch
RU	rack unit
V	volt
VA	volt-ampere
V_{AC}	volt alternating current
V_{DC}	volt direct current
W	watt
W/ft^2	watt per square foot
W/m^2	watt per square meter

5 Site Selection

5.1 Introduction

This section outlines the considerations that should be reviewed and provides recommendations when selecting a location for a data center, whether the location is for a "green field" site that involves the construction of a new data center, reviewing the location of an existing building that will function as a data center, or the ranking of data centers when considering closure or consolidation.

NOTE: When evaluating the suitability of existing buildings and data centers, additional areas (e.g., building structure and architecture, mechanical and electrical systems) should be considered and can be found in other sections of this standard.

The guidance and examples provided are applicable in a wide range of jurisdictions and locations; however, when determining the suitability of a specific site, it is recommended that all applicable local and region guidelines and codes are also reviewed prior to final selection.

In the case that a redundant or disaster recovery data center site selection process is in place, it is important to minimize the likelihood that both the main data center and the redundant data center are affected by the occurrence of the same event.

5.2 Site Evaluation

5.2.1 General Requirements

The suitability of a site shall be determined by a site survey and evaluation and a risk analysis.

5.2.2 General Recommendations

When comparing alternative sites, the feasibility and cost of measures to mitigate the risks identified should be considered as part of the site selection process. An existing site survey should only be referred to if the documents are not older than 6 months. An existing risk analysis for a specific site should only be referred to if it was conducted for a similar objective.

A risk assessment should include the following hazards to be evaluated:

- Natural hazards (e.g., geological, meteorological, and biological)
- Human-caused events (e.g., accidental and intentional)
- Technologically caused events (e.g., accidental and intentional)

NOTE: NFPA 1600, ISO 22301, and ISO 31000 contain additional information on risk analysis and business continuity planning.

5.2.3 Risk Assessment

Risk can form from one or more factors or potential events, and when not identified and planned for, can lead to relatively minor to major impacts of equipment, systems, personnel and operations. Performing a data center risk assessment provides value as it allows the identification, estimation, and communication of the different risk events and their severity that are present at the data center.

Risk can be defined as the product of the probability of occurrence of an event and its impact. Evaluating the impact of an event requires considering the event's ability to disrupt an organization's entire IT operations or a smaller subset of IT operations, and the potential duration of the disruption.

A systematic analysis and evaluation of threats and vulnerabilities is recommended to understand the risk involved. Organizations and stakeholders may be tolerant to different risk levels for a variety of reasons, such as the impact on the facility, the probability of occurrence of the threat, and the perception of a specific threat, risk attitudes and tolerances.

Multiple international standards and guidelines (e.g., ISO/IEC 27001, ISO/IEC 27002, ISO/IEC 27005, ISO/IEC 31000, and NIST SP 800-30) can be used to support the risk management process.

5.2.4 Cost Evaluation Recommendations

The site selection process should include a detailed analysis of all the costs associated with any particular location. Costs that should be considered when comparing available sites are listed below:

- One-time costs that may be significant such that any one may drive the site selection process are:
  - Real estate costs.
  - Local tax incentives.
  - Environmental assessment consulting costs.

    This could include an environmental impact study if wetland or other environmentally sensitive areas are impacted or if the site has any contaminants present. Some sites may require a significant effort to develop the assessment and attend required meetings with the AHJ.
  - Cost to bring adequate utilities infrastructure (e.g., power, water, sewer, gas, telecommunications) to the site in order to support the critical load, both initial and future anticipated growth.
  - Cost to provide redundant utilities (e.g., power, water, gas, telecommunications) to the site as required.

    Determine the additional costs associated with redundant site utilities and any impact that the implementation may have on the schedule. Costs for diverse underground service from an alternate access provider office may be quite high.
  - Demolition costs for any existing structures; site preparation costs.
- Cost and availability of permanent telecommunications service and temporary telecommunications services to support the migration of data from existing data center(s).
- Costs associated with the temporary circuits for movement of data, including:
  - Consider temporary telecommunications circuits that may be needed to support the migration of data from the existing data center(s) to the new data center.
  - Cost of relocation of systems into the new data center:

    Develop a high-level move strategy so that appropriate funds can be allocated for the move of systems and networks into the new data center. Identify any needs for consultants, temporary labor, media, network, server, and storage hardware to support the move and their associated costs.
  - Impact of data center constructability:

    Determine if there are any conditions at a particular site that will affect the constructability of the new data center. A particular site may require a longer approval, permitting, or construction schedule. An extended schedule may affect feasibility because of decommissioning requirements of the existing data center.
- Recurring costs that will have long-term effects on the feasibility of the proposed site:
  - Usage costs for utility services (power, water, sewer, gas)
  - Cost of telecommunications services
  - Prevailing wage for skilled labor in local area
  - Lease costs
  - Taxes
- Intangible costs:
  - Proximity to other corporate facilities (travel time)
  - Proximity of skilled staff

5.2.5 Existing Facilities Requirements

If the data center is moving into an existing building, determine if the building is up to current code and industry standards. It may actually be less desirable to move into a building with an existing electrical and mechanical plant as it may be unsuitable for use in the data center. The existing systems may need to be removed and replaced at considerable expense. See Appendix A for additional items which may need to be assessed.

5.3 Natural Hazards

5.3.1 Introduction

While many things can be determined to be a "natural hazard", this section covers specifically those natural events that are typically major adverse events and may be known as "natural disasters." Locations with high probability of occurrence of natural disasters or environmental threats should be avoided when selecting a site for a data center, as they may affect the structure of the building itself, power, telecommunication and water supply, roads of access to the site and public transportation, and other operational concerns.

5.3.2 General Requirements

The risk from natural hazards identified in this section shall always be evaluated and considered during the site selection process.

5.3.3 Seismic Activity

5.3.3.1 Introduction

Seismic activity (earthquakes) is typically associated with the presence of a geological fault or volcano. Earthquakes can range from a low-level vibration lasting less than a second to a catastrophic event lasting over 20 seconds, severely damaging or destroying structures in the event area.

5.3.3.2 Recommendations

Seismically active areas should be avoided whenever possible. If this is not possible, appropriate seismic equipment supports and structures shall be provided to meet or exceed the requirements of the local AHJ.

In a seismically active area, the equipment within the data center, including the ITE cabinets and racks, should be designed for the level of seismic activity that the data center is designed to resist and have corresponding structural anchorage. Additionally, the building will have higher structural requirements. If one is not already required by the AHJ, consider working with a professional structural engineer to meet the appropriate seismic criteria of the data center facility.

Refer to seismic charts and other seismic activity information for the specific proposed data center site. An example of a global seismic activity map is shown in Figure 5-1.

5.3.4 Volcanic Activity

5.3.4.1 Introduction

Many active volcanoes are located on or near a geological fault but can occur in other areas. (See Figure 5-2). However, volcanoes pose additional risk from the event of an eruption and subsequent lava flow, ash fall, lahars, or flooding.

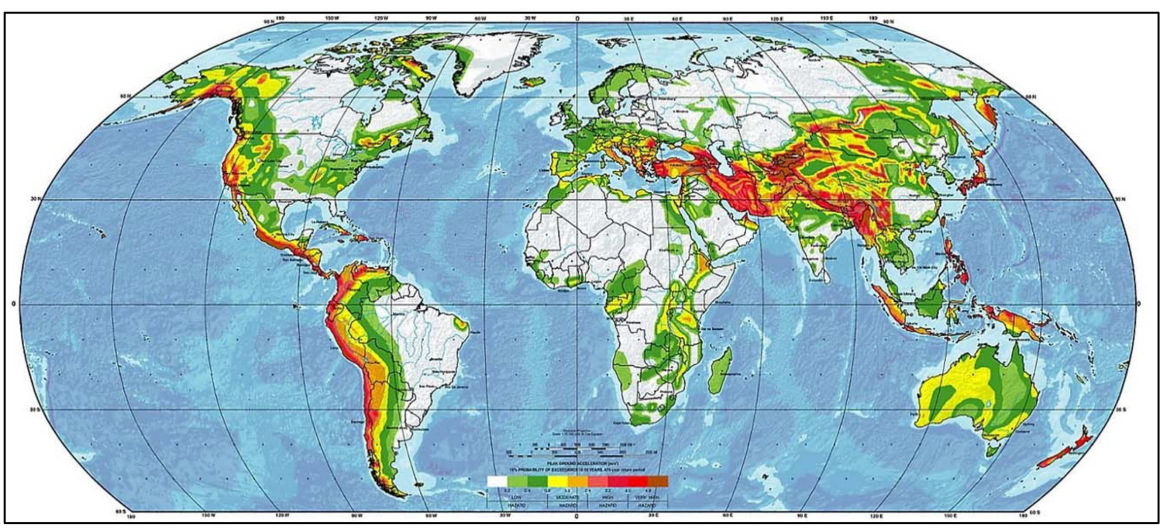


Figure 5-1
Example of a Global Seismic Hazard Map

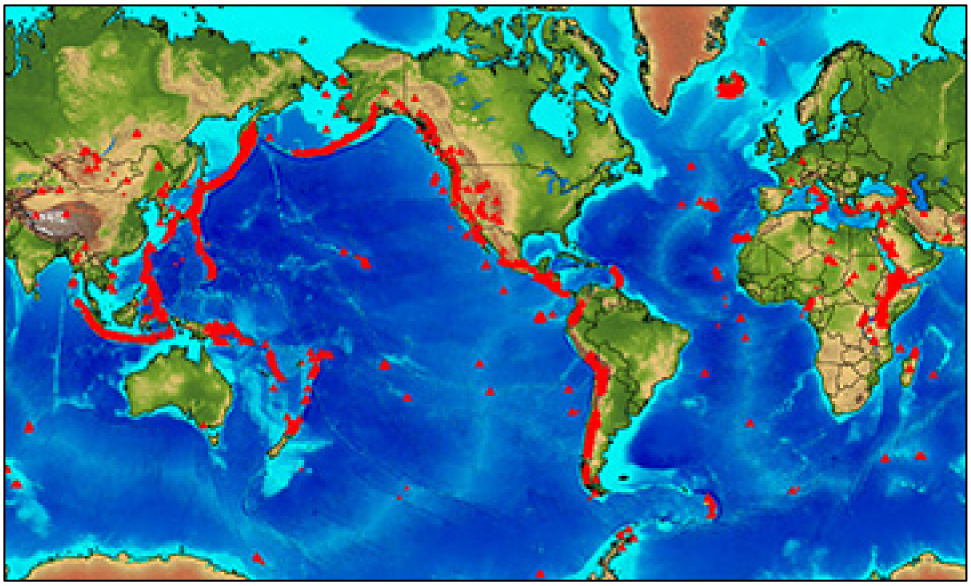


Figure 5-2
Example of a Global Volcano Hazard Map

5.3.4.2 Recommendations

Data centers should be located outside the immediate risk (buffer) area of an active volcano. The hazard zone(s) for a volcano are unique, even when two more volcanoes are in relative proximity. (See Figure 5-3 for an example). Hazard maps for each volcano in the vicinity of the data center should be obtained and evaluated.

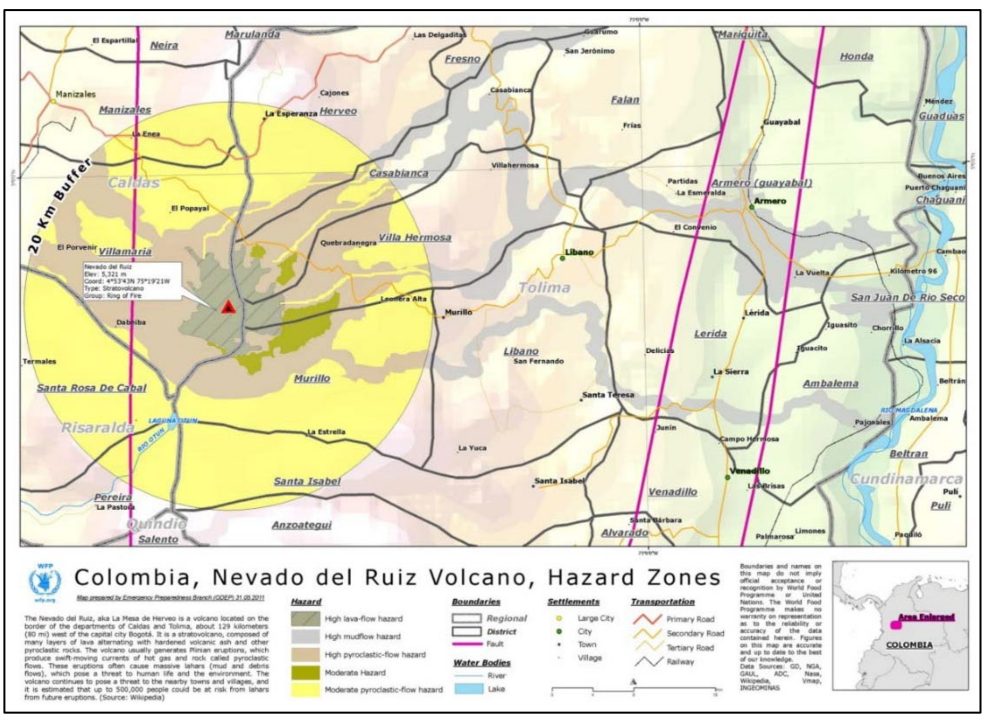


Figure 5-3
Example of a Volcano Hazard Map

5.3.5 Wildfire

5.3.5.1 Introduction

Wildfires can easily spread to 60 km^2 (15,000 acres) or larger. While a site may not be in immediate danger, large wildfires that occur 80 km (50 mi) or farther away from the site can affect an access provider's transmission infrastructure being used by the data center.

Wildfires typically occur away from urban environments. However, depending on the topography of the area and the amount of other development in the area, some sites are susceptible to operational interruption or structural damage from wildfires.

5.3.5.2 Recommendations

Data centers should not be placed on the edge of urban development or near protected natural areas. Data center sites within areas that have historical wildfire events should review all access providers' records for service disruptions because of wildfires.

If a data center is to be placed within an area with moderate to high wildfire risk, redundant access routes should be made available to provide both data center operators and fire suppression crews access to the site. Security and disaster recovery plans should detail procedures for evacuation and continued data center operation in event of required wildfire evacuation.

5.3.6 Flood Plains

5.3.6.1 Introduction

Flooding may occur in a number of areas and may occur in areas not known for significant annual rain or snowfall.

5.3.6.2 Recommendations

The site should be free of flood risk from river flood plain proximity, tidal basin proximity, dam failure, tsunami, or levee failure. The site should not be within the flood hazard and tsunami inundation area as defined in the *IBC*, be within 91 m (300 ft) of a 500-year flood hazard area, or be less than 3 m (10 ft) above the highest known flood level. The site should also have multiple access roads with elevations above the flood recommendations along their entire route.

NOTE: Some locations may warrant a site-specific flood study.

An example of available flood information is Figure 5-4, which shows global flood risk. Information is also available on a region or country basis.

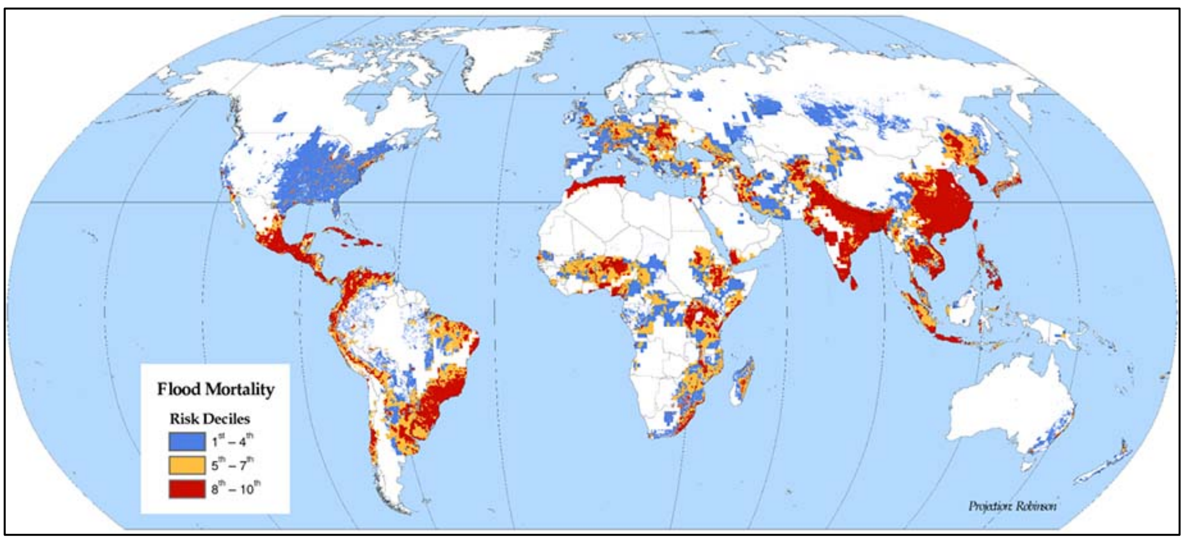


Figure 5-4
Example of a Global Flooding Hazard Chart

5.3.7 Wind

5.3.7.1 Introduction

While wind is prevalent in every area of the Earth, extreme winds because of storms (e.g., tornado, hurricane, cyclone, derechos) can affect a data center's operation.

5.3.7.2 Recommendations

The most desirable location should be an area with winds less than or equal to 53.6 m/s (120 mph) per ASCE 7. When business drivers dictate that a data center be located in an area with greater wind velocity, specific detail in the "hardening" of the facility should be incorporated into the design.

Class 2 and lower data centers should be designed to meet Risk Category I (USA) or designed to withstand at a minimum wind speeds of 4.8 m/s (10 mph) above the highest 100 year mean recurrence interval wind speed. Class 3 data centers should be designed to meet Risk Category II (USA) or designed to withstand at a minimum wind speeds of 8.9 m/s (20 mph) above the highest 100 year mean recurrence interval wind speed, and Class 4 data centers should be designed to meet Risk Category III-IV (USA) or designed to withstand at a minimum wind speeds of 13.4 m/s (30 mph) above the highest 100 year mean recurrence interval wind speed.

Refer to wind charts and other wind activity information for the specific proposed data center site. While wind/windstorm risk maps are typically specific to region or country, Figure 5-5 is an example of a global tornado risk map.

5.4 Natural Environment

5.4.1 Introduction

The natural environment has its own set of risks that while they may not cause the potential destruction of that of an earthquake or hurricane, still have the potential to cause adverse effects to a data center's construction or operation.

5.4.2 Ground Stability

5.4.2.1 Landslides

5.4.2.1.1 Introduction

Landslides occur when the stability of the slope changes from a stable to an unstable condition. A change in the stability of a slope can be caused by a number of factors. Landslides do not need a dramatic difference of elevations as a landslip can occur over a seemingly flat area because of the ground structure underneath.

5.4.2.1.2 Recommendations

For new building locations, the suitability of the site should be verified by current documents, recent geological records, or by appropriate analytical measures.

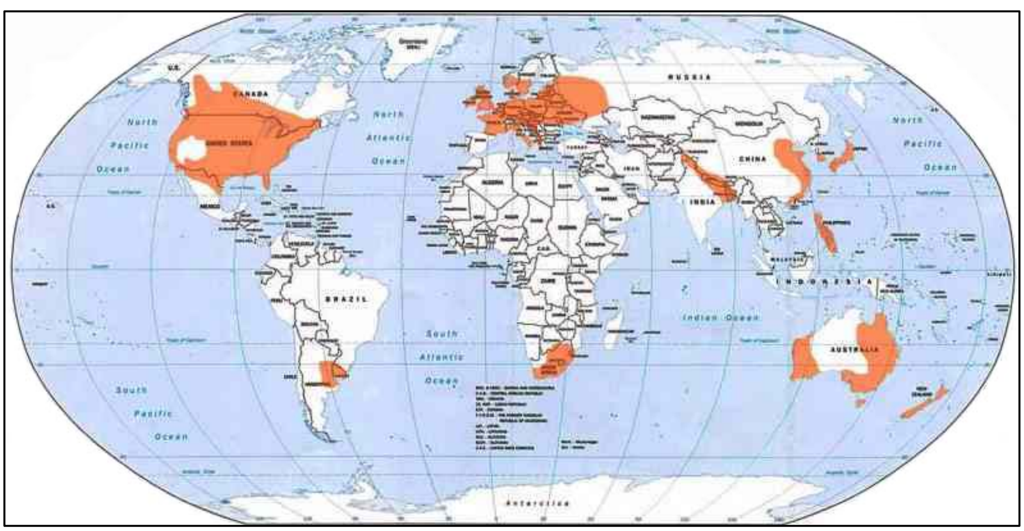


Figure 5-5
Example of a Global Tornado Risk Area Map

5.4.2.2 Soil Stability

5.4.2.2.1 Introduction

While the most dramatic effect of insufficient ground stability is the formation of sinkholes, even minimal instability can cause a building to not uniformly "settle", leading to structure issues and damage.

5.4.2.2.2 Requirements

The ground shall be suitable to support the loads of the facility. The suitability of the site shall be verified by current documents or by appropriate analytical measures.

5.4.2.2.3 Recommendations

The following criteria should be used in determining a site's suitability:

- Avoid the potential for quick, unstable, or expansive soils.
- Ensure that there is no known subsurface contamination from either on-site hazardous waste storage or other adjacent site.
- Ensure that there is no potential of underlying solution-formed cavities common in limestone formations or the source of potential sinkhole problems.

Consider working with a professional geotechnical engineer to meet the appropriate criteria of the data center and to provide a formal written geotechnical report.

5.4.3 Lightning

5.4.3.1 Recommendations

Sites with a flash rate of 10 or less are preferred.

The type and duration of service provider failures should be researched for potential site locations with a flash rate greater than 1 and integrated into the overall site selection and design criteria.

5.4.3.2 Additional Information

Areas with a flash rate of 0.6 or less are typically seen as "lightning free". However, lightning may occur at almost any point on the globe, and a single lightning flash has the potential to cause a downtime event.

Examples of lightning flash data can be found in Figure 5-6.

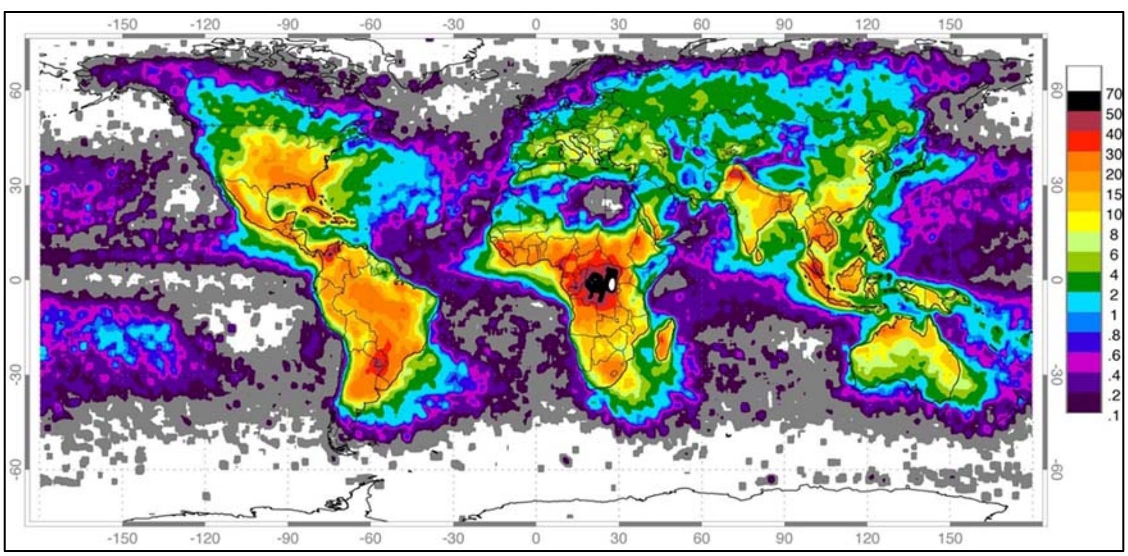


Figure 5-6
Example of a Lightning Flash Data Map

5.4.4 Groundwater

5.4.4.1 Introduction

Groundwater is water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps and can form oases or wetlands.

5.4.4.2 Recommendations

The site should have a water table that is as low as possible; it should be below the utility ducts and below the lowest level of the building at a minimum.

If the data center is a "slab on grade", then placing it at the top of a hill or in a relatively flat topographical area should minimize ground water issues.

If the building has one or more subgrade floors or is located at the bottom of a hill, additional efforts may be required to protect the data center from seepage or the effects of seasonal variances in the water table. If the data center is located at the bottom of a hill, there should be great concern for ground water issues.

Refer to ground water charts and other ground water activity information, such as shown in Figure 5-7, for the specific data center site.

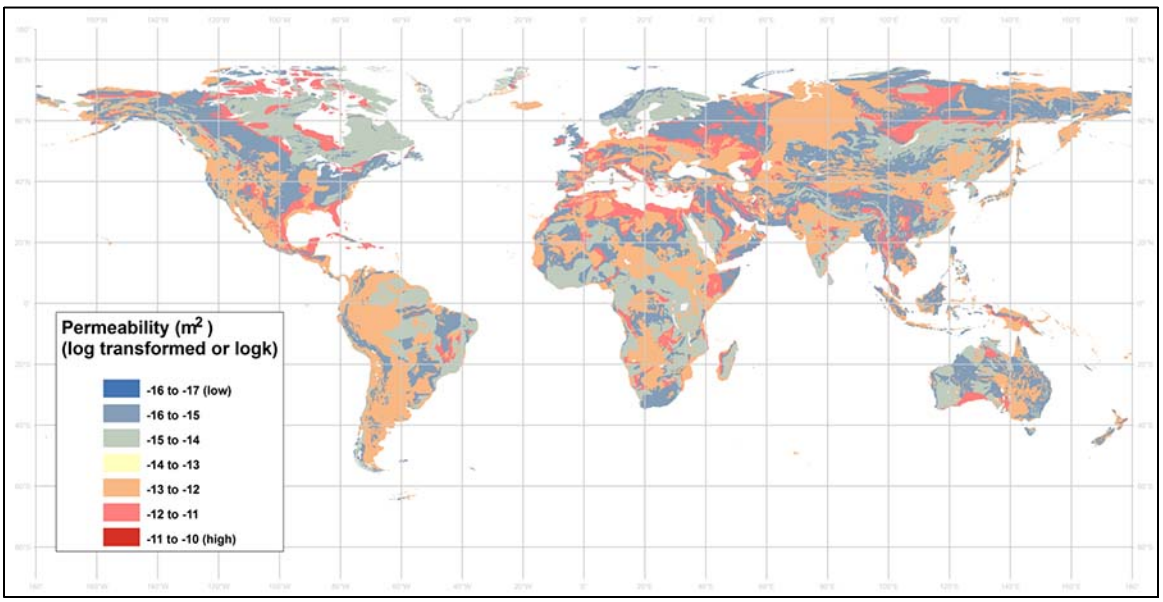


Figure 5-7
Example of a Ground Permeability Chart

5.4.5 Air Quality

5.4.5.1 Intake Recommendations

Air quality issues (e.g., ashes, sand) should be considered for the data center's fresh air intake and for external mechanical components like cooling towers and heat exchangers, as well as anything that may be emitted from the site. Fresh air intake requirements are usually regulated by the local AHJ. Provide appropriate air intake filtration systems as required.

When data centers must be located in densely populated areas or metropolitan areas, consider the effects of noise and emissions from the data center exhausts on neighbors and surroundings. Although usually regulated, it is common to have restaurants, dry cleaners, and other similar businesses requiring venting of chemicals and contaminants into the immediate environment. Special air intake filtration systems may be required for the data center in addition to any regulations.

5.4.5.2 Emission Recommendations

An area with clean air quality is preferred so that emission of gases and particles does not cause a new air quality problem or worsen an existing problem.

In areas with existing air quality problems, regulations may be very stringent regarding emissions produced from fossil fuel consumption.

Ensure that generator run time permitting documents are issued in a timely manner to the jurisdiction overseeing air quality control and other local environmental authorities. In most cases, annual operation hours will be restricted, and compliance must be verified.

If the owner wants to consider cogeneration of electricity, there may be stricter air quality requirements and special permits required.

5.4.6 Noise

5.4.6.1 Introduction

Wind will carry sound long distances. Even the slightest breeze can carry the sound of a facility well beyond the property line.

5.4.6.2 Recommendations

It is recommended to verify acceptable noise levels at the property line and determine the noise levels produced by equipment.

Critical silencers on generator exhausts and sound attenuated enclosures on outdoor equipment, such as generators and cooling towers, should be always considered.

Outdoor equipment located on the ground and on rooftops may require screening for architectural aesthetics or building codes. Consider incorporating sound barriers within the architectural screening.

5.4.7 Other Topography and Natural Environment Recommendations

Avoid sites with larger than a 15% ground slope if possible; otherwise, this may limit the developable area. Sites with steep slopes may be difficult to access in adverse weather conditions.

The site topographical features should not restrict the line of sight to geosynchronous satellites and location of ground dish arrays if required. Line of sight issues may also affect the location of wireless access equipment such as microwave, infrared, and directional antennas.

Sites with wetlands and protected habitat should be avoided because construction in these areas can be delayed, have higher costs, and may create unwanted public awareness of the facility.

A maximum elevation of 3050 m (10,000 ft) is recommended as the effectiveness of air-cooling systems degrades significantly at higher elevations where air density is lower. Generator radiator cooling systems are severely limited at higher altitude (above 450 m/1500 ft), affecting both operating times for prime, standby, or continuous duty engines in addition to the derating of the kW output to maintain a generator system's prime, standby, or continuous rating.

5.5 Man-Made Hazards

5.5.1 Introduction

Man-made hazards from accidents and incidents typically have a greater impact on a data center's operational availability than natural events.

5.5.2 Recommended Separation Distances

The following distances shown in Table 5-1 should be observed when selecting a data center.

NOTE: Each element on the list has its own risk factors and rating dependent on the specific site.

5.5.3 Other Recommendations

Locations that are adjacent to or accessed via routes that could be subject to protest or blockade because of their antisocial nature should be avoided.

When placing a data center in close proximity to a railroad, measurement of vibration and EMI at the site should be conducted over the period of several days to aid in the assessment and mitigation requirements, if any, required at the site.

Risk of terrorist attack can be a significant reason for avoiding a location close to an underground train station. Additionally, underground train traffic can create vibration and provide EMI within a building located directly above the train tunnel.

Table 5-1 Recommended Distances from Man-Made Elements

Man-Made Element	*Minimum Distance*
Airports	8 km (5 mi)
Auto body or other paint shops	1.6 km (1 mi)
Canals	3.2 km (2 mi)
Chemical plants and storage (e.g., fuel, fertilizer)	8 km (5 mi)
Conventional power plants (e.g., coal, natural gas)	8 km (5 mi)
Embassies and political group properties	5 km (3 mi)
Foundries and heavy industry operations	8 km (5 mi)
Gas stations and distributors	1.6 km (1 mi)
Grain elevators	8 km (5 mi)
Harbors and ports	3.2 km (2 mi)
Lakes, dams, and reservoirs	3.2 km (2 mi)
Landfills and waste storage facilities	3.2 km (2 mi)
Military installations and munitions storage	13 km (8 mi)
Municipal water and sewage treatment plants	3.2 km (2 mi)
Nuclear power plants	80 km (50 mi)
Overflow areas for reservoirs and man-made lakes	1.6 km (1 mi)
Quarries	3.2 km (2 mi)
Radio/television transmitters/stations	5 km (3 mi)
Railroads	1.6 km (1 mi)
Research laboratories	5 km (3 mi)
Self-storage facilities	1.6 km (1 mi)
Stockyards and livestock feedlots	3.2 km (2 mi)
Transportation corridors where hazardous material could be transported	1.6 km (1 mi)
Water storage towers	1.6 km (1 mi)
Weather or other radar installations	5 km (3 mi)

Within risk analysis, airports typically represent a low probability but high impact threat. In addition to maintaining a minimum 8 km (5 mi) radial distance from an airport, the length and location of takeoff and landing flight paths should also be considered as part of site selection and risk analysis. Figure 5-8 provides a generic example of takeoff and landing paths for an airport. However, every airport will be different, based on factors such as type of airport (e.g., civilian, commercial, military), natural terrain in the vicinity, regulation (e.g., restricted air space), and proximity to other hazards (e.g., other air traffic).

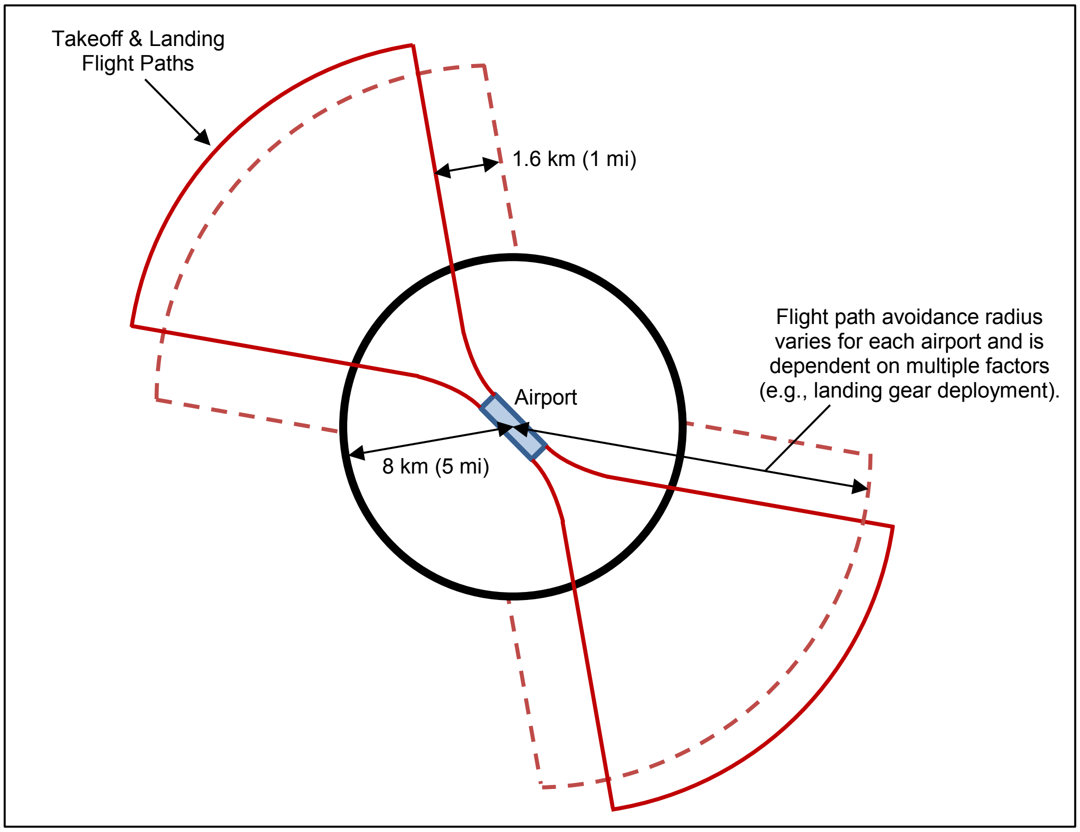


Figure 5-8
Example of Radial and Flight Path Zones for an Airport

5.6 Site Access and Location

5.6.1 Public Road Access Recommendations

The site should allow the placement of the building so that it is not close enough to the road that an adjacent road traffic accident could result in vehicular contact with the building fabric or any external component of the data center's mechanical or electrical systems and the potential for resulting structural damage or the potential for fire.

The site should allow the placement of the building so that it is not close enough to the road that an adjacent road traffic accident could result in the spillage of a toxic or flammable load coming into contact with the building fabric and resulting in structural damage or the potential for fire.

The site should be within reasonable distance—3.2 km (2 mi) to 16 km (10 mi)—to a freeway or other major arterial road. However, it is generally not desirable for the data center to be within 1.6 km (1 mi) of a freeway, railroad, or other major thoroughfare to minimize exposure to contaminants in the event of an accident.

The site should have two or more access roads from the nearest major arterial road with each road having a minimum of 4.3 m (14 ft) height clearance for vehicles throughout. Utilizing a single access road with bridges or tunnels should be avoided.

The sub-structure and surface of the access roads should be designed in a way so that in any weather condition deliveries (e.g., heavy components of the technical building systems, including mobile cranes required for unloading) can be made.

If the data center is on a campus, then the campus should have redundant access roads with either a security checkpoint at the access point to the data center facility or at each access point to the campus.

5.6.2 Adjacent Property

5.6.2.1 Recommendations

The data center should be built far from any other buildings and facilities that may pose a fire threat or that could cause damage to the data center should the other buildings or structures collapse.

A facility located adjacent to a large campus or manufacturing plant may suffer from traffic issues at certain times of the day (e.g., at the start and end of the working day; if adjacent to a 24-hour facility, this could be three times a day or more, depending on shift patterns).

5.6.2.2 Additional Information

The following is a partial list of adjacent properties that have an increased potential to affect data center operations:

- Embassy/consulate
- Military
- Police
- Fire station
- Hospital
- Chemical plant
- Political target
- Research lab
- Publishing house/foreign press

Adjacent vacant lots may cause future issues because of:

- Possible future development and disruption during construction
- Unknown tenant(s)

5.6.3 Proximity to Existing or Redundant Data Center

For disaster backup sites, consider the issue of distance from the primary data center. Distance will be determined by the use of the primary site and whether the backup site must have synchronous or asynchronous replication with the primary data center.

5.6.4 Security and Emergency Services

5.6.4.1 Requirements

Avoid high crime areas. Refer to Section 12 for additional threats and concerns to be considered.

5.6.4.2 Recommendations

Having emergency services reasonably accessible can be a valuable lifesaving resource for site occupants. Ideally, a staffed (or at least volunteer) fire station and police station should be within 8 km (5 mi) of the candidate site and a hospital emergency room within 16 km (10 mi).

Consideration should be made for level and type of perimeter security required for the site, depending on an initial risk and threat analysis. This would include building type, site location, fenestration, and neighborhood. These factors will vary based on the users need.

5.6.5 Proximity to Skilled Labor

If the site is in a rural location, skilled personnel to staff the data center may not be available locally, and skilled people may not be willing to relocate from urban locations. A location close to technical colleges and universities is desirable. The site should be close to the location of vendor technicians that perform maintenance and repair of ITE and facility equipment.

5.7 Utility Services

5.7.1 Introduction

It is of utmost importance for the data center location to have access to reliable high-power quality and high speed telecommunications services. Access to other services such as water, sewage, and other energy sources of conventional (e.g., natural gas, propane, diesel) or renewable energy (e.g., wind, solar) must also be taken into consideration.

5.7.2 Power and Electrical Service

5.7.2.1 Introduction

Figure 5-9 shows an overview of electrical transmission and distribution.

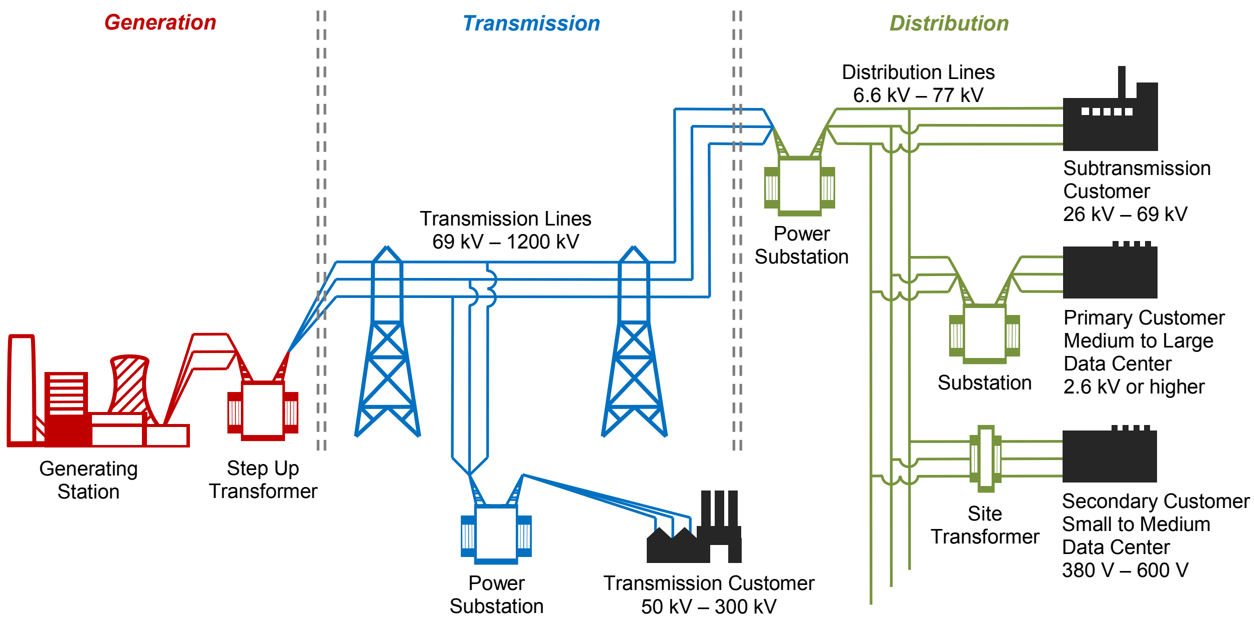


Figure 5-9
AC Electricity Distribution from Generation Stations to Data Centers

5.7.2.2 Capacity Available to Site

5.7.2.2.1 Requirements

Adequate electrical utility capacity to the site shall be provided to meet both current and projected needs of the entire site and depends on the data center Availability Class requirements (as described in Appendix B).

5.7.2.2.2 Recommendations

Consider using multiple electrical utility circuits, each with enough capacity, to handle the entire site requirements.

Circuit capacity to the site should be planned and implemented very carefully. If the data center is designed for minimal initial capacity with large future capacity requirements, careful consideration should be given to the amount of initial power requested to be delivered to the site by the utility company.

Work with a professional electrical engineer and the electrical utility or utilities serving the site. A cost benefit analysis and progressive circuit capacity design/implementation may benefit the site.

5.7.2.3 Unit Substations

5.7.2.3.1 Introduction

Unit substations are usually medium voltage switchgear that is used to parallel electrical utility circuits or to transfer between redundant electrical utility circuits feeding the data center site. Unit substations are generally located outdoors on pads within fenced areas, but in some cases, may be found inside of the data center building (e.g., data centers located in metropolitan settings).

Depending on the size, Availability Class, and location of the data center, a unit substation may be required on the site. Very large data centers typically have substations on the premises. In most cases, the unit substations are owned and maintained by the electric utility. The largest data centers may prefer to have control over the unit substations for security and availability reasons.

Unit substations generally connect to utility transformers sized to meet the building voltage and amperage requirements.

5.7.2.3.2 Recommendations

Data centers should be located in an area with easy sustainable circuit access to utility substations with preference toward an area with utility circuits provided by two or more utility substations.

When selecting a site, consider space for an electrical unit substation and its associated transformers and electrical utility circuit paths. It is preferable that these are located on the data center site in a secure and aesthetically pleasing manner.

5.7.2.4 Utility Transformers

5.7.2.4.1 Introduction

For small data centers, the utility transformer might be pole-mounted or pad-mounted outside of the facility. For most data centers, depending on the data center's size, class, and location, the utility transformer will be onsite. Utility transformers are generally located outdoors, but in some cases, may be found inside the data center building (e.g., data centers located in metropolitan settings).

The utility transformer is usually the last utility-provided device prior to the electric meter, which marks the demarcation between the electric utility and the electricity consumer. In many cases, this transformer is owned by the power consumer, in which case, it is located on the load side of the electric meter.

Utility transformers usually transform the utility's medium distribution voltage to a lower voltage for utilization by the data center. For example, for a large data center, the unit substation might transform voltage in excess of 13 kV to a voltage up to 1 kV. An on-site utility transformer might then transform the voltage to a lower voltage utilized by the building or facility. Consumption voltages vary around the world and will typically be defined by the regulatory authority in the country or region where the data center is located.

5.7.2.4.2 Recommendations

When selecting a site, consider space for one or more electrical utility transformers and their associated electrical utility circuit paths. It is preferable that these are located on the data center site in a secure and aesthetically pleasing manner.

5.7.2.5 Proven Utility Reliability (Percentage Availability)

5.7.2.5.1 Introduction

For critical data centers, there may be benefit in providing a second, independent utility service to the data center site.

5.7.2.5.2 Requirements

A second power utility connection is not required for any Class of data center.

5.7.2.5.3 Recommendations

The benefit of installing a second utility feed should be analyzed based on the mean time between failure (MTBF) rate, mean time to repair (MTTR), and the power quality of the service to the data center.

A second diverse power utility feed is only recommended when all of the following are true:

1) The operational requirements of the data center results in an Operational Level 4
2) The availability requirements of the data center results in an Availability Ranking Level 4
3) The impact of downtime of the data center results in a Catastrophic classification
4) The reliability of the utility, based on the specific MTBF rates of the utility and the required mission time of the data center, is greater than 50%.

For the electrical feed, determine if there are other customers, such as manufacturing plants, that can create electrical noise. An electrical feed that also serves a hospital is generally desirable because such feed is less prone to shutdown by a utility.

5.7.2.5.4 Additional Information

Table 5-2 shows reliabilities of a utility, given examples of MTBF, and the mission times expressed in years. In the table shown, the only scenario that achieves greater than 50% reliability is where the mission time is 5 years with a utility MTBF of 10 years. Within this scenario, the second utility with an example reliability of 50% will result in between 1/10% and 1% of an increase in the overall power systems, assuming the power systems meet a Class 4 topology. The increase in capital expenditures (CapEx) and operational expenditures (OpEx) costs for the second utility must be weighed against the value of increasing the overall reliability by 0.1% to 1%.

The power utility services in the United States average 1.86 outages annually (MTBF equals 1/1.86 = 0.5376 years). For a 2(N+1) electrical topology where the number of generators required to meet the load is N=2, the resulting overall increase in the power systems reliability with a second utility would be approximately 1/100000000% compared to a 2(N+1) backup power generation topology combined with a single power utility connection. This insignificant increase in reliability would not normally be considered worth the significant increase in CapEx and OpEx of the second utility connection.

Table 5-2 Utility Reliability Examples

		Mean Time Between Failure (MTBF) - Years				
		0.5	*1*	*2*	*5*	*10*
Mission Time (Yrs)	*5*	0.004539992976%	0.673794699909%	8.208499862390%	36.787944117144%	60.653065971263%
	10	0.000000206115%	0.004539992976%	0.673794699909%	13.533528326610%	36.787944117144%
	15	0.000000000009%	0.000030590232%	0.055308437015%	4.978706836786%	22.313016014843%
	20	0.000000000000%	0.000000206115%	0.004539992976%	1.831563888873%	13.533528326610%
	25	0.000000000000%	0.000000000139%	0.000372665310%	0.673794699909%	8.208499862390%

5.7.2.6 Utility Service

5.7.2.6.1 General Recommendations

Electrical service entrance feeds should have a minimum separation of 1.2 m (4 ft) from other utilities along the entire route. If redundant feeds are provided to the data center, it is recommended that the electrical service entrances to the facility have a minimum separation of 20 m (66 ft) from the other electrical service entrances along the entire route.

5.7.2.6.2 Overhead Utility Service Recommendations

Overhead utility service to the facility should be avoided whenever possible. Underground utility service to the facility is recommended. This will reduce the potential for system failure caused by overhead utility line damage. Vehicle accidents, wind, snow, and other weather conditions are known factors for utility line damage.

5.7.2.6.3 Underground Utility Service Recommendations

It is recommended that all electrical service entrances and feeds to the facility be underground.

5.7.2.7 On-Site Generation

5.7.2.7.1 Introduction

Backup generators are used to backup data center equipment in case of utility power failure. Emergency generators (as opposed to backup generators) are used to power data center life safety systems (e.g., emergency lighting, fire pumps) if utility power fails.

Backup generators can be as small as a compact car and as large as a full-sized truck. Some generator solutions utilize a space as large as a shipping container or larger. These may be either indoors or outdoors, and it is common to find building rooftop-mounted generators.

5.7.2.7.2 Requirements

For buildings to be occupied for extended power outages, areas of the building outside the data center must provide basic life safety and building occupancy requirements, including but not limited to, lighting, fire alarm, restrooms, elevators, security, and ventilation.

5.7.2.7.3 Recommendations

When selecting a site, consider space for one or more backup and one or more emergency generators and their associated electrical utility and life safety circuit paths. It is preferable that these are located on the data center site in a secure and aesthetically pleasing manner.

Space considerations for generators should also include the necessary fuel pumps, piping, and on-site storage required. For some data center applications, the space required can be quite extensive as operational requirements may dictate performance for a minimum of 48 hours without outside services or deliveries.

5.7.2.7.4 Microgrids

A microgrid is a combination of power generation, storage and a connection point to the primary power delivery system (grid), allowing a site to utilize the primary power system or “disconnect” and run independently. Microgrids are commonly associated with alternative power generation (e.g., thermal, wind, solar), but may also be used by end-users who have sufficient on-site power generation.

Microgrid concepts and techniques may be utilized to manage on-site back-up and emergency power generation, assist with power reliability, and used as a transition mechanism between systems because of maintenance processes, shortages/outages in the primary delivery systems, or operational and financial considerations.

Microgrids can be of any size and their presence may not be readily noticeable during a site visit.

5.7.3 Communications

5.7.3.1 Capacity Available to Site Recommendations

Adequate copper conductor and optical fiber capacity to the site should be provided to meet the current and projected needs of the entire site, and depending on the data center Class requirements, provide one or multiple connectivity paths, each with enough capacity, to handle the entire site requirements.

Connectivity capacity to the site should be planned and implemented very carefully. If the data center is designed for minimal initial capacity with large future capacity requirements, careful consideration should be given to the amount of capacity requested to be delivered to the site by the access providers.

Work with a professional IT consultant and the access providers serving the site. A cost benefit analysis and progressive connectivity capacity design/implementation may benefit the site.

5.7.3.2 Proven Access Provider Reliability (Percentage Availability) Recommendations

The reliability of the primary access provider should be determined to ensure that the required availability requirements can be achieved.

Reliability of the communication services can be improved by either adding redundant circuits from the primary access provider or adding services from alternate access providers. The reliability of the overall communications services can be further increased if the redundant circuits are serviced from separate access provider offices following diverse routes.

5.7.3.3 General Service Recommendations

If redundant telecommunications service cabling is desired or required, telecommunications service cabling pathways should maintain a minimum separation of 20 m (66 ft) along the entire route.

The following is a list of preferences (in successive order) of communication service sources:

1) At least two diversely routed telecommunications service feeds from different access provider central offices with each access provider central office connected to multiple higher-level access provider and multiple long-distance carrier offices.
2) At least two diversely routed telecommunications service feeds from different access provider central offices with both access provider central offices connected to the same higher-level access provider and long-distance carrier offices.
3) At least two diversely routed telecommunications service feeds from one access provider central office.
4) One telecommunications service feed from one access provider central office.

5.7.3.4 Underground Service to Facility

5.7.3.4.1 Requirements

Determine if the site can accommodate customer-owned maintenance holes and if elevation of maintenance holes (utility or customer owned) can cause problems with water infiltration into data center.

5.7.3.4.2 Recommendations

It is recommended that all telecommunications service cabling to the facility be underground with a minimum separation of 1.2 m (4 ft) from other utilities along the entire route.

Provide underground utility service to the facility whenever possible.

5.7.3.5 Overhead Service to Facility

5.7.3.5.1 Introduction

Overhead utility service to the facility is not desirable, especially if there is only one service entrance.

5.7.3.5.2 Requirements

If overhead utility lines to the site cannot be avoided, provide multiple source paths. Ensure that the entrance cables are well protected from physical damage at the drop pole.

5.7.3.5.3 Recommendations

If cables drop from service poles to underground, the drop pole should provide 100 mm (4 in) rigid conduits from below grade up to the elevation where the cables are suspended to protect the entrance cables from physical damage.

5.7.3.6 Proximity to Service Providers or Other Data Centers

Data centers should be located in an area with easy sustainable connectivity to the access provider central offices. Locating a data center in an area with connectivity provided by two or more access provider central offices is recommended for Class 2 and higher data centers.

Redundant data centers for disaster recovery (DR) purposes should be located with sufficient physical separation to reduce single modes of failure (natural or manmade) to within acceptable limits for the critical data. The two locations should be on separate distribution systems to minimize the occurrence of one outage affecting both locations.

5.7.4 Water Service

5.7.4.1 Introduction

The data center may need to have access to reliable significant quantities (e.g., 0.75 – 1.1 m^3/min [200-300 U.S. gallon/min]) of quality water, depending on cooling system design. However, not all areas are able to provide this quantity of quality water continuously independent of long-term weather conditions.

Data centers may require large volumes of water for other uses. Some uses of water that may be required are as follows:

- Domestic water (e.g., drinking water, restrooms, kitchens)
- Irrigation (e.g., lawn watering)
- Fire suppression (e.g., sprinkler systems)
- HVAC (e.g., cooling towers, air humidification)

5.7.4.2 Municipal Water Supply

5.7.4.2.1 Capacity Available to Site Requirements

Provide adequate municipal water delivery to the site to meet the requirements of the data center. For Class F3 or F4 data centers, the ability of the water supply pumping station(s) to deliver water when there is a major power outage must be documented or mitigated.

5.7.4.2.2 Water Quality Recommendations

Although water delivered to sites by most municipalities is generally considered to be potable (drinkable), the water should be tested for contaminants and particulates. Water filtration systems may be required for some or all of the various water uses listed above. It is common to find a water filtration system specific to the domestic water system in a building.

5.7.4.3 Non-potable Water Systems (Greywater)

5.7.4.3.1 Introduction

Non-potable (waste water that doesn't contain serious or hazardous contaminants) systems can be municipally provided or project generated and can be used to minimize a project's impact on the surrounding community and potentially reduce operating costs.

5.7.4.3.2 Requirements

Non-potable water systems shall be used according to the local AHJ.

5.7.4.3.3 Recommendations

Greywater systems should not store grey water for longer than one day to minimize the risk of microbial growth. Greywater storage tanks should be designed to drain completely upon use and have minimal to no anaerobic corners or pockets.

5.7.4.4 Private Well Supply (Well Water)

5.7.4.4.1 Capacity Available to Site

5.7.4.4.1.1 Requirements

If well water is to be utilized, make sure that there is adequate well water delivery on the site to meet the requirements of the data center. It is first necessary to determine the volume and quality of water that will be consumed for all purposes (data center cooling, building plumbing and occupant use, lawn irrigation, etc.) and how much can be recycled.

5.7.4.4.1.2 Recommendations

A hydrogeological risk assessment may be required. The assessment should be conducted by a licensed hydrology engineering firm. An environmental impact study might be required. A hydrogeological report can include information on:

- Groundwater
- Infiltration
- Soil moisture
- Surface water flow
- Precipitation and evaporation
- Uncertainty analysis
- Water quality
- Remote sensing
- Integrating measurement and modeling
- Prediction

5.7.4.4.2 Quality Recommendations

The available on-site water (well water) should be tested for contaminants and particulates. Water filtration systems may be required for some or all of the various water uses listed above. It is common to find a water filtration system specific to the domestic water system in a building.

5.7.4.4.3 Dual Water Supply (Municipal Water Supply and Well Water Supply)

Occasionally, a data center site will require both a municipal water feed to the site as well as using an on-site well. A domestic water system and fire suppression system may be connected to the municipal water source while having the HVAC and irrigation systems connected to the on-site well. An on-site well can also be used as a backup water source for HVAC water systems connected to a municipal water source.

5.7.4.5 Backup Water Supply

5.7.4.5.1 Introduction

Backup systems could be multiple water sources or onsite water storage.

5.7.4.5.2 Requirements

A backup water supply of at least 8 hours at any time shall be provided for data centers with Class F3 or F4 that use evaporative cooling towers for heat rejection.

5.7.4.5.3 Recommendations

Review need and availability of a backup water supply for the facility for domestic uses as well as water cooled cooling systems.

Backup water supply should be provided that meets the minimums listed in Table 5-3.

Table 5-3 Recommended On-Site Supply of Services for Data Center Facility Classes

Class F0	*Class F1*	*Class F2*	*Class F3*	*Class F4*
No requirement	8 hours minimum	24 hours minimum	72 hours minimum	96 hours minimum

5.7.5 Sanitary Sewer

5.7.5.1 Municipal Sanitary Waste Sewer System

5.7.5.1.1 Capacity Available to Site Requirements

Provide adequate sanitary waste capacity from the site to the municipal sanitary waste sewer system. A private sanitary waste system will be required in regions where no municipal sanitary waste sewer system is available.

Sanitary systems or storm drainage systems (depending on local requirements) need to be sized for the amount of expected water usage by cooling systems, including cooling tower blow down or filtration systems, which could be greater than 0.75 m^3/min (200 gpm).

5.7.5.1.2 Remediation Requirements

Coordinate with the local AHJ and provide all remediation as may be required by code and standards. Holding tanks, traps, and the like may be required and need to be planned into the site design.

5.7.5.1.3 Recommendations

A private sanitary waste system is recommended for critical facilities that require on-site operations personnel 24/7 to maintain uninterrupted services. This will help mitigate having to vacate the facility in the event the municipal sanitary waste sewer system fails.

5.7.5.2 Private Sanitary Waste System

5.7.5.2.1 Capacity Available to Site Requirements

Provide adequate sanitary waste capacity from the building to the on-site sanitary waste system (septic system).

5.7.5.2.2 Remediation Requirements

Coordinate with the local AHJ and provide all remediation as may be required by code and standards. Holding tanks, traps, and similar facilities may be required and need to be planned into the site design.

5.7.6 Natural Gas and Other Fuels

5.7.6.1 Introduction

Fuels (e.g., natural gas, propane, diesel) may be used to support primary or back-up systems of a data center. On-site fuel (e.g., propane, diesel) storage tanks are usually located outdoors on the ground and are sometimes buried below grade.

5.7.6.2 Requirements

If natural gas is selected to support the heating systems, cooling systems, or backup electricity generation that the site requires, provide properly sized natural gas feed from the local utilities.

Make sure that the utility company assures full capacity natural gas delivery to the site for the duration of any prolonged power outage or disaster situation.

5.7.6.3 Recommendations

Redundant gas feeds from redundant gas sources is the most desirable, although rarely available, method for natural gas delivery to a site. Natural gas in combination with diesel fuel may also be considered if dual-fuel generators are incorporated into the design. Dual-fuel generators start on diesel but can run on either diesel or natural gas. For sites with natural gas generators sized 25 kW or less, on-site storage of natural gas should be considered. The number of hours or days of reserve should be based upon a risk analysis or meet the recommendations listed in Table 5-3.

The data center site should be carefully planned to support on-site fuel storage when it is required. On-site fuel storage should be located on the data center site in a secure and aesthetically pleasing manner. Fuel should be stored as far away from the data center as practical. Blast containment (proximity to building or actual structure) should always be planned into the site.

Special containment or controls are usually required in case of fuel leaks.

Controls for fuel transfer should be in a secure location, above worst-case flood levels, and protected from other natural disasters.

5.7.6.4 Alternative Fuel Source Recommendations

Other fuel or energy sources (e.g., wind, solar) may be used to support the site. Consider their continuous availability to determine if they can be primary or secondary energy sources. If other energy sources are used, their requisite equipment and system infrastructure (wind generator, photovoltaic panels) will require additional space and may affect building and structural requirements.

Careful consideration should be given to the visual intrusion on neighbors and any effects on the surrounding environment. Zoning, codes, and other governmental/municipal restrictions may not allow for alternate fuel/energy sources.

5.8 Regulations (Local, Regional, Country)

5.8.1 Air Quality Requirements

Determine if local air quality regulations exist such as generator emission restrictions. These regulations may restrict the acceptable hours of operating backup generators.

Particular concerns that data centers may have for local authorities are the emissions of oxides of nitrogen (NOx), carbon monoxide (CO), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), ionic pollutants such as chlorides, and particulate matter (PM-10).

NOTE: The United States government enacted a law through the 1990 Clean Air Act that mandated individual states are required to only meet the minimum requirements of the Act. However, individual states were, and continue to be, permitted to enforce stricter requirements.

5.8.2 Noise Requirements

Determine if there are any local, regional, or federal regulations that identify acceptable levels of noise from equipment operating within the data center facility or campus or that cannot be exceeded at or beyond the property line.

5.8.3 Towers and Tall Structures Requirements

Determine if there are any local regulations that will restrict the height or proximity to other facilities for communication towers, water tanks, cooling towers, and other tall structures.

Determine if there are any federal or local requirements to hide these structures from public view.

5.8.4 Fuel Tanks Requirements

Determine if there are any local regulations that will require double-walled tanks or restrict the size or proximity to other facilities for fuel tanks.

Determine if there are local regulations that will allow above ground fuel tanks only.

Evaluate security of the fuel tanks.

5.8.5 Generator Requirements

Emission levels need to meet state and local emission requirements. Generator hours may be limited by local codes because of air quality emission control or noise abatement.

5.8.6 Site Access and Required Parking

Determine if there are any road restrictions (permanent or seasonal) on the size of vehicular traffic or time of day restrictions for truck traffic.

Determine how the AHJ determines the required number of parking stalls for a new facility. Negotiations with the AHJ may be necessary to try to reduce the number of required stalls if the AHJ treats the data center as typical commercial office space.

Consideration should be given to disaster recovery scenarios, which may require additional parking for the respective personnel.

5.8.7 Setbacks and Sight Lines

Determine the required setbacks from the property line for the building, parking, or perimeter security. Verify with the AHJ that the target location does not have sight line restrictions that must be mitigated or that they can be done so economically.

5.8.8 Environmental Assessment

An environmental assessment could include an environmental impact study if wetlands are impacted or if the site has any contaminants present. An environmental impact study may be required by the AHJ. Ensure sufficient time prior to proceeding with the detailed design phase to allow completing the study and attend AHJ meetings as required to obtain approval.

NOTE: The United States Environmental Protection Agency and the European Commission (i.e., Environmental Impact Assessment Directive 2011/92/EU) may provide further relevant information specific to the site or project.

6 Space Planning

6.1 Overall Facility Capacity

6.1.1 General

The capacity of a data center is based on the size of the computer room space (floor space or rack space available for IT and telecommunications equipment), and the capacity of the power and cooling systems per unit of computer room floor space. High-density data centers have a higher capacity of power and/or cooling per unit of computer room floor space.

A balance between space and capacity needs to be determined at the outset when designing a new data center and when modifying an existing data center space. The balance will depend on the type of IT and telecommunications systems the data center is to support and the number/combination of those systems that are to be placed within each cabinet or rack.

When planning for the overall facility:

- Design to accommodate a defined load (N) over a defined area.
- Consider current and future platforms for servers, storage and networking equipment when identifying the design load and area requirements.
- Consider the physical expansion of the building or additional buildings on the site.
- Estimate the change in IT program and set upper and lower limits that the space and infrastructure plan may be expanded or contracted to meet the ITE and building program.
- Determine percentages for mainframe high-end processing, mid-range processing, small-form or blade servers, communications networks, and storage.
- Identify potential growth rates not only within business units, but also identify growth rates across platforms as these effect capacity and space plans.
- Define the portions or segments in which the data center will be developed between the initial build and final build if not developed to the full capacity at its inception. This will be the “module” size for the life of the facility.
- Define and connect the ITE program to the facility program with the operational expense and capital expense budgets, and the length of time to construct, test and implement following phases of work. Similarly, project the total cost of ownership (TCO) for builds based on the kW development integer chosen and the capital to be expended on the initial build, ultimate build, and the costs of the incremental work between these two points.

If it is perceived that meeting the performance balance will require delivery of both high levels of power and large amounts of cooling to the cabinet or rack, it may be more cost-effective to design and build a more moderate density data center by designing the data center into a space that can accommodate a larger computer room. The resulting space utilization with power and cooling density limitations should be clearly communicated and documented.

6.1.2 Module and Modular Design

Data center “module” sizes might not be in exact size harmony with each other or that they would be added in synch. There are logical break points in the entire system module sizes discussed in the Standard. As long as modules are added at or ahead of ITE need, there will be no risk to the operation’s Class rating falling. Modules may certainly be built out ahead in anticipation of following ITE or data center needs. For example, a data center owner may choose to construct the entire building shell of the data center, only to defer some of the data center space and infrastructure space to a time when it is needed in order to preserve capital. Some modules might actually lag development, which may pose a problem in maintaining the Class rating.

Should a modular infrastructure solution be utilized, link the electrical deployment critical power kW output size to the corresponding cooling capacity additions to the storage and compute cluster module’s growth increment. For example, if 200 cabinets at 6 kW each are anticipated, add 1,200 kW of UPS output power and cooling in addition to any space needed, excluding any safety or design factors. If the 200 cabinets and 1,200 kW of IT load is the typical deployment, then that is the module size.

The time to make facility or ITE deployment decisions must also be factored into space planning decisions and module sizes. The space and infrastructure total deployment time (viewed as the total time to decide an addition is necessary, solicit the bid to develop the space, and turn it over) must be less than the IT planning time offered to the space developers. For example, should the company be incapable of providing IT projections beyond the time it would take to develop the requisite space or infrastructure by a built-in-place approach or by the existing delivery methods and processes, options available would be to either build ahead of the IT need or to adopt a facility or infrastructure solution that can meet that need.

An example of the decision flow for determining module size can be found in Figure 6-1. Alternatively, use of a checklist, as shown in Table 6-1, can be used.

This standard offers no endorsement of any particular building approach as the ultimate choice whether to employ a built-in-place, modular or containerized data center space, or infrastructure solution resides solely in the hands of the space developer or end user. Ultimately, the data center space and infrastructure must fully meet the Class requirements of the operation. This will be affected by the operation's access to capital; the ability to secure an actionable ITE program to support the space and infrastructure builds; and the speed in which space, cooling, and power can be deployed ahead of IT need. There are fewer choices if less time is available.

Density, module size, capital, and schedule requirements for a build and the Class rating of the platform and applications will be powerful contributors to space and infrastructure programs and will determine ultimate facility plans.

6.2 Power Systems

6.2.1 Introduction

The primary considerations when developing the space plan for the power systems include the spacing of electrical feeders, conduit and busbar usage, if the UPS system is centralized or distributed, the additional needs of redundant power systems, replacement space, and required equipment service areas.

6.2.1.1 Requirements

Sufficient clearances shall be provided for safety, access and maintenance for all electrical equipment as specified by the manufacturer, applicable codes and standards, and the applicable AHJ.

Sufficient access shall be provided to the electrical equipment spaces to remove components or systems for maintenance or replacement as specified by the manufacturer, applicable codes and standards, and the applicable AHJ.

6.2.1.2 Recommendations

Minimize the distance or increase the voltage of electrical feeders between various distribution equipment; excessive distances require increased feeder sizes and additional costs.

Provide sufficient space for the conduit runs or busbars with minimal bends. Because the routing of the electrical feeders can be very complex in a data center, coordination with all other disciplines is required.

Provide dedicated space and physical separation for each system in configurations that have redundant power systems or redundant computer systems.

Subsystems of the electrical distribution systems (e.g., main switchboard, generator switchboard, centralized UPS and batteries, and stored energy systems if appropriate) should be installed in dedicated electrical rooms or located outside of the data center computer room space, separated by a fire-rated wall. See Table 7-1 regarding fire-rated construction.

The electrical infrastructure for the data center should be isolated and separate from the base building electrical systems if the building is not exclusively dedicated to the data center function.

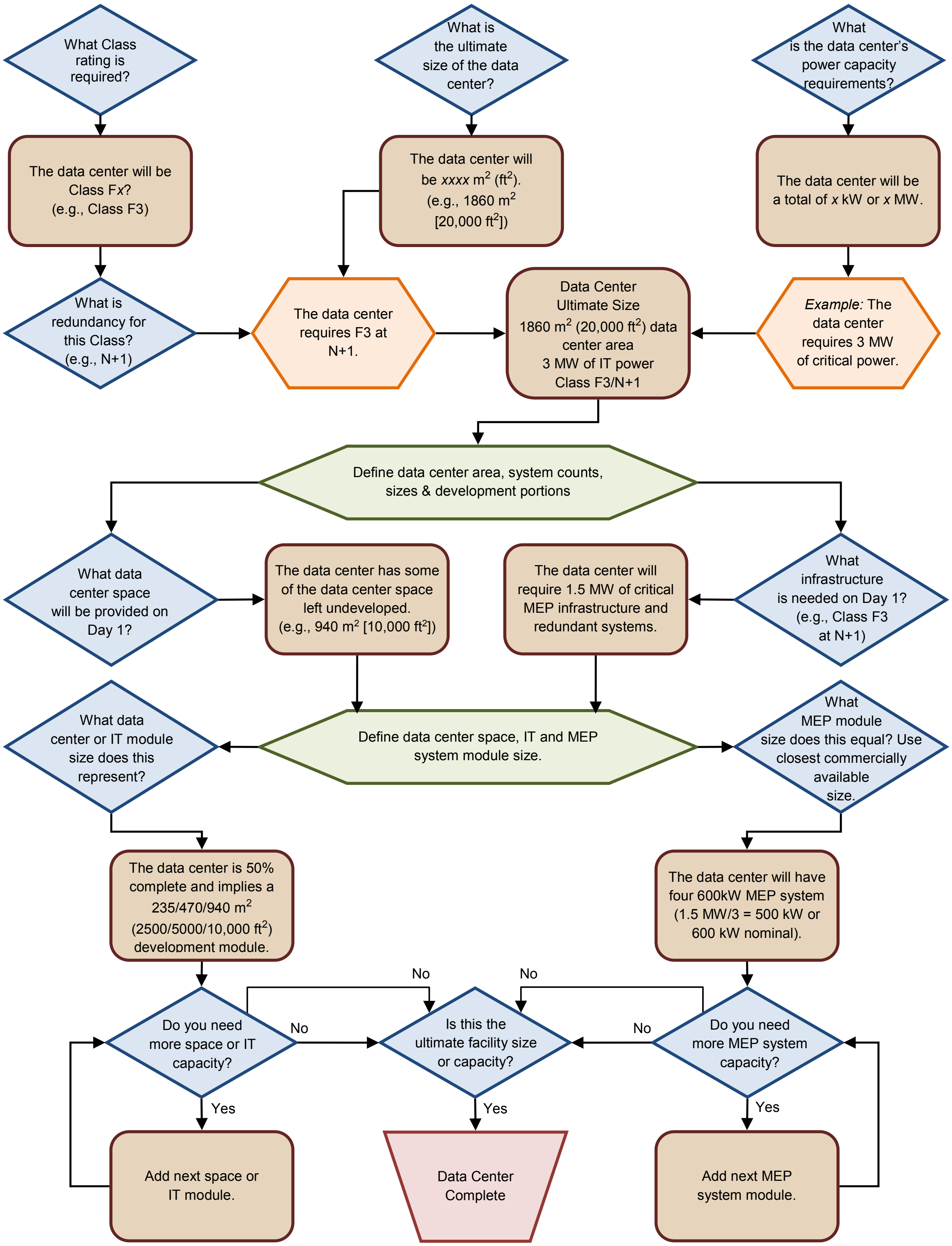


Figure 6-1
Example Module Size Decision Tree

Table 6-1 Example of a Module Size Design Checklist

ID		Question or Item	Purpose or Notes
1		*Class Rating Checklist*	
1.1		Does the data center have a Class rating?	Define Class rating for the project.
1.2		If "Yes", what is it?	
1.3		If "No", here are some questions concerning the data center and aspects of the business the data center support:	Ask question to determine system and service availability levels.
	1.3a	Does the business operate worldwide, located within multiple time zones, or require after-hours access?	
	1.3b	Does the data center fail over to another disaster recovery facility, or is it able to sustain an outage within the facility without undue harm to business operation?	
	1.3c	Does the business have extended or 24/7 operational requirements?	
	1.3d	Does the business require 24/7 processing or storage?	
	1.3e	Does the business require a 24/7 network?	
	1.3f	Can the data center have scheduled outages for maintenance purposes?	
	1.3g	Does the data center support transaction verification or processing?	
	1.3h	If part of the construction is deferred, can business operations sustain an outage during planned system or building additions?	
2		*Data Center Ultimate Size Checklist*	
2.1		What is the target area per rack or ITE position?	What is the area/rack for the data center plan?
2.2		How many rack positions does this data center need?	Define the number of ITE locations.
	2.2a	As a minimum?	
	2.2b	Ideally?	
	2.2c	At an absolute maximum?	
2.3		How many rack positions are needed on day one?	Initial rack or ITE positions needed day one
2.4		Are there any factors that would increase or decrease the data center rack space, capacity or the speed of development?	Identify space planning considerations that will increase or decrease the per unit space assumptions from above
2.5		When does the data center need to be ready for service?	When will the data center be needed?
2.6		What is the growth rate for the data center?	How fast will the data center grow, requiring further development if work, systems, or space is deferred?
2.7		How long does this data center need to be in service?	What is the lifespan of the facility before complete renovation or abandonment?

Table continues on the next page

ID	Question or Item	Purpose or Notes
3	*Data Center Power Density Checklist*	
3.1	What technology is currently being employed?	Technology used today will offer the current power density.
3.2	What technology is projected to be employed?	Technology will indicate the power to be consumed in the future.
3.3	What is the proportion of the systems to be used processing, storage, network?	The mix and proportion of the technologies used will result in the target power density for the facility.
3.4	Are there considerations to current or future use of high-performance computing?	This will increase power density markedly and must be considered.
3.5	Are there any projects or programs likely to come into the data center in the next 3 years that is not here today?	What are the near- and mid-term projects and programs that might adversely affect the power density?
3.6	How much spare capacity is desired or planned?	How much spare capacity is needed for planning and system safety purposes?
3.7	How much growth in load density is planned?	How much do you see the technology mix changing and affecting the power density?
4	*Data Center Phased Development Checklist*	
4.1	How much data center space do is planned to be built initially?	What is the size of the first build?
4.2	Are there plans to leave undeveloped space for future use?	This allows for growth before a larger build must be undertaken?
4.3	Is there correlation between initial build size and data center size (e.g., does the planned development break into sensible portions)?	Power usage per area (e.g., W/m2 or W/ft2) should be equivalent when comparing the data center area and the plant's total area.
4.4	What are the physical area build increments for the data center floor?	When considering the initial build requirement, the ultimate build size, what is the logical space development size (e.g., 1400 m2 [15,000 ft2] modules in four phases for a 5600 m2 [60,000 ft2] data center)
4.5	As the data center grows, is it planned or desired to add electric utility and cooling modules in increments equal to the capacity of the added data center IT modules?	Increasing electric and cooling in increments equal to the increase in IT will minimize operating costs, but it might be more disruptive when IT modules are installed. Operating with less than the designed Availability Class rating can be less disruptive when changes are made, but there will be operating cost penalties for stranded capacity until full capacity is utilized.
4.6	How many development phases are planned or desired?	
4.7	What is the electrical topology for the data center?	What topology have you chosen to meet your Class requirement?
4.8	What is the electrical build increment for the data center floor?	What electrical distribution system meets the Class requirement at the stated power density for a data center space module?
4.9	What is the electrical build increment for the central electrical plant?	What electrical plant-level system meets the Class requirement at the stated power density for a data center space module?
4.10	Can the electrical system be partitioned for future additions without a service interruption?	Has additional equipment or connection capability been accommodated for transparent, future work in concert with your Class rating?

Table continues on the next page

ID	*Question or Item*	*Purpose or Notes*
4.11	What is the mechanical topology for the data center?	What mechanical distribution system meets the Class requirement at the stated power density for a data center space module?
4.12	What is the mechanical build increment for the data center floor?	What mechanical plant-level system meets the Class requirement at the stated power density for a data center space module?
4.13	Can the mechanical system be partitioned for future additions without a service interruption?	Do you need to account for additional equipment or connection to allow for transparent, future work in concert with your Class rating?
5	*Utility Module Size Checklist*	
5.1	Based on the space and load planning conclusions above, what is the logical module size for a given electrical system?	What is the electrical component size viewed in output kW and input kVA for your selected topology?
5.2	Are the electrical module sizes typical "trade" sizes?	What is the typical industry size for your key electrical components – UPS power module, generator, switchboard, critical power distribution, and substation transformer?
5.3	Based on the module size, what is the minimum number of electrical modules needed for the initial build?	Fully consider your Class rating when determining the number of modules for your initial build
5.4	Based on the module size, what is the minimum number of electrical modules needed for the ultimate build?	Fully consider your Class rating when determining the number of modules for your ultimate build
5.5	Based on the space and load planning conclusions above, what is the logical module size for a given mechanical system?	What is the mechanical component size viewed in kW and net tons for your selected topology?
5.6	Are the mechanical module sizes typical "trade" sizes?	What is the typical industry size for your key mechanical components – air handlers, pumps, chillers, coils, piping and the like?
5.7	Based on the module size, what is the minimum number of mechanical modules needed for the initial build?	Fully consider your Class rating when determining the number of modules for your initial build
5.8	Based on the module size, what is the minimum number of mechanical modules needed for the ultimate build?	Fully consider your Class rating when determining the number of modules for your ultimate build
6	*Space Planning Checklist*	
6.1	Knowing the data center development phases and physical sizes from before, what space is required for the associated electrical system?	What is the space size for a given module?
6.2	Does the electrical room require partitioning at this Class level?	
6.3	How many electrical module spaces are required?	
6.4	Do the electrical spaces need to be contiguous?	
6.5	Do the electrical spaces need to be adjacent to each other?	
6.6	Do the electrical spaces need to be adjacent to their data center module(s)?	
6.7	Are there any specific requirements for the electrical rooms to be on an outside wall, have direct access to the outdoors, or possess specific exiting requirements?	

Table continues on the next page

ID	Question or Item	Purpose or Notes
6.8	Does the mechanical room require partitioning at this Class level?	
6.9	How many mechanical module spaces are required?	
6.10	Do the mechanical spaces need to be contiguous?	
6.11	Do the mechanical spaces need to be adjacent to each other?	
6.12	Do the mechanical spaces need to be adjacent to their data center module(s)?	
6.13	Are there any specific requirements for the mechanical rooms to be on an outside wall, have direct access to the outdoors, or possess specific exiting requirements?	

6.2.1.3 Additional Information

The space required for the power systems will be proportional to the required capacity and level of redundancy/reliability of the electrical systems. It is not proportional to the square footage of the computer room alone. For example, a power system for a 1,000 m^2 (10,000 ft^2) computer room with a total critical capacity of 1 MW will require roughly the same physical space as a 500 m^2 (5,000 ft^2) computer room with a total critical capacity of 1 MW at the same redundancy/reliability level.

The following is a partial list of electrical equipment, components, and systems that should be included in the space plan:

- Equipment typically installed in dedicated electrical rooms outside the main computer area:
  - Service entrance switchboard (medium or low voltage, metal enclosed, or metal clad)
  - Unit substation (medium voltage)
  - Tie breaker section for dual entrance configurations
  - Generators (indoor/outdoor)
  - Generator paralleling switchboard
  - Automatic transfer switches (ATS)
  - Load banks (permanently installed or portable load banks on trailers requiring connection to electrical systems)
  - Distribution boards (critical loads, noncritical loads, life safety loads)
  - Transformers
  - Centralized UPS - static system or rotary system
  - UPS battery room (static or rotary system with flooded cell batteries)
- Equipment typically installed in the computer room spaces:
  - Remote power panels (RPPs) – cabinet or rack mounted panels used to provide a concentration of breakers, typically close to the load
  - Power strips within each cabinet that provide power dedicated to the specific cabinet
  - Distributed UPS located in close proximity to the loads they support (i.e., rack or row level) with immobilized electrolyte batteries (e.g., VRLA)
  - OCP open racks containing AC-DC power supplies, busbars and BBUs
- Equipment typically installed outside the computer room
  - Power distribution units (PDUs) are recommended to be installed in dedicated electrical rooms or shared power and cooling equipment rooms outside the computer room space.

    The benefits to locating the PDU equipment outside the computer room is that the electrical operations and maintenance activities are outside the critical computer room space. PDUs come with or without transformers and static transfer switches (STS), depending on the UPS design and load requirements.

Consider whether these systems are to be built-in-place, factory-build modules, or containerized solutions. While they typically reside outside of the data center space, these electrical systems may be included in more comprehensive solutions that include the mechanical and IT space in one built solution set.

When a factory-assembled, modular, or containerized electrical system is chosen for the power solution, the considerations of these system to the non-modular portions of the data center is typically different than if the electrical systems were built in place. Consider items such as installation during construction, additions to the electrical system during ongoing operations, and protection from weather for systems installed outdoors.

6.2.2 Electric Utility Service Feeds

6.2.2.1 Single Entrance Single Pathway

6.2.2.1.1 Recommendations

Independent electric utility service feeds and associated switchboard should be located in a dedicated space that is adjacent or in close proximity to the primary data center electrical distribution space.

6.2.2.2 Single Entrance/Dual Pathway

6.2.2.2.1 Recommendations

The electric utility service feeds and associated switchboard should be located in a dedicated space that is equally distanced between or in close proximity to the dual data center electrical distribution spaces.

6.2.2.3 Dual Entrance/Dual Pathway

6.2.2.3.1 Recommendations

Independent electric utility service feeds and associated switchboard should be located in dedicated spaces separate from each other. Utility entrance space A should be located adjacent to electrical distribution space A, and utility entrance space B should be located adjacent to electrical distribution space B. A catastrophic event affecting one should not affect the other.

6.2.3 Generator Power

6.2.3.1 Indoor/Outdoor Installations

6.2.3.1.1 Introduction

Locating the generators either indoors or outdoors is based upon site and client specific requirements.

While there may not be a large difference in cost between locating the generators indoors or outdoors, factors to consider during the evaluation of generator location include:

- Indoor generators
  - Placement of indoor generators in an area of the building with the lowest cost per square meter to construct
  - Additional costs for items associated with an indoor implementation, such as automated louvers, noise reduction/mitigation, and exhaust management
  - Requirements for weight, vibration, lateral structure, and fire rating of surrounding surfaces of the space intended for a generator
  - Fuel tank capacity and location
  - Accommodation for future generators
  - Local and building regulations, codes, or standards
- Outdoor generators
  - Increased exposure to physical and weather-related damage
  - Requirements for weight, vibration, lateral structure, and fire rating of surrounding surfaces of the space intended for a generator
  - Fuel tank capacity and location
  - Accommodation for future generators
  - Energy considerations; incentives for off-grid operation
  - Air quality or noise abatement restrictions
  - Local and building regulations, codes, or standards

6.2.3.1.2 Requirements

Generators installed outdoors shall be installed within shelters.

Generator exhaust systems shall be located so that they do not flow into building ventilation air intakes, preferably on the prevailing downwind side from building ventilation air intakes.

6.2.3.1.3 Recommendations

It is recommended that generators are installed indoors. With sufficient clearances, indoor generators are easier to monitor and maintain, especially during extreme weather conditions when their operation may be required.

6.2.3.2 Onsite Fuel Storage

6.2.3.2.1 Introduction

Space planning will need to account for onsite fuel storage. The quantity of fuel that is required and can be stored will be affected by the following:

- Availability of backup or disaster recovery site for applications supported by the data center and expected time required to recover applications at the backup site
- Proximity of the data center to locations or services, which provide fuel replenishment
- Priority status of the organization and response time for fuel replenishment during regional disasters, such as earthquakes, floods, and hurricanes
- Criticality of applications and regulatory requirements
- Business drivers requiring self-sustaining operations
- Security considerations
- Protection from the elements (e.g., floods, storms)
- Location of fuel pumps
- Local codes and acceptance by the AHJ
- Environmental requirements

Storage of large amounts of fuel onsite may trigger extensive jurisdictional and environmental permit reviews. Also, the permitting process may be more stringent for underground storage tanks (UST) than for aboveground storage tanks (AST).

6.2.3.2.2 Recommendations

The minimum amount of generator fuel storage required should be between 8 and 96 hours running at full load, depending on the data center availability requirements.

Depending on specific owner needs, the required amount of fuel storage or availability required may be far greater than four days.

6.3 Cooling Capacity

6.3.1 Introduction

The space required to support the cooling systems will vary depending on the type of cooling system selected. Items to consider include:

- Central air handlers versus perimeter CRAC units versus row-based, ceiling mount, or point-of-use cooling systems
- Chilled water versus air-cooled systems
- Liquid-cooled cabinets in the computer processing area (including, but not limited to, controlled racks, rear door heat exchangers, cold plate technology, or even liquid directly to the ITE)
- Immersion-based cooling in which the electronic equipment is continuously and horizontally submerged in tanks of liquid coolant instead of the traditional mounting style in vertical air-cooled racks
- Cooling tower (chilled water system)
- Thermal storage (chilled water system)
- Piping and pumps
- Other required equipment or resources

As with the electrical systems, consider whether these systems are to be built on the site or are to be factory-built modules or containerized solutions. While they typically reside outside of the data center space, these mechanical systems may be included in more comprehensive solutions that include the mechanical and IT space in one built solution set and may also require a commitment to a cooling solution early in the facility's lifetime.

See Table 6-2 regarding the decisions affecting capacity planning for mechanical systems.

Table 6-2 Liquid and Air-Cooled System Options and Primary Design Parameters

Type of System and Related Parameters	
For a liquid-cooled system	*For an air-cooled system*

What type of liquid-cooled system?
• Cooling water system
  ○ Cooling towers
  ○ Direct evaporative cooling (mist cooling etc.)
  ○ Indirect water cooling (sea/river or groundwater used to remove heat from the cooling water via heat exchanger or similar method)
• Chilled water system
  ○ Air-cooled (dry) chillers
  ○ Water-cooled (wet) chillers
  ○ Absorption chillers (for facilities with on-site cogeneration capabilities)
• Immersion cooling
	What type of air-cooled system?
	• DX cooling system
	Usually less efficient than water-based cooling but is more flexible and scalable.
	• Free air cooling
	Highly efficient, but it only works at certain climates, and needs ITE with high environmental tolerances. Usually supplemented with DX or evaporative cooling.
	• Indirect air cooling
	Uses heat exchangers with outside air. Less restriction on climate than free air cooling, but at higher initial cost.

Decide on following parameters:
• Chilled water/cooling water temperature settings (supply and return)
• Water pipe diameters
• Pump capacity and speed
• Chemical additives
• Whether to adopt thermal storage
  ○ Capacity? (minutes or hours)
  ○ Where? (underground or outdoors)
It is desirable to maintain laminar flow inside pipes to reduce pump power requirements.
Minimizing the number of bends and valves in the main pipes and increasing the bend radii reduces the minimum pump power needed.
Both pipe sizes and pump ratings must look forward into 5-7 generations of ITE needs (15-20 years)
	Decide on following parameters:
	• Air duct cross sections
	• Fan capacity and speed
	• Heat exchanger capacity (if applicable)
	As fan power rises proportional to the 4th power of air speed, secure as much duct space as possible in order to reduce air speed.
	Minimizing the number of bends and dampers in the main pipes and increasing the bend radii reduces the minimum fan power needed.
	As air-based cooling is more amenable to modular design, forward capacity planning is less critical than for water-based cooling, but module size needs to be carefully determined.

6.3.2 Recommendations

Mechanical infrastructure for the data center should be isolated and separate from the base building mechanical systems if the building is not exclusively dedicated to the data center function.

The cooling system design capacity should be sufficient to support the electrical distribution system and subsystem cooling requirements within each cabinet, rack, or ITE zone. Cooling equipment and ITE should be powered separately.

When a factory-assembled, modular, or containerized IT system is chosen for the IT program solution, the considerations for these systems is typically different than non-modular portions of the data center with mechanical systems that were built in place for specified component size, system configuration, and cost. Considerations include installing these systems during construction activity, the effects of adding to the mechanical system during ongoing operations and aligning additions with ITE system additions.

Just as there are considerations for the number of utility feeds for the electric service, there should also be equal consideration for how to keep the cooling system up to the required reliability and resiliency of the desired design point. Especially if the cooling system is going to be configured in an N + x or 2N fashion, then there should also be considerations about the number and placement of water ingress and outlet points, primary/variable loops as opposed to dual redundant loops, maintenance capabilities on all different parts of the system with minimal or no impact on the rest of the system, failover capabilities, etc.

The next consideration should be how to achieve cooling in the computer room itself without exposing the ITE to potential water leaks. There are various methodologies to achieve this, including putting the CRAC/CRAH units just outside the computer room such that all the water piping is outside of that space, using various types of heat exchangers outside of the room that connect into the cooling inside the room to remove heat from the air or refrigerant back into the water loop, etc. Various refrigerant systems are fully compatible with ITE rooms because if there is a leak, then the refrigerant turns to a gas at typical room temperatures, thereby protecting the equipment from moisture. Also remember that water has been placed inside the computer room for almost 40 years with few ill effects (such as for mainframes), so it is now coming back into vogue especially in data centers where water goes directly into a cabinet-based cooling system or even directly into the ITE itself to remove the heat with very little need for air movement.

6.3.3 Additional Information

The space required for the cooling systems will be proportional to the required capacity and level of redundancy/reliability for the overall design specification. It is not necessarily proportional to the size of the computer room space alone. For example, the cooling system for a 1,000 m^2 (10,000 ft^2) computer room with a total critical capacity of 1MW will require roughly the same physical space for the cooling infrastructure as a 500 m^2 (5,000 ft^2) computer room with the same critical load (when utilizing the same type of cooling system in both cases). Note, however, that large changes in the assumed rack power density will probably lead to different design choices for the cooling system as well. A key consideration is that as rack power density increases, so does its heat load and the air volume that the ITE will require (unless they are directly liquid cooled, which is still fairly rare except in HPC applications). This means that for the best efficiency and ability to avoid equipment malfunctions or shutoffs because of over-temperature that a closely coupled cooling system should be utilized (which include a variety of methodologies, but usually encompass some type of air containment strategy).

6.4 Data Center Supporting Spaces

6.4.1 Adjacencies of Functional Spaces

6.4.1.1 Introduction

The appropriate adjacencies of spaces can be determined by performing an exercise of required staff and material flow. Figure 6-2 and Figure 6-3 show examples of staff and material flow through a data center; they are not meant to show the physical adjacencies, but they can be used to assist in identifying required functional adjacencies.

The adjacency of programmatic space between traditional and modular and containerized construction varies. In traditional construction, the developer may choose to deploy in phases in a single structure. Circulation paths, the grouping of support elements and the relationship to other buildings and non-data center elements is more flexible for the simple reason that the developer of the data center can define the overall shape of the building and the site.

For modular and containerized data center solutions, the expansion elements are set, either by:

- The physical size of the element, such as the amount of ITE racks that can be accommodated or the size of the supporting utility infrastructures.
- The quantity of modules or containers, especially as it is deployed against the common utility and telecommunications infrastructure that support those modules and containers.

Similarly, modular units and containers may:

- Be installed either indoors or outdoors
- Have dedicated utility and critical power electrical systems to each module or container
- Have a centralized or distributed alternate power source
- Utilize a central cooling plant
- May have multiple telecommunications entrance rooms and MDAs, depending on how the site is configured
- May have support space grouped unlike a traditionally built data center

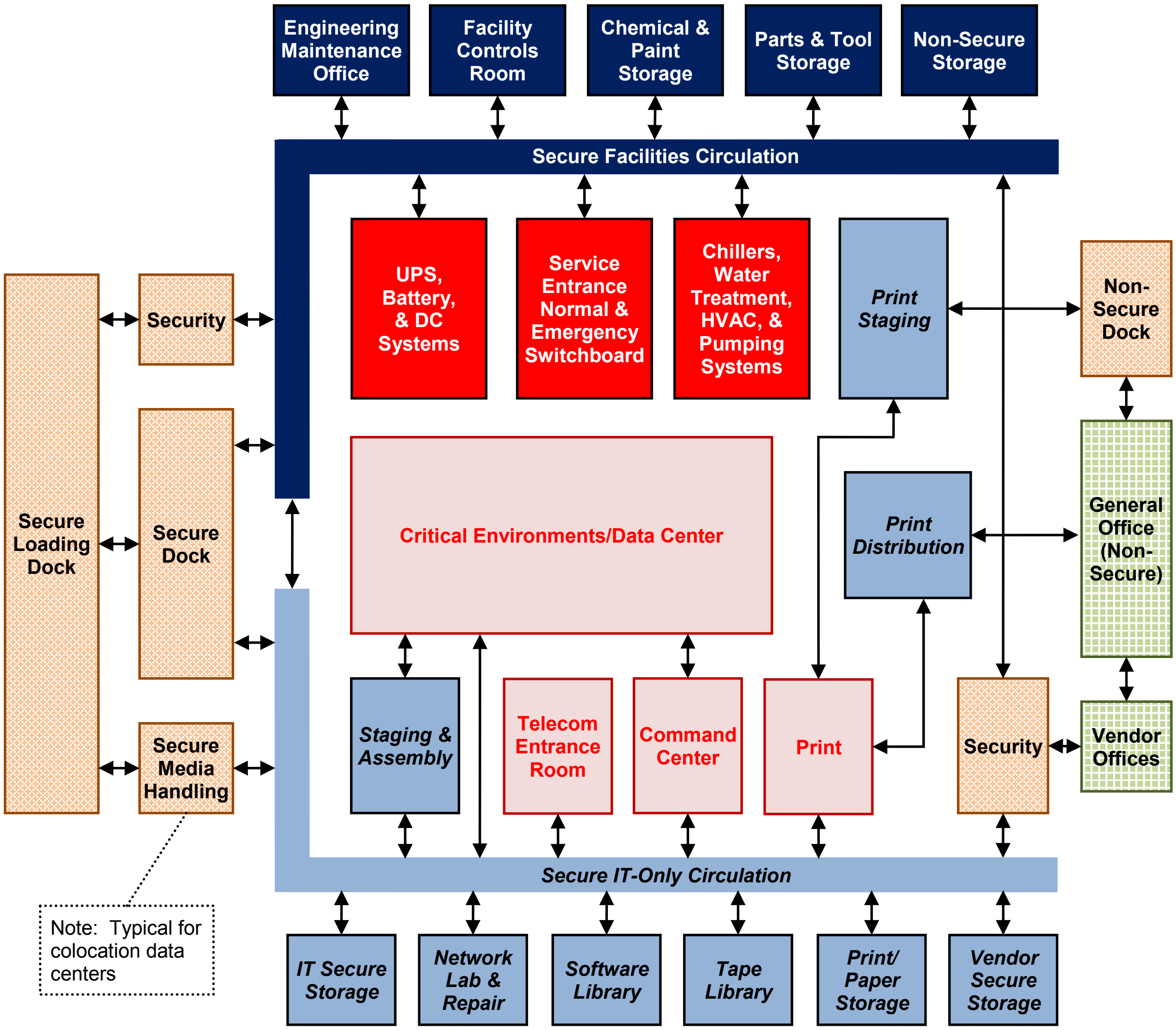


Figure 6-2
Space Adjacencies of a Traditional Data Center

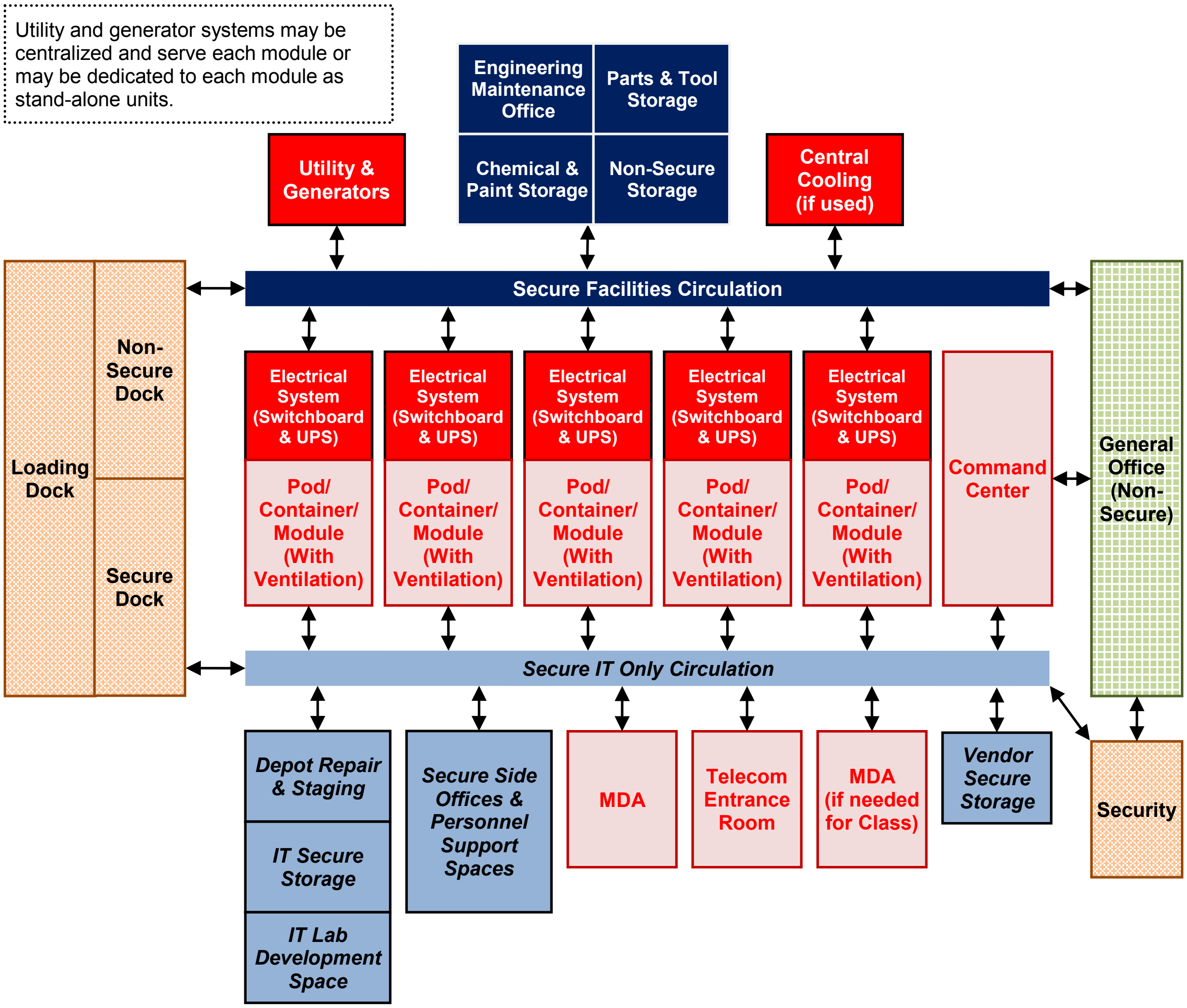


Figure 6-3
Space Adjacencies of Modular or Containerized Data Centers

6.4.2 Security

6.4.2.1 Recommendations

A security room should be located at or adjacent to the main personnel entrance to the facility.

Visitor sign-in area should be physically separate from the facility security operations.

The security room should include the security operations facility, including video surveillance system (VSS) monitors and the database and front-end user interface of the access control system (ACS). When planning this space consider:

- VSS monitoring space requirements
- ACS space and storage requirements
- Unobstructed access to key storage
- Unobstructed access to access-card (temporary and blank) storage
- Fire/smoke alarm monitoring systems
- Restricted access to the security control room

Refer to Section 12 for a detailed description of data center security requirements.

6.4.3 Telecommunications Entrance Room

6.4.3.1 Introduction

The function of the telecommunication entrance room is twofold:

- Provide a secure point where entering media from access providers can be converted from outdoor cable to indoor cable.
- House the access provider-owned equipment such as their demarcation, termination, and provisioning equipment.

Refer to Section 14 for a detailed description of data center telecommunications requirements.

6.4.3.2 Location

6.4.3.2.1 Requirements

The location and space requirements for telecommunications distributors including MDA, IDA, and HDAs, shall be considered. The location of these telecommunications distributors shall consider the maximum channel length of applications supported on the backbone cabling types to be installed.

6.4.3.2.2 Recommendations

The location of the entrance room with respect to the computer room should be designed to accommodate the distance limitations of circuits to be provisioned from the entrance room. Where possible, the entrance room should be adjacent to or be in a secured space within the computer room.

Pay particular attention to distance limitations for T-1, T-3, E-1, and E-3 circuits, the type of media these circuits utilize, and the number of DSX panels and patch panels in the channel. See applicable cabling standards (e.g., ANSI/TIA-942-B for coaxial circuits) for guidance on the maximum distances allowed for T-3 and E-3 circuits in data centers.

The entrance room with the primary bonding busbar (PBB) should be close to the main electrical grounding busbar to minimize the length of the telecommunications bonding conductor (TBC), the conductor that interconnects the main electrical ground bar to the PBB. The TBC shall be sized per applicable standards (e.g., ANSI/TIA 607-C, NECA/BICSI 607, ISO/IEC 30129).

6.4.3.3 Access Provider Considerations

6.4.3.3.1 Recommendations

Where access provision is contracted for the delivery of a service, the access provider's equipment and any associated cabling should be provided with adequate space. Separate or secured cable routes may be required between the entrance room and the access provider's equipment.

Where a separate entrance room is provided, access to the entrance room will be required by both the data center network operations staff and the access providers' technicians. Access to customer-owned equipment in the entrance room and the computer room should be secure from access provider technicians.

The entrance room should be sized to accommodate each anticipated access provider. The designer should meet with each access provider to determine its space requirements before sizing the entrance rooms. Additionally, cabinet and rack space will be required for customer-owned equipment and termination of cabling to the computer room and the rest of the building.

Where required by an access provision contract, each access provider will terminate its entrance cables and connect its equipment in cabinets or racks separate from the other access providers.

The entrance room may be divided into separate areas to provide separation between access provider-owned and customer-owned equipment. If the room is subdivided, there are typically only two spaces, one for the data center owner and one shared by all access providers. However, if there are multiple access providers, they may each request their own space. These requested spaces may be provided within the same room by using secure fencing, or they can be created through the use of walls.

The customer may ask all access providers to place demarcation equipment (patch panels, DSX panels, and IDC blocks) in shared meet-me or demarcation racks. Consolidating all patching to access provider circuits into meet-me racks and locating patch panels for cabling to the computer room in the same racks or adjacent ones simplifies cabling in the entrance room. Placing the demarcation panels and blocks adjacent to the patch panels that support cabling to the computer room allows circuits to be cross connected to the computer room cabling system using short patch cords.

Access provider equipment included in the entrance room consists of access provider-owned patch panels, digital cross-connect (DSX) panels, routers, SONET, DWDM, and circuit provisioning equipment. The power requirement for the entrance room typically ranges from 500 to 1500 watts per access provider. However, the designer should meet with each access provider to determine its electrical, space, interface, and other facility requirements.

6.4.4 Command Center

6.4.4.1 Recommendations

The command center should have monitoring, but not control, capability for all the data center building systems so that the network and system administrators are fully aware of all data center critical building system alerts or alarms.

The telecommunications room (TR) that supports the command center and other nearby data center support spaces should be outside the computer room.

The work area communications devices within the command center may need connectivity back to two different supporting cross-connect fields. Network monitoring may need connectivity directly to the core network hardware located in the MDA space. Corporate LAN and telephony will need connectivity to the general telecommunications cross-connect serving non-computer room communications.

Some applications may require installation of large displays easily visible to all command center personnel.

Depending on the data center, there may be need for CATV systems (e.g., broadcast cable television, satellite service).

6.4.5 Helpdesk

6.4.5.1 Recommendations

The helpdesk does not need to be located near the computer room and may be integrated into the general office space adjoining the data center. Alternatively, it may be acceptable to build the helpdesk and other general office space in a different building when there is no need for its location within the hardened portion of the data center facility.

Operator workstations for the helpdesk should be provided with critical electrical circuits fed from the backup generator and UPS systems to ensure that support functions are not disrupted by power fluctuations or blackouts.

6.4.6 Print

6.4.6.1 Requirements

Printer manufacturers' environmental criteria shall be included in the design parameters of the facility. Typical environmental parameters that are unique for a print room are humidity and temperature.

6.4.6.2 Recommendations

Printers should be located within a dedicated print room separate from the main computer room. The print room should have its own dedicated air handling system.

Power systems supporting the print functions should be considered critical and supported by the backup generator and UPS systems.

The facility layout should include:

- A separate paper storage room near the print room
- A suitable route from the loading dock to the print room and paper storage room to facilitate the movement of bulk paper products on pallets

6.4.7 Loading Dock

6.4.7.1 Requirements

A dedicated data center facility shall include a secure loading dock area.

Ramps within the loading dock shall comply with Section 7.3

6.4.7.2 Recommendations

Location of the loading dock should provide a step-free route through to the computer spaces with sufficient floor loading capacity to withstand material and equipment weights.

A dedicated data center facility should only have secure delivery capabilities such as a secure loading dock. A multi-purpose building with a data center should have a non-secure loading dock, separate from the data center, for general building deliveries.

For all high-value equipment, a secure loading dock should be provided. Some considerations when planning a secure loading dock include:

- Provision of an enclosed area for the delivery truck to protect deliveries from extreme weather
- Use of a dock leveler so that equipment can be safely moved from any type of delivery truck
- Monitoring of the area by the VSS with preference for security guards from the building's guard station to be able to visually monitor all activity
- Controlling access to the loading dock by the facility access control system with the system able to generate a history of all access attempts

6.4.8 Storage

6.4.8.1 Secured High Value

6.4.8.1.1 Recommendations

A secured storage area for high-value equipment should be located adjacent to a secured loading dock.

The space required for secured high-value storage is recommended to be a ratio of 1:10 in comparison to the computer room space. The minimum space recommended is 23 m^2 (250 ft^2). The ratio may be reduced for large data centers depending on the specific operational practices.

The secured storage area should be monitored by the VSS or access controlled by the facility access control system. The system should generate a history of all access attempts.

6.4.8.2 Staging

6.4.8.2.1 Recommendations

All storage and unpacking activities should occur outside the computer room space, either in storage rooms or in staging areas. Preferably, a staging area should be located adjacent to the computer room. For high-value equipment, a staging area should be provided for unpacking and should be separate from any test-bench or lab space.

A staging area should have an air conditioning system separate from the computer room as cardboard boxes and packing materials can generate large amounts of particulates.

Because of the limited space within a lab, the staging area may be used to test and burn-in equipment for larger mainframe or high-end server space. However, this should not be a regular occurrence, and alternatives should be considered.

The staging area should be monitored by the VSS or access controlled by the facility access control system. The system should generate a history of all access attempts.

6.4.8.3 Vendor Storage

6.4.8.3.1 Recommendations

A secured storage area should be provided for vendors' equipment. The space needed depends on the number and type of vendors who will be storing equipment onsite.

The vendor storage area should be monitored by the VSS or located near or adjacent to a secured loading dock.

The security requirements for vendor storage should be the same as the staging area.

6.4.8.4 Print Storage

6.4.8.4.1 Recommendations

Print storage may be located adjacent either to a loading dock or preferably the print room.

6.4.9 Engineering Offices

6.4.9.1 Recommendations

The engineering offices should be located near the electrical switchboard, UPS, generator, chiller, and HVAC rooms with sufficient space provided for power and cooling engineers and support staff.

For these offices, at least 10 m^2 (100 ft^2) of office floor space should be provided with sufficient noise baffling from adjacent equipment rooms to meet ASHRAE NC rating of not more than 35 dB.

6.4.10 Administrative

6.4.10.1 Recommendations

The administrative or general office space may not require the same level of detailed construction as the data center and supporting back-of-house areas.

Items to be considered in the design of administrative space include:

- Disaster recovery and business continuity plans
- Operational policy during extreme weather conditions (e.g., what areas require staffing)
- Locations of emergency or "shelter in place" areas for personnel
- Future administrative space growth requirements, either as an expansion to the overall data center or as a stand-alone project
- Special function rooms such as a large conference or "war room" with wall-to-wall, floor-to-ceiling white boards

6.4.11 Environmental Design

6.4.11.1 Recommendations

Recycling and compliance with local environmental initiatives is recommended. Local, state, or national incentive programs might be available to underwrite some of the cost. Examples of environmental building best practices and metrics include:

- United States Green Building Council (USGBC), Leadership in Energy and Environmental Design (LEED)
- Building Research Establishment Environmental Assessment Method (BREEAM)
- U.S. Environmental Protection Agency (EPA): Energy Star for Buildings
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE): Building Energy Quotient (bEQ)

6.4.12 Waste/Recycle

6.4.12.1 Recommendations

As these facilities generate a large amount of boxes, packing material, and other waste, adequate space should be allocated for its handling. Frequency of removal, fire prevention/protection, local AHJ requirements, and dumpster requirements, such as size, access, and location, should also be considered.

Materials used in the construction of the data center facility should be recycled and/or locally-sourced whenever practical. Recycling and compliance with local environmental initiatives (e.g., Leadership in Energy and Environmental Design [LEED], BRE Environmental Assessment Method [BREEAM]) are recommended.

6.5 Placement of Equipment When Using Access Floors

Raised access floors are useful for distribution of cooling air, power and data cabling, and mechanical piping. However, as power density increases in data centers and operational efficiency becomes a high priority, and where seismic bracing is required, the use of forced air cooling via access floors is becoming less attractive. In addition, when cooling air shares the same space with cabling and piping, cooling management becomes a problem. Despite these concerns, raised access floors are still the most common feature of data center design.

6.5.1 Cooling

6.5.1.1 Access Floor Vents/Perforated Tiles

6.5.1.1.1 Requirements

When using floor cutouts below racks, cabinets, or vertical cable managers, the grommet system used shall not protrude above the access floor and interfere with proper installation of vertical cable managers and leveling of racks or cabinets.

6.5.1.1.2 Recommendations

While the exact locations of the required floor vents or perforated tiles are not typically known at the time the construction documents are issued for the flooring system, the general layout and approximate locations should be identified. The HVAC designer should coordinate the anticipated quantities with the technology consultant or end user and ensure that the construction documents require the appropriate number and type of cutouts for floor vents and quantity of perforated floor tiles. The exact locations can be validated prior to installation of the flooring system.

It is recommended that a CFD model of the floor design be produced to ensure proper placement of floor tiles and that the cooling design will meet the design requirements. Cooling parameters that are affected by raised floors (e.g., directional airflow, variable air volume control (manual or automatic), fan assist unit, multi-zone dampers) must be considered.

Tile cutouts should have a means of restricting airflow for cutouts that are not fully populated with cabling. Open cutouts can cause more than 50% of the air supplied by the air handlers or CRAC units to bypass the perforated tiles.

The location of the tile cutouts and perforated tiles need to be coordinated with the specific design of the equipment cabinets and racks. If floor tile cutouts are used for cabling, open frame racks should have the floor cutouts positioned directly below the back half of the vertical cable management between each rack. Cabinets should have the floor cutouts positioned below the vertical channel that will be used for power and communications cabling within the cabinet.

Consider positioning cabinets with the front or back edges aligned with the edge of the floor tiles to allow the adjacent clear floor tile to be removed without interference from the cabinet.

Perforated floor tiles should not be installed until they are required. The efficiency and performance of the air distribution system will be affected by additional perforated floor tiles.

6.5.1.2 Ducting

6.5.1.2.1 Recommendations

Ducting may be required, particularly for computer rooms without access floors.

There are many factors that may impact the choice of ducting (or not) as well as the type, placement, size, etc. For air containment purposes, it is becoming common to have duct work added to the back or top of a rack which then goes into either a ceiling return plenum or a dedicated set of duct work overhead, which takes the expelled hotter air back to the cooling units. Another variation is to use duct work to bring in the cooled air into a cold air containment aisle, which is more commonly used in "free" air cooling systems or in very high-density environments. In any of these circumstances, an understanding of the maximum volume of air, acceptable flow rates (velocity), additional fan assist or not, etc., needs to be considered for the duct system. Lastly, for space planning purposes, duct work that may be exposed to low temperatures and/or high humidity will probably need to be wrapped in insulation to avoid condensation problems, which can take up more space than the ductwork itself.

6.5.1.3 Air-Handling Units

6.5.1.3.1 Recommendations

The exact location of the air-handling units should be coordinated between the mechanical engineer, technology consultant and end user to ensure that an optimal equipment layout can be determined without hindering airflow requirements or utilization of floor space.

If air handlers are required to be located within the computer room area because of the size and density of the data center, coordination is required to ensure that the ITE layout and low-voltage cable routing is not constrained.

6.5.2 Power Distribution

6.5.2.1 Remote Power Panels (RPP)

6.5.2.1.1 Recommendations

RPP locations should be coordinated with the ITE layout. The preferred RPP configuration is to place the RPPs at one or both ends of cabinet rows.

6.5.2.2 PDU Placement

6.5.2.2.1 Recommendations

The preferred location for PDUs is in a service gallery (a space outside, but adjacent to the computer room). This location is subject to the approval by the AHJ and if the feeder distances to the remote power panels allow such a placement. Security for this space should be the same as for other critical electrical and mechanical spaces.

6.5.2.2.2 Additional Information

The advantages of this approach are that it removes a maintenance item from the computer room, removes a source of heat (if provided with transformers), and allows the PDUs to be located in less expensive space. The disadvantages are less efficient use of building footprint and much longer PDU cables. The cables must pass through computer room walls (which may not be permissible by local codes), and the PDUs may not be listed for applications outside of the ITE room.

6.5.2.3 Plug-In Busway

6.5.2.3.1 Recommendations

Busway locations should be coordinated with the ITE layout. The preferred busway configuration is to place the input feeder at the end of the row at one or both ends of cabinet rows.

6.5.3 Fire Protection Systems

6.5.3.1 Requirements

Spacing requirements for fire protections systems shall meet applicable fire codes and requirements of the AHJ. For computer rooms with an access floor, a fire suppression system for the space below the floor may be required by the AHJ.

NOTE: See Section 11, the *International Fire Code,* and NFPA 75 for additional requirements and information.

6.5.3.2 Recommendations

Space for fire protection system detection and protection equipment in the data center space should be coordinated with the fire protection system engineer.

Sufficient aisle space should be provided and coordinated with ceiling mounted fire detection and protection devices.

The placement of fire detection and protection devices, which are installed below the access floor (including sprinkler or gaseous suppression piping and tanks), should be coordinated with all power and communications underfloor pathways and placement of ITE situated on the access floor.

For computer rooms with fire suppression below an access floor, the suppression system method should be the same the method provided for the space or area above the floor.

6.6 Computer Room

6.6.1 Introduction

For any data center design, there are always tradeoffs, such as:

- Availability of power (and its redundancy factors)
- Availability of cooling (and its redundancy factors)
- Weight load capabilities
- Space for ITE

A number of decisions should be made at the very beginning of the design phase. The mission critical aspects of the applications running on the equipment will have a direct bearing on:

- Power and cooling redundancy and space planning
- Type of power to be deployed in the cabinets (e.g., AC only, DC only, both AC and DC)
- Maximum cabinet density and the related weight that will be supported
- Ability of the power and cooling to be flexible enough to allow for high variability or low variability of cabinet densities. (i.e., Can several high-density racks with blade servers coexist in a general low density environment without disruption?)
- Usage profile of the ITE. For example, if it is a testing environment with a high rate of change, then the racks may not be fully populated. If in a stable production operating environment, it may be possible to make more efficient use of available cabinet and rack space.
- Where OCP open racks are to be deployed, can a non-centralized UPS supply be fed to racks in the computer room where rack battery backup units (BBUs) are deployed, and can Li-ion batteries be allowed in this space.
- Where a mixture of traditional ITE and OCP open racks are to be deployed, can centralized and non-centralized UPS supplies be fed to racks in the computer room.

Eventually a resource will be exhausted prior to the others, so that resource should be anticipated and addressed at the very beginning of the design cycle to ensure that the most important features to the business are identified.

6.6.2 Telecommunications Spaces and Areas

6.6.2.1 Introduction

NOTE: See Section 14 of this standard and ANSI/TIA-942-B for more information on telecommunications spaces.

The computer room will support one or two main distribution areas (MDA) and can support several horizontal distribution areas (HDAs). Some computer rooms require only a single MDA, however a second MDA is often deployed to provide redundancy.

NOTE: Whereas a small data center may only have an MDA and no HDAs, TRs, or entrance room, a large data center may require multiple entrance rooms to be able to provision circuits in all locations of the data center.

The main distribution area will support the main cross-connect for the computer room and network equipment for the computer room (e.g., core routers, core LAN switches, core SAN switches, firewalls), and it can support a horizontal cross-connect for portions of the computer room near the MDA.

The horizontal distribution areas support horizontal cabling to equipment areas (e.g., server cabinets) and LAN, SAN, console, or KVM (keyboard/video/mouse), or other edge layer switches.

Larger data centers will require more HDAs, not only to ensure that maximum horizontal cable lengths are not exceeded, but also to avoid cable congestion. HDAs should not be so large as to completely fill all cable pathways feeding the HDAs during initial occupancy. Because of the high density of cabling in data centers, HDAs are more often required in data centers to avoid cable congestion than to avoid maximum cable length restrictions.

6.6.2.2 Requirements

The entrance rooms, MDAs, and HDAs need to be situated to ensure that maximum cable lengths for applications to be used in the data center are not exceeded (e.g., WAN circuits, LAN, SAN).

6.6.2.3 Recommendations

If the computer room has two MDAs, they should be physically separated. It may not be necessary to place the MDAs on opposite ends of the computer room if such configuration causes cable lengths for distance-limited applications, such as T-1, T-3, E-1, E-3, and SANs, to be exceeded.

Separate areas of the computer room may be designated to accommodate special structures or cabinets for equipment with high heat loads.

The areas in the computer room where the entrance rooms, MDAs, and HDAs are located may be secured with caging. This may be an end user requirement, depending on internal operating procedures and security requirements.

6.6.3 Equipment Racks and Frames

NOTE: Section 14.12 contains additional information regarding cabinets and racks.

6.6.3.1 Rack Unit Capacity

The amount of ITE that should be placed within a cabinet will depend on many factors that vary for each hardware platform, data center, and organization. For example, each organization has its own practices for populating cabinets, and some may prefer not to install servers in all positions, leaving room for patch panels, switches or ease of maintenance.

ITE implementation planning should consider occupying cabinets based upon:

- Platforms (e.g., appliance servers, mid-range, blade servers, OCP servers and storage)
- Departments, independent of platforms
- Occupancy to the desired density independent of platform or departments

Adequate space should be allocated for patch panels, switches, power strips, and cabling for the cabinet when it is at its desired maximum capacity. Patch panels and power strips should not be placed directly behind servers as this may impede access and airflow to the rear of these systems.

The availability of power and cooling, rather than space, may limit the amount of ITE per cabinet or rack. As equipment power densities continue to increase, it is recommended to design the data center so that space constraints are realized before power and cooling constraints.

To ensure that the initial and ultimate power and cooling system capacities will meet the anticipated demands, validate power consumptions either by performing measurements or by obtaining actual power consumption data from manufacturers. Note that nameplate data typically gives maximum power consumption versus typical operating power consumption. Use of nameplate data alone can result in oversizing power infrastructure by as much as 30–50%.

Initial and ultimate system weight loads should be used when verifying the structural design parameters of the various platforms that will be installed within the computer room.

6.6.3.2 Network Racks

There are generally two (2) types of common network racks, open frame (either 2 or 4 post) or enclosed cabinet racks. If the computer room will primarily utilize open frame racks, they should be placed in areas that would allow for other ITE racks to be grouped together (e.g., allowing for an aisle containment system). Typically, this means putting them out on the edges of the computer room, at the end of rows, or if cable runs must be kept short, then both at the end and middle of the row.

Alternatively, if network equipment will be primarily located in enclosed cabinet racks, then wider (e.g., 800 mm [31.5 in]) cabinets are recommended to provide space for adequate cable management and to provide adequate space for baffles to accommodate equipment with side-to-side cooling.

If redundant network equipment is not located in the same cabinet or rack, these cabinets or racks should be separated to ensure facility infrastructure (power, cooling) diversity. This also provides for physical separation of the cabling pathways and cabling from the redundant network equipment to the servers that are connected.

6.6.3.3 ITE Cabinets and Racks

The layout of the computer equipment, electrical equipment, and air conditioning equipment should be done concurrently. One recommended method is to place the RPPs on the ends of the cabinet rows.

Prior to committing to a standard cabinet size, the end user(s) should review, and have vendors provide mock-ups of the various cabinet configurations that will be implemented. A mock-up of the worst-case configuration with maximum number of anticipated servers and cabling should also be provided. Upon completion of the mock-up, power and heat loads should be recalculated to ensure that adequate power and cooling are delivered to the cabinet.

High density of servers within cabinets, higher density port counts per server, and the number of power cords per server create significant cable and cooling management issues within the server cabinets, particularly those with a 600 mm (24 in) width.

Open racks (e.g., OCP Open Rack v2) with the use of OCP servers are designed so that cables are routed at the front of the rack with either top or bottom egress points (See Figure 6-4). This placement provides for easier maintenance and aids cooling as it removes the possibility of cabling restricting the air flow from rear mounted fans.

Additional room for cable management can be gained by increasing the depth or width of the cabinet. However, increasing the width of the cabinets will reduce the number of cabinets that can be installed in the computer room.

Cabinets should be sized as described in Section 14.12 to provide adequate space to install redundant power strips and vertical cable management in the back of the cabinets.

NOTE: Many open racks and OCP rack cabinets do not require power strips or vertical cable management in the rear because of the use of a DC busbar.

6.6.3.4 Large Frame Servers

6.6.3.4.1 Requirements

The layout of the large frame servers shall be coordinated with respect to weight loads, cooling airflow, power and network connectivity requirements, as they will not fit within the standard server cabinet space. Consult the manufacturer to determine what side access is required (if any).

6.6.3.4.2 Additional Information

Some large frame servers have extremely complicated airflow patterns, which may include a combination of bottom to top, front to back, front to top, and even side to side. It is critical to get a detailed description of the requirements from the vendor in order to correctly situate the server to allow for proper cooling. It is not uncommon that a large frame server may have to sit off by itself, away from other racks, to allow for all of the airflow to work properly, and this takes up quite a bit of floor space to accommodate.

6.6.3.5 Storage Devices

6.6.3.5.1 Requirements

The layout of storage devices shall be coordinated with respect to weight loads, cooling airflow, power, and network connectivity requirements as they may not fit within the standard server cabinet space. Consult the manufacturer to determine what side access is required (if any).

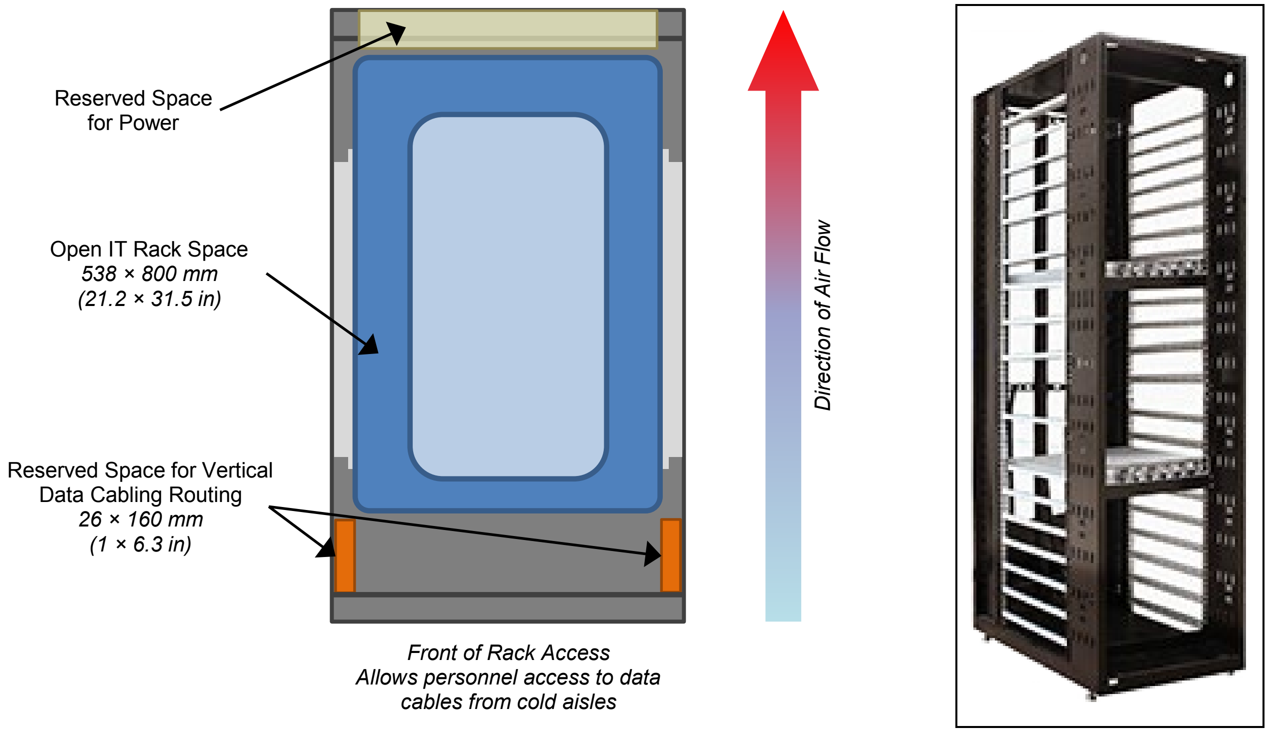


Figure 6-4
Examples of an OCP Open Rack (Top View & Oblique)

6.6.3.5.2 Additional Information

Some storage devices and disk arrays have extremely complicated airflow patterns, which may include a combination of bottom to top, front to back, front to top, and even side to side. It is critical to get a detailed description of the requirements from the vendor in order to correctly situate the storage devices to allow for proper cooling. It is not uncommon that some storage devices are located away from other racks, to allow for all of the airflow to work properly, which takes additional floor space to accommodate. Additionally, the amount of physical disk drives in a single cabinet can easily exceed the floor weight loading characteristics, and it is not uncommon to put down some type of reinforcing plate across extra floor tiles or channel bases under the floor to allow for the placement of the disk cabinet.

6.6.3.6 SAN Frames

6.6.3.6.1 Recommendations

SAN frames are network racks that provide the infrastructure to terminate the media that provide connectivity to the servers. SAN frames typically consist of large quantities of high-density optical fiber termination panels, so they should be located within the SAN equipment area.

SAN frames need to provide proper optical fiber cable management to facilitate interconnects from the patch panels to the SAN equipment.

Where the SAN frames consist of fabric core switches and edge layer switches, the edge layer switches and core switches should be installed in separate racks because the number of edge layer switches may increase. In addition, the amount of moves, adds, and changes at the edge layer is typically much higher than at the core layer. Some SAN frames contain equipment that is primarily side-to-side cooled, so it is common to have them mounted in a wider rack (typically 800–900 mm wide) with internal ductwork to allow for front-side provided air to be directed into the rack, through the side-to-side cooled equipment and then out the back of the rack. Therefore, it is important to consider the additional space that these SAN frame racks can take up in the computer room.

6.6.3.6.2 Additional Information

Some SAN implementations require centralization of SAN storage and switches. Other SAN implementations use core-edge SAN architecture with core switches in the MDA and edge layer switches in the HDA.

6.6.3.7 Telecommunications Distributors

Cabinets in telecommunications distributors (e.g., MD, ID, and ZD in ISO/IEC 11801-5 or in MDA, IDA, or HDA spaces in ANSI/TIA-942-B) shall be a minimum of 800 mm (31.5 in) wide to provide adequate space for vertical cable management.

6.6.4 Computer Room Layout

6.6.4.1 General

For rectangular computer rooms, equipment rows may be run parallel to either long or short walls. The optimum configuration should be determined by examining both options.

However, there can be many complicating factors to consider, including:

- Column placement
- Size and shape (e.g., circular, rectangular, or H-beam)
- Effective "throw" of the CRACs (if used)
- Locations where the most and least air volumes will be available
- Type of cooling methodologies to be implemented (e.g., rear door heat exchangers, actively cooled racks, immersion systems)

It is not uncommon to encounter non-rectangular computer rooms, which add additional complications to the planning process for rack layouts. For best results utilize a combination of a CAD system for overall space efficiency and a CFD modeling system for power and cooling capabilities.

6.6.4.2 Access Floors

6.6.4.2.1 Requirements

For new installations, a preliminary layout of cabinets and racks shall be completed prior to establishing the reference point for the access floor grid in computer rooms, entrance rooms, and TRs. The preliminary layout shall anticipate logical groupings of equipment, flush front alignment of cabinet and rack rows, heat and energy density, proximity to ducting and cooling, and worst-case cabinet depth.

The required clearances for the equipment cabinets, access floor grid, and internal columns will determine where the front alignments of rows of cabinets and racks are best located.

Rear access (or hot aisle width when deployed in hot aisle/cold aisle arrangement) shall allow for minimum service clearance appropriate to the voltage of the equipment per applicable local codes and regulations. Typical hot aisle clearance requirements are 0.9 to 1.2 m (3 to 4 ft) or greater. Because all equipment may not be known at the time of the initial layout, a final layout with adjustments may be required after the access floor grid has been established.

When an access floor is deployed, the access floor grid shall line-up with the preferred layout of the rows of cabinets and allow for easy removal of tiles. For existing installations, the access floor grid has already been determined and equipment layouts and alignments shall be based upon the existing floor grid.

6.6.4.2.2 Recommendations

When an access floor is used, it is a good practice to align one edge of the cabinets flush with one edge of the floor tiles, preferably the front edge to maximize cold aisle airflow by leaving at least two tile positions for perforated tiles. Cabinets and racks should be placed to permit access floor tiles in front and in back to be lifted.

The access floor reference point should be coordinated with the ITE layout, PDUs, CRAHs, chilled water piping, and associated valving.

The reference point should not be selected simply at one of the corners of the computer room without coordinating the placement of the ITE. While having the reference point at one of the corners is the most cost effective from an installation cost perspective as it results in the fewest partial floor tiles, it may not provide the most optimized technology layout. Additionally, the angle between the walls may be slightly more than a perfect 90° angle, resulting in an increasing gap between the access floor tiles and the wall.

The best long-term solution may be to position the reference point some distance away from a corner to accommodate the maximum number of cabinet rows while still maintaining the required clearances.

6.6.4.3 Aisle Lengths

When equipment cabinets or racks are installed adjacent to each other, thus forming a continuous aisle, the length of adjacent cabinets and racks should not exceed 16 m (53 ft). Where one end of an aisle is closed off or has no personnel exit, the maximum length should not exceed 6 m (20 ft). There may be AHJ restrictions on the length of an aisle, which will take precedence over these guidelines.

6.6.4.4 Aisle Widths and Clearances

6.6.4.4.1 Requirements

The minimum width of an aisle shall be the largest value from the following:

- Per applicable local code requirements and required clearances for the voltage level present in cabinet.
- No less than the depth of the deepest equipment within the cabinet(s).
- Per type of aisle:
  - Hot aisle – 0.9 m (3 ft)
  - Cold aisle (raised floor) – 1.2 m (4 ft) with two full tiles between fronts of cabinets
  - Cold aisle (non-raised floor) – 0.9 m (3 ft)
  - Room perimeter – 1.2 m (4 ft)

6.6.4.4.2 General Recommendations

There should be sufficient clearance at the front of cabinets and racks to permit unobstructed access, equipment movement, and maintenance. Where not otherwise specified by code or client requirements, the minimum recommended width of an aisle is:

- Hot aisle – 1.2 m (4 ft)
- Cold aisle (raised floor) – 1.2 m (4 ft) with two full tiles between fronts of cabinets
- Cold aisle (non-raised floor) – 1.2 m (4 ft)

Ceiling heights that are in excess of 3.7 m (12 ft) may require additional aisle space to maneuver support lifts to access ceiling mounted systems (e.g., lighting, fire detection and suppression systems).

Clearance in front of racks and patching frames should provide for safe access and clearance to work. When the swing of a door encounters an obstruction, such as a building support column, a removable door or double (wardrobe) doors may be considered in place of a single door to facilitate full access to the cabinet content.

6.6.4.4.3 Access Floor Recommendations

In addition to the requirements and general recommendations listed previously, aisle widths may need to be 3 or 4 tiles (with a tile typically sized at either 600 mm × 600 mm or 24 in × 24 in giving a total space of 1800 mm to 2400 mm or 6 ft to 8 ft), depending on the HVAC engineer's analysis, requirements for planned equipment and the design of the cooling system.

If the end user has an access floor environment that changes equipment between ITE cabinets and floor standing equipment frequently, it may be desirable to designate two rows of floor tiles for equipment and two rows of floor tiles for aisles (both hot and cold). This provides the flexibility that this situation requires but does reduce the floor space utilization of the computer room.

6.6.4.5 Hot/Cold Aisles

6.6.4.5.1 Requirements

Where access floors are used, the cold aisle shall have at least two rows of floor tiles that can be configured with perforated tiles, providing the required flexibility in airflow management.

6.6.4.5.2 Recommendations

When arranging the computer room space and organizing the hot/cold aisle locations with respect to the cabling and cabinets, consider future changes.

The front of the cabinets and racks should be oriented toward the cold aisle. Additional front (cold) aisle clearance may be required subject to HVAC and operational considerations.

In hot/cold aisle floor layouts, there should not be any gaps in the cabinet row. All gaps should be eliminated to minimize hot air migration into the cold aisle. Any unused rack space should be filled with blanking devices to reduce any nonfunctional airflow migration through the equipment rack.

For access floors, a minimum of two complete rows of floor tiles that can be removed should be provided in the hot aisles at the rear of the cabinets and racks. This allows the designer to make use of two rather than one row of tiles for cable trays. With 1300 mm (52 in) deep ITE cabinets where the front of the cabinets are aligned with the edge of a 600 × 600 mm (24 in × 24 in) floor tile in the cold aisle, there would be 100 mm (4 in) of overlap into the hot aisle, blocking the tiles, which would necessitate an additional row of floor tiles that can be removed (see Figure 6-5).

If cabinets or equipment have a depth that is greater than 1050 mm (42 in), then there will need to be coordination with the hot and cold aisle widths to ensure that the required clearances are provided.

When placed within a hot aisle/cold aisle configuration, OCP open racks are similar to cabinets of traditional IT gear, with OCP open racks using front to back airflow and typically having power densities from 4 kW to 20 kW or more. The amount of airflow per kW of load can vary based on firmware and the design delta temperature across the server.

As a best practice, containment is recommended for any density to improve energy efficiency. One of the advantages of the OCP rack design is that all servicing and cabling of the equipment in the rack can be carried out at the front, so if the racks are contained in a hot aisle then maintenance personnel typically do not need to enter that space, which is normally uncomfortable to work in.

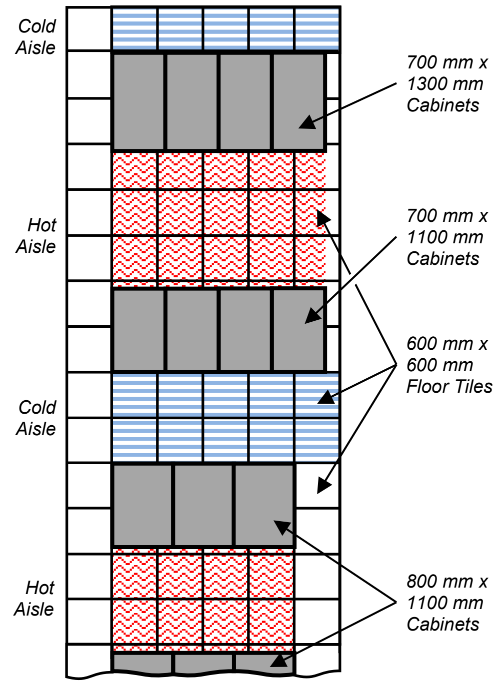


Figure 6-5
Example of Aisle Width with Different Cabinet Sizes

6.6.4.6 Aisle Containment

6.6.4.6.1 Introduction

The effectiveness and efficiency derived from hot and cold aisle separation may be enhanced for air-cooled ITE by a method known as "containment". The objective of containment systems is to prevent mixing of hot exhaust air with cold intake air. This technique can dramatically increase the efficiency of the cooling systems, improve the lifetime of the cooling equipment, and reduce operating cost.

Air isolation management via containment can eliminate hot spots, support high load densities, reduce cooling unit fan energy consumption, increase cooling unit coil efficiency, reduce chiller plant operating energy costs, increase access to economization free cooling hours, and reduce dependence on raised access floor construction. Space planning for hot or cold aisle containment may not need to be much different from that for standard hot aisle and cold aisle space planning, depending upon the method used. The most common containment methods are known as "hot aisle containment" or "cold aisle containment", as appropriate. A third variation is known as "hot air collar" (also called a "chimney" or "air removal unit").

Blanking panels should be used to eliminate voids that allow transfer of air between the hot and cold aisle. Recommended locations for the use of blanking panels include:

- All unused RU and OU positions of ITE cabinets and racks
- Between the equipment rails and sides of the cabinet
- Between the floor and the cabinet frame
- At open positions between cabinets and racks.

In aisle containment systems, the hot or cold aisle is enclosed, usually with transparent, fire-resistant materials. The materials can be solid or flexible. A number of variations are possible, including:

- Fully enclosed hot aisle with row-based cooling — In this method the aisle is fully enclosed. The characteristics include:
  - Cabinet-mounted ITE with front-to rear airflow (i.e., cold intake air in the front and hot exhaust air in the rear)
  - A ceiling over the hot aisle (typically transparent, flame retardant plastic)
  - Doors at each end of the hot aisle that open out (to allow emergency exit of workers inside the hot aisle)
  - Air conditioning units mounted in the two rows that draw in hot air from the hot aisle and blow cold air into the cold aisle.
  - Can be deployed where access floors are not in use
  - Exhaust air returns to cooling units at high temperature, thereby optimizing efficiency of the cooling unit

List continues on the next page

- Partially contained hot aisle without ceiling duct — This method encloses the hot aisle as described above, but barriers do not extend all the way to the ceiling. Ceiling-mounted cooling units above the hot aisle draw in the hot air and blow cold air down into the cold aisle. Some mixing of hot and cold air occurs.
- Contained hot aisle with ceiling duct — This method is similar to the fully enclosed hot aisle, except that there is no "ceiling" over the aisle and there are no cooling units in the rows.
  - Aisle containment barriers extend all the way to the ceiling plenum
  - Hot air is drawn into ceiling-mounted cooling units, or is ducted to CRAC units located at the room perimeter or to cooling units elsewhere in the facility
  - Can be deployed where access floors are not in use
- Hot air collar — Also known as chimney rack or cabinet, this method is a variation of the contained hot aisle with ceiling duct, except that each rack has a duct that extends to a plenum above the ITE rows.
  - When installed on all equipment racks there is no need for hot aisles, hot aisle ceilings, or hot aisle doors.
  - Installation of hot air collars on individual equipment racks is one method of eliminating hot spots.
  - In order to prevent back pressure a fan may be required to ensure one-way hot air movement. The fan will consume some energy, but this slight loss of overall efficiency can be offset by eliminating the need for fully enclosed aisles.
  - Workers are not exposed to extreme heat.
  - Service or removal of one or more equipment racks has no effect on any of the adjacent equipment.
- Cold aisle containment — Cold aisle containment is nearly identical to the hot aisle methods described above except that, as the name implies, it is the cold aisle that is contained. Cold aisle containment minimizes the amount of cold air needed by the ITE by confining the cold air to the space directly in front of the ITE. Air from the hot aisle mixes with room air and is delivered to cooling units via return air ducts.

  Advantages of cold aisle containment include:
  - It is more easily applied to an existing data center, whereas methods such as fully enclosed hot aisles must be pre-designed.
  - It can be used with raised floors, and it can be set to the air inlet temperature specifications of the ITE without affecting the rest of the room.

  Disadvantages of cold air containment include:
  - The temperature within the remainder of the room can exceed the allowed working temperature as specified by the AHJ.
  - Higher temperatures can require derating of power, low-voltage, and communications cabling present within the room.

Utilizing hot or cold aisle containment systems can have an impact on space planning since it may mean that more detection and suppression components be put into place for each contained area. For example, many fire codes and fire marshals require most detection and mitigation points to align with the rows and be able to penetrate into the containment system itself. Some AHJ's even require detection equipment inside of very large ITE such as large scale robotic tape arrays. Also note that most data centers implement some type of very sensitive smoke detection system (e.g., very early warning fire detection system) in addition to regular smoke and fire detection, so space needs to be planned for this pipework and detectors.

6.6.4.6.2 Requirements

One consideration for aisle containment is the impact on fire protection (see Section 11). An analysis shall be made to determine whether the installation of barriers will negatively impact the performance of fire detection and/or suppression equipment. ITE fans can draw inert, clean agent gas through the ITE. If water sprinkler systems are deployed, water spray patterns shall not be obstructed by the aisle containment. Smoke detectors within containment systems shall be rated for the intended temperature and air velocities of the space in which they are installed.

Per requirements of NFPA 75 and NFPA 76, elements of air flow management (e.g., aisle containment, cabinet exhaust chimneys) and hot air collars shall be constructed of noncombustible material, limited combustible materials, or materials that have a maximum flame spread index of 50 and a maximum smoke development of 450 as verified by either ASTM E84 or UL 723.

6.6.4.6.3 Recommendations

Aisle containment is recommended for air-cooled ITE in data centers where there are enough ITE racks to create rows and aisles. It may be necessary to install fire detection and/or suppression devices inside the contained space, or to modify existing detection and suppression systems in order to comply with local regulations. When aisle containment is implemented, best practice is to prevent any mixing of hot and cold air to the maximum extent possible. Partially contained aisles are the least effective.

Computer modeling may be necessary to determine the appropriate quantity, size, and placement of the cooling units.. CFD computer modeling can help in the selection and placement of air containment techniques. Methods utilized should be reviewed and approved by the local AHJ prior to installation.

The following should be considered for all containment systems:

- Temperatures on the hot side of the containment may be warmer than the rating of components. Power distribution units need particular consideration.
- It is vital that all racks have blanking plates in spare RU or OU spaces and all other openings including patch panel cut outs are isolated between the cold and hot sides of the ITE. ITE that vents side to side or other configuration than front to back may require special consideration.
- The containment system should be adaptable to accommodate different rack widths and heights
- Consider placing solid rear doors on passive patching racks, especially where back to back with high density ITE racks, as the hot air may force its way through the small openings in the patch panels.
- Containment systems increase the risk of ITE failure due to high temperatures in the event of a loss of air flow. (See Section 10 for elements of uninterruptible cooling).
- Ideally, all temperature sensitive components should be located on the cold side of containment. All components located on the hot side of containment should be resistant to temperatures of 45 ºC. For areas with high density racks, temperature ratings of component should meet calculated temperatures.

6.6.5 Adjacencies and Other Space Considerations

6.6.5.1 Space Adjacencies

Computer tapes, printer paper storage, and other flammable media should be located in rooms separate from the computer room.

Production, development, and test systems should be in separate areas of the computer room, preferably in separate rooms served by dedicated networks.

NOTE: See Section 11 of this Standard, the *International Fire Code*, or NFPA 75 for additional requirements and information concerning record storage and fire issues.

6.6.5.2 Electrical and Mechanical System Clearances

6.6.5.2.1 Requirements

The clearance between equipment cabinets or racks (including RPPs at the end of the ITE rows) and the perimeter wall or equipment along the perimeter wall shall be a minimum of 1.2 m (4 ft). Clearances provided shall accommodate codes requirements (e.g., clearances because of equipment voltages). the replacement of air conditioning equipment, power distribution equipment, or large frame ITE located within the computer room.

6.6.5.2.2 Recommendations

Traditionally, electrical and mechanical equipment are placed along the perimeter walls for distribution under raised, perforated tiles. Where not required, clearances of 1.8 m (6 ft) are recommended.

When subfloor air distribution is used, there should be a minimum clearance of 1.8 m (6 ft) between the ITE cabinets and CRACs. The closest perforated tile should be a minimum of 2.4 m (8 ft) from the CRACs. This will help reduce the possibility of the effect in which air is drawn from above the access floor through the perforated floor tile because of low pressure caused by the high-velocity air below the floor near the discharge of the CRAC. Distances may be affected by mechanical considerations such as the depth of the access floor, the absence or presence of turning vanes on the discharge of the CRAC unit, the speed of the air discharge, or the deployment of fans that are recessed under the access floor.

ITE cabinet row lengths may be limited by the maximum distance at which the CRACs can provide adequate air pressure for delivering cold air. This distance is a function of the CRAC unit blower, the access floor depth, the distribution of the perforated tiles, and cables or other obstructions under the floor.

When overhead or row-based cooling is provided, the CRAC units should be close coupled to the racks to be cooled, meaning that the CRACs should be as close as possible to the heat source. Close coupling minimizes hot and cold air mixing and improves efficiency because it minimizes the volume of air that must be cooled, and the required fan energy needed.

6.6.5.3 Power and Telecommunications Cable Distribution

6.6.5.3.1 Introduction

Various configurations can be used to distribute power and telecommunications cables. See Section 14.7 for considerations of overhead versus under-floor cable routing.

6.6.5.3.2 Requirements

A telecommunications cable pathway under an access floor (such as cable trays or other containment), regardless of location, shall contain a maximum depth of cable of 150 mm (6 in) when fully populated.

When access floors are used, the bottom of the access floor tiles shall be a minimum of 50 mm (2 in) from the top of the cable tray or maximum allowable height of cables in the tray.

Cable pathways shall meet the clearance requirements of fire detection, suppression, and prevention systems, and these systems must be coordinated with other systems (e.g., electrical, mechanical, telecommunications) and meet the requirements of the manufacturer and the AHJ.

Power cabling, when distributed under an access floor, may have to be plenum-rated, run in raceway, and meet other requirements of the local AHJ. Power cabling run overhead shall be run in cable trays compliant with local AHJ requirements.

6.6.5.3.3 Recommendations

Cable pathways should be sized for the maximum number of cables expected with a 50% additional capacity to allow for future growth. Cable pathway size should be calculated in areas of maximum density such as near MDAs and HDAs.

Where fiber optic cabling is installed under the floor, it should be protected from damage by placing it within a cable tray or other containment. There is no separation requirement between power and fiber optic cabling, except that which is required by the AHJ.

If both power and telecommunications cabling are distributed from below the access floor, then:

- The power cabling should be routed either adjacent to or within the cold aisle.
- The telecommunications cabling should be routed adjacent to or within the hot aisle.

This arrangement minimizes obstruction of airflow in the cold aisles by telecommunications cabling.

If both power and fiber optic telecommunications cabling are distributed from overhead, and copper telecommunications cabling is distributed from below the access floor, then:

- The optical fiber telecommunications cabling should be routed above the power cabling on separate containment and should be coordinated with mechanical and electrical systems above the cabinets.
- The copper telecommunications cabling should be routed adjacent to or within the hot aisles.

Power and communication pathways should be positioned at different heights off the floor so that they can cross each other without interference. Alternatively, at every point where the power and copper cabling cross the path of each other, the crossing should be at a 90° (right) angle.

6.6.5.3.4 Additional Information

Patch cabling within a row of cabinets and racks is often routed overhead to maximize the space available under the floor for horizontal and backbone cabling. This routing also separates patch cabling, which changes often, from horizontal and backbone cabling, which should be more permanent.

The data cabling standards used in the design provide guidance as to the recommended separation between power and copper telecommunications cabling to maintain signal integrity (e.g., ANSI/TIA-942-B, ISO/IEC 14763-2, CENELEC EN 50174-2). Separation and segregation for safety shall be in accordance with the requirements of the AHJ.

6.6.5.4 Airflow Circulation and Equipment Placement Coordination

Consider the following items when coordinating placement of equipment, airflow, and cable routes:

- On-floor equipment:
  - Equipment type and dimensions
  - Orientation with respect to airflow direction
- Underfloor services:
  For the following underfloor services, dimensions, clearances, and orientation with respect to airflow direction should be considered:
  - Electrical services
  - Data cabling
  - Ducting
  - Fire suppression system
  - Fire detection system
  - Air conditioning pipes

6.6.5.5 Fire Protection

6.6.5.5.1 Requirements

The specific fire protection system used shall meet AHJ requirements.

6.6.5.5.2 Recommendations

Various types of fire protection systems will take up different amounts of space, both internal to the computer room as well as in the mechanical spaces and outdoor mechanical yard. For instance, a water-based sprinkler system will need space throughout the ceiling areas for proper spacing and dispersal. A clean agent gaseous system requires some space at the periphery of the ceiling areas, but it also requires a space set aside to contain the gas holding tanks as well as possible duct work to release the gas to the outside atmosphere once it has quenched the fire.

6.6.5.6 ITE Adjacencies

Where possible, exposure to sources of EMI and RFI should be avoided. Transformers, other than those in PDUs, should be placed a minimum of 0.6 m (2 ft) and preferably at least 1.2 m (4 ft) from ITE and data cabling.

The equipment access space for ITE and non-ITE should be coordinated so that access space can be shared whenever possible, maximizing computer room utilization.

6.6.5.7 Network Architecture

Network architecture considerations include:

- Centralized/decentralized location and its impact on space planning
- Copper communications cabling distance limitations and their impact on space planning
- Optical fiber distance limitations and their impact on space planning
- Impact of power and large number of connections for core and distribution switches on space planning (i.e., larger cable pathways)

6.7 Design for Performance

6.7.1 Introduction

Historically, data centers have been designed in a piecemeal manner. Critical components, such as UPS systems, computer room air conditioners (CRACs), power distribution equipment, equipment racks, and the ITE are often specified and purchased separately without a view of how they could all fit together as one cohesive system. Likewise, the buildings in which many data centers are housed were not designed to provide the robust environment required to support and protect mission-critical operations. Many data centers are still designed this way.

To achieve dramatic advances in performance, data center architecture must be designed as a whole, not in pieces. Organizations, such as The Green Grid^{SM}, have published papers and tools directed toward viewing the data center as one integrated system (see an example in Appendix G).

Data center performance can be examined by many factors (e.g., productivity, efficiency, sustainability), with operational availability being the primary concern. As the measure of operational availability does not include factors such as financial performance or expense management, focus on improving operational efficiency is increasing, with emphasis on areas such energy reduction, future operational regulatory requirements, and overall lower cost of ownership.

6.7.2 Data Center Metrics

6.7.2.1 Introduction

Metrics can be defined as measures of quantitative assessment to compare or track efficiency, performance, progress or other parameters over time. Data center metrics help better understand if a design is good or working as intended and can help identify areas for improvement.

Most manufacturers of ITE or IT infrastructure equipment provide some information about equipment power consumption. For code compliance purposes, nameplate data typically includes very conservative numbers on power consumption so that the cables, circuit breakers and fuses will be sized for worst case. Designing for worst case exacts a penalty in efficiency and operating costs.

Accurate measurement of power consumption in real time allows a baseline to be established. Future performance can be compared to the baseline to document changes in data center efficiency and against industry performance in general. Two of the most widely used energy efficiency metrics are PUE and DCiE.

6.7.2.2 Power Usage Effectiveness (PUE)

6.7.2.2.1 Overview

PUE is a measure of the power consumed by the data center as a whole divided by the power consumed by servers, storage devices, and other ITE. It is expressed in Equation 6-1.

$$PUE = \frac{\text{Total facility power}}{\text{ITE power}} \qquad (6\text{-}1)$$

PUE will be greater than 1.0. Many data centers operate with PUE near 2.0. Inefficient or poorly managed data centers have PUE as high as 3.0. A good target to strive for is a PUE within a range of 1.3–2.0.

6.7.2.2.2 Additional Information

To resolves issues within the original method of PUE calculation, the Green Grid published a clarification of how PUE should be calculated and was subsequently adopted within ISO/IEC 30134-2. The following parameters were clarified:

- Both facility and IT power must be based on energy used, (i.e., kWh as opposed to kW), over a period of at least 11 months.
- All energy used by the facility must be included in the calculation, for instance generator fuel
- A method of calculating design PUE for a facility yet to be constructed is included in the standard
- Different classes of PUE can be quoted depending on where the IT energy is measured

NOTE: As PUE is calculated from operational energy usage, ANSI/ASHRAE 90.4 provides design guidance and calculations for mechanical loads and electrical loss that may affect measured PUE.

6.7.2.3 Data Center Infrastructure Efficiency (DCiE)

DCiE is the reciprocal of PUE and is expressed in Equation 6-2.

$$DCiE = \frac{1}{PUE} = \frac{\text{ITE power}}{\text{Total facility power}} \times 100\% \qquad (6\text{-}2)$$

DCiE will result in a number less than 1.0. It is often preferred because, intuitively, it expresses efficiency as a percentage. Either PUE or DCiE can be used, but the industry seems to favor PUE.

6.7.2.4 Other Metrics

Multiple metrics have been developed to measure different aspects of the data center, including efficiency, productivity, sustainability, operations and risk.

- Efficiency has been given substantial attention due to the high energy consumption of the data center sector. Many initiatives have emerged to measure efficiency. Key indicators show how energy efficient site infrastructure, ITE, environmental control systems, and other systems are.
- Productivity gives a sense of work accomplished and can be estimated through different indicators, such as the ratio of useful work completed to energy usage, or useful work completed to the cost of the data center.
- The sustainability of a data center can be measured in different ways, such as the ratio of green energy sources to total energy, estimating the carbon footprint, or the water usage. In addition, an evaluation may be conducted on how environmentally friendly the associated processes, materials, and components are.
- Operations measurements gauge how well managed a data center is. This must include an analysis of operations, including site infrastructure, ITE, maintenance, human resources training, and security systems, among other factors.

Risks that may impact data center performance must be considered. Optimization must involve risk, defined as potential threats that, if materialized, could impact the performance of the data center. A data center pursuing a high performance indicator could end up with a high risk of failure as well.

6.7.3 Scalability

All systems and subsystems should be able to scale to or near their optimum operating efficiency throughout the life of the facility. Designs should be flexible enough to adapt to changing power and cooling requirements and technological improvements that cannot be anticipated at the time of the data center design. This approach has a greater chance of achieving the lowest practical energy consumption over the life of the facility when the planner/designer:

- Pays close attention to establishing a rational model for growth of space and power requirements over time.
- Models power and cooling system performance over the life of the data center in accordance with the growth model.

6.7.4 Instrumentation and Control

6.7.4.1 Introduction

Equipment should have permanent monitoring and maintenance to assure proper and efficient performance. This has following benefits:

- Human errors can be diminished through monitoring, automation, and control systems.
- Using sensing devices, variables such as power, temperature, humidity, airflow, differential air pressure, lighting, water, closures, motion, and vibration can be measured across the entire facility.
- Improves granularity of data center infrastructure monitoring and management.
- Enables stakeholders to make more informed decisions.

It is important to collect the right data and understand its nature, when considering future scenarios.

Improvements by some equipment manufacturers include the ability to directly access, from the equipment processor, measurements of power utilization, temperature, airflow, and resource usage (e.g., CPU, memory, I/O) for each device.

If measurement of PUE is desired, instrumentation should be installed that allows measurement and trend analysis of the energy consumption of the specific equipment that directly supports the data center.

6.7.4.2 Annunciation

All systems and subsystems should be discoverable through the single management system to report and trend such metrics as location, minimum and maximum energy used, and performance level capabilities.

6.7.4.3 Management

All systems and subsystems should be able to network through standardized management, interoperability interfaces, and language. Operations should be automated at all levels via policies set through management infrastructure.

6.7.5 Data Center Energy Saving Design Opportunities

Data center efficiency is most effectively optimized by concentrating on the areas where the greatest gains are possible. It is frequently stated that the cost of operating infrastructure to support ITE is greater than the cost of operating the ITE itself. This suggests a PUE greater than 2.0.

When designing a data center for efficiency, the techniques listed in Table 6-3 should be considered. The values given are subjective, but they give a reasonably good comparison of their impact on a design. Most of the techniques are described in more detail elsewhere in this standard.

Additional design guidance to improve energy efficiency can also be found in *EU Best Practices for EU Code of Conduct on Data Centres* and ASHRAE *Best Practices for Datacom Facility Energy Efficiency*.

Table 6-3 Data Center Energy Saving Opportunities

% of Improvement Possible	*Area for Attention*
Up to 95% per unit of computing operation	high-efficiency ITE such as blade servers, and IT management systems such as server virtualization
Up to 50%	air or fluid economizer cooling systems using heat rejection without refrigeration
10 – 40%	hot-aisle or cold-aisle containment systems
10 – 40%	cabinets with isolated air supply or isolated air return
10 – 30%	modular and scalable architecture for power & cooling considering total life-cycle energy savings.
5 – 15%	hot-aisle/cold-aisle rows with optimally located row-oriented cooling
4 – 15%	locating sites where it is possible to take advantage of economizer modes of air conditioning (air-side or water-side)
4 – 10%	selection of high-efficiency power equipment such as UPS, capable of high efficiencies at low loads
0 – 10%	cooling management systems able to prevent demand fighting in which one unit is humidifying while another is dehumidifying
1 – 6%	where under-floor cooling is used, optimized quantity and location of floor vents or perforated tiles only in the cold aisles, assisted by CFD
1 – 6%	overhead wiring and cabling to prevent blockage of air distribution under access floors (Refer to Section 14.7 for considerations of overhead versus under-floor cable routing)
1 – 5% or more	use of blanking panels in equipment racks to prevent mixing of cold inlet air and hot exhaust air
1 – 5% or more	blocking access floor cable cut-outs and sealing floor tile openings to prevent escape of cold air where it is not needed
1 – 3%	use of energy efficient lighting along with timers, occupancy schedules, or motion detectors

7 Architectural

7.1 Facilities Planning

7.1.1 General Overview

7.1.1.1 Introduction

This section provides information on the architectural and general construction elements of a data center and are applicable to the planning and specification of a computer room and related spaces. Some reference will be made to other elements as the purpose of the architectural elements of a data center is to provide a physical envelope that assists in meeting the needs of the end user (information technology/telecommunications).

The initial planning of the data center must be a cooperative effort involving the client's facilities planners, IT personnel, telecommunications personnel, the client's office users, and all the various disciplines that will assist in the completion of the data center.

Several methods of planning the data center are currently utilized in today's environment. Two of those are:

- IT, telecommunications, and other users collect data and turn it over to the facilities manager who then puts together a team that locates a site, designs, and constructs the data center.
- The facilities and IT personnel select an initial planner or designer to assist in the gathering of information and prepare a document that assists in the search for the site and assists in the budgeting of the project.

From this point, the project is completed one of two ways:

- The initial design team continues to prepare a complete set of construction documents that are bid to a preselected group of contractors (design-bid-build).
- The initial planning information is handed to a preselected design build contractor who provides all documents and construction for the project (design/build).

See Appendix A for more information regarding design and construction approaches.

The appropriate approach for a given project varies, depending on the project. For an entity that has limited specific design requirements, has a preselected location, and trusts the contracting company, the second planning method listed above is the most likely utilized. For entities that want to ensure that the data center plan meets some specific needs, and for those entities that want to ensure that the initial planning decisions meet their detailed user and market requirements, the first planning option listed above is recommended. To determine whether design-bid-build or design/build is best suited for a specific project, the complexity of the data center should be considered. Entities that have several data centers of the same type and complexity may find the design/build process can save time and money. If the space is complex and there are a variety of end users and ITE configurations, then the design-bid process can ensure all the issues are addressed initially and reduce time delays and cost increases later.

It should be noted that the accessibility regulations (e.g., Americans with Disabilities Act [USA], Disability Discrimination Act [Australia]) or similar guidelines may need to be followed for the design and construction of computer rooms and support spaces. The designer should be aware that the AHJ may require adherence to these regulations and other standards and may publish its own enhancements to these documents.

7.1.2 Site Selection

7.1.2.1 Requirements

While most site selection criteria are covered in Section 5, from an architectural/general construction consideration, it is important to ensure that:

- All interfering elements (e.g., vibration, air contamination, site related security risks, flood plains, electromagnetic interference, and hazardous materials) be mitigated or eliminated
- Sufficient space is provided around the building to allow for complete security
- Space is provided for a variety of support equipment, such as:
  - Generator(s)
  - Fuel tank(s) to support the generator
  - HVAC heat rejection systems.
- All electrical service requirements are met (see Section 9)

These elements shall also be secure from public access.

7.1.2.2 Additional Information

See Section 5 for other issues to be considered for site selection such as availability of power, telecommunications connections and stability, fire services, and secure neighborhood.

7.1.3 Data Center Location Relative to Ground Level

7.1.3.1 Requirements

When examining a floor below grade level, water infiltration issues shall be considered, including:

- Height below surrounding drainage systems
- Water detection systems
- Secure and continuous vapor barriers
- Water and vapor extraction systems
- Main building systems that might create damage to the data center
- Hazardous materials stored or utilized in the basement
- Flooding potential during and following severe weather events

The required distributed floor loading capacity is specified in Section 8.

7.1.3.2 Recommendations

For equipment access, the floor nearest prevailing grade level (ground floor) is often the most advantageous. Floor loading considerations also tend to lead to the ground floor as a location. Upper floors can be a solution to security and water issues, but in areas with major lateral force issues (e.g., hurricane, wind, seismic), the upper floor can contribute to structural instability. Many times, the upper floors are not designed for the floor loading required for a data center.

7.2 General Design Concepts

7.2.1 Levels of Reliability

7.2.1.1 Introduction

The level of required reliability plays a major part in the design of the data center. A generally accepted method of describing levels of reliability is the Class system, as shown in Appendix B.

Reliability is defined in relationship to the identified risks. For example, NFPA 75 identifies risks such as life safety, fire threat, loss of revenue, loss of equipment, and loss of telecommunications. It is safe to assume that the failure of the data center structure will affect one or more of the elements above.

In the United States, for further information on construction and protection of computer rooms, refer to NFPA 75.

7.2.1.2 Requirements

The building shall be of construction appropriate for the level of durability and reliability consistent with the best structural practices for data centers. (See Section 8)

7.2.1.3 Recommendations

The building should be designed to meet design criteria for seismic and wind lateral conditions.

7.2.2 Facility Purpose

7.2.2.1 Introduction

The general purpose of the data center affects the construction, operation, and physical security of the data center. Medical, financial, and government information regulations may impose special security requirements. Codes might dictate requirements for certain types of facilities such as hospitals, utilities, telecommunications, and other critical services.

The occupancy category of a data center is dependent on the use of the facility as defined by applicable standard (e.g., ASCE 7) or AHJ. This requirement can be increased by the owner based on the need or desire for the facility to operate after an event (occupancy category IV). Generally, data centers fall into occupancy category II, but they could be rated occupancy category IV if required by use or owner. Wind, snow, ice, flood, and earthquake design requirements for the building and its mechanical and electrical systems are affected by the selected occupancy category.

The importance factor to be used in calculating design requirements may be increased by the owner to provide a more robust design even if the occupancy is less than occupancy category IV.

A project that requires critical power systems per AHJ (e.g., critical operations power systems [COPS]) will affect site selection and the design of the building and its mechanical and electrical systems.

7.2.2.2 Requirements

The design team shall work with the users to determine the purpose of the facility with the focus on the effects of failure of the facility. By utilizing the Class definitions as described in Appendix B, determine the appropriate level of reliability to meet the purpose of the facility.

7.2.3 Multiuser Versus Single User Groups

7.2.3.1 Introduction

Multiuser facilities have more security requirements than single user facilities. Administrative functions require access be limited to a minimum number of authorized personnel. Groups, such as engineering and research may require a greater access to accommodate more frequent equipment setup and changes.

7.2.3.2 Requirements

Data centers that house ITE from multiple users will require physical security, such as walls or cages at the partition levels or electronic controls or physical locks at the cabinet level, for the equipment of each user.

Multiuser facilities may require surveillance systems and additional access control and records, including tenant power metering.

7.2.4 Equipment Change Cycle

7.2.4.1 Requirements

Flexibility needs to be planned into a data center that adds or changes equipment frequently. Designers and users are to determine the expected life cycle for equipment and determine the effect on facilities operations, including the need for space inside and outside the computer room to stage and bring into service new hardware.

7.2.4.2 Recommendations

The average data center may significantly change its ITE inventory every 3 to 5 years. The physical power and cooling infrastructure should be flexible and scalable in order to optimize it for the conditions of power capacity and density at any given time and place within the computer room.

7.2.5 Occupied Versus Unoccupied Data Centers

7.2.5.1 Recommendations

In order to minimize human error, data centers may be designed with a "lights-out" philosophy. A lights-out approach is to have no personnel working within the data center on a normal basis. The design of a lights-out data center will require sophisticated and secure remote monitoring and control capability. A lights-out data center will also have to address operational challenges such as coordinating the delivery of supplies and ITE to a facility that has no personnel on-site on a regular basis.

7.2.6 Data Center Location Within Building

7.2.6.1 Requirements

If the data center is on a floor above the first (grade level) floor, ensure that access is provided for the equipment required in the data center.

The data center shall be located as close as possible to incoming power to reduce the power cabling lengths.

The computer room shall be located on a floor that has the structural capabilities to support the equipment (per the structural engineer).

7.2.6.2 Recommendations

The computer room should be located in close proximity to the telecommunications entrance room(s) of the building.

The computer room is best located on the ground floor. It is generally desirable to locate the computer room away from exterior walls, although it may be appropriate to design a data center where the computer rooms have an exterior wall with knock-out panels for future expansion or integration of certain free cooling options. Where knock-out panels are used, precautions against storm/blizzard damage and temperature extremes (e.g., condensation) should be taken.

7.2.7 Type of Building

7.2.7.1 Requirements

Critical data centers shall be installed within a steel or concrete framed building such as a Type I, II, or III building as defined in the International Building Code. Under certain conditions, Type IV construction can be utilized if constructed in accordance with NFPA 75.

The exterior of buildings shall be nonflammable and of durable material, resistant to the foreseen weather conditions for the expected lifetime of the facility.

The building section shall allow a minimum clear access height of 3 m (10 ft) from finished floor to any obstruction such as sprinklers or lighting.

NOTE: Floor to ceiling heights are structurally difficult to modify once built. This allowance provides flexibility when considering the placement or expansion of areas, such as the computer room, within a building level. As an allowance, this does not prevent functional spaces in the data center (e.g., lobby, break room, non-IT corridors) from having finished clearances of less than 3 m (10 ft) and in compliance with AHJ requirements.

7.2.7.2 Recommendations

The slab to structure above should be a minimum of 4.5 m (15 ft).

7.2.8 Multitenant Buildings

7.2.8.1 Requirements

Where a data center is in a multitenant building, the data center shall be located away from hazards and mutual access points with other tenants.

All water lines, sprinkler lines, ductwork, and gas lines serving areas outside of the computer room shall not pass through the computer room area. No systems hazardous to the computer room shall be located in or around the computer room.

All supply lines (e.g., electrical, water), ductwork, and telecommunication pathways serving the computer room shall not pass through the rooms of other tenants if comprehensive monitoring, protection against intrusion, and accessibility for maintenance cannot be guaranteed.

7.2.8.2 Recommendations

Services to the data center should be separate from services to other tenants.

7.2.9 24/7 Operation of Data Center

7.2.9.1 Introduction

Critical data centers are often operational 24 hours per day, 7 days per week.

7.2.9.2 Requirements

The data center, including office and command center functions, shall be arranged in a manner to provide security to personnel within the data center and security to arrival and departure locations. At high security facilities, walls, windows and doors of rooms typically permanently staffed (i.e., command center, guard station) should be hardened or bullet resistant.

Twenty-four-hour operations shall have break facilities within the building in the vicinity of the data center.

7.2.10 Temperature and Humidity Control

7.2.10.1 Requirements

The computer room shall be located so that temperature and humidity can be maintained with minimum energy usage.

The design of the computer room shall include proper insulation and moisture control to maintain steady temperature and humidity ranges within the data center.

7.2.11 Materials

7.2.11.1 Requirements

The computer room shall be designed and built with new materials, which are durable, of superior quality, and easy to maintain and operate. Where recycled materials will not affect the operation of the space, they may be considered for use.

7.3 General Paths of Access

7.3.1 General Access

7.3.1.1 Introduction

Once the site is selected, planning the layout of the data center will begin. Access is crucial. The points of access included in this section include main data center personnel access; non-data center personnel access; equipment vendor access; equipment access; access to support equipment (e.g., UPS and batteries, HVAC equipment); miscellaneous electrical equipment repair access; telecommunications vendor access; and separate user group access.

7.3.1.2 Requirements

All entries into the data center shall be secured.

7.3.2 Data Center Access

7.3.2.1 Requirements

In buildings with a lobby and building guard, direct communications shall be established between the control center of the data center and the building guard station. For high-security sites, communications shall be both audio and visual.

For ramps, the maximum slope shall be the lesser of:

- 8° from horizontal for movement of cabinets without equipment,
- A rise of 1:12 or about 4.8° for movement of cabinets with equipment, and
- Per applicable accessibility regulations.

Ramps shall be at least 900 mm (36 in) clear width and have a 1.5 m× 1.5 m (5 × 5 ft) clear landing at the top and bottom. Hand rails shall be provided and meet all applicable regulations.

If the computer room has only one ramp, it shall meet AHJ accessibility requirements. One ramp for equipment and an elevator or ramp for wheelchair access is acceptable.

7.3.2.2 Recommendations

The maximum slope of any ramp should not exceed a rise of 1:12 or about 4.8°. Railings on ramps should have a height between 900 mm – 1000 mm (36 – 39 in).

The main access to the data center should be secured via some form of access control. This control can be a combination of personnel and electronics or solely electronics. Each client should consider the level of security necessary for protection of the data being processed.

Sites without a building guard should have both audio and visual controls at the initial point of access to the data center.

In data centers occupied 24/7, it is recommended the initial main access route lead into a secure location outside the computer room that provides additional control prior to entrance into the computer room. Observe life safety code regarding egress.

7.3.3 Equipment Access

7.3.3.1 Requirements

The data center shall allow for the delivery of ITE and telecommunications equipment to the facility. The computer/telecommunications equipment delivery pathway, including doors, shall allow for delivery of equipment as large as 3 m (10 ft) long by 1.2 m (4 ft) deep by 2.4 m (8 ft) high, weighing greater than 3400 kg (7500 lb).

Lifts and elevators used as part of the delivery path shall meet or exceed the following as applicable:

- Opening door height of 2.4m (8 ft)
- Opening door width of 1.2 m (4 ft)
- Open cabin depth of 1.5 m (5 ft)
- Lifting capacity of 1500 kg (3300 lb)

The support equipment rooms (e.g., UPS and battery room, HVAC room) typically require access for equipment even larger than mentioned above. The routes for mechanical and electrical equipment shall be large enough to permit installation of new equipment and removal of old equipment—a clear height of at least 2.7 m (9 ft) is typically required along routes from the loading docks to the electrical and mechanical rooms. Clear height requirements shall consider the height of equipment, packaging, and moving equipment.

7.3.3.2 Recommendations

To accommodate cabinets and racks larger than 42 RU or 42 OU, vertical clearances and the height for doors and elevators within the delivery path should be at least 3 m (10 ft). Lifts and elevators used as part of the ITE and telecommunications equipment delivery path should have a minimum opening door width of 1.5 m (5 ft) and a lifting capacity of 3000 kg (6600 lb).

7.3.4 Telecommunications Access Provider Entry into Computer Rooms

7.3.4.1 Requirements

The local access providers require access to the telecommunications entrance rooms, but they are generally restricted from access to the computer room unless:

- The entrance room is a portion of the computer room.
- The computer room houses access provider equipment such as DWDMs, SONET multiplexers, or other circuit provisioning equipment.
- The carrier demarcation points (e.g., DS-1 or DS-3 DSX panels) reside in the computer room.

7.3.5 Vendor Access

7.3.5.1 Requirements

Access control shall allow access by essential vendors that support the processing equipment. The access control system may require that such vendors be escorted. This control shall allow the data center personnel to know when and where the vendors access the data center.

7.3.6 Support Equipment Service Access

7.3.6.1 Recommendations

As much as possible, support equipment that requires servicing should be serviced on the perimeter of the data center to prevent untrained personnel from inadvertently damaging the processing equipment.

7.4 Planning Detail

7.4.1 Entry

7.4.1.1 Requirements

Consideration shall be made for the initial entrance through a controlled lobby or vestibule, allowing for the entrance to the computer room to be a distance from the visible exterior. The entry to the computer room from noncomputer room spaces shall lead into a controlled space within the data center, prior to providing access to the computer room areas.

Entry for equipment, if separate from main entry, shall be controlled by the data center personnel only.

7.4.1.2 Recommendations

The entry to the computer room should be positioned away from the direct access to the exterior.

Equipment entry should be located near a staging/storage area for unpacking and preparation of equipment prior to entry into computer room.

7.4.2 Command Center and Personnel Areas

7.4.2.1 Recommendations

Command centers may be located within the data center or located in a secure location remote to the data center.

If the command center is located in the data center, it should be near the main entrance to the computer room, direct access to the computer room space is recommended. The command center will have space for the number of data center operators present at any given time and house monitors at their individual operator workstations. Additional monitors may also be ceiling hung or wall mounted so that they are viewable by all operators.

Monitoring of the facility systems should also be incorporated into the command center, as either audio/visual annunciators or system monitors, to provide the command center operators real time reporting on the status of the facility power distribution, cooling equipment and computer room environmental conditions. The monitoring of the facility systems within the command center does not normally include control capabilities.

Office space adjacent to the command center may be required for supervisory functions. Conference facilities should be provided adjacent to the command center to form a war room or emergency troubleshooting area.

7.4.3 Printer Room

7.4.3.1 Requirements

For centers that require printing, a printer room shall be provided adjacent to the personnel areas. The printer room shall be self-contained with a filtration system on the return air leaving the room. Space shall be provided for paper staging within the printer room to ensure the stabilization of paper.

7.4.4 Media Storage Room

7.4.4.1 Requirements

For facilities that produce in-house removable record storage media and store in-house for an extended time the media that has been removed from the library, a separate room shall be provided for media storage. When media is removed from the library and directly transferred to a permanent off-site storage location, a separate media room is not required.

Storage of critical media shall be contained within a 2-hour fire rated enclosure.

7.4.5 Restrooms and Break Rooms

7.4.5.1 Requirements

Restroom and break room areas shall be provided with easy access to the operations and office areas. Restrooms shall be accessible, for both genders per the governing local codes and standards.

7.4.5.2 Recommendations

For 24/7 operational data centers, access to restrooms and break rooms should be from security-controlled area of the data center where practical. To maintain security boundaries, consider providing separate restrooms for unsecured areas, such as the lobby and loading dock.

7.4.6 Computer Room

7.4.6.1 Introduction

In general, it is anticipated that circulation and support equipment (e.g., HVAC floor mounted air handlers, coolant distribution units, electrical PDUs, RPPs, static switches, fire suppression tanks) can require as much as 40% of the overall space in the equipment area. In the case of Class F3, and especially Class F4, the physical infrastructure space requirement may be over 50% of the total facility square footage.

7.4.6.2 Recommendations

In planning the cabinet and rack layout, care should be taken to allow for maximum flexibility. A data center may significantly change its ITE inventory every 3 to 5 years.

The data center planner should coordinate early on with mechanical and electrical systems designers.

The computer room should be designed in a manner to provide adequate space for current equipment, growth, technology refresh, personnel and equipment circulation, and support equipment.

Production, development, and test systems should be in separate areas of the computer room, preferably in separate rooms served by dedicated networks.

Expansion should be planned for computer rooms. With the multitude of elements that affect the IT environment, it is difficult to plan for exact expansion needs. It is generally good to determine the expected life of the facility, look at the past growth trends, analyze current and next generation technology trends, analyze technology refresh capacity requirements, and develop a 6 to 9-year technology capacity profile incorporating growth and technology refresh requirements. Extrapolate the 6 to 9-year technology capacity profile into a facility capacity profile, which often covers a 15 to 20 year life cycle.

For Class F3 and F4 facilities, consideration should be given to segregate mechanical from ITE in the computer room since installation, servicing, and maintenance will typically be performed by different personnel. This could be accomplished by erecting a physical barrier (e.g., a fence) between the mechanical and ITE, permeable to the airflow, or by installing the HVAC -components in a separate room adjacent to the computer room, with openings for the airflow.

7.4.7 Entrance Rooms

7.4.7.1 Requirements

The entrance room, if separate from the computer room, shall be accessed without going through the computer room.

Class 3 and higher data centers shall have separate entrance rooms.

7.4.7.2 Recommendations

Class 2 and lower data centers may have a single entrance room.

The entrance room should be contiguous with the computer room.

In determining the space for the entrance rooms, consideration should be made for cable termination hardware, protectors, splicing hardware, cabling pathways, space for cable pulling equipment, carrier equipment, electrical equipment, air conditioning equipment, security equipment, building automation systems, and telecommunications equipment.

7.4.8 Mechanical Equipment Space

7.4.8.1 Introduction

Mechanical equipment will be in the computer room (as mentioned) as well as in a mechanical equipment room/area outside the computer room.

7.4.8.2 Requirements

The architect and data center planner shall coordinate with the mechanical system designer for sizing and the amount of equipment in the computer room. Outside of the computer room, provide space for the heat rejection equipment and associated pumps, fuel tanks, and controls.

7.4.8.3 Recommendations

- Mechanical components and cooling systems within a computer room should be located separate from the ITE rows in order to provide maintenance access, unless placement in or close to the ITE row is necessary for enhanced cooling effectiveness.

7.4.9 Electrical Room and UPS Room

7.4.9.1 Requirements

A separate room shall be provided to contain the data center associated electrical equipment, including the switchboard, various electrical panels, generator automatic transfer switch(es), UPS systems, and input/output boards.

Electrical and UPS room shall be as near as possible to both the main building electrical room and the generator.

7.4.9.2 Additional Information

The electrical room may require two exits, with doors opening in the direction of egress from the room, and the doors and equipment with panic hardware as required by AHJ. Secondary exit routes may pass through other associated spaces such as the battery room, if permitted by AHJ.

7.4.10 Battery Room

7.4.10.1 Introduction

If a centralized UPS system is utilized, a battery room most often accompanies the UPS room.

7.4.10.2 Requirements

Battery rooms with batteries containing liquid, free flowing electrolyte shall include electrolyte spill containment and exhaust systems as required by local codes.

7.4.10.3 Recommendations

If the batteries are in a dedicated battery room, the battery room should be adjacent to the associated electrical room.

The size of the battery room will depend on the type and number of batteries and racks/cabinets.

The battery room should be located at grade level if feasible. Below grade can create a flooding hazard. Above grade can create a floor loading hazard.

The battery room should be designed to accommodate the anticipated maximum floor loading.

The battery room should not be located above a computer room space.

The electrical engineer or local codes may prescribe additional requirements regarding the location of the battery room or battery room equipment. Coordinate with the electrical systems designer.

Consult applicable IEEE battery installation standards and see the additional battery information in Section 9.5.5.

7.4.10.4 Additional Information

The AHJ may require that the battery room have two exits.

7.4.11 Fire Suppression Room

7.4.11.1 Requirements

For Class 4 data centers, a separate room shall be provided for the preaction sprinkler control valve system; a separate room is recommended for critical or Class 3 data centers.

Space shall be provided for the placement of clean agent fire suppression tanks as required. Tanks shall be located to assist easy serviceability. Tanks shall not be located in the ceiling area above equipment.

7.4.12 Circulation

7.4.12.1 Requirements

Clear pathways allowing for the movement of racks, processing, and support equipment shall be provided throughout the space in a direct path.

Circulation pathways shall be a minimum of 1.2 m (4 ft) wide with a minimum clear overhead of 2.4 m (8 ft).

7.4.13 Equipment Staging and Storage

7.4.13.1 Requirements

To prevent contaminants in the computer room, arriving equipment shall be stored, uncrated, and prepared in room(s) intended for storage and staging. This separate room shall have filtration on the return air leaving the room.

For both arriving equipment and backup equipment, such as boards and servers, a storage room shall be adjacent to the equipment entrance of the data center. The storage room can be a component of the staging room or a separate room near the staging area.

A staging area shall be provided that has space for the uncrating and preparation of arriving equipment.

Provide space for the large number of boxes and packing material handled by these facilities. Consider fire protection requirements, frequency of removal, and recycling to comply with local requirements. Consider dumpster requirements, access, and location.

7.4.14 Equipment Repair Room

7.4.14.1 Recommendations

A separate room for repair should be provided with easy access to both the equipment access pathway and the computer room.

An equipment repair room should have a work surface with multiple power and communications connections.

Shelving/caged areas should be provided for spare parts as necessary.

7.5 Construction Considerations

7.5.1 Structure Preparation

7.5.1.1 Requirements

If the data center is a new building, prepare the slab and all below grade components of the building with a continuously sealed rubberized moisture barrier.

The building slab shall comply with all local building code requirements for protection against flooding, such as height above flood plain and setbacks from a flood plain.

All exterior openings and penetrations shall be sealed prior to work on interior walls or finishes in the computer room.

7.5.2 Floor Slab

7.5.2.1 Requirements

Floor slabs shall be as per the calculations of the structural engineer, but no less than a floor loading of 732 kg/m^2 (150 lbf/ft^2).

For elevated slabs, the concrete topping over metal deck flutes shall have a thickness of at least 100 mm (4 in) to allow for the adequate embedment of epoxy and anchor bolts.

The floor slab shall be leveled and sealed with a non-penetrating seal, such as epoxy, which is a moisture barrier and prevents the generation of dust and particulates.

See Section 8.3.1 for additional floor loading requirements.

7.5.2.2 Recommendations

To accommodate initial or future high-density equipment (e.g., disk arrays, fully loaded server cabinets), a minimum floor loading of 1221 kg/m^2 (250 lbf/ft^2) is recommended.

7.5.3 Computer Room Envelope Wall Construction

7.5.3.1 Requirements

The perimeter walls to the computer room shall be slab-to-slab.

See Table 7-1 regarding fire rated construction requirements.

The perimeter walls of the computer room shall provide the appropriate level of airtightness suitable for a clean agent fire suppression system. All wall penetrations shall be fire sealed and sealed to prevent chemical fire suppression leaks.

The thickness and shapes of wall structural elements shall meet AHJ requirements for the specific wall height to be built. For example, within the United States, metal studs used in constructing interior walls shall have a minimum thickness of 0.64 mm (0.025 in / 22 Gauge) for walls up to a height of 3.5 m (11.5 ft) and a minimum thickness of 1.0 mm (0.039 in / 18 Gauge) for walls exceeding a height of 3.5 m (11.5 ft).

Studs shall have a minimum depth of 140 mm (5.5 in) to accommodate boxes and piping to be installed in the wall. Coordinate the wall thickness, as all electrical and mechanical items (e.g., switches, outlets, controllers) shall be recessed or flush mounted.

Walls shall meet the minimum fire rating as listed in Table 7-1.

Where partitions touch a deck or vertical structural members, a joint isolator shall be provided to prevent transfer of vibration and structural loads.

Walls and other structural elements shall be designed for minimum deflection and securely fastened with isolation from all mechanical units and isolation pads or caulking at the top of the partitions.

For envelope walls separating the computer room from a unconditioned or exterior space, insulation is to be provided as necessary to stabilize temperature migration. A minimum of R-3.3 $m^2 \cdot K \cdot h/W$(R-19 $ft^2 \cdot °F \cdot h/BTU$) insulation is recommended.

7.5.3.2 Recommendations

Class 3 and Class 4 data centers may want to consider concrete masonry unit (CMU), concrete filled CMU, or tilt up concrete panels for the interior walls of the ITE, electrical, and mechanical space to provide additional structural integrity and high fire ratings.

7.5.4 Nonrated Partitions

7.5.4.1 Requirements

In the interior of the computer room, partitions that are not required for rated separation shall be from top of access floor to ceiling above unless additional height is required for security or environmental control.

Nonrated walls shall be braced at a minimum of every 3 m (10 ft) and as required to meet lateral bracing requirements of the *IBC*.

7.5.5 Vapor/Moisture Seal

7.5.5.1 Recommendations

A moisture/vapor seal should be provided completely around humidity-controlled spaces to prevent vapor infiltration to or from the computer room.

7.5.6 Door and Glazed Openings

7.5.6.1 Door Requirements

Doors shall be large enough to move equipment between various data center rooms. Doors must be high enough to allow equipment entry on pallets without tilting. (See Section 7.3.3)

Doors shall have a minimum thickness of 45 mm (1.75 in) and be a minimum of 1.1 m (3.67 ft) wide by 2.4 m (8 ft) high for a single door or 1.8 m (6 ft) wide by 2.4 m (8 ft) high for a pair of doors. Doors shall be mounted within steel frames, have a solid core, and be either wood or steel

The primary access door to the computer room shall be a pair of doors, meeting the requirements listed above. These doors shall have neither a center post nor doorsills.

All doors and frames within a rated partition assembly (1-hour or 2-hour) shall be rated at the code required rating of that assembly for occupancy rated separations. Doors shall have air tight and fire-rated weather stripping all around the opening.

NOTE: NFPA 76 requires fully rated doors)

7.5.6.2 Door Recommendations

All doors along the entire route (e.g., from the loading dock to the computer room) should be a pair of doors. Where doors are present, they should provide for an opening at least 2.7 m (9 ft) high by 1.2 m (4 ft) wide. To allow unimpeded movement, doors should not have thresholds.

7.5.6.3 Glazed Opening Requirements

Glazing within doors shall not exceed 0.065 m^2 (100 in^2). These requirements are for equipment and main exit doors to the computer rooms. Where personnel access is required, it should follow the requirements of Section 12.6.3.

Glazing within rated doors shall be fire rated and set in metal frames.

Glazed openings within rated partitions shall not exceed code limitations as set by the *IBC*.

Glazed openings within partitions shall be of metal frame construction with glazing set in continuous stops (such as neoprene) to prevent vibration.

7.5.7 Fire-Rated Construction

7.5.7.1 Requirements

Walls separating computer room, electrical rooms, battery rooms, mechanical rooms, and separate TRs from other areas within the building shall be a minimum of 1-hour separation or as required by applicable codes and regulations.

Doors and frames within a rated wall shall match the rating of the wall construction.

Glazing within a rated wall shall match the rating of the wall. Electrical rooms and battery rooms, as defined by *IBC* Table 608.2, shall have glazing within the doors only.

See Table 7-1 for the fire rating of spaces. Floors above and below each of the spaces listed in Table 7-1 shall be rated as defined in *IBC*.

7.5.8 Access Control Systems

7.5.8.1 Requirements

Access control shall be provided at all entrances to the data center and all entrances to the computer room. A system that allows for multiple levels of controls shall be installed to provide for different levels of security in different portions of the data center.

The access control system shall allow for easy modification of access control, be completely programmable, and provide a digital and hard copy of all access to the data center and its various components.

Table 7-1 Minimum Fire Rating of Spaces

Area	*Minimum Fire Rating of Walls*
ITE space (computer rooms, entrance rooms, dedicated distributors [MDA, IDA, HDA], telecommunications rooms)	1-hour rating, slab-to-slab, may be required by AHJ between adjacent ITE spaces
Command center	1-hour rating, slab-to-slab
Printer room and printer supply storage room	1-hour rating, slab-to-slab
Critical media storage	2-hour rating, slab-to-slab
Electrical room	1-hour rating, slab-to-slab
Battery room	1-hour rating, slab-to-slab
Staging and storage room	1-hour rating, slab-to-slab
Loading dock	1-hour rating, slab-to-slab

7.5.9 Airborne Particles

7.5.9.1 Introduction

Airborne particles can be detrimental to proper operation of the electronic equipment. There are 2 types:

- Nonconductive: This dust can be absorbed by the ventilation fans and obstruct the airflow, thereby increasing power consumption or increasing the risk of overheating of the equipment.
- Conductive: This dust can deposit on the electronics and cause short circuits and arcing in electrical equipment. A main cause of conductive dust is zinc whiskers.

Metal whiskers "grow" from ferrous (steel) surfaces, especially those that have been coated with tin, zinc, and cadmium to help protect them from corrosion. These fine metallic filaments, normally only a few microns in width but of several hundred up to a few thousand microns in length can break off to become airborne.

7.5.9.2 Requirements

The computer room shall provide an operational environment in line with the limits and requirements set out in the applicable telecommunications cabling and data center standards for an $M_1I_1C_1E_1$ environment (see ISO/IEC 11801-1 or ANSI/TIA-568.0-D).

7.5.9.3 Non-Conductive Airborne Particles Recommendations

Non-conductive airborne particles can be minimized by:

- Doing all unpacking, cutting, and drilling outside the computer room
- Keeping cardboard boxes and manuals outside the computer room
- Prohibiting food or drink inside the computer room
- Avoiding carpets in computer rooms
- Using ceiling panels that have an impervious surface such as drywall panels with a vinyl covering
- Use of air filtration with regular replacement of filters
- Keeping printers, copiers, and tape media in separate rooms with separate HVAC systems
- Occasional professional cleaning of the access floor, subfloor, and overhead ducts
- Preventive maintenance cleaning of equipment, cabinets, and racks
- Place brushes, grommets, or other material in access floor openings to minimize loss of air pressure and airborne particulates.

Fire marshals usually require that all combustible materials be stored outside the computer rooms and, in cases where aluminum floor tiles are used, keep printer toners out of the computer room to avoid thermite reactions.

7.5.9.4 Conductive Airborne Particles Recommendations

Typical equipment with ferrous material are floor tiles, supports, raceways, cable trays, racks, cabinets, and the chassis of servers and switches.

It is recommended that the designer verify that the manufacturer has tested for the resistance of zinc whisker development or has taken action through the manufacturing process to mitigate whisker development. Some examples of mitigation include:

- Electroplated zinc coated or hot dip galvanized zinc coated with special addition of other material preventing whisker growth.
- Powder coated with sufficient thickness
- Use of non-ferrous or stainless-steel materials

NOTE: Non-ferrous or stainless steel have not demonstrated the capability to develop whiskers.

7.5.10 Access Flooring Systems

7.5.10.1 Introduction

An access floor system can be used for the distribution of power and signal cables, HVAC piping, and cooling air through perforated tiles to equipment racks if the capacity is sufficient for the load.

Access floors consist of interchangeable square panels selected to meet specific load requirements, supported by adjustable pedestal assemblies, which positively locate, engage, and secure panels and that accommodate horizontal stringers connecting the heads of the pedestals.

7.5.10.2 Requirements

Access floor systems are not required; the requirements of this section apply where access floors are used.

Underfloor concrete shall be cleaned and sealed after all major underfloor work has been done, including installation of the access floor system itself.

The access floor shall be a minimum of 450 mm (18 in) above the slab. When determining the minimum raised floor height for an air plenum, the mechanical designer shall analyze the height required to achieve the desired air distribution. Considerations shall include all under-floor airflow obstructions such as network cabling pathways, power systems and pathways, and cooling system piping. Raised floor heights of 900 mm (36 in) are common.

The access floor performance shall meet or exceed the minimum specifications listed in Table 7-2. Additionally, the floor tile or system must have the ability to withstand two times the loads specified in Table 7-2 without failure. While concentrated and rolling loads are dependent on the equipment being placed, any equipment being placed shall not exceed the rolling load and concentrated load listed in Table 7-2.

When designing and selecting access floor performance in conjunction with pre-loaded cabinets and racks, access floor performance shall meet or exceed the values listed in the *Recommended Column* of Table 7-2.

The building's structural system supporting the access floor must support the access floor and all imposed loads.

The assembly shall be leveled and locked at a selected height, requiring deliberate action to change the height setting and preventing vibration displacement.

Pedestals shall be secured to the slab using a method acceptable to the access floor manufacturer and AHJ. This is typically performed using bolts, adhesives, or seismically isolated floor systems.

Stringers shall be used for all access floors exceeding the height of 500 mm (20 in).

All tiles shall be supported at all four sides/corners, and the tile surface shall have anti-static properties in accordance with IEC 61000-4-2.

Removal of tiles in unstringered systems or tiles and stringers in stringered systems in an operational data center will destabilize the structural integrity of the access floor. A structural engineer shall be consulted to provide a recommended maximum number of contiguous tiles and stringers that can be removed at any one time, and this information shall be incorporated into the operational guidelines for the data center.

The space below an access floor shall include a method of fire detection if required by local codes. See Section 11 for additional information.

Table 7-2 Computer Room Access Floor Performance Specifications

Performance Specification	*Minimum (medium duty)*	*Recommended (heavy duty)*
Rolling load (access floor tile) Local surface deformation 0.5 mm (0.02 in) Total permanent set 1 mm (0.04 in)	567 kg (1250 lb)	680 kg (1500 lb)
Impact load (access floor tile) Drop weight, dropped from 305 mm (12 in) height on 645 mm^2 (1 in^2) local surface with deformation 1.5 mm (0.06 in)	68 kg (150 lb)	79 kg (175 lb)
Concentrated load (access floor tile) Load on 645 mm^2 (1 in^2) point with maximum deflection 2 mm (0.08 in) anywhere on the panel	567 kg (1250 lb)	680 kg (1500 lb)
Uniform load (access floor system) Load rating of access floor system, including panels, pedestals, and stringers	732 kg/m^2 (150 lb/ft^2)	1221 kg/m^2 (250 lb/ft^2)

7.5.10.3 Recommendations

For higher power density equipment where the underfloor space is used for cooling, the access floor should be a minimum of 900 mm (36 in) above the slab.

In locations where seismic activity is present, the access floor selected should be designed by the manufacturer for seismic applications, installed in accordance with the manufacturer's instructions, and certified by a professional structural engineer.

Additional structural and operational criteria/factors to consider should include:

- Panel drop tests
- Maintaining panel integrity for a given cut-out size
- Pedestal axial loads
- Pedestal overturning moment
- Stringer mid-span concentrated loads
- Permanent sets and deformations of any system components
- Pedestal bases should be glued directly to the concrete slab and not to the epoxied/painted slab

Refer to Section 14.13.2 for the access floor grid coordinate system to be used to locate equipment in the data center.

Stringers should be used for increased stability regardless of access floor height. Access floors for computer rooms should use a bolted stringer system as they are more stable than stringerless systems. Additionally, access floor stringers should be 1.2 m (4 ft) long installed in a "herringbone" pattern to improve stability.

Access floor tile cuts should have edging or grommets along all cut edges. If the edging or grommets are higher than the surface of the access floor, they shall be installed so as not to interfere with placement of cabinets and racks. The edging or grommets shall not be placed where the cabinets and racks normally contact the surface of the access floor.

In the case of floor discharge HVAC systems, floor tile cuts should be limited in both size and quantity to ensure proper airflow. Static air pressure should be controlled at all floor tile cuts and openings. Various methods for containing static air pressure are available, including brush systems that can be field fabricated or are commercially available. It is recommended that the HVAC system be properly balanced once all equipment cabinets and racks are in place. The HVAC system should be rebalanced with the addition and removal of floor cuts, equipment racks, and cabinets.

Floor tile openings under cabinets and racks should be no larger than required for entry of cables to minimize loss of underfloor pressure.

7.5.10.4 Additional Information

Access floor performance ratings are based on Ceilings and Interior Systems Construction Association (CISCA) standards and ANSI/TIA-569-D.

Load information as applicable to Table 7-2:

- Concentrated load – the access floor tile's capability to handle a point or static load. Use CISCA testing guidelines for concentrated load.
- Uniform load – the load applied over the entire area of the panel in kg per m^2 or lb per ft^2.
- Rolling load (or dynamic load) – the access floor tile's capability to handle movement of equipment on wheels. Rolling loads are determined by the number of passes, and the physical properties (e.g., size, hardness) of the wheels. Rolling loads typically have a more damaging effect on a panel than a static load.
- Impact load – defined by the weight of the load and the height the object is dropped.
- Ultimate load – the load at which the panel structurally fails and is sometimes expressed as a multiple of concentrated load.

Hollow steel panels are light and do not create particulates that wood filled or concrete filled tiles can create, but they do not have the static or dynamic load capability of filled tiles. Some data centers use a mix of concrete filled steel tiles (in more heavily trafficked aisles and print areas) and hollow steel tiles.

Damage to access floor tiles during move-in can be reduced by temporarily covering pathways with 13 mm (0.5 in) thick plywood or hardboard.

High-pressure laminate (HPL) is a good material for the top surface covering of access floor tiles as it is easy to maintain and helps dissipate static electrical charge.

7.5.11 Ceilings

7.5.11.1 Requirements

In data center computer rooms and telecommunications spaces (e.g., entrance rooms, TRs), the minimum ceiling height should not be less than 3 m (10 ft) from the finished floor to any obstruction such as sprinklers, lighting fixtures, or cameras. At least 450 mm (18 in) clearance from sprinklers to raceways, cabinets, and racks shall be maintained to ensure that they do not disrupt the sprinkler distribution pattern subject to the AHJ.

7.5.11.2 Recommendations

The recommended ceiling height for computer room spaces (from slab-to-slab) is 4.5 m (15 ft) or greater.

A suspended ceiling may not be required for computer rooms that do not use the ceiling space as an air-return. Benefits of an open ceiling (where not required for cooling) are the visibility of any technical problem and the ease of access to installations and pathways mounted underneath the ceiling slab.

Where the HVAC and cabinet solution has been designed to suit, having a ceiling partition where hot air can be fed into and directed to the air handling units, thus preventing the hot air from recirculating into general room space, is better than having a high ceiling alone.

Office-type ceilings should not be installed in new data center spaces. Depending on the design for the cabinets and the HVAC solution, there may be a HVAC solution design requirement to provide a ceiling return air plenum. (Refer to Section 14.7 for considerations of cable routing). The materials used and the design of this type of ceiling shall consider any need to support cable trays or other cable pathways for overhead cabling in the data center.

Ceiling requirements should be developed by taking into consideration elements, such as tile particulate generation, vapor resistance, hold down clips for gaseous fire suppression discharge or high-volume airflow, and acoustics. Materials known for metal whiskers (e.g., zinc, tin, cadmium), whether electroplated, pregalvanized, or hot dip galvanized, should be excluded from ceilings.

Where suspended ceilings are deployed consideration should be given to infrastructure that will need to be hung below the ceiling and what can be concealed above the suspended ceiling. Table 7-3 below provides recommendations for infrastructure mounted above and below the suspended ceiling.

In order to support the items hanging below the suspended ceiling, the ceiling grid should have a hanging capacity of 1197 N/m² (25 lbf/ft²) and a point load capacity of 60 kg (132 lbf).

Table 7-3 Suspended Ceiling Infrastructure Mounting Recommendations

Item	*Access Requirement*	*Frequency*[1]	*Location*
Power cables	Fixed wire testing and inspection	2-5 years	Above ceiling
Power connections	New or replacement equipment	Monthly, weekly, daily	Below ceiling
Data cables, backbone	Additions, upgrade	5-10 years	Below ceiling
Data cables, horizontal	Additions, upgrade	Annually	Below ceiling
Fire suppression pipes	Inspection	5 years	Above ceiling
Wiring to lighting, smoke detectors, other ancillary equipment	Inspection, reconfiguration	5-10 years	Above ceiling

NOTE: Some AHJs may have requirements which takes precedence over this column

7.5.12 Equipment Bracing Systems

7.5.12.1 Introduction

Various locations, including high seismic and wind-loading areas, will require special attention to the bracing of equipment.

7.5.12.2 Requirements

Equipment cabinets and racks shall be braced in accordance with local codes.

Cabinets braced at the top can utilize the cable ladder rack system, if present, with an attachment that provides rigid four-directional lateral bracing. Equipment mounted on access floors in seismic areas shall be braced to the underfloor slab with an approved method.

7.5.12.3 Recommendations

The bases of cabinets and racks should be braced to the slab as appropriate for the seismic demand in accordance with local seismic codes or requirements such as ASCE 7.

7.5.12.4 Additional Information

As an option, lateral movement at base of cabinet may be controlled utilizing a base isolation platform rated for the loading of the cabinet.

7.5.13 Computer Room Finishes

7.5.13.1 Requirements

Equipment rooms and related walls shall be finished with particulate-free, water-based epoxy paint finish, smooth finish. Prior to painting, drywall board shall be sealed with a compatible sealing primer.

All penetrations in the perimeter walls shall be completely sealed up to the deck height.

7.5.14 Roof Systems

7.5.14.1 Requirements

Data center roofing shall be designed to handle the loading requirements of the roof top mechanical systems.

The roof system shall be designed to provide a continuous seal above the entire data center. Parapets and coping systems shall be of construction to ensure moisture infiltration is prevented.

Roof drains and leaders shall be kept away from the computer room.

7.5.14.2 Recommendations

Roof penetrations over the command center computer rooms, entrance rooms, or electrical rooms are not recommended and should be avoided whenever possible.

8 Structural

8.1 Building Code Compliance and Coordination

8.1.1 Requirements

Local building codes shall be consulted in the planning and implementation of changes to the building and its mechanical, electrical, and life safety systems.

NOTE: Building code references within this standard are generally to the current edition of the *IBC* and ASCE 7.

All building systems shall meet local building and seismic code requirements. If local building or seismic codes do not exist or are deemed inadequate for a data center, building systems shall meet IBC and ASCE 7 requirements listed within this section and should meet UFC requirements listed within this section.

8.1.2 Additional Information

State, provincial, and local municipalities often adopt their respective national building codes by incorporating them into their specific building codes for their jurisdiction. However, these adoptions often have amendments to specific sections, and the scope of the amendments may be significant. Always check the local amendments before making decisions based on code requirements.

Compliance to the *IBC* and ASCE 7 does not assure functionality following an environmental event such as wind, snow, and earthquakes. If a facility is intended to be functional, additional guidance is provided in documents such as the UFC 3-310-04 and the UFC 3-301-01. The most critical of facilities should consider using the requirements for Occupancy Category V per UFC 3-310-04 and UFC 3-301-01 if a regional equivalent does not exist. Additional guidance particular to data centers is contained within *Structural and Vibration Guidelines for Datacom Equipment Centers* from ASHRAE.

8.2 Impact of Site Location on Structural Loading

8.2.1 Introduction

All loads on the structure are divided into various types as defined in ASCE 7:

- Dead loads, soil loads, hydrostatic pressure loads
- Live loads
- Flood
- Snow
- Rain
- Ice
- Seismic
- Wind

The magnitude of forces on any structure is a function of its geographic location. Both ASCE 7 and the *IBC* identify the forces expected to be applied to buildings and nonstructural components. The applied forces are a function of probability at a given location for environmental loads (e.g., wind, ice, snow, flood, tsunami, earthquake).

8.2.2 Recommendations

Data centers requiring higher building or structural performance should consider loads and performance requirements contained in the UFC 3-310-04 and UFC 3-301-01, or regional equivalents.

Additional loads that may warrant consideration for data centers include tsunami and ice impact loads because of shedding on adjacent structures such as telecommunication towers.

8.3 Structural Concerns Specific to Data Center Design

8.3.1 Floor Load

8.3.1.1 Requirements

Floor loading (superimposed live load) shall be a minimum of 732 kg/m^2 (150 lbf/ft^2) with 122 kg/m^2 (25 lbf/ft^2) hanging dead load (weight that can be supported from the underside of the floor or roof). This floor load is adequate for most data center areas.

8.3.1.2 Recommendations

Although some industry standards specify a minimum floor superimposed live loading of 732 kg/m^2 (150 lbf/ft^2) with 122 kg/m^2 (25 lbf/ft^2) hanging dead load, the recommendation in this standard is a uniform load of 1221 kg/m^2 (250 lbf/ft^2) with 244 kg/m^2 (50 lbf/ft^2) hanging dead load to provide flexibility in the location of higher floor loads such as large storage arrays, printing facilities, and densely populated blade server cabinets. In specific regions of the access floor area where this equipment is located, the structural engineer should be notified of the specific operating weights.

Floors for battery rooms should be designed for a minimum superimposed live load of 1221 to 2441 kg/m^2 (250 to 500 lbf/ft^2).

Roof areas over battery rooms should be designed to support a minimum suspended dead load of 146 kg/m^2 (30 lbf/ft^2).

8.3.2 Raised Access Floors

8.3.2.1 Requirements

Raised access floors are commonly used in data centers. For data centers with raised access floors, all raised access floors shall meet local code requirements or ASCE 7 special access floor requirements.

In seismically active areas, computer rooms shall be designed to provide the required level of seismic protection:

- For computer rooms with a raised floor
  - Seismic rated raised floor and bracing for equipment
  - Seismic rated floating base for equipment
  - Seismic rated floating floor
  - Seismic rated floating building
- For computers rooms without a raised floor
  - Seismic rated bracing for equipment
  - Seismic rated floating base for equipment
  - Seismic rated floating building

In seismically active areas, which ever seismic protection system is implemented, the building systems and equipment shall be designed as a Designated Seismic System and shall have Special Certification Requirements as defined by local codes or ASCE 7. For raised floor systems, the response spectra shall be calculated at the bottom and at the top of the raised access floor to determine the demand on the equipment mounted on the floor. The response spectra shall be computed for the in-structure response accounting for the structural support in addition to the response characteristics of the raised access floor.

The overturning of equipment mounted on the computer room floor shall be computed, and if required restraints to be provided for seismic design categories C through F. Positive mechanical attachments shall be provided as required to prevent overturning.

8.3.2.2 Recommendations

The *IBC* and ASCE 7 do not appropriately address seismic vertical ground motions and the amplifications of vertical ground motions in the structure. The nuclear industry and military industry require the calculation of the seismic demand because of vertical ground motions that is referred to as the seismic demand. UFC 3-310-04 can be used as a reference to determine methodology to seismically qualify raised access floors.

Because of the importance of data centers, an in-structure response analysis should be used to compute the coupled response of a raised access floor. A coupled response can then be used to develop response spectra for equipment mounted on the raised access floor.

8.3.3 Mission Critical Equipment in Seismically Active Areas

8.3.3.1 Requirements

Equipment that is determined to be mission critical shall be designed and tested to determine the seismic demand and the equipment fragility. The seismic demand of mission critical equipment shall be determined at the point of attachment of the equipment.

Equipment determined to be mission critical shall specify the performance expectations. The seismic demand shall be determined at the point of attachment. The point of attachment may be a structural element, or it may be a nonstructural component (such as a raised access floor). If required, a coupled dynamic analysis may be required to determine seismic demand.

8.3.3.2 Recommendations

The *IBC* and ASCE 7 do not appropriately address equipment seismic qualifications for mission critical equipment and the in-structure seismic demand. The fragility defines the ability of an element to resist seismic ground motion. UFC 3-310-04 can be used as a reference to determine methodology to seismically qualify mission critical equipment. Further guidance is contained in within *Structural and Vibration Guidelines for Datacom Equipment Centers*.

8.3.3.3 Additional Information

UFC 3-310-04 defines equipment as Mission Critical 1 (MC 1), Mission Critical 2 (MC 2), or Not Mission Critical (NMC). Once each piece of equipment and distributed system is categorized, the methods to qualify the equipment relative to the classification are defined in UFC 3-310-04. The UFC also defines how inspections and peer reviews are to be performed.

8.3.4 Wind

8.3.4.1 Introduction

Proper design and selection of structural components and building cladding is critical for a facility to mitigate or resist wind loading. For data centers, equipment such as air handling units and external generators should also be incorporated within designs to reduce the potential for the formation of leaks or impact damage from debris caused by extreme wind events. ASCE 7 provides a series of maps with wind velocity depending on the Risk Category.

8.3.4.2 Recommendations

In the design of data centers, the Enhanced Fujita Scale level of EF3 is commonly used for wind-loading calculations. EF3 yields a ground wind speed for design purposes of between 60.8 m/s (136 mph) and 73.8 m/s (165 mph). The wind speed is then multiplied by a set of empirical coefficients to translate the effect into resulting kilopascals (pounds force per square foot) lateral load on the facility. If tornado winds are to be considered, a map of tornado wind velocities is contained in the ASCE 7 Commentary.

8.3.4.3 Critical Facilities

For any data center, the integrity of the building envelope shall be maintained. Wind-borne debris is a common source of breaching of the building envelope. If the building is required to be functional following a given wind event, the building windows, doors, walls, and roof that comprise the envelope shall be designed to resist breaching by wind-borne debris. Guidance is provided in the ASCE 7 Commentary for the design considerations of wind-borne debris.

Consideration for wind-borne debris should also be included for any critical components such as air handling units or generators.

NOTE: UFC 3-310-04 defines enhanced wind loads in order to provide a higher level of performance.

8.3.5 Earthquake

8.3.5.1 Introduction

Earthquake-resistant design of structures is complex, as seismic energy is imparted to the structure through the foundation as a dynamic load. This means that the response of the building to the earth shaking will be a function of type of foundation system used, type of soil encountered, the magnitude of the earth displacement, the length of time associated with the earthquake, and the location of the structural or equipment elements within the building. It is common for structural engineers to design facilities in such a way that the facility may undergo a planned permanent deformation to prevent collapse. While this may be adequate for the building code-required design of the building to maintain life safety, it is not adequate design for an essential facility, such as a data center, to function following a major earthquake.

8.3.5.2 Recommendations

Typically, data centers are placed in IBC Risk Category IV because of their criticality. Owners may elect to use a reduced Risk Category rating of II if the facility does not have to operate after an earthquake. As Risk Category IV does not ensure functionality after a major seismic event, data centers intended to be operational immediately following a major seismic event should be designed in accordance with the provisions of Risk Category V per UFC 3-310-04.

Additionally, attention must be paid to the design of specific nonstructural components, such as raised access floors, that will have a direct impact on the survivability of the computer functions after an earthquake. Depending on the height of the raised access floor and the amount of mass supported as well as the magnitude of the earthquake, it may be necessary to isolate the access floor from the rest of the structure. The process of isolation is generally referred to as base isolation. Base isolation is also a valid consideration for the entire building. Base isolation creates other concerns for elements that cross the plane of isolation.

Care must be taken in the anchorage of generators, chillers, fans, switchboard, piping and conduit, and racks. The force on the supports for these elements will be substantially increased as a function of their mass multiplied by the dynamic coefficients addressed in the code enforced earthquake design. The in-structure demand response spectra must be compared to the fragility of the nonstructural component. Guidance for Risk Category V nonstructural components may be found in UFC 3-310-04.

Where local seismic safety codes require or presence of seismic activity dictate, consider using passive dampers to provide base isolation and building energy dissipation.

8.3.6 Blast and Terrorist Attack

8.3.6.1 Recommendations

Many data centers are designed to resist the effects of a terrorist attack. Terrorist attacks can be in many forms, but the most prominent attack is in the form of a blast from some manner of vehicle-borne improvised explosive device (VBIED). Security experts and law enforcement should be consulted to quantify the size of explosive device. Security and physical site barriers should be constructed to maximize the distance that a VBIED can be from the data center. The blast dynamic pressures can be calculated and compared to the response of the data center structure and building envelope elements. Guidance for blast-resistant design may be found in ASCE 59. Mitigation techniques for smaller explosive devices include screening processes that occur at a location, as defined a security plan, that is separated from the facility or building entrance

Terrorist attacks can take many forms that can include introducing chemical, biological, or radiological agents into a facility. Protection should include screening for compounds that could be brought into a facility clandestinely and controlling air supply into a facility.

8.3.7 Ice Shard Impact

8.3.7.1 Recommendations

In addition to the loads defined by ASCE 7, data centers adjacent to communication or broadcast towers should calculate the dynamic loads because of ice impact from ice shedding from the adjacent tower and design appropriate mitigation. Towers tend to accrete ice in many geographic areas. The ice that forms on the towers will eventually fall from the tower in the form of ice shards. Ice falling from adjacent towers has resulted in significant damage to roof structures of facilities. Mitigation can take many forms, including armoring the lower roof, locating the facility outside of the ice shedding area, or heating elements on the tower to preclude the formation of ice.

9 Electrical Systems

9.1 Overview

9.1.1 Introduction

Section 9 explains the application of redundancy and the reliability and availability Classes (described in Appendix B) to electrical power distribution and availability within a data center. This section also provides both experience-based suggestions and performance-based metrics for each of the Classes in the standard.

The only criterion for securing a given Class is conformance to the performance metrics and values of this section. No endorsement of a given design style is offered nor is any particular type of technology given preference. The project designer and owner should select the system and topology needed for a comprehensive critical power delivery system, whereas the project team should determine the appropriate MTBF and MTTR figures, which when combined with the given set of needs will offer the most appropriate solution.

At the end of this section, Table 9-17 denotes requirements for each Class and may provide additional system features and requirements for the Classes that are not specifically listed within the text of Section 9.

This section will include references to other systems in this standard that when considered and used together will yield a strong, coordinated and appropriate critical environment utility system. In the areas of batteries and stored energy systems as well as in bonding and grounding, this section has attempted to extract relevant information from published standards of the IEEE, UL, and other existing industry organizations.

9.1.2 Requirements

Section 9 defines requirements solely as performance-based criteria. The purpose of such approach to defining Classes is to uncouple them from electrical topologies and applications. Thus, to achieve a given Class, a proposed design must conform to the normal, maintenance, and failure modes of operation. This provides system designers, owners, and equipment manufacturers sufficient latitude in selecting a design or product without stifling innovation.

A data center shall meet the general requirements of this section.

Any data center that does not meet the minimum requirements of Class F1 shall be considered Class F0.

There are several methods for the physical development of electrical systems, traditionally or "stick" built, modular or "factory" built systems, or a combination of traditional and modular construction. Modular electrical construction now addresses all aspects of the data center's electrical construction—electrical rooms, ITE space (either as containers or skid-type systems installed inside a traditional building), critical power distribution systems, and supporting electrical systems outside of the data center proper. The employment of modular electrical systems are a cost, schedule, and risk management tool for the development of the project and are subject to the same demands of this chapter as traditionally-built electrical systems.

The impact of altitude on insulation and heat removal capabilities shall be considered in all electrical equipment specifications and deployments. Most electrical equipment, including batteries, has a specified altitude range for which the voltage/capacity is applicable. If equipment needs to be used above the specified altitude range, consult with the equipment manufacturer concerning operational limits and restrictions.

Within the standard, the term switchboard is commonly used to referenced electrical distribution equipment. Switchgear may be used in lieu of switchboards based on design requirements and preference.

9.1.3 Availability and Uptime

The presence of single points of failure has a direct bearing on the Class achieved by any given system or design. Single points of failure should be eliminated whenever possible, in order to improve redundancy and reliability, both within the data center and support infrastructure as well as in the external services and utility supplies.

The following issues should be addressed:

- Availability and uptime have been used in the industry on an interchangeable basis. With the varying Class ratings, systems or applications availability may not change state as a result of the failure or maintenance of the supporting electrical infrastructure. During these times, selected portions of the underlying electrical infrastructure may be out of service or unavailable. This would retard the electrical system's ability to respond to any subsequent events or failures, which may result in an outage to the IT systems.

List continues on the next page

- The elimination of single points of failure within the electrical systems is a requirement for Class F3 and Class F4 (explained in Appendix B).
- Single points of failure have greater consequences the farther they are upstream from the load. The closer they are to an individual load, the smaller the impact is likely to be on the entire system. For example, whereas a failed single branch circuit might affect one load or one equipment rack, the failure of a main circuit breaker can take down an entire distribution panel and all connected loads.
- Redundancy increases both fault tolerance and maintainability, but it also increases system complexity, which is a leading cause of human error outages in data centers. Redundancy and overall system complexity must be weighed against the system capacity, ease of operation, cost and schedule.

9.1.4 Redundancy

Within this document, the following terms describing levels of redundancy are used:

- N (N=Need) or Baseline Requirement

  System meets base requirements for minimum load kW and has no redundancy.
- N+1 Redundancy

  N+1 redundancy provides one additional unit, module, path, or system in addition to the minimum required to satisfy the base requirement. The failure or maintenance of any single unit, module, or path will not disrupt operations.
  For smaller fault-tolerant systems where a single module can accommodate the critical load, the N+1 and 2N models are synonymous.
- N + 2 Redundancy

  N + 2 redundancy provides two additional units, modules, paths, or systems in addition to the minimum required to satisfy the base requirement. The failure or maintenance of any two single units, modules, or paths will not disrupt operations.
- 2N Redundancy

  2N redundancy provides two complete units, modules, paths, or systems for every one required for a base system. 2N is also referred to as "dual-path topology." Failure or maintenance of one entire unit, module, path, or system will not disrupt operations.
  For smaller fault-tolerant systems where a single module can accommodate the critical load, the 2N and N+1 models are synonymous.
- 2(N+1) Redundancy

  2(N+1) redundancy provides two complete (N+1) units, modules, paths, or systems. The failure or maintenance of one unit, module, path, or system will still leave intact a system with full redundancy and will not disrupt operations.
- Multi-N Redundancy (*x*N)

  A multi-N system topology is used primarily in fault tolerant or large-scale power systems where more than two large systems are employed together. In such a system topology, the critical load connection at the PDU or the branch circuiting level is the primary means of achieving the redundancy and Class of the system.

9.1.5 Capacity Versus Utilization Efficiency

9.1.5.1 Definitions

The following terms are used in this section:

- Capacity: the kW required to serve the load, plus the design margin and growth factors. This does not include redundant power, or the power required for support services, such as HVAC.
- Module loading ratio: comparison of the power (kW) required by the load (ITE) to the total installed power (kW).
- Design utilization ratio: a comparison of the total number of power supplies, including those used for redundancy, to the minimum number required to support the load.

9.1.5.2 Overview

Capacity is the power required by the load and is designated as "N". High-density loads require substantial kW to operate; therefore, a substantial power system infrastructure is required to support them. Higher levels of availability (based on the criticality of the activity supported by the data center) require higher levels of redundancy, which drives the Class described in Appendix B.

The size of the system required to serve the load on an N basis (the capacity) should not be confused with the overall system size that would be required for the selected Class. Because higher Classes require higher levels of redundancy and power protection, the highest level of availability will seldom have the highest utilization efficiency.

An effective method for communicating the load-required kW versus the total installed kW is the design maximum module loading ratio. Within a given Class, the higher the ratio, the better the efficieny. Table 9-1 shows some examples of design efficiency ratios. Design efficiency or utilization efficiency should not be confused with "operating efficiency", which is a performance characteristic of an installed device or system.

Table 9-1 displays four different levels of design efficiencies for an N+1 topology. For example, if N is 100 kVA, N+1 redundancy can be achieved in any one of the following ways:

- 2 × 100 kVA modules (50%)
- 3 × 50 kVA modules (66%)
- 4 × 33 kVA modules (75%)
- 5 × 25 kVA modules (80%)

Class F3 systems are similar to Class F2 on a systems basis, except they possess the second power path. Class F3 and Class F4 systems rarely have design efficiencies over 66%. There is a mathematical point of diminishing returns for large UPS systems with the number of distinct plants versus the power paths to the load.

Increasing the number of components beyond the minimum needed results in more components, which usually implies less reliability and a higher probability of failure. Having two 100kVA modules is typically less expensive and more reliable than having five 25kVA modules. However, other factors might be considered. For example, one might choose a higher number of modules because:

- Smaller modules may be easier to install or to replace.
- Consequences of a failure in any one of the modules may be less.
- Smaller modularity allows for scalability.
- Overall operating efficiency (and operating cost) may be better.

Table 9-1 Design Efficiency Ratios

Topology	*UPS or power systems ratio*	*Design efficiency (required kW/installed kW)*
N	1:1	100%
N+1	2:1	50%
N+1	3:2	66%
N+1	4:3	75%
N+1	5:4	80%
2N	2:1	50%
2(N+1)	6:2	33%
N + 2	3:1	33%
N + 2	4:2	50%
N + 2	5:3	60%
N + 2	6:4	66%

9.1.6 Electrical Class Ratings

9.1.6.1 Introduction

Appendix B describes data center facility Availability Classes in general terms and provides details on how they are calculated. This section details the application of data center facility Availability Classes to electrical systems and provides specific design information concerning the electrical system for achieving each Class. The standard includes five Classes relating to various levels of reliability of the data center facility infrastructure. The Classes are completely performance related.

The five Classes are:

- Class F0 - a single path data center that meets the minimum requirements of the standard, but doesn't meet the requirements of an F1 or higher level data center
- Class F1 - the single path data center
- Class F2 - the single path data center with redundant components
- Class F3 - the concurrently maintainable and operable data center
- Class F4 - the fault tolerant data center

Several factors can affect Class over the life of the data center, including:

- Redundancy
- Capacity
- Expandability
- Maintainability
- Survivability
- Quality

While some elements of higher Classes are only more expansive versions of lower Classes, there are segments of the electrical systems that make a specific and notable change when jumping between Classes. This can be seen in the change between Classes in the critical power system.

Classes might not be consistent throughout the utility infrastructure systems. Electrical systems are circuited to the loads that they serve, and specifically, the mechanical and electrical systems are matched as an integrated approach for the data center and facility as a whole. For example, if the mechanical ventilation system is offered at N + 2, the electrical system must maintain the mechanical system's Class through the electrical system's normal, maintenance and failure modes of operation.

Oftentimes, the electrical system may not possess a consistent Class between different electrical subsystems. This is completely appropriate. While it is desirable to render the electrical system at a consistent Class for the entire electrical system, it is often not practical because of cost, space, operability, or reliability. To discover the Class need of a given system, criteria needs to be developed that meets the end user's availability and reliability needs for the facility. The purpose of this evaluation is to discover the actual needs for the critical load or constituent components. This "needs assessment" then allows the end user and system designer to choose the most appropriate system for their situation. (See Appendix B for the general guidelines for the evaluation process.)

As a part of this evaluation process, the end user and system designer need to determine the ability of a given system to respond to normal, maintenance, and failure modes of operation and how that system affects their critical facility operations. Therein lies the performance-based definition. The kinds of questions asked when defining a Class are:

- Is the load disconnected with a given outage?
- Is the load disconnected during a given maintenance activity?
- Is redundancy lost with a given outage?
- Is redundancy lost during a given maintenance activity?
- For components that are deferred from the initial construction, can they be added transparently to the existing, operating loads, or is a shutdown or some form of accommodation in excess of optimum facility operation required?
- If the system loading changes on the UPS or generator, will that affect the Class?
- How long can the system run with an absence of utility power?

Redundancy increases both fault tolerance and maintainability. However, it also increases system complexity, which is a leading cause of human error. Redundancy and overall system complexity must be weighed against the overall system capacity, ease of operation, cost, and schedule. Therefore, while redundancy and the resulting availability figures might be quite good, the time the system is available might be reduced because of the system's complexity and configuration.

While the concept of Classes is useful for specifying the levels of redundancy within various data center systems, circumstances might dictate a combination of Classes. For example, a data center located where utility electric power is less reliable than average might be designed with a Class F3 electrical system but only Class F2 mechanical systems. The mechanical systems might be enhanced with spare parts to help ensure a low mean time to repair (MTTR).

The total data center Class is only as high as the lowest rated Class subsystem. For example, the overall data center would be rated Class F2 with a Class F2 mechanical system even though it has a Class F3 electrical rating.

NOTE: There is no allowance for a plus or minus rating to a Class, and the use of terms, such as Class F3+, are not recognized by this standard.

It should also be noted that human factors and operating procedures could also be very important. Hence, the actual availability of two Class F3 facilities may vary widely.

9.1.6.2 Class F0 Description

A Class F0 electrical system is an electrical infrastructure that meets the general requirements of Section 9, but it does not meet one or more requirements listed for Class F1.

The system cannot be maintained while it is operating and a failure of any element in the power path will likely result in the loss of electrical service to the load. Some form of power conditioning, such as voltage regulation or surge suppression, may be available, but a loss of utility power will almost definitely result in dropping the load. Single points of failure are common throughout the system. Any downtime, whether planned or unplanned, will result in critical load interruption.

A representation of a Class F0 topology is shown in Figure 9-1.

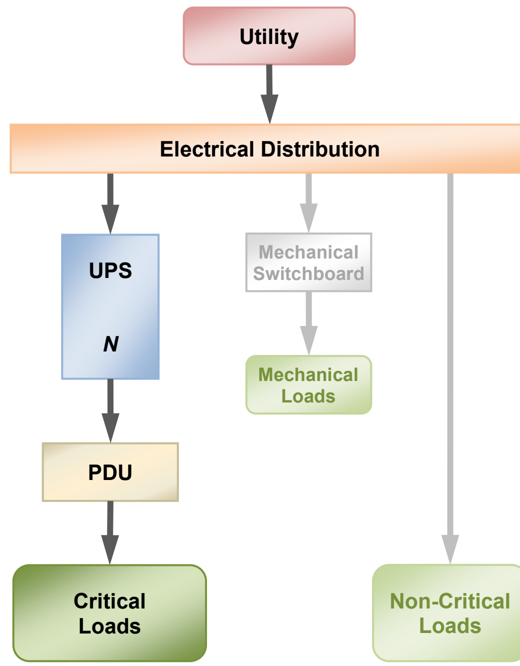


Figure 9-1
Class F0 Electrical Concept Diagram
(Configuration Without Backup/Alternate Power)

Table 9-2 Class F0 Electrical System Overview

Industry description:	Single path
Component redundancy:	None
System redundancy:	None
Power sources available to critical load:	One
UPS sources available to the critical load:	None (Optional)
Ability to be maintained while under load:	No
Ability to recover from failures:	No
Resulting definition:	Single path/single module/single source

9.1.6.3 Class F1 Description

A Class F1 electrical system is an infrastructure with no redundancy. This system cannot be maintained while it is operating, and a failure will likely result in a loss of electrical service to the load. Single points of failure are common throughout this system. Critical load interruptions are likely during planned and unplanned downtime.

A representation of a Class F1 topology is shown in Figure 9-2.

Table 9-3 Class F1 Electrical System Overview

Industry description:	Single path
Component redundancy:	None
System redundancy:	None
Power sources available to critical load:	One
UPS sources available to the critical load:	One
Ability to be maintained while under load:	No
Ability to recover from failures:	No
Resulting definition:	Single path/single module/single source

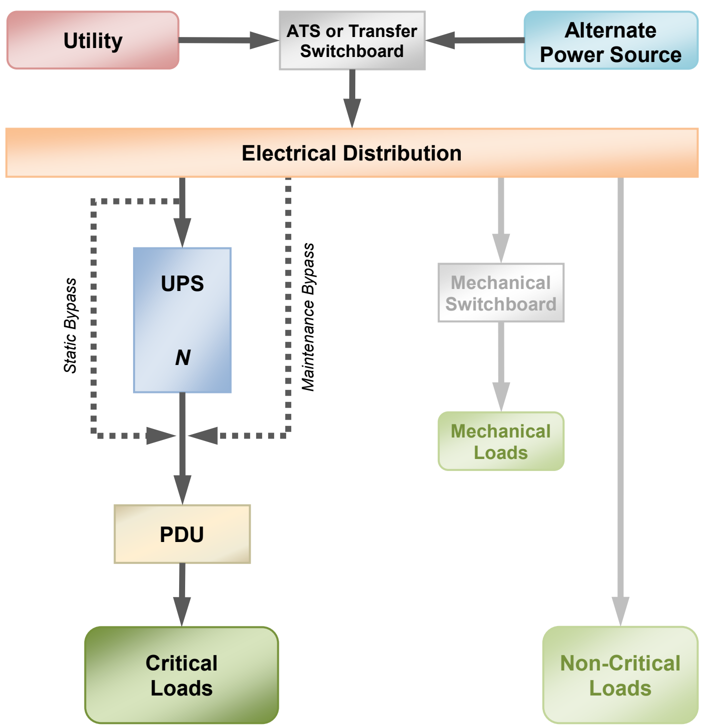


Figure 9-2
Class F1 Electrical Concept Diagram

9.1.6.4 Class F2 Description

A Class F2 system possesses component redundancy, but it does not have system redundancy. Redundant components may exist on an N+1 and paralleled basis in the UPS and generator systems, but a Class F2 system does not offer redundancy in the distribution system. A failure in one of the N+1 components may not result in a load failure, but it would reduce the redundancy level in the systems to N. This system has a single electrical supply to the load and no source diversity. Any failure in the distribution system will likely result in a loss of electrical service to the load. Large-scale system maintenance cannot be performed without interruption to the load.

Single points of failure are present in the distribution system, and critical load interruptions are likely during both planned and unplanned downtime. A representation of a Class F2 system is shown in Figure 9-3.

Table 9-4 Class F2 Electrical System Overview

Industry description:	Single path with redundant components
Component redundancy:	N+1
System redundancy:	None
Power sources available to critical load:	One
UPS sources available to the critical load:	One
Ability to be maintained while under load:	At the system level only, but not in the distribution system
Ability to recover from failures:	Only at the system level.
Resulting definition:	Single source/multiple module/single path

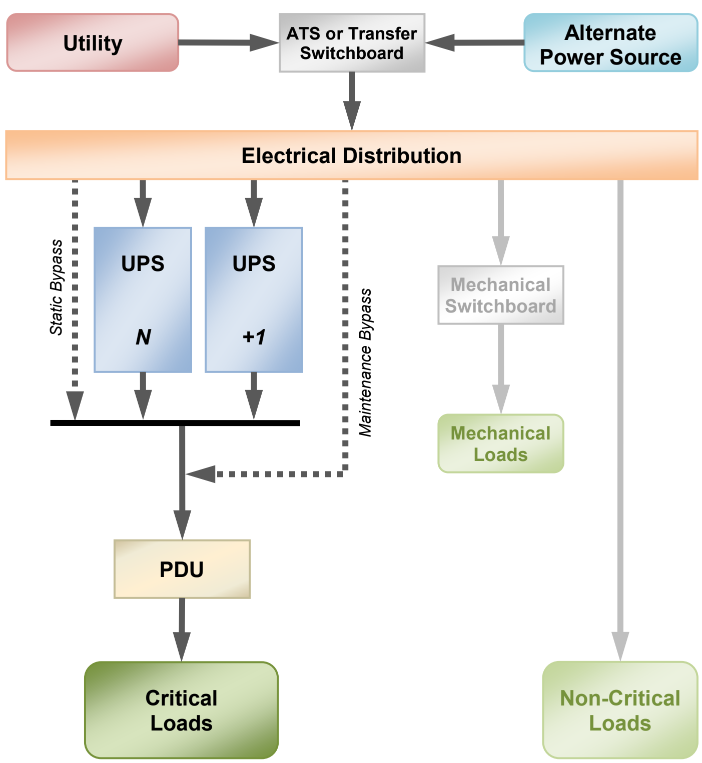


Figure 9-3
Class F2 Concept Diagram

9.1.6.5 Class F3 Description

The Class F3 system possesses redundancy in the power paths to the critical load, but only one of those paths needs to be UPS powered. The alternate path may be UPS powered, but this Class requires that it only be available and dedicated to the IT load. On a dual-corded IT device, one input would be fed from the UPS power system, while the other input is fed from the non-UPS source.

The individual critical power systems are rated for a portion of the total load with a common and centralized dedicated UPS system providing the redundant supply to the line systems. The redundant system, similar to the line systems, may possess either single or multiple modules. This concurrently maintainable system provides load source selection either via static transfer switches (STS) or by the internal power supplies in the IT systems themselves. There are no single points of failure in either the critical power system or the power systems supporting the mechanical or vital house/support loads.

The Class F3 system allows for complete maintenance during normal operations (on a planned basis), but it loses redundancy during maintenance and failure modes of operations. STSs are required for single-corded loads to provide power redundancy where no IT component redundancy exists. STSs are not required for dual-corded loads.

All maintenance and failure modes of operation are transparent to the load.

Three representations of a Class F3 system are shown in Figure 9-4, Figure 9-5, and Figure 9-6.

It is not a requirement to parallel all UPS outputs so long as UPS units can transfer loads without interruption. UPS units can be configured in "Catcher" configuration (see Section 9.1.6.7).

Table 9-5 Class F3 Electrical System Overview

Industry description:	Concurrently maintainable and operable
Component redundancy:	N+1, as a minimum
System redundancy:	N, N+1 or 2N as required to provide concurrent maintainability, as dictated by electrical distribution topology
Number of utility sources:	One source with two inputs or one source with single input electrically diverse from backup generator input.
Power sources available to critical load:	Two
UPS sources available to the critical load:	One UPS system with one UPS power path to the load.
Ability to be maintained while under load:	Yes, with a reduction of the system redundancy from N+1 or better to N during maintenance activities.
Ability to recover from failures:	At the plant and distribution level, but with a reduction of the system or distribution redundancy from N+1 or better to N after failure and prior to the recovery.
Resulting definition:	Multiple source/N rated single or multimodule system/dual or multiple path

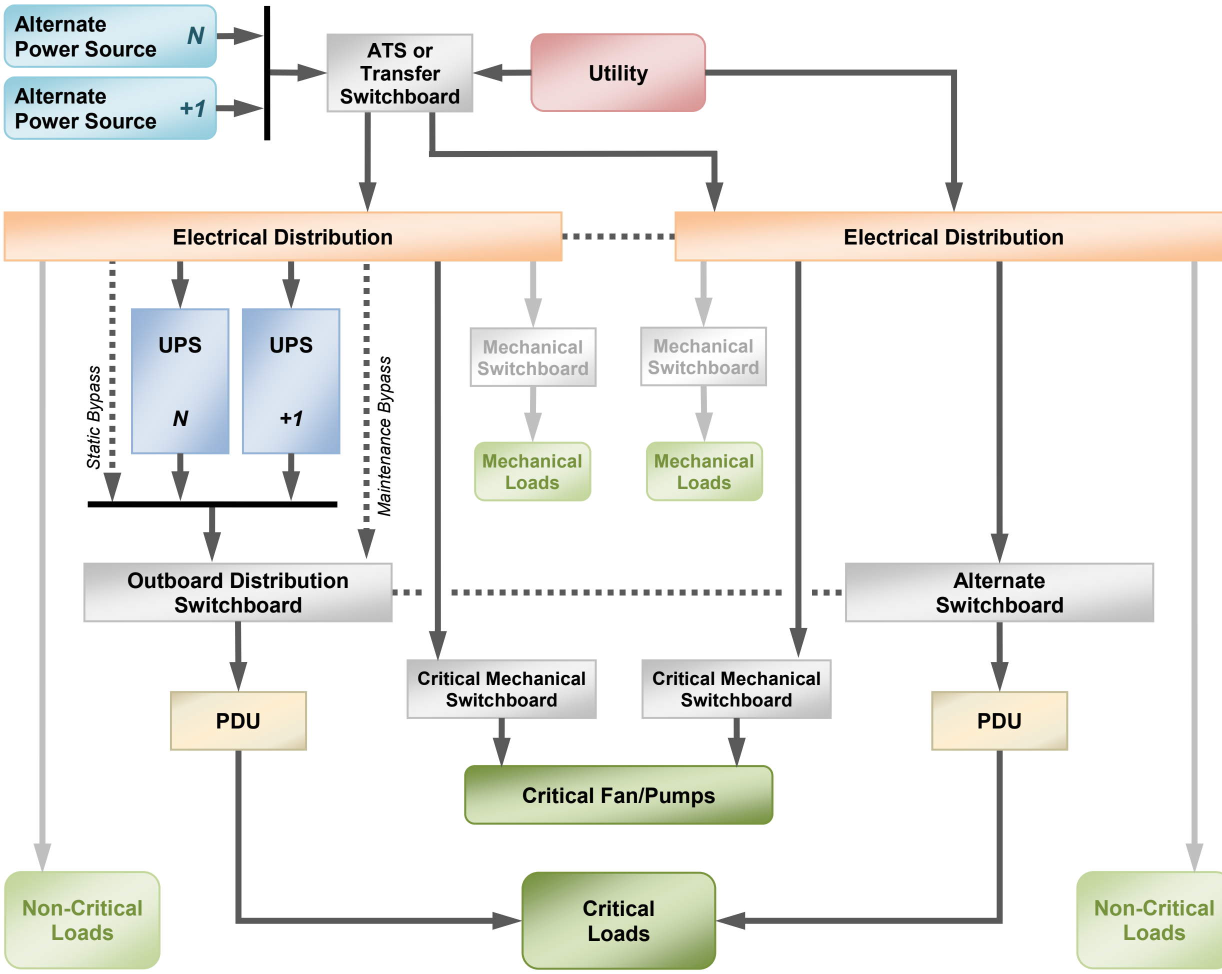


Figure 9-4
Class F3 Single Utility Source with Two Utility Inputs

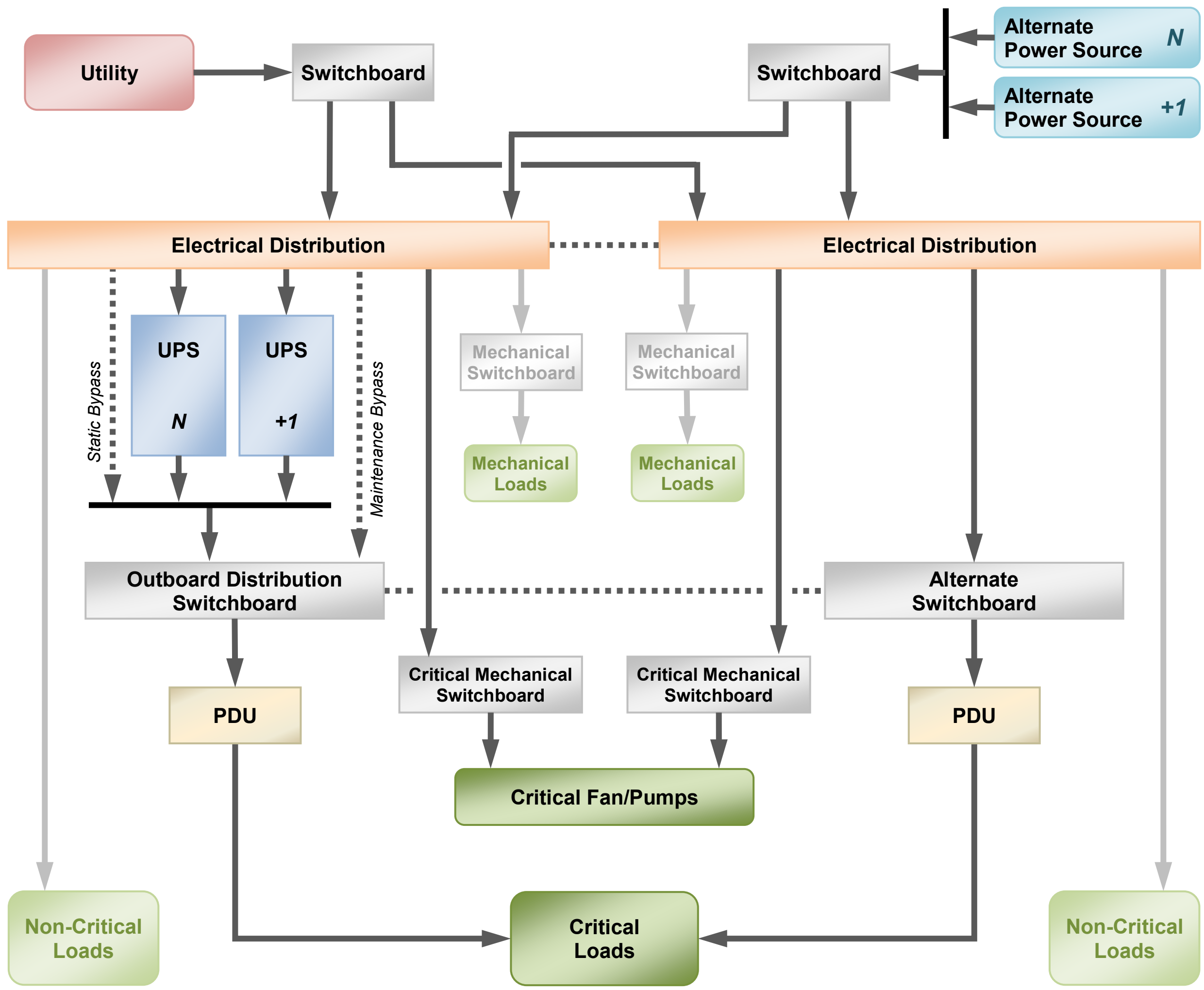


Figure 9-5
Class F3 Single Utility Source with Single Utility Input

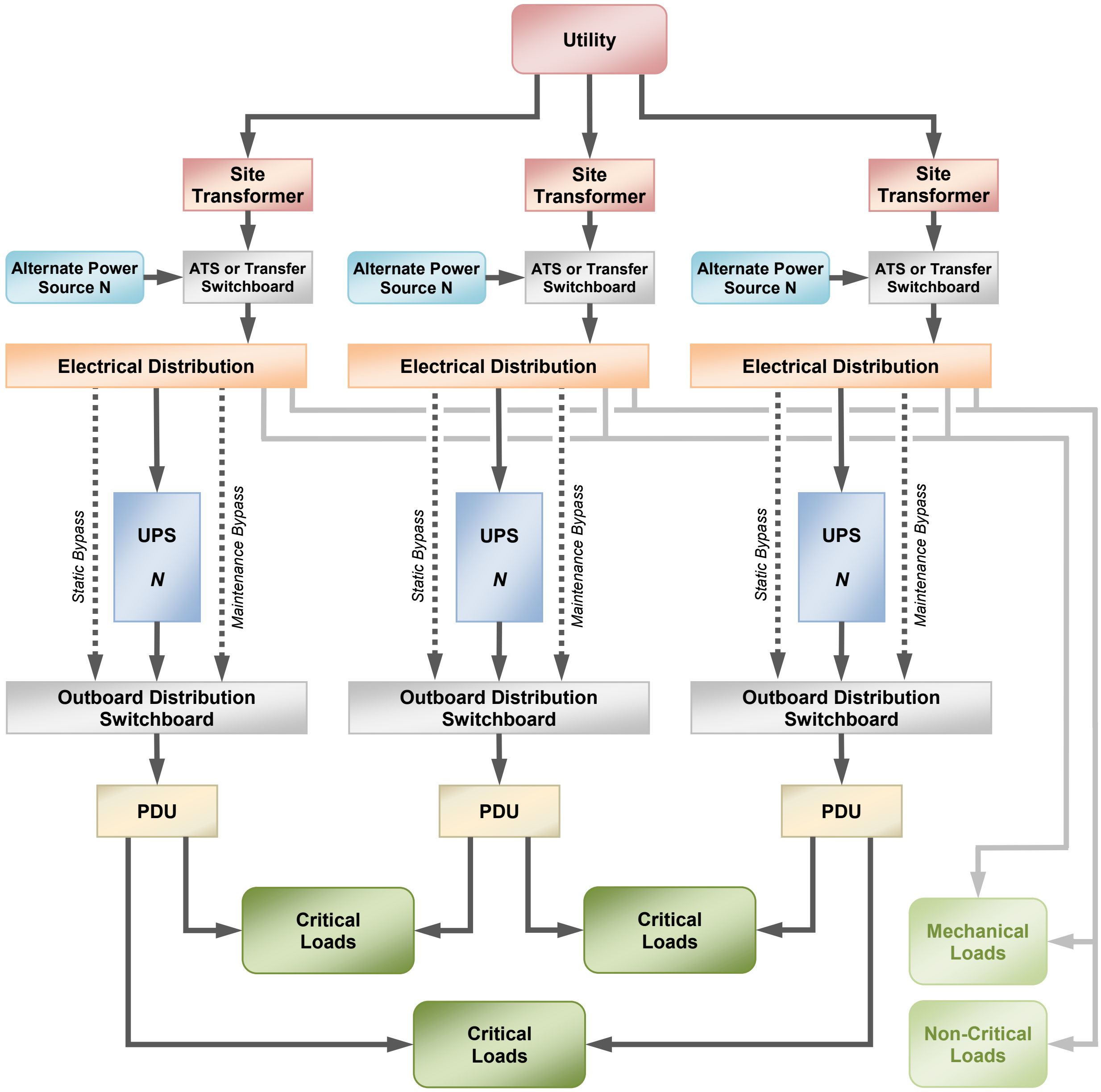


Figure 9-6
Class F3 Electrical Topology (xN Or Distributed Redundant)

9.1.6.6 Class F4 Description

A Class F4 system possesses redundancy in the power paths, and there may be more than two independent sources of UPS power to the critical load. The individual critical power systems are rated for the complete load for the 2(N+1)/system-plus-system option. For larger loads, the system may have multiple UPS systems where the system diversity is provided solely by the connection of the critical loads to the multiple UPS systems. Each UPS system could be a multimodule UPS system or a single/high-kW UPS system. The fault tolerant system provides load source selection either via static transfer switches or by internal power supplies in the IT systems themselves. There are no single points of failure in either the critical power system or the power systems supporting the mechanical or vital house/support loads. The Class F4 system allows for complete maintenance during normal operations and does not lose redundancy during either failure or maintenance modes of operations.

All maintenance and failure modes of operation are transparent to the load.

Redundant components should be compartmentalized and separated in different rooms to enhance survivability.

Continuous cooling is required for ITE. Typically, this will require fans and pumps to be on UPS power.

The Class F4 representation for a shared/distributed redundant and 2N are illustrated in Figure 9-7 and Figure 9-8.

It is not a requirement to parallel all UPS outputs so long as UPS units can transfer loads without interruption. UPS units can be configured in “Catcher” configuration (see Section 9.1.6.7).

Table 9-6 Class F4 Electrical System Overview

Industry description:	Fault tolerant
Component redundancy:	Equal to or greater than N+1
System redundancy:	Yes
Number of utility sources:	One or more sources with two inputs
Power sources available to critical load:	Two or more
UPS sources available to the critical load:	Two or more
Ability to be maintained while under load:	Yes, with a reduction to no worse than N+1 during maintenance activities.
Ability to recover from failures:	Yes, automatically with a reduction to no worse than N+1 after the failure and prior to the recovery.
Resulting definition:	Dual or multiple sources/2 (N+1 or better) power systems/multiple paths with redundant components.

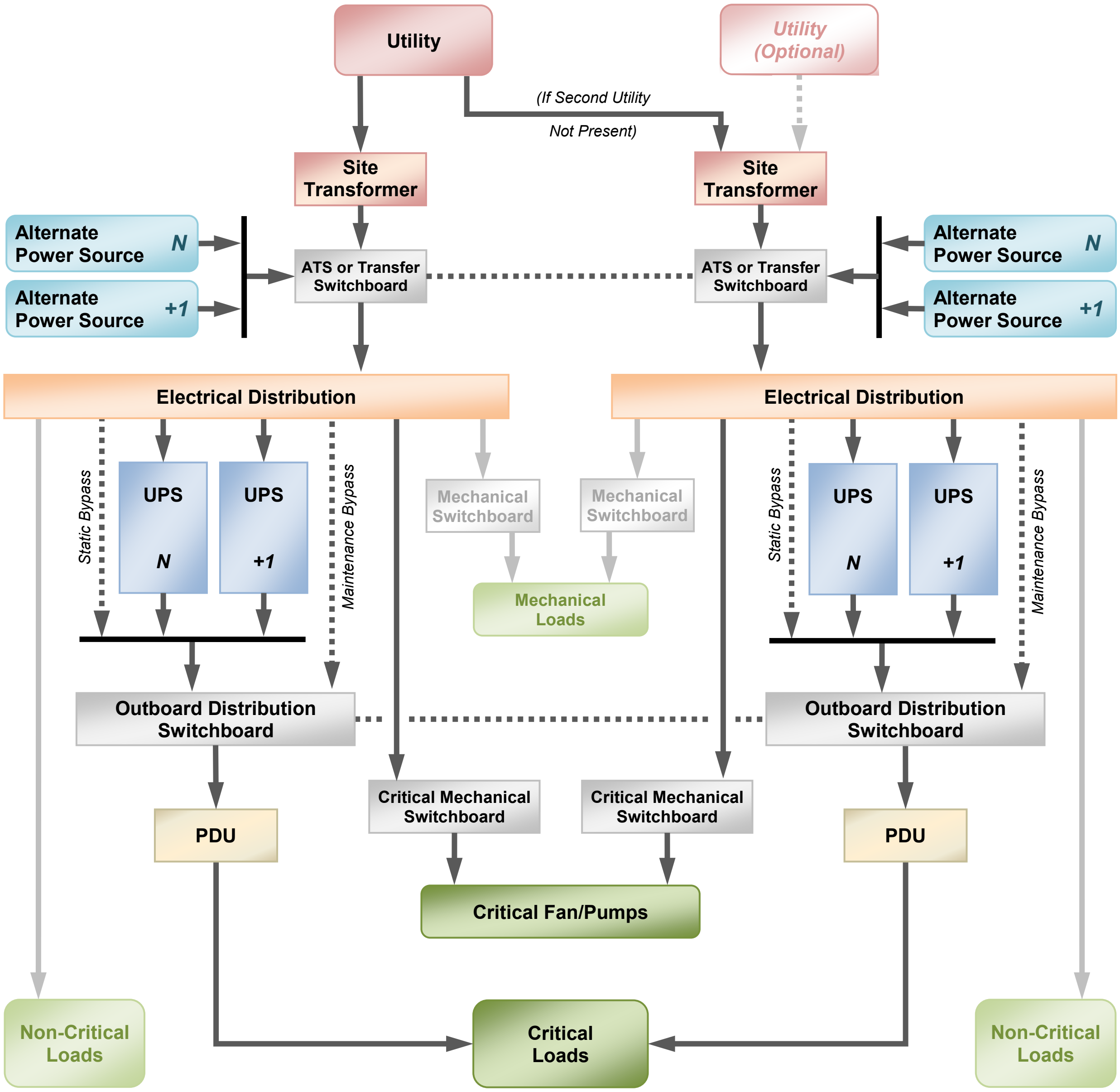


Figure 9-7
Class F4 Electrical Topology (System-Plus-System)

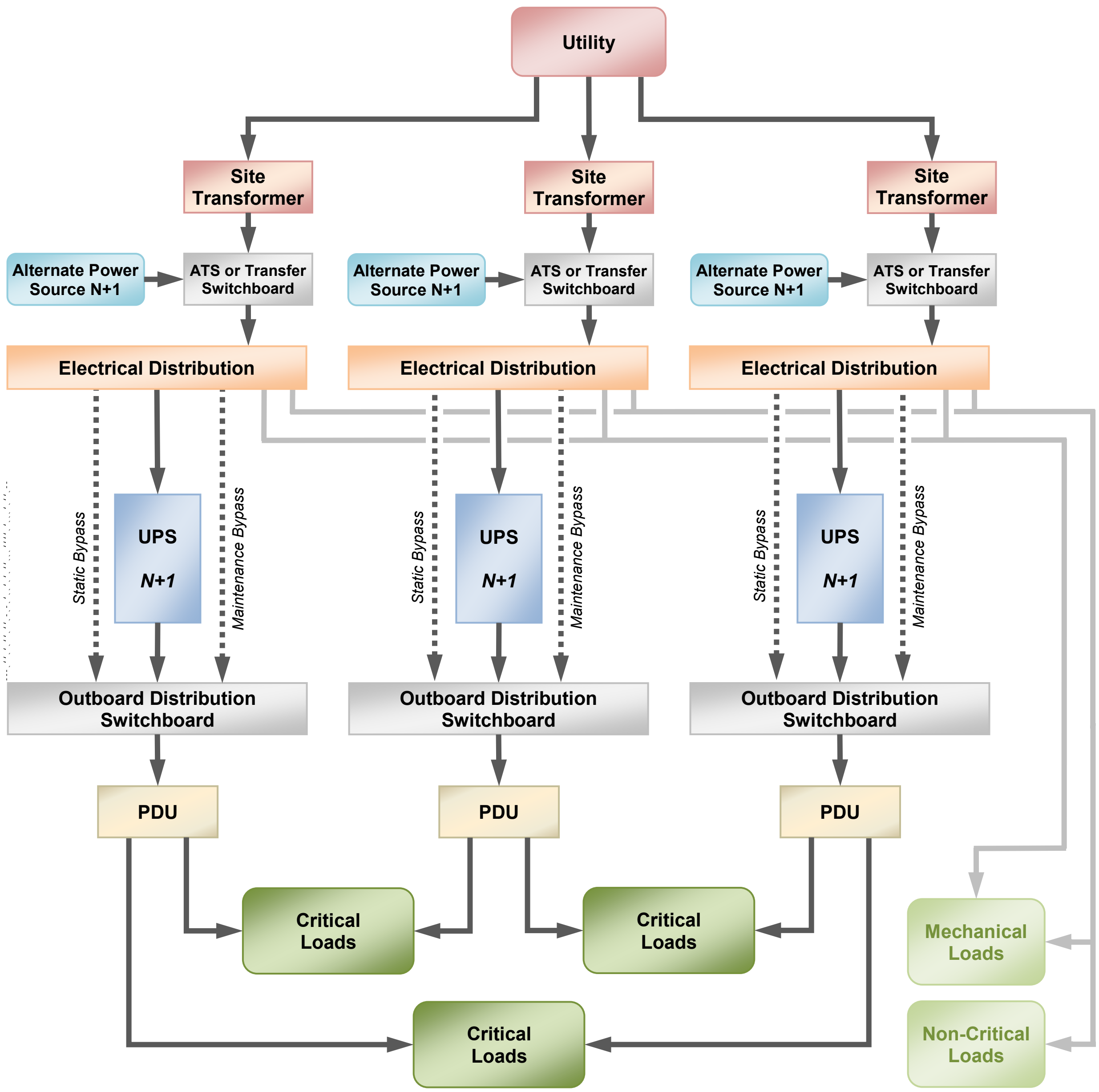


Figure 9-8
Class F4 Electrical Topology (xN Or Distributed Redundant)

9.1.6.7 Electrical System Topologies with Uninterrupted Transfer of Loads

9.1.6.7.1 Introduction

The UPS output need not be paralleled in order to qualify for F3 or F4 level so long as the uninterrupted transfer of load between normal and standby UPS modules is facilitated. A “Catcher” UPS system in which multiple “live” UPS units share a single standby unit (which also acts as a synchronizing unit) via internal static bypass is one such example.

The Catcher UPS topology is a combination of what has been known as “isolated redundant” and “block redundant.” The Catcher topology is similar to the isolated redundant topology in that the output of the redundant UPS module is connected to the static bypass inputs on the normal UPS modules. It is also similar to the block redundant topology in that the output of the redundant UPS module is also connected to the critical UPS output distribution boards. However, in a block redundant topology, the UPS output distribution boards are automatically fed from either the normal UPS module or the redundant UPS module through an automated transfer scheme. In the Catcher topology, the selection of the UPS output distribution board’s input source is a manual operation, selecting either the normal or redundant UPS module. This manual operation is an added feature to provide planned concurrent maintainability, and the isolated redundant functionality provides the automated failover in the event of a component or system failure.

9.1.6.7.2 F3 Electrical System Based on “Catcher” UPS configuration

In Figure 9-9, a sample F3 design with single utility source is shown. In an F3 design, the A and B side of a critical load can both come from the same UPS unit as there is a static transfer to the standby UPS unit available in the event of the failure of the normal UPS. Putting A and B sides on different UPS units will further improve reliability, particularly if the two UPS units are normally supplied from different medium voltage (MV) distributions.

Under normal operating conditions, each “live” UPS unit synchronizes to its bypass circuit, which is, in turn supplied from the "Standby" unit output. Therefore, each UPS unit is individually synchronized to the standby unit without using any centralized synchronization system.

NOTE: See Figure 9-20 for the internal configuration of a typical ‘Catcher’ UPS unit.

9.1.6.7.3 F4 Electrical System with “Catcher” UPS Configuration

In Figure 9-10, a sample F4 design with two utility sources is shown. With the current trend toward high density computing with average load per rack of 10 kW or more, there is no longer enough thermal capacity in the server rooms to keep server inlet temperature below 40 °C (104 °F). In these scenarios, critical cooling systems (e.g., CRACs, chilled water pumps, fans) are placed on their own dedicated and redundant UPS.

NOTE: When the number of modules to make N is greater than 1, the Catcher system requires more UPS modules than a 2(N+1) Class F4 configuration.

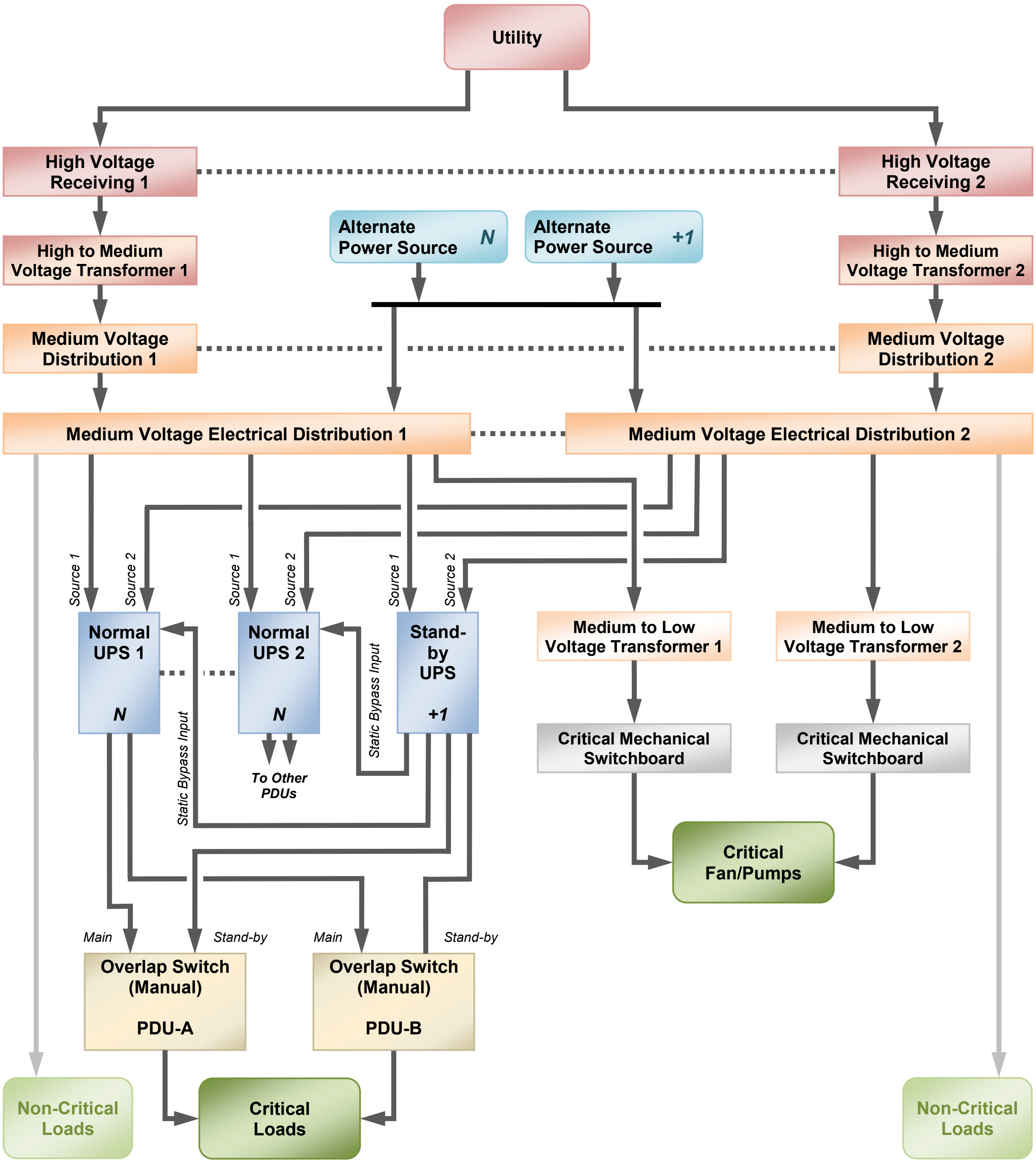


Figure 9-9
Class F3 Single Utility Source with Two Utility Inputs "Catcher" System

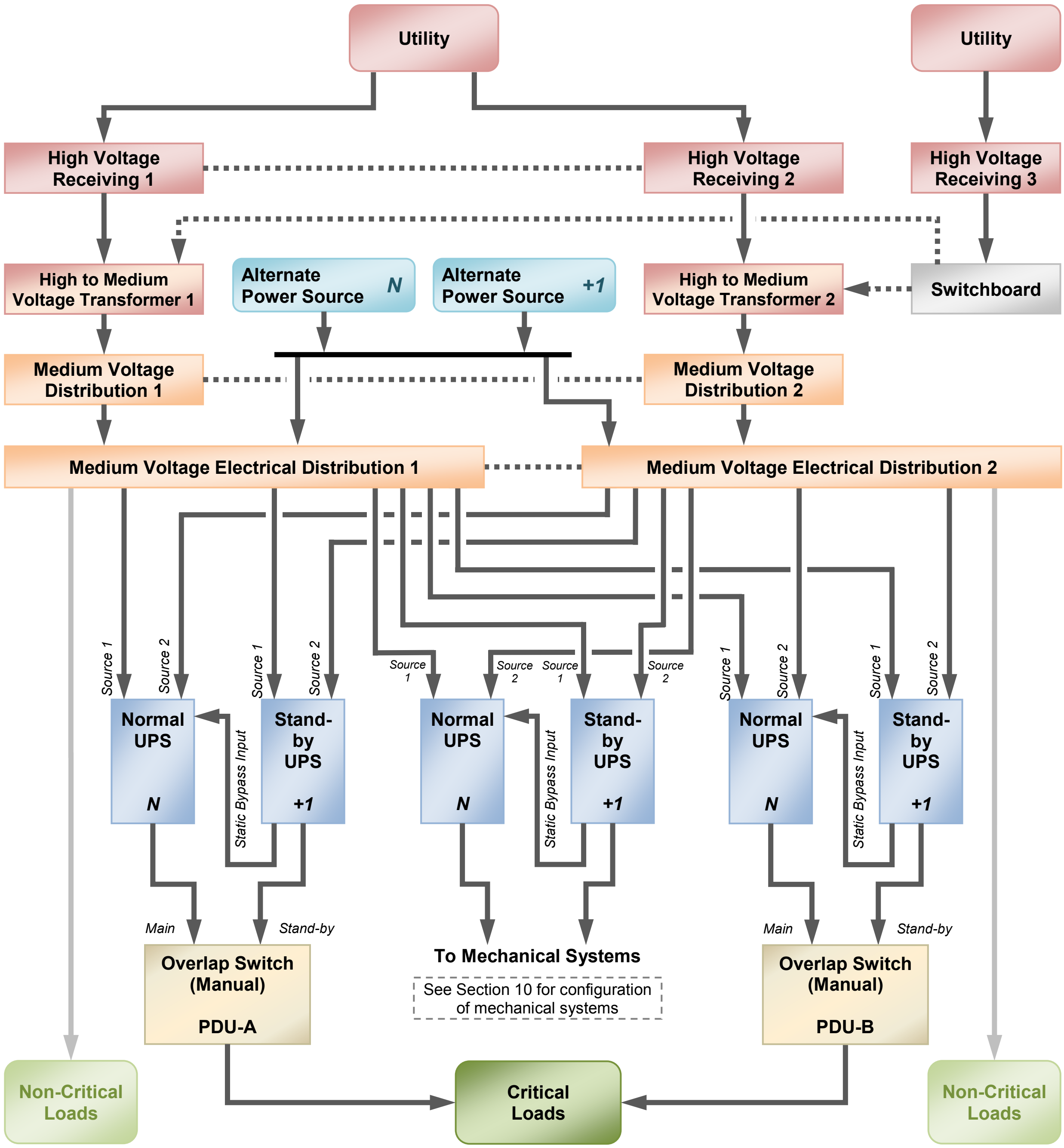


Figure 9-10
Class F4 2(N+1) Electrical Topology with Dual Utility Inputs

9.2 Utility Service

9.2.1 Utility Service Planning

9.2.1.1 Recommendations

NOTE: Section 5.7 contains additional information applicable to utility service planning.

When considering the power services to a given site, the utility should be treated the same as the generator sources.

NOTE: Not all certification agencies consider the utility as an N source and only consider on site power sources for classifying the data center.

While it is not possible to control the utility, it does constitute an N source to the facility.

Several planning issues concerning the utility service should be considered. For example, consideration should be given to what other utility customers are served by the same utility feeder. Hospitals are desirable neighbors because they typically receive high priority during outages or are classified as a no-shed block in the utility's distribution system. Industrial users are not desirable neighbors because of the transient voltage disturbances and harmonic conditions they often impose on the feeders and the utility systems. Many of these conditions either can reduce the life of the data center's systems, especially the batteries and UPS modules, or require other sophisticated power quality mitigation measures.

While planning for utility services, the following issues should be addressed:

- Is there a need for a dedicated service based on the load size or redundancy requirements for the site?
- Is the site on a shared service and, if so, is anyone else on the service?
- Are there any high impulse loads on the bulk substation such as foundries, paper plants, and smelters that would have an impact on power quality?
- Is service to the site primarily overhead or underground?
- What are the initial and the ultimate capacities of the service, and how can these services be expanded if needed?
- Are diverse services available?
- Are diverse services routed separately to the site?
- What are the service voltages in the area?
- What are the requirements for closed transition operation, if employed?
- What are the circuit protection requirements that the site must provide?
- What are the service construction requirements?
- What are the reliability and availability of the service to the site?
- What is the available fault duty at the main switch?
- What are the ground and short-circuit fault current discrimination requirements both upstream and downstream?
- What automatic reclose/transfer is performed at the local utility substation, and how will it affect ATS timing?

This analysis occurs during the preliminary project phases with the utility company's service representative to the user or area. The purpose here is to ascertain the electrical performance, short circuit duty, and power quality for the utility.

Underground utility feeders are preferable to overhead feeders to minimize exposure to lightning, weather, trees, traffic accidents, and vandalism.

There is no mandatory service voltage. It is left to the designer and user to select the service voltage that is appropriate for the site's data center power system from among the voltages available from the utility. However, in most countries, the incoming supply voltage options are decided by the electricity supply company based on the required load.

When diverse services are utilized, the designer should establish the point of common coupling of the supplies with the utility company. The supplies should be routed to the site separately and should enter the data center on opposite sides of the property and building. In this situation, a bond is required between systems to ensure an intersystem grounding reference.

An intersystem grounding reference for diverse services can be accomplished by a building ground (electrode) ring. See Section 9.9.6 for requirements and recommendations for a building ground (electrode) ring.

9.2.2 Low-Voltage Utility Services

9.2.2.1 Introduction

In North America the demarcation between low voltage and medium voltage utility services has always been 600 V_{AC} between line conductors, whereas elsewhere around the world it is 1000 V_{AC}. This changed within the United States with publication of the *National Electrical Code* in 2014 when the demarcation was raised to 1000 V_{AC} (although changes to regulations, standards, and equipment designs will not be immediate). Table 9-7 provides a listing of low voltage distribution voltages present within some major data center locations worldwide.

Service entrance distribution equipment provides several functions: the interface between the utility and the site, the distribution of utility power to downstream systems and, in some cases, the transfer controls and transfer point between the utility and generator.

Table 9-7 Low-Voltage Distribution Voltages in Some Major Data Center Locations

Country	*Voltage(s) (V)*	*Tolerance (%)*	*Phase/Wire*	*Frequency (Hz)*
Australia	415/240	+/- 6	3P4W	50
	440/250	+/- 6	3P4W	50
	440[1]	+/- 6	1P1W	50
EU	380/220	+/- 10	3P4W	50
	380	+/- 10	3P3W	50
	220	+/- 10	1P2W	50
Hong Kong	346/200	+/- 6	3P4W	50
	380/220	+/- 6	3P4W	50
Japan	100	+/- 10	1P2W, 3P3W	50 (East)/60 (West)
	200	+/- 10	1P2W, 3P3W	50 (East)/60 (West)
	100/200	+/- 10	1P3W	50 (East)/60 (West)
	400	+/- 10	3P3W	50 (East)/60 (West)
	400/230[2]	+/- 10	3P4W	50 (East)/60 (West)
Singapore	400/230[2]	+/- 3	3P4W	50
South Korea	380/220	+/- 5	3P4W	60
USA	480/277	+/- 5	3P4W	60
	480	+/- 4	1P2W	60
	460/265	+/- 5~10	3P4W	60
	460	+/- 5~10	1P2W	60
	240/120	+/- 5~10	3P4W	60
	240/120	+/- 5	3P4W	60
	240/120	+/- 4~5	3P4W	60
	240/120	+/- 5	1P3W	60
	240	unavailable	1P2W	60
	230	+/- 5~10	1P2W	60
	208/120	+/- 4~10	3P4W	60
	208/120	+/- 5	3P4W	60
UK	415/240	+/- 6	3P4W	50

NOTE 1: Single wire to ground, mines only

NOTE 2: IEC 60038:2009 indicates the standard voltage is 400/230V though other voltages may still be in use.

9.2.2.2 Recommendations

The distribution equipment should be designed for growth, maintenance, and the ultimate load expected for the facility while maintaining the Class level's redundancy. The utility distribution equipment should either be sized for the ultimate load for the site or should possess the ability to add capacity later without undue disruption to ongoing operations.

When the service entrance distribution equipment is double-ended (with two utility entrances), the tie breakers should be provided in pairs. This allows the complete isolation and maintenance of one side of the distribution equipment while the opposite side carries the load.

Consider:

- Using switchboard with compartmentalization in lieu of switchboard with open construction for greater resiliency and separation of components to minimize internal damage because of faults.
- Using drawout or withdrawable circuit breakers to allow addition or maintenance of circuit breakers without interrupting power to operating equipment.
- Arc flash hazards when designing distribution equipment. Lower arc flash hazard ratings may allow preventative maintenance and infrared scanning to be performed more often and allow safe operation of operating equipment.

Circuit breakers should be interchangeable where possible between spaces and distribution equipment line-ups. Careful consideration should be given to breaker standardization throughout the entire project. Concurrent maintainability of any system is directly related to its Class level.

9.2.2.3 Additional Information

Low-voltage services may require utility-controlled disconnecting means at the property line. The local fire department might also require a shunt trip for the complete disconnection of power to the site when they respond to a fire.

Surge protective devices (SPDs) should be provided for all Classes to mitigate problems because of switching surges or transients from sudden power outages.

9.2.3 Medium-Voltage and High-Voltage Utility Services

Medium-voltage refers to utility services that are between 1001 V_{AC} to 35 kV_{AC} between line conductors. As utility services vary between regions and countries, check with the AHJ for the local voltage definitions and standards of medium voltage and high voltage.

A medium voltage service has the same recommendations as the low-voltage service, but the medium voltage service may have different grounding criteria. The service configuration may be in concert with the generator plant configuration acting together as multiple sources or providing an input to various unit substations located in the data center facility.

9.2.4 Protective Relaying

9.2.4.1 Requirements

The use of protective relaying is based primarily upon how the service is delivered and whether transfers between the utility(s) and the onsite generator plant(s) are either closed- or open-transition. Multifunction relays are typical, but the utility may require utility-grade, individually mounted relays. The utility will also typically extend its relaying specification to any closed-transition systems. Relay specifications will be coordinated with the utility's protection system, and the manufacturer and model of the relay system may be dictated by the utility.

9.3 Distribution

9.3.1 Requirements

The distribution system design shall accommodate the number and diversity of the power paths to the loads, the ability to readily maintain the loads, and the ability to recover from failures.

Common to all systems is the type of termination for cables and busway connections. See Table 9-17 for busway and cable connections.

9.3.2 UPS Rectifier or Motor Inputs

9.3.2.1 Requirements

Paralleled module inputs shall be fed from the same unit substation or distribution point where all modules in the paralleled system must have the same input. Distributed or individual modules in larger UPS systems may be fed from their different upstream substations or distribution systems as long as those systems possess some form of output or load-side synchronization.

9.3.2.2 Recommendations

All distribution feeder and branch circuit conductors are recommended to be made of copper.

9.3.3 Static Switch Bypass Inputs

9.3.3.1 Introduction

All solid-state UPS systems and some rotary UPS systems have static bypass capability. Its function is to automatically transfer load between the UPS and an alternate power source without human intervention when the UPS system controls detect a condition in which the UPS cannot function properly.

9.3.3.2 Requirements

For UPS systems with a static bypass switch, either a single power module system's controls or a paralleled system's control cabinet shall be synchronized to the static system input.

9.3.4 UPS System Bypass

9.3.4.1 Introduction

A maintenance bypass provides a manually operated and closed-transition power path external to the static bypass power path. A maintenance bypass allows the UPS module(s), paralleling controls, and static switch to be totally de-energized so that unscheduled remedial or scheduled preventive maintenance can be safely performed.

9.3.4.2 Requirements

Maintenance bypasses shall be provided for all Class F1 through Class F4 systems.

Isolating circuit breakers shall be provided to allow for the maintenance of the UPS collector bus, static switch, or output breaker.

Static bypass switches may be located in the individual module or separately for paralleling multiple UPS systems with multiple power modules. For modules utilizing individual static switches, commonly called distributed paralleling, caution must be taken when an individual module in a paralleled installation is placed into static bypass in order to avoid uneven current flow through the modules. This may require that all modules in the distributed parallel installation be placed into bypass per the manufacturer's recommendation.

9.3.4.3 Recommendations

Where used, power strips should comply with the following recommendations:

- Metering may be provided on individual power strips. The ability to monitor power strip loads remotely via a centralized monitoring system is recommended for high-density and large-scale facilities. The accuracy of metering on some power strips can be affected by voltage and current distortion caused by harmonics or other causes. The accuracy of power strip meters should be considered if the measurements are being aggregated for PUE calculations.
- Power strips should not have internal surge suppression.
- Power strips should not be placed under the access floor.

9.3.5 Input Source Transfer

9.3.5.1 Introduction

When considering the top layer of the electrical distribution system, the first consideration is the management of the utility and generator sources and the transfer scheme most appropriate for the facility. Similarly, the transfers may occur within a self-contained system such as an automatic transfer switch (ATS), or via a circuit breaker transfer pair. Another consideration is the ability to bypass the transfer location either via a bypass power path external to the ATS or in another circuit breaker transfer pair.

For many sites, the generator system, as a whole, powers the entire site or building. Should this be the case, the generator controls and the input source transfers become part of the utility's service entrance equipment. In this case, the utility metering and circuit protection may be included in the transfer controls. Figure 9-11 illustrates ATS of various sizes.

For transfer protocols, there are four families of controls:

- Open transition
- Closed transition/quick transfer
- Closed transition/load walk-in
- Closed transition/parallel operation

Regardless of the transfer protocol, a utility outage almost always results in an open transition transfer upon the loss of the utility because of the momentary loss of source(s) and the resulting utility dead bus.

9.3.5.2 Open Transition

9.3.5.2.1 Introduction

Open transition occurs when the transfer between sources breaks before the opposite connection is made. This transfer technique is the most common, requires the least amount of electrical controls and relaying to assure its success, and typically does not require the utility's approval to deploy. The downside to this technique is that any transfer between energized and available sources results in a brief load disconnection. The loss of main's power forces the UPS to draw upon its stored energy source, thereby reducing the UPS battery system's life. It also typically causes the mechanical system (air conditioning systems) to stop and restart, thereby putting stress on the equipment and creating a potentially sharp increase in heat.

9.3.5.2.2 Recommendations

Open transitions should be several seconds long to allow power supply capacitive energy to dissipate.

9.3.5.3 Closed Transition/Quick Transfer

9.3.5.3.1 Introduction

In the closed transition/quick transfer the utility and generator (and consequently, the site) are paralleled for less than 100 ms to up to one minute, depending on the utility provider and designer. The paralleling time is typically the operating time of the ATS or the breaker transfer pair. The primary benefit of this method is that there is no load interruption between the two energized and available sources.

Figure 9-11
Example ATS Sizes

The downsides to this technique include:

- Requiring more controls and relaying than open transition
- The electrical system's short circuit duty must account for both the utility's and the site generator's contribution.
- The transfer can be delayed or prevented if the sources are present and do not remain synchronized within voltage and frequency tolerance.
- Capacitive or harmonic feedback from the load(s) may cause logic errors.
- The utility may not allow this type of operation in a customer's system.

9.3.5.3.2 Recommendations

Close coordination with the utility is vital in this instance.

9.3.5.4 Closed Transition/Load Walk-in

9.3.5.4.1 Introduction

The closed transition/load walk-in varies from the closed transition/quick transfer technique in that the generator and utility share load for a period of several seconds or as long as a minute or two. This can be very desirable as it places a substantially less amount of stress on the site's electrical system and eliminates load inrush. The downside is that it requires a substantial amount of relaying and forces a complex sequence of operation in the electrical system.

9.3.5.4.2 Recommendations

Close coordination with the utility is vital in this instance.

9.3.5.5 Closed Transition/Parallel Operation

9.3.5.5.1 Introduction

In the closed transition/parallel operation, the generator and utility share load for an indefinite period of time. This can be for peak shaving or cogeneration purposes. The downside is that it requires a substantial amount of relaying and forces a complex sequence of operation in the electrical system.

9.3.5.5.2 Recommendations

Close coordination with the utility is vital in this instance. Review of environmental restrictions will be required. Coordination will include short circuit bracing for facility equipment for extended transfer times, conditions for manual transfers, and extended relay coordination and functionality.

9.3.6 Generator Controls and Paralleling

9.3.6.1 Introduction

Generator systems can be either distributed or paralleled for any of the Classes. Some generator control systems consist of traditional switchboard systems while some systems utilize controls on board the generators and ATS's. Regardless of the method or technology used, the controls must match the Class requirements to achieve the overall availability demanded by the critical, mechanical, and house power systems. Specific consideration should be given to paralleling switchboard systems that might represent single points of failure. While a paralleled generator system may offer an N+1 or N + 2 level of redundancy for components, the single paralleling bus or the master controls may represent a single point of failure. Paralleling switchboard should be provided with fully redundant paralleling controls for Class F3 and Class F4 applications. Generator controls address numerous critical functions for the site and generator systems.

These functions may include:

- Automatic load control and assumption upon loss of the utility source
- Retransfer to utility once it is restored after a preset retransfer delay
- Exercise and maintenance rotation of the engine(s)
- Distribution of generator power to any remote source transfer locations

9.3.6.2 Recommendations

Generator controls for individual machines should not be centralized, and each controller should be completely contained on the generator skid or within the generator control module in the switchboard line-up. The generator control section or module should possess all controls and metering for the individual machine and will not require any form of outside influence or connection for its individual operation. Individual machines should be able to operate regardless of the availability of the paralleling controls.

The enclosure or room where generators are installed should be temperate, but not necessarily conditioned. Draw-out type switchboard is recommended for Class F3 and Class F4 facilities, but it may also be used for lower Classes. Standby power systems should be installed in a manner that allows for 360-degree maintenance and technician access to the machine, both while it is in operation and when it is not.

The primary switchboard should be designed to handle all projected requirements as this equipment is difficult to replace once the data center is in operation. The system should be designed to allow for maintenance and expansion pursuant to the site's ultimate load requirements.

Paralleled generators should be capable of manual synchronization in the event of failure of automatic synchronization controls. Consideration should be given to manual bypass of each generator to feed directly individual loads in the event of failure or maintenance of the paralleling switchboard.

See Sections 9.3.16, 9.7.2, and 9.10 for other requirements.

9.3.7 Unit Substations

9.3.7.1 Introduction

Unit substations may combine several functions at one location: the medium voltage input selection or utility input, a step-down from the utility or site's medium to low voltage, utility metering, low-voltage power distribution, and input source control. These systems can utilize multiple medium-voltage inputs from different upstream sources, provide medium-voltage transfer systems (primary selection) or a low-voltage transfer system (secondary selection), and may be double ended for further source and distribution redundancy.

9.3.7.2 Recommendations

The unit substations may be located where the normal-alternate transfer is addressed on the input side of the system or serve as the upstream input to downstream ATSs. For larger systems, the input source transfer may occur at the input main (one from the utility and one from the generator or alternate system) where it is coupled with a dedicated alternate power input. Unit substations are routinely located immediately upstream of the UPS power plant, major mechanical loads, and the noncritical systems.

Unit substations are also defined as a pad-mounted transformer and the main switchboard.

There also may be an interposing main breaker system to relocate the main arc flash hazard to outside the electrical room. While consisting of different components than a traditional unit substation, this type of system is now in wide use and is analogous to the unit substation systems herein described.

See Sections 9.3.16, 9.7.2, and 9.10 for EPO monitoring, labeling, and similar considerations that could apply to unit substations.

9.3.7.3 Additional Information

An oil transformer is generally located outside because of fire risks. Because of extreme heat, the oil can leak and further spread the flames. A dry type, less flammable liquid cooled or SF6 gas-insulated transformer can be located indoors and does not require the same degree of maintenance. In Europe, reference CENELEC EN 50541-1 for dry-type transformers. It defines much lower allowable losses and noise limits.

9.3.8 UPS Systems

9.3.8.1 Introduction

The project designer and end user should determine the precise distribution topology that is most appropriate to the final design based on the client's needs.

While the static UPS system is the prevalent technology used, the requirements of this section apply to all types of UPS technology.

Power system distribution addresses six areas:

- UPS module rectifier inputs
- Static system inputs
- Maintenance and external bypass inputs and configurations
- Output switchboard configuration
- Output switchboard ties and alternate power paths
- Multi-system UPS power system synchronization

These systems are considered to reside between the unit substations and the critical power distribution switchboards.

One of the key issues for UPS systems is grounding simplicity and the prevention of harmonic circulation (this problem is reduced for modern ITE loads). In this case, the discussion for all of the UPS power system assumes a 3-wire input and output with 4-wire systems only being used for stand-alone UPS systems where the step-down transformer is part of the output transformer function of that module and for 400/230V UPS systems.

For Class F1 and F2 systems, UPS power distribution is basically linear with no crossties or mixing of loads. For Class F3 systems, multiple second power paths emerge although not all are required to be UPS powered. The goal for the Class F3 model is to provide multiple power paths as close to the critical load as possible.

For the Class F4 model, UPS power topology may include different numbers of UPS power plants versus the number of UPS power delivery paths. For example, there may be a site with 3 or 4 distinct UPS plants but many more individual UPS power distribution systems. Therefore, numerous UPS power distribution systems can be connected below a given UPS plant.

Bonding and grounding is further discussed in Section 9.9.

9.3.8.2 Bypass Switch Inputs

9.3.8.2.1 Introduction

The bypass system directly affects the Class of any UPS system. The static bypass, the maintenance bypass, the output breaker, and any load bank testing connections can all have a direct impact on the maintenance and failure response of the UPS system.

Class F0 systems (in which a UPS is optional) and Class F1 systems might have a single input into a UPS system in which a static bypass circuit is tapped internally to the UPS module (see Figure 9-12). For all other Classes, the static bypass has a dedicated input circuit.

As with all components of the electrical system, the ability to maintain a system while operating is a foundation of Class F3 systems and maintaining a power path and redundancy are required for a Class F4 rating.

Bypass configurations can affect UPS functionality as follows:

- Combining maintenance bypass and static bypass paths from a single input feeder will typically result in a lower Class because it reduces the ability to remove a module or system without interrupting the service to the downstream critical loads.
- Load bank connections that are independent of the UPS output source can contribute to a high Class because they allow for testing without interrupting the service to the downstream critical loads.
- Locating circuit breakers on the collector bus or on the output bus of paralleled UPS systems rather than making them internal to a power module will contribute to a high Class by allowing a module to be removed from the service without shutting down the entire system. These are also known as isolation breakers.
- The presence of a maintenance bypass will allow for the removal or testing of a UPS module or for the replacement of a static switch in the event of a catastrophic failure. This has a dramatic effect on the mean time to repair (MTTR).

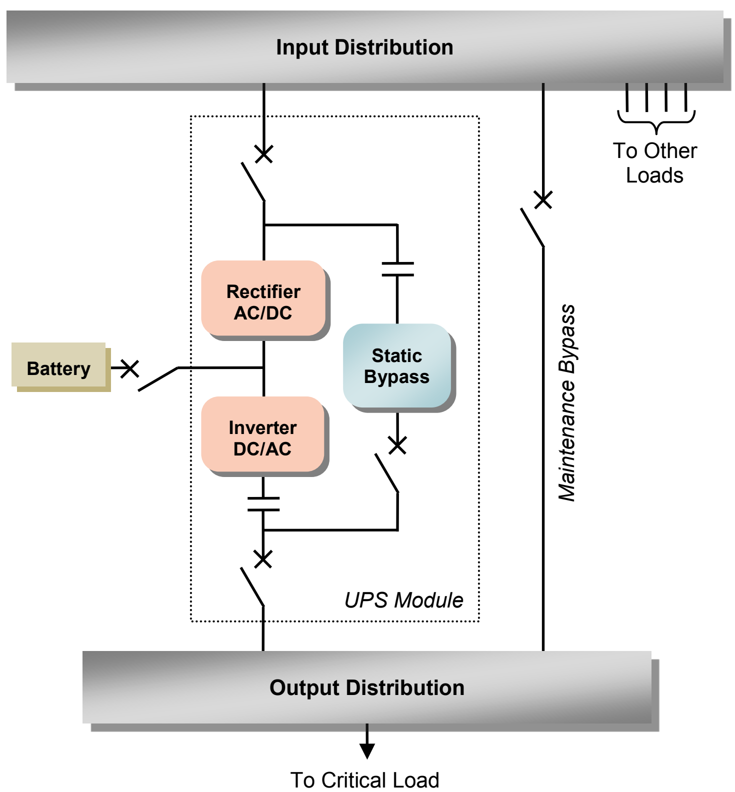


Figure 9-12
Single-Module UPS with Internal Static Bypass and Maintenance Bypass from the Same Source

External maintenance bypasses are optional for Class F0 (when a UPS is present), Class F1, and Class F2 systems. Maintenance bypass is mandatory for all Class F3 and F4 applications and for system control cabinets. As discussed in the preceding paragraphs, static bypass inputs may be combined with the rectifier inputs on Class F0 and Class F1 applications. The static bypass is the recommended means by which to synchronize the UPS to its maintenance bypass (see Figure 9-16 and Figure 9-17, and the discussion for Figure 9-17, Figure 9-18 and Figure 9-19). Classes F1 through F4 all require some form of maintenance bypass (whether it is factory provided in the bypass cabinet/system or externally developed).

Permanently installed load banks are optional for all Classes and are recommended for Class F3 and F4. They are not included in all of the examples shown in Figure 9-13 through Figure 9-19.

For designs that incorporate temporary connected load banks, the electrical distribution should be provided with spare breakers sized and positioned within the distribution to be able to test the generators, UPS and critical distribution.

9.3.8.2.2 Requirements

Refer to Figure 9-13, Figure 9-14, and Figure 9-15. When the inputs to the rectifier, static bypass, and maintenance bypass are from the same input distribution bus, the designer shall consider the capacity of the input distribution bus and how the critical load could be affected during testing. The capacity of the input distribution bus shall be able to support the critical load on the maintenance bypass plus the full load testing of the UPS system. Also, if the input distribution supports non-critical loads, such as in a Class F1 or Class F2 design, those loads shall be considered in the capacity calculation of the input distribution. The designer shall also consider how any disturbance on the input distribution could affect the critical load while operating in this mode and this type of design, including disturbances caused by:

- Testing of the UPS
- Testing of non-critical loads connected to the same bus
- Turning on and off non-critical loads connected to the same bus
- Fault conditions

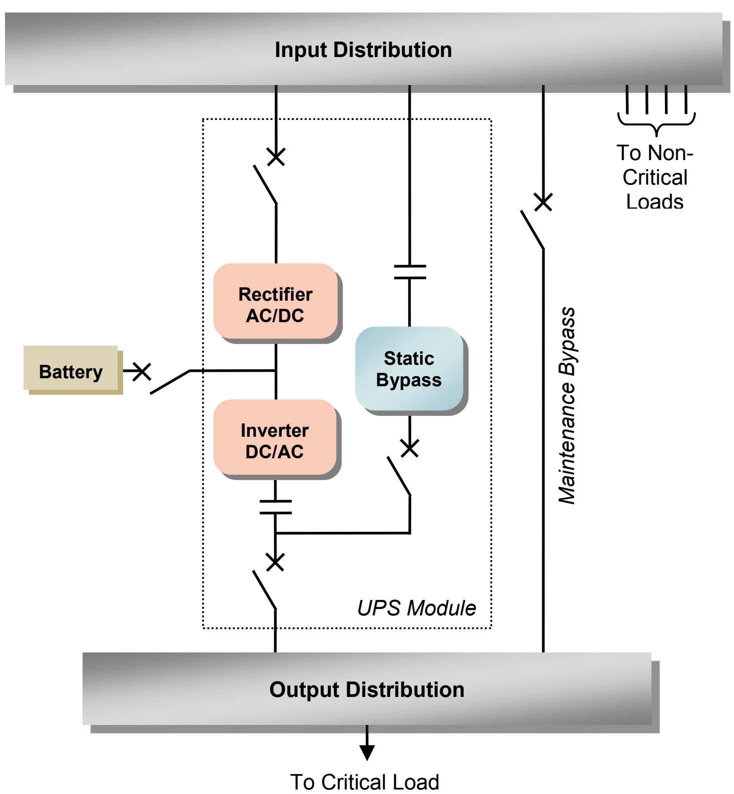


Figure 9-13
Single-Module UPS with Inputs to Rectifier, Static Bypass, and Maintenance Bypass from the Same Source

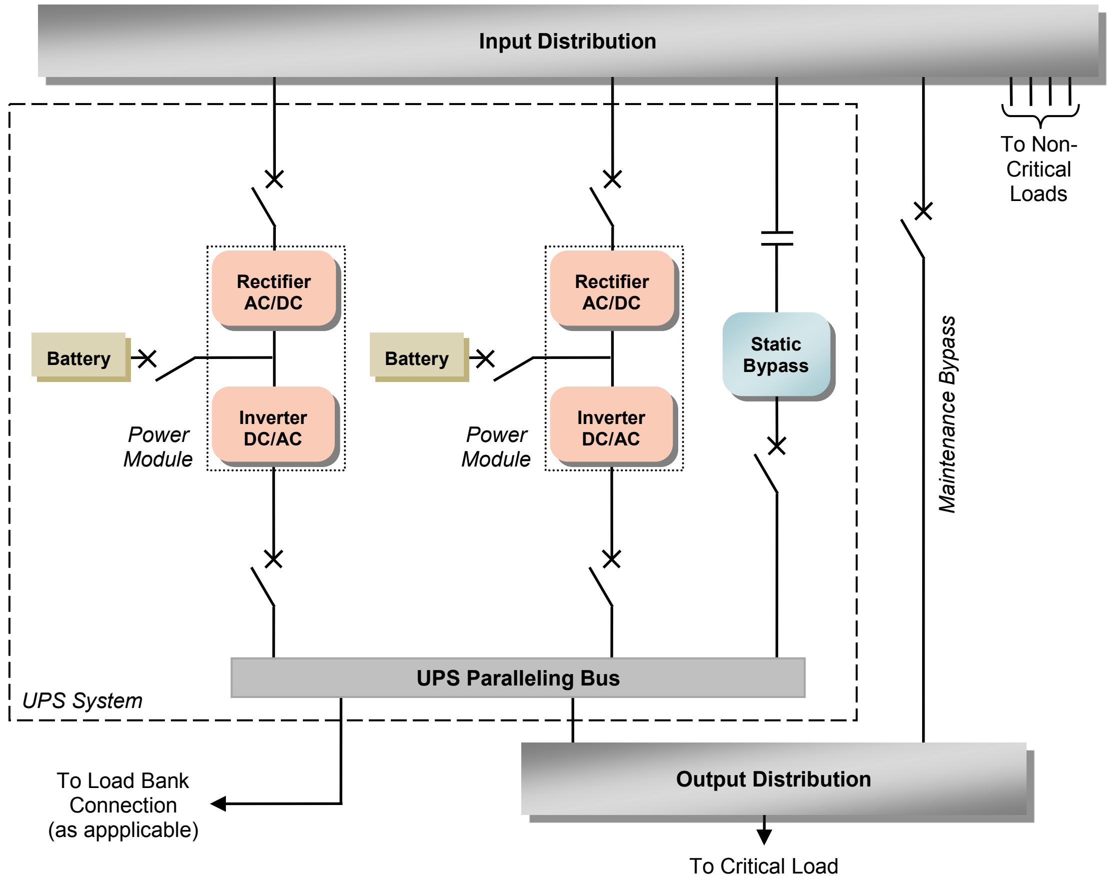


Figure 9-14
Multiple-Module UPS with Inputs to Rectifier and Maintenance Bypass from Same Source – Centralized Static Bypass

A single module with an internal static bypass is shown in Figure 9-12. The paralleled installation for modules with individual static bypasses looks similar as shown in Figure 9-15. In this case, the static bypass input for the system occurs at the module level. That static bypass input can be combined with the rectifier input, or the module may receive a dedicated static bypass input. Paralleling of UPS modules with an internal static bypass requires close coordination and synchronization with other UPS modules. Check manufacturer's requirements when applying different static bypass and rectifier inputs in distributed paralleled UPS power systems.

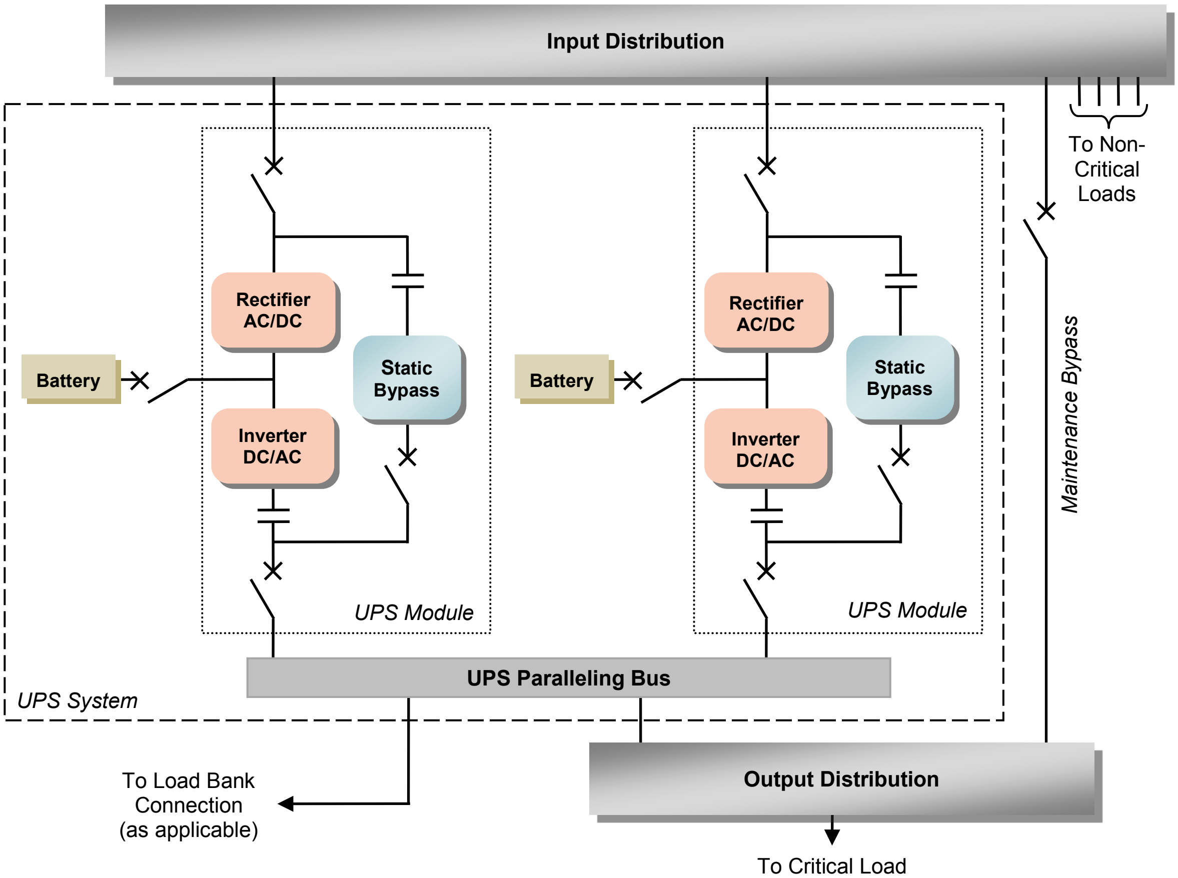


Figure 9-15
Multiple-Module UPS with Inputs to Rectifier and Maintenance Bypass from Same Source – Paralleled Installation

Refer to Figure 9-16 and Figure 9-17. When the input to the rectifier is from one bus and the static bypass and maintenance bypass originate from a different bus, the designer shall consider:

- The capacity of the input distribution bus
- The sources of power to the static and maintenance bypasses
- How the critical load could be affected during testing or if a fault were to occur on that bus

For testing purposes, when the two bypasses are derived from the same input distribution bus, the capacity of the input distribution should be able to simultaneously support the critical load on the maintenance bypass plus the full load testing of the UPS system (e.g., full load transfers to and from static bypass). In addition, if any non-critical loads are present, they shall also be considered in the capacity calculation of the input distribution bus. The designer shall also consider how any disturbance on the input distribution could affect the critical load while operating in this mode and this type of design, including disturbances caused by:

- Testing of the UPS
- Testing of non-critical loads connected to the same bus
- Turning on and off non-critical loads connected to the same bus
- Fault conditions

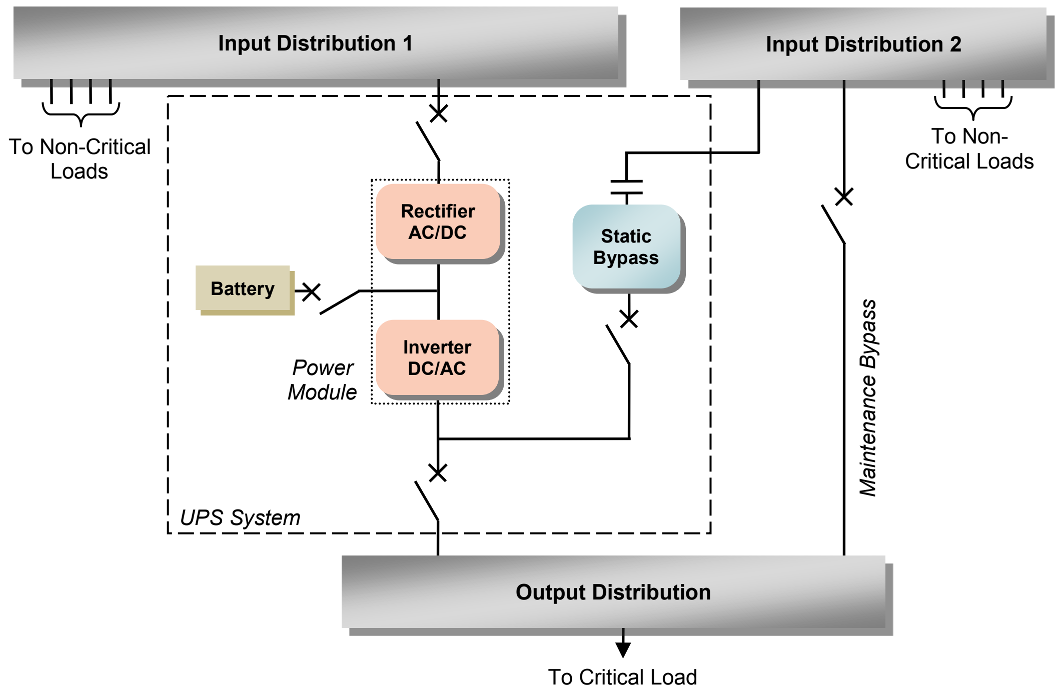


Figure 9-16
Single-Module UPS Bypass – Alternate Bypass Source - Input to Rectifier from Primary Source; Inputs to Static Bypass and Maintenance Bypass from a Second Source

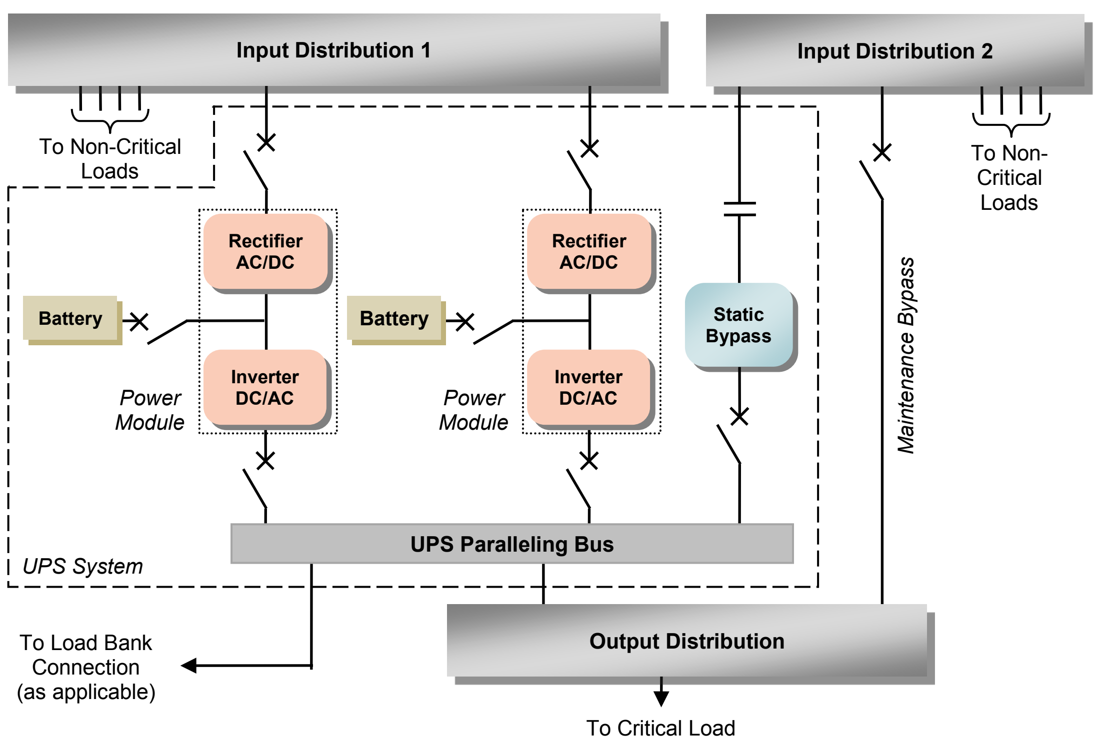


Figure 9-17
Multiple-Module UPS Bypass – Alternate Bypass Sources - Inputs to Rectifiers from Primary Source; Inputs to Static Bypass and Maintenance Bypass from a Second Source

In normal mode, the UPS shall synchronize its inverter to this bypass source. Therefore, if the bypass source has a disturbance, the UPS will more than likely go into an alarm state. When the static bypass input is lost for a system, the UPS system shall run in a free mode until either the static bypass input has been restored or the paralleled UPS control assigns a lead module on the system. There is one additional scenario to consider for this configuration. In the event a repair or fault removes the input distribution bus from service, the static bypass source will be lost and will place the UPS system into a less reliable operating mode.

Figure 9-17 illustrates a central static bypass for a paralleled UPS operation. Observe the conditions of use and design application for individual UPS modules and static bypasses in a paralleled mode of operation as noted in this section.

Refer to Figure 9-18 and Figure 9-19. When the input to the rectifier and the static bypass originate from one bus (Input Distribution 1) and the maintenance bypass originates from a separate bus (Input Distribution 2), the critical load shall be transferred without interruption or disturbance to an isolated source, either utility or generator, depending on the design, while the UPS is repaired or tested. When non-critical loads are connected to the bus that supports either the rectifier and static bypass (Input Distribution 1) or the maintenance bypass (Input Distribution 2), the designer shall also consider how any disturbance on the input distribution could affect the critical load while operating in this mode and this type of design, including disturbances caused by:

- Testing of the UPS
- Testing of non-critical loads connected to the same bus
- Turning on and off non-critical loads connected to the same bus
- Fault conditions

Inputs to the static bypass and maintenance bypass shall not be derived from separate sources unless the two sources are synchronized in phase and frequency (see Figure 9-18 and Figure 9-19). Lack of synchronization will result in an unreliable design that should require open transition (i.e., shut down the loads and then restart from the alternate source).

Note that synchronization of sources is difficult because load imbalances and phase shifts (such as transformers introduced downstream) can force circuits out of synchronization. The best practice is to power both the static bypass and the maintenance bypasses from the same source as shown in Figure 9-16 and Figure 9-17. (See also Section 9.3.8.3).

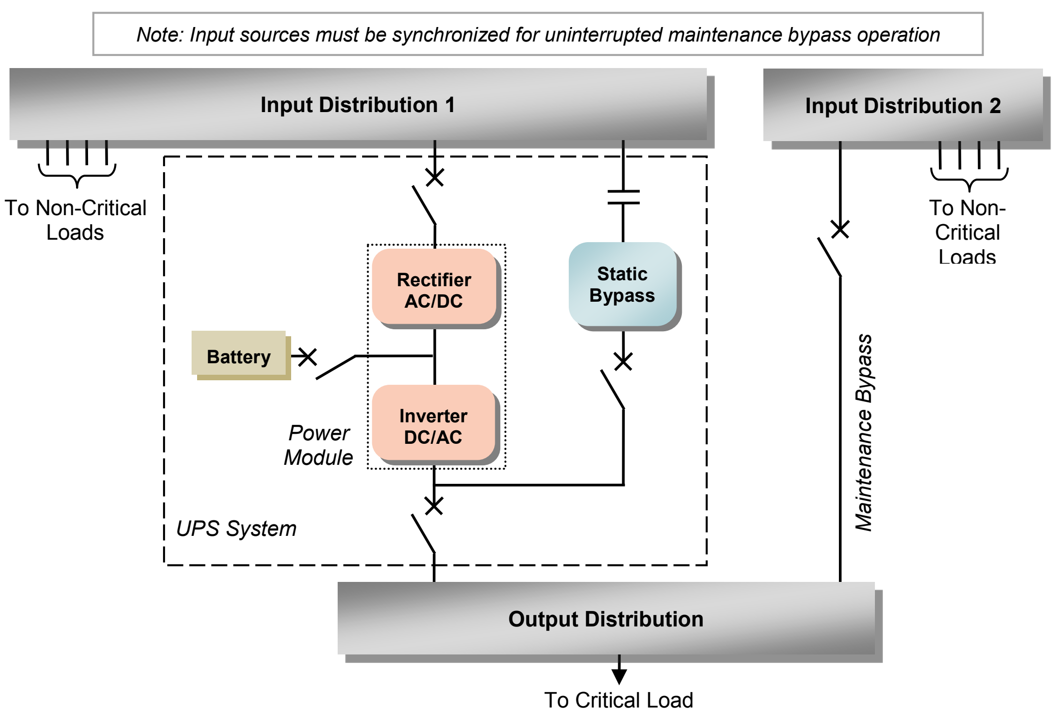


Figure 9-18
Single-Module UPS Bypass – Multiple Bypass Sources - Inputs to Rectifier and Static Bypass from Primary Source and Input to Maintenance Bypass from a Second Source

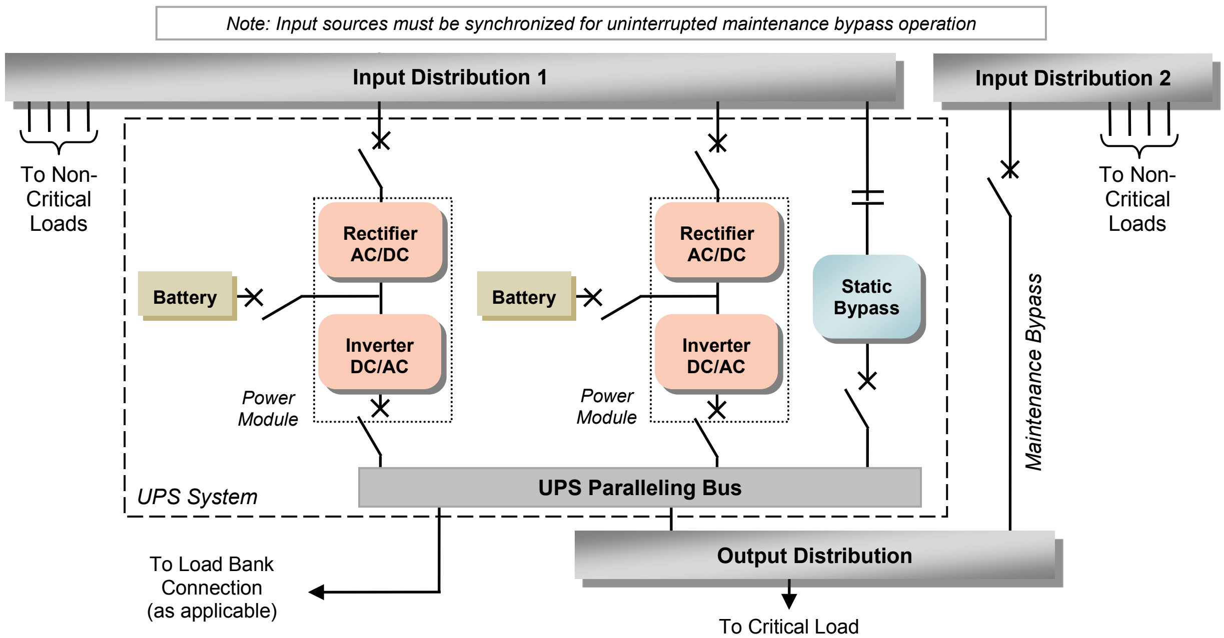


Figure 9-19
Multiple-Module UPS Bypass – Multiple Bypass Sources - Inputs to Rectifiers and Static Bypass from Primary Source, and Input to Maintenance Bypass from a Second Source

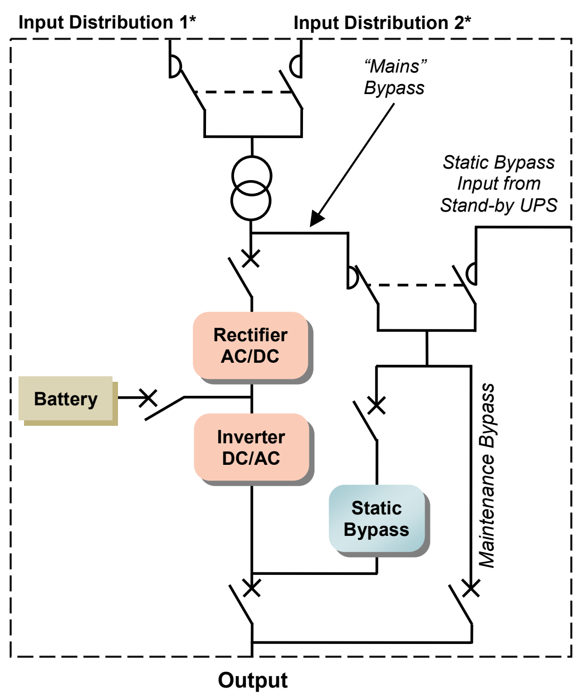
Figure 9-19 indicates a central static bypass for a paralleled UPS operation. Note the conditions of use and design application for individual UPS modules and static bypasses in a paralleled mode of operation previously discussed in this section.

Figure 9-20 shows the internal configuration of a typical "Catcher" UPS unit.

A Catcher UPS has two inputs to the rectifier from primary and secondary sources, with the "mains" bypass sharing these same two sources with than input from a stand-by UPS. The static bypass in each unit ensures that the output will be bypassed either to the standby UPS unit or to the mains power without interruption in the event of the UPS unit failure.

9.3.8.2.3 Recommendations

The UPS system static bypass and maintenance bypass designs should consider using the same source or type of source for the closed transition transfer mechanisms. Normally, this would require the power module inputs, static bypass input, and the maintenance bypass input to be synchronized to the same source. Depending upon the configuration, some UPS could be exempted from this rule when the static bypass input and the output of the UPS are synchronized. For example, input to power module inputs could be fed from utility 480 V_{AC} wye source "A" while the static bypass and maintenance bypass could be fed from utility (or generator) 480 V_{AC} wye source "B".



*There is an interlock between Source 1 and Source 2, so that only one of them is closed at any given time.
In the event of an outage of the primary source, there is an automatic transfer to the secondary source.

Figure 9-20
Topology Inside an UPS Unit

Other UPS configurations may have the maintenance bypass external to the UPS system to enable the UPS to be taken off-line for maintenance or replacement. It is acceptable to have the maintenance bypass internal to the UPS system in a Catcher system since the Standby UPS system can function as the external alternate path in the event the UPS system needs to be taken off-line for maintenance or replacement.

Attention shall be paid with respect to the configuration of disconnects external and internal to the UPS system to enable maintenance of rectifiers, inverters, or static bypass components in a safe manner.

A dedicated input to the static bypass that is separate from the rectifier input allows the critical load to further sustain faults that could be associated with the rectifier. In Class F0 and Class F1 applications, a single source of input power for both the rectifier and the static bypass is permitted (see Figure 9-13).

In Class F2 applications, a single source of input power to the rectifiers and to a static bypass is permitted (see Figure 9-14), but not recommended. For Class F2 applications it is recommended to provide an input path to the static bypass that is discrete from the rectifier input (see Figure 9-16). Momentary-duty equipment is allowed where designs incorporate individual modules into the topology.

Fully-rated static bypass switches with dedicated inputs are recommended for all Class F3 and Class F4 applications and for all paralleled system control cabinets (see Figure 9-16).

If proper breaker coordination has been completed, the input(s) to the rectifier(s) should be selectively protected from a static bypass input breaker failure.

9.3.8.3 Synchronization

9.3.8.3.1 Introduction

Synchronization can occur in one of two ways for UPS systems:

- Actively based on some form of external control system
- Passively by the management of the static switch inputs to the given modules or via active systems specific to the UPS manufacturer, depending upon the chosen UPS topology

The active systems offer excellent synchronization functionality, especially when the UPS system uses batteries. The passive system is important as vital system transfers are assured to be coordinated when the static inputs are managed and considered in the design. A lack of input or output synchronization could result in a failure of ASTS operation or an out-of-phase transfer, thereby resulting in a dropped load and possible equipment damage.

9.3.8.3.2 Requirements

UPS systems shall be synchronized in one of two ways:

- Line-side (source) synchronization
- Load-side (output) synchronization

In either event, synchronization is vital and shall be required for a high-reliability system at the Class F3 and Class F4 levels. Since Class F0, Class F1, and sometimes Class F2 systems are single module/single plant systems, no external synchronization is required.

When system-level synchronization is not possible, static switching at the loads or critical power buses may be required.

Table 9-8 Static Bypass Switch Input, By Availability Class

Class	*Description and Input source(s)*
F0	(UPS optional) Single power module with a single input to both the rectifier and the static switch
F1	Single power module with inputs to both the rectifier and the static bypass switch from the same upstream breaker
F2	Single or multiple power modules; all power module inputs from the same upstream distribution; static bypass switch input from a separate upstream breaker than the power module inputs.
F3	Multiple power modules; all power module inputs from the same source; static bypass switch input from a separate upstream breaker than the power module inputs
F4	Multiple power modules; all power module inputs from the same source; static bypass switch input from a separate upstream breaker than the power module inputs

9.3.8.4 UPS Output Switchboards

9.3.8.4.1 Recommendations

Output switchboards directly support the PDU and ASTS systems downstream of the UPS power plants. For Class F1, F2, and F3 systems, UPS outputs should be vertically organized to the UPS output distribution system downstream. Simpler electrical topologies may not have separate UPS output switchboards and critical power distribution switchboards.

For Class F3 systems, the second path may be derived from a non-UPS source. For Class F4 systems, there may be multiple power paths, but these are kept separated until they meet at the critical load.

Section 9.3.15 discusses the UPS power distribution downstream from the UPS output switchboards and how these loads are served by these diverse power paths.

9.3.8.5 Ties and Interconnections

9.3.8.5.1 Introduction

As long as the UPS sources are synchronized and are not overloaded, UPS systems may transfer load between each other. Except on a plant level, the UPS is the foundation of the multicorded system for critical loads. All transfers are done via closed-transition, and the control systems for this type of operation are typically redundant or offer some other form of manual operation in the event that the control system fails.

9.3.8.5.2 Requirements

System ties are common in system-plus-system configurations, and several UPS system manufacturers offer pre-engineered solutions for this design feature. For *x*N or other types of UPS topologies, the system designer shall engineer a solution for the given UPS module and plant configuration.

9.3.8.5.3 Recommendations

Ties and interconnections should also prevent the propagation of failures and should limit short circuit fault current.

See Section 9.7.2 for monitoring requirements.

9.3.9 UPS Output Distribution

9.3.9.1 Introduction

UPS output distribution switchboards are located immediately downstream of the UPS power plants and extend to the PDU or data processing room levels. One important consideration for these systems is that they do not have to follow the redundancy level or plant counts found in the UPS power plants.

For example, for Class F1 systems, the UPS output distribution switchboards are single units. For Class F2 systems, there may be module redundancy, but there may not be UPS power path redundancy. In both cases, UPS systems would match the total UPS power paths. In a Class F3 system with a single UPS power plant, there are at least two UPS output powered critical distribution switchboards, one on the active path and one on the alternate, or non-UPS, path. For a Class F4 system, there are at least two critical power switchboards, if not more.

A summary of the UPS output distribution switchboard counts and configurations for each Class are shown in Table 9-9.

Table 9-9 Summary of UPS Output Switchboard Counts for Classes

Class	*UPS power plants*	*UPS power paths*	*UPS output switchboard count*
F0	One	One	One
F1	One	One	One
F2	One	One	One
F3	One or more	One or two	Two
F4	Two or more	Two or more	Two or more

9.3.9.2 Recommendations

UPS output distribution switchboards may come in numerous specifications and configurations, all depending on the maintenance and failure mode of the critical loads downstream and UPS systems upstream. The UPS output distribution switchboards may be in any of the following configurations:

- Stand-alone or double-ended:

  Stand-alone switchboards are typically used for Class F1 and Class F2 applications or for Class F3 and F4 systems where load is not shared among UPS systems in pairs. Double-ended or interconnected switchboards are typically found in systems where the critical load is shared between a pair of systems or UPS power paths where they may be interconnected for inter-UPS output distribution redundancy. The switchboard configuration is most centrally related to the ability to shift load off an individual switchboard for maintenance. Some designs use the UPS paralleling switchboard or the UPS output distribution switchboard as a vehicle for closed transition load transfer and sharing either via chokes or static switching. This switch is located between the output buses and acts as a tie between them. The switch may feed the load directly or just provide lateral relief for maintenance or failure recovery. This concept is illustrated in Figure 9-21.

- Automatic versus manual controls for source transfer:

  Controls are locally operated. Failure mode response is always automatic (and that might mean doing nothing and letting other system components swing the load around) while maintenance mode response is always manual.

- Always closed transition to avoid load interruption:

  Since the UPS output distribution switchboards are located downstream of the UPS system, any switching operations need to be closed-transition (make-before-break) to avoid load interruption.

The diversity and configuration of the UPS output distribution switchboards is at the discretion of the system designer and user.

An example of critical power switchboard interconnection and diversity is shown in Figure 9-21. Figure 9-21 indicates central static switch for a paralleled UPS operation. Note the conditions of use and design application for individual UPS modules and static switches in a paralleled mode of operation noted in this section.

9.3.10 Power Distribution Units (PDUs)

9.3.10.1 Introduction

While most PDUs in North America have transformers, this is not typical in countries where the nominal voltage is already 230/400V. PDUs with an isolation transformer create a separately derived neutral for downstream loads although this may not be necessary for 3-phase loads or for systems in which the load utilization voltage is created at the UPS. PDUs with transformers convert the output voltage of the UPS system to the utilization voltage of the critical loads as needed. Regardless of the application, the PDU always has output branch circuit panelboards or distribution circuit breakers that serve the downstream critical loads or subpanelboards serving downstream critical loads. The overcurrent protective devices are usually circuit breakers although fuses are sometimes used for DC distribution systems.

9.3.10.2 Recommendations

A PDU is usually provided as a fully integrated, factory-tested, and listed product. In addition, the term “PDU” can be applied to a combination of site-connected elements, including a transformer, metering, controls, and power distribution panelboards.

If the PDU has an isolation transformer, its inrush characteristics should be coordinated with the upstream UPS peak load tolerances for normal, failure, and maintenance modes of operation. Low inrush transformers may also be employed depending on the UPS system’s design.

Where PDUs are expected to run close to their rated loads or one or more loads will generate large harmonic currents, a K-factor transformer might be considered. Harmonic currents can be created by ITE (e.g., switched mode power supplies [SMPS]) and mechanical equipment (e.g., fans, cooling unit inverters) that are connected to the PDU critical bus. High harmonic currents, especially those caused by single-phase power supplies in the ITE that create triplen harmonics (odd multiples of the 3rd harmonic, such as 3rd, 9th, 15th, 21st), can cause PDU output voltage distortion and transformer overheating. This heating reduces the efficiency of the transformer and increases the load on cooling equipment. These problems can be exacerbated when the PDU’s transformer is operated close to its rated capacity.

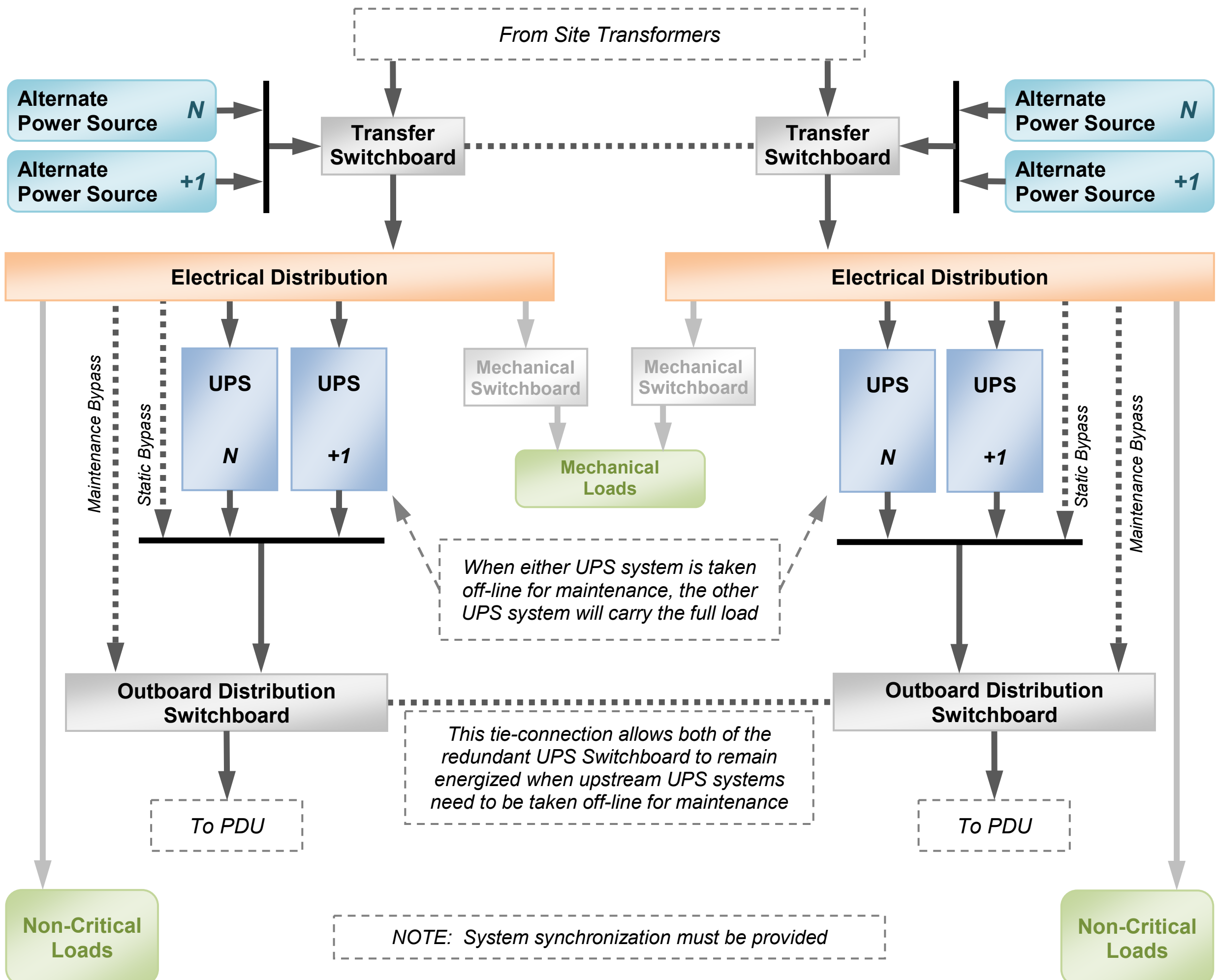


Figure 9-21
An Example of an Approach to UPS Output Switchboard Load Management

Transformers are frequently rated to K-9, but they may also be as high as K-13 to K-20. K-factor rated transformers are larger, more expensive, and less efficient than non-K-rated transformers, thereby increasing both capital and operating expenses, so they should be deployed judiciously. For Class F3 and Class F4 facilities where the transformer seldom operates at greater than 40% of its rated load, K-factor rated transformers may not be necessary as harmonics can be tolerated up to a certain level.

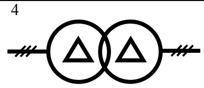
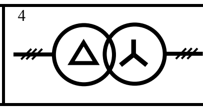
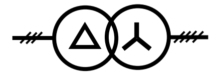
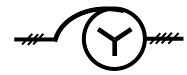
For existing loads, it is possible to measure the harmonic content to determine how much, if any, harmonic content must be addressed. For greenfield (new) installations where the load is unknown, it would be advisable to specify the permissible level of harmonic distortion when purchasing the ITE power supplies or other loads, and to operate fans and variable speed drives (VFDs) on separate circuits where feasible.

The PDU may possess the following attributes:

- It may be a stand-alone system or may be coupled with a static switch for the management of single- or poly-corded ITE loads.
- It may have single input or dual input depending on the UPS system topology.
- It may have a harmonic-tolerant (or K-rated) transformer.
- It may have a low inrush transformer to prevent unintended upstream circuit breaker trip.

See Table 9-10 for transformer wirings and output voltages commonly used in data centers.

Table 9-10 Transformer Wirings and Output Voltages Commonly Used in Data Centers

	3-phase 3-wire [1,2]		*3 phase 4 wire* [3]	*Autotransformer*
Wiring	[4] 	[4] 		
Output voltages	100V or 200V		400V and 230V 208V and 120V 200V and 115V	400V and 230V 208V 3 phase 4 wire

NOTE 1: These symbols are from IEC 60617

NOTE 2: 3-wire configuration with no neutral wire is popular in some locations to reduce the number of conductors, using delta-open delta transformers to step down to 100V.

NOTE 3: In general, delta configuration reduces harmonic content, but it has difficulty creating grounded neutral.

NOTE 4: There exists options for 6 or 7 wire outputs to provide dual output voltages at a ratio other than 1.732:1 such as 210V/105V_{AC}.

Considerations for selecting a PDU include:

- It should have larger-than-standard wiring gutters for easy circuiting.
- It should have a base plate tall enough for the ready connection of conduit for underfloor cabling applications.
- It should be located where thermographic testing can observe all critical connections, circuit breakers, and transformer cores while operating.
- Consider efficiency ratings at the expected operating loads pursuant to local energy guidelines. Specify no load and loaded losses at 25%, 50%, 75%, 90%, and 100% loads.
- 3-phase output
- 400V class (380-480 V_{AC}) output
- RPP/Busway design considerations

PDUs can be grouped together with other PDUs from alternate UPS power output sources such as the A and B systems collocated for matched circuit impedance and direct wiring. However, for higher Classes, it may be desirable to maintain physical separation of all elements in the critical power path as much as possible.

In the case where the UPSs are in a "catcher" configuration, it is possible to achieve concurrent maintainability of the UPSs without using an STS by using an overlap switch at the PDU source to switch between normal and standby UPS, which are both synchronous. This enables uninterrupted transfer of the PDU load between normal and standby UPS modules, improving both availability and operational flexibility.

For a PDU pair using a static switch, the load connections for single-corded and dual-corded devices might appear as illustrated in Figure 9-22. Within a cabinet or rack, an automatic transfer switch (either separate or integrated within a power strip) should be installed for all single-corded loads.

See Sections 9.3.16, 9.7.2, and 9.10 for further information.

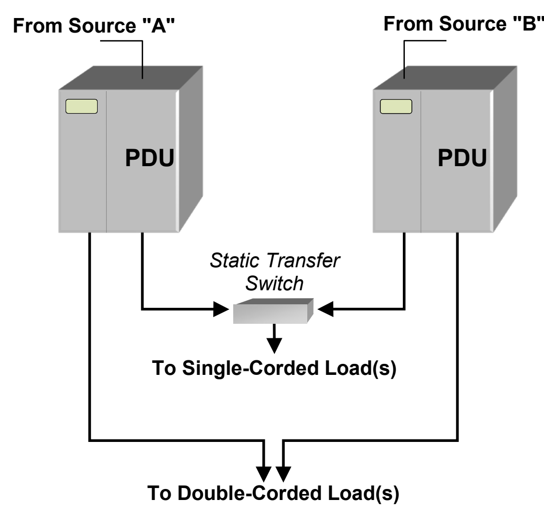


Figure 9-22
PDU Configuration: Single-Corded and Poly-Corded Devices

9.3.11 Automatic Static Transfer Switches

9.3.11.1 Introduction

Automatic static transfer switches (ASTS) are used in power systems where subcycle, high-speed source switching outside of the ITE is desirable. The operation of ASTSs is similar to that of mechanical ATSs in that the ASTS automatically transfers on loss of preferred source or retransfer on loss of alternative source when preferred source has returned. A majority of ITE comes either single- or dual-corded with some newer systems IT devices requiring multiple-corded loads (some IT devices require 3, 4, 5, or more cords). When this occurs, the ASTS allows for a multiplication of the UPS power distribution paths without the multiplication of the UPS plants.

Other loads vital to the data center's operation include temperature control and building monitoring systems, operation or control room video and control systems, security systems, and single-corded IT systems. At the Class F0, F1, and F2 levels where the UPS power distribution and circuiting systems are single path, static switches are not typically utilized.

9.3.11.2 Recommendations

Since ASTSs represent a single point of failure (because they, like the loads they support, are single output systems), their use needs to be balanced with the overall reliability and failure mode analysis for the critical power distribution system. The ASTS can provide reliable recovery for an unexpected input source loss, but by its nature, it is a complex system that will cause the loss all of the downstream loads if it fails.

Features of the ASTS might include:

- Solid state transfer systems (e.g., silicon control rectifier [SCR]) instead of mechanical contacts seen in ATSs.
- Dual-input and bypass-able for all loads—some ASTSs have been specified and built as three input systems, but these are typically custom units.
- Rack-mounted or floor-mounted options.
- Control systems that allow for transfer control within a few phase angle degrees.
- Fault-tolerant internal controls and wiring systems if needed.
- Mated to PDUs for numerous transfer and distribution options.

See Figure 9-24 for examples of transformer and distribution system configurations utilizing an ASTS.

See Sections 9.3.16, 9.7.2, and 9.10 for additional details on emergency power off, monitoring, and marking (respectively) as they apply to ASTS.

9.3.12 Power Strips

9.3.12.1 Introduction

Power strips allow multiple IT devices to plug into a single branch circuit. An example of a power strip is shown in Figure 9-23.

9.3.12.2 Requirements

Where used, power strips shall comply with the following requirements:

- Only AHJ permitted connections, such as junction boxes, shall be allowed under an access floor.
- Power strips shall be listed for ITE.
- Power strip ratings shall be coordinated with the upstream breaker and wiring system.
- Power strips shall be positively and mechanically attached to the cabinet interior.

Multiple power strips mounted in a cabinet shall bear proper labeling and shall be organized not to interfere with network cabling. Similarly, power strips shall be located in order to minimize crossing of the distinct power supply cords (e.g., A and B) as they are routed to the power strip from the IT platform.

Figure 9-23
Example of a Power Strip for Mounting in ITE Cabinets

9.3.13 Direct Current (DC) Power Systems

9.3.13.1 Introduction

DC power systems that serve critical loads are common in two forms:

- The primary power source for access provider and carrier equipment
- As an alternative to AC power in computer rooms because of energy efficiency, design simplification, and ease of paralleling alternative energy sources

DC power distribution systems function within the data center in the same way as the AC systems providing power to a variety of loads. However, DC-based systems can offer additional features that can be attractive to data center designers and operators. It is also possible to mix DC and AC systems in hybrid configurations, for example, providing DC to critical loads and AC to mechanical loads.

DC power system operating voltages are affected by several factors such as:

- Battery technology (e.g., lead-acid varieties, nickel-cadmium, nickel-metal-hydride, lithium-ion varieties, sodium varieties, flow varieties)
- Rectifier output regulation in maintaining constant voltage under dynamic loads
- Voltage drops in DC power conductors—cable sizes and lengths
- Operating voltage limits of various connected loads
- Derating for environmental conditions such as altitude
- Availability of DC-rated components

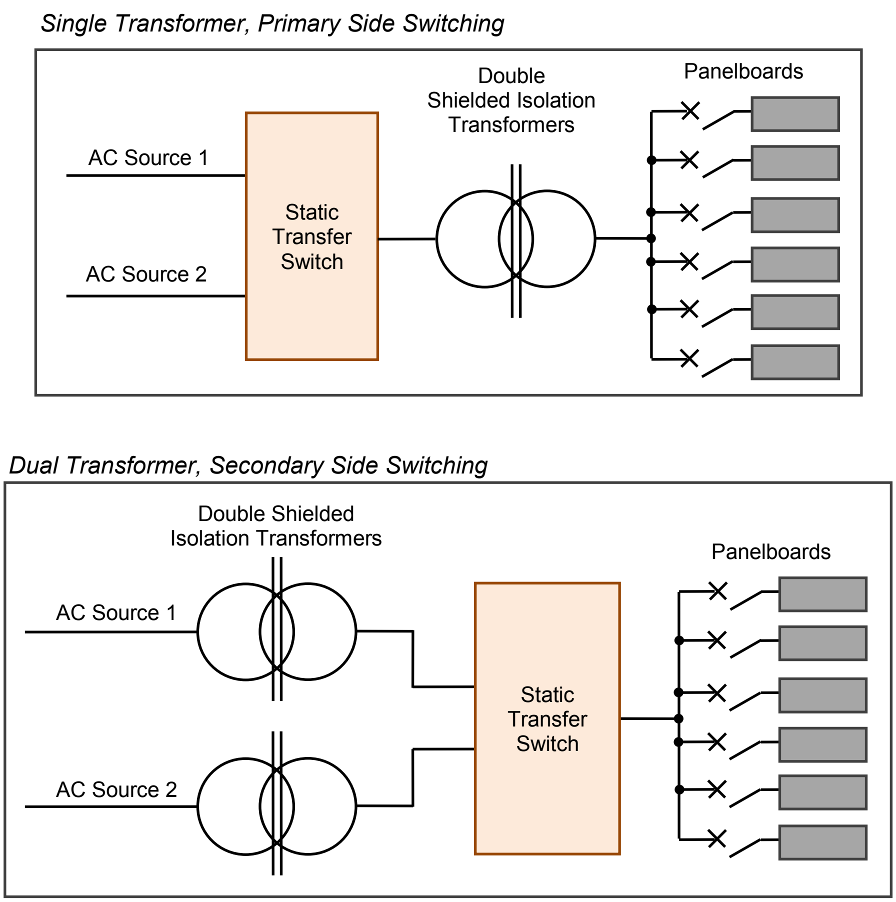


Figure 9-24
Automatic Static Transfer Switches

9.3.13.2 General Requirements

All DC equipment shall be properly and clearly marked according to the applicable electrical or building codes and as required by the appropriate listing agency. DC equipment includes, but is not limited to:

- Cords
- Cables
- Raceways
- Busways
- Power connectors
- Junction boxes
- Batteries
- Generators
- Flywheels
- Circuit breakers
- PDUs
- Rectifiers
- DC-UPS

The design of all DC-powered ITE shall likewise comply with applicable sections of required electrical and building codes and shall be rated, listed, and marked for DC operation at the anticipated voltage range.

Electrical safety clearance rules are applicable to both AC and DC circuits. For DC circuits, the clearance requirements shall generally be the same as those for AC circuits having the same nominal voltage to ground.

9.3.13.3 General Recommendations

Direct current systems should meet the same requirements for availability, reliability, maintenance, and safety as AC power systems. While DC-based critical power systems are an emerging and potentially viable option for mission-critical environments, it is advisable at the present time to work closely with the designers, equipment providers, and electrical contractors who have experience in the direct current applications.

Designers, operators and others involved in DC systems should refer to the appropriate standards such as NFPA 70E, IEEE C2, and others.

NOTE: NFPA 70E Article 130 defines DC approach boundaries and, hazard/risk category classifications for DC equipment; Article 340 outlines Safety-Related Work Practices: Power Electronic Equipment.

For installation and maintenance of batteries, standards applicable to the battery technology (e.g., IEEE 450 for vented lead-acid batteries, IEEE 1188 for valve-regulated lead-acid batteries, IEEE 1106 for nickel-cadmium batteries) should be followed.

While DC-based critical power systems are an emerging and potentially viable option for the mission-critical environment, insufficient data exists to offer complete design guidance in this standard.

Applying DC power system telecommunications utility practices to the nonregulated environment of a data center requires additional considerations. Design considerations should include, but are not limited to:

- Per ATIS 0600336, the highest DC voltage covered by the telephone/telecommunications/ITE industry is 160 V_{DC}. The utilization of higher DC voltages (such as 240 V_{DC} or 380 V_{DC}) is essentially new territory and will require some additional safety and performance investigation. However, established principles are not expected to change.
- Overcurrent protection devices (OCPD) and disconnect devices for DC power systems will need further investigation for higher voltage DC systems. AC-rated devices cannot automatically be used on a DC power system at the same rated voltage and current. The established 2:1 protection coordination scheme for DC fuses is not readily applicable since data centers typically utilize circuit breaker technology.
- Transients for other than 48 V_{DC} systems are not well described.
- Battery disconnect or other DC disconnect usage at voltages above 50 V_{DC} is not well established. Disconnects may or may not be required, depending upon local requirements. 2-pole or even 3-pole disconnects may be required, perhaps at multiple points within a system. Interrupting capacity and withstand ratings may need to be selectively coordinated.
- Conductor sizing regulations for DC are not well established; sizing per AC code requirements may be inappropriate for DC conductors.

List continues on the next page

- If the rectifier technology is switched mode power supply (SMPS), it may require use of electrical noise control via power line filters (possibly connected to the return or DC equipment ground conductor) and might create additional audible noise from cooling fans.
- Rectifier operation modes at the higher voltages, such as 380 V_{DC}, may need verification for AC input power factor correction, load sharing, paralleling, voltage sensing, and current limitation.
- The choice of distribution method may vary within different areas of a data center, as some methods (e.g., rigid busbar) can withstand potentially extreme fault current conditions (e.g., a direct short across the batteries). Other methods may be sufficient for the application being supported (e.g., telecommunications 48 V_{DC} system). The type of distribution may also be affected by planned physical location (e.g., underfloor).
- Voltage drop is a concern, especially if DC is run for distances longer than a few meters. Guidelines for calculating voltage drop can be found in IEEE 946.
- For metallic battery racks, determine the AHJ requirements for sizing the bonding conductor. 13.3 mm^2 (6 AWG), which is typically specified for telecommunications applications below 50 V_{DC}, may not be acceptable for higher voltages (e.g., 380 V_{DC}).
- Consult with the AHJ regarding limitations for the location of centralized DC power systems in the computer room.
- Determine the grounding methods required by the ITE. The 380 V_{DC} system might be operated as a positive grounded system (similar to the 48 V_{DC} telecommunications system) as a negative grounded system (similar to the 24 V_{DC} telecommunications system) or as an ungrounded system (similar to higher voltage UPS systems).
- Some ITE cabinets or racks (e.g., OCP open racks) have integrated busbars which can be used to distribute 12 V_{DC} or 48 V_{DC} from rack mounted power shelves or PSUs to ITE. Such configurations may provide increased energy efficiency and design simplification.
- ITE cabinets can also contain integrated battery back-up units (BBUs) to act as rack-based UPS if a centralized UPS is not utilized within the data center.

9.3.13.4 Voltage Ratings

9.3.13.4.1 Introduction

Direct current nomenclature differs somewhat from alternating current nomenclature in terms of range. In AC terminology, the “nominal voltage” is the voltage at which the ITE is expected to operate under conditions of normal operation. AC equipment has a tolerance range within which it can operate reliably (e.g., +10% / -15% of nominal).

In DC equipment, there is generally assumed to be a battery, so the DC voltage range is usually determined by the needs of the battery. In most cases, a battery is charged (and the ITE operates) at a constant “float voltage” for a high state of readiness. When a battery is required to discharge (i.e., upon loss of mains [utility] power), the voltage declines until it reaches a cut-off voltage. When the battery is recharged, a higher voltage is pumped through the cells until the battery reaches capacity at which time the charger drops the voltage back down to the “float voltage” level. In some cases, an even higher voltage may be applied to “equalize” the cells. The “nominal voltage” is a point somewhere around the middle of the range.

The connected DC load equipment is expected to operate within an entire band range of DC voltages. The industry speaks of “narrow range” and “wide range.” The efficiency of the ITE will vary, depending for which band it is designed. For example, a narrow range system could be 361-399 V_{DC} with nominal midpoint of 380 V_{DC}, whereas a wide range could be 294-380 V_{DC} with a nominal midpoint of 336 V_{DC}.

The industry has adopted the term “high voltage direct current (HVDC)” to distinguish it from the traditional telecom systems which operate below 50 V_{DC}. Data center voltages are generally identified at two voltage levels:

- 240V HVDC—the system provides 240 V_{DC} nominal voltage and 270 V_{DC} floating voltage
  - (nominal = 2 V_{DC} per battery cell x 120 cells)
  - (floating = 2.27 V_{DC} per battery x 120 cells)
- 380V HVDC—the system provides 336 V_{DC} nominal voltage and 380 V_{DC} floating voltage
  - (nominal = 2 V_{DC} per battery cell x 168 cells)
  - (floating = 2.27 V_{DC} per battery x 168 cells)

Thus, the existing HVDC systems should be categorized as:

- 240V wide-band HVDC system (240 V_{DC} nominal/270 V_{DC} float charge)
  Primarily designed, deployed and operated in China by telcos and a few Internet companies.
- 380V wide-band HVDC system (336 V_{DC} nominal/380 V_{DC} float charge)
  Adopted in North America, Europe, and Japan. Research laboratories, such as Lawrence-Berkeley National Laboratory, and experimental installations (e.g., Duke Energy, NTT) are based on this system.
- Under-400V narrow-band HVDC system
  Incorporates all the narrow-band HVDC systems, which provides constant but adjustable output voltage under 400 V_{DC} and complies with standard ETSI 300 132.

NOTE: By definition in the narrow-band system, there is no "float" voltage, because the DC voltage is regulated.

9.3.13.4.2 Additional Information

DC power distribution systems can be designed with the same topology as comparable AC systems. In the simplest implementation, the DC system can follow the same principles and tier structure as AC data centers. This would entail replacing the AC-based UPS and all the downstream AC equipment (e.g., switchboards, PDU, STS, PSU) with DC-based power systems and equipment. In a more sophisticated approach one can design a microgrid type of DC system, which can incorporate a variety of sources (DC and AC with their AC-to-DC conversion) and a variety of loads (DC loads such as DC PSU and DC telecom equipment, DC VFDs driving the HVAC motors for cooling systems as well as DC building lighting).

With regards to arc flash safety, NFPA 70E has provided guidance for arc flash hazards in AC systems for a number of years. In the 2012 version of the standard, guidance on arc flash hazards in DC systems was added.

One has to notice that the different standards define different voltage ranges for the DC systems (e.g., 0-250 V_{DC}, 250 V_{DC} – 600 V_{DC} or < 750 V_{DC} and > 750 V_{DC}). Although there is no consistency between the various standards on voltage ranges for a given voltage selected for a data center (such as 380 V_{DC}), one can easily extract the applicable sections of the other standards related to safety of such a system.

Renewable sources of energy and short-term energy storage systems, such as photovoltaic (PV) arrays, fuel cells, microturbines, battery systems, ultracapacitors, and flywheels, are very compatible with the DC systems. With the increasing awareness of sustainability, these sources and energy storage technologies are finding their way into the data centers. Since many of these sources and storage systems are intrinsically DC based or utilize equipment that converts variable AC to DC and then to main frequency AC (50 or 60 Hz), it is only natural that they can be easily adapted to the DC distribution systems by eliminating the last DC to AC conversion. This can improve overall system reliability (fewer components), system efficiency, and control over dispatching energy throughout the entire DC network.

Moving forward, there is interest in using direct current at voltages as high as 600 V_{DC} although 380 V_{DC} nominal is emerging as a global standard (except in China where 240 V_{DC} is being widely deployed). The claimed advantage of DC power over AC power is that fewer power conversions result in higher efficiency and greater reliability although such claims have yet to be verified through wide adoption. Some of the initial attractiveness of DC power systems has been their natural efficiency. In recent years, AC power efficiency has reached or exceeded the levels of DC, making DC less relevant for efficiency. However, there are still persuasive arguments to be made regarding parts reduction and, thereby, improved reliability. Distributed versus centralized rectifier plants will affect the data center design both for power distribution and for grounding and bonding.

9.3.14 Busway Power Distribution

9.3.14.1 Introduction

Use of busway with plug-in tap off units for power distribution to ITE cabinets or racks provides a greater level of flexibility for different ITE power requirements. The busway should be considered as a long thin power distribution unit.

9.3.14.2 Requirements

Busway used for providing power connections to ITE cabinets or racks shall comply with AHJ safety requirements.

Busway and its power supply shall be rated for the maximum power load of ITE that could be connected.

The busway shall be securely supported at locations where it can be reached by an operative to install tap-offs without risk to health and safety or the ITE. Tap-offs shall include breakers or fuses and have the capability to incorporate ammeters.

For F3 and F4 class facilities, at least two physically diverse busways will be required for each row of ITE cabinets or racks.

9.3.14.3 Recommendations

Busway used for providing power connections to ITE cabinets or racks should meet the following:

- Busway length should be restricted to a row of ITE cabinets or racks, with each row having its own power supply.
- The spacing between tap-off connection points along the length of the busway should be uniform. Intervals should not be smaller than 18 in (450 mm), with the chosen interval spacing able to accommodate the width of the cabinets being served.
- Busway systems should support tap-offs of both single and three phases with a continuous load rating of up 35 kW ITE.
- Tap-offs should be able to be connected to the busway with the busway live and under load of other tap-offs.

9.3.15 Computer Room Equipment Power Distribution

9.3.15.1 Introduction

Unlike upstream UPS plants and critical power distribution, distribution to the critical loads must be exactly mapped to the redundancy of those loads and the cord and circuit diversity that they require.

The upstream systems must be able to deliver the source diversity to the computer room circuiting under normal maintenance and failure modes of operation as prescribed in the Class performance descriptions.

At this level, the electrical system is downstream from the PDU or transformer level, and this system is typically operating at the utilization voltage level for the ITE or critical equipment. This distribution can be present in several forms such as busway or individual circuits.

For high-density loads, a given design may separate the panelboard branch circuit sections of the PDU into cabinets near the critical loads. This system may have either single or dual-inputs and is commonly known as a remote power panel (RPP). RPPs reduce installation labor and reduce the cable and circuit length to the load.

Distribution to the loads may be either overhead or underfloor. Underfloor power distribution is most commonly accomplished using liquid-tight flexible metallic conduit, but the AHJ may require the use of rigid conduit or specific types of cable construction (e.g., armored). IEEE 1100 recommends hard steel conduit with an AHJ-approved insulated grounding wire for added safety, performance, and EMI protection. Power distribution pathways should be located adjacent to or within the cold aisle and telecommunications cabling pathway should be located adjacent to or within the hot aisle to minimize air blockages. Overhead power distribution can frequently eliminate the cost of conduits (with the addition of cable tray or busway) and can have the added benefit of eliminating cables as a cause of underfloor air blockage. Overhead cabling, if used, should be planned to minimize blockage of airflow above the floor. Refer to Section 14.7 for considerations of overhead cable routing.

For future and high-density loads, traditional power strips in the IT cabinets, and in some installations, 3-phase power strips with appropriately sized circuit capacity may be required to support the load. To accommodate future power requirements, installation of 200 V_{AC} three-phase cabling at currents of up to 50 or 60 A, or voltages of around 400 V_{AC} is recommended even if such power is not immediately required.

Single phase power strips with 220 V_{AC} and 16 A may not be sufficient for power loads in the ITE cabinets. If 32 A or higher amperage, or 3 phase circuits are used, fuses or breakers may also be required to protect the power leads and plug sockets. Some AHJs have lower than 32A minimum amperage for requiring fuses or breakers.

9.3.15.2 Load Connections

9.3.15.2.1 Requirements

Unused or abandoned cables not terminated at equipment or marked for future use shall be removed.

See Sections 9.3.16, 9.7.2, and 9.10 for additional details on emergency power off, monitoring, and marking (respectively) as they apply to load connections.

9.3.15.2.2 Recommendations

Load connection best practices are listed below:

- Twist-lock receptacles and plugs for all underfloor or overhead receptacles should be provided. Consider using locking equipment power cords, power strip receptacles, or retention clips for power strips within a cabinet or rack. The busway's design should allow new load taps to be installed while the bus is energized without creating any arcing or transients.

List continues on the next page

- Locking receptacles should be used for connecting the input cords of the power strips and for larger ITE. For in-rack loads using straight-blade cords, anti-pullout tie downs should be used where cords plug into the power strips.
- Power distribution cables originating from different source PDUs, RPPs, electrical phases, taps off the same PDU, or electrical panels should be clearly identified as to their source, phase, and load capacity. If permitted or required by the AHJ, cables from different sources may have different color jackets and connectors.
- Branch circuit overload protection devices should be de-rated by a design factor of 20% (e.g., be at least 25% larger than their connected ITE load) to ensure that circuits are not operating at the edge of their circuit breaker trip rating.
- For equipment and systems that require power feeds from more than one power source to provide availability (typically Class F3 or Class F4), the power cords should be split across two of the cabinet power strips. To provide availability for single-corded equipment and for equipment that utilizes multiple cords but is not power feed-fault tolerant, these items should be plugged into a rack-mounted power strip or receptacle fed by a larger upstream, automatic static transfer switch (ASTS), or some other point-of-use ASTS.
- Equipment with three power cords should have one of the three plugs on a rack-mounted power strip or receptacle fed by a static transfer switch or point-of-use switch. The other two plugs should be plugged into receptacles supported by different PDUs. These other two receptacles should not be on static transfer switches.
- Power cords should be mechanically connected at the point of entry to the rack or piece of ITE. This may be accomplished via the ITE manufacturer’s cable tie downs, hook-and-eye straps, cable ties, or similar attachment that allow for the secure attachment of the power cable to the enclosure and would prevent the accidental disconnection or damage of cable. Provide slack loop, as appropriate, in the tie down to allow for some cable movement.
- UPS sources should be paired or grouped together and represented by individual panels or remote power panels for ease and clarity.
- Plugs and rack-mounted power strips should be located where thermographic testing can observe all critical connections and overcurrent protection devices while operating.
- Cable management should be used.
- Disruption to future operations should be minimized by locating distribution equipment to permit expansion and servicing with minimal disruption.
- All power receptacles and junction boxes should be labeled with the PDU/RPP/panel number and circuit breaker number. Each PDU/RPP/panel circuit breaker should be labeled with the name of the cabinet or rack, or the grid coordinates of the equipment that it supports.
- All power receptacles and junction boxes installed under an access floor system should be attached to the access floor or the structural floor per manufacturer’s recommendations when required by the AHJ. Receptacles and junction boxes should be mounted on channel to keep raceways and equipment above the sub floor. This attachment may be made mechanically via concrete anchors, brackets attached to the access floor pedestals, or even industrial hook-and-loop NRTL-listed fasteners, which make an excellent, dust-free alternative to drilling in an anchor or adhesives. Additionally, boxes and other electrical devices should be mounted at least 25 mm (1 in) above the sub floor to prevent water intrusion in the event of a leak.
- Every computer room, entrance room, access provider room, and service provider room circuit should be labeled at the receptacle with the PDU or panelboard identifier and circuit breaker number.
- Receptacles on UPS power should be color coded, have a color-coded label, or have a colored dot to indicate the specific upstream UPS power source.
- Supply circuits and interconnecting cables identified for future use should be marked with a tag of sufficient durability to withstand the environment involved.

9.3.15.3 Load Management

9.3.15.3.1 Introduction

Data center load management deals with the physical connection of critical loads to the critical power system in a manner consistent with the normal, failure, and maintenance modes of operation. At this level, it is assumed that the ITE load’s internal power supplies will switch between the input sources independent of the critical power system’s response to a failure. Knowing this, the data center or critical environment circuiting must agree with the response of the systems serving them. This is known as circuit mapping, and the same thinking that applies to all other parts of the critical power system applies here.

9.3.15.3.2 Requirements

Once equipment has been selected, continuous duty and design safety factors must be prudently applied to the critical power system. Safety factors are explained in more detail in Section 9.5.2. The maximum power required for a given critical power topology is then applied to the combined duty cycles and safety factors, resulting in the practical loading of the system. This practical loading accounts for all normal, failure and maintenance modes of operation of the critical power system.

This calculation varies depending on the Class and UPS topology. Most importantly, a facility operator needs to understand how this factor is applied at the PDU and critical power branch panelboard level in their facility so that they can readily and most efficiently use the critical power they have available.

The formula for rating a critical power system is:

$$\text{System kVA} \times \text{continuous duty factor (if not rated for 100\% duty)} \times \text{design safety factor} \times \text{system power factor} = \text{usable kW of critical power} \qquad (9\text{-}1)$$

The power factor is the ratio of the real power (kW) used to do the work and the apparent power (kVA) used to supply the circuit. This difference can come from a phase delay between the current and the voltage, harmonics, or distorted current waveforms. An ideal power factor is equal to 1, and anything lower means that the electrical infrastructure needs to be oversized to supply the load. Furthermore, although this difference of power is not actually consumed by the equipment, it is possible for the service provider to invoice it or apply penalties according to the power factor value. Therefore, the objective is to maintain the power factor closest possible to 1. Some methods that can be used are:

- Use equipment that is less inductive. The ITE is constantly improving to be closer to 1.
- Use a UPS with power factor 1.
- Use a power factor correction device, also called capacitor bank, located between the UPS and the substation. It can be fixed or automatically adjusting and can include monitoring.

9.3.15.3.3 Recommendations

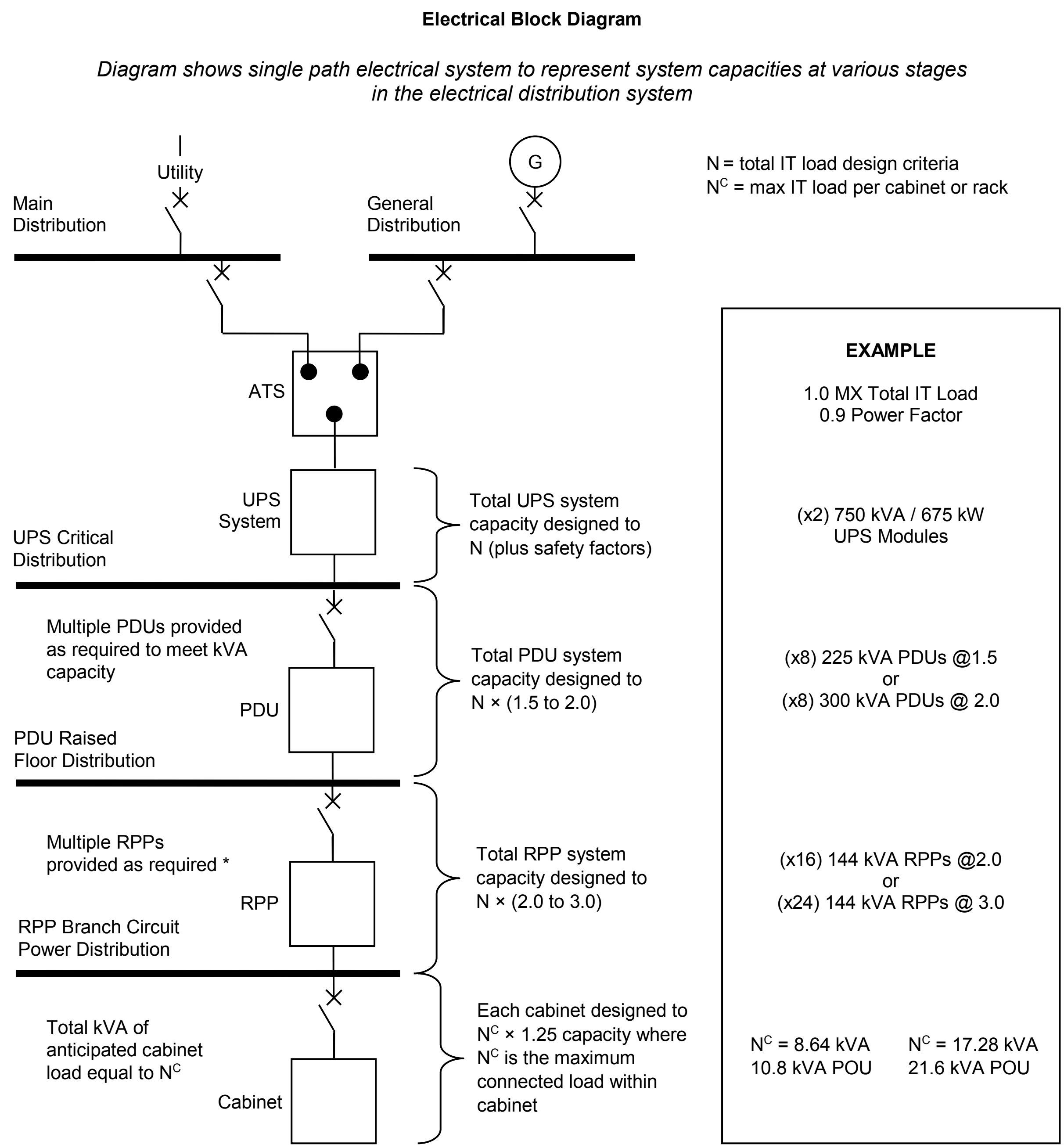
Power distribution design should have sufficient flexibility and scalability to allow the load to increase or decrease in any cabinet, rack, or ITE zone within acceptable design limits. If the total anticipated data processing load has a capacity criteria of N, the multipliers for each subsystem within the electrical distribution system (as shown in Table 9-11) will provide sufficient capacity to meet normal equipment layout diversity and scalability, thereby preventing the creation of areas where the power available is insufficient to support the connected load.

Redundancy reduces the load on any given device, with a corresponding impact on efficiency and operating cost. Equipment selection should consider operating cost at the anticipated load levels in addition to capital costs and footprint.

Figure 9-25 shows a single path electrical system to represent system capacities at various stages of the electrical distribution system.

Table 9-11 Multipliers for Electrical Distribution System Components

Distribution System Component	*Multiplier (N = ITE load design criteria without safety factors)*
UPS and UPS critical distribution	N (plus safety factors)
Power Distribution Units (PDU)	N × 1.5 to 2.0
Remote power panels (RPP) or overhead power plug busway	N × 2.0 to 3.0
Power strips (POU)	N^C × 1.25



* Quantity of RPPs is not only dependent on the total IT load "N" but also the:

- Layout of the ITE, coordinate with number of cabinet rows or equipment zones.
- Capacity of RPPs shall be sized to accommodate total N^C of all IT hardware within rows or zone covered by RPP.
- Number of pole positions required to support quantity of circuits required for IT hardware within rows or zone covered by RPP, pole positions (min.) = 2 × circuits required.

Figure 9-25
System Capacities at Various Stages of the Electrical Distribution System

9.3.15.4 Circuiting Protocols

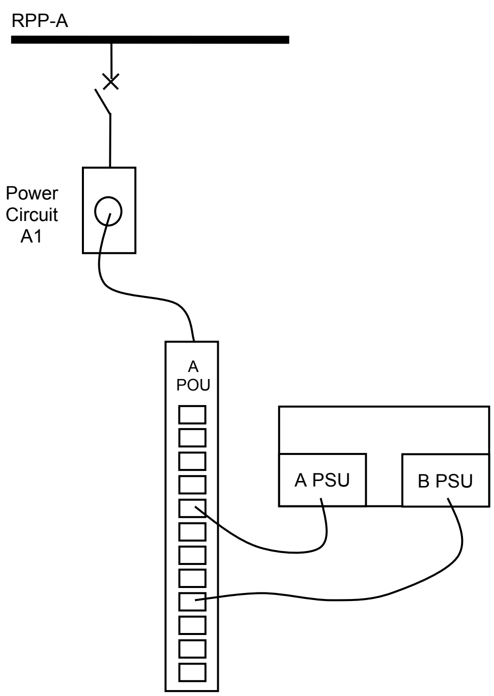
9.3.15.4.1 Introduction

One of the most effective methods for preventing system overloading is the management of ITE loads in the critical environment. The management of the ITE loads must be considered for both the normal mode of operation and for maintenance modes of operation. While it may be difficult to overload a PDU or UPS system, improper cord management may lead to a lack of adequate circuit diversity for the ITE loads. As a result, the failure mode response of the ITE loads may be compromised.

Figure 9-26 through Figure 9-32 show how Class characteristics may be manifested in the data center's circuiting environment. The individual power circuits shown within the figures would be sized to support the ITE power demand.

9.3.15.4.2 Circuit Mapping

There is no redundancy in the critical power system's pathways until Class F3 is realized. The model for the Class F0 and F1 critical power systems would be as shown in Figure 9-26.



Each POU, power circuit receptacle and power circuit breaker sized to meet the total capacity requirements of the ITE load in the cabinet.

Figure 9-26
Class F0 and F1 Circuit Mapping

For Class F2, although there is no redundancy in the critical power backup generation, UPS system, or system's pathways, it is recommended that multiple power strips (POU) be provided within each ITE cabinet. Each POU would be fed from separate dedicated upstream breakers. The power circuits for a POU pair within a cabinet will often be fed from a common upstream RPP or PDU for a Class F2 electrical distribution. The model for the Class F2 critical power systems would be as shown in Figure 9-27.

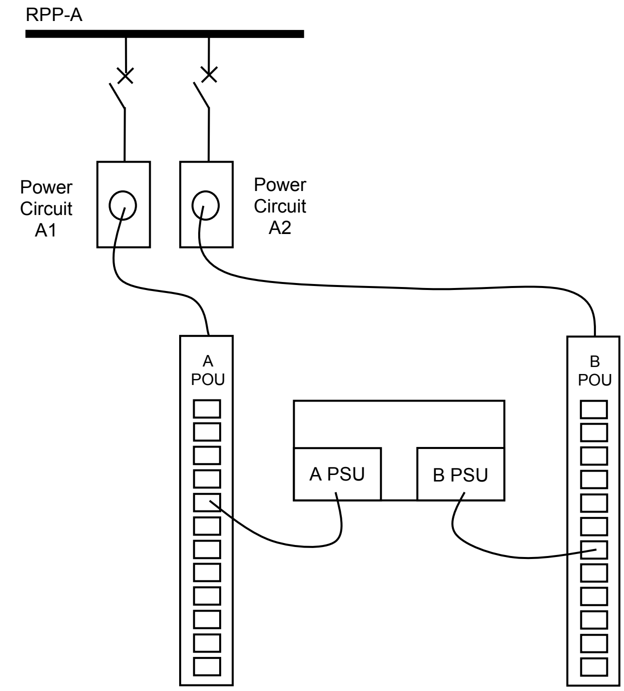


Figure 9-27
Class F2 Circuit Mapping

With the diversity in the critical power paths in the Class F3 and Class F4 systems, the complexity of the circuiting systems in the data center increases. The key point to the higher Classes is that the circuits that serve the ITE must be derived from separate sources, and the power distribution downstream from the UPS must be concurrently maintainable for Class F3 and Fault Tolerant for Class F4.

There is a misconception within the data center industry that redundant power supplies have been implemented within critical server, storage, and network devices to enable concurrent maintainability of the power distribution supporting the devices. This was not the initial intent for redundant power supplies. The redundant power supplies have been provided because the power source and the power supplies represent a component or system that has higher failure rates, and in order for the IT hardware manufacturers to ensure high availability of the systems, redundant power supplies were implemented. It may be acceptable to a data center owner to use the redundant power supplies to assist in facilitating concurrent maintainability; however, the risks with this approach must be understood by the IT team.

When power on one leg of dual power supplies is interrupted and then returns after some period of time, the failure rate of power supplies could be as high as 5%. Empirical data suggests that the failure could go undetected until power on the surviving leg is interrupted and the ITE load is lost, but the probability of such ITE failure is less than 1%; ITE on other circuits will be unaffected.

If the data center server architecture is one where there are hundreds or thousands of servers for both capacity and redundancy supporting a single function and the loss of up to 5% at any time would not be considered business disruptive, then using the dual power supplies within the ITE to support concurrent maintainability of the power distribution would be a reasonable approach. However, for data centers where a business-critical application is supported by high availability IT hardware clustered pairs or where there is a single large frame server in the primary data center supporting a critical function, a failure rate of 5% can represent a significant risk. In this case, attention to providing multiple redundant power circuits from the RPP, in addition to providing closed-transition tie breakers between redundant UPS output distribution switchboard to support each ITE cabinet, is recommended for Class F3 and F4 data centers.

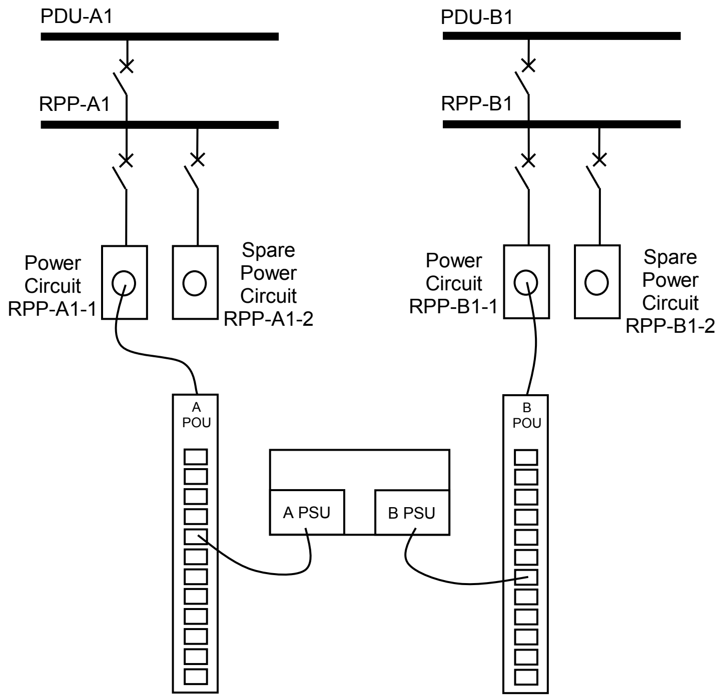
For Class F3, the power distribution between the UPS and the ITE shall be concurrently maintainable. Concurrent maintainability can be achieved through manual operational processes with multiple circuits or automated systems through the use of multiple static transfer switches. If there is significant coordination between the data center's facility and IT operations teams, then concurrent maintainability can also be achieved by moving the application from one virtual server to another. The critical application on the power circuit that requires maintenance can be moved to another virtual server within the data center whose physical server is connected to an alternate upstream PDU or RPP.

A method of providing concurrent maintainability through manual operational processes is to have each cabinet provided with two power circuits and receptacles from each of the redundant power paths. This would enable, for example if the "A" power path required maintenance, the operations team to manually disconnect the "A" POU within each cabinet and connect it to the spare "B" power path. It would likely be impractical to use this practice to maintain one side of the power distribution (where closed-transition tie breakers do not exist in the distribution downstream from the UPS) for a large data center, but it may be more applicable for mid- to small-size data centers or for maintenance of individual PDU or RPP within the computer room. The benefit this operational process offers is that if a power supply fails, then the high availability clustered pair should not be impacted (the clustered pairs should never be located within the same cabinet). The failed power supply can be replaced prior to proceeding with the remaining cabinets. If overhead power distribution buses with plug-in receptacle units are used instead of RPPs, the design is simplified. With an overhead power bus, there is no need to pull extra circuits; only spare plug-in receptacle units are required. If the "A" overhead power bus required maintenance, the spare plug-in receptacle unit would be installed in the "B" overhead power bus.

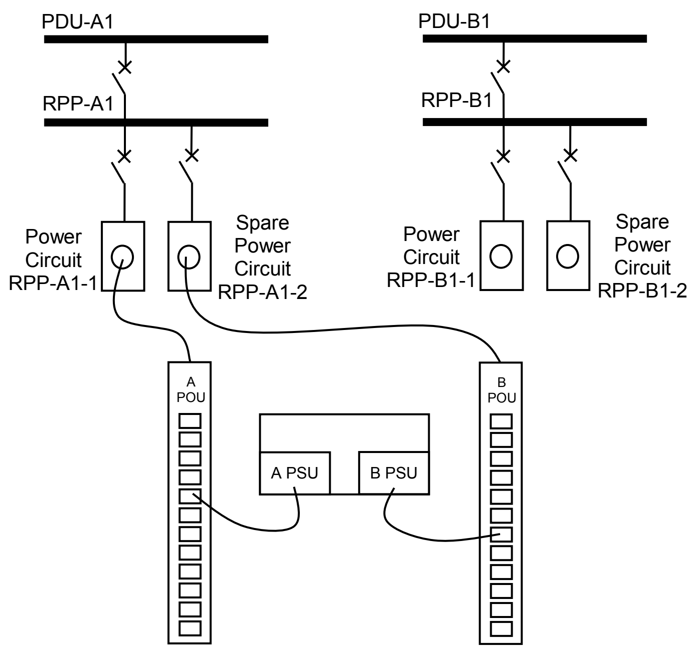
A method of providing concurrent maintainability through automated systems is to provide two POUs with an integrated STS within each cabinet. Each POU would be connected to both "A" and "B" power paths with one STS set to "A" as the primary source and the other set to "B" as the primary source. This method allows the facilities team to maintain either power path without the ITE seeing a disruption to either of the redundant power supplies.

CAUTION: The MTBF data for the STS or ATS components should be provided by the manufacturer and analyzed by the designer prior to the use of rack mounted STS or ATS components in order to provide concurrent maintainability between the UPS outputs and the POU within the cabinet. Inadvertent and non-predictable failures of rack-mounted STS and ATS components have resulted in unplanned outages. When using this circuit mapping topology, it is recommended that the STS or ATS have a defined replacement cycle, which could be every 3 years or less depending on the MTBF.

Figure 9-28 shows a normal mode and manual operations maintenance mode of operation for circuiting a Class F3 critical power systems, whereas Figure 9-29 shows the circuiting for normal and automated operation maintenance modes.



Normal Mode of Operation



Maintenance Mode of Operation: Cabinet power outlet unit cord moved from RPP-B1-1 to RPP-A1-2 to enable maintenance on any upstream component on the "B" power distribution.

Each POU, power circuit receptacle, and power circuit breaker sized to meet the total capacity requirements of the ITE load in the cabinet.

Figure 9-28
Class F3 Circuit Mapping (Manual Operations)

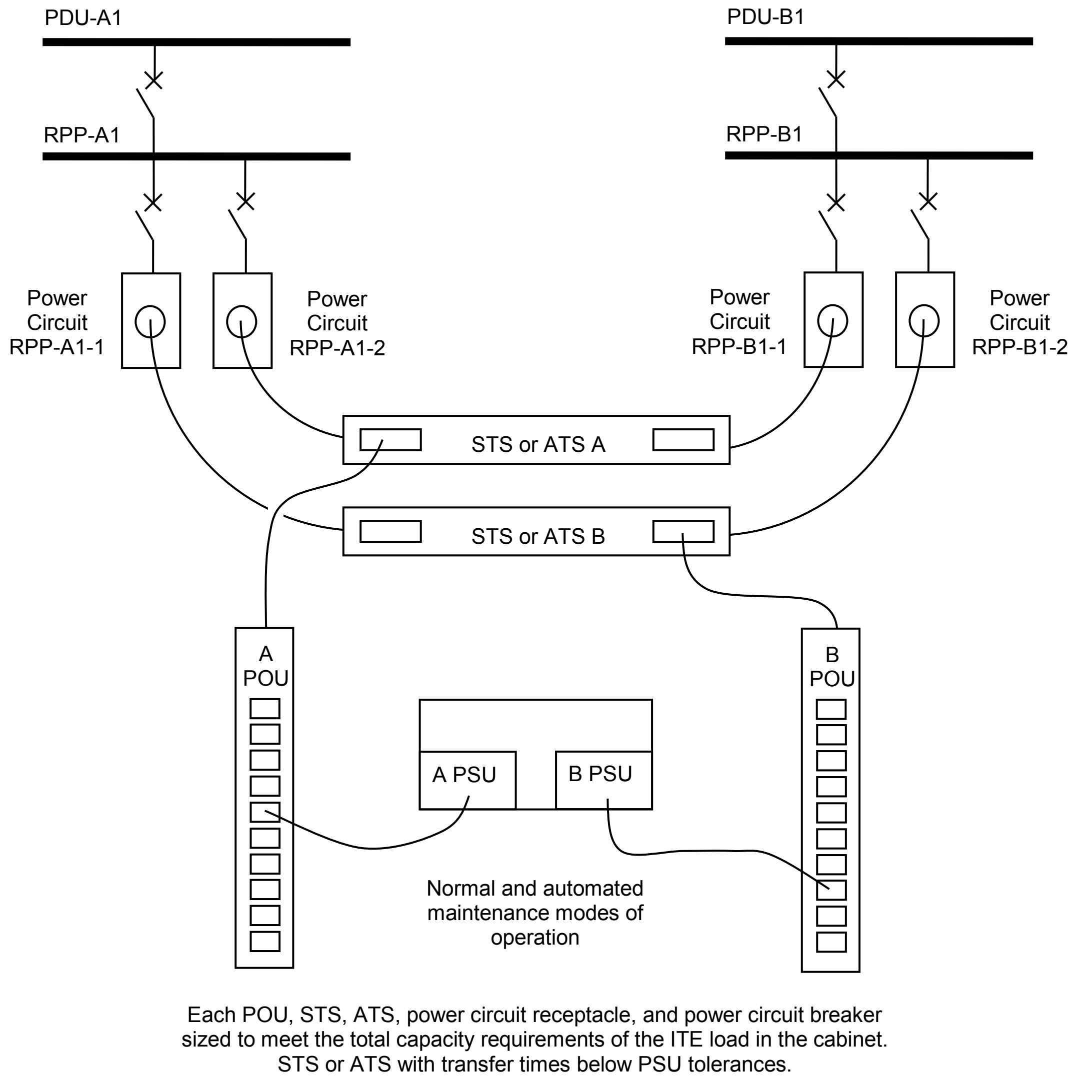


Figure 9-29
Class F3 Circuit Mapping (Automated Operations)

For Class F4, it is not possible to achieve concurrent maintainability plus fault tolerance at the ITE level when the ITE contains dual power supplies (or any N+1 power supply configuration). Only if all the ITE is provided with N+2 power supplies, then the power distribution consists of an "A”, "B”, and "C" redundant power plants all sized to "N" and with power circuits from each power plant connected to the N+2 power supplies is concurrent maintainability and fault tolerance achievable for ITE. This type of ITE power supply configuration and power distribution topology has not typically been implemented. However, Class F4 fault tolerance capabilities can be provided for the power distribution up to the ITE cabinet, ensuring that power distribution component redundancy is provided even when either an "A" or "B" upstream component or system is off-line for maintenance.

CAUTION: The MTBF data for the STS or ATS components should be provided by the manufacturer and analyzed by the designer prior to the use of rack mounted STS or ATS components in order to provide concurrent maintainability and fault tolerance between the UPS outputs and the POU within the cabinet. Inadvertent and non-predictable failures of rack mounted STS and ATS components have resulted in unplanned outages. When using this circuit mapping topology, it is recommended that the STS or ATS have a defined replacement cycle, which could be every 3 years or less, depending on the MTBF.

Figure 9-30 shows a method for circuiting a Class F4 data center's critical power systems.

The figures showing Class F3 and F4 represent one method available to implement the required level of redundancy. PDU and RPP manufacturers have options that enable other means to achieve the required level of redundancy, ensuring concurrent maintainability to the cabinet for Class F3 or fault tolerance to the cabinet for Class F4.

The implementation of a 50 to 600 V_{DC} power distribution from the output of the UPS can significantly simplify the concurrent maintainability and fault tolerance of the power distribution and circuit mapping from the UPS to the ITE. A Class F3 or F4 electrical distribution would consist of redundant double-ended overhead bus with each bus connected to both the "A" and "B" UPS system. This would enable the maintenance of any PDU or power circuit between the UPS and the ITE while maintaining fault tolerance on the circuits supporting the ITE. This is a significant benefit that 50 to 600 V_{DC} computer room power distribution offers.

Figure 9-31 shows a method for circuiting a Class F3 50 to 600 V_{DC} critical power system and Figure 9-32 shows a method for circuiting a Class F4 50 to 600 V_{DC} critical power system.

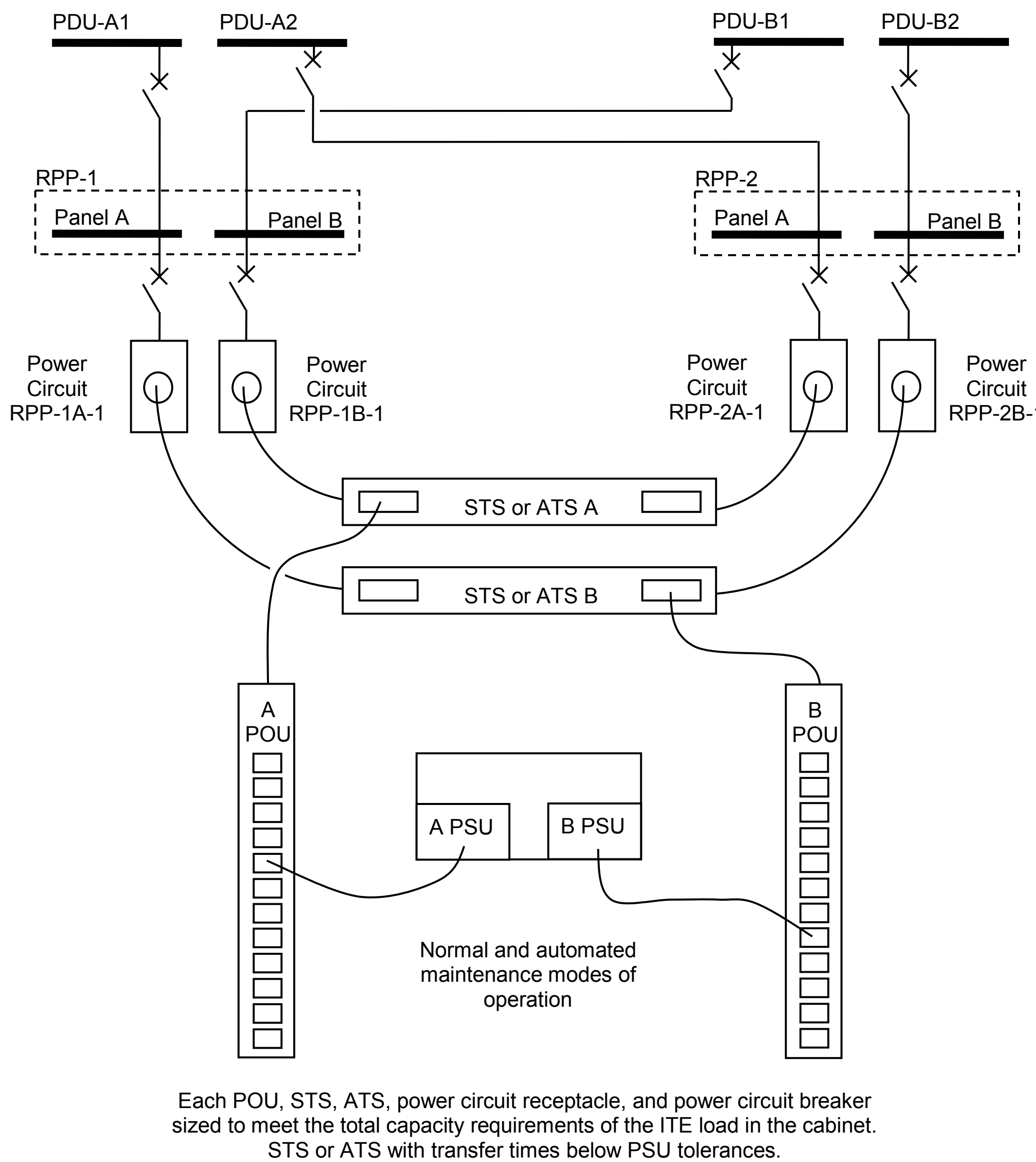


Figure 9-30
Class F4 Circuit Mapping

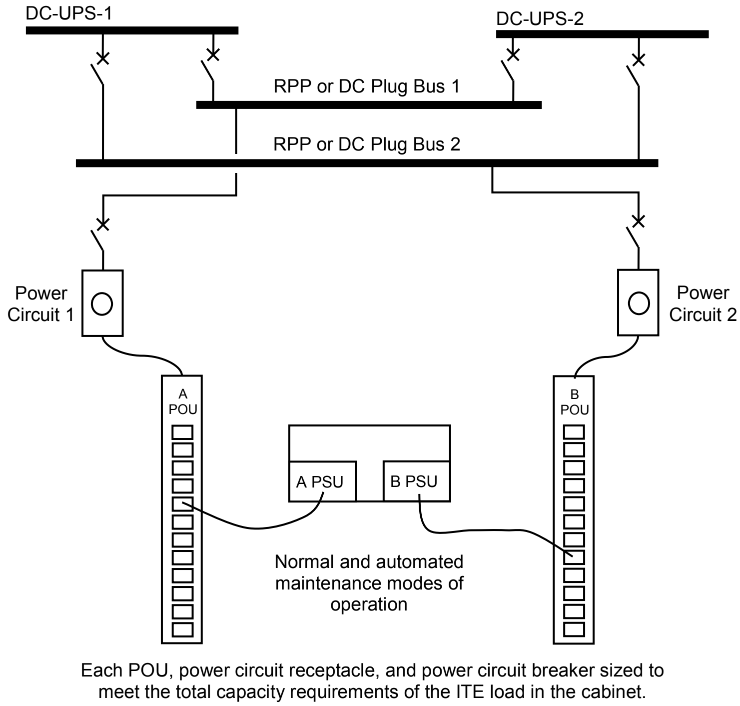


Figure 9-31
Class F3 50 to 600 V_{DC} Circuit Mapping

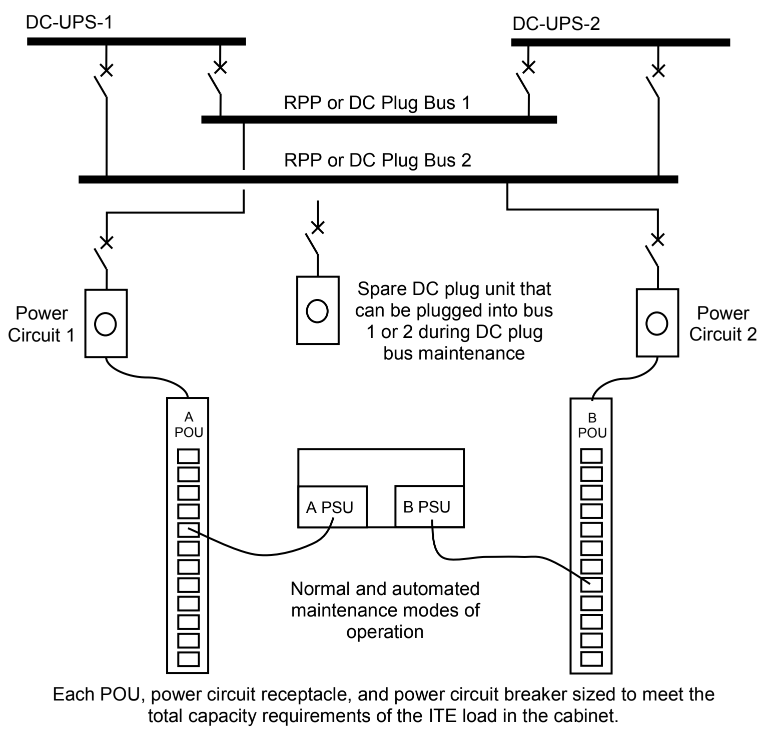


Figure 9-32
Class F4 50 to 600 V_{DC} Circuit Mapping

9.3.15.4.3 Power Cord Mapping

In addition to circuit mapping, it is important that the IT team understand how to implement power cord mapping based on the ITE being implemented. There are several power cord and redundant power supply configurations provided by ITE manufacturers, such as:

- 2 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration
- 3 power supplies, 1 to 3 cords each power supply, 2 power supplies in 2N configuration plus 1 non-redundant power supply configuration
- 3 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration
- 4 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration
- 4 power supplies, 1 to 3 cords each power supply, 2N power supply configuration
- 5 power supplies, 1 to 3 cords each power supply, 4 power supplies in 2N configuration plus 1 non-redundant power supply configuration
- 5 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration
- 7 power supplies, 1 to 3 cords each power supply, 6 power supplies in 2N configuration plus 1 non-redundant power supply configuration
- 7 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration
- 9 power supplies, 1 to 3 cords each power supply, 8 power supplies in 2N configuration plus 1 non-redundant power supply configuration
- 9 power supplies, 1 to 3 cords each power supply, N+1 power supply configuration

It is critical to fully understand how the power connections of the ITE with 3 or more power supplies have been configured within the ITE. If the power supplies are configured in a 2N+1 configuration, it is vital that it is specifically known which power supply is the "+1" non-redundant power supply and that it is connected to an STS with dual inputs. If the power supplies are configured in an N+1 configuration, then any one of the power supplies can be connected to an STS with dual inputs.

When power supply units have multiple input power connections, it is also important that the IT designer fully understand how the inputs are configured within each PSU and how they respond to all the failure modes. Some ITE have options to reconfigure how the input cords and power supply units are configured. It may be that all input cords to a PSU should be grouped to the same upstream distribution, or it may be required that the inputs to each PSU must be connected to separate upstream distributions in order for all the power supply units to perform as intended. As indicated, the IT designer must fully understand how multiple PSU inputs and multiple PSUs are configured for each ITE, and the network or system administrators must also fully understand the configuration before any changes are implemented within the ITE to alter the configuration.

Improper implementation of the power cord or power supply configuration with the redundant upstream power distribution can result in unplanned downtime because of human error, even if both the ITE and the power distribution have been designed as Class F3 or F4 systems.

9.3.16 Emergency Power Off (EPO) Systems

9.3.16.1 Introduction

A means of disconnecting the electrical supply, more commonly known as emergency power off (EPO), while not mandated by standards, is sometimes required by local codes. An EPO presents the greatest risk to electrical system availability in the data center as an EPO activation can be intentional, caused by sabotage, or accidental, via physical contact, mechanical failure, and human error during maintenance (such as the manipulation of the EPO system's link to the fire suppression system). A failure of the electrical supply feeding the EPO circuit can cause catastrophic failure of the ITE power because EPO shuts down ITE power when its own power supply is lost.

Organization of an EPO system is illustrated in Figure 9-33.

9.3.16.2 Requirements

Local codes or insurance carriers often require EPO for the safety of firefighters, but they may allow some exceptions (such as when "orderly shutdown" is necessary). Additionally, some jurisdictions or codes may allow the EPO for the data center to be eliminated based on 24/7 occupancy of the facility or other considerations.

When a single point EPO for the data center or larger portion of the building is required and implemented, the EPO shall be supervised on a 24/7 basis.

NOTE: A single point EPO is typically an individual project requirement, negotiated at the time of the project's development.

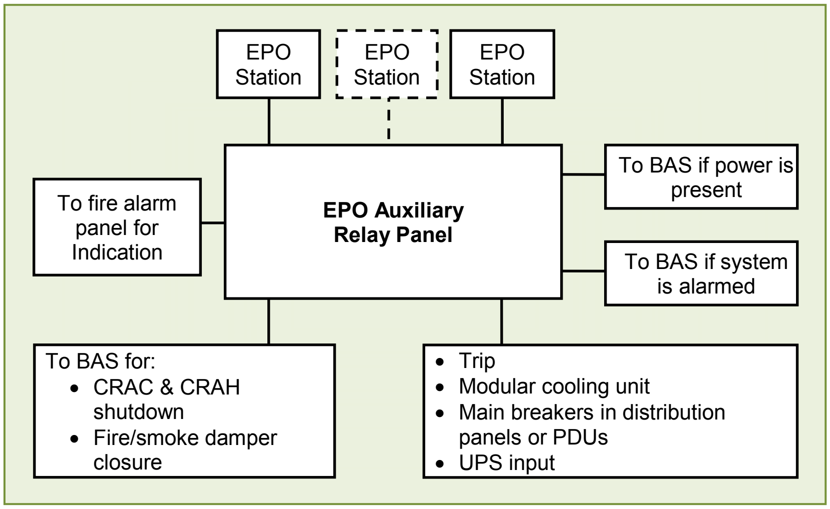


Figure 9-33
Example Organization of an EPO System

Where the back-up power supply to the EPO circuit is a battery, the charge shall be monitored and the battery able to be replaced without triggering the EPO.

9.3.16.3 Recommendations

When not required by code, the owner must carefully balance the needs of business continuity with personnel and building safety. When an EPO system is to be installed, a number of features can be included to make it more reliable, including:

- Delay to EPO activation after button push
- EPO override switch (keyed or non-keyed)
- EPO activation countdown timer
- Multiple stage systems

  NOTE: EPO systems used in data centers should be three-state systems, with *off*, *test*, and *armed* modes of operations.
- EPO activation stations requiring multiple steps to operate them such as lift-hold-and-pull or the simultaneous operation of two buttons (when not prohibited by ADA and similar accessibility regulations).
- EPO activation stations that include a pre-alarm function, in which an audible and visual alarm is activated when the EPO button cover is lifted. This allows someone who has accidentally lifted a cover to know that there is a danger of activating the EPO system.
- EPO activations that allow a time delay, deactivation of a smaller areas of the data center, or centralized as part of an integrated electrical system.

  NOTE: All of these techniques should be reviewed and approved by the local AHJ prior to implementation.
- Multiple disconnecting means to de-energize ITE and cooling equipment.

Decisions during installation can also affect reliability. Recommendations that should be followed include:

- In an N+N system, power to the EPO circuit should emanate from more than one UPS, to minimize risk of power failure to the EPO.
- Security cameras should be installed at EPO stations so that the face of the operator of the EPO can be clearly seen.
- EPO systems should be capable of being isolated from the fire alarm system so that when the fire alarm system is undergoing routine maintenance, the EPO is not accidentally activated.
- Do not specify or disconnect onboard, device-specific EPO buttons, if present, from UPS modules, UPS control cabinets, PDUs, static switches, and any other factory-installed EPO button. If the EPOs cannot be safely removed, the covers should be tied down to prevent accidental activation. These EPOs are not required if the room they reside in has one since they disconnect only one system or device as opposed to all of the room's equipment.

List continues on the next page

- Activation of an EPO circuit should also remove power to dedicated HVAC systems serving the room and should cause all required fire or smoke dampers to close unless a hazard/risk assessment determines, and the AHJ agrees, that cessation of air movement would pose a greater hazard than continuous ventilation.
- The disconnecting means may be permitted to be located in a secure area outside of the computer room, but this should be reviewed and approved by the local AHJ prior to implementation. Consideration should also be given to security risks if the EPO is not in a controlled access space.

Additionally, unless required by code or the local AHJ, EPO systems should not be installed:

- In UPS, chiller, and battery rooms
- Near light switches, phones, or any other device that is routinely touched

9.3.17 Fault Current Protection and Fault Discrimination

9.3.17.1 Introduction

As a result of reducing electrical loss, the power circuit impedance in data center electrical systems have become lower, leading to greater fault currents flowing towards a short circuit, particularly at locations where multiple circuits converge. Components such as static switches, PDU's, and rack power busway are at particular risk. If the component is not rated for the possible inrush current a major short circuit can cause the component to fail or even explode.

In a correctly designed system, a fault on a circuit should only result in a disconnection of the first fuse or breaker upstream of the fault. This is called fault discrimination, and is difficult to achieve for the entire system

9.3.17.2 Recommendations

Fault current protection and fault discrimination must be considered in the design from early conception, using software tools. It may be necessary to reconsider the concept to achieve compliance.

9.4 Mechanical Equipment Support

9.4.1 Introduction

Mechanical systems are as vital in the data center as the UPS systems that serve the ITE. The ability to have little or no interruption to the cooling services while maintaining temperature and humidity within a relatively narrow band is vital for the operation of most high-performance computing systems.

There have been several instances of thermal runaway where the heating of the data center could not be stunted in time to prevent the ITE from shutting down on a high temperature condition.

Some computing systems consume so much power and operate at such a high-power density (as viewed in W/m^2, W/ft^2, kW/cabinet, or kW/floor tile) that an interruption of cooling medium for only one minute can result in ITE shutting down. In this light, ITE requires uninterruptible power and nearly uninterruptible cooling.

There are two considerations for the electrical system when it supports the mechanical system—the restart of the cooling system (viewed in its entirety from the cooling plant to the ventilation systems) and the diversity of the electrical paths to the mechanical systems that matches the redundancy of the given mechanical components being served.

In traditional chiller plants (not including slaved DX units to a given air handler), the compressor restart time for the chiller can lead to thermal runaway in the data center during a power failure. This is caused by the ITE loads still operating under UPS power while the chillers, powered by the generator system, undergo a complete and protracted restart cycle following a power interruption.

Battery run time for UPS power systems that are supporting continuous cooling system needs to be coordinated with generator start and transfer time. Similarly, critical house and control systems need to consider any reboot or transfer time ahead of any mechanical equipment restarting.

While the restart control sequence is the purview of the mechanical designer, careful consideration needs to be paid to the following as soon as possible after an outage or retransfer from generator to normal power:

- Keeping chilled water moving in the system
- Keeping the ventilation systems operating
- Reestablishing the cooling plant (regardless of its design).

Generally speaking, a Class F4 mechanical system does not have the same topology as a Class F4 electrical system. Since the Class F4 mechanical system must meet the performance definitions defined for Class F4, the electrical system that supports the mechanical system must map to the normal, failure, and maintenance modes of operation for the mechanical system.

In many ways, the circuiting of the mechanical system is similar to circuiting of multicorded equipment loads in the computer rooms; multiple power paths must be used to ensure that a given piece of equipment survives a failure or is still on line during maintenance. Since Class F1 and Class F2 systems do not offer load supply redundancy, these Classes are not offered as solutions. The circuiting pathway for support of mechanical loads for a Class F3 facility is illustrated in Figure 9-34.

An example of a power distribution system supporting a Class F4 mechanical system is illustrated in Figure 9-35.

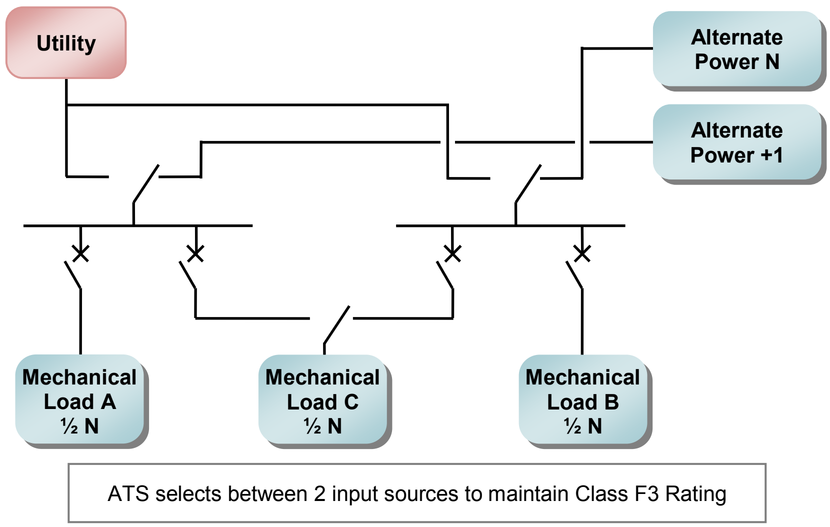


Figure 9-34
Sample Power Circuits for a Class F3 Mechanical System

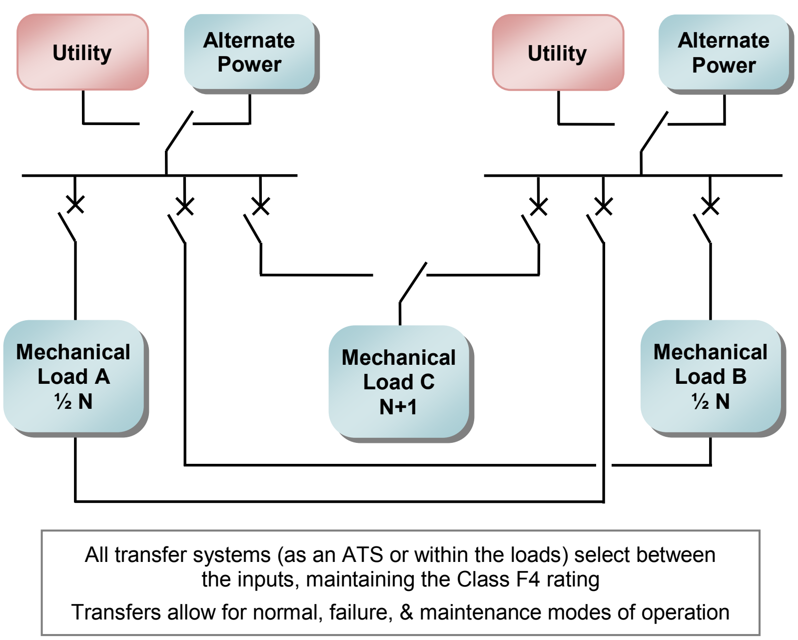


Figure 9-35
Sample Power Circuits for a Class F4 Mechanical System

9.4.2 Requirements

Temperature controls shall be maintained during normal, maintenance and failure modes of operations. Where redundant temperature and cooling plant controls are provided, redundant circuits shall be provided commensurate with the diversity of the control system.

Cooling water pumps may require uninterrupted power. If the decision is made to support motors and pumps without interruption, they shall have a dedicated UPS suitable for the high inrush currents characteristic of such loads. Motors and pumps shall not share the same bus as ITE loads. (See Sections 9.1.6.5 and 9.1.6.6).

9.4.3 Recommendations

9.4.3.1 General Considerations

Having mechanical system controls on UPS power may provide faster cooling system restart times; however, this would need to be verified with the mechanical system vendor as it can be dependent on the manufacturer/model of system implemented. If the chiller is on unprotected power but the chiller controls are backed by UPS, upon loss of utility power, the chiller controls might lock out the chiller and remain in failed state. This constraint may not be factory or field adjustable.

Chiller and cooling systems often require substantial restart time, and these systems will take some time to return to full operation. This demands a few considerations:

- While the cooling systems are restarting, the UPS systems are still providing power to the load. Heat generated by the ITE loads operating on that UPS power will build in the data center spaces. Cooling plant restart times are often much longer than the time it may take for heat to rise sufficiently in the room to a point where ITE will shut down.
- The diversity of the electrical systems serving the mechanical plant must address maintenance and failure modes of operation to ensure that the cooling system restart time does not cause ITE loads to fail because of overheating.
- Substantial cooling water may exist in the cooling water piping system to help bridge the time or capacity gap for the cooling plant restart. In this light, keep cooling and condenser water pump running at all times.
- Some heat transfer may take place by simple ventilation, so keeping the fan system running can mitigate some of the heat rise in the room.
- For cooling plant restart, the following sequence of load additions to active service are recommended (all loads on alternate power):
  - Ventilation
  - Pumps
  - Chillers and cooling plant
- For higher power densities, there may be only a couple of minutes or dozens of seconds before the room heat "runs away" to a point where, even if cooling is restored, ITE may drop out or be damaged because of temperature. In this case, some of the mechanical support loads must be maintained on a 24/7 basis and may require UPS power in support of the IT mission. For high-density loads, some pumps and fans will require power from a dedicated UPS.
- Prudent design calls for the ability, first, to determine the rate of heat gain in the data center versus the restart time in failure or maintenance modes of operation and, second, to ensure that the electrical system offers sufficient capacity and diversity to prevent thermal run away in the facility.
- For fast chiller restart the chiller controls (but not the pumps) should be on UPS.

9.4.3.2 Chillers and Central Cooling Plant

Chiller and cooling plants have particular challenges to overcome for high-availability applications. Chillers, towers, and pumps tend to be single input type of machines with only a single feeder serving them. For open-circuit cooling systems utilizing cooling towers, chillers are sometimes paired with a cooling tower and pumps while in other cases, they work independently from each other. Whichever the case, the chiller input power must be coordinated with the mechanical plant's chiller redundancy scheme. For some high-availability sites, heat exchangers and thermal storage systems are employed and must be considered in the circuiting of the cooling plant.

In all events, the pumping and other supporting systems, such as controls, must also be energized and maintained during normal, maintenance and failure modes of operation. Dual input to the chillers, cooling towers, and associated cooling equipment via automatic or manual transfer systems may be required.

For high-density computing environments, it is essential that some form of cooling be maintained during the generator start and mechanical cooling plant restart cycles. Some form of cooling equipment may have to be placed on UPS power in order to maintain temperature and humidity control in the data center.

9.4.3.3 Pumps

Pumping systems for data centers come in numerous forms—chilled water primary and secondary, condenser water, make up water, well water, and booster pumps. Most of these systems are configured as parallel redundant systems, operating on an N + x basis (where x can be an integer or a percentage, depending upon the design criteria). Occasionally, a 2N system might be seen as well. Pumping systems typically operate much like paralleled generators or UPS modules might, sometimes equally sharing the load and sometimes not, depending on the drive and control configuration. Therefore, each pump for a given system needs to be powered independently of its partners. The circuit mapping also needs to follow the Class requirements and maintenance and failure modes for the equipment.

For high-density computing environments, it is essential that water flow be maintained, possibly requiring that some water flow systems be placed on dedicated UPS power.

9.4.3.4 Air Handling Systems

Air handling systems typically possess a higher degree of diversity than any other mechanical load in the data center. For example, 10 air handlers might be required for the load, and 13 are installed. This can be due to air distribution, the designer's preference, or the room's physical organization or dimensions. Serving that from two or three mechanical load buses poses a challenge without the use of manual or automatic transfer systems for individual or groups of air handlers. Similar to chillers and pumps, the air handler diversity and the N + x basis (where x can be an integer factor or a percentage factor depending upon the design criteria) must be known. Then the electrical system circuiting should be overlaid to support them.

For high-density computing environments, it is essential that air circulation be maintained, possibly requiring that some air handling systems be placed on UPS power.

9.4.3.5 Humidification

Humidification can occur either locally or centrally in a data center, depending on the mechanical designer's technique. If the humidity control is local to the air handler, the power for the humidity system may be integral to the air handler. Note that humidification and dehumidification can be very energy intensive, which means that each unit having its own control can be very wasteful. Additionally, there is the potential for units to "fight" each other (i.e., one unit is adding humidity which triggers another unit to reduce humidity), which is extremely wasteful. Thus, current best practice is to have a more centralized control of humidity either at a room, module, or entire data center level. The air handler's circuiting will accommodate it pursuant to the Class' requirements. If the humidification is not powered by the air handler, a separate circuit for the humidifier is needed and the same set of circuiting requirements for the given Class. The same can be said for humidification or dehumidification systems that are independent of the air handlers that are mounted either in the data center itself or in the air supply ductwork.

9.5 Uninterruptible Power Supply (UPS) Systems

9.5.1 Introduction

NOTE: UPS systems are also discussed in Section 9.3.8 as part of the distribution system.

Using an analogy in which the electrical distribution system can be considered the arteries of the critical power system, the UPS systems are the heart—the nexus of power conversion and continuity. While there are several methods and designs for achieving a topology that will meet a given Class goal, the sizing and considerations of the UPS power plant itself has several common issues. This section will address the varying technologies, design applications, and other considerations for the UPS plant. These include:

- Sizing and application
- Technology
- Paralleling and controls
- Batteries and stored energy systems.

Appropriate selection of the UPS topology depends on the criticality of the applications supported by the data center. It is acknowledged that every business demands different levels of criticality and that the topology chosen has substantial impact on cost, space, complexity of operation, cost of operation, and expected lifespan.

9.5.2 Sizing and Application

9.5.2.1 Application

UPS and critical power system applications are focused on delivering quality power, whether originating from an electric utility or from internal energy storage, on an assured, 24/7 basis. While there are several issues related to loading and topology, the primary concern of UPS system design for Class F3 and F4 systems is the maintenance of critical power services while accommodating known failures or allowing for safe and logical preventive maintenance. There are several points to consider when selecting equipment or employing UPS systems and critical power components into a cohesive critical power system.

Similarly, system bypasses, whether they be static or external/maintenance, must offer a safe and clear method for rolling load on and off the UPS module or system. System designs should be arranged so that a failure in a single module or system is not allowed to propagate to adjacent or paralleled systems. Failure compartmentalization should also be used for other portions of the critical power system.

The main design and application considerations for UPS and critical power systems are:

- Automatic, single-step response to a failure
- Failures limited to the system that failed
- UPS power plant maps correctly to the critical power distribution system
- Stored energy system able to carry the critical load during all input power failures

9.5.2.1.1 Automatic, Single-Step Response to a Failure

System failures should be automatically corrected without risking the load. Failure response should allow the UPS system to settle into a steady state as expeditiously as possible. The response to a fault may transfer the load from the UPS module or system to another UPS system or to an unconditioned bypass source. Regardless, the UPS system has its highest chance of maintaining the critical power load's continuity with a single transfer or operation, also known as the "one step save." If the UPS system requires several steps to arrive at a revised steady state, it may fail in the transition process, resulting in a critical power load loss.

Failures should be limited to the system or portion of the critical power chain that experienced the failure. For example, a failure of a single module in a multiple module, paralleled system should limit the failure to the module that failed. In the case of a distributed system, the interconnection of the systems should not allow a failure to cause a failure in the supporting systems. This only speaks for system changes of state and not the normal, customary, and predicated load transfer to the other UPS systems that are expected based on the Class or system constitution.

There is a word of caution for some of the UPS plant designs that seek to establish a "ring" bus to share redundancy for multiple UPS power plant outputs or in the distribution system. Power quality, especially switching transients, resonance, or "ringing", need to be carefully examined to ensure that the UPS waveform is not corrupted by the failure mode operation of any portion of the system.

9.5.2.1.2 UPS Power Plant Maps Correctly to the Critical Power Distribution System

There are several instances when the N count of the UPS systems may not agree with the N count of distinct critical power distribution channels downstream of the UPS plants. ITE loads are typically dual-corded with many systems being more-than-two-corded. This brings up the phenomenon where the UPS plants' pathways do not directly map to the number of pathways of the downstream power distribution system. An easy plant-to-distribution map is a 2N system with a PDU capacity matching the UPS system (not considering the idiosyncrasies of the individual PDU setups).

For distributed systems, the failure modes of the individual critical power circuits need to be mapped upstream to the PDUs, then the PDUs need to be mapped against the critical power distribution systems or switchboards, and then the critical power distribution switchboards need to be compared against the UPS plants to which they are connected. While this is a straight forward exercise for normal operations, the failure and maintenance modes of operations need to be examined for loading and change of state operations as well to ensure that the critical power is maintained at all times under all modes of operations.

9.5.2.1.3 Stored Energy System Able to Carry the Critical Load During All Input Power Failures

Since an alternate source of power is an integral part of the data center's design, a utility power failure should result in the generator starting and the facility being transferred to the generator or that alternate source of power. The ability to carry vital ITE loads and critical support loads during the power resumption on the generator or maintaining services during the retransfer from generator to utility is necessary for any data center design.

With the advent of the high-density computing environment, the maintenance of cooling systems and the room environment is as vital to maintaining the IT processes as the UPS systems' stored energy systems.

The stored energy systems for the UPS modules and systems will be discussed in detail in Section 9.5.5. Every UPS power system must have some form of stored energy to bridge the transfer to the alternate source of power and the retransfer to utility and normal operating conditions or for any situation where the input power falls outside of the system's tolerances. For single corded loads, subcycle static transfer switches may be employed where the ITE loads themselves do not offer redundancy. In many cases, the ITE loads themselves will arbitrate which power input is most appropriate for its use.

For certain computing environments, UPS power may be derived from batteries, flywheels, or another stored energy system that provides the ability for a power or cooling system to maintain or restart loads before an impact to the computing environment. In some cases, this might mean that the chilled water pumping systems or chiller water storage system must be on UPS power. In other cases, the ventilation system must be maintained on the UPS power system.

In any event, these collateral, nontechnology loads must be added to the ITE loads to arrive at the proper UPS plant size for the facility.

9.5.2.2 System Sizing

System sizing is linked to the Class, system design, and topology chosen by the designer. The UPS system design should be based on kilowatts (kW) with consideration given to kilovolt-amperes (kVA) and the resulting power factor. The system kW must consider derating factors such as:

- Altitude
- Run time at a given load level
- Operating temperature of the electrical room or the location of the systems and equipment

The critical power system sizing is based on fully meeting the critical power load with the fewest modules or pathways available during maintenance or failure modes of operation (fairly assuming that the normal mode of operation always has more systems or pathways than failure or maintenance modes of operation).

The UPS power system capacity is always determined at the output of the UPS system. PDU or transformer losses related to generating ITE utilization voltage are to be considered part of the ITE load and are not to be included in the power capacity calculations. This method considers all UPS module and system losses but it does not penalize critical power distribution systems that may not employ PDUs or transformers or any further voltage conversion below the UPS systems. When determining power density (rendered in W/area), the output kW rating of the UPS power system is to be utilized for the calculation.

9.5.2.2.1 Loading Levels

As for many power systems, there is a fine balance between an overloaded and an under loaded electrical system. While the issues of overloading are clear (e.g., heating, breaker tripping, and reduction of Class), under loading may lead to system instability or, for some older systems, an inability to operate.

While this is not a big issue for a single module system, this can be a huge issue for large-scale paralleled or distributed-redundant systems where load is being shared equally among several, equal components. Loading levels must be considered for normal, maintenance and failure modes of operation. The fact is that for higher Class rated systems, there are often many systems sharing a modest critical power load sometime during the lifespan of the facility.

Overloading factors are noted below in the next section, and it is recommended that a given UPS system be operated at no less than 20% and no more than the safety factor discussed below under normal, maintenance and failure modes of operation.

Critical power system loading is load growth versus the Class. For example, a Class F4 system, when it passes a certain loading level, may revert to a Class F3 level. This occurs because power modules that were formerly used for redundancy may now be required for capacity (i.e., to serve a larger critical power load).

9.5.2.2.2 Safety Factors

It is impractical to load any electrical system to its full capacity. While some manufacturers have purported or proven 100% system rating and a resulting 0% safety factor when weighed against the critical power load kW rating, best practice is to always apply a safety factor in system design. This addresses unanticipated load fluctuations, inrush currents, and code-required continuous-duty system ratings.

A load factor of 90% is recommended with a 95% maximum, leaving a design of 10% to 5% safety factor. This does not include the continuous-duty rating demanded by the applicable code (e.g., *NEC*). For most designs, the code-mandated safety factor required for continuous load could also be used as the design safety factor.

9.5.2.2.3 Maximum Critical Power Load

The UPS plant and systems must be designed to accommodate the maximum critical load that the facility is expected to require during its useful life. These loads include ITE loads, critical cooling systems, and other supporting systems. This maximum critical power load must be supported by the utility and alternate/generator power plants as well.

9.5.2.2.4 Scalability

Modular system architecture may allow for a phased installation of UPS components. The initial, interim, and final system configuration must anticipate the maximum capacity. The design must offer a system count that logically addresses system loads at any time during the system lifespan while offering an individual module size that is neither too large nor too small to achieve the Class specified for the system.

The key point in system sizing and application is that the system design and configuration must address both the normal mode as well as failure and maintenance modes of operation. The resulting system capacity must be sufficient to support the load that is present at any point in the system's life during all modes of operation.

9.5.3 Technologies

9.5.3.1 Technology Considerations

For UPS systems, several criteria must be met regardless of manufacturer, system organization, or type of UPS system technology being employed. UPS systems may consist of individual UPS modules, individual UPS systems, or a group of several paralleled modules. However, the recommendations for the performance of these systems regarding maintenance, failure and normal mode responses are similar:

- The UPS technology should compartmentalize failures so as not to allow failures to spread to other modules or systems.
- Each module should be provided with a means of individual isolation without affecting the integrity of operation, overall redundancy, or Class.
- Each system should be capable of both automatic and manually-initiated bypass and should be provided with external means to bypass the system to avoid interruption of power in the event of system failure or maintenance.
- Modules and systems should possess an ability to be isolated from the critical loads and inputs. This allows the module or system to be fully isolated from power and control input for safety, maintenance, or replacement of the UPS module or system.
- The UPS system always possesses some form of stored energy system using batteries, mechanical stored energy systems, such as flywheels, or clutch-based systems for momentary ride-through of the critical load.

9.5.3.2 UPS Operating Modes

IEC 62040-3 identifies 3 basic modes of UPS operation, listed in ascending order of reliability:

- Voltage and frequency dependent (VFD)

  The UPS AC output voltage and frequency are identical to the input voltage and frequency from the AC source. This type of architecture is typical of a static "off-line" or "standby" UPS. During normal operation, the system is idle and the load is run directly from the primary (e.g., utility) power source. When an overvoltage, an undervoltage, or an outage occurs, the system detects the condition and switches to on-line (double conversion) operation. VFD systems are typically the most efficient and least expensive, but they must rely on the ITE loads' internal power supplies to keep operating long enough for the UPS to sense and respond to the outage. Most ITE power supply units (PSUs) have only about 10 ms of hold-up time.
- Voltage independent (VI)

  The UPS provides a stable output voltage to the load(s), but its frequency is identical to the input AC source. This type or architecture is typical of a rotary UPS with a synchronous motor generator, or a static standby UPS with some form of voltage regulation on the bypass line. This architecture may be attractive to applications in which the load PSUs can tolerate a wide range of frequency variation. Clock functions cannot be synchronized to frequency.
- Voltage and frequency independent (VFI)

  The UPS is able to provide stable voltage and stable frequency to the connected loads independently of the input AC source. In static UPS systems, this is referred to as a "double conversion" or "on-line" UPS and has historically been the dominant UPS architecture in data centers.

Today's UPS systems can have multiple modes of operation, thereby allowing the owner to determine which mode of operation is appropriate based upon considerations such as the criticality of the mission and the desired operating efficiency. These modes, which may be manually or automatically selected, can include (but are not limited to):

- Full on-line operation (VFI) — voltage and frequency are always regulated without any interruption
- Partial standby operation (VI) — some power conditioning such as transient suppression or voltage regulation
- Off-line operation (VFD) — voltage and frequency are regulated only after a brief interruption of power
- Automatic bypass operation (VFD) — load is transferred automatically to utility or secondary source because of detection of a fault condition
- Manual bypass operation (VFD) — load is transferred manually to utility or secondary source for service

Because of the desire for data centers to maximize their power utilization effectiveness (PUE) or efficiency, facility scale UPS systems can offer what is commonly referred to as "eco mode" operation, meaning that the UPS can gain one or two points of efficiency by operating in less than full VFI mode. This may be attractive for Class F1 or Class F2 operation or for Class F3 in which the primary side is in full VFI operation and the secondary side is in VI or VFD operation.

9.5.3.3 UPS System Types

9.5.3.3.1 Introduction

UPS systems use numerous technologies and configurations to support critical loads.

While the technology is important, designers fashion all forms of critical power systems from many types of UPS technologies, thereby meeting the needs of their clients and the attendant critical load. For this section, technology is less important than how that technology is employed to address the normal, maintenance and failure modes of operation.

9.5.3.3.2 Static UPS Systems

A static UPS system uses transistors or other types of power electronics to convert incoming AC power to DC power, stores the DC power, and when the stored power is needed, a second power electronics string converts the DC power back to AC and is supplied.

NOTE: This process is known as double-conversion and is voltage and frequency independent. Some static UPS use the same fundamental AC output, but they use delta-conversion technology for the DC−AC conversion. This difference removes the independence of frequency.

DC power may be stored using traditional chemical batteries or inertial stored energy systems such as high- or low-speed flywheels, compressed air, or other technology.

There are two primary types of static UPS. The conventional type is a single unit with fixed power that can be connected in parallel to provide higher power or redundancy. The modular type is a chassis with control board(s) that can accept multiple power modules inside.

They key advantages of the conventional are:

- Generally larger capacity
- Fewer components, generally meaning lower mean-time-to-failure

The key advantages of the modular type are:

- Smaller modules allowing smaller granularity and optimized load
- Easier module replacement, sometimes hot-swap, allowing greatly improved mean-time-to-repair

Static UPS power modules offer two types of configurations when addressing magnetic isolation, transformer-type and transformer-less. Transformer-less UPS modules can offer better efficiency while on inverter in that the isolation or autotransformer losses are not present as there simply is no transformer present. AC and DC internal bus fault response, internal module power electronics design, downstream critical load fault isolation and system efficiency are some of the considerations when considering the UPS power module specification. There is a sufficient installed base of transformer-less UPS power modules to consider this design an accepted technology.

9.5.3.3.3 Rotary UPS Systems

In rotary UPS power modules, the input to output power conversion is mechanical and accomplished via a synchronous machine. They differ from static UPS power modules in that static modules convert power electrically. Some rotary modules do possess complimentary power electronics similar to static UPS systems, and the discriminating factor in this design is that the primary conversion from AC−AC power is via a rotating motor, not transistorized power electronics. The stored energy system attendant to a rotary UPS would be any and all of the technologies and system types prevalent in a static UPS module.

9.5.3.3.4 Hybrid UPS Systems

Hybrid UPS power systems combine three components:

- Backup power generation source, typically a diesel engine
- The component that reproduces the ITE critical power output waveform, either a rotating machine (rotary UPS) or static component (static UPS) that reproduces the waveform using solid state components
- A stored energy source, either a chemical energy storage device (batteries) or kinetic inertial storage device (flywheel)

A hybrid UPS combines any two or all three components into one packaged solution from a single vendor. The other traditional UPS systems are designed solutions that are field installed, combining the three components using solutions from two or more vendors. A majority of hybrid UPS power systems use kinetic stored energy systems, though designs may also use batteries.

Some hybrid systems may also include an electrically- or mechanically-coupled generator system. Mechanically-coupled systems share a common shaft between the alternator and the generator. The stored energy system would bridge the time between a power outage and the generator assuming the load. This ride-through component would be provided by a manufacturer-specific design. Electrically-coupled generators would not be mechanically-connected to the UPS power system, but they possess controls that are completely integrated to and included with the UPS and continuous power system.

There are three defining factors for a hybrid UPS power system:

- These systems are designed, manufactured and operated as a single system where rotary and static UPS systems are assembled and integrated in the field from the products of several manufacturers.
- Components may not be readily swapped or replaced with another OEM source.
- The control system is specific to the manufacturer and subsumes the power conversion, stored energy, and power generation systems into one, manufacturer-integrated system.

9.5.3.4 Direct Current UPS Systems

Direct current power systems eliminate the output power inverter to achieve improved efficiency and reliability. DC systems supply power to the critical load at voltages appropriate to the load requirements (for example 48 V_{DC}, 240 V_{DC}, or 380 V_{DC}). The output voltage will vary within the high and low voltage range of the batteries and is specific to the tolerance of the systems being supplied. System topologies can range from centralized DC power plants to point-of-use systems. Because there is no possibility of bypass, DC systems require redundancy to achieve the same or better availability of comparable AC systems.

9.5.4 Paralleling and Controls

Paralleling and controls should follow the rules set forth in Section 9.7, which calls for local operation and automatic response to failures. While bypasses may be rated for momentary duty for some UPS systems, Class F3 and Class F4 systems have a continuous-duty rated bypass. Controls should present a clear and concise message and exact system presentation to the operator, denoting the power flow, metering levels of all electrical values, summary functions, and alarms. This is traditionally done via some form of graphical user interface (GUI), each unique to the given system manufacturer.

For paralleled systems with a single control, all available power modules should share load equally under normal operating conditions and under failure and maintenance modes of operation. For physically paralleled systems where the outputs are connected directly and physically to a single collector bus, the controls are traditional and are built into the PLC or control logic of the UPS system's control cabinet.

The challenge resides in a virtually paralleled system such as the *x*N Distributed Redundant Class F4 system. In this case, there is no centralized load balancing and control like the system control cabinet of the physically paralleled system. For the *x*N system and those like it, the control system is actually the sequence of operations for the system. In summary, the virtually paralleled system's controls are based on how the individual UPS systems respond to external changes in the other systems.

9.5.5 Batteries and Stored Energy Systems

9.5.5.1 Introduction

Batteries, flywheels, thermal, compressed gas, and induction clutch systems are all examples of viable stored energy sources for UPS systems. The critical points are:

- A stored energy system must be appropriately matched and engineered to the UPS power system it serves.
- A stored energy system must carry the critical load until the input source is restored and the UPS system returns to its particular form of AC power input.

Although a generator or alternate source of power must be present to apply a Class F1 or greater classification, the stored energy system may vary in its capacity, known as the watt-hour rating. The watt-hour rating is related to the stored energy technology used and the amount of backup time required by the system's design.

9.5.5.2 Applications

9.5.5.2.1 Risk Analysis

A well-constructed risk analysis will be crucial in the determination of a data center Class, which, in turn, will drive decisions on specifications for an energy storage solution. The probability of power interruption factored against the criticality of the load will influence the type, duration, and investment in energy storage.

9.5.5.2.2 Common Versus Distributed Energy Storage Systems

While using a common energy storage system to serve several UPS modules can reduce the installation cost, this introduces a single point of failure and reduces overall reliability. Thus, a common energy storage system is strongly discouraged and should not be used for higher Classes.

For distributed energy storage, individual battery strings should be provided for each power module. Multiple battery strings may be provided for each power module for additional capacity or redundancy.

9.5.5.2.3 Runtime and Overall Capacity

If the only requirement was to ride through a transfer from one AC input source to another (e.g., between a generator and a utility), only a few seconds of stored energy would be required. However, one must weigh the possibility of failure or unavailability of the transfer mechanism or the alternate power source. For example, if the standby generator failed to start, would it be feasible for the stored energy source to support the loads until they could be gracefully shut down or to transfer data to a hot site? If so, one must calculate the time required to respond and accomplish the necessary activity.

Some mechanical and hybrid systems are quite effective at riding through the few seconds required to bring the alternate power source on line. For longer ride through times, the more common approach has been to use a chemical energy storage device such as a battery or a hybrid chemical/mechanical system. Some chemical technologies are comparatively unstable at the low end of watt-hour requirements, so the technology itself can dictate a longer backup time. For example, lead-acid batteries are rarely recommended to be sized for less than five minutes. As most chemical energy storage devices lose capacity as they age, one should size the battery ride-through time based on the nominal capacity at the predicted end-of-life. Other sizing considerations can include derating batteries and cables for extreme temperatures and DC voltage drop over cable runs between the battery and the UPS.

While a specific minimum backup time is not stated in this section, a system capacity of 5 minutes is a safe minimum rating for most applications. Some facilities, such as access provider central offices, primarily use DC power systems and have several hours of storage capacity. Attention should be paid to paralleled systems or redundant module systems where the battery strings of the "greater than N systems" offer greater run time than the sum of the rating of the individual modules. For example, a four module, N+1 paralleled UPS system with individual 15 minutes batteries can yield a battery backup time well above 15 minutes as long as all battery strings are connected (e.g., not taken out of service for preventive or remedial maintenance).

9.5.5.3 Choice of Stored Energy Technology

The choice of stored energy technology will significantly influence the design, construction, and operation of the data center. Most UPS systems can only work with one energy storage technology, so the energy storage decision can greatly influence the type of UPS system that is selected. The following paragraphs summarize a few of the factors that must be considered.

9.5.5.3.1 Physical, Regulatory, and Environmental Considerations

The following are considerations for the deployment of battery systems:

- Hazardous materials—does the solution include materials that could be hazardous to operators and technicians and under what conditions?
- Hazard class—does the solution create a condition that will require special construction and occupancy requirements (such as special room or container construction), and can it be collocated with other equipment?
- Hazardous conditions—what conditions can lead to heightened safety concerns (such as off-gassing during overcharge or destruction due to vibration)?
- Disposal and recycling requirements—does the solution require recycling or return to manufacturer at end-of-life and are recycling plants available?
- Space construction—does the solution require special room construction (e.g., fire resistance, restricted access); can it be installed inside or outside; how much space will it take up; what is the footprint; can the floor support the weight?
- Ventilation and exhaust—does the solution require special ventilation or air conditioning?
- Gas detectors—does the solution require gas detectors to prevent build-up of toxic or flammable gasses under any operating conditions; who is responsible for installation, maintenance and calibration?

  NOTE: Hydrogen detectors are sometimes considered for lead-acid batteries, but because of a high false-positive alarm rate and frequent recalibration their use is discouraged.

- Spill containment—does the solution include hazardous liquids that would require containment in the event of a container breach?
- Safety equipment and materials—is special personnel protective equipment (PPE) required for personnel near the energy storage device; are eyewash stations required; is it necessary to keep chemicals in the space to render harmless any chemicals that might be released from the solutions; who can use them; what are the qualifications to become certified?
- Floor drains—does the solution require floor drains to redirect any hazardous liquid or fuel?
- Temperature and humidity controls—does the solution require a narrow temperature and humidity environment? What are the penalties for operating outside the thresholds?
- Fire protection—does the solution introduce unique fire protection requirements (such as water-reactive materials)?
- Code requirements—are there local code requirements (e.g., fire, mechanical, electrical) that impose special requirements?
- Audible noise and vibration—does the solution create noise or vibration that could be harmful or annoying to operators or occupants?

9.5.5.3.2 Performance Considerations

These are the performance considerations when selecting battery systems:

- Cycling ability—how many times can the solution be discharged and recharged before it must be replaced; what is the significance of shallow (short-duration) and deep (long-duration) discharges?
- Recharge characteristics—following a discharge, how long does it take to recover to full rated capacity; does the recharge affect other systems (such as draw high current or create excess heat)?
- Life expectancy—how long can the solution be expected to be used before it must be replaced under the expected operating conditions; what is the warranted life, and what is the depreciation rate?
- Maintainability—who can maintain the solution (e.g., can the owner perform routine and emergency maintenance, or does it require certified technicians); how often is remedial maintenance required; can the solution be monitored remotely?
- Demonstrated reliability—does the solution have a proven performance record?
- Availability—is the solution available from more than one supplier; are repair parts readily available?
- Lifecycle cost—over a defined life expectancy for a data center (e.g., 20 years), what will be the projected cost of installing, operating, maintaining, replacing, removing, and recycling the solution?

9.5.5.4 Chemical Energy Storage Options

9.5.5.4.1 Lead-acid Batteries

Although many stored energy technologies exist, the great majority of UPS systems rely on some form of batteries. Lead-acid batteries are unquestionably the most common energy storage solution, even though other batteries are available that can provide higher power density, lighter weight, or other benefits. They get the name because the active material of the positive electrode is lead dioxide; the active material of the negative electrode is lead; and the electrolyte is dilute sulfuric acid. Lead-acid batteries generally come in two types—vented and valve regulated—although there can be significant variations in materials, construction, and suitability for any given application.

A lead-acid battery is considered to have reached the end of its life when it cannot deliver more than 80% of its rated capacity. Other chemical battery technologies allow for adequate operation with lower capacities. Temperature affects the life span or capacity of a battery string (optimum is around 20 to 25 °C [68 to 77 °F]), with long-term excursions above or below the rated design temperature significantly affecting the battery string's capabilities. Generally, the life of a lead-acid battery is cut in half for every 8 to 10 °C (14 to 18 °F) rise in continuous operating temperature above rated optimal temperature. Lower operating temperatures will cause a lead-acid battery to deliver less than its rated watt-hour capacity and thus give reduced backup time but can have a positive effect on battery life. The opposite happens at high temperatures; backup time is increased, but life expectancy is decreased as temperatures rise.

It is also the nature of a lead-acid battery to take a large dip in voltage when it is first discharged, after which it recovers to or near its normal float voltage. This phenomenon is called *coup de fouet* and can cause some systems to shut down if the DC voltage drops below a threshold. For this reason, lead-acid batteries are rarely rated for operation below 1 to 5 minutes.

Lead-acid batteries should be recycled. Recycling centers are readily available in most countries.

A note of caution about AHJ requirements and code enforcement: some battery regulations are based on the volume of the electrolyte (which is mostly water) in a liquid-filled battery, while some others are based on the actual hazardous material (such as sulfuric acid in a lead-acid battery or potassium hydroxide in a nickel-cadmium battery). The electrolyte volume triggers various storage, installation, ventilation, and reporting requirements for the stationary battery system:

- Vented (flooded) lead-acid (VLA) batteries—so called because the byproducts of electrolysis, hydrogen and oxygen, continuously escape into the atmosphere through vents. VLA batteries are also called flooded because the plates are immersed in free-flowing liquid electrolyte. These types of batteries are further defined by the types of alloys used in their grids such as lead-calcium, lead-antimony, lead-tin, and many others. Because they continuously vent flammable gas, VLA batteries require dedicated rooms with spill containment, dedicated ventilation, and exhaust. VLA batteries require regular maintenance and water replenishment. Because they are liquid-filled, VLA batteries are always installed upright, usually on open racks, and require spill containment. Because of potential exposure to high energy and hazardous chemicals, they must be installed in spaces with controlled access.
- Valve-regulated lead-acid (VRLA) batteries—derive their name from valves that prevent gas from escaping except when internal pressure builds too high. VRLA batteries recombine hydrogen and oxygen back into water. Their electrolyte is immobilized, either by a gelling agent (gel), which is popular in Europe, or by absorbed glass mats, which is more common in North America and the rest of the world. Many VRLA batteries can be installed sideways and can be stacked, creating a greater power density. Because VRLA batteries take up less space, require less maintenance, require no spill containment, and are sealed under normal operating conditions, they are often preferred, despite a shorter life span (hence more frequent replacement and higher life cycle cost) compared to VLA batteries. Cabinet-mounted VRLA batteries are often used inside computer rooms.

9.5.5.4.2 Nickel-Cadmium (Ni-Cd) Batteries

Ni-Cd batteries are usually "flooded" batteries that vent gas in much the same way as lead-acid batteries do. The active material of the positive electrode is nickel oxyhydroxide, the active material of the negative electrode is cadmium, and the electrolyte is dilute potassium hydroxide.

Because they continuously vent flammable gas, Ni-Cd batteries require dedicated rooms with spill containment, dedicated ventilation, and exhaust. Ni-Cd batteries require regular maintenance and water replenishment. Note that the electrolyte of a Ni-Cd battery is highly alkaline, so safety precautions differ from lead-acid batteries.

Primarily because of their comparatively high price, Ni-Cd batteries are uncommon in UPS applications except where extremes of temperatures or frequent discharges are expected. Ni-Cd batteries are popular as starting batteries for generator systems.

Because they are liquid-filled, Ni-Cd batteries are always installed upright, usually on open racks, and require spill containment. Because of potential exposure to high energy and hazardous chemicals, they must be installed in spaces with controlled access.

Ni-Cd batteries should be recycled. Because of the cadmium content, recycling centers may not be readily available in all countries.

9.5.5.4.3 Stationary Lithium Ion Batteries

Lithium ion (Li-ion) batteries are primarily known for versatility and relative lightness compared to other battery technologies. There are many variations of lithium batteries with some performing better than others in high-rate UPS applications.

The advantages of Li-ion batteries, as compared to other battery types include:

- Higher power density, which means less space for the same amount of power
- Longer life
- Excellent cycling capabilities
- Higher ambient operating temperatures

The main disadvantage is a tendency for thermal runaway, where the rate of internal heat generation exceeds the rate at which the heat can be expelled. Prolonged thermal runaway can lead to battery failure and fire.

NOTE: Thermal runaway can be caused by overload or damage to the internal separation of the anode and cathode.

The various types and applications of lithium ion batteries relating to the data center are shown in Table 9-12 with perceived advantages and disadvantages, but these must be checked and compared using manufacturers data and recommendations.

NOTE: Comparisons in Table 9-12 are with other types of Li-ion batteries only.:

Li-ion battery cell construction should include internal fuses, vents, and/or shutdown separators that become a barrier between the anode and the cathode if temperatures exceed a certain level to reduce the risk of shorts and thermal runaway. Manufacturing quality control should include x-ray testing of each completed cell as part of the automated process.

Cells shall be handled with care and any that are mishandled or show signs of external damage returned to the manufacturer.

To function correctly, Li-ion batteries must have a battery management system. This should be included within cost differential considerations to other battery types, particularly in class F3 and F4 applications where this is required.

The battery management system is critical to the safe operation of large multiple module systems and shall protect the batteries and modules against:

- Over charge voltage
- Over discharge voltage
- Over current,
- Over and under temperature conditions.

The battery management system shall be a balancing circuit that keeps cells at the same level. The battery system including battery management should be tested and certified to UL 1973.

Li-ion batteries do not emit any gasses during normal operation, therefore continuous ventilation is not required. In the event a cell failure leads to thermal runaway, a fire may occur. Fire resulting from Li-ion thermal runaway requires proper extinguishants to prevent the production of hydrogen gas and highly reactive molten Lithium metal particles. For this reason, sprinklers are not recommended in rooms containing some types of lithium ion batteries. Consideration should be given to emergency ventilation after a fire has been extinguished. See further recommendations in Section 11.

Table 9-12 Types and Applications of Li-ion Batteries

Battery type	*Chemistry*	*Chemical abbreviation*	*DC application*	*Pros*	*Cons*
Li-aluminum or NCA	Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$	In-rack battery back-up (open compute)	High capacity, moderate power	Requires special extinguishing of fire (e.g., FM200)
Li-phosphate or LFP	Lithium Iron Phosphate	$LiFePO_4$	Centralized UPS	High power, flat discharge voltage, long life, very safe	Low capacity
Li-manganese or LMO	Lithium Manganese Oxide	$LiMn_2O$	In-rack battery back-up (open compute)	High power, safer than some options	Low capacity
NMC	Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$	Centralized UPS	High capacity and high power	Requires special extinguishing of fire (e.g., FM200)
Combination Li-manganese and NMC	As above, trend is to increase percentage of LMO to reduce reliance on limited cobalt supplies.	As above	Centralized UPS	As above, low cost	As above, short life span
Li-titanate or LTO	Lithium Titanate	$Li_4Ti_5O_3$	Centralized UPS	Long life, fast charge, wide temperature range, safe	Low capacity

9.5.5.4.4 Monitoring

Like every component of the data center electrical system, the battery systems should be monitored. Most UPS modules have built-in, proprietary monitoring that indicates string voltage, run time, and other basic battery monitoring functions. Battery monitoring is required for Class F2 and higher. Monitoring is required for the individual modules, for paralleled systems, and the entire set of battery strings. However, UPS-based battery monitoring systems may not be capable of detecting individual battery cell failure, which can greatly affect runtime and reliability of an entire battery system.

For Class F3 and Class F4 systems with lead-acid batteries, strong consideration should be given to a battery monitoring system capable of recording and trending individual battery ohmic values. A stand-alone battery monitoring system, capable of monitoring the ohmic values of each individual battery cell or container as well as predicting and alarming an impending battery failure, provides much greater detail on the actual battery status. Such systems are most effective when comparing a data point against an established base line, which requires comprehensive record keeping and trend analysis. These systems are recommended for Class F3 and F4 systems. Systems capable of providing cell charge equalization and charge management are desirable for Class F3 and Class F4 systems.

9.5.5.4.5 References

For full details on battery systems, the reader is directed to the IEEE standards, recommended practices, and guidelines as in listed in Table 9-13.

Table 9-13 Battery Standards Cross-Reference Table (IEEE Standard Number)

	Lead-acid batteries		*Nickel cadmium (Ni-Cd)*	
	Vented (flooded)	*VRLA*	*Normal use*	*Photovoltaic (PV)*
Selection/sizing	IEEE 485	IEEE 1189	IEEE 1115	IEEE 1013
Installation	IEEE 484	IEEE 1187	IEEE 1106	IEEE 1145
Maintenance/testing	IEEE 450	IEEE 1188	IEEE 1106	

	UPS	*Monitoring*	*Spill Control*	*Ventilation*
Special interest	IEEE 1184	IEEE 1491	IEEE 1578	IEEE 1635

9.5.5.5 Mechanical Energy Storage Options

- Flywheel—flywheels have been around for many years to ride through short duration sags or interruptions (subsecond to many seconds). Advances in composite materials have allowed some systems to achieve minutes of ride-through. However, price and complexity of controls have limited their widespread adoption. Flywheels are almost immune to heat, but they can be affected by seismic activity.
- Flywheel/battery hybrid—for some hybrid UPS systems, very specific systems are provided and coupled with a power conditioning system (typically a mechanically-isolated synchronous machine with a variety of input and output filtering) with a generator system and some form of bridging system that allows for an expedited generator start and load assumption. These clearly and fully satisfy the need for the stored energy system to carry the critical load until the failed utility input is replaced by the generator or some other planned input. In this case, the UPS is a systems-based solution that meets the requirements of the critical load.

  Other variations allow the mechanical inertia to sustain conditioned power to the load for short duration (subsecond) disturbances, but they will switch to battery backup for longer power interruptions. The battery sustains the load until the primary or alternate source of AC input power is available or until all useful energy is removed from the battery.
- Induction coupling—This type of batteryless UPS marries a generator and a prime mover (usually a diesel engine) into a single system via an induction coupling system. The prime mover sits idle until the main input power is interrupted. An inner rotor of the induction coupling stores sufficient energy to bridge the prime mover start time. The generator provides electrical power to the load during an outage. In normal mode, the generator acts as dynamic filter and provides power factor correction.

  In any system with a UPS using batteries, the UPS can "ride through" a short interruption or disturbance without the need to start the generator; it is usual to have a timer on the utility power sensing device. On diesel rotary UPS with no battery back-up, the generator must start and engage the clutch immediately on a utility interruption or disturbance because of the short autonomy time available. Therefore, a flywheel only diesel rotary UPS should be selected with care in areas where there are frequent short interruptions or disturbance to utility power.

9.5.5.6 Emerging Energy Storage Technology Options

The following technologies collectively represent less than 10% of the installed base at the time of publication, but they are expected to increase market share in the coming years:

- Stationary lithium polymer batteries—These batteries are known for their flexibility in form factor and shape as well as their versatility, high-energy density, and light weight in small, portable applications. Lithium metal polymer batteries showed promise for high temperature environments, but because of quality control and safety reasons, they have been withdrawn from the market.
- Stationary nickel-metal hydride batteries—Although they are not as small and light as Li-ion batteries, they still have many advantages over lead-acid batteries, specifically in size and weight, and appear to perform better than Li-ion batteries in UPS applications, especially for applications with constantly changing loads.
- Supercapacitors—A supercapacitor or ultracapacitor is an electrochemical capacitor that has an unusually high-energy density when compared with common capacitors. They are of particular interest in UPS applications as a supplement to batteries. They are able to ride through thousands of short duration power sags or interruptions (subcycle to a few seconds) without forcing the UPS to exercise the battery and can be rapidly recharged. At the present time, supercapacitors are not seen as a practical replacement for most battery systems.
- Fuel cells—Fuel cells are gaining more interest as a replacement for standby and emergency generators because they are quiet and efficient, have no byproducts harmful to the environment, and can be put in places where a generator cannot. Because fuel cells cannot supply energy instantly upon demand, they still require a battery or supercapacitor system to bridge the time period required for the fuel cell to ramp up to full capacity.
- Compressed air storage (CAS)—CAS systems use compressed air as the energy storage medium. CAS systems have limited applications and have more mechanical components than many other energy storage technologies.

9.6 Standby and Emergency Power Systems

9.6.1 Sizing and Application

9.6.1.1 Introduction

Standby power systems are intended to support the data center in the event of a loss of primary power lasting longer than the capacity of the UPS battery (e.g., utility outage lasting for hours or days). Interest in fuel cells and other sources of on-site generation is growing, but the penetration of such emerging technologies into the IT space is still only a small percentage. The overwhelming preference is for generator systems, usually diesel, but turbine and gasoline-powered systems are also in use, especially in smaller data centers. For purposes of this document, assume that the standby power source is a diesel generator system.

The generator plant is a site-controlled power system that offers a stable, reliable power supply during critical maintenance operations and in the absence of utility power. For some installations, a campus-based power plant or some other legitimate, alternate power source can satisfactorily substitute for a generator plant.

The rating of a generator or the entire generator system requires consideration of the harmonic content and power quality of the load itself as well as starting and transfer requirements of the IT, mechanical, and noncritical loads. When addressing starting current, the maximum droop typically seen is 15%. It is not suggested that this large a droop be allowed, as with voltage drops of this magnitude, running systems can drop out unexpectedly. Conversely, lightly loaded generators operate poorly, tend to wet-stack (the buildup of particulate on the fuel injection, valves and exhaust system because of lower operating temperatures of the engine) and eventually operate at a lower capacity.

For 50 Hz systems, generators operate at lower revolutions per minute than those found in the US with 60 Hz systems. Resultantly, 50 Hz generation systems have a lower kW step loading tolerances when compared to equivalent designs rendered in 60 Hz. Care needs to be exercised when loading 50 Hz generator systems as the same step loading considerations for 60 Hz systems cannot be accomplished in identical 50 Hz systems. 50 Hz voltage droops will be larger in amplitude and longer in duration to recover to steady state voltage under the same load condition of 60 Hz systems. For US-based 60 Hz designs being duplicated overseas, output kW ratings do not match the 50 Hz engine-generator systems. Verify output kW for the generator set, with air quality derating factors considered, before final system selection and sizing all 50 Hz designs.

9.6.1.2 Requirements

Generators supplying the entire load of a data center that is identified as an emergency system as defined in the AHJ electrical codes and in prevailing standards such as *NEC* Article 700 shall be equipped with separate ATSs. The emergency system loads shall be separated from the rest of the data center loads with their own ATSs.

Most jurisdictions have substantial planning and operating requirements for stationary generator plants. These requirements include noise abatement, pollution allowance and abatement, fuel storage, operating hour limitations, structural attachment, fire suppression, and operating permits. Check with the local AHJ during the planning phase of the data center project in order to ascertain the precise requirements for the undertaking and to determine who is responsible for reviewing and approving the installation.

9.6.1.3 Recommendations

The following conditions should be considered when sizing individual generators and when using paralleled systems:

- Transfer scheme—closed or open transition
- Standby, continuous, or prime engine run time duty
- Harmonic content of the load
- Allowable voltage sag or droop for the mechanical and lighting systems
- Generator system topology and unit count—how many units are required for the load, maintenance rotation, and redundancy
- Inrush and motor starting loads on the initial outage as well as when loads are being brought back on manually after maintenance
- Operating humidity and temperature, based on ASHRAE or local equivalent, extreme temperature for the area of operation
- Altitude of the site
- Engine derating required by pollution abatement systems
- Pollution abatement—air quality, location in relation to building ventilation
- Noise abatement
- Expected run time for the system
- Minimum and maximum load levels and the specification of standby, continuous, or prime-rated systems
- Coordination of reactors and high-resistance grounding with the remainder of the electrical system
- Coordination of UPS battery recharging loads

The following additional items should be considered when planning generators for data centers:

- Exhaust muffler
- Muffler drain
- Louvers and dampers
- Proximity to building air intakes
- Impact of operating noise on surroundings
- Emergency and safety equipment
- Frequency droop tolerance of UPS input

The generators should support all loads related to the data center process or ITE loads, cooling and ventilation as well as noncritical and building loads. For larger campuses where the data center is an important but not the largest tenant, the generator plant may be sized to accommodate other loads on the site requiring standby power.

For all Classes, the generator load is suggested as the entire load of the data center as well as any other loads required to support the data center, such as well pumps, security systems and other campus- or site-based systems. When data centers are installed in health care facilities, the data center load qualifies as an equipment branch load for the emergency power system. For Class 2 data centers, it is recommended to have an additional generator(s) or a generator tap box located on the building external wall to quickly connect a temporary generator to the electrical distribution.

When the application of a data center affects life safety, the generator and the downstream power distribution system will be given an “emergency” designation, in which its use can be dedicated to specific loads and not shared with other loads. Two systems might be required: one for standby operations and one for emergency operations. This may be accomplished with a separate life-safety branch that exclusively serves life-safety loads, while data center loads would be served by other systems under a single generator or generator system.

9.6.2 Starting Systems

9.6.2.1 Introduction

The most common generator problem is a failure to start. Larger generators tend to have multiple starters based on the size of the engine. However, having multiple starters does not provide additional redundancy; multiple starters only allows for a quicker engine start.

9.6.2.2 Recommendations

For data center applications where the restoration and continuity of power is vital, the site's generator(s) needs to start, and assume the facility's load as quickly as possible. Depending on the AHJ, generators that support emergency loads may be required to restore power to critical loads within ten seconds or less.

Faster starting can be attained by numerous methods such as larger-than-standard starters, stronger/higher ampere-hour batteries, or redundant starting systems. In all instances, starting systems can be upgraded to starting systems that allow servicing during operation. Where DC power distribution is used, utilization of rack mounted battery back-up units may decrease generator start up times.

Like all batteries, the batteries onboard the generators do best at their rated temperature. Higher or lower temperatures will result in shorter battery life or lower cranking power. For high availability applications, battery systems can be combined using a best battery selector or auctioning bridge.

9.6.3 Fuel Systems

9.6.3.1 Introduction

Poor fuel quality is a leading cause of system interruption during extended generator runs. Poor fuel quality tends to clog injectors and filters, thereby strangling the fuel supply to the generator. Fuel quality is managed in three separate ways: fuel additives, fuel treatment, and fuel filters on the generators.

Bulk fuel storage can be compromised by water, microbes, or particulates that infiltrate the fuel tank under normal weather and operating conditions. Fuel additives and treatments can help mitigate this condition, but they do not offer a foolproof method of safeguarding the fuel supply.

Fuel treatment takes place in a separate fuel polishing system on the primary fuel supply lines to the generator(s). The polishing system removes the majority of the microbes and particulates and water from the fuel and takes the pressure off the generator-based fuel filters as the single point of fuel cleaning. Fuel polishing should allow the filters to be bypassed if they become clogged, reverting to the generators for the primary fuel filtering function. The fuel polisher should be able to be serviced while fuel is passing through the system on the bypass loop.

The final stage of fuel filtering is the onboard fuel filters on the generator itself.

9.6.3.2 Requirements

Single-stage spin-on-type fuel filters (100 micron or 30 micron) with individual valves for removal while the engine is operating are the minimum requirement for Class F1 and Class F2 facilities. Three-stage, spin-on-type fuel filters (100 micron, 30 micron, and 10 micron) with individual valves for removal while the engine is operating are required for Class F3 and Class F4 facilities.

In case of turbine or other non-diesel engine generators, follow the manufacturers' fuel filtering requirements rather than the requirements shown here.

Systems rated for continuous operation even during servicing are required for all installations for Class F3 and Class F4 facilities.

NOTE: Continuous operation rated systems have consumable components (e.g., fuel filters) and servicing systems used in continuous-duty engines such as those found in marine engines. These consumable components or supporting systems are required to be replaced, refilled, or serviced while the engine is operating under load without risk to the operator or the mechanic servicing the engine or to the surrounding environment via spills.

9.6.3.3 Recommendations

Systems rated for continuous operation even during servicing are recommended for all installations. Fuel lines on the generators should be braided steel (e.g., marine-grade), with all connection points to the chassis routed through insulated bushings.

For filters located upstream of day tanks or for filters used by generators in N+1 or greater redundancy, spin-on-type is recommended, but is not required.

Generators should each have their own day tank to allow for fuel cooling when the engine is consuming fuel at less than rated levels and to avoid having the fuel tank being a single point of failure. While it is sometimes not practical to divide the main bulk fuel storage tank into individual or partitioned tanks, this is highly desirable for Class F3 and Class F4 facilities.

The data center's fuel supplier should have a large reliable source of fuel that is available for delivery when needed, regardless of day or time. The supplier should be able to continue to supply the data center with fuel if there is an area disaster. Alternatively, the data center's fuel tanks need to have enough capacity to provide electricity during an extended power outage caused by an area disaster such as an earthquake, flood, or hurricane.

9.6.4 Fuel Tank and Piping

9.6.4.1 Recommendations

All fuel systems with bulk fuel storage should incorporate the following basic features:

- Leak detection and annunciation for both the tank and piping
- Remote monitoring of fuel level
- Physical protection for piping from main tank to building
- Fuel filtration or polishing
- Security at tank fill points (e.g., locking covers)
- Training of operators to understand fill equipment operation to prevent accidental entry of water in tanks (underground tanks only)

9.6.4.2 Additional Information

Fuel tanks may serve a single generator or be part of a multiple generator system. Installing multiple bulk storage tanks versus a single larger tank may not increase the reliability of a system as multiple tanks may add complexity. Site issues can significantly affect the number of tanks that can be installed, as some sites may only have room for a single tank where others may not be suitable for underground tanks because of ground water or flooding issues.

9.6.5 Exhaust Systems

9.6.5.1 Introduction

Exhaust systems are linked to two issues for the site: the pollution abatement system and sound abatement requirements. Silencers come in three types: residential, industrial, and critical grades. The silencers affect engine efficiency with quieter silencers affecting engine capacity. Sound abatement on the air intake and radiator exhaust system can also affect the airflow to the engine. The silencers are linked to the overall noise abatement plan for the site.

In addition to silencers, pollution abatement systems may be required by local and regional authorities. Pollution abatement addresses two forms of emissions—particulate emissions and NOx emissions. The engine specification itself will need to be coordinated with any low emission site. Also, scrubbers (devices to remove impurities) may be required on the exhaust.

The exhaust system is typically airtight with welded construction and flexible metal connections between the engine exhaust manifolds, the silencers, and abatement systems.

9.6.5.2 Recommendations

Exhaust piping that terminates horizontally is typically angle cut to prevent water infiltration while vertical piping is provided with a flapper or hat-style cap. Flapper or hat style caps can obstruct air flow and may not be allowed because of air emission restrictions. In areas with freezing temperatures, consider the possibility of the flapper freezing in the closed position and not allowing the engine to start.

9.6.6 Cooling Systems

9.6.6.1 Introduction

Cooling systems can be via skid-mounted radiators, remotely mounted radiators, or high-reliability central water systems. For higher reliability applications, cooling systems are typically automotive-type glycol/water-based fluid radiator systems with crank-driven cooling fans that are isolated to the individual machine.

9.6.6.2 Requirements

If centralized cooling for the engine blocks is being considered, the water delivery system shall possess redundancy in the pumping and piping systems.

9.6.6.3 Recommendations

The cooling system should ensure that the generator windings and engine block water jacket remain within the manufacturer-specified temperature ranges.

Cooling system ratings have a direct and profound effect on the output kW of the generator set. Altitude must be considered when sizing generator sets, and this is typically accounted for in the radiator system. Remote or shaft-driven radiator fans also may present parasitic loads to the generator, depending on how the radiator is configured. Consult the engine manufacturer during the design and system sizing process.

9.6.7 Mounting

Generators offer the compounded issue of large live loads that vibrate while operating. Substantial foundations are required for any generator, and this is coupled with some form of vibration isolation. Vibration isolation could be in the form of pads or spring-isolation devices. In areas subject to seismic events, snubber-type bases that allow for operation while the unit is being shaken are typical and are used pursuant to the site's given seismic risk.

9.7 Automation and Control

9.7.1 Introduction

Monitoring is defined as the telemetry and ability to view what is going on within a given system. In some cases, monitoring systems can integrate and manage alarm and trouble signals from the monitored systems. For the purposes of this section, control is defined as any device that directly regulates a change in state in a given system. Controls are an active system, and may be either:

- Manually initiated and automatically operated based on human input or decision
- Automatically initiated and operated based on a predetermined script or response to a failure or external change of state

9.7.2 Monitoring

9.7.2.1 Requirements

Without monitoring, operators are not able to respond to failures or to determine the loading or operation of their systems. Monitoring is mandatory for all Classes with increasing levels of observation scope and granularity with increasing Class. Temperature sensors shall meet the Class requirements in Table 9-14.

Table 9-14 Class Requirements for Temperature Sensors

System / Class	*F0*	*F1*	*F2*	*F3*	*F4*
One sensor in cold and one in hot aisles to measure compliance to ASHRAE RP1499.	Recommended	Recommended	Required	Required	Required
Two sensors in cold and two in hot aisles, at different heights, to measure compliance to ASHRAE RP1499.	Optional (Recommended when aisles are not contained)	Optional (Recommended when aisles are not contained)	Optional (Recommended when aisles are not contained)	Optional (Required when aisles are not contained))	Optional (Required when aisles are not contained))

9.7.2.2 Recommendations

As Class level increases, monitoring increases by replacing summary alarms with individual alarm points and by presenting systems virtually for the system operators. For Class F4 systems, a virtual single line, which clearly shows system loading and power flow, should be provided. In some instances, a simulator is also provided where changes of state can be tried in a virtual setting to see the outcome prior to employing them in the live, working environment. Electrical systems should divulge all changes in state, alarms, pre-alarms and positions of all breakers, and switches as well as general system information.

Power quality monitoring (PQM) for data centers is recommended since IT systems may be sensitive to power quality, transients, harmonics, and other types of waveform disruption. Power monitoring is also vital as waveform disturbances offer a precise definition of experienced failures and outages.

When addressing power system monitoring, there are three facets of observation:

- Power levels noting voltage, current, and frequency
- Harmonic content
- Waveform imaging and capture

Power monitoring offers sampling of the power system's quality in a manner similar to a mechanical system's monitoring of temperature or water chemistry to the chiller/cooling system. PQM should be located at portions of the electrical system that offer a complete view of the vital locations where power is being converted. No particular favor is made over switchboard-integrated monitoring or stand-alone systems. The key element is how they are used. For the varying levels and locations for PQM as well as systems and component monitoring for each of the Classes, see Table 9-17 (located in Section 9.13).

9.7.3 Control

9.7.3.1 Recommendations

The operation of electrical systems should be automated to the extent possible to minimize human error, which is the predominant cause of system outages. The system should be thoroughly documented, and maintenance staff should be thoroughly trained. Training should include a good understanding of automated procedures and manual override procedures if it is necessary to override the control systems.

Power system control offers substantial challenges to both physical safety and operational assurance. Remote control of critical power systems offers an opportunity to remotely respond to changes of state. However, remote control also offers the hazard of operating large power systems without clear, in-person visual indication as to the result or consequence of the action. Remote control also introduces security concerns and will require provisions to prevent unauthorized access via the internet or other means.

Power system controls should follow these guidelines:

- Use local control only.
- Always implement remote monitoring.
- Utilize control methodologies that react only to the attendant system.
  Upstream and downstream systems should react to the changes in state of adjacent or attendant systems without a direct, physical control connection. Controls should be autonomous from any centralized controls unless the facility chooses to operate the system remotely.
- Control interfaces on each piece of equipment should be clear and concise.
  Color-coding equipment to denote the particular system, internal switchboard busing (known as mimic busing), position indicating lights, and clearly written labels and nameplates are best practices.
- Standard operating procedures should be posted on each piece of equipment.

9.7.4 System Integration

9.7.4.1 Recommendations

The use of a system integrator is typical for more complex or widespread monitoring systems. These systems are commonly referred to as an electrical power monitoring system (EPMS). The electrical system should integrate to a single "electrical" supervising management system. This system may be a stand-alone, dedicated electrical monitoring system or may be integrated into an overall monitoring and control system that addresses temperature and mechanical system control and monitoring.

The integrator offers a lower workload and database function that categorizes alarm and trouble signals by time or system. Aside from that, the electrical system's monitoring integrator should also mask and manage duplicate alarms for subordinate systems through consolidated control points such as paralleled UPS modules or generators.

9.8 Lighting

9.8.1 Introduction

Lighting systems are to be designed to provide lighting levels sufficient in output and quality for the task in each area while being of maximum energy efficiency. Elements to be considered are:

- Fixture types
- Lamping types
- Ease of relamping
- Emergency lighting capabilities
- Lighting controls for both safety and for energy efficiency

9.8.2 General Recommendations

The following are recommended to be considered when planning lighting:

- Day lighting of personnel areas such as command center, offices, conference rooms, and break areas with day lighting interface controls is recommended where at all practicable.
- Indirect or a combination of direct/indirect lighting is recommended for personnel and processing equipment areas.
- Switching and controls are recommended to be located so as to be convenient for all of access points to ITE rows and working areas.

It is recommended that a three-level lighting protocol be used in data centers depending on human occupancy:

- Level 1: When nobody is scheduled to be in the data center space, the lighting level should be just high enough that security personnel (stationed outside the unoccupied data center spaces) can monitor the space with surveillance cameras. Cameras should be specified for low-light operation.
- Level 2: Motion detectors should automatically initiate a higher level of lighting once access is detected. The level of lighting should be high enough to clearly permit identification via security cameras. These motions sensors can also replace a manually-switched lighting control system.
- Level 3: Lighting should be a minimum of 500 lux (50 ft-candles) in the horizontal plane and 200 lux (20 ft-candles) in the vertical plane, measured 1 m (3 ft) above the finished floor in the middle of all aisles between cabinets. It is permissible to divide the space in zones and either activate level 3 lighting only in selected zones that require work on equipment or illuminate the complete facility with an override switch. When only selected zones have level 3 lighting activated, the remainder of the space should be on level 2 lighting for human safety reasons.

The motion sensor-based lighting controls would activate lighting in phases, depending on which area of the data center requires occupancy for work or passage. The lighting control system would "sweep" the area and extinguish the lighting after a preset time in order to conserve energy.

Lighting levels required to maintain Code-required egress from the space should be maintained at all times and should be coordinated with the Level 2 lighting requirement noted above.

12/24 V_{DC} lighting systems may provide additional energy savings and be integrated with other building and facility systems. Standards such as ANSI/BICSI 007 provide additional information on these systems.

9.8.3 Computer Rooms

9.8.3.1 Requirements

Computer room lighting systems shall adhere to all local code requirements, including (but not limited to):

- Emergency lighting: exit signage, egress lighting
- Energy efficiency requirements
- Building management systems

9.8.3.2 Recommendations

In locations where people are present, the computer room should have a minimum of 500 lux (50 ft-candles) maintained in the horizontal plane and a minimum of 200 lux (20 ft-candles) maintained in the vertical plane of the data racks, both measured at 1 m (3 ft) above the finished floor. The lighting uniformity (difference between highest and lowest light levels) within the lighting zone(s) should exceed 90% before any equipment or cabinets are installed.

Lighting fixtures should be selected to prevent glare on equipment monitors. Lighting control should be located at the room's exits with occupancy sensors being highly desirable.

Fluorescent lighting fixtures should be specified with low-RF ballasts. While high-intensity discharge (HID) lighting, such as metal halide or mercury vapor, are not specifically excluded, the restrike time of the fixtures should be as short as possible to prevent long-term lighting outages in the room.

Since the data processing rooms are typically windowless, instant-on lighting is required for the safety of personnel working in the data processing areas during the time an utility outage occurs and the generators assume the load. In this case, 50 lux (5 ft-candles) maintained over 50% of the room is suggested.

Portable, battery-powered lanterns are recommended to be placed in all computer rooms.

9.8.4 Support Areas

9.8.4.1 Requirements

Support area lighting systems shall adhere to all local code requirements, including (but not limited to):

- Emergency lighting: exit signage, egress lighting
- Energy efficiency requirements
- Building management systems

9.8.4.2 Recommendations

All support spaces should be lit pursuant to the Illuminating Engineering Society (IES) recommendations.

For control rooms, operations center, and other locations where computer screens are present, fixture systems should be selected that reduce or eliminate glare on computer displays. Lighting systems for this area should be commensurate with the noncritical office areas within the facility. The lighting uniformity (difference between highest and lowest light levels) in the rooms should exceed 90%.

Lighting control should be located at the room's exits with occupancy sensors being highly desirable.

Fluorescent lighting fixtures may be specified with standard RF ballasts. In some support spaces, such as generator rooms or large-area central plant spaces, HID lighting such as metal halide or mercury vapor may be used. Should HID sources be used, the restrike time of the fixtures should be as short as possible to prevent long-term lighting outages in the room.

9.9 Bonding, Grounding, Lightning Protection, and Surge Suppression

9.9.1 Introduction

The comprehensive electrical protection required for the critical facility is achieved using a system approach to integrate lightning protection, overvoltage and surge suppression and bonding and grounding.

Grounding is addressed in three sections: electrical distribution, PDU, and within the computer room.

It is the intent of this standard to provide a bonding and grounding system that substantially equalizes any non-transient potential differences so that all the enclosures, raceways, and all bonded metal found in the computer room are effectively at the same ground potential (substantially equalized). At higher frequencies, consideration must be given to the impedance of a conductor, not just the resistance. A conductor's impedance can be significantly influenced by its routing path in relation to other nearby circuit conductors and parallel paths such as a metal tray bottom.

Bonding and grounding of data centers relates most specifically to maintaining the facility's common electrical bonding and grounding system along with any desired supplementary bonding and grounding for the ITE. Bonding and grounding also addresses such vital issues as harmonic current management and fault current mitigation. Bonding and grounding also integrates voltage transient suppression by the application of SPD systems as well as lightning protection systems. The bonding and grounding system is one of the few electrical systems completely systemic to the entire critical facility.

If properly organized and installed, the ground system is essentially a radial system from the electrical service entrance. There are a few subtleties for critical facilities that vary from other buildings. Where generators are not treated as separately derived sources, neutrals and grounds are routed with the associated phase wiring and carried back (without being switched) to the main service and terminated on the main service's neutral and ground buses. Where generators are treated as separately derived sources, grounds are carried back to the main service and terminated on the main services ground bus.

Data center bonding and grounding addresses all bonding and grounding within the building containing a data center. These systems include:

- The separately-derived system at the PDU
- Ground path to the load
- Critical environment grounding—supplementary at the ITE
- ITE bonding and grounding
- Personal grounding and static discharge.

Bonding and grounding for a data center involve several entities such as:

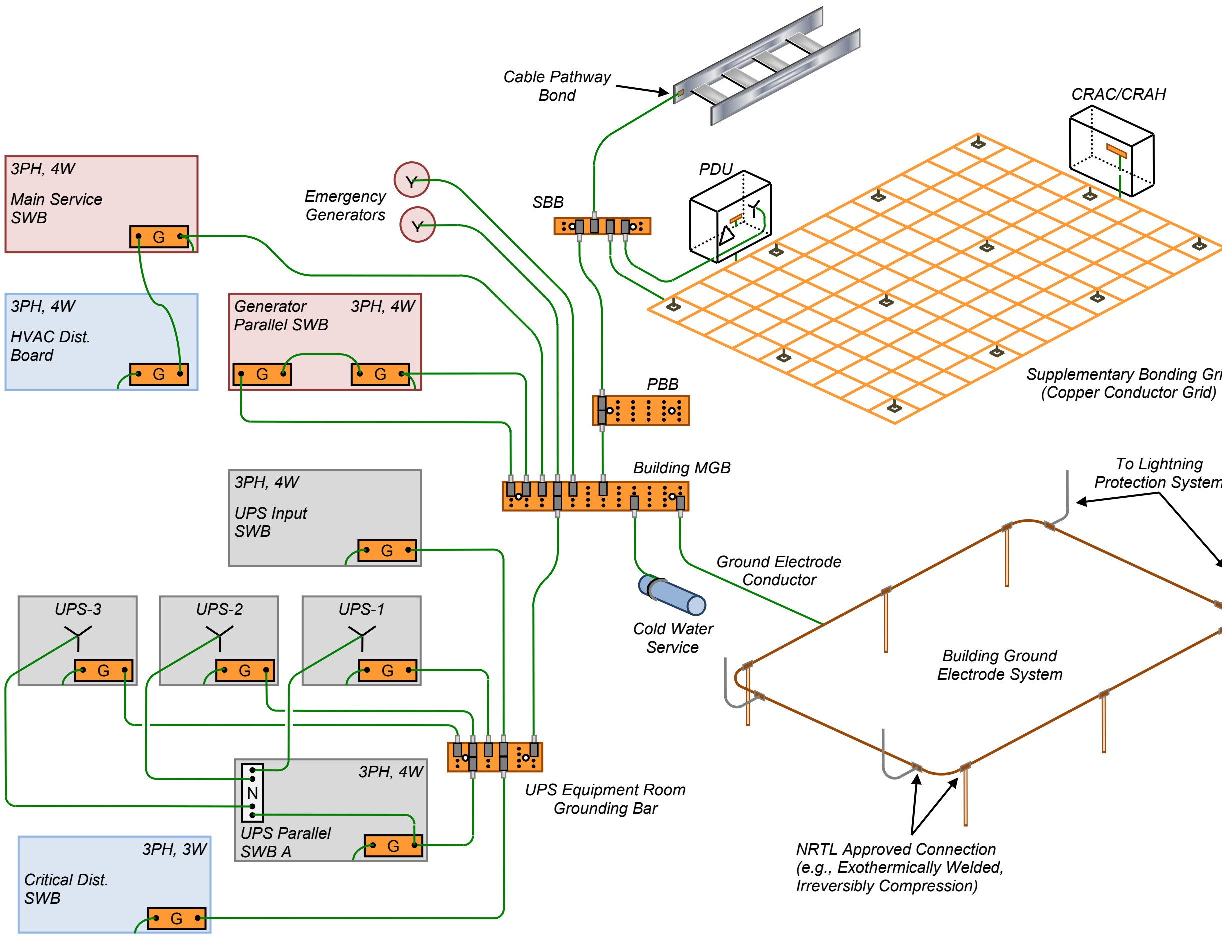
- A common grounding electrode system (GES)for the building, involving the intersystem bonding of a:
  - Grounding electrode system for the electrical power
  - Grounding electrode system for the lightning protection system (LPS)
  - Grounding electrode system for the telecommunications service provider cables and protectors
- Grounding electrode conductors for grounding each power service entrance
- Grounding electrode conductors for grounding each separately derived power source such as an engine-generator for standby power
- Grounding electrode conductors for grounding each telecommunications service entrance
- Bonding and grounding infrastructure for telecommunications utilizing components such as the telecommunications bonding conductor (TBC), primary bonding busbar (PBB), telecommunications bonding backbone (TBB), secondary bonding busbar (SBB), and backbone bonding conductor (BBC) as described in ANSI/TIA-607-C or ISO/IEC 30129.
- Equipment grounding conductor for power distribution from the service/source to the load
- Structural metal
- Grounding conductors such as the down conductors for a LPS and SPDs
- The common bonding network (CBN) within the building
- Supplemental bonding and grounding structures for electronic equipment such as:
  - Mesh-bonding network (mesh-BN)
  - Isolated bonding network (IBN)
  - Supplementary bonding grid.

NOTE: The common bonding network (CBN) is the set of metallic components that are intentionally or incidentally interconnected to form the bonding network (a mesh) in a building. The CBN always has a mesh topology and connects to the grounding electrode system via one or more grounding conductors.

The data center or critical environment specifics are noted later in this section. A simplified example model for a critical facility bonding and grounding system is shown in Figure 9-36.

Figure 9-37 provides an example of the bonding and grounding infrastructure of a data center that has two entrance rooms with one MGB with Figure 9-38 providing an example of a Class 4 bonding and grounding infrastructure supporting two entrance rooms and two electrical distributions, each with its own MGB.

Serving power systems and electronic equipment bonding and grounding primarily involves the serving power source and the power distribution to the IT and other electronic equipment. This primary level of bonding and grounding is required to be in accordance with the NRTL product safety listing of the power system and the electronic equipment (load). The entities of concern are the grounding electrode conductor (system) and equipment grounding (bonding) conductor (or green wire). These dedicated circuit conductors are required for the safe operation of the equipment, including any ground faults. In some instances, equipment may be designed as "double insulated", whereby the NRTL requirements for the equipment grounding conductor may be eliminated (e.g., a two-prong plug or receptacle). Although data center electrical and electronic equipment may be considered "grounded" according to its NRTL requirements, supplementary bonding and grounding are recommended.



Note 1: Not all items shown are present in every data center.
Note 2: Actual wiring should take into account local rules and conditions.

Figure 9-36
Example Critical Facility Bonding and Grounding Diagram for Class F2 and Lower

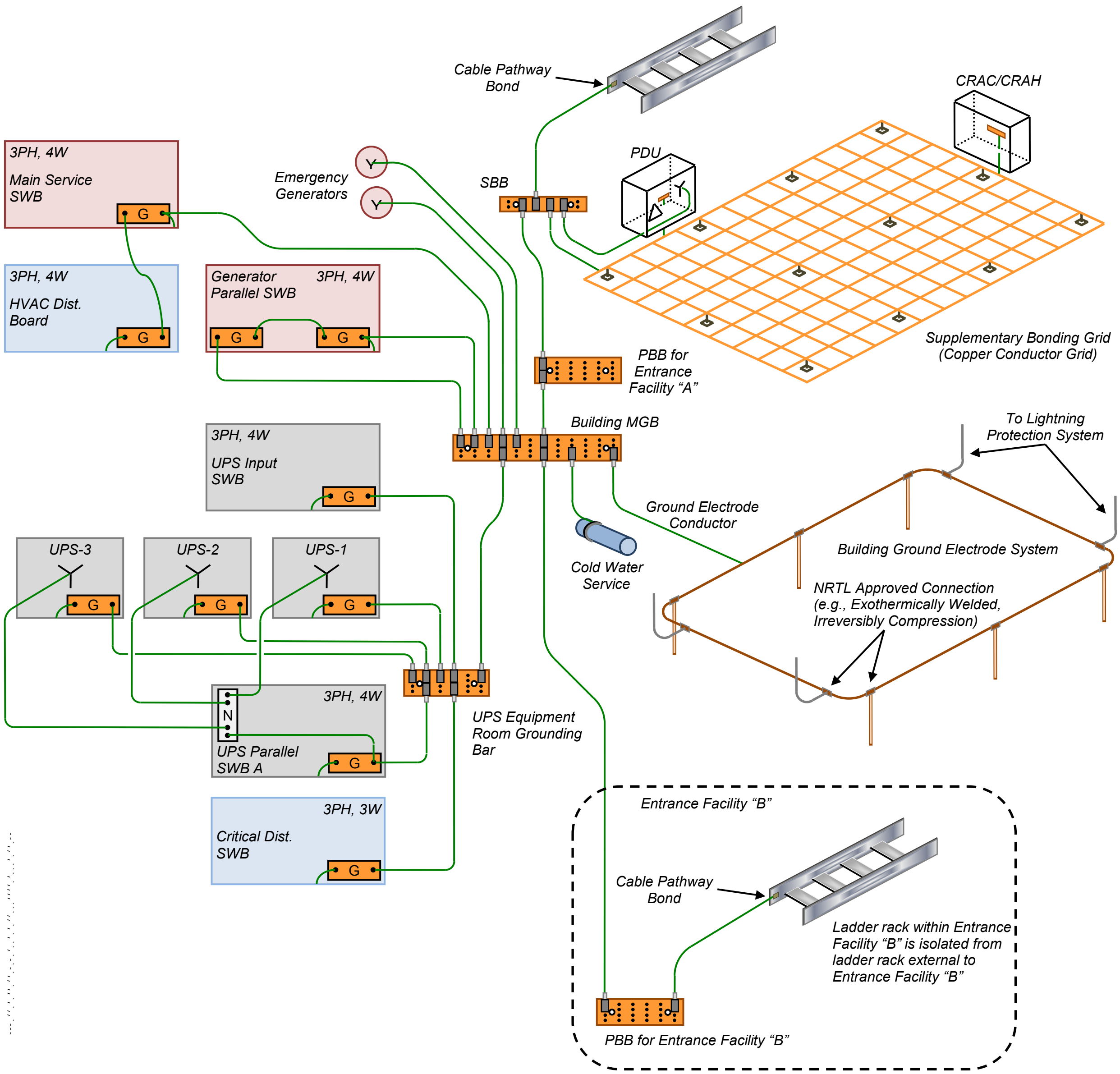


Figure 9-37
Example of Critical Facility Bonding and Grounding Diagram for Class F3

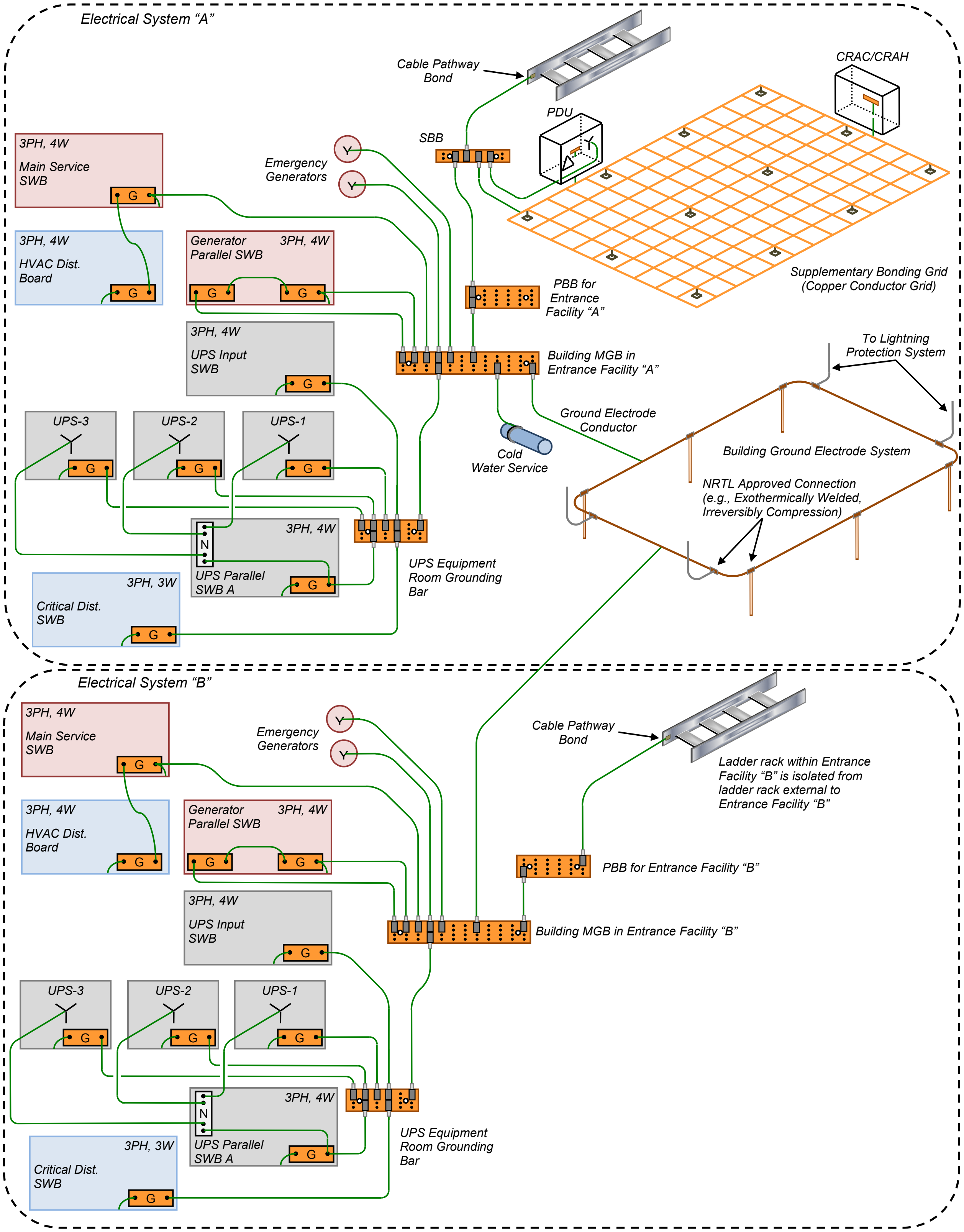


Figure 9-38
Example Class F4 Bonding and Grounding Diagram (Two MGB and Two Entrance Facilities)

High-resistance/impedance grounding (HRG) systems can be used in lieu of solidly grounded systems. HRGs are typically designed to limit a ground fault current to 10 Amps or less. The advantages of using HRGs are:

- Safety enhancements because of mitigation of phase-to-ground fault currents
- Operational enhancements because of reduction of ground fault current trips
- Reduced cost because of the elimination of four-wire feeders

Historically, HRGs were utilized in industrial facilities with critical processes. More recently, they are being deployed in a growing number of mission-critical facilities. They are most useful where process control requires an orderly shutdown to avoid high costs of restoration of the process.

Typically, the HRGs are installed at the service transformer. They function down to the first separately-derived source in the distribution system. Where used for ITE installations, consideration should be given to any impact on the resistance/impedance of the grounding systems. HRGs may influence the level of electrical noise versus earth ground at higher frequencies such as for filters. The impact may occur because of reactance of the resistance/impedance devices such as an inductor or wire-wound resistor. Inductive/reactance grounded power systems are not recommended for low voltage systems. Check with the UPS system manufacturer if it is not connected to solidly grounded neutral sources as they typically will provide neutral grounding kits for their UPSs.

See ANSI/NECA/BICSI 607 for additional requirements and recommendations for the installation of telecommunications bonding and grounding.

9.9.2 General Recommendations

The following considerations are important for understanding the complexities of bonding and grounding for a data center:

- All metal infrastructure within the data center should be grounded (this includes empty cabinets, racks, conduits, and cable trays).
- Equipotential grounding becomes increasingly difficult across an expanse such as a building or larger data center.
- Distributed grounding (within a building or complex) cannot accomplish equipotential grounding.
- A dedicated and separate ground for data center equipment is NOT recommended and is likely to be an electrical safety violation.
- Especially where multiple services (power and communications) enter the building at separated locations, a buried ground ring is recommended to provide equipotential bonding. Where multiple power service entrances are involved, the ground ring conductor should be sized at 107 mm2 (4/0 AWG) minimum bare copper.
- Where equipment is designed for double insulation, grounding that equipment may be a secondary concern (pending its product safety listing requirements and electromagnetic emissions compliance).
- Any electrical grounding infrastructure (such as that specified by NECA 331) placed for the electrical power system should not replace the separate bonding and grounding infrastructure for telecommunications (e.g., ANSI/TIA-607-C, ISO/IEC 30129).
- The infrastructure described in ANSI/TIA-607-C and ISO/IEC 30129 is better placed in the central portions of the building and away from exterior locations where current from lightning is more likely.
- Supplementary bonding and grounding of data center equipment is recommended (this is over and above bonding and grounding of the serving power distribution) as it:
  - Provides for more locally grounded equipment
  - Maintains a level of grounding even if the serving power circuit grounding is interrupted
  - Provides dispersed path(s) for ESD currents to follow
  - Provides conductive paths among interconnected equipment where common configurations include grids and planes. A mesh-BN (depending on its installation techniques), inclusion of a supplementary bonding grid, the mesh density, and the routing pattern of signal and power cabling may:
    - Further reduce the levels of inter-unit common-mode electrical noise on signal and power cabling
    - Provide a lower resistance and lower impedance inter-unit ground reference
    - Reduce damage to inter-unit equipment during power fault and surge events
  - An isolated bonding network (IBN) may be utilized for certain telecommunications applications whereby the electronic equipment system is only grounded via a single point connection window. This concept has been used by the telecommunications service providers (primarily for DC powered systems but may also be applicable for AC powered systems).
- Data circuits between data centers and different floors should be decoupled to prevent issues related to unwanted electrical transients. Fiber optic circuits and links are ideal for decoupling. Some types of circuits may utilize suitable transformer isolation for decoupling.

9.9.3 Lightning Protection

9.9.3.1 Introduction

Lightning events can cause fires, damage to buildings, and breakdowns of electrical, telephone, and computer installations, which may result in considerable losses in operational revenues and increased customer dissatisfaction. Damage results from electromagnetic fields from the lightning strike, voltage differentials in ground systems, and structural damage from ohmic heating or mechanical forces. This damage can be attributed to insufficient direct strike protection; deficient grounding, bonding, and shielding techniques for the susceptibility level of the installed electronic equipment systems; and deficient selection and installation of surge protective devices.

Depending on the geographical location for the data center, there may be local guides available specific to the country or region, such as the risk analysis guide provided in NFPA 780, which takes into account geographical location and building construction among other factors in determining the suitability of a lightning protection system. If a lightning protection system is installed, it shall be bonded to the building grounding system as required by the prevailing standards and AHJ and as required for maximum equipment protection.

9.9.3.2 Requirements

For some locations, lightning protection is required by AHJ for basic building safety and protection.

If a lightning protection system is present, the lightning protection system shall be:

- Applied as a comprehensive system
- Integrated with properly sized and installed SPDs
- Implemented to cover all systems and buildings serving the critical environment

9.9.3.3 Recommendations

Where protection from lightning-caused voltage fluctuations and transients is to be provided for protection of critical facilities, installation should be in accordance with industry recognized standards such as NFPA 780, IEC 62305-3, or IEC 62305-4.

9.9.4 Surge Suppression/Surge Protective Devices (SPDs)

9.9.4.1 Introduction

Surge suppression, as used in this section, encompasses all surge protective devices or SPDs.

NOTE: Within surge suppression for low voltage AC power circuits, the term *surge protective device (SPD)* has replaced the term *transient voltage surge suppression (TVSS)* with TVSS no longer in use.

Surges and transient power anomalies are potentially destructive electrical disturbances with the most damaging being overvoltage occurrences and short duration events. High-energy transient power anomalies can arise from inductive load switching or other events within the power system or from capacitive and inductive coupling from environmental events such as nearby lightning activity. Environmental and inductive power anomalies are wideband occurrences with a frequency range from close to DC to well into the RF high-frequency spectrum. It is critical that each point-of-entry (e.g., power, HVAC, telephone, LAN, signal/control, RF) into the equipment area be protected against these anomalies. This protection is essential to reduce the risk of personal injury, physical equipment damage, and loss of operations. Although lightning can cause the most visible damage, it is not the predominant cause of transient voltages.

Sources of transient voltage include, but are not limited to:

- Power company switching
- Generator transfer
- Shared commercial feeders with poor line regulation
- Load switching
- Fault currents
- HVAC units
- Heating elements
- Power tools
- Electric motors
- Fluorescent lights.

SPDs and large-scale surge suppression are an integral part of the high voltage lightning protection for a facility. Additional low voltage transient mitigation is typical for an information technology facility to protect against internally-generated transient events.

For lower Classes of data centers, SPDs are located on the utility entrance with transients not being addressed further downstream unless the site demands it. For higher reliability Classes, SPDs are prevalent throughout the power system. As the data center Class increases, SPDs may be found in the following locations:

- Utility service entrances
- Generator buses
- UPS inputs
- UPS outputs
- UPS power distribution switchboards
- PDUs and critical power distribution panels

9.9.4.2 Requirements

The installation of surge protective devices is a requirement for all data centers Class F1 and higher. A lack of surge protective devices would result in a Class F0 rating.

SPDs shall be provided and installed in the locations specified in Table 9-15 based on the Facility Class.

SPDs shall not be mounted inside the switchboard (unless specifically designed, manufactured, NRTL listed, and properly installed for integral installation) and shall be installed with minimum lead lengths and separation of input/output wiring in order to perform properly. For application guidance on the use of facility level SPDs for AC power systems, see IEEE C62.72 and IEEE 1100.

NOTE: For DC power surge protection, see IEEE 1100.

9.9.4.3 Recommendations

SPDs should meet the following minimum criteria:

- Listed to AHJ requirement (e.g., UL 1449)
- Provide surge current diversion paths for all modes of protection:
  - L-N, L-G, and N-G in WYE systems
  - L-L and L-G in DELTA systems.
- Modular in design with redundant protection circuitry
- Visible indication of proper SPD connection and operation
- Audible alarm for diagnostic monitoring, activated upon failure of a SPD
- EMI/RFI filtering using MIL-STD-220A methodology or equivalent AHJ requirement

For application guidance on the use of facility level SPDs for AC power systems, see IEEE C62.72, IEEE 1100, and NFPA 70, Article 285.

Over time, SPDs have a risk of ground faults because of degradation of insulation. One method to mitigate insulation degradation is to monitor neutral current for signs of degradation.

Table 9-15 SPD Locations as per Class

System	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Utility Service Entrance	Recommended	Required	Required	Required	Required
Generator Buses	Recommended	Recommended	Required	Required	Required
UPS Rectifier Inputs	Optional	Recommended	Required	Required	Required
UPS Static Bypass Inputs	Optional	Recommended	Recommended	Required	Required
UPS Maintenance Bypass Inputs	Optional	Recommended	Recommended	Required	Required
UPS Outputs	Optional	Optional	Optional	Optional	Optional
Critical Switchboards (downstream from UPS)	Optional	Optional	Optional	Optional	Optional
PDU or RPP	Optional	Optional	Optional	Optional	Optional

9.9.5 Telecommunications Surge Protection

9.9.5.1 Requirements

9.9.5.1.1 Primary Protection

The purpose of primary protection is to help ensure personnel safety and help protect internal cables from extremely high voltage. The installation of primary SPDs shall comply with all applicable codes. The devices shall be designed to comply with one or more of the following:

- UL 497
- UL 1449 (latest edition)

and shall be marked with one or more of the following:

- UL listing
- CE certification listing mark (where recognized)
- Other local codes or standards as established by the AHJ

The SPD shall be installed at the entrance point into any building and within close proximity (adjacent) to the electrical service entrance and the building electrical main ground bar. Minimizing the grounding conductor lead-length between the SPD and electrical service entrance will improve the efficacy of the SPD device by reducing the self-inductance of the grounding lead. This will help reduce the voltage rise between the SPD and the electrical service entrance. In lightning prone areas, a SPD shall also be installed on each end of an inter-building cable run to help ensure that high energy is not allowed to penetrate the building interior. In some applications, a fused type primary SPD may be required.

The primary SPDs in telephone circuits, data circuits, and control circuits shall be grounded in accordance with NFPA 70 or other applicable codes or standards. Primary SPDs shall have the ground terminal bonded to the building MGB, PBB, or a dedicated ground bus conductor. The conductor shall be free of sharp bends. The grounding conductor for a single line primary SPD shall be 5.26 mm^2 (10 AWG) or larger; the grounding conductor for multiple line primary SPDs shall be 13.3 mm^2 (6 AWG) or larger.

9.9.5.1.2 Secondary Protection

The primary purpose of secondary SPDs is to limit the magnitude of current that can be imposed on the secondary wiring from the primary SPD to the ITE. To be effective, the secondary protection must properly coordinate with the primary protection. A collateral purpose is to limit transient overvoltages to within the prescribed withstand level of the protected equipment. The SPD also serves as a barrier against transient anomalies that may be induced between the cable entrance point and the equipment and in cable runs within the building.

Secondary SPDs shall be installed as close to the equipment being protected as possible. This includes, but is not limited to, the circuits associated with the base stations, repeaters, remotes, modems, consoles, network interface units and channel banks that extend from the room or equipment area. Secondary SPDs shall comply with safety and performance standards for their designated function. The devices shall bear the UL 497A listing mark, the international CE certification mark (where recognized), or as required by AHJ.

A separate bonding conductor shall be used to bond each secondary SPD grounding conductor or ground terminal of the frame to the PBB, SBB, or other approved ground bus conductor that serves the associated equipment. The grounding conductor for a single line secondary SPD shall be 5.26 mm^2 (10 AWG) or larger; the grounding conductor for multiple line secondary SPDs shall be 13.3 mm^2 (6 AWG) or larger. If a separate rack ground bar is installed for the SPDs, it shall be effectively bonded back to the equipment ground bus system.

This conductor shall be as short as possible, free of sharp bends, and shall be routed as directly to the equipment grounding conductor or ground bus as is possible. The operating voltage and SPD configuration is application dependent. Where the ITE is already rated for internal secondary protection, the stand-alone secondary protector is not required.

9.9.5.2 Recommendations

The selected level of secondary surge suppression rated voltage should be chosen to ensure selective coordination with the protected equipment.

When several secondary SPDs are installed at an equipment cabinet or rack, the SPDs should be placed at a central location within the cabinet or rack. This allows the SPD to be effectively bonded to either rack ground bar within the equipment cabinet or rack, or bonded to a separately installed rack ground bar.

To reduce the need for fuse replacement, devices that incorporate resettable fuse technology are recommended.

9.9.6 Building Ground (Electrode) Ring

9.9.6.1 Requirements

A building ground electrode ring shall be installed for facilities where a lightning protection system is installed or where there are multiple power service entrance locations along the periphery of the facility.

All below grade grounding connections shall be made by NRTL-approved methods such as exothermic weld or high-compression connectors.

As required by local codes and standards, the ground ring shall be bonded to structural metal at every other column or more often. Concrete-encased electrodes (also known as Ufer electrodes) shall be used in new construction as a method of supplementing the grounding electrode system. Concrete-encased electrodes improve the effectiveness of the grounding electrode system because of concrete having hygroscopic properties and by providing a much larger surface area in direct contact with the surrounding soil:

- Concrete-encased electrodes shall be encased by at least 51 mm (2 in) of concrete, located within and near the bottom of a concrete foundation or footing that is in direct contact with the earth.
- Concrete-encased electrodes shall be at least 6 m (19.7 ft) of bare copper conductor not smaller than 21.1 mm^2 (4 AWG) or at least 6 m (19.7 ft) of one or more bare or zinc galvanized or other conductive coated steel reinforcing bars or rods at least 12.7 mm (0.5 in) in diameter.
- Concrete-encased electrodes shall be bonded to any other grounding electrode system at the site.

This building grounding system shall be directly bonded to all major power distribution equipment, including all switchboards, generators, UPS systems, and transformers, as well as to the telecommunications systems and lightning protection system. The facility shall possess a building electrical main ground bus (MGB) where all the large-load feeder facility grounds terminate. This is the location, coupled with the PBB, where the grounding system can be validated for both continuity and impedance.

9.9.6.2 Recommendations

A building ground electrode ring should be installed for all facilities. Single or triplex ground rod fields as the only earthing vehicle are not adequate for a critical facility. Generally, the direct burial connections should meet appropriate electrical testing requirements as set out in the applicable standards and codes to ensure durability. Designs may vary according to the site parameters such as available real estate, earth resistivity, frost line level, and the depth of the water table.

Ground bus bars should be placed so as to facilitate bonding and visual inspection.

The ground ring should be 107 mm^2 (4/0 AWG) minimum bare copper wire buried a minimum 800 mm (30 in) deep and a minimum 1 m (3 ft) from the building wall. For larger sizes, stranded conductors are recommended. Ground rings encircling buildings should be installed just beyond the roof drip line. The size of the ground ring conductor is recommended to be the same as the largest size required by AHJ for a grounding electrode conductor to promote the accomplishment of intersystem bonding. Additionally, ground rods should be connected to the ground ring. Typical ground rods are 19 mm by 3 m (3/4 in by 10 ft) copper-clad steel ground rods spaced every 6 to 12 m (20 to 40 ft) along the perimeter ground loop.

Test wells for the building ground electrode ring should be provided at the four corners of the loop.

In its entirety, the common grounding electrode system should not exceed 5 ohms to true earth ground as measured by the fall of potential method (IEEE 81). As noted in the NEC, IEEE 1100, and IEEE142, common bonding of different systems plays a crucial role along with grounding.

9.9.7 Supplementary Bonding and Grounding

9.9.7.1 Introduction

Supplementary bonding and grounding methods are those provided in addition to the bonding and grounding measures typically required by the applicable electrical safety codes and product safety standards. Supplementary bonding and grounding methods are intended to improve facility and equipment performance related to bonding and grounding. Examples of supplementary bonding and grounding entities may include metallic raceways, racks and cable trays; under the raised floor or above the cabinet and rack metallic grid work; metal plates and metal sheets; multiple bonding conductors from equipment to a grounding/bonding structure, etc.

9.9.7.2 Supplementary Bonding and Grounding Structures

A grounding system for a data center with raised floor is illustrated in Figure 9-39. It includes not only the power system ground but also supplementary bonding and grounding.

A supplementary bonding and grounding system commonly in the form of a mesh-bonding network (mesh-BN) equipped with a supplementary bonding grid (SBG, also historically known as a signal reference structure—SRS) is frequently utilized in data centers where there is a raised floor. As noted in IEEE 1100, the default equipment bonding topology is the common bonding network (CBN) and the supplementary bonding grid can be readily utilized for efficient direct bonding of equipment and other apparatus to the grounding system. For the typical data center, the supplementary bonding grid becomes a component of the mesh-BN. The supplementary bonding grid is an externally installed network of conductors used to effectively bond together disparate metal cabinets, rack frames, and enclosures. Such an arrangement provides efficient grounding and inter/intra-unit bonding of metal cabinets, racks, and miscellaneous metal objects (especially when they are not powered). Additionally, the mesh-BN ensures grounding reliability of the equipment in the event the equipment grounding conductor of the serving power circuit is compromised or disconnected during maintenance. Electrostatic charge dissipation is also greatly aided by the multiple grounding paths of the mesh-BN (see Figure 9-39).

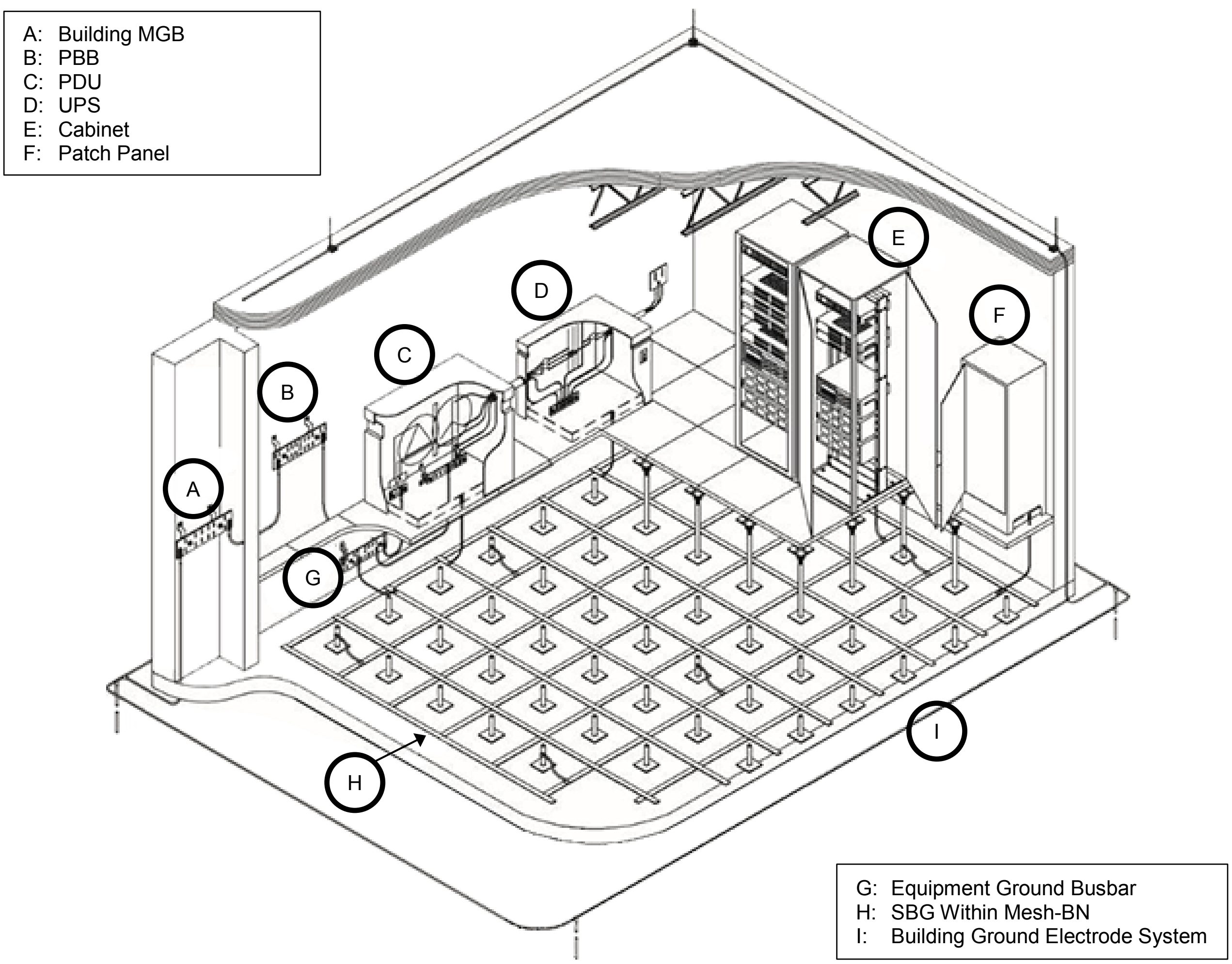


Figure 9-39
Typical Data Center Grounding Schema (shown with raised floor)

9.9.7.3 Mesh-BN

9.9.7.3.1 Introduction

The supplementary bonding grid (SBG) may be a recommendation from, or an actual part of, the equipment manufacturer's installation package. Typically, it is part of an aftermarket, field-installed wiring effort.

The mesh-BN has three primary purposes:

- It may enhance the reliability of signal transfer between interconnected items of equipment by reducing inter-unit common-mode electrical noise over a broad band of frequencies. When properly designed, installed and utilized it can be effective for noise control across low-frequency single-ended signaling links or poorly designed communication links. This function is typically limited to around 30 MHz using 600 mm (24 in) grid spacing.
- It is intended to prevent damage to inter-unit signal circuits by providing a low impedance (low inductance) path and thus an effective ground reference for all externally installed AC and DC power, telecommunications, or other signal level, line-to-ground/chassis-connected SPD equipment that may be used with the associated equipment.
- The mesh-BN is intended to prevent or minimize damage to inter-unit signal-level circuits and equipment power supplies when a power system ground-fault event occurs.

The mesh-BN creates a functional equipotential ground reference for the computer room and may reduce stray high-frequency signals

The mesh-BN may include a supplementary bonding grid in the form of a bare round wire or flat copper strip joined together via welding, brazing, compression or a suitable grounding clamp arrangement at each of the crossing points. The mesh-BN can also include field assembling a grid from the raised floor pedestals using standard or bare round wire.

9.9.7.3.2 Requirements

When used, the mesh-BN becomes an integral part of the CBN; it shall not be insulated or isolated from the building electrical system ground. Where utilized, the mesh-IBN (isolated bonding network) shall be insulated or isolated from the CBN except through a single point connection window. The mesh-IBN typically does not utilize an access floor or underfloor bonding grid as a supplementary bonding entity to the mesh-IBN. The reason is that the cabinets and racks are insulated/isolated from the flooring in order to accomplish the single point grounding scheme back to the single point connection window. Otherwise, the mesh-IBN intra-unit bonding is very similar to that used in a mesh-BN.

The mesh-IBN is further described in IEEE 1100. The mesh-IBN is not considered typical for a commercial data center installation but may be encountered in an access provider data center.

If ground clamps are used, they shall be listed (e.g., UL 467) for the application. Wire hangers or positioning devices (e.g., UL 2239) shall not be used as ground clamps.

If constructed using round conductors, the cross-section of the conductors shall be no smaller than 13.3 mm^2 (6 AWG) and up to 42.4 mm^2 (1 AWG) is typical. The conductors may be bare or insulated copper.

All metal surfaces, with the exception of lighting fixtures, door frames, window frames, and pathways shorter than 1 m (3 ft), shall be bonded to the bonding grid.

NOTE: Conduit sleeves, metallic firestop systems, and other isolated pathways and devices shorter than 1 m (3 ft) do not need to be bonded to the grounding system.

9.9.7.3.3 Recommendations

The mesh-BN should include a SBG such as a copper conductor grid on 600 mm to 3 m (24 in to 10 ft) centers that covers the entire computer room space. The ideal spacing for the grid is between 600 mm to 1.2 m (24 in to 4 ft). If the declared bandwidth is to be realized and the SBG is to provide enhanced reliability of signal transfer (as discussed in the introduction above) by reducing inter-unit common-mode electrical noise over a broad band of frequencies, the grid spacing must be kept at 600 mm (24 in) or less and the associated cabling must be routed in close proximity to the SBG.

The flat copper strip form of the supplementary bonding grid is typically installed with a prefabricated mesh. The grid should be prefabricated out of a minimum 0.40 mm (26 gauge) × 50 mm (2 in) wide copper strip with all crossing inter-connections welded, not punched (see Figure 9-40). The grid spacing of the mesh-BN should be 600 mm (24 in). Adjacent rolls of mesh-BN are exothermically welded in the field to form a continuous grid (see Figure 9-41). The copper strips are typically factory welded into a grid pattern prior to installation and then rolled out onto the floor in sections with some minor exothermic welding performed on site prior to occupancy and IT operations commencing to complete the installation.

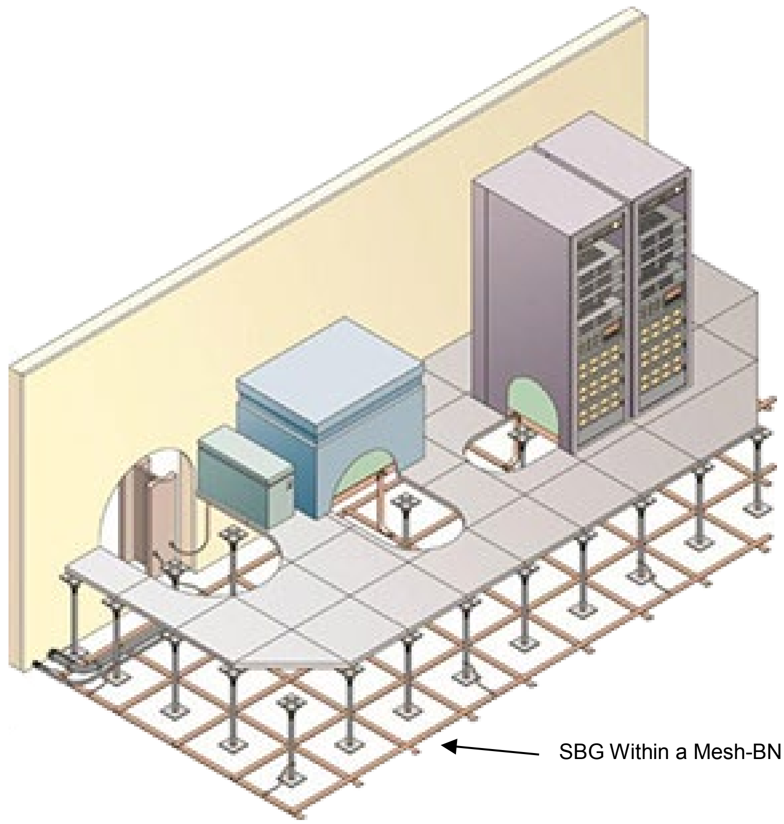


Figure 9-40
Typical Configuration of Flat Strip-Type SBG Within a Mesh-BN

- In all cases, the SBG should be bonded to the pedestals of the raised floor system. If the grid is in the form of a flat strip grid (600 mm (24 in) spacing), at least every 6th pedestal should be bonded to the grid. If the grid is formed from the raised floor system, then at least every second pedestal should be bonded to the grid. The bonding jumper from the pedestal to the supplementary bonding grid should be no greater than 600 mm (24 in) in length. When using the access floor with bolted stringers as the supplementary bonding grid, note that it may not be as effective as a bonding grid that is built in place using copper conductors and exothermically-welded joints or mechanical conductor clamps. Considerations include the removal of access floor tiles for temporary work, etc.

  The grounding and bonding infrastructure and ITE components should have the connections listed in Table 9-16.

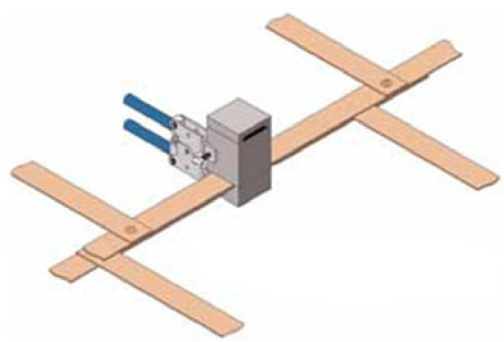


Figure 9-41
Adjacent Rolls Of Flat-Strip-Type SBG Being Exothermically-Welded Together

Table 9-16 Grounding and Bonding Connection Schedule

Connection	*Minimum Conductor Size*	*Note No.*
PBB – Building Main Ground Bus	130 mm^2 (250 MCM) bare	
EGS – PBB	130 mm^2 (250 MCM) bare	
PDU – PBB/SBB	Per applicable code (e.g., NEC 250-122)	
HVAC equipment – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	
Steel column – mesh-BN/SBG	21.1 mm^2 (4 AWG) bare	1 and 2
Rebar mat foundation – mesh-BN/SBG	21.1 mm^2 (4 AWG) bare	3
Cable management – cable tray, conduit	13.3 mm^2 (6 AWG) bare	4
Access floor pedestal – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	5
Sprinkler piping – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	
HVAC ductwork – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	
Cabinets – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	6
Equipment enclosures – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	6
Frames – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	6
Other metallic system enclosures – mesh-BN/SBG	13.3 mm^2 (6 AWG) bare	

NOTE 1: Size in excess of ANSI/TIA-607-C for the design of the telecommunications bonding and grounding infrastructure. Ground size should be this size or should match the ground conductor required at the electrical service entrance, whichever is larger.
NOTE 2: Proper NRTL listed mechanical lugs and clamps or exothermically-welded connections to steel column.
NOTE 3: Weld to rebar mat before pour.
NOTE 4: Every joint should have a bonding jumper.
NOTE 5: Utilize mechanical lugs, clamps, or exothermically-welded connections on pedestal body and spade-type tab under stringer screw-down.
NOTE 6: Cabinets, racks, frames, and equipment enclosures shall be individually bonded to the mesh-BN/SBG—not bonded serially.

A SBG may be fabricated from standard, bare round wire or flat copper strip joined together via welding, brazing, compression or a suitable grounding clamp arrangement at each of the crossing points (see Figure 9-42). Because of the larger surface area, flat strap provides better transient protection, especially at higher frequencies.

For a wire grid, bare (non-insulated) copper is preferred because it provides greater ease of attachment of equipment to the mesh-BN. Since the immediate grid area is being rendered to the same potential, inadvertent or intermittent contact points should not be an issue if personal grounding systems are being used.

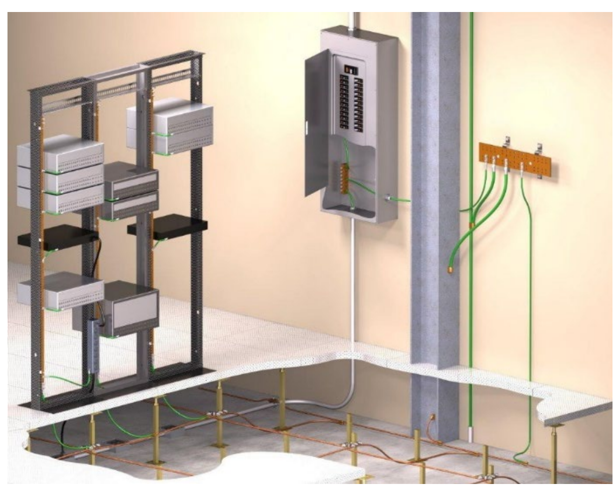


Figure 9-42
Data Center Grounding Infrastructure (Room Level) Example

9.9.7.4 Equipment Bonding and Grounding to the Mesh-BN

9.9.7.4.1 Requirements

All metallic enclosures shall be supplementary grounded and bonded in addition to required safety grounding provided by the serving power circuit. This provides for both staff safety as well as grounding continuity, which is the logical extension of the data center grounding infrastructure to the load itself. Each equipment cabinet and rack requires its own grounding connection within the mesh-BN. (See Figure 9-43). Grounding connection hardware used to bond to the mesh-BN shall be installed per manufacturer's instructions, ensuring the quantity and size of conductors bonded per connection device does not exceed manufacturer's specifications. A minimum of a 13.3 mm^2 (6 AWG) insulated stranded copper conductor exothermically welded or mechanically terminated within the mesh-BN and mechanically terminated to the cabinet via a proper machine screw through-bolt connection or factory-provided spot weld.

Bare metal-to-bare metal contact is mandatory for all ITE enclosure bonding connections with anti-oxidant applied at the connection point of the equipment either in the field or by the factory prior to shipping the equipment.

Each cabinet or rack shall have a suitable connection point (or points where multiple connections are desirable) to which the rack framework grounding conductor can be bonded. Alternatives for this connection point are:

- Rack ground bus:
  Attach a dedicated copper ground bar or copper strip to the rack. A bond between the ground bar or strip and the rack shall exist. The mounting screws shall be of the thread-forming type, not self-tapping or sheet metal screws. Thread-forming screws create threads by the displacement of metal without creating chips or curls, which could damage adjacent equipment.
- Direct connection to the rack:
  If dedicated copper ground bars or strips and associated thread-forming/self-tapping screws are not used, then paint shall be removed from the rack at the connection point, and the surface shall be brought to a shiny gloss for proper bonding using an approved antioxidant.
- Bonding to the rack:
  When bonding the rack framework grounding conductor to the connection point on the cabinet or rack, it is desirable to use two-hole lugs. The use of two-hole lugs helps to ensure that the ground connection does not become loose because of excessive vibration or movement of the attaching cable.

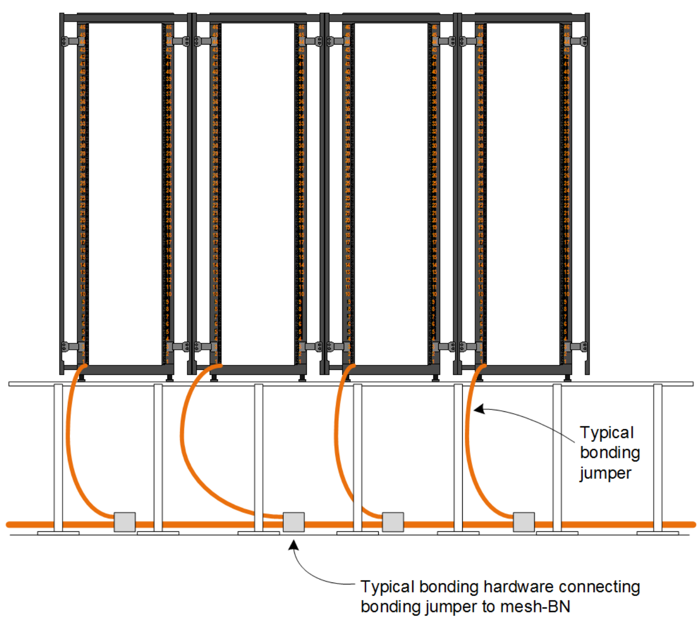


Figure 9-43
Example of Equipment Rack Bonding to a Mesh-BN

9.9.7.4.2 Recommendations

The recommended method for all bonding is the use of an insulated, stranded copper grounding wire, sized as recommended, and terminated by a two-hole compression lug or exothermic weld.

When bonding equipment cabinets or racks to the mesh-BN, it is recommended that each bonding hardware at the mesh-BN and bonding jumper be dedicated to a single cabinet or rack. As shown in Figure 9-44, the use of a single bonding jumper or single bonding hardware at the mesh-BN to bond multiple cabinets is not recommended. If a single bonding jumper or single bonding hardware is used to bond to the mesh-BN, the bonding hardware shall be listed for the application.

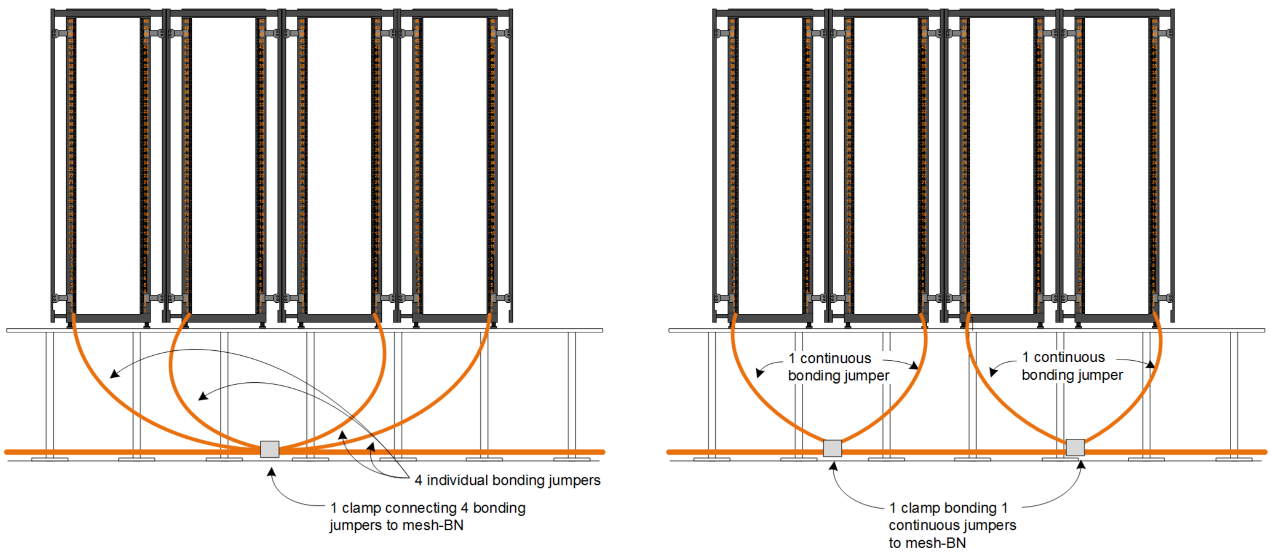


Figure 9-44
Examples of Inappropriate Equipment Rack Bonding to a Mesh-BN

A rack grounding busbar (RGB) or 13.3 mm^2 (6 AWG) rack bonding conductor (RBC) ground wire should be installed in each cabinet or rack, mounted on the backside of one upright running the entire height of the cabinet to provide an easy access grounding facility within each cabinet or rack. See Figure 9-45.

9.9.8 Information Technology Equipment Interconnections

9.9.8.1 Introduction

An integral part of the bonding and grounding network in the access floor area or any critical environment is the grounding of the IT support equipment and static discharge management during ongoing operations. This includes the connection of a cabinet of ITE chassis to the mesh-BN, connections between various IT systems and cabinets, and personal grounding checks and static charge dissipation.

9.9.8.2 Rack Connections to the Mesh-BN

It is common for cabinets to be physically connected for structural integrity, and they also may be logically, virtually, or network connected, acting as an integral platform.

This is achieved by the manufacturer assembling the cabinet or rack in such a way that there is electrical continuity throughout its structural members. For welded racks, the welded construction serves as the method of bonding the structural members of the rack together.

All adjacent cabinets and systems should be bonded in order to form grounding continuity throughout the rack structure itself.

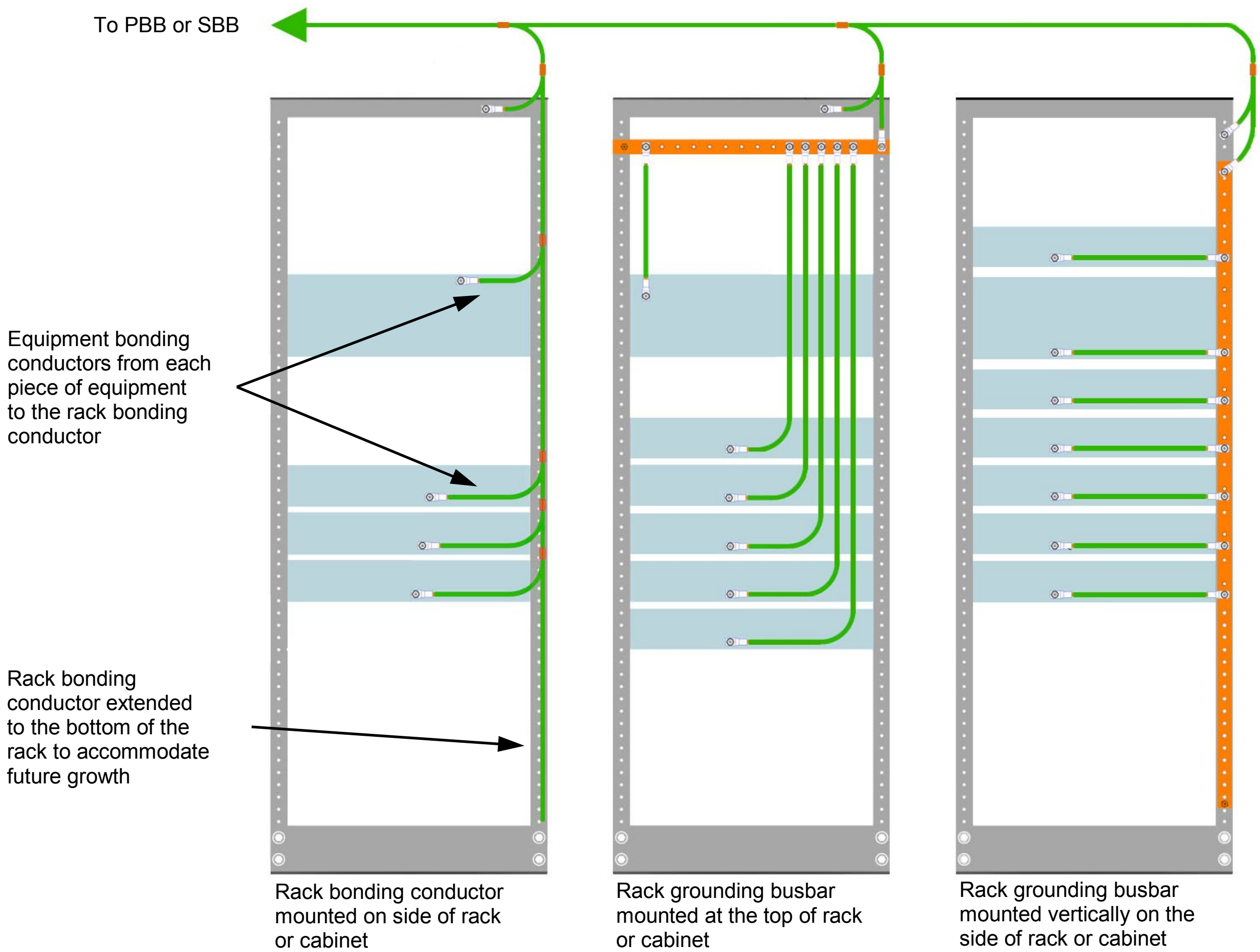


Figure 9-45
Examples of a Rack Bonding Conductor and Rack Grounding Busbar Mounting

Electrical continuity cannot be assumed using nut and bolt connections used to build or stabilize equipment cabinets and racks. Bolts, nuts, and screws used for rack assembly may not be specifically designed for grounding purposes, and unless grounding bonding jumpers are installed, do not assume electrical continuity for the cabinet lineup. Further, most cabinets and racks are painted, and as paint is nonconductive, this negates any attempt to accomplish desired grounding. Therefore, paint or cabinet coating has to be removed in the bonding area for a proper bond to be formed.

Most power is routed over the top or bottom of the rack. Without a reliable bond of all four sides of the rack, a safety hazard exists from potential contact with live feeds.

9.9.8.3 ITE Bonding to the Cabinet or Mesh-BN

9.9.8.3.1 Requirements

The ITE chassis shall be bonded to the rack using one of the following methods:

- Manufacturer-provided grounding location:
  Ideally, the manufacturer will supply a separate grounding hole or stud. If present, this hole or stud shall serve as the primary grounding site for the ITE chassis and shall be used with a conductor of proper size to handle any fault currents up to the limit of the circuit protection device feeding power to the equipment unit. Each end of this chassis grounding conductor will be bonded to the chassis hole or stud, and the other end will be properly bonded to the copper ground bar or strip. In some instances, it may be preferable to bypass the copper ground bar or strip and bond the chassis grounding conductor directly to the data center grounding infrastructure.

List continues on the next page

- Grounding via the mounting system:

  If the equipment manufacturer suggests grounding via the chassis mounting flanges and the mounting flanges are not painted, the use of thread-forming screws and normal washers will provide an acceptable bond to the rack.

  If the equipment mounting flanges are painted, the paint can be removed, or the use of the same thread-forming screws and aggressive paint-piercing lock washers, designed for this application, will supply an acceptable bond to safety ground through the rack.

Grounding through the equipment AC (alternating current) power cord does not meet the intent of this section where the power path and the equipment path offer redundant and specific ground paths for the ITE loads. While the AC-powered equipment typically has a power cord that contains a ground wire, the integrity of this path to ground cannot be easily verified. Rather than relying solely on the AC power cord ground wire, it is desirable that equipment be grounded in a verifiable manner such as the methods described in this section.

Once the cabinets or racks are grounded, the equipment installed within the cabinet or rack shall be bonded to the mesh-BN ground reference as well. Some of this has been undertaken by equipment manufacturers for enterprise-level or factory-configured systems. For field-assembled rack-mounted systems, equipment grounding must be added to complete the ITE-to-mesh-BN grounding connection via the cabinet chassis.

9.9.8.3.2 Recommendations

Cabinet doors and side panels should be bonded to the cabinet frame with the frame connected to the grounding system. (See Figure 9-46).

9.9.8.4 Personal Grounding and Static Discharge

Electrostatic discharge (ESD) is the spontaneous transfer of electrostatic charge. The charge flows through a spark (static discharge) between two bodies at different electrostatic potentials as they approach each other.

CAUTION: Electrostatic discharge (ESD) may cause permanent damage or intermittent malfunction of networking hardware. Anyone that touches network equipment or network cabling becomes a potential source of ESD as it relates to telecommunications equipment. Network cabling that has been installed but not connected may become charged when these cables are un-spooled and slid over carpet or other surface that contributes to the buildup of ESD. The charged cabling may become a source of ESD to the telecommunications equipment to which it connects. Charged cabling should be discharged to an earth ground prior to connection to network equipment. ESD charges may remain for some time, especially in dry conditions.

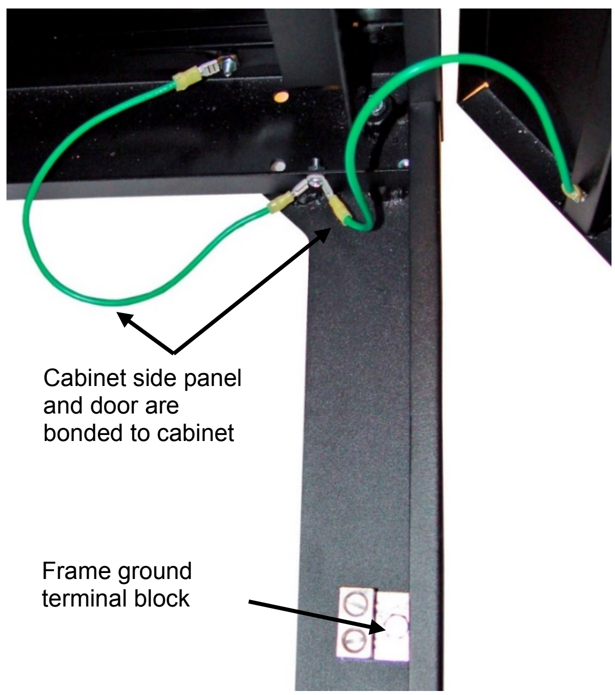


Figure 9-46
Example of Bonding of Cabinet Side Panel and Door

Factors affecting ESD charge retention include:

- Cable design
- Dielectric materials
- Humidity
- Installation practices

Low humidity and static-generating building materials are the primary causes of ESD. There should be no significant ESD charge retention difference between types of telecommunication cabling as all cables have a nearly identical ability to acquire a static charge (see Sections 14.8 and 14.9 for additional information about telecommunication cabling).

It is important to follow all ESD specifications and guidelines provided by the applicable network equipment manufacturer. Mitigation techniques, such as anti-static flooring and humidity control, are important for critical installations.

The use of static discharge wrist straps when working on or installing network or computer hardware is specified in most manufacturers' installation guidelines. Wrist strap ports should be attached to the rack by a means that ensures electrical continuity to ground. Pedestrian static discharge mats may be required for certain access floor environments or spaces with standard resistance flooring.

9.9.9 Power System Bonding and Grounding

9.9.9.1 Introduction

In the past, 4-wire systems were normal in critical facilities, mimicking the X-O bonding and services in traditional commercial spaces. This led to some substantial problems caused by ITE loads producing harmonics that were able to readily propagate through the power system. These harmonics caused problems such as large-scale and objectionable ground currents (often in the hundreds of amps), the failure of small X-O bonds on branch circuits, and ITE disruption and failure. Nuisance tripping of ground fault elements was also experienced.

The designer is faced with the question of what purpose the neutral serves in the 480/277 V_{AC} and 208/120 V_{AC} system. Only lighting and small-scale loads are served by the 480/277 V_{AC} and 208/120 V_{AC} neutral (when compared to the critical facilities overall load).

Without some form of isolation for these noncritical 480/277 V_{AC} and 208/120 V_{AC} neutrals, the incoming 480 V_{AC} service would be forced to generate a neutral at the highest point in the low-voltage electrical system to serve this minority of loads. This allows harmonics to propagate across several systems because they are being connected to a 4-wire switchboard or system. The balance of the loads in the facility are essentially 3-wire since there is no need for X-O bonds or a separately-derived system for the 3 phase, 3-wire mechanical system, or for the rectifier side of the UPS system. Some form of a separately-derived system or X-O bond is required for these small 480/277 V_{AC} and 208/120 V_{AC} loads. However, because generating a fourth wire for those systems and their X-O bond presents an issue for most of the electrical system, an isolation transformer for the small 480/277 V_{AC} loads is desirable.

Since isolating these loads is a positive design element and that an isolation transformer will be provided for the small 480/277 V_{AC} loads, 3-wire feeds then become the standard for the balance of the loads in facility. This indicates that the X-O bond for the 208/120 V_{AC} loads within the critical environments and below the inverters of the UPS systems are below the UPS on the load side of those systems.

All loads in the critical environment will be provided with dedicated and insulated ground wires from the load to the derived ground point at the PDU.

9.9.9.2 Bonding and Grounding – AC and DC Powered Telecommunication Systems

IEEE 1100 integrates many of the traditional telecommunications recommendations and describes how to integrate the AC and DC power systems to accomplish the important safety and performance objectives of each. The key concepts related to bonding and grounding deal with both the serving power system and the ITE. The serving power system is grounded to the building's grounding electrode system. The grounding electrode system is connected to the common bonding network within the building (see Figure 9-47). For ITE, IEEE 1100 refers to multipoint connections as the common bonding network and a single point of connection as an isolated (insulated) bonding network.

Much of the guidance on bonding and grounding DC power systems for telecommunications and ITE is rooted in the traditional telephone (telecommunications) utility (regulated) industry. The basis of this guidance is supported in IEEE 1100 for the commercial (deregulated) industry with some modifications made to meet requirements of the commercial market segment.

A significant observation is that, historically, telecommunications is DC powered and historically ITE is AC powered. Therefore, the bonding and grounding standards for these different types of power systems is historically different because of the DC being predominantly utilized in a regulated environment considered "under the exclusive control of the utility" (NFPA 70).

For the data center, a telecommunications bonding and grounding infrastructure, in accordance with ANSI/TIA-942-B, ANSI/TIA-607-C, ISO/IEC 30129, and IEEE 1100, is expected. This infrastructure is bonded to the electrical power grounding electrode system, to structural metal (where accessible), and to the serving AC power panel equipment ground at each floor. Grounding needed for the data center equipment is obtained from the appropriate ground bar on that floor (such as a SBB). Note that this bonding and grounding infrastructure is not the same physical structure as the grounding infrastructure that might be placed for the electrical power system.

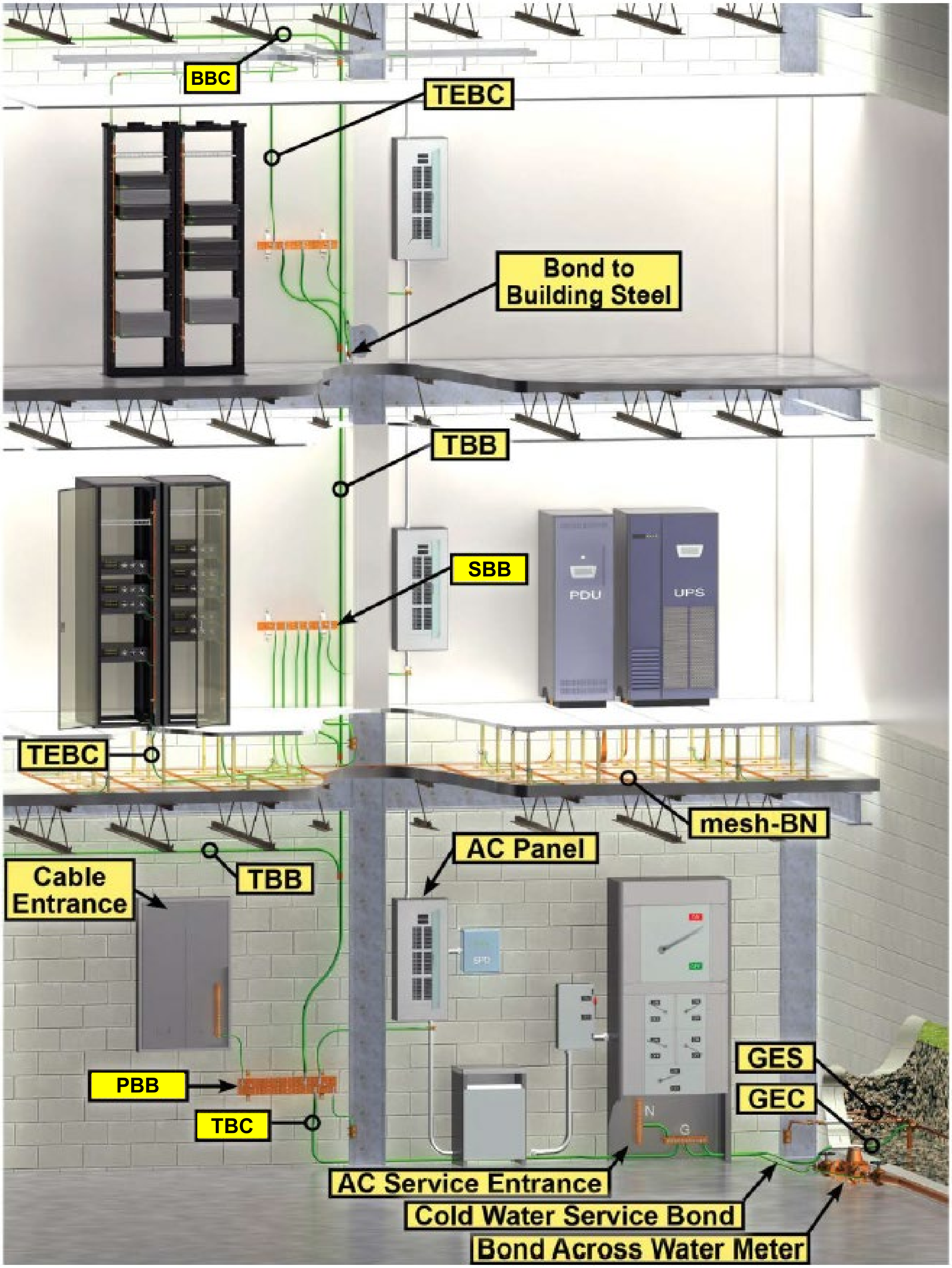


Figure 9-47
Telecommunications Bonding and Grounding Infrastructure

In no situation should a totally separate grounding system be deployed because this may lead to safety and performance problems.

Noise concerns for the data center equipment do involve common mode noise generated and distributed by the power system to the electronic load equipment. Generally, the equipment AC input power supplies are quite tolerant of common mode noise. It should also be expected that server and other equipment manufacturers will design and test their equipment's (higher voltage) DC input power supplies to ensure that they will be similarly robust. This is already accomplished for 48 V_{DC} telecommunications equipment meeting the requirements of Telcordia GR-1089-CORE-2006 and placed into a common bonding network (CBN).

9.9.9.3 Bonding and Grounding—Telecommunications DC Systems

Generally, telecommunications DC power systems date back to the first telephone systems where DC was used for signaling circuits and for operating switching and control relays. Centralized (bulk) DC power plants (systems) had primary components such as rectifiers, a powerboard, primary and secondary distribution feeders, and fuse bays. The DC power system was grounded to earth (often more than once). The grounded conductor was termed the return. The connected load equipment was called telecommunications load equipment (TLE [hereafter referred to as ITE]).

Modern DC power systems are more compact, use much smaller footprint components, and are more efficient. Today, a small, centralized DC power system can be contained in a single rack. For standards compliance purposes, this equipment is generally classified as ITE. For the purposes of evaluating DC powered ITE, robustness of the system is a key consideration. Accordingly, certain questions arise regarding grounding, bonding, and protection of the installation. Example questions include:

- Is the ITE suitably robust (per Telcordia GR-1089-2006) to operate in a Common Bonding Network (CBN)?
- Is the ITE not suitably robust (per Telcordia GR-1089-2006) and therefore, must be operated in an isolated bonding network (IBN)?

  NOTE: The significant role of the IBN topology is to isolate the ITE from currents flowing through the CBN, especially lightning.

- Is the DC power supply dedicated to a single type of equipment bonding network (CBN or IBN), or is it to be a shared resource?
- Where is the planned location for the DC power supply relative to the location of the ITE?
- Is any of the ITE required to integrate the return and DC equipment grounding conductor (DCEG) at the DC power input?
- Availability requirements for ITE in a data center may not need to be specified to all of the points required for a telecommunications service provider (TSP) such as at a telecommunications central office. The availability specification will determine if an IBN may be appropriate for the data center or a portion of the data center.

Generally, the modern centralized DC power system is designed to operate as a single-point grounded system. An equipment-grounding (bonding) conductor is installed as part of the distribution circuit to ground any metal parts of the ITE and to clear any ground faults by facilitating the timely operation of the upstream overcurrent protection device. The system grounding (electrode) conductor is termed the DCG and is connected to the return near the DC power source. The return is only grounded once. This arrangement is very similar to bonding and grounding an AC power system per NFPA 70 with some possible variations allowed by UL60950. See Figure 9-48 through Figure 9-52.

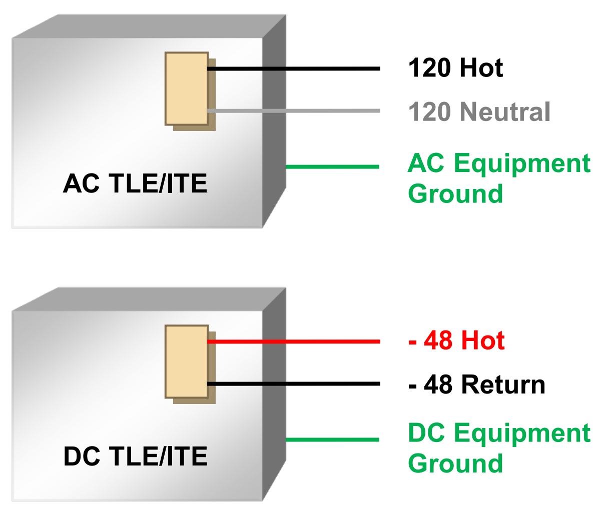


Figure 9-48
Similarity of Recommended Grounding for AC and DC Power Systems and Load Equipment

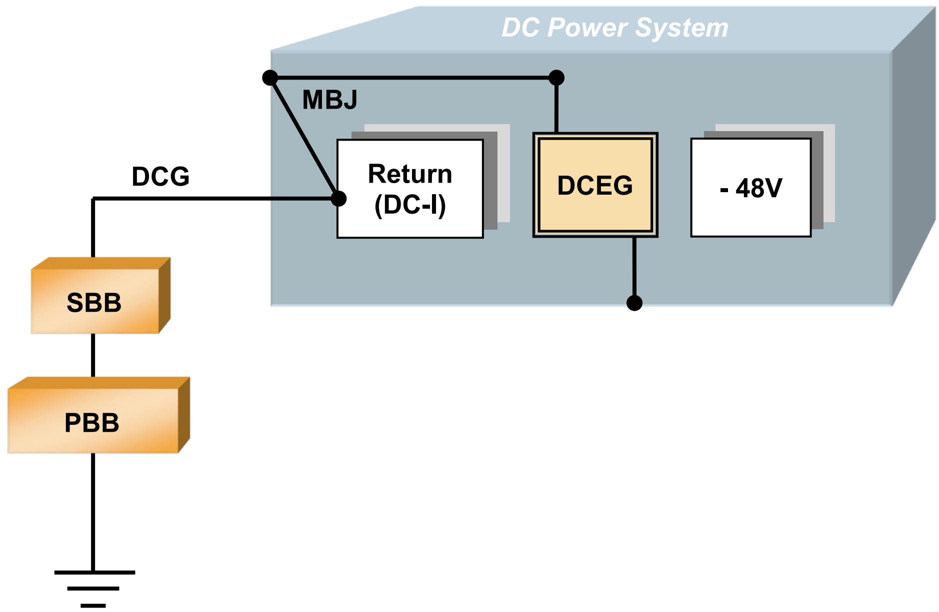


Figure 9-49
DC Power System Showing a Single-Point Grounded Return

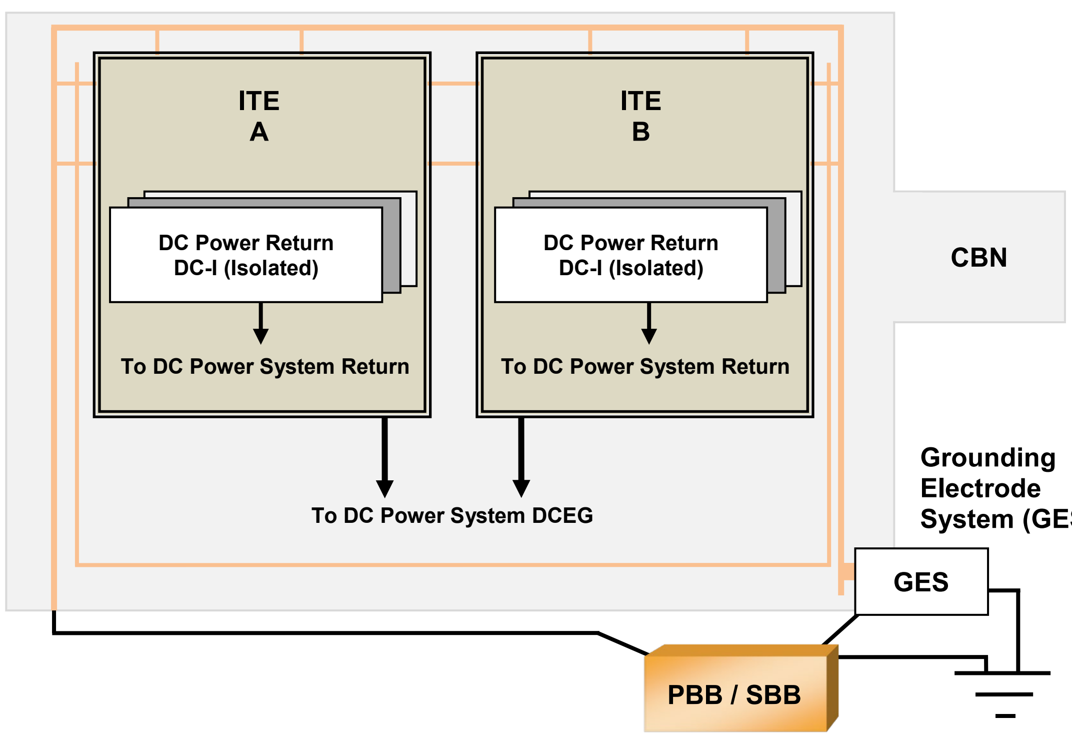


Figure 9-50
Information Technology Equipment Showing Grounding of DC Power Input (Return Is Insulated)

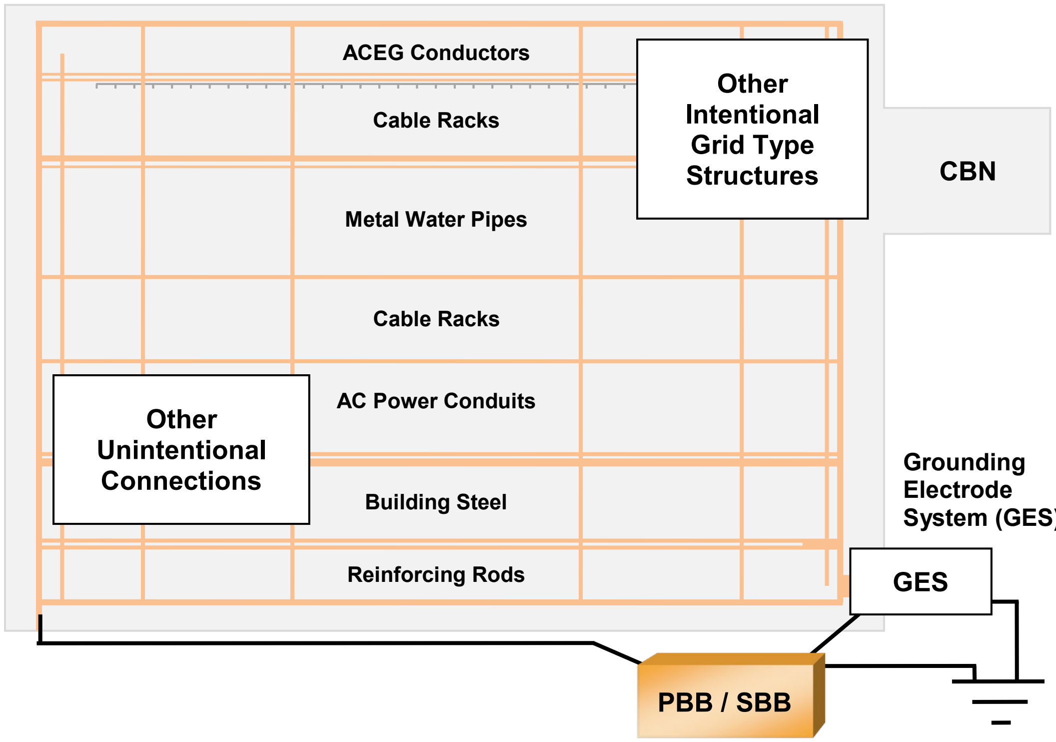


Figure 9-51
Common Bonding Network

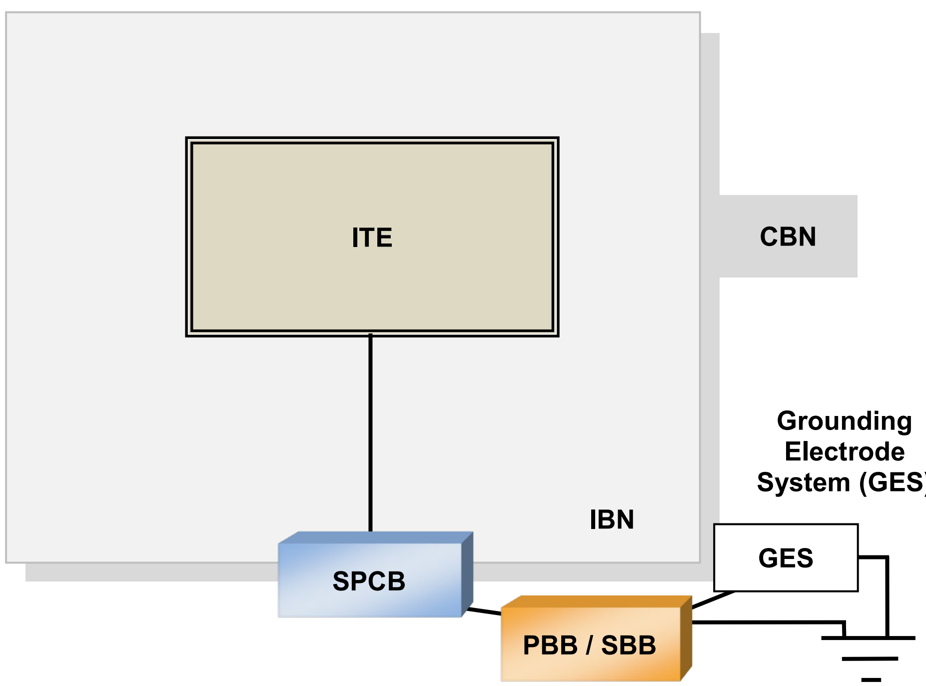


Figure 9-52
Isolated (Insulated) Bonding Network

9.9.9.4 Bonding and Grounding—Higher Voltage DC Systems (above 160 V_{DC})

9.9.9.4.1 Requirements

DC power systems for data centers shall meet applicable bonding and grounding requirements. Grounding and bonding methods shall comply with all requirements of the AHJ, including those for point-of-system grounding connections, equipment grounding, and conductor sizes for the grounding electrode system and equipment bonding jumpers.

9.9.9.4.2 Recommendations

For 380 V_{DC} systems, the preferred grounding method is high resistance mid-point grounding of the output of the DC power source (DC rectifier or DC UPS or other DC source equipment); however, other means of grounding are possible as solid mid-point grounding, positive side grounding, negative grounding, and even floating point (ungrounded) systems. The selection of the grounding methods depends primarily on the protection and fault detection for the entire system, and it should be consistent through the entire network. For more detailed requirements, please refer to the applicable standards.

9.9.9.4.3 Additional Information

There are several existing standards outlining recommended practices, including IEEE C2, IEEE 1100, and ANSI T1.311.

Applying DC power system telecommunications utility practices to the nonregulated environment of a data center requires additional considerations. These considerations include:

- The point at which the DC system grounding electrode conductor (DCG) attaches to the centralized DC power system and whether it is allowed to occur between the source and the telecommunications load equipment (per UL60950).
- Whether the DC power system equipment grounding conductor (DCEG) is allowed to be routed separate from the DC supply and return circuit conductors per UL 60950.
- Whether the DC equipment ground is permitted to be bonded to the return at the load equipment per UL 60950.

Based upon these considerations, the prudent approach is to utilize IEEE 1100 as the base document for bonding and grounding the DC power system in a data center as it:

- Provides a topology similar to that of an AC power system
- Provides a single-point grounding of the DC power system at the source location
- Provides a co-routed DC equipment grounding conductor with the circuit wiring (supply such as – 48 V return)
- Prohibits bonding of DC equipment grounding conductor to the return at the load equipment
- Provides fully controlled paths for direct current

9.10 Labeling and Signage

9.10.1 Introduction

Labeling and signage falls into several categories:

- Building information such as room names and numbers
- Hazard and safety such as chemical and shock hazard signage, exit signs, wet or open floor rope-offs, safety data sheet (formerly called material safety data sheet) locations, EPO signage, and warning signs for personnel, operation, or safety
- Indicating signage such as equipment labeling and the color-coding of systems
- Informational such as routine and exceptional informational posting on bulletin boards

9.10.2 Requirements

Systems and labeling shall be color coded according to IEEE standards (e.g., IEEE), and are subject to approval by the AHJ.

Labeling shall be integrated to the individual systems and shall provide the operator an understanding of system status under cursory examination. Labeling works hand in hand with the graphical user interface (GUI) and the physical organization of the equipment and systems themselves.

The GUI is typically a visual dashboard for the complete operation of the system. Information that the GUI typically includes are a color -coded power flow diagram, electrical performance, electrical characteristics, and alarm status.

Equipment may have a mimic bus display, indicating how power flows through the system and how the individual breaks are connected. It may also be color-coded for the critical, utility, and generator power systems. For example, a critical power system with four distinct UPS systems could be labeled UPS-A, UPS-B, UPS-C, and UPS-D. Such a system could bear a unique color-coding where the A system might be red, the B system might be blue, the C system might be green, and the D system might be yellow. This color-coding would be carried all the way through the system.

All branch and data center circuits shall be marked with their individual circuit designations. Conduit systems and junction boxes shall also be color-coded by system, and power feeders may also bear their specific designation (e.g., UPS A Input). Conduit color-coding may be via a label, cladding, or painting.

9.10.3 Recommendations

Circuits that are on the output of an UPS or that support critical loads should be color-coded to readily distinguish them from non-critical circuits. This color-coding may be in the form of colored self-adhesive labels or nameplates.

Equipment labeling should possess all critical information concerning the system to which it is affixed. This information should include:

- Equipment nomenclature and designation (e.g., Generator AH54)
- System capacity rating in kVA and kW (e.g., 750 kVA/675 kW)
- Input voltage, phasing, and connection (e.g., 480 V, 3-phase, 3-wire)
- Output voltage, phasing, and connection (e.g., 480 V, 3-phase, 3-wire)
- Power factor (e.g., 0.9 lagging)
- System or switchboard serving this piece of equipment
- System, switchboard, or load that is being served by this equipment

See Figure 9-53 for an example of an equipment nameplate.

Uninterruptible Power Supply
System 1A

750 kVA / 675 kW
480 V, 3 Phase, 3-wire Input
480 V, 3 Phase, 3-wire Output
60 Hz, 0.9 pf lagging

Served By Substation 1A, Circuit Breaker 5
Located in Room B-121

Serving Critical Power Distribution Switchboard 1A
Located in Room B-141

Figure 9-53
Sample Equipment Nameplate

Color-coding of equipment power cords, power strips, cables for branch circuits, and receptacle labels to identify A and B feeds is recommended. A common choice I to use red for 'A' and blue for 'B', where the 'B' in blue matching the 'B' electrical source.

Equipment power cords should be labeled at both ends to avoid disconnecting the wrong power cord when making changes. Also consider using locking power cords, receptacles, or retention clips on power strips.

9.10.3.1 Arc Flash Labels

A Class F3 or Class F4 data center can be designed to allow concurrent maintenance so that work should never be required on energized equipment. However, such architecture may be prohibitively expensive or inappropriate for the application. So-called "hot work" is not a best practice and should be avoided whenever possible, but in a 24/7 data center operation, scheduled down time may not be available on demand. Work on energized equipment would require an authorized energized equipment work permit (EEWP).

Labeling should conform to requirements of local codes, but typical minimum requirements identify:

- Voltage
- Fault current
- Flash and shock boundaries
- Incident energy levels
- Recommended minimum levels of PPE

Figure 9-54 shows an example of an arc flash label.

WARNING

Arc Flash and Shock Hazard
Appropriate PPE Required

1. Check with Master Work Permit Issuing Official before start of work.
2. Clear the area of Unqualified Personnel before start of work.
3. Wear the PPE listed below if working within the flash zone on exposed energized parts.
4.

Voltage: **480 V**
Available Fault Current: **80 kA**
Flash Zone: **5.0 ft.**
Incident Energy: **40 cal/cm^2**
PPE Class: **4**
PPE Required:

- Untreated natural fiber T-shirt
- FR shirt and pants or 5 APTV coveralls
- Flash suit jacket, pants and hood
- Hard hat with FR liner
- Safety glasses or goggles
- Ear plugs (ear canal inserts)
- Steel toe leather work boots with no cuts or abrasions that expose the metal

Figure 9-54
Example Arc Flash Warning Label (United States)

9.11 Testing and Quality Assurance

9.11.1 Requirements

All functional testing shall examine normal, failure and maintenance modes of operation.

9.11.2 Recommendations

Testing and design/construction quality assurance are vital to validate that the design and installation will operate as intended. While this may appear to be a daunting task, by approaching this process as a sequential, reinforcing, non-redundant set of activities, it can present a logical and direct solution to systems validation needs.

For electrical systems and the sheer complexity and safety required to operate these systems, there are two fundamental camps—basic electrical construction quality control and system functional testing. The electrical quality control considerations include feeder continuity testing, basic switchboards testing, feeder landing/torque testing, labeling, overcurrent short circuit validation, trip settings per the coordination study, and safety signage such as arc flash indication. Basic system startup, assisted by the manufacturer's representatives, is also included in this group of activities.

The system functional testing assumes that the basic field quality controls will render a complete, safe, and functional system pursuant to the design and specifications. Testing steps assume that the installation has fully met the requirements of a specific testing level prior to proceeding to the next phase of testing.

9.12 Ongoing Operations

9.12.1 Recommendations

Facility and maintenance operations are an integral part of any critical facility. Human error is the leading factor in outages and errors related to MTBF, and these errors also bear upon MTTR, the crux of availability. There are recognized best practice management frameworks that cover these in detail, but the following are some high-level recommendations:

- All work should be scripted and specific to the activity being undertaken, and all risks associated with such activity should be identified prior to performing the tasks.
- IT and facility operations should work collaboratively regardless of Class or business.
- Planned activities should include preventive and programmable maintenance, repair and replacement of components, addition or removal of capacity components, and testing of components and systems.
- Work on energized equipment should be eliminated whenever possible. Where such work is unavoidable, personnel should be trained, certified, authorized, and provided appropriate personal protective equipment.

9.13 Electrical Systems Matrix

Table 9-17 provides a summary of Section 9, *Electrical Systems*, with the items in the table presented in sequential order. Additional information has also been placed in the table that was not necessarily presented or explained in the preceding text. Readers are cautioned that some of the additions can include requirements where so indicated, and that Table 9-17 is to be used in conjunction with the text of Section 9.

Table 9-17 Electrical Systems Availability Classes

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.1 (Electrical systems) Overview					
Common industry description	Single path data center that meets the minimum requirements of the standard, but doesn't meet the requirements of an F1 or higher	Single path	Single path with redundant components	Concurrently maintainable and operable	Fault tolerant
Number of power delivery paths to the critical load	One	One	One	Two, one active minimum with one passive/non-UPS power or one additional active	Two or more active
Redundant system components (e.g., UPS and generators)	No	No	Yes	Yes	Yes
Distinct UPS sources (e.g., A and B)	Optional/may not be present	Single or N	Single or N	Single or more, depending on the critical power topology	At least two resulting in a minimum of N + 2
System allows concurrent maintenance and operations	No	No	Within some systems with paralleled components, but not consistent throughout the electrical system.	Yes	Yes
System allows fault tolerance and self-healing failures?	No	No	No	Possible, depending on system configuration	Yes
Loss of redundancy during maintenance or failure?	Yes. Redundancy is zero, so load loss or systems interruption would be expected.	Yes. Redundancy is zero, so load loss or systems interruption would be expected.	Yes, for the power paths. Redundancy may exist in paralleled systems, and system topology may prevent load loss or interruption during routine maintenance or expected failures.	Yes, but the redundancy level reduced to N during maintenance or after a failure	No, but the redundancy level reduced to a level of >N during maintenance or after a failure.

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
ITE and telecommunications equipment power cords	Single- or dual-cord feed with no redundancy up to critical power system capacity. No ability to switch automatically between input sources via static switch-based PDU or panel.	Single- or dual-cord feed with no redundancy up to critical power system capacity. No ability to switch automatically between input sources via static switch-based PDU or panel.	Single- or dual-cord feed with no redundancy up to critical power system capacity. No ability to switch automatically between input sources via static switch-based PDU or panel.	Single-, dual- or poly-cord feed with either 100% capacity on each cord or adequate capacity on each cord mapped to the individual ITE system should a given source fail (e.g., 5 to make 6 or 2 to make 3 inputs).	Single-, dual- or poly-cord feed with either 100% capacity on each cord or adequate capacity on each cord mapped to the individual ITE system should a given source fail (e.g., 5 to make 6 or 2 to make 3 inputs).
Ability to add systems or components without interruption to existing loads	No	No	No	If planned during the initial design	Yes
Single points of failure	One or more	One or more	One or more	None	None
UPS redundancy	If present, N or <N	N	A minimum of N+1	A minimum of N+1	Multiple N, 2N, 2N+1 or any configuration greater than N+1 that does not compromise redundancy during failure or maintenance modes of operation
UPS topology	If present, single module or parallel non-redundant system	Single module or parallel non-redundant modules	Parallel redundant modules or distributed redundant modules	Parallel redundant or distributed redundant or isolated redundant system	Parallel redundant or distributed redundant or isolated redundant system
9.2 Utility service					
Utility entrance	Single feed	Single feed	Single feed	One source with two inputs or one source with single input electrically diverse from backup generator input	One or more sources with two inputs. Dual feeds from different utility substations recommended
Multiple services	Not required	Not required	Optional – multiple services only based upon the service size	Optional – multiple services only based upon the service size	Recommended – multiple services based upon the service size
Service entrances physically separated	N/A	Optional	Optional	Recommended	Required

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Location	Secured or unsecured	Secured or unsecured	Secured or unsecured	Secured	Secured
Underground or overhead	Underground or overhead	Underground or overhead	Underground or overhead	Underground (recommended)	Underground (required)
Concrete-encased for underground	Optional	Optional	Optional	Recommended	Recommended
9.2.2 Low voltage services					
Utility – generator transfer scheme	Typically not available	ATS or breaker	ATS or breaker	ATS or breaker	ATS or breaker
Main	80% rated	80% rated	80% rated	80 - 100% rated	100% rated
Data center loads served from	Non-dedicated switchboard	Main switchboard	Main switchboard	Dedicated subsystem	Dedicated subsystem
Location	Indoor or outdoor	Indoor or outdoor	Indoor	Indoor	Indoor
Rating	Series or fully rated	Series or fully rated	Fully rated	Fully rated	Fully rated
Construction	Switchboard	Switchboard	Switchboard	Switchboard	Switchboard
Breaker types	Fixed or drawout	Static or drawout	Static or drawout	Drawout only	Drawout only
9.2.3 Medium voltage services					
Utility – generator transfer scheme	ATS or breaker if generator or alternate source is available	ATS or breaker	ATS or breaker	ATS or breaker	ATS or breaker
Main	100% rated	100% rated	100% rated	100% rated	100% rated
Data center loads served from	Main switchboard or non-dedicated switchboard	Main switchboard	Main switchboard	Dedicated subsystem	Dedicated subsystem
Location	Indoor or outdoor	Indoor or outdoor	Indoor	Indoor	Indoor
Rating	Fully rated	Fully rated	Fully rated	Fully rated	Fully rated
Construction	Switchboard	Switchboard	Switchboard	Switchboard	Switchboard
Breaker Types	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount or drawout, depending on system redundancy	Fixed-mount or drawout, depending on system redundancy
9.2.4 Protective relaying					
Type	Commercial or utility grade	Commercial or utility grade	Commercial or utility grade	Commercial or utility grade	Utility grade
9.3 Distribution					
Cable terminations	Mechanical or compression lug	Mechanical or compression lug	Mechanical or compression lug	Mechanical or compression lug	Compression lug
Busway terminations (where used)	Locking washer	Locking washer	Locking washer	Locking or Belleville washer	Locking or Belleville washer

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Busway treatment (where used)	Tinned joints optional	Tinned joints optional	Tinned joints optional	Tinned joints optional	Tinned joints recommended
9.3.6 Utility/generator transfer control and generator paralleling switchboard					
Transfer system	Automatic transfer switch or interlocked circuit breakers, if generator present	Automatic transfer switch or interlocked circuit breakers	Automatic transfer switch or interlocked circuit breakers	Automatic transfer switch or interlocked circuit breakers	Automatic transfer switch or interlocked circuit breakers
Critical load system transfer	Automatic or manual transfer if a generator is present. Maintenance bypass optional. UPS power system may be optional.	Automatic transfer with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic transfer with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic transfer with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.	Automatic transfer with maintenance bypass feature for serving the switch with interruption in power; automatic changeover from utility to generator when a power outage occurs.
Transfer type	Open or closed transition	Open or closed transition	Open or closed transition	Open or closed transition	Open or closed transition
Transfer and control points	One for the whole critical load.	One for whole critical load	Multiple ATSs or 2N on the utility	One for each UPS system; one for each mechanical branch and one for the non-critical load or common loads	One for each UPS system; one for each mechanical branch and one for the non-critical load or common loads
UPS	One, combined with all loads if generator present	One for whole critical load	Dedicated to UPS	Dedicated to UPS path	Dedicated to UPS path
Mechanical	One, combined with all loads if generator present	One for whole critical load	Dedicated to mechanical	Dedicated to each mechanical path	Dedicated to each mechanical path
Non-critical load	One, combined with all loads if generator present	One for whole critical load	Dedicated to non-critical load	Dedicated to non-critical load	Dedicated to non-critical load, maintain diversity of system
Generator control switchboard	If needed	If needed	If needed	If needed	If needed
Location	Indoor or outdoor	Indoor or outdoor	Indoor	Indoor	Indoor
Rating	Fully rated	Fully rated	Fully rated	Fully rated	Fully rated
Construction	Switchboard	Switchboard	Switchboard	Switchboard	Switchboard
Breaker types	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount, with drawout preferred	Drawout only
Controls	Single/Stand-Alone	Single/Stand-Alone	Single or Redundant	Redundant	Redundant
Relay type	Commercial grade	Commercial grade	Commercial or industrial grade	Commercial or industrial grade	Industrial grade

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.3.7 Unit substations					
Transformer MV primary protection	Fused or breakers, depending on utility	Fused or breakers, depending on utility	Fused or breakers, depending on utility	Fused or breakers, depending on utility	Fused or breakers, depending on utility
Transformer specification	High-flash point oil, air or cast core	High-flash point oil, air or cast core	High-flash point oil, air or cast core	High-flash point oil, air or cast core	High-flash point oil, air or cast core
Rating	Fully rated	Fully rated	Fully rated	Fully rated	Fully rated
Construction	Switchboard	Switchboard	Switchboard	Switchboard	Switchboard
Breaker Types	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount, with drawout preferred	Drawout only
Controls	Single/Stand-Alone	Single/Stand-Alone	Single or Redundant	Redundant	Redundant
9.3.8 UPS					
UPS Maintenance Bypass Arrangement	Optional	UPS module, static switch and maintenance bypass from same switchboard	UPS module, static switch and maintenance bypass from same switchboard	UPS module may be fed from opposite system for redundancy. Alternatively, the downstream critical load being served may be provided from a separate and redundant UPS power system and path. This redundant path may be connected upstream at an ASTS or at the load itself via multiple power cords	UPS module may be fed from opposite system for redundancy. Alternatively, the downstream critical load being served may be provided from a separate and redundant UPS power system and path. This redundant path may be connected upstream at an ASTS or at the load itself via multiple power cords
UPS power distribution – panelboards	If UPS present, panelboard incorporating standard thermal magnetic trip breakers	Panelboard incorporating standard thermal magnetic trip breakers	Panelboard incorporating standard thermal magnetic trip breakers	Panelboard incorporating standard thermal magnetic trip breakers	Panelboard incorporating standard thermal magnetic trip breakers
Method of distribution to ITE and telecommunications equipment	PDU or individual panelboards if UPS present.	PDU or individual panelboards	PDU or individual panelboards	PDU	PDU
Multi-system UPS power system synchronization	N/A	N/A	Optional	Optional. May be via static inputs or an external control system.	Optional. May be via static inputs or an external control system.
UPS power system segregated from mechanical or support loads	N/A	Optional	Recommended	Recommended	Recommended

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
External maintenance bypass	Optional	Recommended	Recommended	Recommended	Recommended
9.3.9 UPS Output (critical distribution) switchboards					
Location	Indoor	Indoor	Indoor	Indoor	Indoor
Rating	80% - 100% rated	80% - 100% rated	80% - 100% rated	80% - 100% rated	Fully rated
Construction	Switchboard	Switchboard	Switchboard	Switchboard	Switchboard
Breaker Types	Fixed-mount or drawout	Fixed-mount or drawout	Fixed-mount or drawout	Drawout only	Drawout only
Controls	Single/Stand-Alone	Single/Stand-Alone	Single or redundant	Redundant	Redundant
9.3.10 Power distribution units					
Inputs	Single	Single	Single or dual	Single or dual	Single or dual
Transformer K-rating	K-rated, depending on load or application	K-rated, depending on load or application	K-rated, depending on load or application	K-rated, depending on load or application	K-rated, depending on load or application
Location	In computer room, service gallery (subject to AHJ approval), or electrical room	In computer room, service gallery (subject to AHJ approval), or electrical room	In computer room or service gallery (subject to AHJ approval)	In computer room or service gallery (subject to AHJ approval)	In computer room or service gallery (subject to AHJ approval)
Rating	Continuous duty	Continuous duty	Continuous duty	Continuous duty	Continuous duty
Breaker Types	Fixed-mounted	Fixed-mounted	Fixed-mounted	Fixed-mounted	Fixed-mounted
Controls	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Stand-alone
9.3.11 Static transfer switches					
Use of STS	Critical load switching when alternate source is available	Critical load switching when alternate source is available	Critical load switching when alternate source is available	Critical load switching	Critical load switching
Configuration	Primary or secondary	Primary or secondary	Primary or secondary	Primary or secondary	Primary or secondary
Inputs	Two	Two	Two	Two or three	Two or three
Location	In computer room, service gallery, or electrical room	In computer room or service gallery	In computer room or service gallery	In computer room or service gallery	In computer room or service gallery
Rating	Continuous duty	Continuous duty	Continuous duty	Continuous duty	Continuous duty
Short circuit tolerance	Fused or unfused short circuit protection integrated to internal circuit breakers	Fused or unfused short circuit protection integrated to internal circuit breakers	Circuit breaker protection for short circuits	Circuit breaker protection for short circuits or ability to transfer from a shorted bus	Type 3 circuit breaker protection for short circuits or ability to transfer from a shorted bus
Breaker Types	Fixed-mounted	Fixed-mounted	Fixed-mounted	Fixed-mounted	Fixed-mounted
Controls	Stand-alone	Stand-alone	Stand-alone	Stand-alone	Stand-alone

System/Class	Class F0	Class F1	Class F2	Class F3	Class F4
9.3.14 Busway power distribution					
Number of busways per row	If used, minimum of one	If used, minimum of one	If used, minimum of one	If used, minimum of two	If used, minimum of two
9.3.15 Computer room equipment power distribution					
Individual circuits in separate conduits or cables	Optional	Optional	Recommended	Recommended	Recommended
Receptacles labeled with individual circuit	Optional	Optional	Recommended	Recommended	Recommended
Color-coded conduit and junction boxes per upstream UPS source	Optional	Optional	Recommended	Recommended	Recommended
Twist-lock receptacles for equipment or power strips	Optional	Optional	Recommended	Recommended	Recommended
Circuits mapped to UPS plant capacity/redundancy	Yes, if UPS power system present	Recommended	Recommended	Recommended	Recommended
9.3.16 Emergency power off (EPO) systems					
Computer room EPO system					
Single Step system	Optional	Optional	Not recommended	Not recommended	Not recommended
3 state system – off/test/armed	Optional	Optional	Not recommended unless mandated by code	Not recommended unless mandated by code	Not recommended unless mandated by code
Video surveillance camera on EPO station	Optional	Optional	Optional	Optional	Recommended
Shutdown of UPS power receptacles in computer room area pursuant to Code	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
Shutdown of AC power for cooling equipment in room	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
Compliance with local code (e.g., separate systems for UPS and HVAC)?	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
Ability to safely turn off fire alarm connection for maintenance	Recommended	Recommended	Recommended	Recommended	Recommended

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
When present, automatically activate EPO when fire suppressant is released	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
Fire suppressant release for single zone system after emergency power off (EPO) shutdown	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
Second zone fire alarm system activation. Sounds pre-release on first zone with suppressant release and EPO on the second zone	Optional	Optional	Optional	Recommended	Recommended
Delay to EPO activation after button push	Optional	Optional	Optional	Optional	Optional
EPO override switch (keyed or non-keyed)	Optional	Optional	Optional	Optional	Optional
EPO activation countdown timer	Optional	Optional	Optional	Optional	Optional
Whole building EPO	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ	According to local AHJ
9.4 Mechanical equipment support					
9.4.3.2 Chillers					
Feeds	Single	Single	Single	Single or dual, depending on mechanical plant redundancy	Single or dual, depending on mechanical plant redundancy
Source Selection	Not required	Not required	Not required	Manual or automatic	Manual or automatic
Source Mapping	N - single path	N - single path	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.
9.4.3.2 Cooling towers					
Feeds	Single	Single	Single	Single or dual, depending on mechanical plant redundancy	Single or dual, depending on mechanical plant redundancy
Source Selection	None	None	None	Manual or automatic	Manual or automatic

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Source Mapping	N - single path	N - single path	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.
9.4.3.3 Pumps					
Feeds	Single	Single	Single	Single or dual, depending on mechanical plant redundancy	Single or dual, depending on mechanical plant redundancy
Source Selection	None	None	None	Manual or automatic	Manual or automatic
Source Mapping	N - single path	N - single path	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.
9.4.3.4Air handling systems					
Feeds	Single	Single	Single	Single or dual, depending on mechanical plant redundancy	Single or dual, depending on mechanical plant redundancy
Source Selection	None	None	None	Manual or automatic	Manual or automatic
Source Mapping	N - single path	N - single path	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.
9.4.3.5 Humidification					
Feeds	Single	Single	Single	Single or dual, depending on mechanical plant redundancy	Single or dual, depending on mechanical plant redundancy
Source Selection	None	None	None	Manual or automatic	Manual or automatic
Source Mapping	N - single path	N - single path	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.	Mapped to mechanical redundancy. Dual input will require internal or external transfer switch.
9.5 UPS					
Use of UPS	Optional	Required	Required	Required	Required

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.5.3.3.2 Static UPS					
Sizing	Either not present, or rated at <N for the connected critical load	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor
9.5.3.3.3 and 9.5.3.3.4 Rotary and hybrid UPS					
Sizing	Either not present or rated at <N for the connected critical load	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor	To kW rating of the load with system designer's safety factor
9.5.4 Paralleling and controls					
Static switch duty type	Momentary, if present	Momentary	Momentary or continuous	Continuous	Continuous
External Synch	N/A	N/A	By design	By design or active control	By design or active control
9.5.5 Batteries and stored energy					
Flywheel or battery	Either	Either	Either	Either	Either
Sizing	kW	kW	kW	kW	kW
Spill containment	By code	By code	By code	By code	By code
Monitoring interface with BMS	Optional	Optional	Optional	Recommended	Recommended
One or more battery strings per module	Optional	Optional	Recommended	Recommended	Recommended
Minimum full load standby time	Minimum safe time to transfer to and from generator within the capabilities of the energy storage device. Longer time optional.	Minimum safe time to transfer to and from generator within the capabilities of the energy storage device. Longer time optional.	Minimum safe time to transfer to and from generator within the capabilities of the energy storage device. Longer time optional.	Minimum safe time to transfer to and from generator within the capabilities of the energy storage device. Longer time optional.	Minimum safe time to transfer to and from generator within the capabilities of the energy storage device. Longer time optional.
Battery full load testing/inspection schedule	Every two years or as recommended by manufacturer	Every two years or as recommended by manufacturer	Every two years or as recommended by manufacturer	Every two years or as recommended by manufacturer	Every two years or as recommended by manufacturer
Batteries separate from UPS/switchboard equipment rooms	Optional, depending on battery type and size of system	Optional, depending on battery type and size of system	Optional, depending on battery type and size of system	Recommended	Recommended
Battery monitoring system	UPS self monitoring if UPS power system present	UPS self monitoring	UPS self monitoring	Recommended (ohmic readings are less reliable for large vented lead-acid batteries)	Recommended (ohmic readings are less reliable for large vented lead-acid batteries)

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.6 Standby power systems					
Generator or assured alternate power source utilized	Optional	Required	Required	Required	Required
Fuel run time	No requirement	Based on disaster plan; 8 hrs recommended	Based on disaster plan; 24 hrs recommended	Based on disaster plan; 72 hrs recommended	Based on disaster plan; 96 hrs recommended
Rating	No requirement	kW load only	kW load only	kW load only	kW load only
Load Supported	No requirement	All loads	All loads	All loads	All loads
Installation	No requirement	Outdoor or indoor	Outdoor or indoor	Recommended indoor	Recommended indoor
Redundancy	No requirement	N	N N+1 or generate tap box recommended	N+1	Greater than N+1
Bearing Sensors	No requirement	No	No	Optional	Recommended
9.6.2 Starting systems					
Start time delay (maximum for 1st generator on and load transferred	No recommended time in excess of AHJ requirements	10 second or as required by AHJ	10 second or as required by AHJ	10 second or as required by AHJ	10 second or as required by AHJ
Maximum load assumption time (all loads)	No recommended time in excess of AHJ requirements	3 min	2 min or as required by AHJ	1 min or as required by AHJ	1 min or as required by AHJ
Battery capacity	N	N	N	2N/independent	2N/independent
Starter count	N	N	N	2N	2N
Best battery selection system	Optional	Optional	Optional	Recommended	Recommended
9.6.3 Fuel systems					
Fuel filters					
Grade	Standard	Standard	Standard	Continuous operation	Continuous operation with fuel/water separator
100 micron	Recommended	Recommended	Recommended	Recommended	Recommended
30 micron	Optional	Optional	Optional	Recommended	Recommended
10 micron	Optional	Optional	Optional	Optional	Recommended
Spin-on/off while operating	Optional	Optional	Optional	Recommended	Recommended
Fuel polish	Optional	Optional	Optional	Recommended	Recommended
Fuel additive/treatment	Optional	Optional	Optional	Recommended	Recommended
Fuel line type	Standard	Standard	Standard	Marine/Braided Steel	Marine/Braided Steel

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.6.5 Exhaust systems					
Sound rating	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ
Air quality	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ
Pollution abatement	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ	As required by the local AHJ
Exhaust piping	Welded	Welded	Welded	Welded	Welded
Connections to engine	Steel and flexible	Steel and flexible	Steel and flexible	Steel and flexible	Steel and flexible
9.6.6 Cooling systems					
Rating	Match engine rating for continuous, standby or prime rating	Match engine rating for continuous, standby or prime rating	Match engine rating for continuous, standby or prime rating	Match engine rating and ASHRAE (or local equivalent) extreme temperature published for the project location	Match engine rating and ASHRAE (or local equivalent) extreme temperature published for the project location
9.6.2 – 9.6.6 Monitoring and controls					
Controls	Onboard generator	Onboard generator	Onboard generator or centralized if paralleled	Onboard generator or centralized if paralleled	Onboard generator or centralized if paralleled
Pre-Alarm Conditions Reported	No	No	Yes, summary only	Yes, by point	Yes, by point
Alarm Conditions Reported	Yes, summary only	Yes, summary only	Yes, summary only	Recommended by point	Recommended by point
Trouble Conditions Reported	Yes, summary only	Yes, summary only	Yes, summary only	Yes, by point	Yes, by point
9.6.7 Mounting					
Mounting	Pursuant to AHJ requirements	Pursuant to AHJ requirements	Pursuant to AHJ requirements	Pursuant to AHJ requirements	Pursuant to AHJ requirements
9.7 Automation and control					
9.7.2 Monitoring					
Summary alarm and trouble alerts	Optional	Optional	Recommended	Recommended	Recommended
Dynamic/real time single line	Optional	Optional	Optional	Optional	Recommended
Operations simulator	Optional	Optional	Optional	Recommended	Recommended
Utility bus/buses	Optional	Optional	Optional	Recommended	Recommended
Generator bus/buses	Recommended	Recommended	Recommended	Recommended	Recommended
Generators	Recommended	Recommended	Recommended	Recommended	Recommended

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Non-critical and mechanical power systems	Optional	Optional	Optional	Recommended	Recommended
UPS output bus	Optional	Optional	Recommended	Recommended	Recommended
UPS modules	Optional	Optional	Recommended	Recommended	Recommended
Batteries/stored energy system	Optional	Optional	Recommended	Recommended	Recommended
PDUs	Optional	Optional	Recommended	Recommended	Recommended
Collector bus or static bypass cabinet	Optional	Optional	Recommended	Recommended	Recommended
Branch circuit distribution	Optional	Optional	Optional	Recommended	Recommended
EPO system (when present)	Optional	Optional	Recommended	Recommended	Recommended
Fire alarm system	Recommended	Recommended	Recommended	Recommended	Recommended
Power quality	Optional	Optional	Recommended on the UPS output, optional on other portions of the system	Recommended only on the utility, generators and UPS output, optional on other portions of the system	Recommended throughout
Database for alarm and trouble signals	Optional	Optional	Optional	Recommended	Recommended
Power quality monitoring	Optional	Optional	Recommended	Recommended	Recommended
Utility	Optional	Optional	Optional	Recommended	Recommended
Generator	Optional	Optional	Optional	Optional	Recommended
UPS output bus	Optional	Optional	Recommended	Recommended	Recommended
PDU	Optional	Optional	Optional	Optional	Recommended
One sensor in each cold and hot aisle	Recommended	Recommended	Required	Required	Required
Two sensors at different heights in each cold and hot aisle	Optional (recommended in open aisle configuration)	Optional (recommended in open aisle configuration)	Optional (recommended in open aisle configuration)	Optional (Required in open aisle configuration)	Optional (Required in open aisle configuration)
9.7.3 Power control					
Controls clearly indicated and posted	Recommended, if present	Recommended, if present	Recommended	Recommended	Recommended
9.7.4 System integration					
Integrated electrical system monitoring	Optional	Optional	Optional	Recommended	Recommended

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Electrical monitoring integrated to overall system	Optional	Optional	Optional	Recommended	Recommended
Electrical monitoring integrated to IT management system	Optional	Optional	Optional	Recommended	Recommended
9.8 Lighting					
9.8.3 Computer rooms					
Level	500 lux	500 lux	500 lux	500 lux	500 lux
Uniformity	>90%	>90%	>90%	>90%	>90%
Control	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors
Emergency	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for 100% room coverage at 5 foot-candles	Instant-on battery packs for 100% room coverage at 5 foot-candles
9.8.4 Support areas					
Level	As required by IES	As required by IES	As required by IES	As required by IES	As required by IES
Uniformity	>90%	>90%	>90%	>90%	>90%
Control	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors	Local, manual or occupancy sensors
Exterior areas	Lighting sufficient for working at night and in inclement weather as well as for security	Lighting sufficient for working at night and in inclement weather as well as for security	Lighting sufficient for working at night and in inclement weather as well as for security	Lighting sufficient for working at night and in inclement weather as well as for security	Lighting sufficient for working at night and in inclement weather as well as for security
Emergency	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for safety and a minimum of 50% room coverage at 5 foot-candles	Instant-on battery packs for 100% room coverage at 5 foot-candles	Instant-on battery packs for 100% room coverage at 5 foot-candles
9.9 Bonding and grounding					
Grounding resistance	If 5 ohm or greater, may not conform to IEEE or BICSI	5 ohm or less, conforming to IEEE and BICSI	5 ohm or less, conforming to IEEE and BICSI. 3 ohms recommended	5 ohm or less, conforming to IEEE and BICSI. 1 ohm recommended	5 ohm or less, conforming to IEEE and BICSI. 1 ohm recommended

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
Electrical distribution grounding					
Lighting fixtures (277 V) neutral isolated from service entrance derived from lighting transformer for ground fault isolation	Optional	Optional	Optional	Recommended	Recommended
Building electrical main grounding busbar	Optional	Recommended	Required	Required	Required
Ground wires in all feeders and branch circuits (Grounding conductors shall be carried in all power system raceways)	Recommended	Recommended	Required	Required	Required
Grounding method	Solidly grounded or impedance grounded	Solidly grounded or impedance grounded	Solidly grounded or impedance grounded	Solidly grounded or impedance grounded	Solidly grounded or impedance grounded
Critical power system grounding					
mesh-BN, mesh-IBN, or combination thereof in computer room	Recommended	Recommended	Required	Required	Required
Lightning protection system	Based on risk analysis as per NFPA 780	Based on risk analysis as per NFPA 780	Based on risk analysis as per NFPA 780	Based on risk analysis as per NFPA 780	Based on risk analysis as per NFPA 780
Lightning detection system	Optional	Optional	Optional	Recommended for areas subject to lightning	Recommended for areas subject to lightning
Online weather system on site	Optional	Optional	Optional	For areas subject to lightning	Recommended
9.9.4 Surge protective devices (SPDs)					
Present	Recommended	Required	Required	Required	Required
Utility entrance(s)	Recommended	Required	Required	Required	Required
Distribution panel/below source transfer or ATS	Optional	Recommended	Recommended	Recommended	Recommended
UPS input	Optional	Recommended	Required for rectifier input, recommended for all other inputs	Required for all inputs	Required for all inputs
UPS output	Optional	Optional	Optional	Recommended	Recommended
PDUs/panels	Optional	Optional	Optional	Optional	Optional

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.10 Labeling and Signage					
Hazard signage installed	Required	Required	Required	Required	Required
Instructions posted	Required	Required	Required	Required	Required
Safety data sheets posted or in library	Required	Required	Required	Required	Required
All equipment labeled	Required	Required	Required	Required	Required
Equipment color coded	Optional	Optional	Recommended	Recommended	Recommended
Single line diagrams posted	Optional	Optional	Optional	Recommended	Recommended
All electrical systems tested prior to operation	Optional	Required	Required	Required	Required
All electrical system equipment labeled with certification (from 3rd party test laboratory if available)	Optional	Required	Required	Required	Required
9.11 System Start Up and Commissioning					
Equipment subject to in-factory testing prior to project delivery – Level 1 Commissioning	Optional	Optional	Recommended	Required	Required
Pre-functional start-up by manufacturer – Level 2 Commissioning	Recommended	Recommended	Recommended	Required	Required
Equipment functional testing – Level 3 Commissioning	Optional	Optional	Recommended	Required	Required
System functional – Level 4 Commissioning	Optional	Optional	Recommended	Required	Required
Electrical system testing – Level 4 Commissioning	Optional	Optional	Recommended	Required	Required
Whole building testing – Level 5 Commissioning	Optional	Optional	Recommended	Required	Required

System/Class	*Class F0*	*Class F1*	*Class F2*	*Class F3*	*Class F4*
9.12 Critical Facility Operations and Maintenance					
Change control/change management	Optional/likely not present	Optional/likely not present	Present/not integrated with IT	Present/coordinate with IT	Present/integrated with IT
Work rules	Not scripted	Not scripted	Scripted	Scripted	Scripted/back check
Maintenance staff	Onsite day shift only. On call at other times	Onsite day shift only. On call at other times	Onsite day shift only. On call at other times	Onsite 24 hrs M-F, on call on weekends	Onsite 24/7
Preventative maintenance	Optional	Recommended	Recommended	Limited preventative maintenance program	Comprehensive preventative maintenance program
Facility training programs	Optional	Recommended	Recommended	Comprehensive training program	Comprehensive training program including manual operation procedures if it is necessary to bypass control system

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10 Mechanical Systems

10.1 Codes, References and Terminology

10.1.1 Code Compliance and Coordination

Codes that are commonly enforced globally include:

- *International Building Code (IBC)*
- *International Mechanical Code (IMC)*
- *International Plumbing Code (IPC)*
- *International Fuel Gas Code (IFGC)*

The IMC establishes specific requirements for ventilation rates, in coordination with ASHRAE 62.1, and specifies battery room exhaust requirements.

State and local codes may have additional requirements and restrictions enacted by amendments to specific sections of national and international codes and regulations. As the scope of amendments may be significant, local amendments shall be checked before making decisions based on code requirements. In addition, local building codes shall be consulted in the planning and implementation of changes to the building, mechanical, electrical, and life safety systems.

10.1.2 References

Within Section 10, references to the following documents are listed in Table 10-1. The notation used for standards (e.g., NFPA 70) remains unchanged.

Table 10-1 Section 10 Text References

Text Reference	*Complete Document Title*
ASHRAE Air Contamination	ASHRAE: *Particulate and Gaseous Contamination in Datacom Environments, Second Edition*
ASHRAE Design Considerations	ASHRAE: *Design Considerations for Datacom Equipment Centers, Second Edition*
ASHRAE IT Power Trends	ASHRAE*: IT Equipment Power Trends, Third Edition*
ASHRAE Liquid Cooling Guidelines	ASHRAE*: Liquid Cooling Guidelines for Datacom Equipment Centers, Second Edition*
ASHRAE Thermal Guidelines	ASHRAE: *Thermal Guidelines for Data Processing Environments, Fourth Edition*
NEBS	*Telcordia NEBS GR-3028-CORE*

NOTE: ASHRAE and NEBS guidelines and standards are under constant review, check for latest version

10.1.3 Terminology Differences Between Codes and Telecommunications Standards

Terminology used in building codes and by building code officials may differ from terms commonly used in the computer and telecommunications industry. For example, codes use the term “equipment room” to describe rooms housing mechanical or electrical equipment such as air handlers, pumps, chillers, transformers, and switchboard. However, *ASHRAE Thermal Guidelines* defines equipment such as servers, storage products, and PCs.

10.2 Selection of Heat Rejection Systems

The heat rejection system should be selected according to the following to suit the required availability class whilst achieving the best possible efficiency. The following must be considered:

- ITE equipment air or water cooled, or some of each
- Local environmental conditions. Minimum, maximum and average temperatures and humidity. Particulate and gaseous contamination of outside air.
- Whether it is acceptable for internal conditions (ITE intake) to stray from recommended to allowable as defined in *ASHRAE Thermal Guidelines*.
- The design of the data center building, specifically the size and location of space available for the heat rejection plant
- The required fire protection strategy, note that direct outside air supply is not suitable for use with gaseous extinguishing systems

10.2.1 Temperature and Humidity Requirements

10.2.1.1 Requirements

ASHRAE Thermal Guidelines specifies allowable and recommended environmental limits for four classes of environments and NEBS in both product operation and power off modes. For a typical operating computer room, the ASHRAE Class A1 recommended conditions apply, see Table 2.1 in *ASHRAE Thermal Guidelines* for all other conditions. Of note, TIA guidelines correspond to the ASHRAE Class A1 Recommended conditions.

ASHRAE Environmental Guidelines specifies that the recommended maximum dry-bulb temperature should be derated by 1 °C/300 m above 1800 m (1.8 °F/1000 ft above 6000 ft).

ASHRAE Thermal Guidelines notes that environments for tape products are more critical than ITE. This footnote sets ASHRAE Environmental Class A1 as the standard and includes limits for humidity rate of change.

10.2.1.2 Recommendations

The heat rejection design should consider and provide for:

- Controls for temperature and humidity at the ITE inlet
- Adequate filtration and ventilation
- Special needs of direct cooled equipment
- Airflow patterns for heat dissipation within the room
- Avoidance of recirculation of hot air and bypass of cold air to the ITE
- Redundant cooling systems to suit the class of facility
- Architectural features such as a tight air and vapor barrier

Control of temperature and humidity is achieved when conditions at the ITE cooling intake are maintained within the limits established by *ASHRAE Environmental Guidelines* or GR-3028-CORE. Limits include both high and low values of temperature, humidity, and rate of change for temperature. Because relative humidity varies with temperature without the addition or removal of moisture, it is a moving target, and therefore, not a good indicator of stable environmental conditions. A much more effective parameter is dew point. Whenever possible, space environmental controls should seek to achieve a stable dew point over the acceptable temperature range. This strategy will improve the stability of both temperature and humidity in the computer room.

10.2.2 Equipment Heat Release and Airflow Specifications

10.2.2.1 Recommendations

Whenever possible, power and cooling requirements for electronic equipment should be determined based on the manufacturer's actual published data for the specific configuration in question. GR-3028-CORE and *ASHRAE Thermal Guidelines* propose a standardized template for equipment manufactured to report power and cooling requirements for use by both end users and the designers of power and cooling infrastructure.

In the absence of the data noted above, refer to *Datacom Equipment Power Trends and Cooling Applications* to estimate power and cooling requirements. Within this document is a method for planning a data center based on equipment, applications, and space and both historical data and future trends for equipment power and cooling requirements for the typical data center platforms.

10.2.2.2 Use of Operating Rather Than Nameplate Load

ITE manufacturers now provide heat release data to allow more effective planning of cooling system capacity. Using this data will result in significantly more accurate estimates of the heat release than by applying a derating factor to nameplate electrical ratings. *ASHRAE Thermal Guidelines* provides a template for ITE manufacturers to use in reporting heat release and airflow (volumetric flow rate and configuration). Data is provided for Minimum, Full, and Typical configurations, and some manufacturers also have configuration tools available to allow for more accurate estimation of specific hardware configurations.

10.2.2.3 Current Equipment Heat Release and Trends

Datacom Equipment Power Trends and Cooling Applications provides estimates of power and cooling trends through the year 2020 for various hardware platforms. In all cases, these densities are well in excess of the cooling ability of most existing data center HVAC systems. The value of the trend charts is for forecasting a data center life capacity plan based on an actual baseline starting point, regardless of the year designation on the trend lines. Based on some anticipated number of technology refreshes and associated application proliferation over the life of the data center, the trend line slopes provide valuable planning thresholds.

10.2.2.4 Additional Information

ASHRAE Thermal Guidelines includes an example of a Thermal Report. In this example, the Nominal Airflow column is where the manufacturer will report the air volume moved through the electronics by the internal server fans. For any particular row of racks, the total of all server airflows in that row represents the total airflow through the racks from the cold aisle to the hot aisle. This is not the same as the volume of air that must be supplied to the cold aisle by the HVAC system. The HVAC system must supply more air since the temperature difference produced by the HVAC equipment will generally be lower than the temperature rise through the electronics equipment, because of bypass air waste and related mixing of supply air and return air.

10.2.3 Control of Airborne Contaminants (Gases and Particles)

10.2.3.1 Requirements

Provide filtration of incoming and recirculated air in the spaces containing ITE as required to limit contaminants to *ASHRAE Gaseous and Particulate Contamination Guidelines for Data Centers*, or applicable local codes or standards.

Provide pressurization of the spaces containing ITE to limit air borne contaminant ingress if required to limit contaminants to *ASHRAE Gaseous and Particulate Contamination Guidelines for Data Centers*, or applicable local codes or standards.

10.2.3.2 Recommendations

Particulates in the air degrade computer operations. Good operating practices will limit or prohibit the most common sources of particulate contamination from the computer room (i.e., cardboard and storage of paper). Maintaining a controllable positive pressure in the computer room with respect to adjacent spaces will aid in reducing infiltration of particulates and humid/dry air. However, excess positive pressurization can be detrimental.

The air-handling unit supplying outdoor air should be equipped with filters to at least MERV 13 (ASHRAE 80% to 90%) to ensure a clean air supply. When this is not possible, the air supplied to the computer room for pressurization should be filtered to this level before it is supplied to the space.

Air handling units supplying outdoor air should be equipped with low-leakage filter holding frames to limit bypass to less than 1% at 0.7 kPa (3 in WC) differential pressure.

10.2.3.3 Additional Information

Pressurization of the computer room with air supplied from outside the space is the most effective means of controlling infiltration of particulate that could migrate from surrounding spaces.

Particulate contamination originating from the building's construction should be addressed, where possible, by thoroughly cleaning of the space before it is occupied. It is important to understand that increasing the filtration level at the air handlers has only a marginal benefit compared to the additional energy expended by the fan systems.

When operating a data center in a polluted location, monitor the level of copper / silver corrosion to less than 300 and 200 angstroms per month.

10.3 Heat Rejection and Computer Room Cooling Technologies

10.3.1 Introduction

Common heat rejection and cooling systems are presented in the following sections with applicable characteristics, requirements, and recommendations.

10.3.2 Requirements for All Heat Rejection and Cooling Systems

Requirements include:

- Heat rejection and cooling systems shall be designed to operate 24/7, 365 days per year, subject to the chosen availability class.
- The heat rejection system shall be designed to operate without failure at and between minimum and maximum historical external climatic conditions and continue to provide air to the ITE inlet at temperature and humidity conditions within *ASHRAE Thermal Guidelines* allowable range for the appropriate class of ITE.
- Cooling systems shall be designed to limit rate of change in temperature and humidity in accordance with *ASHRAE Thermal Guidelines.* Cooling systems must be considered in conjunction with power systems and if necessary, incorporating thermal storage or connecting pumps and fans connected to UPS to prevent thermal runaway in the period between utility failure and a backup power system's acceptance of the load.
- Maximum dry-bulb temperature at ITE inlet shall be derated at altitudes above 1800 m (6000 ft) as set out in *ASHRAE Thermal Guidelines.*
- All equipment and plant shall be de-rated in accordance with *ASHRAE Design Considerations* at altitudes above 1800 m (6000 ft).
- The cooling system shall be designed to operate in the local environment for the required life span, taking into account natural contamination (e.g., salt laden air in coastal locations, airborne seeds or other plant material, sandstorms) and local sources of pollution.
- As part of the critical data center plant, the external heat rejection plant shall be secured and protected as appropriate.
- External heat rejection plant air intakes and outlets shall be designed to avoid recirculation from each other and any other sources of hot air (e.g., generator flues and cooling air exhausts, solar gain onto dark colored roof, air exhausts from nearby buildings).
- All cooling and heat rejection plants shall be designed to operate efficiently and effectively at 10% to 100% of ITE design heat load.

10.3.3 Recommendations for All Heat Rejection and Cooling Systems

Recommendations include:

- The selection of the cooling system and components should consider energy efficiency and whole life cost. Where water resources are limited the use of water for evaporation should also be minimized.
- Care should be taken not to over specify cooling load which can result in poor efficiency and effectiveness. Where possible, consider a modular approach to add capacity as it is needed.
- All electric motors which power fans (including condenser fans), compressors and pumps should be EC (electronically commutated) or AC type with VFD (variable frequency drives) speed controls. Where possible motor speed control should be provided to vary the speed according to cooling load and climatic conditions.
- Humidification and de-humidification should only be provided where necessary to achieve conditions at the ITE inlet in accordance with *ASHRAE Thermal Guidelines.* Note that deviations from recommended into allowable range may be acceptable for relatively short periods of time.
- Provide monitoring of operational parameters and energy consumption, remote alarm annunciation, trend logging, and set point adjustment for all cooling plant and equipment. This may be by web page interfaces or integration with a DCIM or BMS system.
- Consider all available energy saving options, such as those shown in Figure 10-1 - Figure 10-3

10.3.4 Fluid Based Heat Rejection and Cooling Systems

10.3.4.1 Introduction

Any combination of the following fluid-based heat rejection systems and computer room cooling systems may be implemented within the computer room cooling design.

NOTE: Where used, sensible cooling refers to the dry bulb temperature of the area of space and latent cooling refers to the wet bulb temperature of the area of space.

10.3.4.2 Heat Rejection Systems

10.3.4.2.1 Chiller with Evaporative Condenser Heat Rejection System (Figure 10-1)

Heat Rejection:	Evaporative cooling (cooling tower)
External Cooling Circuit:	Water or glycol
Heat Exchanger:	Indoor chiller
Internal Cooling Circuit:	Water
Limiting External Conditions:	Not suitable in areas with high temperature and humidity (wet bulb temperature). Requires reliable and plentiful water supply
Requirements:	Freeze protection of external cooling circuit and water supply if required for location. Chillers and condensers suitable for 10% to 100% of design computer room load. See requirements for cooling towers in Section 10.8.5.
Recommendations:	Constant flow external and variable flow internal chilled water circuits. Evaporative condenser and external chilled water pump speed should be controlled to suit the heat rejection plant requirements. Internal chilled water pump speed should be controlled by pressure sensors to circulate the volume of water required for the variable ITE load. Chilled water temperature to provide maximum sensible and minimum latent cooling. Consider other options to glycol if freeze protection is required.

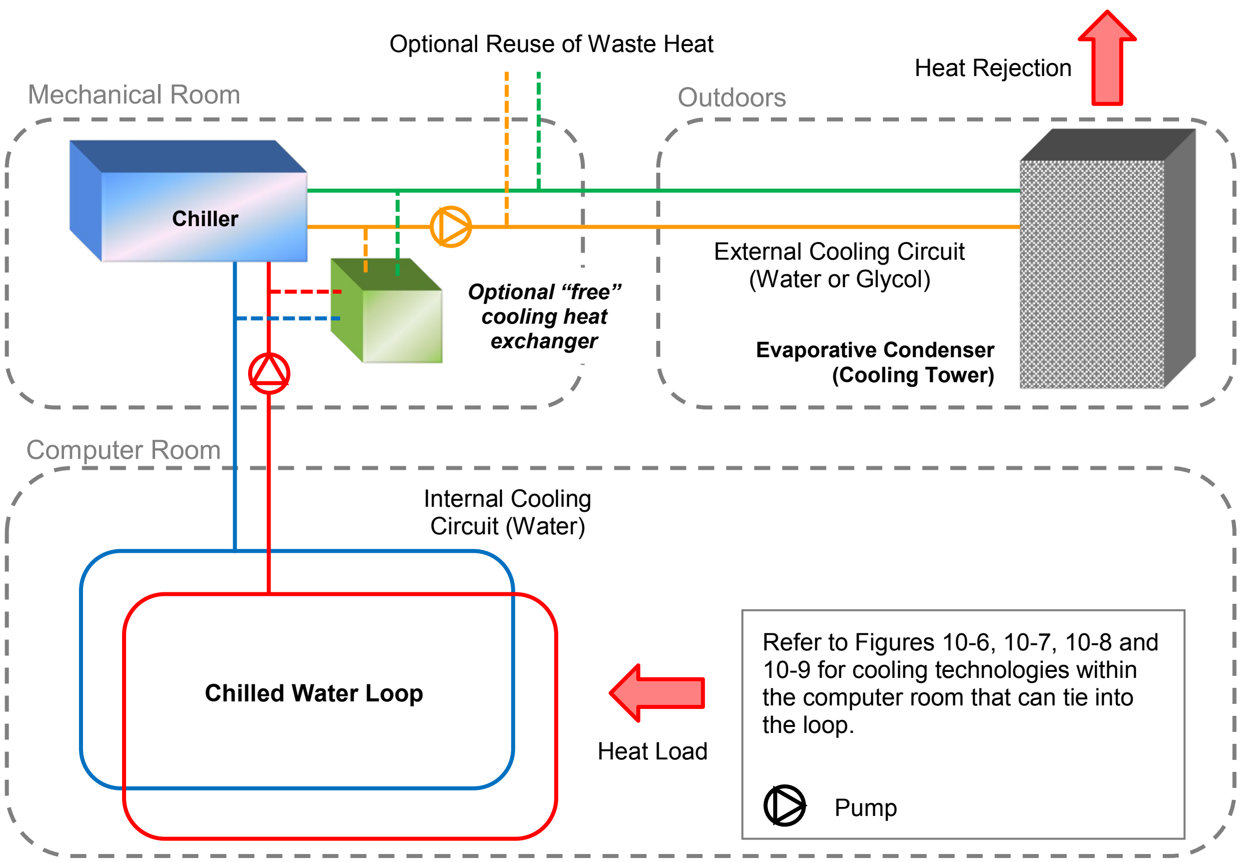

Figure 10-1
Chiller with Evaporative Condenser Heat Rejection System

10.3.4.2.2 Chiller with Air-Cooled Condenser Heat Rejection System (Figure 10-2)

Heat Rejection:	Air-cooled condenser (dry-cooler)
External Cooling Circuit:	Water or glycol
Heat Exchanger:	Indoor chiller
Internal Cooling Circuit:	Glycol
Limiting External Conditions:	Not suitable in areas with very high dry bulb temperature
Requirements:	Freeze protection of external cooling circuit if required for location. Chillers and condensers suitable for 10% to 100% of design computer room load
Recommendations:	Constant flow external and variable flow internal chilled water circuits. Pump speed for condensers and external cooling circuits should be controlled to suit the heat rejection plant requirements. Internal chilled water pump speed should be controlled by pressure sensors to circulate the volume of water required for the ITE load. Chilled water temperature to provide maximum sensible and minimum latent cooling. Consider other options to glycol if freeze protection is required.

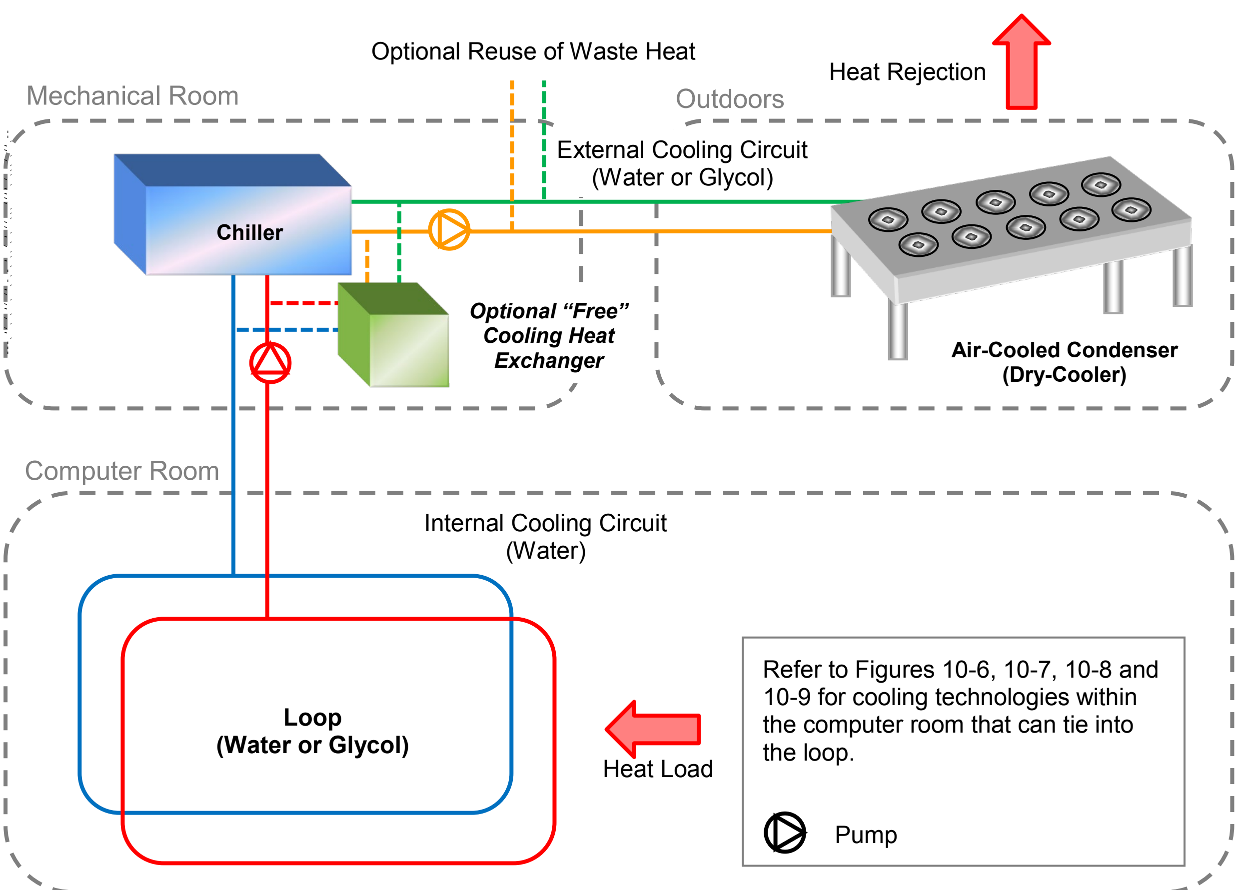

Figure 10-2
Air-Cooled Condenser Heat Rejection System

10.3.4.2.3 Air-Cooled Chiller Heat Rejection System (Figure 10-3)

Heat Rejection:	Air-cooled
External Cooling Circuit:	Integral to packaged outdoor chiller
Heat Exchanger:	Packaged outdoor air-cooled chiller
Internal Cooling Circuit:	Water or glycol
Limiting External Conditions:	Requires more external space than other options, chiller may require "high ambient kit" in areas of very high dry bulb temperatures. Chiller is noisier than other options
Requirements:	Freeze protection of cooling circuit if required for location. Chillers suitable for 10% to 100% of design computer room load. Attenuation of chiller compressors if required by local code
Recommendations:	Variable flow internal chilled water circuits. Internal chilled water pump speed should be controlled by pressure sensors to circulate the volume of water required for the ITE load. Chilled water temperature to provide maximum sensible and minimum latent cooling. Consider other options to glycol if freeze protection is required.

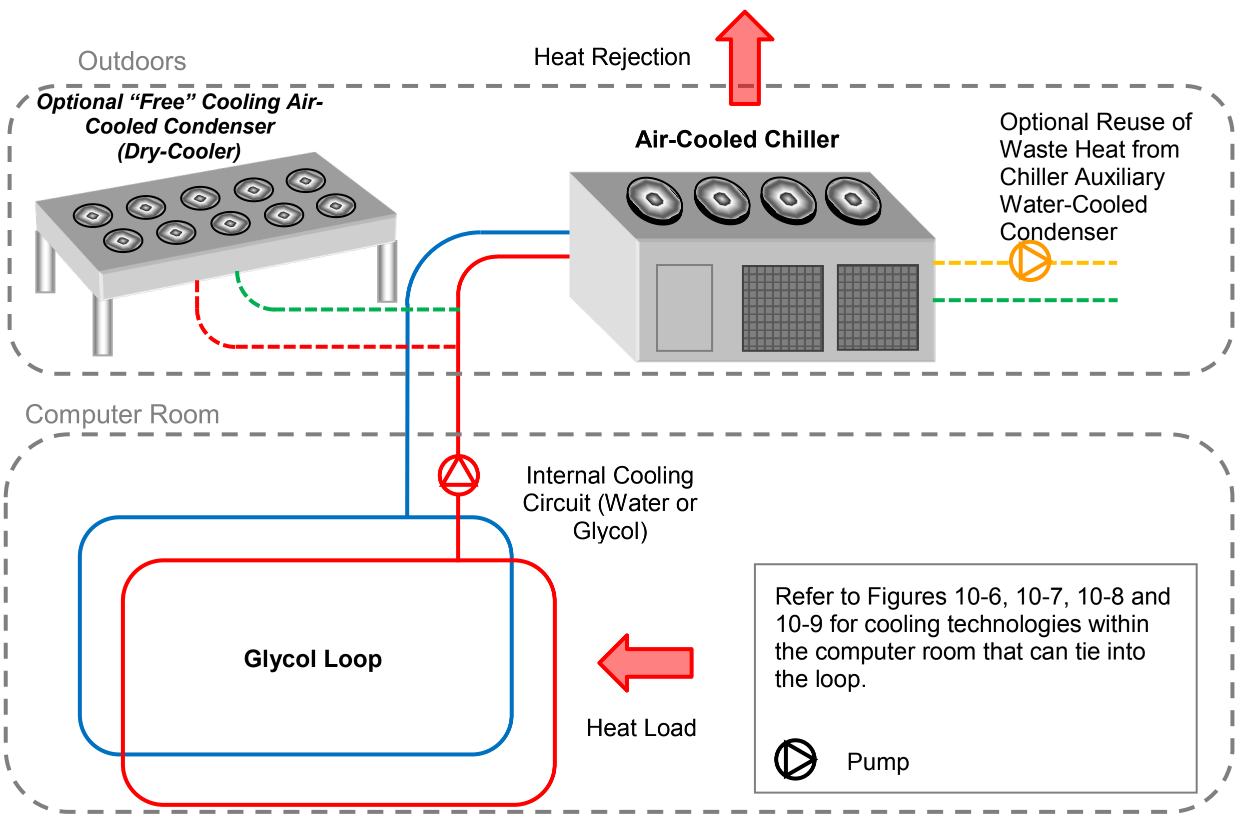

Figure 10-3
Air-Cooled Chiller Heat Rejection System

10.3.4.2.4 Evaporative Condenser Heat Rejection System (Figure 10-4)

Heat Rejection:	Evaporative cooling (cooling tower)
External Cooling Circuit:	Water or Glycol
Heat Exchanger:	Plate heat exchanger
Internal Cooling Circuit:	Water
Limiting External Conditions:	Only suitable for areas with moderate temperature and humidity (wet bulb temperature) Requires reliable and plentiful water supply
Requirements:	Computer room cooling must be designed to suit elevated cooling water temperatures. Freeze protection of external cooling circuit and water supply if required for location. Cooling towers suitable for 10% to 100% of design computer room load. See requirements for cooling towers in Section 10.8.5. Internal cooling water pump speed should be controlled by pressure sensors to circulate the volume of water required for the ITE load.
Recommendations:	Consider other options to glycol if freeze protection is required

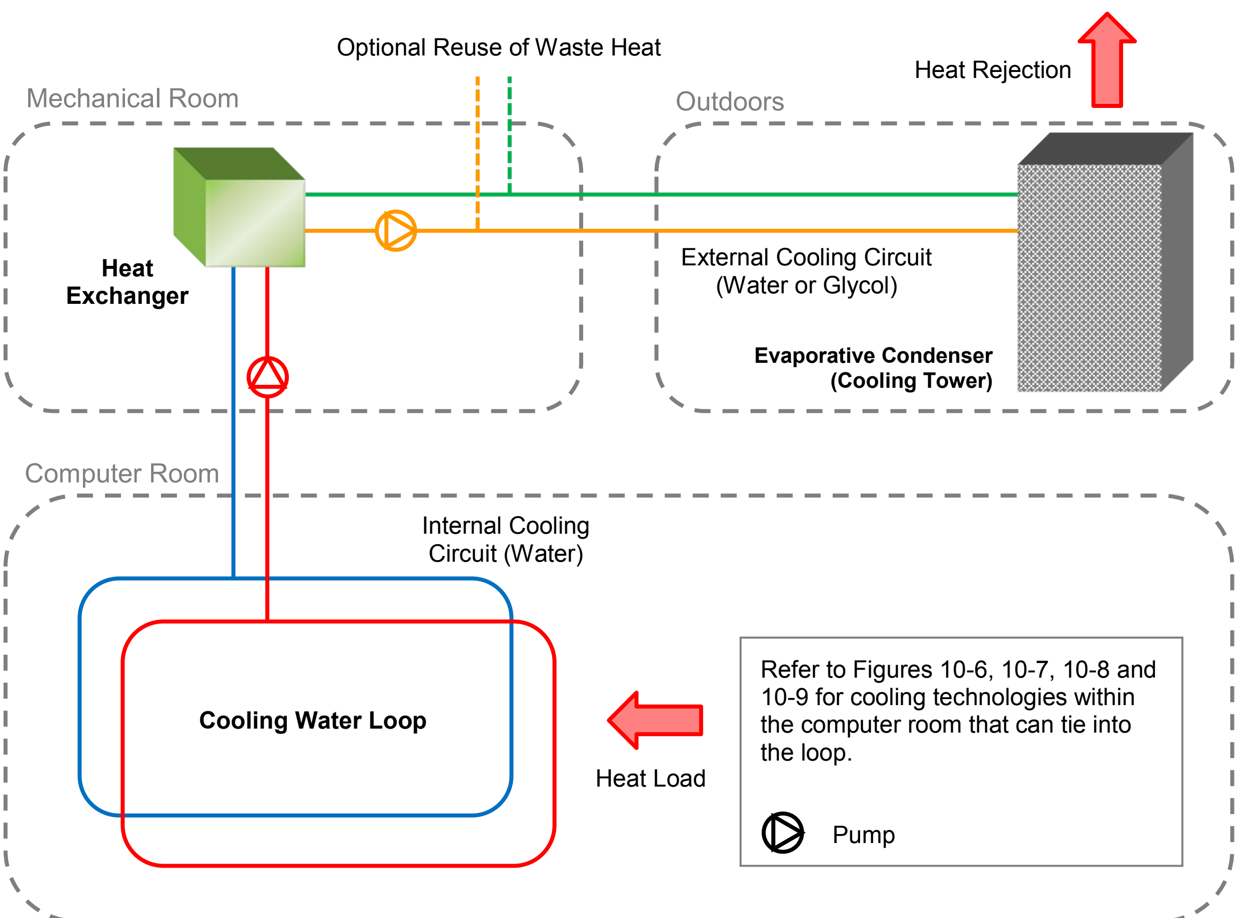

Figure 10-4
Evaporative Condenser Heat Rejection System

10.3.4.2.5 Natural Water Heat Rejection System (Figure 10-5)

Heat Rejection:	Natural water mass (e.g., rivers, lakes, ocean, groundwater)
External Cooling Circuit:	Natural water
Heat Exchanger:	Plate heat exchanger
Internal Cooling Circuit:	Water
Limiting External Conditions:	Large volume of natural water required
Requirements:	AHJ must approve extraction of water or replacement with warm water.
	Ensure water extraction and replacement with warm water will not affect local environment.
	Inlets and outlets from natural water sufficiently far apart to ensure that there is no recirculation.
	Heat exchanger, pump and pipes on natural water circuit must be designed to withstand salt, algae and any other substances and solids present in the water.
	Water inlets must be properly protected against clogging or blocking by waterborne debris, flora, and fauna (e.g., algae, jellyfish, barnacles).
Recommendations:	Consider combining with heat rejection to air as above alternatives to reduce reliance on natural water availability.
	Control pump speeds to suit the ITE load and temperature of the natural water

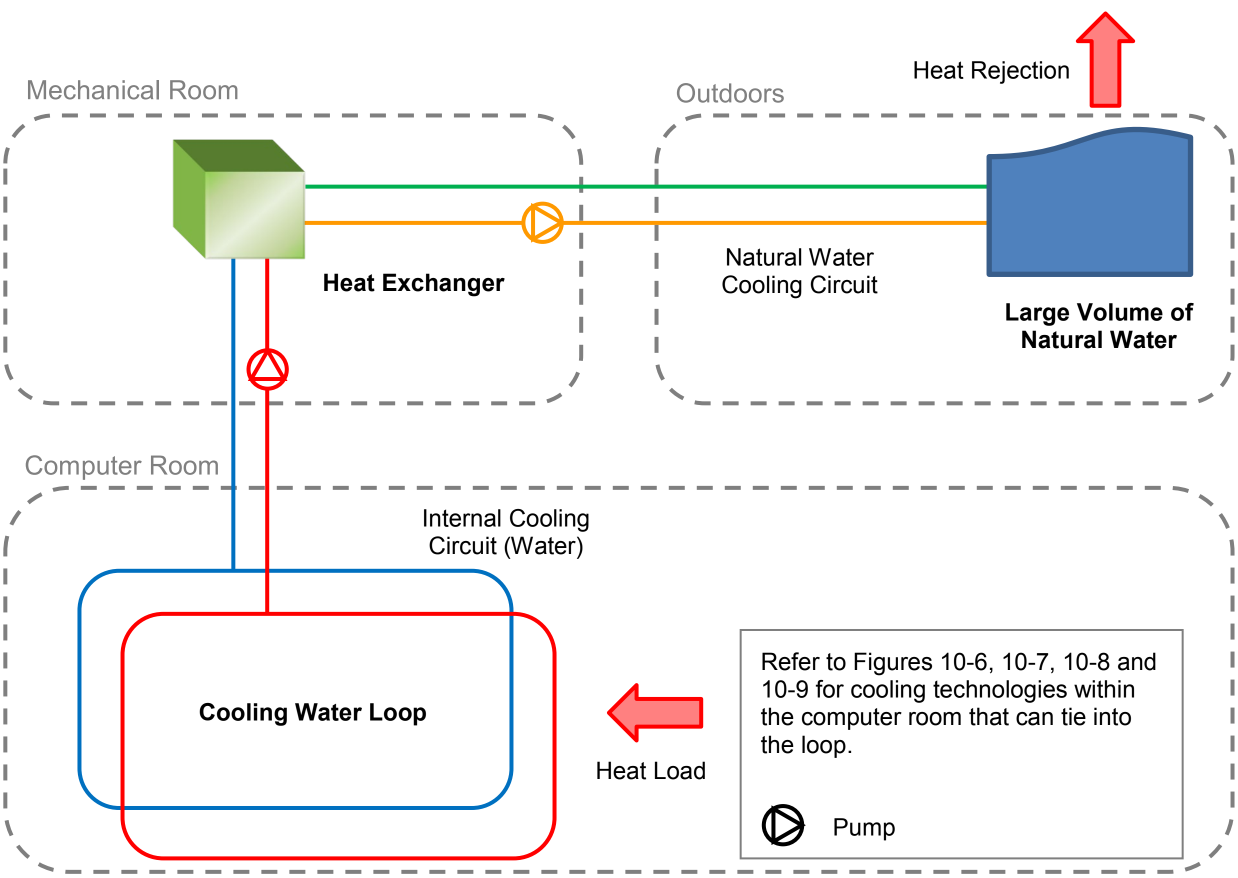

Figure 10-5
Natural Water Heat Rejection System

10.3.4.3 Computer Room Cooling Systems

10.3.4.3.1 Computer Room Air Handler Cooling System (Figure 10-6)

Cooling Unit:	CRAH
ITE Cooling Circuit	Air distribution with underfloor supply and open room return, ducted supply, ducted return, or vertical heat collars above cabinets up to plenum return
ITE Heat Rejection:	Air-cooled heat sink
Requirements:	Control CRAH supply air temperature from supply air sensor to make air intake to ITE stay within the limits of *ASHRAE Thermal Guidelines*. CRAH cooling control valves must be 2 port type to match pressure control of pump
Recommendations:	Segregate computer room supply and return air paths with containment, plenums and ducts to minimize bypass and recirculation. Control speed of CRAH fans to suit air flow volume and temperature differential of ITE. If unavoidable, some bypass is preferable to any recirculation of air to ITE. Locate CRAH units in service corridor immediately adjacent but separate to computer room to mitigate risk of water leakage and avoid the need for service engineers to enter the computer room

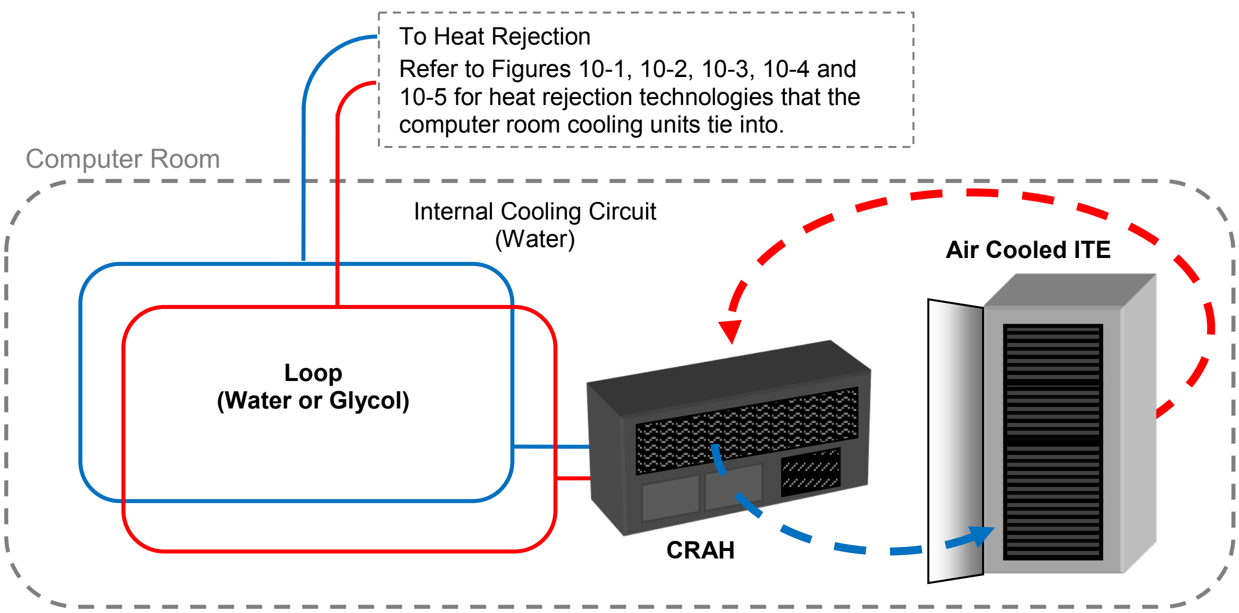

Figure 10-6
Computer Room Air Handler Cooling System

10.3.4.3.2 Computer Room Close Coupled Cooling System (Figure 10-7)

Cooling Unit:	Row-integrated, in cabinet, rear door or overhead
ITE Cooling Circuit	Air path shortened to single row or single cabinet
ITE Heat Rejection:	Air-cooled heat sink
Requirements:	Control supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines.* Cooling control valves must be 2 port type to match pressure control of pump
Recommendations:	Segregate supply and return air paths with containment for row-integrated option. Apply liquid leakage risk mitigation such as semi rigid joint free pipe systems, drip trays, leak detection and isolation valves on loops. Control speed of cooling unit fans to suit air flow volume and temperature differential of ITE.

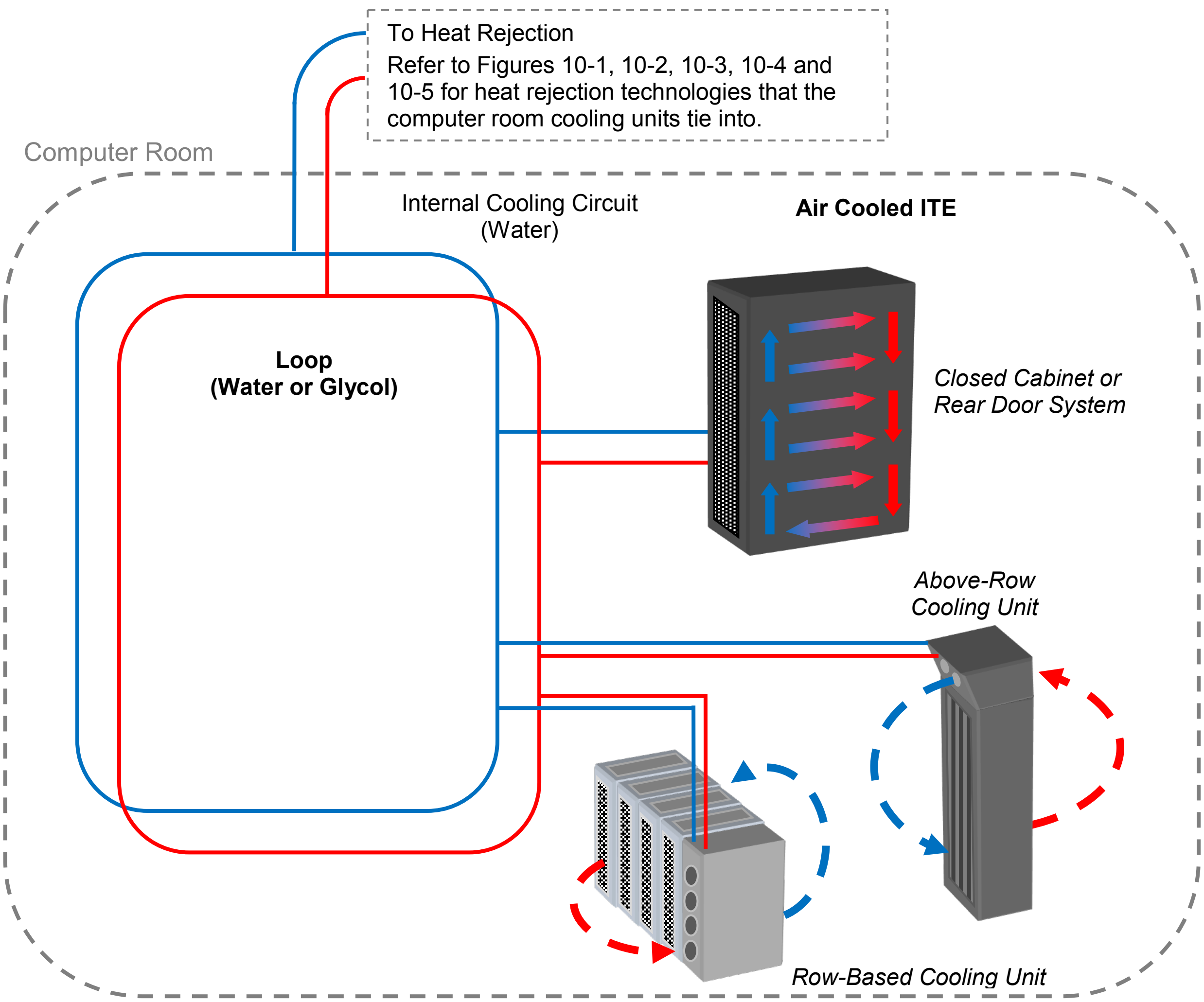

Figure 10-7
Close Coupled Cooling System

10.3.4.3.3 Liquid-Cooled ITE Cooling System (Figure 10-8)

Cooling Circuit:	Integrated with ITE
ITE Cooling Circuit	Liquid cooled chip heat sink or dielectric fluid bath
ITE Heat Rejection:	Liquid cooling (liquid-to-air or liquid-to-liquid exchange)
Requirements:	Design water temperatures to *ASHRAE Liquid Cooling Guidelines* using the appropriate class (W1 to W4). If designing to *ASHRAE Liquid Cooling Guidelines* W3 or W4 the cooling water may be 55°C (130 °F) or higher. Allow for thermal expansion of pipes and components.
Recommendations:	Divide liquid cooling into separate primary, secondary and tertiary circuits linked by heat exchangers to minimize risk of water leakage as recommended in *ASHRAE Liquid Cooling Guidelines.* Apply liquid leakage risk mitigation such as semi rigid joint free pipe systems, drip trays, leak detection and isolation valves on loops. For mixed liquid cooled and air cooled ITE requirements consider a single heat rejection system which will provide the lowest whole life cost

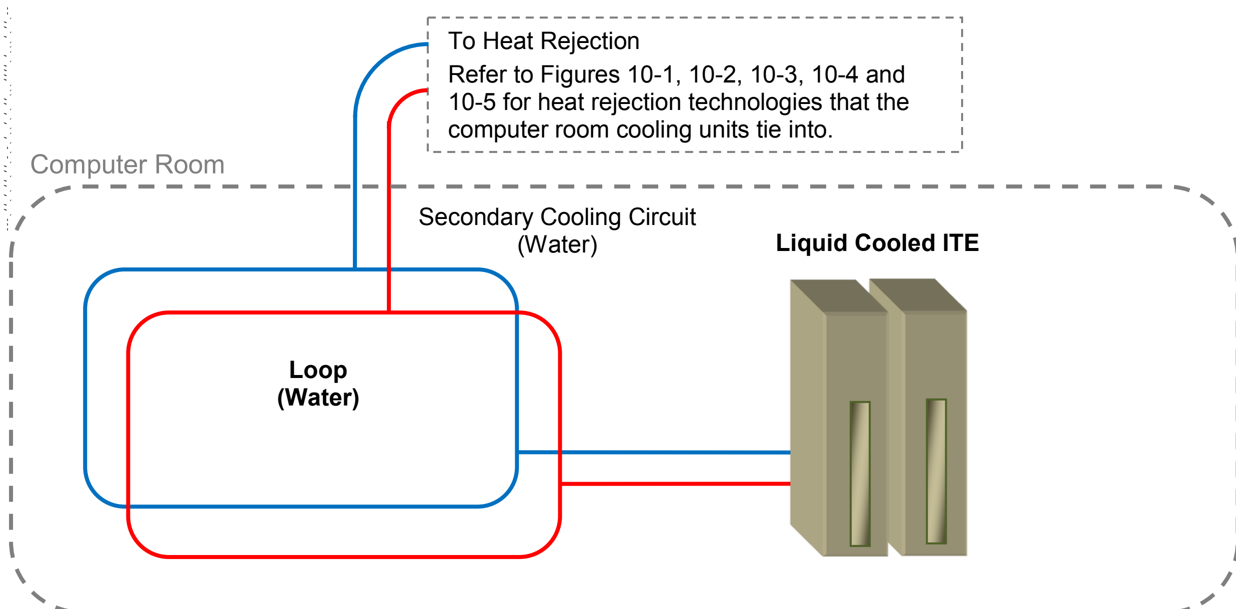

Figure 10-8
Liquid Cooling ITE Cooling System

10.3.4.3.4 Row Integrated Cooling Systems (Figure 10-9)

Cooling Circuit:	Above-row/row-based refrigerant sub-system
ITE Cooling Circuit	Air distribution
ITE Heat Rejection:	Air-cooled heat sink
Requirements:	Control supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines*. Ensure that leakage of refrigerant into computer room or any enclosed accessible space cannot reach a concentration that would be hazardous
Recommendations:	Segregate supply and return air paths with containment for row-integrated option. Locate pumping unit in service corridor adjacent but separate to computer room to mitigate liquid leakage risk. If unavoidable apply liquid leakage risk mitigation such as semi rigid joint free pipe systems, drip trays, leak detection and isolation valves on loops. Control speed of cooling unit fans to suit air flow volume and temperature differential of ITE.

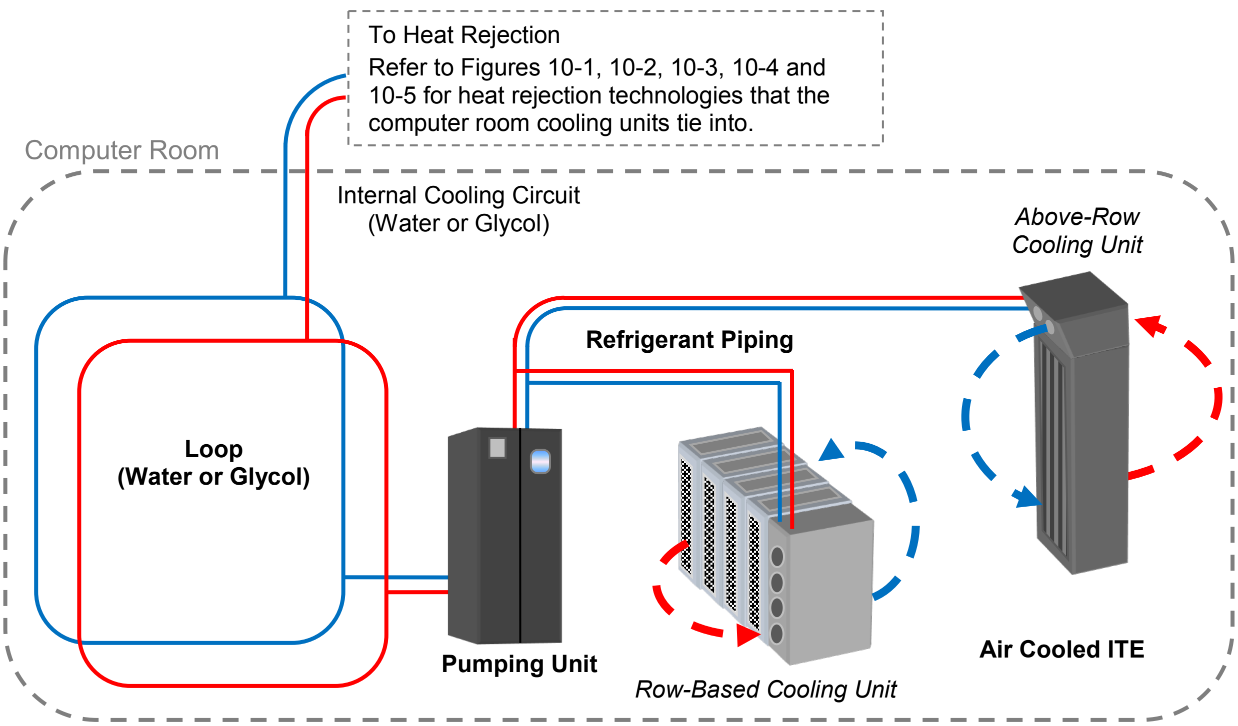

Figure 10-9
Row Integrated Cooling Systems

10.3.5 Direct Expansion Cooling Systems

10.3.5.1 Introduction

Direct expansion systems for cooling avoid the use of a chiller. Information and illustrations on common direct expansion cooling systems are presented below.

10.3.5.2 Computer Room Air Handler Cooling System (Figure 10-10)

Heat Rejection:	Air-cooled condenser (1 condenser for each CRAC)
External Cooling Circuit:	Refrigerant
Heat Exchanger:	Integrated within computer room air conditioner (CRAC)
Internal Cooling Circuit:	Internal to CRAC
Cooling System:	CRAC with compressor
ITE Cooling Circuit:	Air distribution with underfloor supply and open room return, ducted supply, ducted return, or vertical heat collars above cabinets up to plenum return
ITE Heat Rejection:	Air-cooled heat sink
Limiting External Conditions:	May require "high ambient kit" in areas of very high temperatures
Requirements:	CRAC units must have speed-controlled compressors and electronic expansion valves to supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines*. Ensure that leakage of refrigerant into computer room or any enclosed accessible space cannot reach a concentration that would be hazardous
Recommendations:	Segregate computer room supply and return air paths with containment, plenums and ducts to minimize bypass and recirculation Control speed of CRAC fans to suit air flow volume and temperature differential of ITE. If unavoidable some bypass is preferable to any recirculation of air to ITE. Avoid locating condenser below level of CRAC unit if possible, requires special features which affects efficiency.

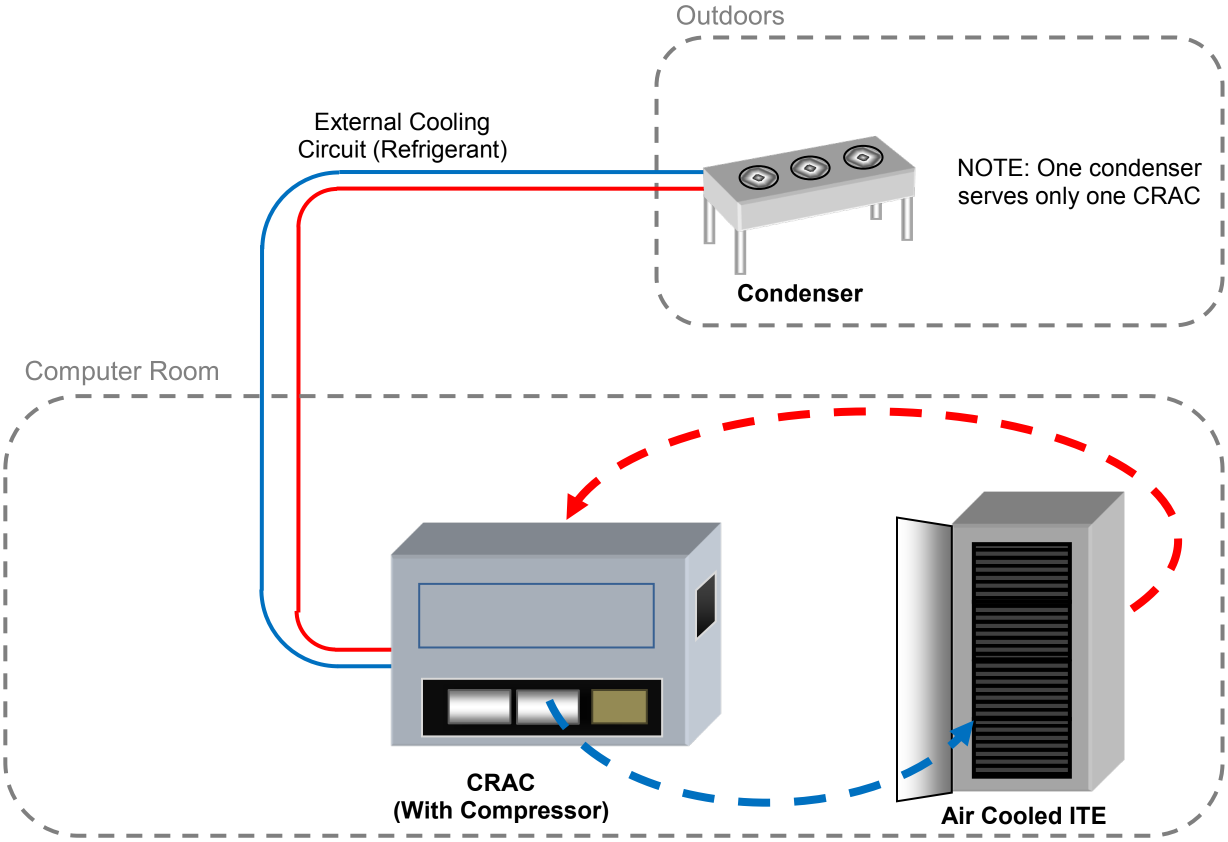

Figure 10-10
Direct Expansion Computer Room Air Handler Cooling System

10.3.5.3 Integrated Cooling System (Figure 10-11)

Heat Rejection:	Air-cooled condenser (1 condenser for each DX module)
External Cooling Circuit:	Refrigerant
Heat Exchanger:	Direct expansion module
Internal Cooling Circuit:	Refrigerant
Cooling System:	Above-row or row-based cooling units
ITE Cooling Circuit:	Air distribution
ITE Heat Rejection:	Air-cooled heat sink
Limiting External Conditions:	May require "high ambient kit" in areas of very high temperatures
Requirements:	DX module must have speed-controlled compressors and electronic expansion valves to supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines*. Ensure that leakage of refrigerant into computer room or any enclosed accessible space cannot reach a concentration that would be hazardous

Recommendations can be found on the next page

Recommendations:	Segregate computer room supply and return air paths with containment, plenums and ducts to minimize bypass and recirculation. Provide containment of hot or cold aisle for row-integrated option. Control speed of row-integrated and overhead fans to suit air flow volume and temperature differential of ITE. If unavoidable some bypass is preferable to any recirculation of air to ITE. Locate DX module in mechanical room or service corridor immediately adjacent but separate to computer room to avoid the need for service engineers to enter the computer room. Avoid locating condenser below level of DX module if possible, requires special features which affects efficiency.

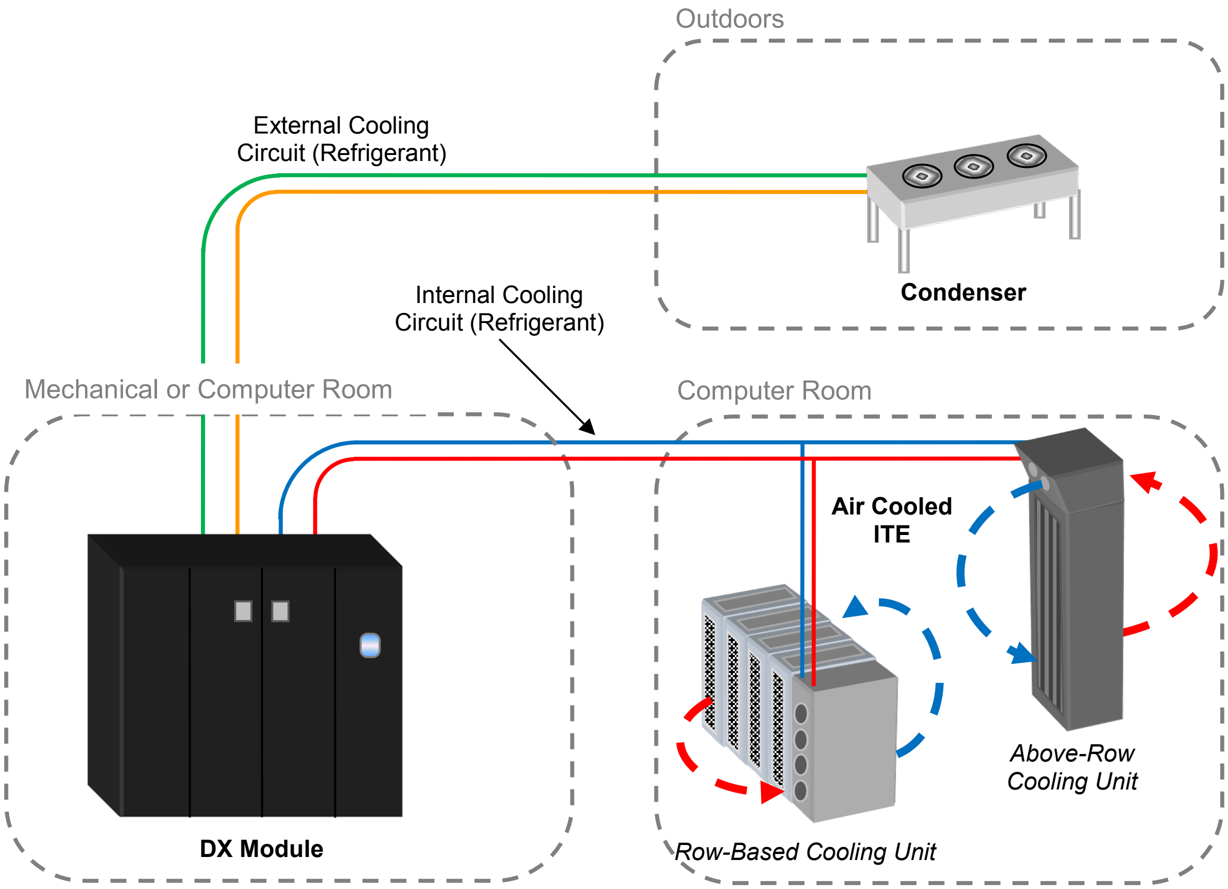

Figure 10-11
Direct Expansion Integrated Cooling System

10.3.5.4 Closed Cabinet Cooling System (Figure 10-12)

Heat Rejection:	Air-cooled condenser (1 condenser for each cabinet)
External Cooling Circuit:	Refrigerant
Heat Exchanger:	Direct expansion integrated within closed cabinet
Internal Cooling Circuit:	Internal to cabinet
Cooling System:	Compressor integrated within closed cabinet
ITE Cooling Circuit:	Air distribution
ITE Heat Rejection:	Air-cooled heat sink
Limiting External Conditions:	May require "high ambient kit" in areas of very high temperatures
Requirements:	Closed cabinet system must have speed-controlled compressors and electronic expansion valves to supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines*. Ensure that leakage of refrigerant into computer room or any enclosed accessible space cannot reach a concentration that would be hazardous
Recommendations:	Avoid locating condenser below level of CRAC unit if possible, requires special features which affects efficiency.

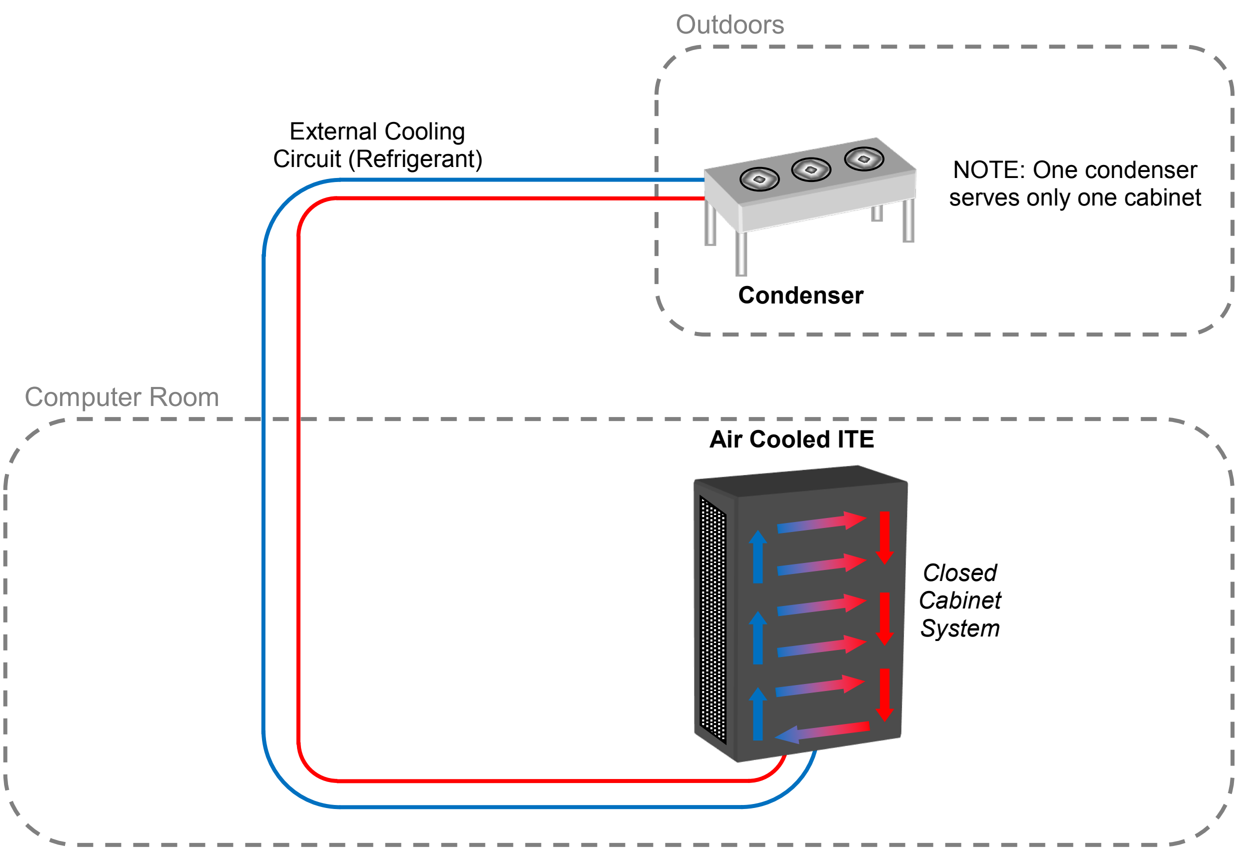

Figure 10-12
Direct Expansion Closed Cabinet Cooling System

10.3.6 Air-Side Economizer Systems

Air-side economizer systems are gaining acceptance as data center cooling solutions as a result of the potential of significant cooling energy savings.

Where required the cooling available from outside air only can be augmented by adiabatic cooling and/or a direct expansion refrigerant cooling coil in the supply air stream.

The two types of systems, direct and indirect, are described below.

10.3.6.1 Direct Air-Side Economizer (Figure 10-13)

Heat Rejection:	Direct to outside air
External Cooling Circuit:	Refrigerant and/or adiabatic cooling of intake air stream
Heat Exchanger:	Integrated within air handling unit
Internal Cooling Circuit:	Internal to air handling unit
Cooling System:	Adiabatic cooler/humidifier with optional DX cooling
ITE Cooling Circuit:	Air distribution with underfloor supply and open room return, ducted supply, ducted return, or vertical heat collars above cabinets up to plenum return
ITE Heat Rejection:	Air-cooled heat sink
Limiting External Conditions:	Not suitable for very humid climatic conditions, may not be economic for high temperature climate. Requires reliable and plentiful water supply
Requirements:	Control AHU supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines*. Control speed of supply fan to suit air flow volume and temperature differential of ITE. If unavoidable some bypass is preferable to any recirculation of air to ITE. Control speed of extract fan to limit pressure differential to outside to approx. 20Pa. Locate air intake to AHU away from condenser and extract fan discharge to avoid recirculation. Provide multi-stage filtration on cooling intake to achieve *ASHRAE Air Contamination* limits. Consider fire protection strategy, not suitable for gas extinguishing systems
Recommendations:	Segregate computer room supply and return air paths with containment, plenums and ducts to minimize bypass and recirculation. Avoid locating condenser below level of DX coil in AHU if possible, requires special features which affects efficiency. Consider air bypass around DX cooling coil if provided to avoid pressure loss when not required.

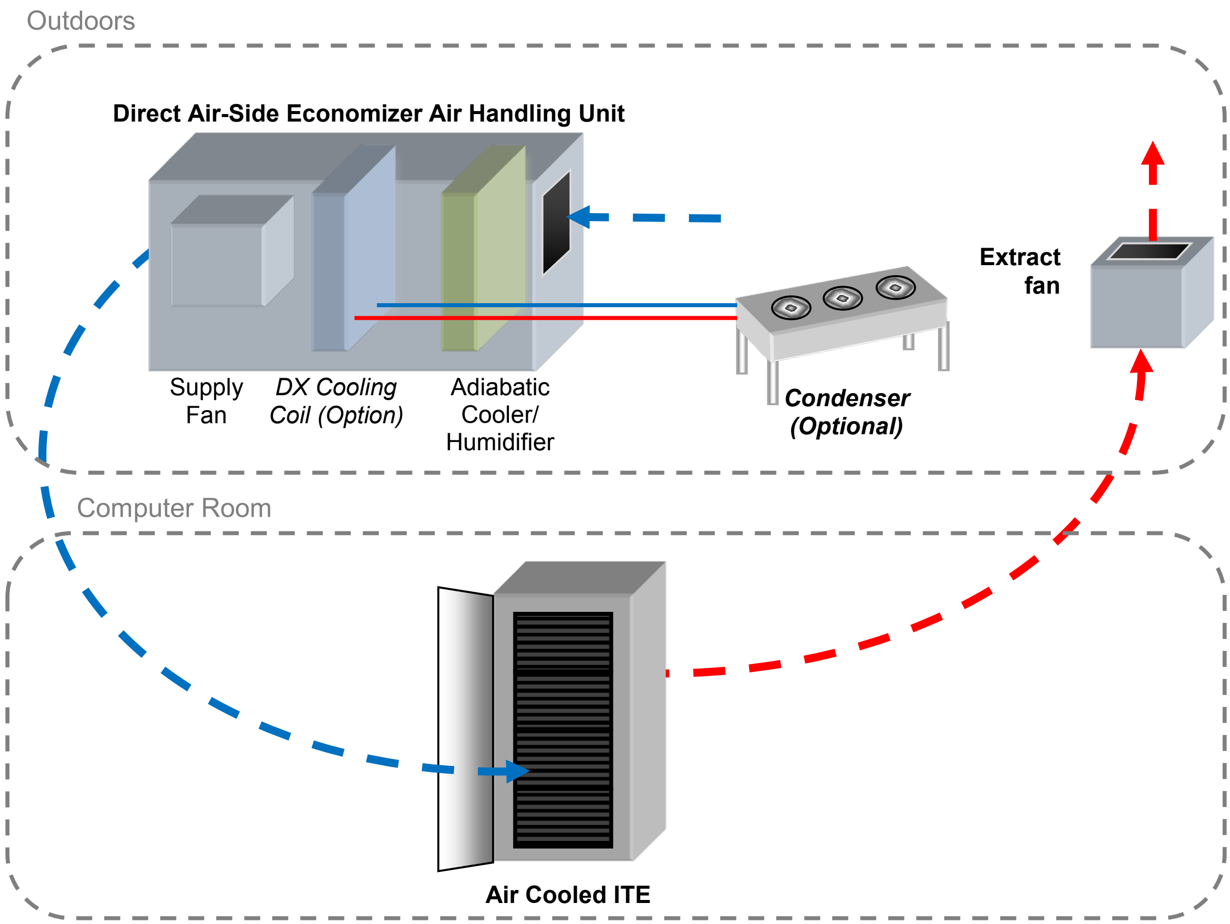

Figure 10-13
Direct Air-Side Economizer

10.3.6.2 Indirect Air-Side Economizer (Figure 10-14)

Heat Rejection:	Indirect to outside air
External Cooling Circuit:	Water for cooling of intake air stream
Heat Exchanger:	Integrated within air handling unit
Internal Cooling Circuit:	Optional direct expansion cooling coil for hot climates
Cooling System:	Air to air heat exchanger and adiabatic cooler with optional DX cooling
ITE Cooling Circuit:	Air distribution with underfloor supply and open room return, ducted supply, ducted return, or vertical heat collars above cabinets up to plenum return
ITE Heat Rejection:	Air-cooled heat sink
Limiting External Conditions:	Not suitable for extreme humid climatic conditions. Requires reliable and plentiful water supply
Requirements:	External (process) air must not mix with internal (computer room) air. Control AHU supply air temperature from supply air sensor to achieve air intake to ITE to *ASHRAE Thermal Guidelines.*

Requirements continue on the next page

	Control speed of internal fan to suit air flow volume and temperature differential of ITE. If unavoidable some bypass is preferable to any recirculation of air to ITE.
	Control speed of external fan to suit ITE load and climatic conditions.
	Locate air intake to AHU away from condenser and external air discharge to avoid recirculation.
	Provide filtration on cooling intake to protect components in external air path
Recommendations:	Segregate computer room supply and return air paths with containment, plenums and ducts to minimize bypass and recirculation.
	Avoid locating condenser below level of DX coil in AHU if possible, requires special features which affects efficiency.
	Consider air bypasses around heat exchanger DX cooling coil if provided to avoid pressure loss when not required.

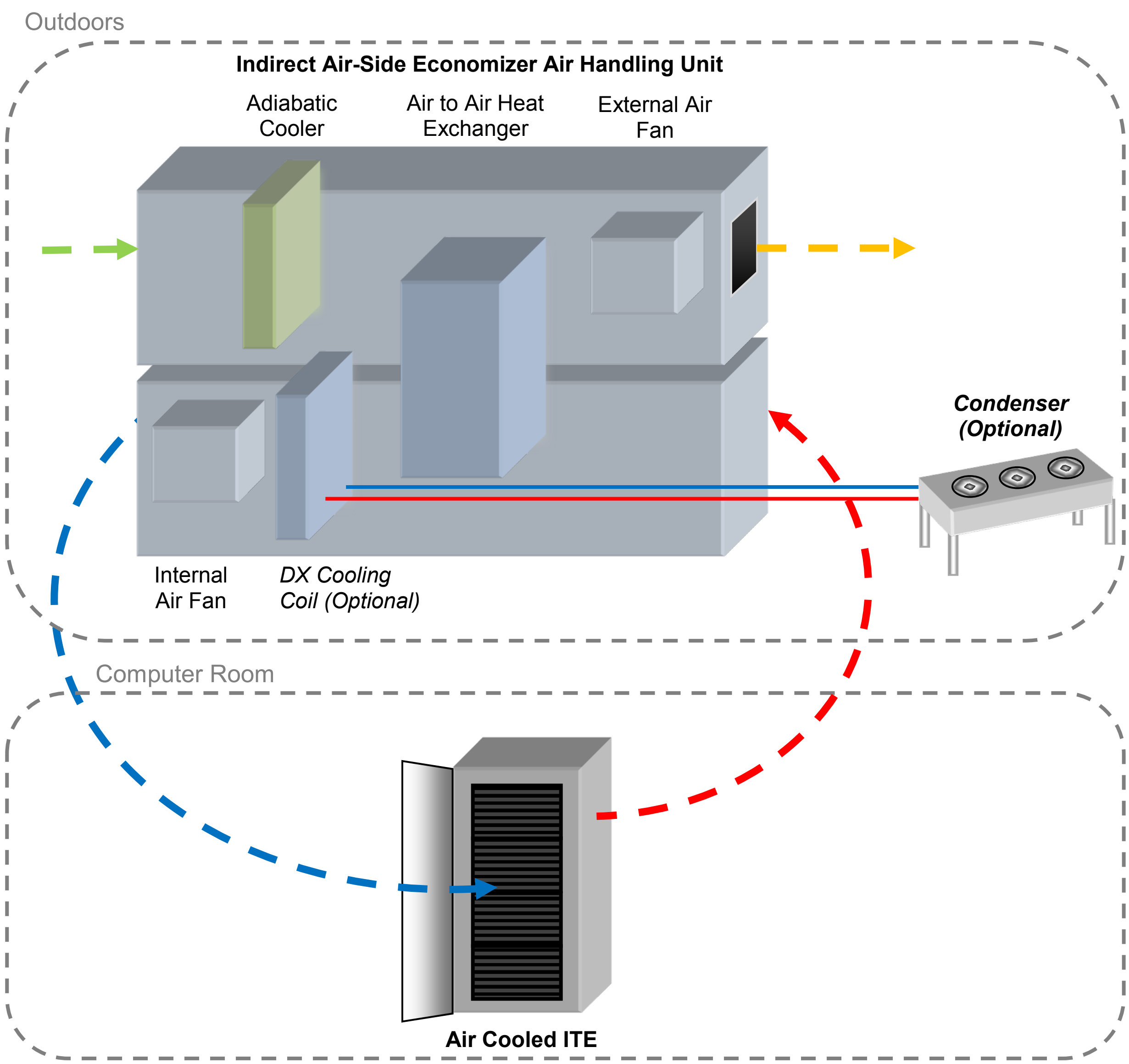

Figure 10-14
Indirect Air-Side Economizer

10.3.7 Dual Coil Cooling Solution

In mechanical solutions that have dual coils with one coil utilizing a water-based heat rejection system and the other coil utilizing a DX heat rejection system, the water-based coil may be used in the unit to provide an energy efficient mode of operation (compressor-less). The water-based system would only need to be an "N" solution as each of the air handlers would have a dedicated condensing unit. The redundancy provided by the quantity of air handlers and their associated condensing units would need to match the level of redundancy required for the Class of the data center.

Dual coil CRAHs with each coil connected to different chilled water system also exist and can provide 2N CRAH redundancy in conjunction with a dual fan configuration.

10.4 Mechanical Class Ratings

10.4.1 Introduction

This section expands upon the data center facility availability classes described in Appendix B and provides specific design information of the mechanical systems for achieving each Class. The standard includes five Classes relating to various levels of reliability of the data center facility infrastructure. The Classes are completely performance related.

The five Classes are:

- Class F0 and F1—The Single Path Data Center
- Class F2—The Single Path Data Center with Redundant Components
- Class F3—The Concurrently Maintainable and Operable Data Center
- Class F4—The Fault Tolerant Data Center

10.4.2 Class F0 and F1 Description

The mechanical systems cannot be maintained while operating. A failure of any element in the mechanical systems will likely result in the loss of cooling capability for the load. Single points of failure are common throughout the system. Any downtime, whether planned or unplanned, will result in cooling interruption.

Table 10-2 Class F0 and F1 Mechanical System Overview

Industry Description	Single Path
Component Redundancy	None
System Redundancy	None
System Controls	Single system
Power Feed	All power feeds from common upstream distribution
Ability to be maintained under load	No
Ability to recover from failures	No

Some representations of a Class F0 and F1 topology are shown in Figure 10-15 and Figure 10-16.

The configuration shown in Figure 10-15 represents only one method of providing the level of redundancy required. Any solution that meets the performance requirements specified in Section 10.4.2 satisfies the reliability requirements.

Chiller piping and valve redundancy are not required for Class F0 and F1.

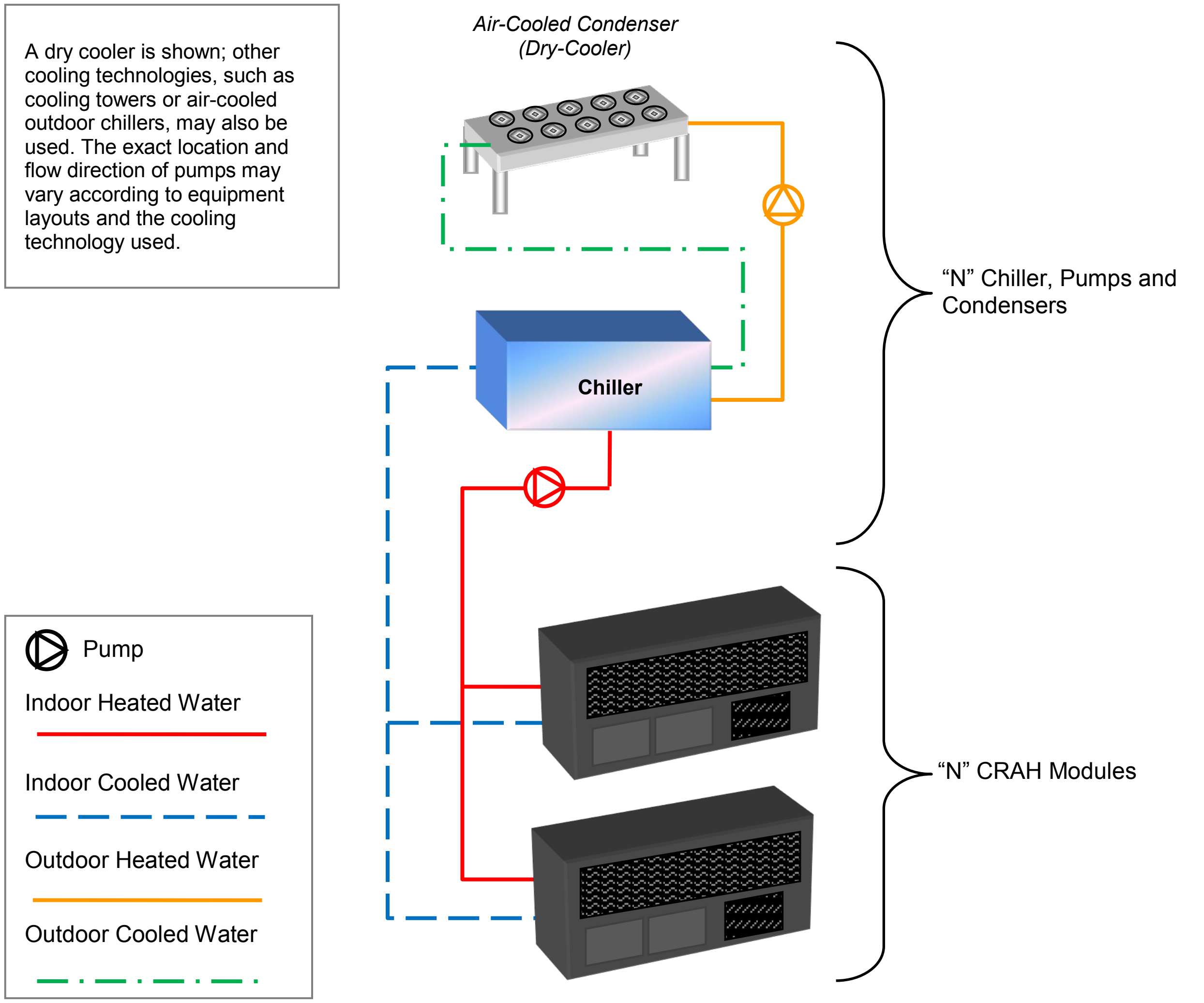

Figure 10-15
Class F0 and F1 Chiller System Example

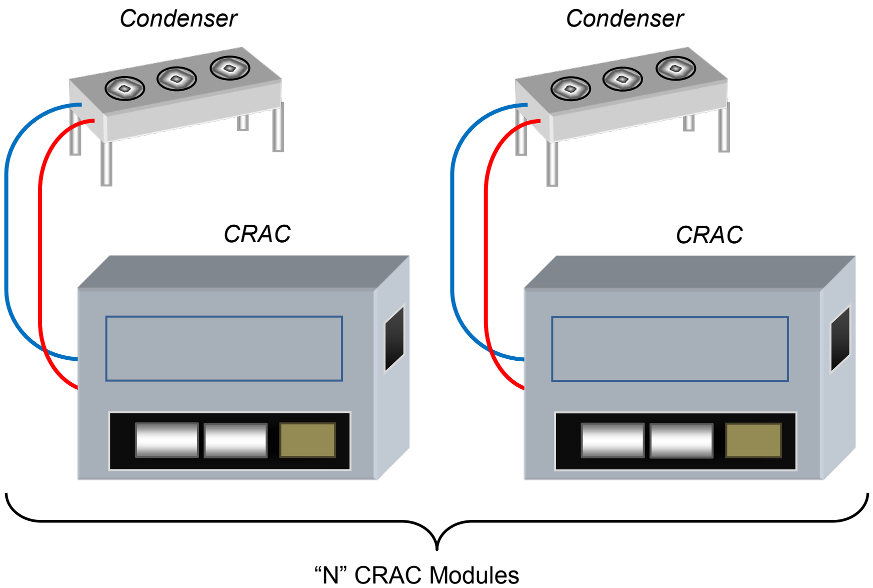

Figure 10-16
Class F0 and F1 Direct Expansion System Example

10.4.3 Class F2 Description

The mechanical systems possess some component redundancy but do not have any system redundancy. The mechanical components with redundancy can be maintained while operating. A failure of any element in the mechanical systems without component redundancy will likely result in the loss of cooling capability for the load. Single points of failure often exist within the overall cooling system. A minimum of N+1 components shall be provided for components with high failure rates, more than N+1 is recommended as the number of modules required to meet "N" increases.

Table 10-3 Class F2 Mechanical System Overview

Industry Description	Single path with redundant components
Component Redundancy	Yes for components with high failure rates
System Redundancy	None
System Controls	Single system
Power Feed	All power feeds from common upstream distribution
Ability to be maintained under load	For components with redundancy only
Ability to recover from failures	No

Some representations of a Class F2 topology are shown in Figure 10-17 and Figure 10-18.

The configuration shown in Figure 10-17 represents only one method of providing the level of redundancy required. Any solution that meets the performance requirements specified in Section 10.4.3 satisfies the reliability requirements for Class F2.

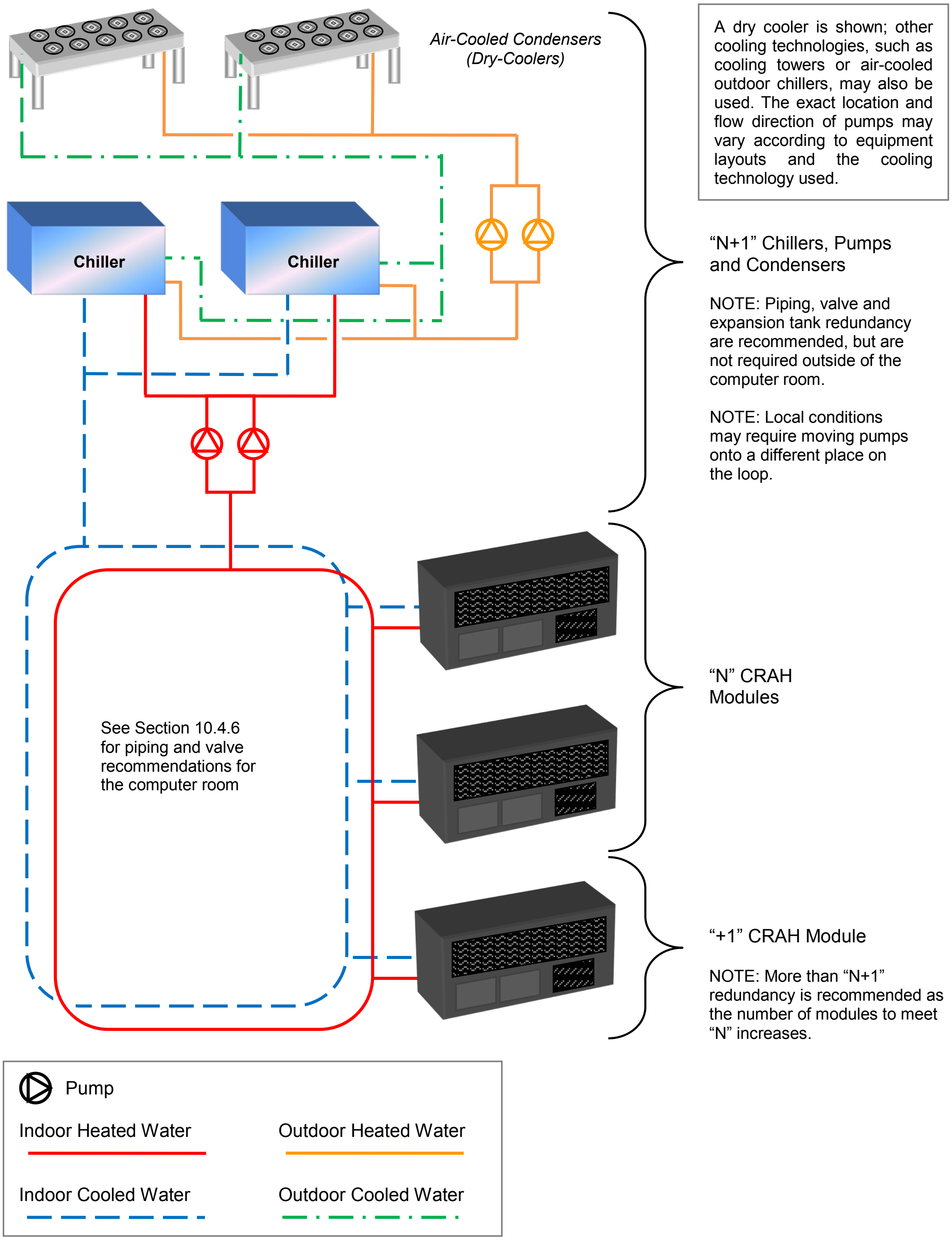

Figure 10-17
Class F2 Chiller System Example

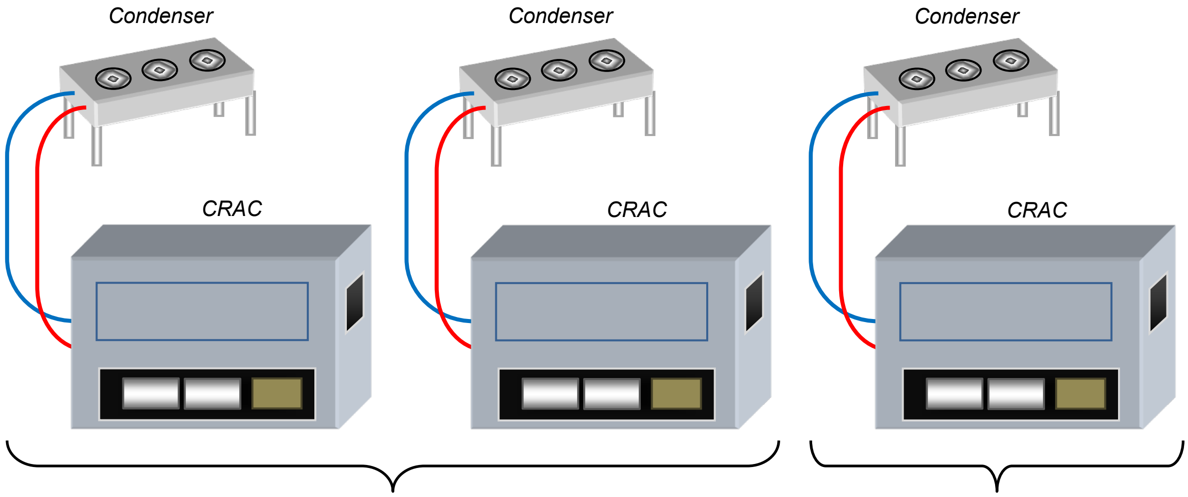

Figure 10-18
Class F2 Direct Expansion System Example

10.4.4 Class F3 Description

The mechanical systems possess redundancy so that any system or component may be taken off-line without impacting the system's ability to meet the "N" cooling capacity required. The level of redundancy required will be either at a system level or at a component level in order to ensure that all mechanical components can be maintained without impacting IT operations. A failure of any element in the mechanical systems will not result in the loss of cooling capability for the load. Single points of failure shall not exist within the overall cooling system. A minimum of N+1 components shall be provided for components with high failure rates; more than N+1 is recommended as the number of modules required to meet "N" increases.

Some representations of a Class F3 topology are shown in Figure 10-19 and Figure 10-20.

Table 10-4 Class F3 Mechanical System Overview

Industry Description	Concurrently maintainable and operable
Component Redundancy	Yes for all components not included within a redundant system
System Redundancy	Yes for all systems whose combination of components cannot be concurrently maintained by simply providing component redundancy
System Controls	Redundant components or systems to ensure concurrent maintainability of cooling system
Power Feed	Mechanical equipment and controls with redundant systems shall have the "A" systems feed from upstream "A" electrical distribution and "B" systems feed from upstream "B" electrical distribution. Mechanical equipment and controls that are limited to redundant components shall be feed from the electrical distribution in such a way as to ensure that the cooling capacity does not drop below "N" upon taking any mechanical component or upstream electrical distribution offline for maintenance, which is accomplished with the implementation of mechanical equipment with dual power feeds or ATS upstream on the power circuits feeding the mechanical equipment.
Ability to be maintained under load	Yes without reducing cooling capacity to less than "N"
Ability to recover from failures	Yes at the system or component level without reducing the cooling capacity to less than "N"

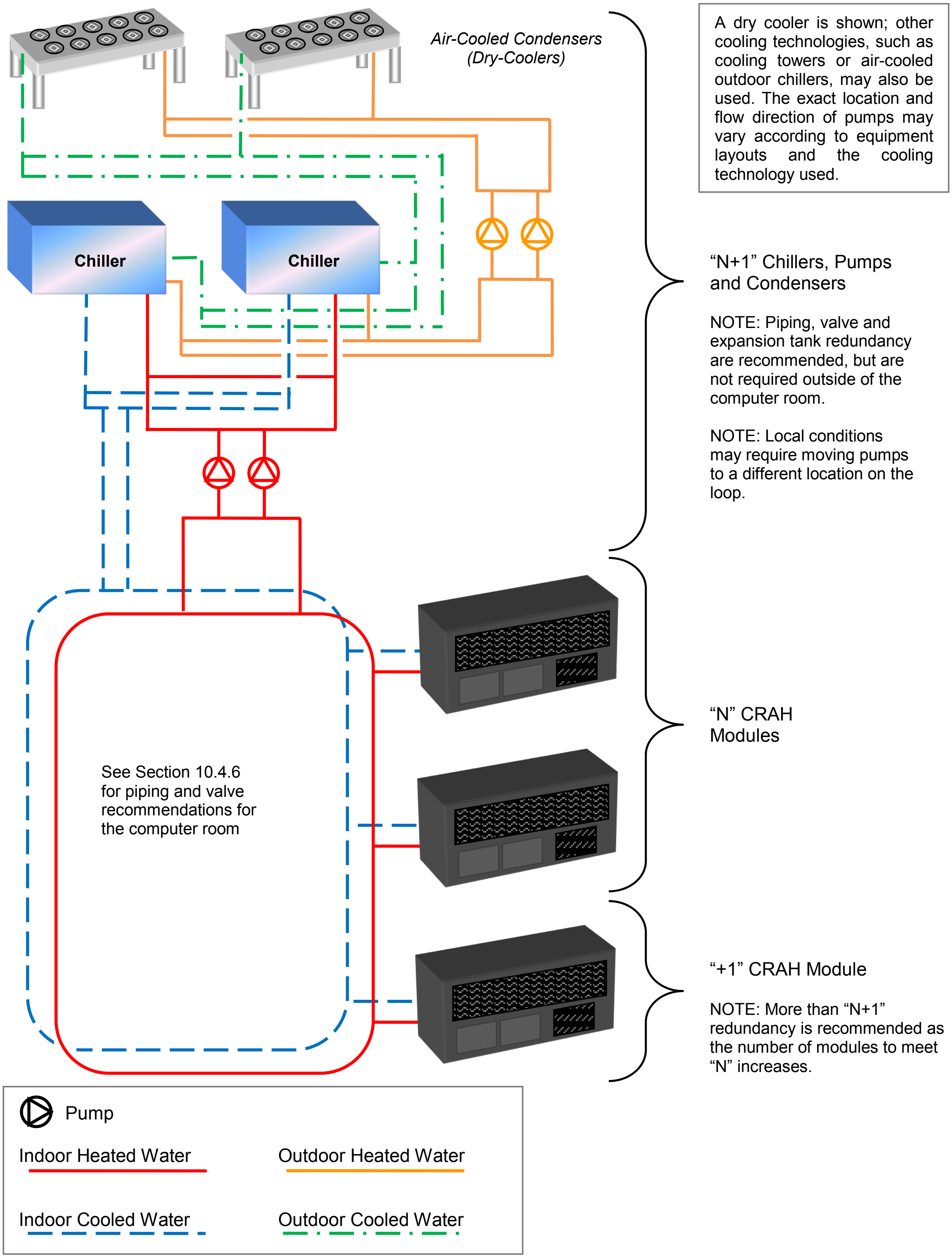

Figure 10-19
Class F3 Chiller System Example

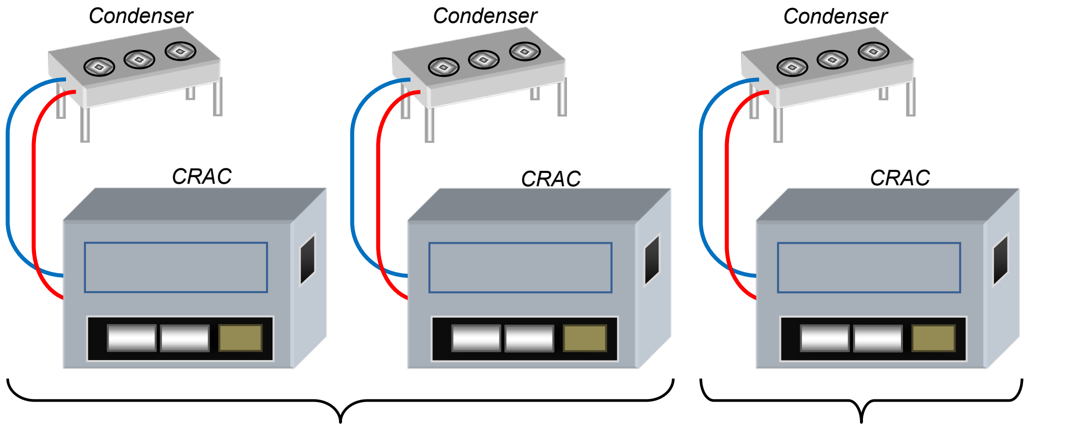

Figure 10-20
Class F3 Direct Expansion System Example

The configuration shown in Figure 10-19 represents only one method of providing the level of redundancy required. Any solution that meets the performance requirements specified in Section 10.4.4 satisfies the reliability requirements for Class F3.

10.4.5 Class F4 Description

The mechanical systems possess redundancy so that any system or component may be taken off-line without impacting the system's ability to meet the "N+1" cooling capacity required. The level of redundancy required will be either at a system level or at a component level in order to ensure that a mechanical component can experience a fault while maintaining any other mechanical component or system without impacting IT operations. A failure of any element in the mechanical systems will not result in the loss of cooling capability for the load. Single points of failure shall not exist within the overall cooling system. A minimum of N+2 components shall be provided for components with high failure rates; more than N+2 is recommended as the number of modules required to meet "N" increases.

Some representations of a Class F4 topology are shown in Figure 10-21 and Figure 10-22.

Table 10-5 Class F4 Mechanical System Overview

Industry Description	Fault tolerant
Component Redundancy	Yes, "N+1" for all components within a redundant system, and "N+2" for all components not within a redundant system.
System Redundancy	Yes for all systems whose combination of components cannot be fault tolerant by simply providing "N+2" component redundancy
System Controls	Redundant systems to ensure fault tolerance of cooling system
Power Feed	Mechanical equipment and controls with redundant systems shall have the "A" systems feed from upstream "A" electrical distribution and "B" systems feed from upstream "B" electrical distribution. Mechanical equipment and controls that are limited to redundant components shall be feed from the electrical distribution in such a way as to ensure that the cooling capacity does not drop below "N+1" upon taking any mechanical component or upstream electrical distribution offline for maintenance, which is accomplished with the implementation of mechanical equipment with dual power feeds or ATS upstream on the power circuits feeding the mechanical equipment.
Ability to be maintained under load	Yes without reducing cooling capacity to less than "N+1"
Ability to recover from failures	Yes, at the system or component level without reducing the cooling capacity to less than "N+1"

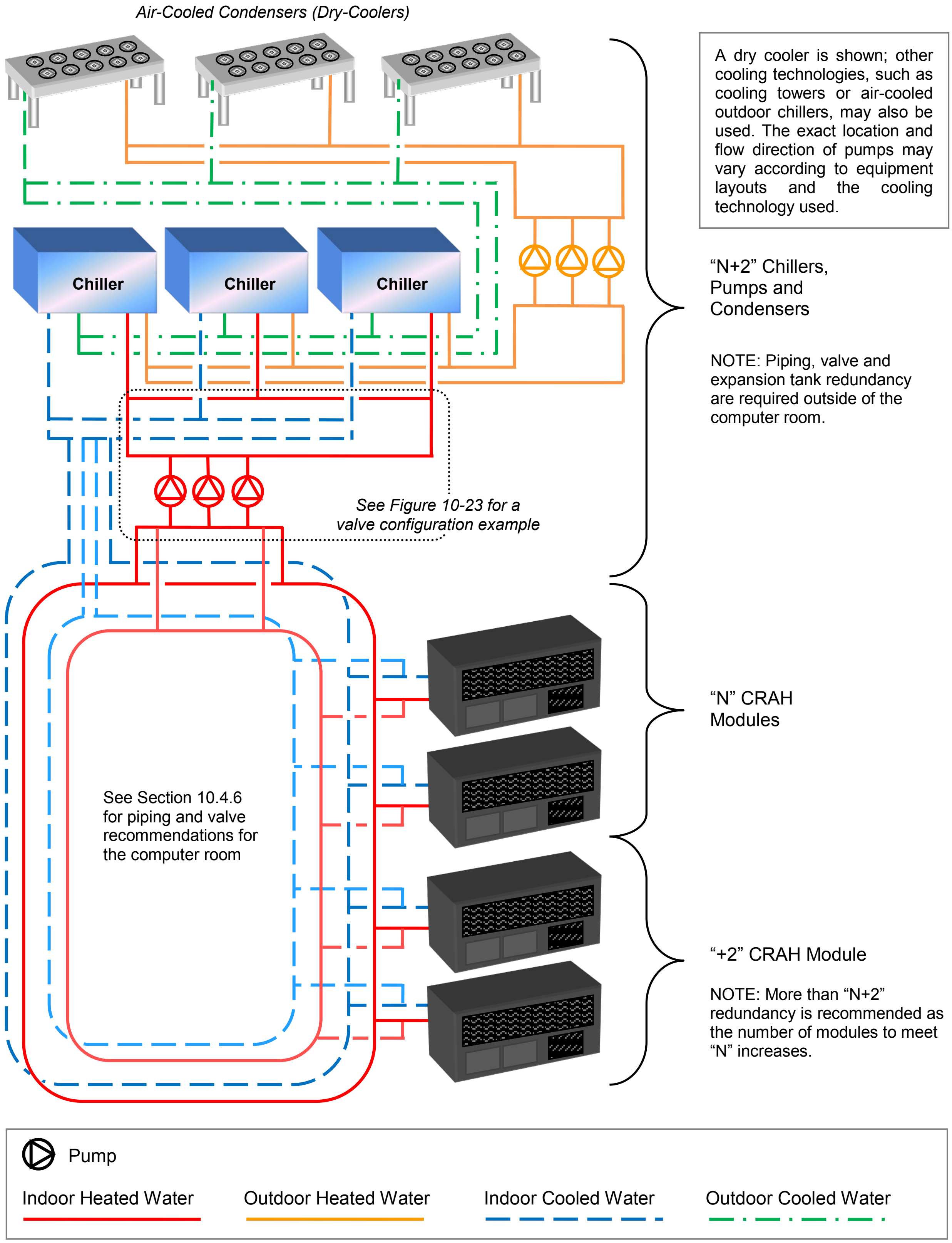

Figure 10-21
Class F4 Chiller System Example

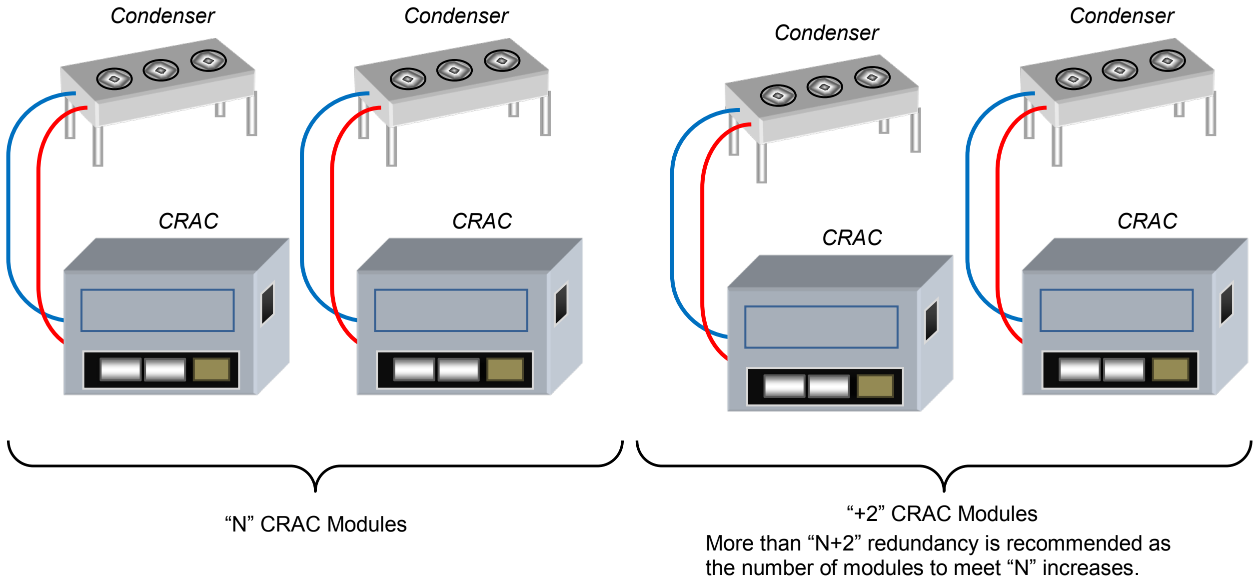

Figure 10-22
Class F4 Direct Expansion System Example

The configuration shown in Figure 10-21 represents only one method of providing the level of redundancy required. Any solution that meets the performance requirements specified in Section 10.4.5 satisfies the reliability requirements for Class F4.

Figure 10-21 also shows the supply and return piping from two piping loops, with interlocks to avoid loop mixing. A dual coil CRH or 2N CRAH solution that separates the loops are also options.

Figure 10-23 shows an example valve layout that facilitates concurrent maintainability of the pumps and piping in an N+1 pump redundant layout.

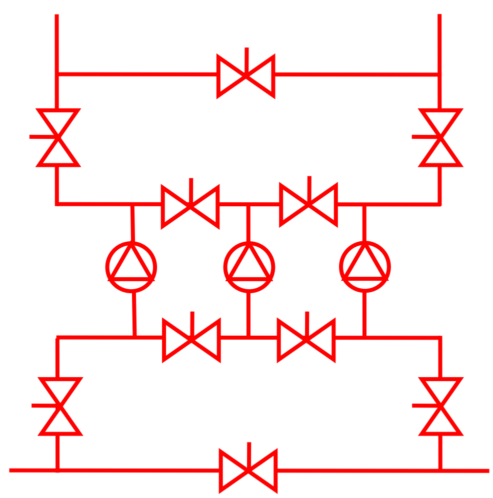

Figure 10-23
Valve Configuration Example for Pumps in Class F4 System (Shown in Figure 10-21)

10.4.6 Chiller Piping and Valve Redundancy

For higher class data centers, redundancy in chiller piping systems and valve components is a complex balance between providing concurrent maintainability or fault tolerance and simplicity. The standard provides the performance requirements and some concept-level examples to facilitate the discussions and decisions that will need to be made regarding piping and valve redundancy, maintainability, and operations.

10.4.6.1 Class F0 and F1 Requirements

Class F0 and F1 data centers do not require piping or valve redundancy.

10.4.6.2 Class F2 Requirements

Class F2 data centers shall have piping redundancy within the computer room, which is typically accomplished with a looped piping system. Piping redundancy outside the computer room is not required. Valve redundancy is not required.

10.4.6.3 Class F3 Requirements

10.4.6.3.1 Introduction

See Figure 10-24 for an example Class F3 piping and valve redundancy.

10.4.6.3.2 Requirements

Class F3 data centers shall have piping redundancy within the computer room, which is typically accomplished with a looped piping system.

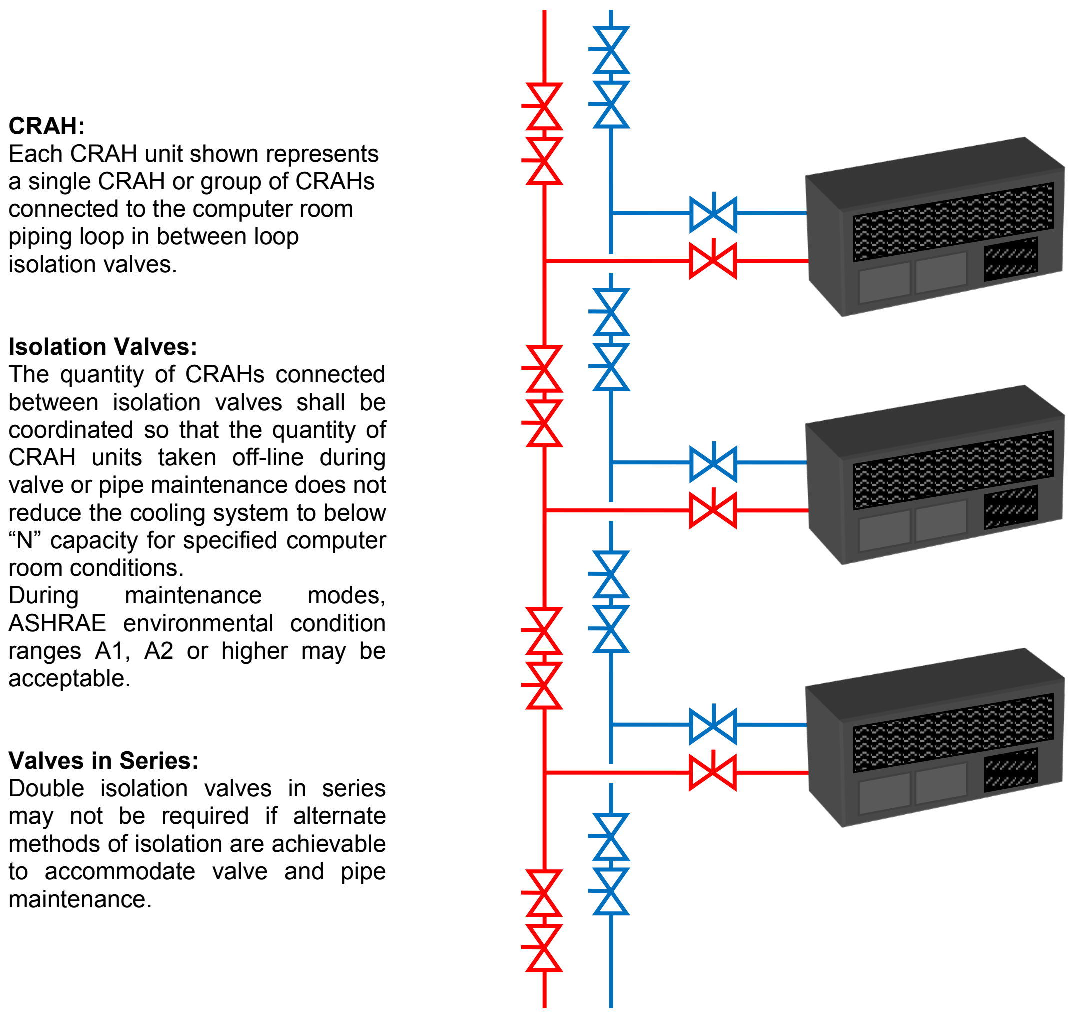

Figure 10-24
Class F3 Piping and Valve Redundancy Example

In a Class F3, the quantity of CRAHs or similar units connected between isolation valves shall be coordinated so that the quantity of units taken off-line during valve or pipe maintenance does not reduce the cooling system to below "N" capacity. Depending on computer room design conditions, room conditions at ASHRAE allowable A1, A2, or higher environmental conditions may be acceptable during maintenance modes.

Double isolation valves may not be required if alternate methods of isolation are achievable to accommodate valve and pipe maintenance.

10.4.6.3.3 Recommendations

Valve redundancy within the computer room is not required, but it is recommended. Piping and valve redundancy outside the computer room is not required, but it is recommended. Valve maintenance may be achievable without valve redundancy through other manual maintenance options, such as freezing the pipe in the area to be maintained.

10.4.6.4 Class F4 Requirements

10.4.6.4.1 Introduction

See Figure 10-25 for an example Class F4 piping and valve redundancy.

CRAH:
Each CRAH unit shown represents a single CRAH or group of CRAHs connected to the computer room piping loop in between loop isolation valves.

Isolation Valves:
The quantity of CRAHs connected between isolation valves shall be coordinated so that the quantity of CRAH units taken off-line during valve or pipe maintenance does not reduce the cooling system to below "N+1" capacity for specified computer room conditions.
During maintenance modes, ASHRAE environmental condition ranges A1, A2, or higher may be acceptable.

Valves in Series:
Double isolation valves in series may not be required if alternate methods of isolation are achievable to accommodate valve and pipe maintenance.

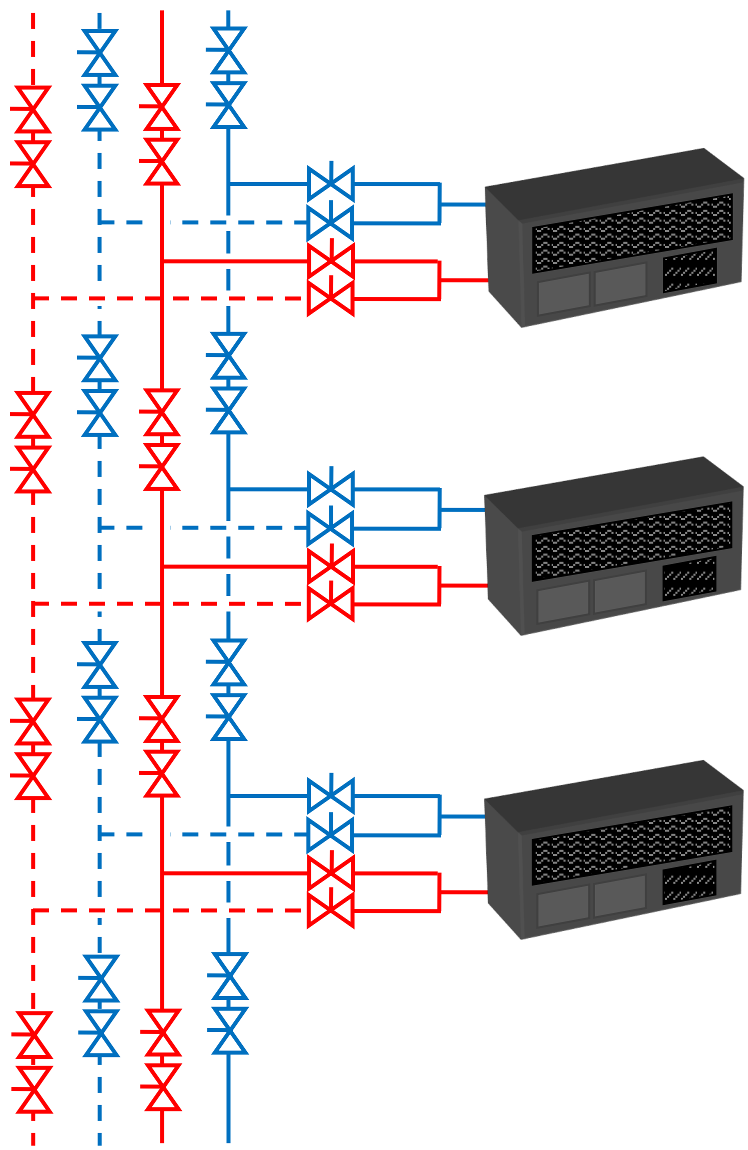

Figure 10-25
Class F4 Piping and Valve Redundancy Example

10.4.6.4.2 Requirements

Class F4 data centers shall have fault tolerant piping redundancy within the computer room, which is typically accomplished with a double looped piping system. Valve redundancy within the computer room is required.

In a Class F4, the quantity of CRAHs or similar units connected between isolation valves shall be coordinated so that the quantity of units taken off-line during valve or pipe maintenance does not reduce the cooling system to below "N+1" capacity. Depending on computer room design conditions, room conditions at ASHRAE allowable A1, A2, or higher environmental conditions may be acceptable during maintenance modes.

Double isolation valves may not be required if alternate methods of isolation are achievable to accommodate valve and pipe maintenance.

10.4.6.4.3 Recommendations

Piping and valve redundancy outside the computer room is not required, but recommended. Valve maintenance may be achievable without valve redundancy through other manual maintenance options such as freezing the pipe in the area to be maintained.

10.5 Air Flow Management

10.5.1 General Considerations

The fundamental requirement of air flow management is to deliver air to the intake of the ITE from the cooling equipment, and to return air from the ITE to the cooling equipment. Bypass air (air delivered from the cooling equipment that returns without passing through the ITE) should be minimized. Recirculation air (air that passes from the ITE exhaust to the ITE intake without passing through the cooling equipment) should be eradicated if possible.

Cooling systems and cooling equipment must always be selected using a holistic approach. The choice of air distribution method should never be considered without evaluating other significant factors, such as whether or not an access floor is used, the return air path, location of CRAC/CRAH units or air handling equipment relative to server racks, orientation of hot/cold aisles, ceiling height, methods for humidity control, and provisions for future expansion, to name just a few. Each choice affects the others, and the overall performance of the data center cooling system will be dictated by the entire package of decisions. *Datacom Equipment Power Trends and Cooling Applications* and *ASHRAE Design Considerations* provide general descriptions of the various air delivery methods and some of the cooling system technologies available, but they do not provide hard and fast rules for selection since there are so many combinations of the factors noted above. A knowledgeable and experienced data center cooling engineer/consultant is essential to achieve a successful outcome.

10.5.2 Introduction to Air Flow Management

Well-designed airflow management brings significant performance and efficiency benefits. Every opportunity to improve air circulation and isolate the hot and cold airstream should be considered in the design of primary cooling systems for new data centers. These techniques can also be applied to correct hot spots or when expansion of the primary system is too costly or disruptive to correct the problem at hand.

Effective heat removal from ITE requires attention to the direction of airflow. An important part of thermal management of air-cooled ITE is air management. Selection of the appropriate cooling system and equipment are made based on many factors. There is no single cooling solution that is appropriate for all data centers, and some systems may be inappropriate for a particular combination of factors. Each of the factors noted below, either individually or in combination, can have a significant impact on the selection of the appropriate system and cooling equipment:

- Room size
- Overall cooling density (watts per square meter or watts per square foot), which is established by the maximum kW load for the ITE used in the electrical design. Cooling load should match actual operating load as opposed to nameplate load
- kW per cabinet or module
- Number and capacity of cooling units required to meet load and redundancy criteria and their location relative to ITE layout
- Room location relative to mechanical support spaces
- Room location in the building relative to outdoors
- Ceiling height
- Absence or presence of access floor

List continues on the next page

- Access floor height
- Future expansion needs
- Reliability requirements
- Available maintenance personnel
- Local climate

10.5.2.1 Recommendations

ANSI/TIA-942-B: Equipment that utilizes front-to-rear cooling schemes should be used in conformance to ANSI/TIA-942-B and *ASHRAE Thermal Guidelines,* so as not to disrupt the functioning of hot and cold aisles.

Also refer to NEBS GR-3028-CORE: Airflow Protocol Syntax (EC-Class).

ITE cabinet cooling intake temperature measurement points should be selected in accordance with *ASHRAE Thermal Guidelines*.

10.5.2.2 Additional Information

Access floors have traditionally been the first choice for medium to large rooms with higher power/cooling densities. A factor in this has been the commercial availability of specialized data center cooling equipment.

Several HVAC equipment manufacturers now offer equipment capable of cooling very high-density loads with localized overhead or horizontal air distribution. This equipment is sometimes suited to specific heat rejection technologies and may not be appropriate for all buildings.

Access floors offer fewer air distribution advantages for small data centers. Smaller cooling equipment can perform very well in small spaces where the ITE is in close proximity to the cooling unit.

10.5.3 Hot Aisle/Cold Aisle Concept

10.5.3.1 Requirements

Limit air flow velocity in segregated hot and cold aisles and plenums to a maximum of 3 m/s.

Where segregated hot and cold aisles are deployed all parts of the segregation must be sealed, including:

- Space under cabinets and racks (remove feet)
- Perforations in cabinets and racks that form part of the hot/cold segregation
- Horizontal and vertical blanking plates in cabinets and racks
- Cable openings

In computer rooms where CRAC/CRAH units are not segregated from the ITE, stand-alone ITE and ITE racks and cabinets shall be placed in rows not exceeding a length of 8 m (27 ft) and arranged front-to-front, back-to-back. CRAC or CRAH units shall be aligned with the hot aisles.

NOTE: Alignment may be applicable with row-based cooling solutions.

10.5.3.2 Recommendations

NOTE: See *ASHRAE Thermal Guidelines* for a more in-depth discussion of hot and cold aisles.

The hot aisle/cold aisle concept for arrangement of ITE in the computer room should be used, regardless of whether air distribution is overhead or supplied from an access floor plenum.

Pressure differential between segregated cold and hot aisle should be designed for a maximum of 5 Pa, less if possible.

10.5.3.3 Additional Information

Conventional wisdom regarding data center supply air considers recirculation of return air from hot aisles to cold aisles as a condition to avoid. The following example illustrates this and also why controlling environmental conditions based on relative humidity is difficult:

> With the ASHRAE Class A1 recommended equipment inlet conditions of 18 to 27 °C (64.4 to 80.6 °F) (dry bulb temperature) and a relative humidity of -9 °C DP to 15 °C DP and 60%, server exit conditions are very often close to 38 °C (100 °F) and 20% RH. The typical CRAC unit supplies air between 13 and 16 °C (55 and 60 °F) and close to 90% RH; clearly conditions that are outside the range required by the typical server manufacturer. To achieve 18° to 27 °C (64.4° to 80.6 °F) at the server inlet, mixing between hot and cold airstreams must occur in the proper proportion, and the resultant air should be uniformly distributed along the entire server rack, top to bottom, unless supply air and return air can be completely isolated from each other and the supply air can then be delivered within the required use parameters. Since server fans generally vary the airflow to maintain a balance between temperature and power consumption, the airflow through the server cabinets is not constant.

The temperature and relative humidity displayed on the CRAC unit control panel is measured at the return air to the CRAC unit t. This temperature represents the mixed condition of all the air that makes it back to the CRAC unit. In most data centers, the CRAC unit temperature set point is set between 20 to 25 °C (68 to 77 °F), and the CRAC unit operates to maintain this temperature. This tells the data center manager/operator that enough hot aisle air has mixed with enough cold aisle air in the space between the CRAC unit and server racks to ensure that the right conditions exist at the CRAC unit inlet, but it tells nothing of the conditions that are most important—the actual temperature at the server inlets. For the condition described above to exist, the air temperature at the server inlets will be well below the temperature range recommended by ASHRAE with a corresponding elevation of relative humidity.

Airflow in the typical data center consists of two flow loops:

- CRAC units (a few big fans) circulate air within the entire room.
- Servers (many little fans) circulate air between cold and hot aisles.

These loops are "decoupled;" they do not depend on each other, and one will continue to operate if the other is shut off, or if the flow rates do not balance. Hot air is buoyant and will tend to rise, and all air will take the path of least resistance relative to the room pressure gradients. Air will tend to flow back toward the CRAC unit inlets, but the greater the distance from the CRAC unit, the less momentum the air mass has to overcome turbulence.

The temperature difference between inlet and supply is typically expressed as ΔT. For the two airflow loops described above, each operates with a different ΔT. However, as energy in the loops must balance between the two, all of the heat rejected from the servers must also be further rejected in the CRAC unit. Therefore, the relative airflow rates of the two loops will be proportional to the temperature difference of each loop. The air temperature rise through servers is not constant since most servers use variable speed fans to balance CPU temperature, power consumption, and noise, but a ΔT of 11 to 17 °C (20 to 30 °F) is common. CRAC units typically will operate at a constant volume, and varying temperature rise based on load, depending on the type of cooling technology employed. A typical CRAC unit ΔT is 8 to 11°C (15 to 20 °F) and is dependent on whether the CRACs are chilled water units or are air/glycol cooled. The CRAC unit loop can circulate 50% more air than the sum of all the server fans.

The "ideal" data center HVAC design would supply air at the desired inlet temperature for the server and at a volumetric flow that matches the server fans. All hot aisle air would be returned to the air-handling units without the mixing or bypass of air from outside the hot aisle. When such isolation cannot be achieved, careful attention must be paid to monitoring server intake supply air to be sure the proper calibration is maintained of the mix of source air and return air.

10.5.4 Access Floor Air Distribution

10.5.4.1 Access Floor Versus No Access Floor

The necessity or use of an access floor for any particular data center depends on a number of factors. As with the selection of an HVAC system, access floor decisions should be made as part of a larger consideration of needs and requirements, many of which are unrelated to the mechanical system.

Advantages of access floor with underfloor air distribution:

- Allows great flexibility in location of load to CRAC unit
- Imposes fewer limits on locating CRAC units in the space
- Piping services may be concealed below the access floor
- More compatible with gravity condensate drainage from cooling coils and humidifiers
- No overhead supply ductwork to obstruct the return air path or to interfere with lighting, sprinkler heads, or overhead power/cable distribution systems
- Permits the use of nearly any cooling technology, regardless of air supply/return configuration

Disadvantages of access floor for HVAC:

- The underfloor space is an air distribution plenum—all cable must be listed for data processing or plenum rated for flame spread and smoke developed characteristics or installed in conduit, (See Section 14.7 for considerations of overhead versus under-floor cable routing).
- Poor planning of underfloor utilities can result in blocked airflow and poor cooling performance.
- Poor management of cable openings can result in reduced airflow at perforated tiles, supply air grilles, or other supply air openings.

10.5.4.2 Recommendations

The type of air delivery method through an access flooring system should be consistent. Do not mix perforated tiles with supply air grilles as the differences in flow/pressure drop characteristics will result in inconsistent and unpredictable performance. Similarly, large, relatively unobstructed openings in the access floor can have significant adverse effects on the underfloor pressurization and should be avoided as the larger the opening, the smaller the pressure drop corresponding to a particular cubic meters or feet per minute. Since air takes the path of least resistance, large openings will starve the perforated floor tiles. *Large* means any opening that is large relative to a single perforation in an access floor tile. Many (relatively) small openings can begin to look to the HVAC system like a few very large openings.

Cable penetrations into the bottom of cabinets should be filled to minimize the flow of air directly into the cabinet from below. The area of the unobstructed portion of a cable opening looks to the HVAC system like a large opening. It is not uncommon for unprotected cable cutouts to allow up to half of the total CRAC unit airflow capacity to bypass the perforated tiles.

Access floor systems provides a flexible method of delivering cooling to data centers, as perforated floor tiles can be easily added or moved to accommodate high heat load areas. Floor height should be selected based on the combined needs for airflow, power distribution, network/communications cabling, and chilled water distribution, if used. Access floor heights greater than 900 mm (36 in) may introduce additional considerations for personnel access and safety, increase costs of the flooring system, and may not enhance the uniformity of air distribution below the floor.

Chilled air should always be delivered into the cold aisle in front of the cabinets and not be delivered directly into the bottom of the cabinet. There are three main reasons for this:

1) Openings provided below the racks for this purpose will generally be large compared to the tile perforations.
2) Some of the air will bypass out through the back of the rack into the hot aisle.
3) Air supplied directly into the bottom of a cabinet may be significantly below the minimum temperature prescribed in *ASHRAE Thermal Guidelines* or GR-3028-CORE. CRAC unit discharge air temperatures are typically in the 13 to 16 °C (55 to 60 °F) range, and 80% to 90% RH at that temperature. With underfloor distribution, the air coming out of the perforated tiles will usually be below 20 °C (68 °F). Room temperature measurement points should be selected in conformance to *ASHRAE Thermal Guidelines*:

Temperature measurement sensors should be regularly calibrated.

A significant difficulty with temperature and humidity measurement point locations is the physical installation in meaningful locations. Sensors typically must be mounted on a fixed surface, making the mid-aisle 1500 mm (60 in) above floor locations impractical for permanently installed devices. Temperature and humidity sensors furnished with CRAC units are factory installed in the units at their inlet and do not indicate the conditions of the air at the ITE inlets. Wireless sensors are helpful to monitor the ITE inlet conditions.

Temperature-measuring points should ideally mimic the equipment inlet conditions since these conditions define the equipment comfort.

Floor plenums should be as airtight as possible relative to adjacent spaces and cleaned prior to being put into use.

10.5.5 Overhead Air Distribution

Overhead air distribution can be used effectively, although it will generally not be as flexible for future equipment placement as underfloor supply. Fixed diffuser locations limit reconfiguration.

Overhead ductwork must be closely coordinated with lighting, sprinklers, and power or network cabling in data centers where these utilities are not located below an access floor. Overhead ducts wider than 1200 mm (48 in) will require sprinkler heads to be located below the ductwork.

Supply air should be placed in the cold aisles only.

10.5.6 Row-Integrated Cooling

For ITE that takes cool air in the front and discharges hot exhaust air out the back, cooling units can be applied within the rows of equipment racks. The cooling units should be designed for row integration with an airflow pattern from back to front. These types of units, which can be refrigerant or chilled water based, are designed to capture the hot air being exhausted out the back of the equipment into the hot aisle and to discharge cool supply air into the cold aisle in front of the racks. By placing the cooling units very close to the heat source (ITE), the length of the hot air return path to an air conditioner can be greatly reduced, thereby minimizing the potential for mixing of hot and cold air streams (e.g., bypass, recirculation). Fan power can be lower, and capacity and efficiency can be higher because of the higher return air temperatures to the cooling units.

Higher return air temperatures also lead to a very high sensible heat ratio, minimizing the amount of unnecessary dehumidification (and a subsequent need for rehumidification to maintain constant humidity levels).

This type of configuration can work well for low- to medium-density loads. For higher load densities, it is recommended to install a containment barrier to ensure that the hot exhaust air is isolated from the cool supply air.

10.5.7 Equipment Layout

Printers and other potential contamination sources should not be located in the computer room.

Cabinets and racks shall be arranged in rows with fronts of cabinets/racks facing each other in a row to create hot and cold aisles. Equipment should be placed in cabinets and racks with cold air intake at the front of the cabinet or rack and hot air exhaust out the back, top, or both. However, reversing the equipment in the rack will disrupt the proper functioning of hot and cold aisles. Blanking panels should be installed in unused cabinet and rack spaces to improve the functioning of hot and cold aisles.

When placed on an access floor, cabinets and racks shall be arranged to permit tiles in the front and rear of the cabinets and racks to be lifted. Cabinets should be aligned with either the front or rear edge along the edge of the floor tile per ANSI/TIA-942-B.

Cabinet size, location for air entry, location for cable entries, and access to front and rear should be planned for consistency according to ETSI EN 300-019.

CRAC units should be located in the hot aisle path when the return air path is the free space in the room (e.g., not ducted to the CRAC unit inlet).

10.5.8 Supply Air Layout

When underfloor cooling is used, perforated access floor tiles should be located in the cold aisles only to support the functioning of the hot and cold aisles. For an overhead air distribution system, the supply diffusers should be placed above the cold aisles only.

10.5.9 Return Air Layout

Return air should be positioned to capture the highest heat concentration such as return air intakes directly over the hot aisles or directly over equipment producing the highest heat. Capturing the heat with return grilles and not entraining it in the supply air should be the goal of return and supply layouts. When using a return air system to reduce recirculation, supply air temperature should be controlled to very near the highest acceptable equipment inlet temperature.

In a computer room with open room return air path, a ceiling height of at least 3 m (10 ft) above the access floor will allow for an effective hot air area above cabinets and racks and optimize the return air path. Rooms with high-density cooling loads should consider ceilings higher than 3 m (10 ft).

10.5.10 Cable Management

The cold aisle plenum space should remain unobstructed by raceways in conformance to ANSI/TIA-942-B.

Floor tile cutouts for cable egress to cabinets and damping around cables should conform to ANSI/TIA-942-B.

When overhead cable systems are used in lieu of or in addition to underfloor cabling, placement and grouping of cable should be planned to minimize the effects on return air. Obstructions in the return air path could contribute to higher levels of hot air recirculation to the cold aisles, depending on the configuration of the cable system relative to the rack layout (refer to Section 14.7 for additional considerations of overhead versus under-floor cable routing).

Telecommunications cabling under the access floor should run parallel to CRAC air delivery path in accordance with applicable standards (e.g., BSRIA BG 5/2003). Where the cable pathways cross the front of the air delivery system care should be taken to reduce the impact on the air flow.

Cables shall not be left abandoned under access floor, in overhead raceways, or above suspended ceilings. Inactive cables shall be removed or terminated on at least one end and marked “for future use”.

10.6 Ventilation (Outside Air)

The standard filters furnished with packaged computer room air conditioning equipment have either 20% or 30% ASHRAE efficiency ratings. Higher efficiency filters at CRAC units will not provide significant improvements in air quality and will result in higher energy costs. See the *ASHRAE Handbook* or ASHRAE 52.2 regarding minimum efficiency reporting value (MERV) ratings of filters.

Manufacturers offer optional high-efficiency filters, usually up to 85% ASHRAE efficiency (some equipment offered in Europe is available with near-HEPA filter quality filters). Selecting high-efficiency filters will require a higher static pressure blower and correspondingly higher horsepower motors.

10.6.1 Computer Rooms

10.6.1.1 Introduction

Human occupancy in data centers is typically low. However, removal of internally generated pollutants and maintaining a positive pressure in the computer room and entrance space should be considered when determining a ventilation rate. Maintaining a positive pressure in the computer room and entrance room spaces relative to adjacent spaces is important as contaminants or dirt could migrate into the data center. It is especially important when the adjacent space is outdoors as wind effects can create pressure differentials that will exceed the space pressurization, resulting in increased outdoor air infiltration.

10.6.1.2 Recommendations

ANSI/TIA-942-B specifies a positive pressure differential with respect to surrounding areas. A typical range for the pressure differential between the computer room and any adjacent rooms is 3 to 12 Pa (0.012 to 0.05 in WC).

Controlling room pressure differential with a building control system and a system of dampers or variable speed fans is often complicated, with limited effectiveness, especially if doors are frequently opened and closed. Generally, manual balancing to achieve the desired pressure differential is sufficient. Room pressure differential should be monitored.

Loose or leaky construction (such as oversized, unsealed openings created for piping, conduit, or cabling, abandoned openings, and poor construction methods) that may exist in older buildings will significantly increase the volume of makeup air required for pressurization. Care should be taken during construction to seal cracks and openings that prevent adequate pressurization. Absence or presence of vapor barriers must be considered to ensure acceptable environmental control and to prevent mold growth.

10.6.1.3 Additional Information

Ventilation is defined by ASHRAE as air supplied to or removed from a space for the purpose of controlling air contaminant levels, humidity, or temperature. It is typically interpreted as the portion of the supply air that is “fresh” outdoor air that has not been recirculated or transferred from any other space.

Ventilation rates prescribed by codes (*International Mechanical Code* or other mechanical codes adopted by the local or state jurisdiction) and by ASHRAE 62.1 are concerned with meeting the needs of occupants. Meeting the requirements of ASHRAE 62.1 may not provide sufficient ventilation for adequate space pressurization, but code compliance must always be documented in the design process.

As ventilation rates increase, the potential for introducing contaminants into the computer room may also increase. This is because typical filter holding frames provided by the manufacturers of air handling units allow for some bypass around the filters. As the volume of outdoor air supplied to the computer room increases, the volume of unfiltered bypass air will also increase. Filter frame leakage efficiency is addressed in Section10.2.3.

10.6.2 Battery Rooms

NOTE: Additional information can be found in the *IMC* and NFPA 70E.

10.6.2.1 Requirements

When mechanical ventilation is provided, the minimum required exhaust flow is 0.3 m^3/min per m^2 of room area (1 ft^3/min per ft^2 of room area) with hydrogen concentration limited to 1% of the total room volume. Conservative HVAC engineers often design the battery room exhaust system for 0.6 m^3/min per m^2 of room area (2 ft^3/min per ft^2 of room area).

Ventilation is required for both VRLA and flooded cell batteries. It may not be required for Li-ion batteries, check with vendor and local codes.

10.6.2.2 Recommendations

Battery rooms (or enclosures) should limit the concentration of hydrogen gas to less than 1% concentration.

In most cases, a dedicated exhaust system is provided to remove hydrogen gas that may accumulate.

Battery ventilation is a code-required safety system and is independent of Class. Redundant exhaust fans are not required by codes but should be provided for Class F3 and Class F4 data centers to be consistent with the reliability goals of such facilities along with an alternate source of makeup air in the event of a makeup air system failure. Exhaust fan operation/status should be monitored.

If hydrogen detection systems are provided, they should be monitored by the central security monitoring or building automation/management system.

10.7 Other Design Considerations

10.7.1 Humidity Control

10.7.1.1 Recommended Operational Relative Humidity

See *ASHRAE Thermal Guidelines* and *NEBS* specifications. Note these are at the ITE inlet.

10.7.1.2 Other Recommendations

One of the more practical considerations regarding dew point temperature limits in a computer room is to avoid cold surfaces in the computer room. If equipment is brought into the room when its surface temperature is below the room dew point, condensation on that cold surface will occur. The same is true for building components; insufficient insulation of an exterior wall or roof assembly could result in a surface temperature below the room dew point with condensation resulting.

10.7.1.3 Location of Humidification and Dehumidification

Humidification and dehumidification may be located at either the CRAC/CRAH units or the central air handlers. It may be located at the pressurization supply air if provided but in this instance the air will require pre-warming.

On direct air-side economizers the humidifiers must be located on the recirculated (warm) air.

10.7.1.4 Additional Information

A study of local environmental conditions in conjunction with building construction will determine requirements for humidification/dehumidification. If ultrasonic humidifiers are used, deionized water should be provided to prevent formation of dust from dissolved solids in the water. If availability of deionized water over the life of the data center is uncertain, ultrasonic type humidifiers should be avoided.

The integrity and construction of the building envelope, use of vapor barriers, pressurization of the computer room relative to adjacent spaces, and the conditioning of outdoor air supplied to the space must be considered in the context of local environmental conditions when selecting a humidity control scheme. If a central steam boiler used for building heating is also used for direct steam humidification, the type of boiler water chemicals should be considered. Generally, steam generating humidifiers (using electricity, natural gas, or steam as the energy source) have a lower life cycle cost than ultrasonic, spray or spinning disk humidifiers, which need a sterilized or deionized water supply. Evaporative humidifiers can be very effective and save energy when air from the hot aisle is used to evaporate water. Refer to *ASHRAE Design Considerations*.

Humidifiers and reheat coils can be included in individual CRAC units. However, when two or more CRAC units are in a space, care should be taken to ensure that the controls and sensors are calibrated so that individual units do not fight each other (e.g., some humidifying while others are dehumidifying). It may be beneficial to use a centralized humidification system to avoid this issue as well as for ease of maintenance. Refer to *ASHRAE Design Considerations* for information on different types of humidification systems.

10.7.2 Maximum Altitude

NEBS: 4000 m (13,000 ft)

ASHRAE: 3050 m (10,000 ft)

Maximum altitude is specified to account for the limitations of HVAC equipment.

10.7.3 Noise Levels

Room air distribution noise level should follow guidelines as established by ASHRAE and be at or below the maximum level of NC-45 using the Beranek Noise Criteria (NC) Method.

10.7.4 Supplemental Cooling

Supplemental cooling is typically used to mitigate thermal issues that cannot be effectively resolved by existing cooling system design alone. These auxiliary methods may include:

- Spot cooling
- Cooled cabinets
- Rear door heat exchangers
- Row-based cooling
- Immersion cooling

The following types of redundancy for supplemental cooling may be required in addition to redundancy for power to support them:

- Backup supplemental systems
- Generator feed for supplemental cooling systems
- Dual power feeds for supplemental cooling systems

Supplemental cooling systems are any method of heat management that is added to an existing data center to supplement the primary or original cooling system, either by mitigating local hot spots or by adding cooling capacity. *Design Considerations* lists five common approaches to supplemental cooling. Each of these approaches is aimed at increasing the local cooling effect by one of the following means:

- Improving or regulating air circulation either at the inlet or discharge of the ITE cabinet or rack
- More closely coupling cooling equipment with the ITE
- Isolating hot and cool airstreams from one another to reduce recirculation or mixing
- Directing cool air from the cooling equipment discharge into the ITE inlets
- Directing hot air from the ITE discharge into the return air path to the cooling equipment

The choice of supplemental cooling systems depends partially on whether the problem is a shortfall of cooling capacity, or lack of cooling effectiveness. A capacity shortfall can only be addressed by systems that provide heat rejection to the outdoors or to an existing system such as chilled water. System effectiveness problems are most likely the result of airflow deficiencies, which may be improved by airflow solutions.

10.7.4.1 In-Room

Supplemental chilled water room cooling units may be used to cool room hot spots when floor space and chilled water are available in accordance with the system descriptions of GR-3028-CORE.

10.7.4.2 In-Frame

Supplemental in-frame chilled water-cooling may be used where water can be introduced into the computer room and where a solution does not exceed the standard cabinet floor utilization specifications to deliver the cooling benefits described in GR-3028-CORE.

10.7.4.3 Direct Return

Direct return air systems may increase the cooling capacity of the supply duct system when equipment is located per GR-3028-CORE and has an acceptable interface between the equipment exhaust and the ductwork.

One method of direct return is to install rack-mounted fan air-removal units to capture 100% of the exhaust air from each rack and direct the hot air to an overhead return air plenum. This solution works well as a solution for isolated hot spots or for new installations. Because it requires unique ducting on every rack, some of the benefits can be offset by the cost and reduced flexibility.

Another method of direct return is to install barriers that will channel 100% of the hot exhaust air from a rack into an adjacent row-integrated cooling unit. This solution is very effective for extreme high-density applications.

A third method of direct return is to use row-integrated air conditioning units and a totally enclosed hot aisle. The hot aisle becomes the return duct to all cooling units installed on either side of the hot aisle. This method is effective when there are many high-density racks in close proximity, thereby creating a high-density zone within the computer room. Provisions must be provided to comply with local codes for smoke detection and fire suppression within the enclosed aisle.

A weakness of direct ducting is that the delta temperature (ΔT) will typically exceed the range of DX cooling units with one possible result being a resultant increase in the supply air temperature. This can be addressed by specifying standard water-cooled units or special DX cooling units that operate efficiently at wider ΔTs.

Loosely coupled direct ducting in the ceiling plenum space provides opportunities for "conditioning" the return air with ceiling grates that would allow for some mixing with bypass make-up air. In addition, in environments where there might be reason for mixing ducted exhaust cabinets with standard cabinets, the ceiling grills would be required to move the free-space return air from the room and introduce it into the return air path in the plenum. This could occur where there were high-density cabinets mixed in a room with low- or moderate-density.

A fully deployed ducted exhaust system also greatly reduces the detail management of air delivery to just setting the overall room temperature and ensuring it is pressurized just above the consumption rate of the room's cumulative load. This eliminates the negative effects of low-pressure vortices formed under the floor by cycling between air handlers for service and maintenance.

10.8 Mechanical Equipment (Design and Operation) Recommendations

10.8.1 General Recommendations

Most of the following recommendations and topics are also addressed in more detail in the *Design Considerations for Data and Communications Equipment Centers*.

HVAC availability and redundant power access should conform to the requirements of the Class that best satisfies the reliability goals of the enterprise. The Class chosen will then drive selection and configuration of the HVAC systems and equipment selected. For example, providing CRAC units and other mechanical cooling equipment with dual power sources to ensure continuous operation if one source of power is lost is to be considered for Class F3 and Class F4 but is not mandatory under the requirements of this standard and is not required for Class F2 or lower facilities. Mechanical equipment, including specialized mission-critical equipment, such as CRACs, is not offered by manufacturers with provisions for dual power sources as a "standard option." Specifying this feature for mechanical systems should be done only after careful consideration of the costs and complexities involved compared to alternative approaches to achieve the same or similar result.

Use mechanical equipment that is designed for mission-critical installations.

Air ducts, water pipes, and drain pipes not associated with the data center equipment should not be routed through or within the data center spaces.

Electrical power for mechanical systems should be on generator backup.

There should be two independent sources of water for the HVAC systems or one source and on-site storage.

Air filters in air conditioning equipment should have a Class F1 rating. Class F1 filters are less able to support combustion than Class F2 filters.

Duct coverings and insulation should have flame spread ratings less than 25 and smoke developed ratings less than 50.

In areas where there is no equipment to cool, replace perforated tiles with solid tiles and close air ducts.

Mechanical equipment should be anchored to the elements that support them. Equipment that vibrates should be mounted on vibration isolators. The vibration characteristics of the floor should be carefully reviewed.

10.8.2 Computer Room Air Conditioning (CRAC) and Computer Room Air Handling (CRAH) Units

At minimum, each computer room in a Class 2 or higher data center should have one redundant CRAC/CRAH although analysis-using tools, such as CFD modeling, may determine that more than one redundant CRAC/CRAH may be required to maintain adequate airflow to all areas of the room.

Arrange CRACs/CRAHs and air ducts to enhance the proper functioning of hot and cold aisles. If CRACs/CRAHs are not fully ducted for both air intake and discharge, they should be arranged perpendicular to rows of equipment.

Return ducts for CRACs/CRAHs placed on the room perimeter should be placed as high up in the ceiling as possible and be aligned with hot aisles.

In computer rooms with an access floor, CRAC or CRAH units located in the room should be supported independently such that they do not transmit vibration to the access floor system.

10.8.3 Chilled Water Systems

Systems using chillers as the primary cooling source (with either chilled water CRAH units or built-up air handling systems) can be more energy efficient than systems using air-cooled packaged CRAC units. Packaged air-cooled machines can be less efficient than straight air-cooled CRACS, but offer benefits other than efficiency. Chilled water systems overcome distance limitations on air-cooled CRAC refrigerant piping, allow free-cooling in many climates, and enable thermal storage. Chillers are not as cost effective for smaller systems. There is no strict load that defines smaller, but in general, critical loads below 300−400 kW may be too small to provide economic justification for installation of a chilled water system unless the load is expected to grow significantly over the life of the facility. Each project must be evaluated to determine the suitability of chilled water compared to other cooling solutions.

The entire chilled water system consists of chillers, pumps, cooling towers, controls systems, water treatment, and chilled water distribution piping. Many configurations are possible to achieve alignment with the reliability goals established for the data center.

If dual power paths are provided to the individual components in a chilled water system, the use of transfer switches, either manual or automatic, must be provided at each system component.

10.8.4 Chillers

The chiller technology chosen can depend on the size of the load served and the availability of space indoors in a dedicated equipment room. Chillers located outdoors will be packaged, air-cooled units with capacity limited to approximately 1760 kW (500 refrigeration tons) each. If larger chillers are desired, indoor units must be used. Equipment located indoors is better protected from physical and environmental hazards and may receive better service from maintenance personnel.

10.8.5 Cooling Towers

Dry cooling towers operate by heat transfer through a surface that separates the working fluid from ambient air, such as in a tube to air heat exchanger, utilizing convective heat transfer. They do not use evaporation.

Wet cooling towers or open circuit cooling towers operate on the principle of evaporative cooling. The working fluid and the evaporated fluid (usually water) are one and the same.

Fluid coolers or closed-circuit cooling towers are hybrids that pass the working fluid through a tube bundle, upon which clean water is sprayed and a fan-induced draft applied. The resulting heat transfer performance is much closer to that of a wet cooling tower with the advantage provided by a dry cooler of protecting the working fluid from environmental exposure and contamination.

For Class F3 and Class F4 facilities, a reliable backup source of water or water storage must be provided.

Evaporative cooling towers are generally the most maintenance intensive part of the chilled water system. When evaporative towers are used, installation and maintenance of a condenser water treatment system is essential. Evaporative towers are dependent on a steady source of makeup water (typically domestic, potable water) to provide heat rejection of the building load. Interruption of this water supply will result in a complete cooling system shutdown.

Both open circuit cooling towers and closed-circuit cooling towers are very high risk for the production and spread of legionella bacteria through water droplets and if inhaled by humans the effects can be fatal. In some jurisdictions the designers or operators of the system may be held criminally responsible. Cooling towers must be designed and operated following local codes and regulations for mitigation of risks associated with legionella bacteria, if none exist then follow good practice associated with water treatment and monitoring.

Cooling towers are susceptible to rapid corrosion in areas where water is hard. Good quality stainless steel or other corrosion protection is recommended together with softening of evaporative water.

10.8.6 Adiabatic Cooling and Humidification

Adiabatic coolers and humidifiers which recirculate evaporative water have a similar risk to the production and spread of legionella bacteria as cooling towers. Therefore, these coolers and humidifiers shall be designed and operated following local codes and regulations for mitigation of risks associated with legionella bacteria. If local codes and regulations do not exist, good practice associated with water treatment and monitoring shall be followed.

Water supplies to spray or spinning disk type humidifiers will normally require treatment and/or sterilization of the water supply.

10.8.7 Thermal Storage

The thermal storage system should be designed for the simplest operation with the minimum number of components that must operate and start.

Goals for thermal storage as a concept must be clearly defined and understood by all parties and coordinated with the electrical system design. The purpose and function of the thermal storage system will define the scope and design of the system. Site considerations are important as some sites do not have adequate space for thermal storage.

Thermal storage systems for data centers are used to provide chiller load leveling and short-term cooling at times such as during a chiller short-cycle lockout. In this case, the energy stored in the thermal storage tank may be required to be available at the point of use in less than two minutes.

10.8.8 Piping and Pumps

The most effective way (e.g., practical, cost effective) to accomplish "dual path" supply in a chilled water system is to provide a looped piping system, allowing both ends of the loop to be supplied from the chiller plant. Dual piping systems are not practical for most data centers as they introduce significant cost and complexity.

A piping loop may be installed below the access floor on its perimeter, or preferably, outside the room. Sectionalizing valves installed at intervals in the loop will permit isolation of one or more CRAC units or air handlers for servicing a leaking isolation valve at the unit inlet. If a sectionalizing valve is installed between each CRAC unit branch pipe, then two adjacent CRAC units would need to be shut down to isolate a single leaking sectionalizing valve. An alternative method for valve servicing is to freeze the pipe.

Circulating pumps, dry coolers, and close-circuit fluid coolers (where used) are subject to the same restrictions regarding dual power as chillers—automatic or manual transfer switches must be installed as part of the electrical design.

Piping itself is very reliable, especially when care is taken in the design and water quality is maintained. Catastrophic failure of piping is rare when compared to other failure modes such as slow leaks from threaded joints or valve stems and end connections. These concepts should be kept in mind when evaluating designs to achieve high reliability.

Thoughtful design and layout coordinated with the reliability goals of the data center are essential. For example, adding more valves for isolation is not a solution by itself as installing more valves may only increase the likelihood of failures. Instead, the use of very high quality valves (industrial quality versus commercial quality) can be a cost effective way to achieve higher reliability levels.

All pipelines and components of systems that are likely to have exposed surfaces below dewpoint must be thermally insulated and vapor sealed.

10.8.9 Leak Detection

Leak detection should be provided at any location where water can exist or at the very least where water is most likely to exist. The most common sources of water are leakage from piping or valves and condensation on cooling coils in HVAC equipment. Whenever possible, install leak detection in drip pans below the areas that have the highest leak potential. Drip pans can minimize the amount of leak detection equipment required and provide some degree of containment.

In piping systems, leakage will most likely occur at screwed or flanged connections, at valve stems, or at unions. Welded or soldered joints in piping have a much lower leak potential. However, especially in insulated piping systems, water can "travel" along a sloped pipe and drip off many feet from the source of the leak. A continuous drip pan below piping, with either spot or continuous detection, is desirable.

If drip pans are not feasible, the piping should be equipped with leak detection cables installed directly within the thermal insulation to provide for early leak detection. Additional leak detection cables should be installed below the piping on the floor in areas with screwed or flanged connections or valves.

Air handling units should be provided with drip pans below with spot detection in the drip pan. If drip pans are not feasible, a loop of leak detection cable around the unit will detect but not contain a leak. The most common failure modes in air handlers that result in leaks are:

- Failed condensate pump. Gravity drainage is always preferable to a pump.
- Overflow of condensate drain pan. This happens either because of plugging of the outlet with biological material growing in the pan, or the result of an improperly configured drain trap.
- Leaking coil connection.

10.8.10 Water Supplies and Drainage

The following additional items should be considered when planning plumbing for data centers:

- Domestic water
- Tempered water—safety shower/eyewash equipment
- Sanitary sewer
- Storm drainage system

10.8.10.1 Requirements

Design water supply and drainage systems to minimize the risk of leakage into the spaces containing ITE.

10.8.10.2 Recommendations

Do not route water supply and drainage pipes through the spaces containing ITE. If unavoidable deploy suitable risk mitigation such as drip trays, pipe in pipe and leak detection.

Any drain gullies within or in close proximity to spaces containing ITE should be protected by an anti-flood valve on the connection to the sewer if below ground level.

Avoid locating drainage manholes in or in close proximity to spaces containing ITE

10.8.11 Materials in Air Plenums

Problems can arise if the materials used are of an improper size, strength, or spacing. Finishes must be suitable and not cause danger to persons or equipment.

10.8.11.1 Requirements

Materials, such as wire and cable jacketing, plastic piping, and insulation jacketing shall meet all code and Listing requirements (e.g., flame spread, smoke development characteristics) as per the AHJ. Additionally, all materials installed in air plenums shall meet installation requirements of the AHJ.

PVC piping shall not be used within air plenums.

10.8.11.2 Additional Information

Many AHJs have additional requirements for telecommunication, BAS, or other non-electrical cabling located within access flooring. An example is that plenum-rated or LSZH cable may be the minimum performance required concerning flame spread and smoke development.

CPVC piping with an appropriate rating is available and may be used within plenums if allowed by the AHJ.

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