Unified Physical Infrastructure (UPI) Strategies for Data Center Networking

Planning Considerations for Smart Data Center Facilities Systems

WHITE PAPER

Extensive research by PANDUIT Laboratories continues to address key areas of the data center. These areas include both network and facilities infrastructures, and effective server and storage configurations. This research enables PANDUIT to deliver comprehensive data center solutions for markets from finance and health care to government and education. This white paper describes the elements necessary to develop a reliable data center facilities infrastructure that can grow with your business.

Introduction

Data centers are at the core of business activity, and the growing transmission speed and density of active data center equipment is placing ever-increasing demands on the physical layer. Enterprises are experiencing enormous growth rates in the volume of data being moved and stored across the network. The deployment of high-density blade servers and storage devices in the data center to handle these workloads has resulted in spiraling rates of power consumption and heat generation.

The implementation of a robust, integrated infrastructure to handle these demands and support future data center growth is now more critical than ever. This white paper shows how business priorities can be balanced with power, cooling, and structured cabling practicalities to develop an integrated comprehensive data center support system. This “capacity planning” process optimizes network investment by ensuring reliable performance now and the flexibility to scale up for future business and technology requirements.

Top of Mind Issues

Based on PANDUIT Labs’ research on data centers, the following issues emerge repeatedly as critical to the strategic planning process for both new builds and upgrades. Therefore facilities and IT managers should keep them in mind from start to finish on any data center project:

- **Capacity Planning:** Decisions regarding data center design and future growth increasingly center on power, cooling, and space management. The collective awareness of these issues is defined as “capacity planning”. The effective deployment and management of these core resources allows the data center to operate efficiently and scale up as required.
- **Reliability:** A reliable infrastructure is comprised of adequate power and cooling capacity; effective bonding and grounding of system elements; and pathways that protect, route and manage the structured cabling. By using robust systems comprised of quality components and materials, you can minimize network interruptions and maximize uptime and business continuity.
- **Budget:** The high cost of operating a data center is a reality in today’s competitive business world. Facilities managers have responsibility for a substantial portion of the annual data center operating costs. Effective deployment of facilities infrastructure resources is directly connected to annual cost savings and lowest total cost of ownership (TCO).
- **Aesthetics:** Traditionally the focus of the facilities manager has been, “Is it in place and functional?” However, the data center represents a very high financial investment, with value residing in both functionality and aesthetics. Today’s data centers have become showcase areas to demonstrate to customers a visually appealing reflection of the company image. In this sense, facilities managers are expected to maintain an infrastructure that is highly professional in appearance.

Developing the Data Center Facilities Solution

Data center planning can be perceived as a place where the needs of various business teams collide. Indeed, it requires the close collaboration of business, IT, and facilities management teams to develop an integrated solution. Understanding some general planning relationships will help you translate business requirements into practical data center facilities solutions.

Business Planning Meets Facilities Planning

The typical life of a data center can reach 10-15 years, and with regular maintenance the facilities infrastructure and structured cabling are both expected to last as long. Active equipment refreshes commonly occur every 3-5 years, so the infrastructure must be planned to power, cool, and support up to three generations of IT equipment.

Business requirements ultimately drive these and all data center planning decisions. On a practical level, these requirements directly impact the type of applications and Service Level Agreements (SLAs) adopted by the organization.

One core facilities performance metric is uptime, commonly identified in the SLA. Once uptime requirements are in place and active equipment to support applications has been specified, the supporting bandwidth, power, and cooling loads can be estimated, and the necessary square footage of data center space can be determined. Figure 1 shows the process by which data center stakeholders can work together to develop an integrated facilities solution.

Data Center Tier Levels

Facilities planning also involves defining data center Tier level goals. TIA-942 Annex G classifies data centers from Tier I to IV in terms of the site-level infrastructure required to sustain specific levels of uptime. Although the standard classifies the Tier model as advisory (i.e., not mandatory), it has become standard language to connect uptime goals with the level of redundancy built into the data center infrastructure.

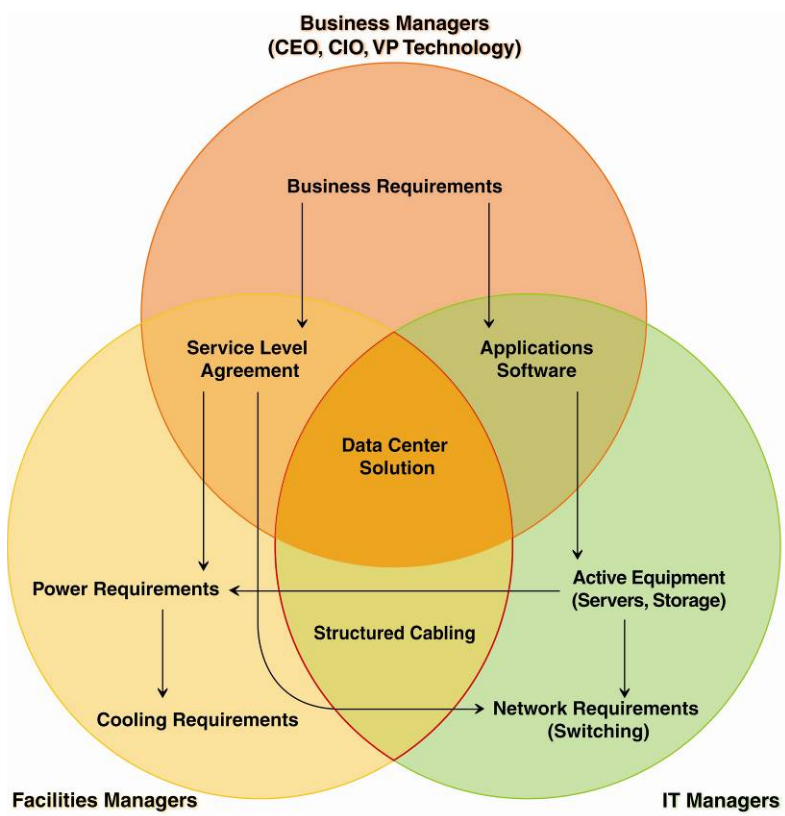

Figure 1. Data Center Solutions Involve Many Stakeholders

The Tiers progress upward as single points of failure are eliminated. Data centers achieving Tier II contain at least one set of fully redundant capacity components (i.e., N+1 capacity) such as uninterruptible power supply (UPS) units, and cooling and chiller units. Tier III data centers arrange redundant capacity into multiple distribution pathways, including power and cooling functions, and Tier IV systems extend fault tolerance to any and every system that supports IT operations.

As a consequence Tier level may impact the square footage of data center space. As single points of failure are eliminated, more facilities equipment is required to support redundant capacity and distribution. It also is important to note that the data center itself is rated only as high as the weakest subsystem that will impact site operations. For example, an owner of a Tier II data center could upwardly invest in dual-powered computer hardware and Tier III electrical pathways to enhance uptime; however, the rating of the data center would remain at Tier II.

Relevant Standards (TIA-942)

Several published resources exist to guide the facilities planning process. The *Telecommunications Infrastructure Standard for Data Centers* (TIA-942) is the most comprehensive of these publications. This standard specifies the minimum requirements for both telecommunications and facilities infrastructures, and establishes a topology for connecting and accessing these elements. In addition, the standard recommends ways to achieve a manageable balance between architectural, mechanical, and electrical design considerations. Other organizations that have published widely on facilities planning issues include the Uptime Institute, BICSI, and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

Powering Up for Today and Tomorrow

The power system is a key element in the facilities infrastructure, and is expected both to supply power now and to meet growing demands over time. Increasingly high-density computing environments are driving up power consumption (and operational costs) at a very fast rate. One recent estimate indicates that aggregate electricity used by servers (both U.S. and worldwide) doubled between 2000 and 2005.[1]

The critical challenges of powering modern data centers are:

1. Meeting present data center power needs
2. Deploying a reliable system to meet uptime requirements
3. Maintaining the flexibility to meet future power demands
4. Minimizing cost

Meeting Present Power Needs

Data center power use consists of both IT loads (primarily servers) and facilities loads (primarily cooling equipment). North American data centers use AC power that typically is distributed from the utility at 480 V and is stepped down to 208 V or 120 V (USA) for distribution within the facility. The availability and price of power varies widely from state to state, as does real estate cost. The best balance of these factors will help stakeholders locate and power their data center. A worksheet to help you estimate the power load of your data center is available in the *PANDUIT* white paper "Facility Considerations for the Data Center".

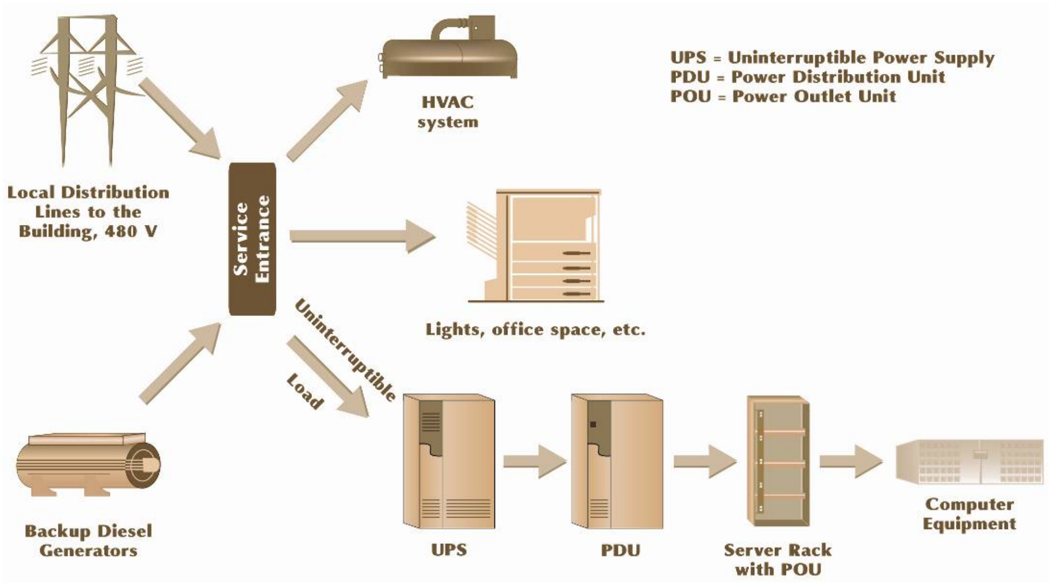

Figure 2. Example Architecture for Data Center Power System

The typical data center power distribution system includes generators, uninterruptible power supply (UPS) systems, batteries, transfer switches, surge suppressors, transformers, circuit breakers, power distribution units (PDUs), and power outlet units (POUs) (see Figure 2). POUs have been historically referred to as power strips, plug strips, and PDUs. UPS systems are coupled with batteries for energy storage, to ensure that active data center equipment is not over-exposed to power interruptions or power line disturbances. POUs are deployed within racks and cabinets to distribute power to active equipment.

Both modular and fixed capacity power systems are available to help facilities managers maximize power delivery per square foot of data center space. Modular power systems often are deployed in smaller data centers. They can easily grow and adapt to changing power requirements, and can be run at lower capacity to save energy whenever possible. Furthermore, a power system that utilizes standardized, hot-swappable, user-serviceable modules can reduce mean time to repair (MTTR) intervals for improved reliability. However, modular power systems are deployed in racks alongside active equipment; these systems can take up considerable rack space and add an unacceptable amount to the cooling load. Fixed capacity systems typically are best suited for medium to large-size data centers, which benefit from the economies of scale that can be achieved with larger stand-alone power supply units.

Facilities managers can work with IT managers to implement power-saving techniques in active equipment areas. Common techniques include deploying energy-efficient servers and high-efficiency power supplies, practicing server consolidation and virtualization and decommissioning inactive servers. Also, the U.S. EPA currently is developing a new product specification for enterprise servers, and has submitted a draft report to Congress on data center and server energy efficiency.

Deploying a Reliable Power Infrastructure

Providing reliable power to the data center is expensive, but the extra cost is often borne without question in order to meet business requirements and network uptime goals. Many variables affect a system's availability, including human error, reliability of components, redundancy, maintenance schedules, and recovery time. A power system with mistake-proofing features (such as modular, intelligent, and/or pluggable design) and reduced single points of failure (such as bypass functionality) improves system availability by streamlining maintenance tasks and minimizing unplanned downtime.

Many redundancies can be designed into a power system to meet N+1 reliability requirements, including power conversions, paralleling controls, static transfer switches and bypass connections. PDUs are often connected to redundant UPS units for higher availability in case one UPS fails or is taken down for maintenance service or repair. In addition to UPS redundancy, the power supplies in the servers themselves are often redundant, with two or even three power supplies in each server box capable of powering the server completely if one or more of them fails.

Future-Proofing via Excess Power Capacity

It is common for facility managers and other data center stakeholders to plan for future power requirements by building in maximum estimated capacity from the start. Facilities managers estimate these loads by working with IT managers to identify the power required to operate and cool active equipment, both initially and over the data center life cycle (i.e., two or three equipment refreshes). If necessary, modular power architectures can help managers deploy additional capacity in a phased manner if the power consumption of next generation switches and servers grows beyond room capacity.

Secondary Facilities Systems

Several facilities systems support other elements of the data center. These critical secondary systems include chilled water, bonding and grounding systems, and the raised floor itself. Each should be sized to last the life of the data center, as these systems are not designed for modular, phased deployment.

Raised Floor

The installation of a raised floor is often used to distribute cooled air and manage the cabling found within data centers, and to enhance the appearance of the room. The bulk of secondary system components (i.e., pipes, cables, power cords) can be deployed safely under the raised floor, in order to maximize the available space above-floor for cabling and active equipment subject to moves, adds and changes (MACs). All data center stakeholders should work together to ensure that the different underfloor infrastructure components integrate smoothly along pre-designated routes.

When deploying a raised floor, its height, anticipated loading requirements, and seismic requirements all must be carefully considered. Current trends and best practices indicate that a raised floor height of 24-36 inches enables adequate cooling capacity (see Figure 3). Sites with shallow raised floors will struggle to deliver sufficient air volume, and balanced airflow will be difficult to achieve.

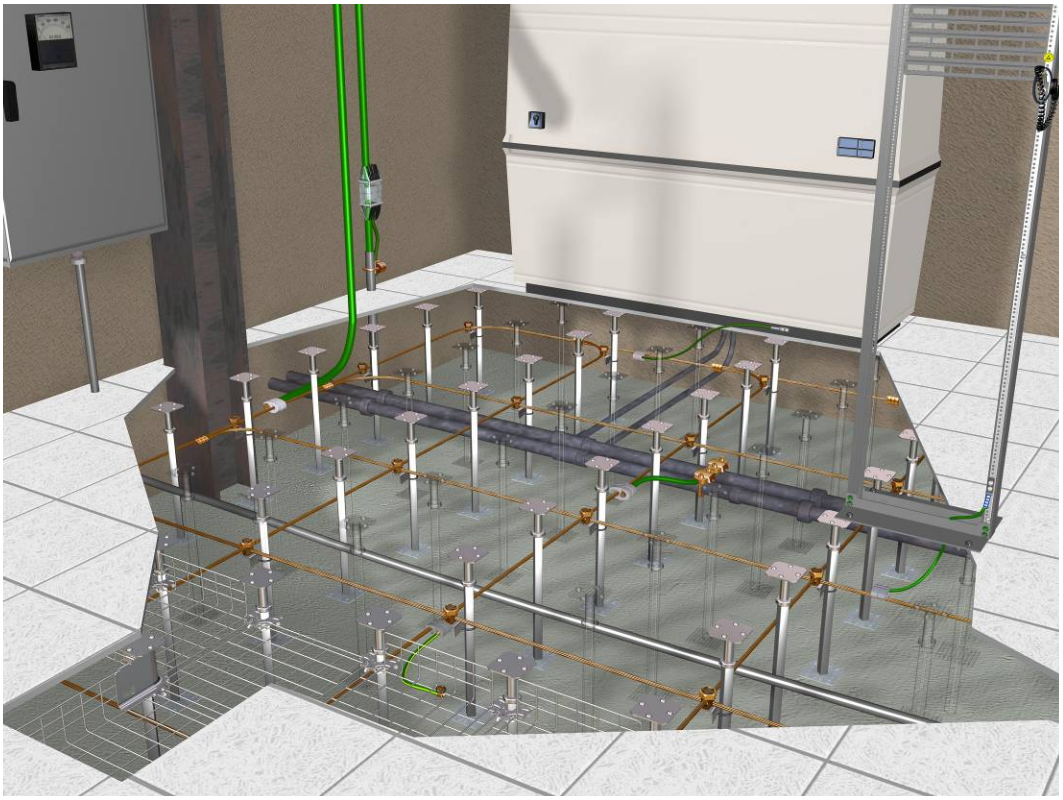

Figure 3. Example Raised Floor and Pedestals

In addition, certified performance data on the mechanical strength of the floor should be provided by the raised floor manufacturer in accordance with the Ceilings and Interior Systems Construction Association's (CISCA's) "Recommended Test Procedures for Access Floors", to verify that the floor will meet data center design requirements.

Grounding and Bonding System

As the raised floor is set in place, the bonding and grounding system is installed. Proper grounding and bonding is essential for efficient data center performance. The grounding system is an active functioning network designed to maximize equipment uptime, maintain system performance and protect personnel.

The primary purpose of the grounding and bonding system is to create a robust path for electrical surges and transient voltages to return either to their source power system or to earth. Lightning, fault currents, circuit switching (motors on and off), activation of surge protection devices (SPD) and electrostatic discharge (ESD) are common causes of these electrical surges and transient voltages. An effective grounding and bonding system can minimize or eliminate the detrimental effects of these events.

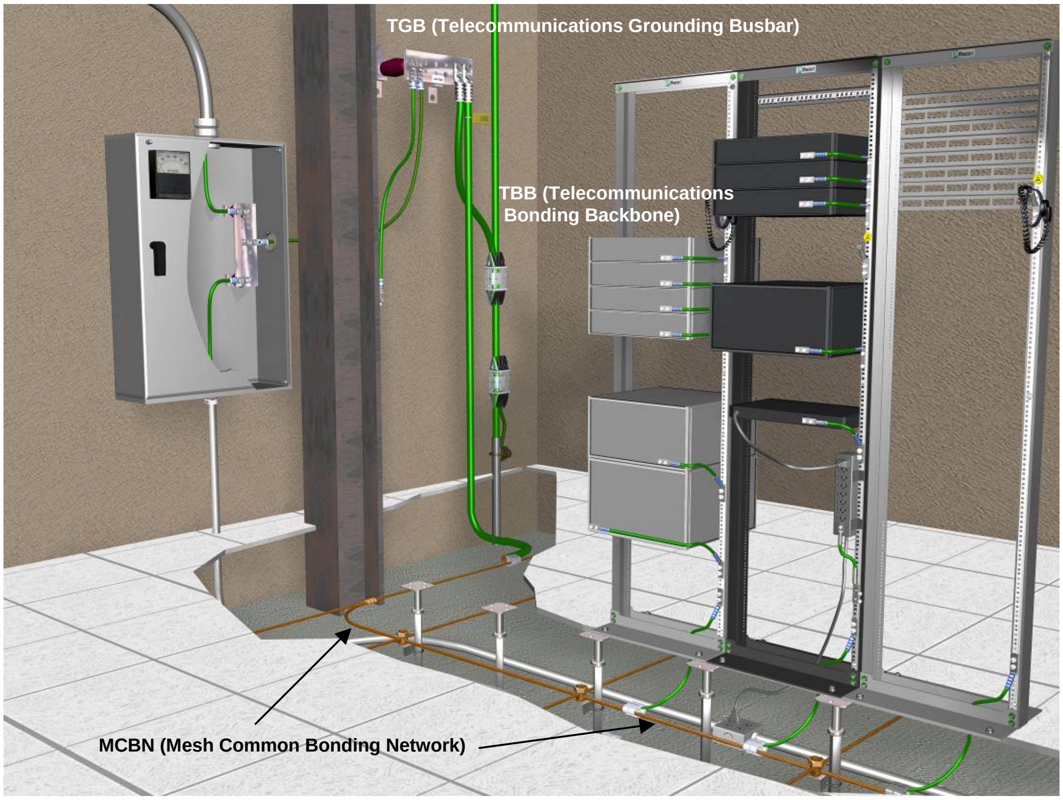

Figure 4. Example Bonding and Grounding System

According to standards TIA-942, J-STD-607-A-2002, and IEEE 1100 (the Emerald Book), a properly designed grounding system as shown in Figure 4 has the following characteristics:

1. Is intentional: each connection must be engineered properly, as the grounding system is only as reliable as its weakest link
2. Is visually verifiable
3. Is adequately sized to handle fault currents
4. Directs damaging currents away from sensitive electronic equipment
5. Has all metallic components in the data center bonded to the grounding system (e.g., equipment, racks, cabinets, ladder racks, enclosures, cable trays, water pipes, conduit, building steel, etc.)
6. Ensures electrical continuity throughout the structural members of racks and cabinets
7. Provides grounding path for electrostatic discharge (ESD) protection wrist straps

In addition to meeting these standards, all grounding and bonding components should be listed with a nationally recognized test lab (such as Underwriters Laboratories, Inc.) and must adhere to all local electrical codes. The *PANDUIT*® *STRUCTUREDGROUND*™ System for data center grounding provides robust connections that have low resistance, are easy to install, and are easily checked during yearly inspections.

Chilled Water Pipes

If chilled water loops are required for cooling, then chilled water lines need to be planned for. This system should be deployed early in the data center build-out process, to ensure that pipes are placed properly and can be adjusted if needed. The building chilled water supply should be accessible if an equipment water loop for supplementary cooling is required. Above-floor space should be reserved for a coolant distribution unit (CDU), which is the control interface between building chilled water and the equipment water loop. Underfloor space should accommodate flexible hoses that transport water from the CDU to the cooling devices.

Labeling Considerations

A properly identified and documented infrastructure allows managers to quickly reference all telecommunication and facility elements, reduce maintenance windows, and optimize the time spent on MACs. TIA-942 recommends that data center identification start with the floor tile grid system. Each 2 ft x 2 ft floor tile is assigned an alphanumeric grid identifier, so that a lettered system for rows (AA, AB, AC, etc.) and a numbered system for columns (01, 02, 03, etc.) can be used to reference any given component in the data center by specific location (i.e., rack located at grid location AB03). Grid identifiers can range from computer printable adhesive labels to engraved marking plates.

A thorough identification strategy will include the following: labels for cabling infrastructure (cables, panels, racks, cabinets, and pathways); labels for active equipment (switches, servers, storage); labels for cooling pipe, electrical, and grounding systems; and floor grid markers, voltage markers, firestops, and other safety signage. TIA/EIA-606-A is the standard for labeling and administration of structured cabling, and TIA-942 Annex B provides supplemental recommendations for data centers. "TIA/EIA-606-A Labeling Compliance" discusses how to implement standards-based labeling solutions.

Cooling and Airflow Through the Data Center

The cooling system is critical to data center reliability and total cost of ownership (TCO). Every piece of equipment that requires maintenance, repair, or replacement due to heat exposure drives uptime down and costs up. Cooling systems can include computer room air conditioning (CRAC) and computer room air handling (CRAH) units, chillers, cooling towers, condensers, ductwork, pump packages, piping, and any supplemental rack- or ceiling-level cooling or air distribution devices.

Based on data collected by the Uptime Institute, it is estimated that the cost to power the cooling system will be approximately equal to the cost of powering active equipment.[2] Therefore, the cooling system requires careful design and constant oversight to maintain an acceptable level of performance at a reasonable cost. A worksheet to help you estimate the cooling load of your data center is available in the *PANDUIT* white paper "Facility Considerations for the Data Center".

Hot Aisle/Cold Aisle Layout

Movement of cool air through the data center is achieved through strategic layout of CRAC units and physical layer elements. Equipment rows can follow the hot aisle/cold aisle layout defined in TIA-942 and in ASHRAE's "Thermal Guidelines for Data Processing Environments". In this layout, a CRAC unit distributes cool air underneath the raised floor with the expectation that this air will enter the room through strategically placed perforated floor tiles. Active equipment is positioned to face cold aisles, and cool air is drawn through racks and cabinets by equipment fans and released as exhaust into hot aisles to the rear (see Figure 5).

A perforated tile with 25% open area and a cool air throughput rate of 150-200 cubic feet per minute (cfm) can disperse about 1 kW of heat. For loads much greater than that, or for heat loads that increase with active equipment loads over the life of the data center, several options are available to expand cooling capacity. These options include increasing tile open area (from 25% to 40-60%), minimizing air flow leaks, and increasing additional CRAC capacity. Also, supplemental cooling units such as chilled water racks and ceiling-mounted air conditioners/fans can be deployed as active equipment is added and refreshed.

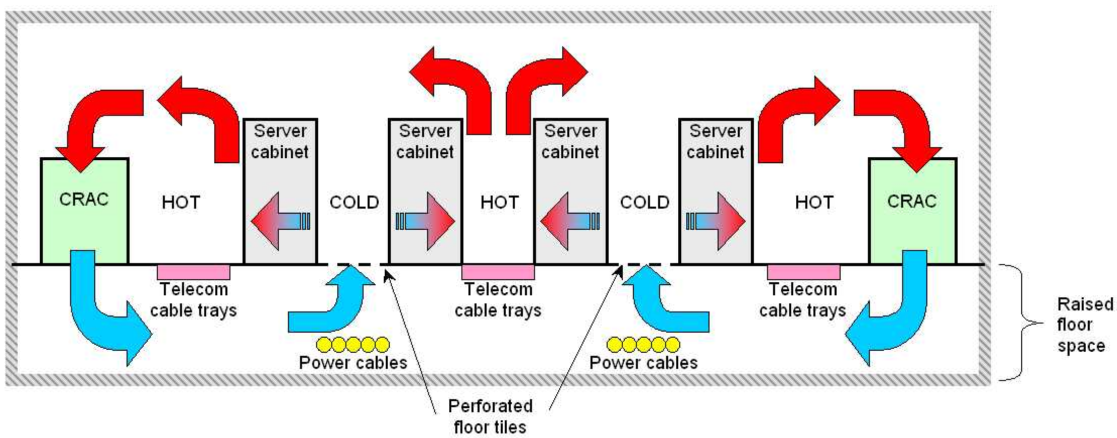

Figure 5. Placement of Cable Trays in Hot Aisle/Cold Aisle Layout

Minimize Bypass Air to Maximize Cooling

Conditioned air sometimes bypasses equipment that it is intended to cool and is delivered directly to the hot aisle. Industry data indicates that up to 60% of available cooling capacity is wasted by bypass airflow, due to incorrect positioning of perforated tiles, poor placement of CRAC/CRAH units, or cutout spaces in floor panels beneath racks and cabinets for underfloor cable routing.

One useful tool for analyzing airflow through the data center is computational fluid dynamics (CFD) software. Basic CFD programs simulate airflow paths and calculate the flow rates and air temperatures through perforated panels so facility managers can determine whether equipment cabinets are being supplied with enough cold air. Advanced CFD programs model temperature distributions and spaces above the floor.

Strategies for reducing bypass air (and thereby increasing uptime by preventing active equipment from overheating) include installing blank panels in unused rack spaces and closing cable cutouts in the raised floor with air sealing devices. These techniques help promote airflow along preferred routes while keeping underfloor cables accessible. Furthermore, air sealing grommets can provide abrasion resistance for cables as they pass by the sharp edges of the raised floor tiles and provide a conductive path from the cable to the floor for electrostatic discharge. As a result, thermal management can lead to significant cost savings.

The Hidden Impact of Cabling

Structured cabling is expected to sustain growth and change over the 10-15 year life cycle of the data center. Effective cable management is considered key to the reliability of the data center network infrastructure. However, the relationship between cabling and facilities systems is often overlooked. This relationship centers on the successful deployment of structured cabling along pathways that complement facilities systems. Effective cable pathways protect cables to maximize network uptime, and showcase your data center investment.

Calculating Pathway Size and Cost

The primary value of pathways in a data center is to provide functional, protective containment for the structured cabling infrastructure in an often dense cabling environment. Pathways that are versatile and accessible accommodate data center growth and change, and protect cables from physical damage. Well-designed cable pathways also strengthen the visual impact of your data center.

The key capacity planning issue is an accurate estimation of cable count and volume in order to specify pathway size. For initial deployments, maximum fill should be 25-40% to leave room for future growth. A calculated fill ratio of 50-60% will physically fill the entire pathway due to spaces between cables and random placement. The *PANDUIT* online fill calculator tool can help you determine the size of pathway needed for a specified cable quantity and diameter.

The TCO of cable routing systems also must be considered before making final purchasing decisions. The costs associated with installation, maintenance, accessibility, physical protection and security should all be considered as components of TCO. Features that promote low cost of ownership include:

- Snap-together sections that require minimal use of tools
- Hinged covers that provide easy access and cable protection
- Bend radius control and no sharp edges to ensure cable performance
- Integrated grounding/bonding.

Designing Cable Pathways

The variety and density of data center cables means that there are no “one size fits all” solutions when planning cable pathways. Designers usually specify a combination of pathway options. Many types and sizes are available for designers to choose from, including wire basket, ladder rack, J-hooks, conduit, solid metal tray, and fiber-optic cable routing systems. Factors such as room height, equipment cable entry holes, rack and cabinet density, and cable types, counts, and diameters also influence pathway decisions.

One effective pathway strategy is to use overhead fiber optic cable routing systems to route horizontal fiber cables, and use underfloor wire baskets for horizontal copper and backbone fiber cables. This strategy offers several benefits:

- The combination of overhead and underfloor ensures physical separation between the copper and fiber cables, as recommended in TIA-942

- Overhead pathways such as the *PANDUIT*® *FIBERRUNNER*® System protect fiber optic jumpers, ribbon interconnect cords, and multi-fiber cables in a solid, enclosed channel that provides bend radius control, and the location of the pathway is not disruptive to raised floor cooling (see Figure 6)
- Underfloor pathways hide the bulkiest cabling from view; also, copper cables can be loosely bundled to save installation cost, and each underfloor pathway can serve two rows of equipment
- The overall visual effect is organized, sturdy, and impressive.

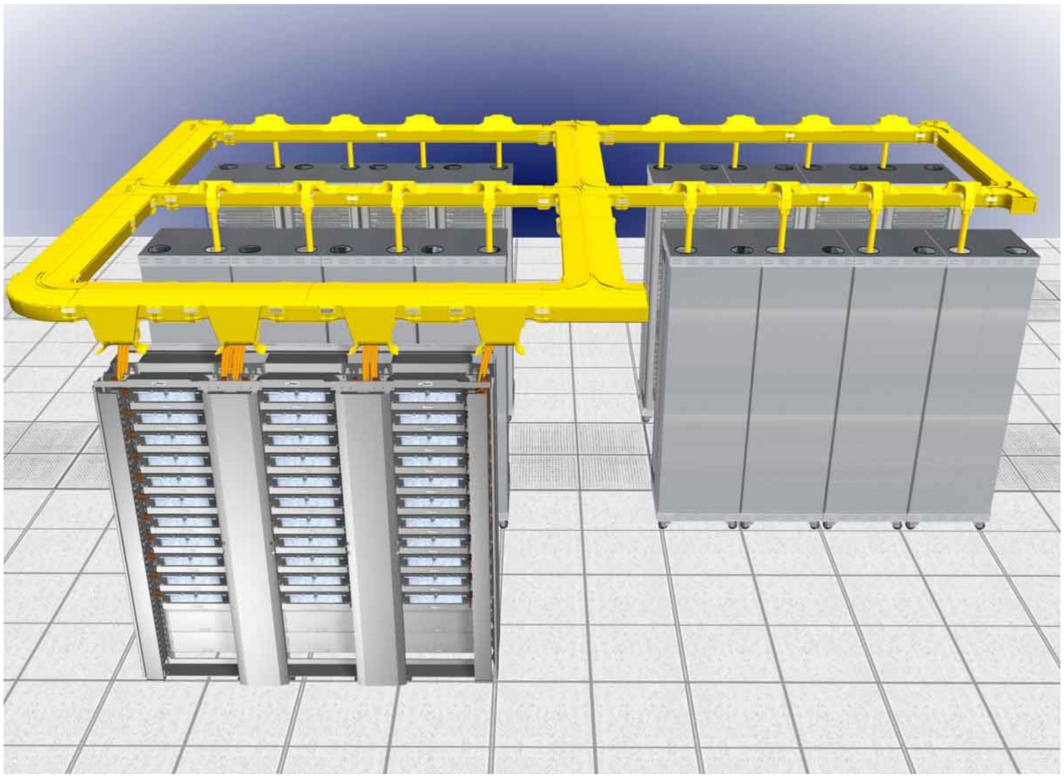

Figure 6. Example Overhead Cabling Pathway System

Underfloor cabling pathways should complement the hot aisle/cold aisle layout to help maintain cool airflow patterns. TIA/EIA-942 and -569-B state that cable trays should be specified for a maximum fill ratio of 50% to a maximum of 6 inches (150 mm) inside depth. TIA-942 further recommends that cable trays for data cables should be suspended from the floor under hot aisles, while power distribution cables should be positioned in the cold aisles under the raised floor and on the slab.

These underfloor pathway strategies are recommended for several reasons:

- Pathways for power and twisted pair data cables can be spaced as far as possible from each other (i.e., 6-18 inches), to minimize longitudinal coupling (i.e., interference) between cables
- Copper and fiber cable pathways are suspended under hot aisles, the direction toward which most server ports face
- Cable pathways do not block airflow to the cold aisles through the perforated tiles.

Bundling and Routing Cables

Once cable pathways are in place, attention can be directed to placing the cables in the pathways. Cable bundling strategies have been developed to effectively and neatly route cables through pathways, retain flexibility for operators to make frequent MACs, and not obstruct airflow. These strategies include use of cable ties and pathway accessories that protect and manage high-performance copper and fiber cabling, in accordance with TIA/EIA-568-B.1 Section 10.1.1 and GR-1275-CORE Section 13.14, in order to maintain network integrity. Cable ties and accessories must be operator safe without protruding sharp ends or edges that can potentially cut or abrade cables. Plenum-rated cable tie designs are required for cable bundling within air handling spaces such as ceiling voids and underfloor areas, in accordance with National Electrical Code (NEC) Section 300-22 (C) and (D).

A variety of cable bundling solutions are effective in high-density data center cabling environments (see Figure 7). For example, *PANDUIT* hook & loop cable ties can be used to bundle cables across overhead areas and inside cabinets and racks, and are approved for use within air handling spaces in accordance with the NEC. They are adjustable, releasable, reusable, and soft, enabling installers to deploy bundles quickly in an aesthetically pleasing fashion as well as to address data center scalability requirements.

PANDUIT cable rack spacers are used with ladder racks as a stackable cable management accessory that helps ensure proper cable bend radius and minimize stress on cable bundles. Also, *PANDUIT* waterfall accessories provide bend radius control as cables transition from ladder rack or conduit to cabinets and racks below.

Wire Basket with Hook & Loop Cable Ties

Ladder Rack with Stackable Cable Rack Spacers and Waterfall Accessories

Figure 7. Example Cable Bundling Strategies

Cabinets and Racks Enable Passive Cooling Solutions

Next-generation servers and switches (e.g., blade server technologies) are increasing the density of equipment and cabling in the data center. This increased heat load presents new challenges to traditional cooling systems. The strategic deployment of rack and cabinet hardware can have a considerable impact on data center cooling efficiency, both now and over the life of the data center.

Unused space in server and switching enclosures has the potential to cause two problems–hot exhaust recirculation and cool air bypass. Hot exhaust from equipment may recirculate back to the equipments intake, which can quickly lead to overheating of equipment and adversely affect system uptime. Cool air may bypass the intakes, which compromises system efficiency and raises cost.

PANDUIT cabinet, rack, and cable management solutions achieve superior cable and equipment management while enhancing the airflow and professional appearance of the data center. The passive cooling features of the NET-ACCESS™ Cabinet optimize thermal performance by facilitating airflow in high-density switching environments. Exhaust fans move air through the equipment from side to side. Ducting placed in vertical cabinet spaces helps direct exhaust air into hot aisles, reducing hot air recirculation (see Figure 8).

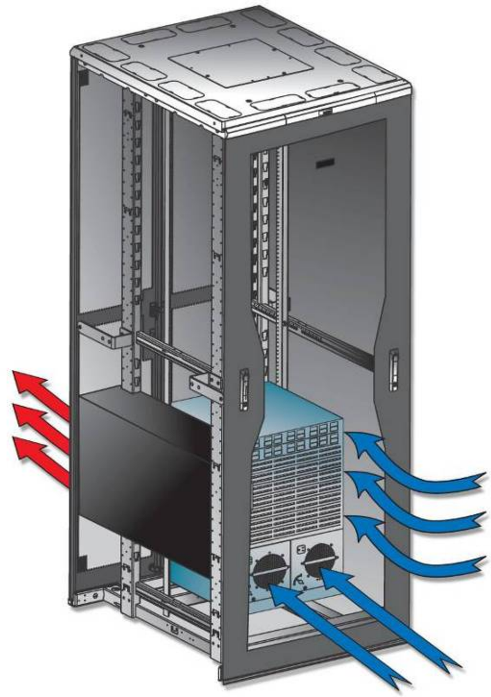

Figure 8. The *PANDUIT NET-ACCESS*™ Cabinet Promotes Passive Cooling

A combination of passive cooling solutions also helps disperse heat and direct airflow in server areas. Cabling in these areas is less dense than in switching areas, with more power cables but fewer data cables. Filler panels can be deployed in horizontal and vertical spaces to prevent cold air bypass and recirculation of warm air through the cabinet and equipment. Use of wider cabinets and effective cable management can reduce static pressure at the rear of the cabinet by keeping the server exhaust area free from obstruction. Also, door perforations should be optimized for maximum cool airflow to equipment intakes. Deployment of racks and cabinets should follow standards established in TIA/EIA-310-D.

Conclusion

Next-generation active equipment is drawing more power, generating more heat, and moving more bits in the data center than ever before. Essential systems like power and cooling must work closely with structured cabling to achieve an integrated facilities infrastructure that can meet aggressive uptime goals and survive multiple equipment refreshes.

Successful capacity planning of these systems is a process that requires the combined efforts of all data center stakeholders. Facility managers in particular are in a unique position to survey the overall data center planning landscape to identify power, cooling, grounding, pathway, and routing strategies that achieve lowest TCO. Communication between facilities managers, IT managers, and senior executives will ensure that business requirements are balanced with power, cooling, and cabling practicalities to craft a robust, reliable, and visually attractive data center.

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About *PANDUIT*

PANDUIT is a world-class developer and provider of leading-edge solutions that help customers optimize the physical infrastructure through simplification, increased agility and operational efficiency. *PANDUIT's* Unified Physical Infrastructure (UPI) based solutions give Enterprises the capabilities to connect, manage and automate communications, computing, power, control and security systems for a smarter, unified business foundation. *PANDUIT* provides flexible, end-to-end solutions tailored by application and industry to drive performance, operational and financial advantages. *PANDUIT's* global manufacturing, logistics, and e-commerce capabilities along with a global network of distribution partners help customers reduce supply chain risk. Strong technology relationships with industry leading systems vendors and an engaged partner ecosystem of consultants, integrators and contractors together with its global staff and unmatched service and support make *PANDUIT* a valuable and trusted partner.

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