1

DATA CENTERS—STRATEGIC PLANNING, DESIGN, CONSTRUCTION, AND OPERATIONS

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1.1 INTRODUCTION

In a typical data center, electrical energy is used to operate Information and Communication Technology (ICT) equipment and its supporting facilities. About 45% of electrical energy is consumed by ICT equipment, which includes servers, storages, and networks. The other 55% of electrical energy is consumed by facilities, which include power distribution system, uninterruptible power supplies, chillers, computer room air conditioners, lights, and so on. Improving power consumption by ICT equipment and facilities is imperative for efficient use of energy. Many studies have proven increasing greenhouse gases due to human activities resulting in global warming.

1.1.1 Data Centers and Global Warming

A study by the journal *Science* estimates that, from 1992 to 2012, the melting ice from Greenland and Antarctica has raised the global sea level by 11.1 mm (0.43 in.). Rising sea levels have gained more attention from the flooding caused by the superstorm *Sandy* in 2012 that struck the heavily populated U.S. East Coast.

A report titled *Climate Change 2013: The Physical Science Basis* [1], prepared by the Intergovernmental Panel on Climate Change (IPCC), set up by the World Meteorological Organization and the UN's Environment Program, states as follows: "Warming of the climate system is unequivocal. Since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased". "The rate of sea level rise since the mid-nineteenth century has been larger than the mean rate during the previous two millennia (*high confidence*). Over the period 1901–2010, global mean sea level rose by 0.19 [0.17–0.21] m."

The World Bank issued a report in November 2012, titled *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided* [2]. The report describes what the world would be like if it warmed by 4°C (7.2°F). "The 4°C world scenarios are devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many region, increase frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef system."

"The science is unequivocal that humans are the cause of global warming, and major changes are already being observed: global mean warming is 0.8°C above pre-industrial levels; oceans have warmed by 0.09°C since the 1950s and are acidifying; sea levels rose by about 20 cm since pre-industrial times and are now rising at 3.2 cm per decade; an exceptional number of extreme heat waves occurred in the last decade; major food crop growing areas are increasingly affected by drought."

Human beings generate all kinds of heat from cooking food, manufacturing goods, building houses, passenger and freight transport, and ICT activities. ICT continues as a pervasive force in the global economy, which includes Internet surfing, computing, online purchase, online banking, mobile phone, social networking, medical services, and exascale

Data Center Handbook, First Edition. Hwaiyu Geng.

Companion website: http://www.wiley.com/go/datacenterhandbook

machine (supercomputer). They all require energy in data centers and give out heat as a result. One watt input to process data results in 1 W of heat output. As a result, all data centers take energy and give out heat. We can't stop giving out heat, but we can reduce heat output by efficiently managing energy input.

1.1.2 Data Center Definition

The term "data center" means differently to different people. Some of the names used include data center, data hall, data farm, data warehouse, computer room, server room, R&D software lab, high-performance lab, hosting facility, colocation, and so on. The U.S. Environment Protection Agency defines a data center as:

- "Primarily electronic equipment used for data processing (servers), data storage (storage equipment), and communications (network equipment). Collectively, this equipment processes, stores, and transmits digital information."
- "Specialized power conversion and backup equipment to maintain reliable, high-quality power, as well as environmental control equipment to maintain the proper temperature and humidity for the ICT equipment."

Data centers are involved in every aspect of life running Amazon, AT&T, CIA, Citibank, Disneyworld, eBay, FAA, Facebook, FEMA, FBI, Harvard University, IBM, Mayo Clinic, NASA, NASDAQ, State Farm, U.S. Government, Twitter, Walmart, Yahoo, Zillow, etc. This A–Z list reflects the "basic needs" of food, clothing, shelter, transportation, health care, and social activities that cover the relationships among individuals within a society.

A data center could consume electrical power from 1 to over 500 MW. Regardless of size and purpose (Table 1.1), all data centers serve one purpose, and that is to process information. In this handbook, we use "data center" that refers to all names stated earlier.

1.1.3 Energy Consumption Trends

"Electricity used in global data centers during 2010 likely accounted for between 1.1 and 1.5% of total electricity use, respectively. For the U.S., that number was between 1.7 and 2.2%" [3].

IDC IVIEW, sponsored by EMC Corporation, stated [4] as follows: "Over the next decade, the number of servers (virtual and physical) worldwide will grow by a factor of 10, the amount of information managed by enterprise data centers will grow by a factor of 50, and the number of files the data center will have to deal with will grow by a factor of 75, at least."

Gartner estimated [5], "In 2011, it is believed that 1.8 Zettabytes of data was created and replicated. By 2015, that number is expected to increase to 7.9 Zettabytes. That is equivalent to the content of 18 million Libraries of Congress. The majority of data generation originates in North America and Europe. As other global regions come online more fully, data generation is expected to increase exponentially."

Evidently, as a result of increasing activities such as big data analytics, online services, mobile broadband, social activities, commercial business, manufacturing business, health care, education, medicine, science, and engineering, energy demand will continue to increase.

1.1.4 Using Electricity Efficiently

A data center houses ICT equipment and facilities that are used to cool ICT equipment. While air cooling is still the most economical way to cool servers in racks, water cooling is the most efficient way to remove heat generated by processors.

Based on "Power Usage Effectiveness, March 2012"[2] prepared by LBNL, 33.4% of total energy is used in power and cooling a data center and 66.6% by IT load (Fig. 1.1). For a typical server, 30% of power is consumed by a processor and 70% by peripheral equipment that includes power supply, memory, fans, drive, and so on. A server's utilization efficiency is estimated to be at a disappointing 20% [6].

TABLE 1.1 Data center type, server volume, and typical size

Facility types	Volume servers	Estimated servers per facility	Typical size in sq. ft. (m^2)	Estimated number of facilities (in the United States)	2006 electric use (billion kWh)
Server closets	1,798,000	1–2	<200 (19)	900,000–1,500,000	3.5
Server rooms	2,120,000	3–36	<500 (46)	50,000–100,000	4.3
Localized data center	1,820,000	36–300	<1000 (93)	10,000–13,000	4.2
Midtier data center	1,643,000	300–800	<5000 (465)	2,000–4,000	3.7
Enterprise-class data center	3,215,000	800–2000+	5000+ (465+)	1,000–2,500	8.8

Sources: EPA, 2007; CHP in Data Centers, ICF International, Oak Ridge National Laboratory, 2009.

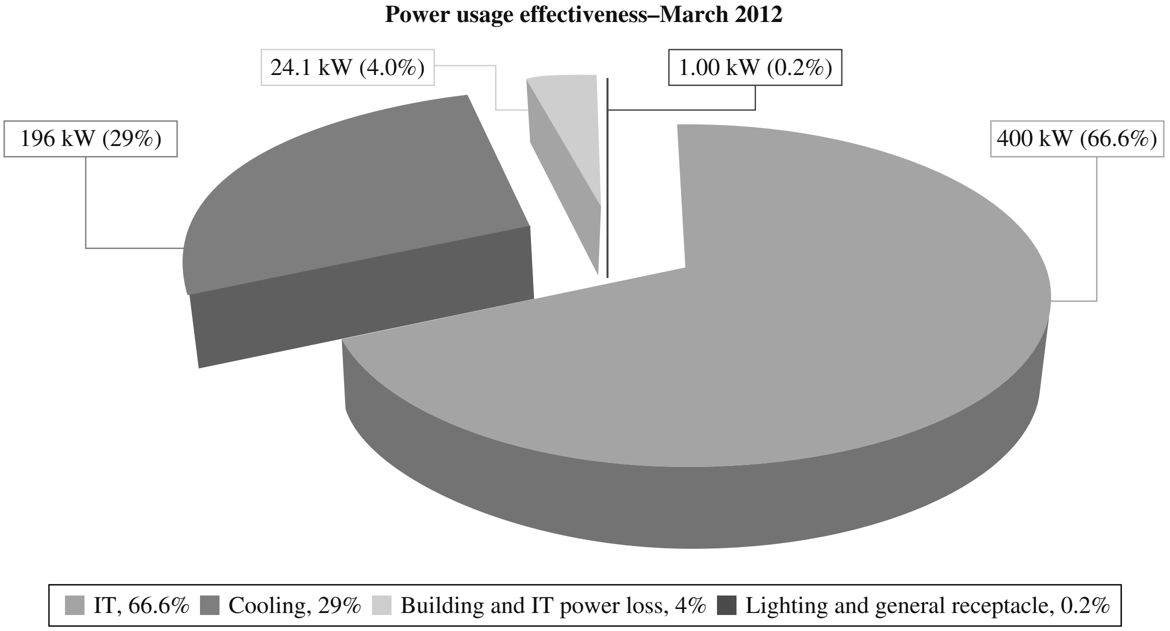

FIGURE 1.1 The DOE national average PUE for data centers is 1.75. 50B-1275 data center has evolved from an average PUE of 1.65 (calculated in 2009) to today’s 1.47. Getting there, staying there, and further improving the PUE is an ongoing effort (Source: Nina Lucido, Data Center Utilization Report, March 2012, LBNL, U.S. Department of Energy. https://commons.lbl.gov/display/itdivision/2012/04).

Opportunities of saving energy at the server level include the use of ENERGY STAR-rated equipment, water cooling server, solid-state drive, and variable-speed fan in servers. Virtualization could be applied to improve the server’s utilization efficiency.

1.1.5 Virtualization, Cloud, Software-Defined Data Centers

As illustrated in Figure 1.2, “Virtualization is a method of running multiple independent virtual operating systems on a single physical computer. It is a way of allowing the same amount of processing to occur on fewer servers by increasing server utilization. Instead of operating many servers at low CPU utilization, virtualization combines the processing power onto fewer servers that operate at higher utilization [7].”

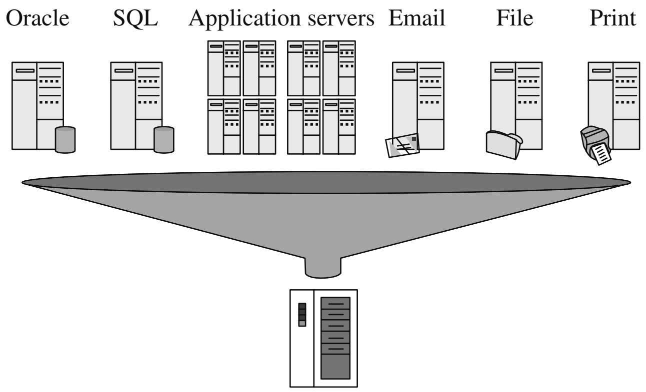

FIGURE 1.2 Virtualization (Source: https://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_virtualization).

Cloud computing is an evolving model [8]. It is characterized as easy access, on demand, rapidly adaptable, flexible, cost-effective, and self-service to share pool of computing resources that include servers, storage, networks, applications, and services. Cloud capacity could be rapidly provisioned, controlled, and measured.

Cloud computing provides various service models including Software as a Service (SaaS), Infrastructure as a Service (IaaS), and Platform as a Service (PaaS). HP’s “Everything as a Service” provides service model as follows: “Through the cloud, everything will be delivered as a service, from computing power to business processes to personal interactions.” Cloud computing is being deployed in public, private, community, or hybrid cloud models. It benefits data center managers by offering resource pooling and optimizing resource uses with lower costs. IDC estimate that by 2015, 20% of the information will be “touched” by cloud computing.

The Software-Defined Data Center (SDDC), pioneered by VMware, is an architectural approach that has all ICT infrastructure (server, storage, networking, and security) virtualized through hardware-independent management system. SDDC can be a building block to Cloud, or Cloud can be an extension of an SDDC [9]. Virtual machines can be deployed in minutes with little human involvement. Provisioning applications can be operational in minutes that shorten time to value. SDDC maximizes the utilization of physical infrastructure [10]. As a result, SDDC reduces capital spending, advances asset utilization, improves operational efficiency, and enhances ICT productivity. SDDC is likely to drive down data center hardware costs.

1.2 DATA CENTER VISION AND ROADMAP

Table 1.2 provides a framework of vision, possible potential technology solutions, and key benefits. This table consolidates the ideas and solutions from 60 experts who attended the Vision and Roadmap Workshop on Routing Telecom and Data Centers Toward Efficient Energy Use. The table could be tailored to individual needs by enhancing with emerging technologies such as SDDC, fuel cell technology, etc.

1.2.1 Strategic Planning and Roadmap

Strategic planning for a holistic data center could encompass a global location plan, site selection, design, construction, and operations that support ICT and emerging technology. There is no one "correct way" to prepare a strategic plan. Depending on data center acquisition strategy (i.e., host, colocation, expand, lease, buy, or build) of a new data center, the level of deployments could vary from minor modifications of a server room to a complete build out of a green field project.

Professor Michael E. Porter's "How Competitive Forces Shape Strategy" [12] described the famous "Five Forces" that lead to a state of competition in an industry. They are threat of new entrants, bargaining power of customers, threat of substitute products or services, bargaining power

TABLE 1.2 ICT vision and roadmap summary [11]

Equipment and software	Power supply chain	Cooling
	Visions	
ICT hardware and software will increase the computing power of a watt by at least an order of magnitude, meeting future demand without increasing energy consumption or total cost of ownership and substantially decreasing the environmental footprint of ICT facilities	Reduce power losses in date centers and telecommunications central offices by 50% from service entrance to end use—while maintaining or improving reliability the total cost of ownership	Reduce cooling energy as a percentage of ICT power to a global average of ≤20% for retrofit and <5% for new construction. Cooling systems will be adaptable, scalable, and able to maximize utilization and longevity of all assets over their lifetime—while maintaining system resiliency and lowering total cost of ownership
	Potential technology solutions	
• Advanced power management in ICT hardware • Dynamic network power management • New data storage technologies • Free cooling and equipment standards • Hardened ICT equipment • Novel computing architectures *Game-Changing Technologies* • Nanoelectronic circuitry • All-optical networks • Superconducting components	• Eliminate voltage conversion steps • High-efficiency power system components • Efficiency-optimized control systems • Transition to DC operation • On-site DC generation and microgrid	• Advanced air cooling • Liquid cooling of hardware • Advanced cooling of individual hardware components • Efficiency-optimized control systems
	Key benefits	
• Efficiency gains in ICT equipment as software drive savings in all areas of ICT facilities by reducing loads for the power supply chain and cooling systems • Hardening equipment to perform reliably in extreme environments may obviate or greatly reduce ICT cooling	• Improved efficiency will reduce power system losses and associated cooling loads • Most strategies to reduce power losses focus on reducing the number of voltage steps, which likely will reduce the number and cost of power system components • Green energy can avoid carbon output	• New approaches for cooling can lower energy costs and facilitate greater ICT hardware densities

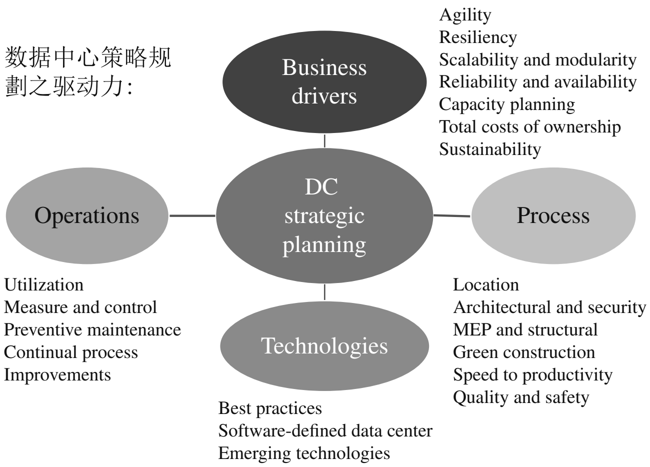

FIGURE 1.3 Data center strategic planning forces (Courtesy of Amica Association).

of suppliers, and the industry jockeying for position among current competitors. Chinese strategist Sun Tzu, in *The Art of War*, stated five factors: the Moral Law, Heaven, Earth, the Commander, and Methods and Discipline. Key ingredients in both strategic planning reflect the following [13]:

- What are the goals
- What are the knowns and unknowns
- What are the constraints
- What are the feasible solutions
- How the solutions are validated
- How to find an optimum solution

In preparing a strategic plan for a data center, Figure 1.3 [14] shows four forces: business driver, process, technologies, and operations. “Known” business drivers and philosophies of a data center solution include the following:

- Agility: Ability to move quickly.
- Resiliency: Ability to recover quickly from an equipment failure or natural disaster.
- Modularity and Scalability: “Step and repeat” for fast and easy scaling of infrastructures.
- Reliability and Availability: Reliability is the ability of equipment to perform a given function. Availability is the ability of an item to be in a state to perform a required function.
- Sustainability: Apply best practices in green design, construction, and operations of data centers to reduce environmental impacts.
- Total cost of ownership: Total life cycle costs of CapEx (e.g., land, building, green design, and construction) and OpEx (e.g., energy costs) in a data center.

Additional “knowns” to each force could be added to suit the needs of individual data center project. It is clear that “knowns” Business Drivers are complicated and sometimes conflicting. For example, increasing resiliency, or flexibility, of a data center will inevitably increase the costs of design and construction as well as continuous operating costs. Another example is that the demand for sustainability will increase the Total Cost of Ownership. “He can’t eat his cake and have it too,” so it is essential to prioritize business drivers early on in the strategic planning process.

A strategic plan should also consider emerging technologies such as using direct current power, fuel cell as energy source, or impacts from SDDC.

1.2.2 Capacity Planning

Gartner’s study indicated that data center facilities rarely meet the operational and capacity requirements of their initial design [15]. It is imperative to focus on capacity planning and resource utilization. Microsoft’s top 10 business practices estimated [16] that if a 12 MW data center uses only 50% of power capacity, then every year approximately US$4–8 million in unused capital is stranded in UPS, generators, chillers, and other capital equipment invested.

1.3 STRATEGIC LOCATION PLAN

In determining data center locations, the business drivers include market demands, market growth, emerging technology, undersea fiber-optic cable, Internet exchange points, electrical power, capital investments, and other factors. It is essential to have an orchestrated roadmap to build data centers around global locations. Thus, it is important to develop a strategic location plan that consists of a long-term data center plan from a global perspective and a short-term data center implementation plan. This strategic location plan starts from considering continents, countries, states, cities to finally the data center site.

Considerations for a macro long-term plan that is at continent and country levels include:

- Political and economic stability of the country
- Impacts from political economic pacts (e.g., EU, G8, OPEC, and APEC)
- Gross Domestic Products or relevant indicators
- Productivity and competitiveness
- Market demand and trend
- Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis
- Political, Economic, Social, and Technological (PET) analysis (PEST components)

Considerations for a midterm plan that is at province and city levels include:

- Natural hazards (e.g., earthquake, tsunami, hurricane, tornado, and volcano)
- Electricity sources with dual or multiple electrical grid services
- Electricity rate
- Fiber-optic infrastructure with multiple connectivity
- Public utilities (e.g., natural gas and water)
- Airport approaching corridor
- Labor markets (e.g., educated workforce and unemployment rate)

Considerations for a microterm plan within a city, which is at campus level, include:

- Site size, shape, accessibility, expandability, zoning, and code controls
- Tax incentives from city and state
- Topography, 100-year flood plan, and water table
- Quality of life (staff retention)
- Security and crime rate
- Proximity to airport and rail lines
- Proximity to chemical plant and refinery
- Proximity to electromagnetic field from high-voltage power lines
- Operational considerations

Other tools that could be used to formulate location plans include:

- Operations research
  - Network design and optimization
  - Regression analysis on market forecasting
- Lease versus buy analysis or build lease back
- Net present value
- Break-even analysis
- Sensitivity analysis and decision tree

As a reference, you might consider to compare your global location plan against data centers deployed by Google, Facebook, or Yahoo.

1.4 SUSTAINABLE DESIGN

Every business needs data centers to support changing environment such as new market demanding more capacity, new ICT products consuming higher power that requires rack-level cooling [17], and merge and requisition. Sustainable design is essential because data centers can consume 40–100 times more electricity compared to similar-size office spaces on a square foot basis. Data center design involves architectural, structural, mechanical, electrical, fire protection, security, and cabling systems.

1.4.1 Design Guidelines

Since a data center is heavily involved with electrical and mechanical equipments that cover 70–80% of data center capital costs (Fig. 1.4), oftentimes, a data center is considered an engineer-led project. Important factors for sustainable design encompass overall site planning, A/E design, energy efficiency best practices, redundancy, phased deployment, and so on. Building and site design could work with requirements as specified in the Leadership in Energy and Environment Design (LEED) program. The LEED program is a voluntary certification program that was developed by the U.S. Green Building Council (USGBC). Early on in the design process, it is essential to determine the rack floor plan and elevation plan of the building. The floor plate with large column spacing is best to accommodate the data center's ICT racks and cooling equipment. A building elevation plan must be evaluated carefully to cover needed space for mechanical (HVAC), electrical, structural, lighting, fire protection, and cabling systems. Properly designed column spacing and building elevation ensure appropriate capital investments and minimize operational expenses. Effective space planning will ensure maximum rack locations and achieve power density with efficient and effective power and cooling distribution [18].

International technical societies have developed many useful design guidelines. To develop data center design

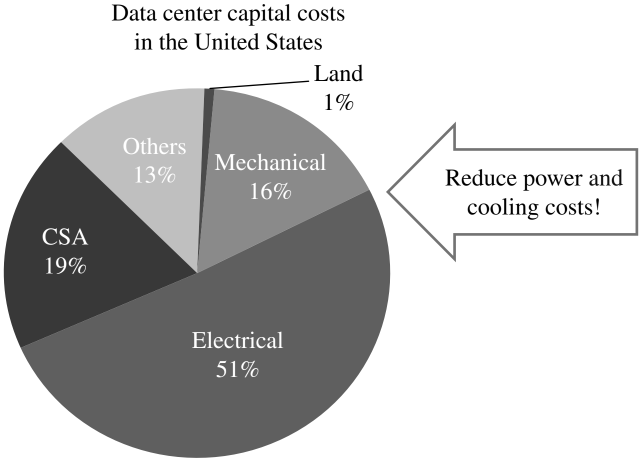

FIGURE 1.4 Focus on mechanical and electrical expenses to reduce cost significantly [16] (Courtesy of Microsoft Corporation).

requirements and specification, the following guidelines could be consulted:

- LEED Rating Systems[1]
- ANSI/ASHRAE/IES 90.1-2010: Energy Standard for Buildings
- ASHRAE TC 9.9 2011: Thermal Guideline for Data Processing Environments—Expanded Data Center Classes and Usage Guidance
- ASHRAE 2011: Gaseous and Particulate Contamination Guidelines for Data Center
- ANSI/BICSI 002-2011: Data Center Design and Implementation Best Practices
- ANSI/TIA-942-A (August 2012): Telecommunications Infrastructure Standard for Data Center
- Data Centre Code of Conduct Introduction Guide (EU)
- 2013 Best Practices Guidelines[2] (EU)
- Outline of Data Center Facility Standard[3] by Japan Data Center Council (JDCC)[4]
- *Code for Design of Information Technology and Communication Room* (GB50174-2008)

1.4.2 Reliability and Redundancy

"Redundancy" ensures higher reliability but it has profound impacts in initial investments and ongoing operating costs.

Uptime Institute® pioneered a tier certification program that structured data center redundancy and fault tolerance in a four-tiered scale. Different redundancies could be defined as follows:

- *N*: base requirement
- *N*+1 redundancy: provides one additional unit, module, path, or system to the minimum requirement
- *N*+2 redundancy: provides two additional units, modules, paths, or systems in addition to the minimum requirement
- 2*N* redundancy: provides two complete units, modules, paths, or systems for every one required for a base system
- 2(*N*+1) redundancy: provides two complete (*N*+1) units, modules, paths, or systems

Based on the aforementioned, a matrix table could be established using the following tier levels in relation to component redundancy categorized by telecommunication, architectural and structural, electrical, and mechanical:

Tier I Data Center: basic system
Tier II Data Center: redundant components
Tier III Data Center: concurrently maintainable
Tier IV Data Center: fault-tolerant

The Telecommunication Industry Association's TIA-942-A [19] contains tables that describe building and infrastructure redundancy in four levels. JDCC's "Outline of Data Center Facility Standard" is a well-organized matrix illustrating "Building, Security, Electric Equipment, Air Condition Equipment, Communication Equipment and Equipment Management" in relation to redundancy Tiers 1, 2, 3, and 4. It is worthwhile to highlight that the matrix also includes seismic design considerations with Probable Maximum Loss (PML) that relates to design redundancy.

The Chinese "National Standard" Code (GB 50174-2008) defines "Design of Information Technology and Communication Room" in A, B, and C tier levels with A being the most stringent.

Data center owners should work with A/E consultants to establish balance between desired reliability, redundancy, and total cost of ownership.

1.4.3 Computational Fluid Dynamics

Whereas data centers could be designed by applying best practices, the locations of systems (e.g., rack, air path, and CRAC) might not be in its optimum arrangement collectively. Computational Fluid Dynamics (CFD) technology has been used in semiconductor's cleanroom projects for decades to ensure uniform airflow inside a cleanroom. CFD offers a scientific analysis and solution to validate cooling capacity, rack layout, and location of cooling units. One can visualize airflow in hot and cold aisles for optimizing room design. During the operating stage, CFD could be used to emulate and manage airflow to ensure that air path does not recirculate, bypass, or create negative pressure flow. CFD could also be used to identify hot spots in rack space.

1.4.4 DCiM and PUE™

In conjunction with CFD technology, Data Center Infrastructure Management (DCiM) is used to control asset and capacity, change process, and measure and control power consumption, energy, and environment management.[5] The Energy Management system allows integrating information

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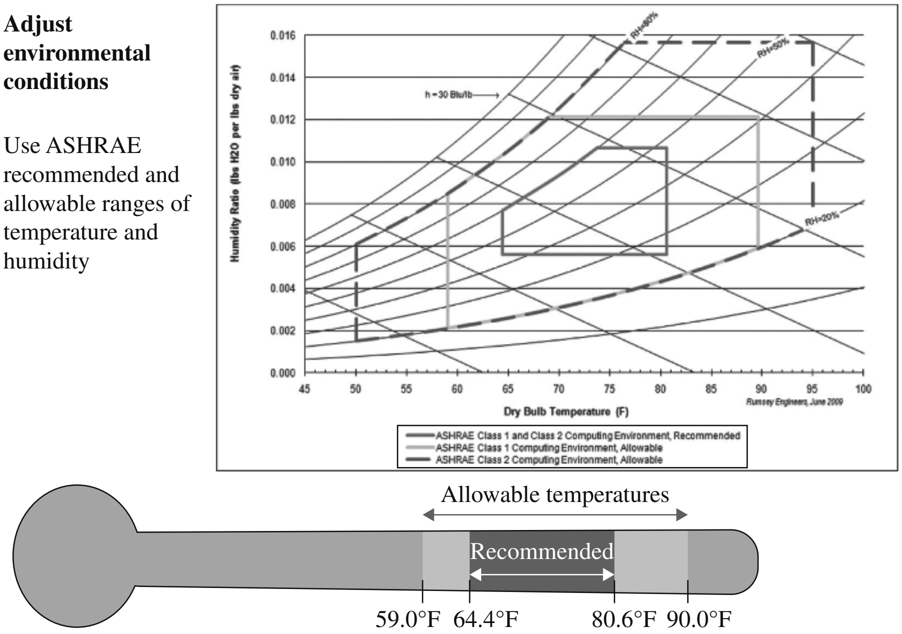
[1] http://www.usgbc.org/leed/rating-systems

[2] European Commission, Directorate-General, Joint Research Centre, Institute for Energy and Transport, Renewable Energy Unit.

[3] http://www.jdcc.or.jp/english/facility.pdf

[4] http://www.jdcc.or.jp/english/council.pdf

[5] http://www.raritandcim.com/



Adjust environmental conditions

Use ASHRAE recommended and allowable ranges of temperature and humidity

FIGURE 1.5 Adjust environmental conditions (FEMP First Thursday Seminars, U.S. Department of Energy).

such as from the Building Management System (BMS), utility meters, and UPS into actionable reports, such as accurate asset inventory, space/power/cooling capacity, and bill-back reports. A real-time dashboard display allows continuous monitoring of energy consumption and to take corrective actions.

Professors Robert Kaplan and David Norton once said: “If you can’t measure it, you can’t manage it.” Power Usage Effectiveness (PUE™), among other accepted paradigms developed by the Green Grid, is a recognized metrics for monitoring and thus controlling your data center energy efficiency.

Incorporating both CFD and DCiM early on during design stage is imperative for successful design and ongoing data center operations. It will be extreme costly to install monitoring devices after construction of a data center.

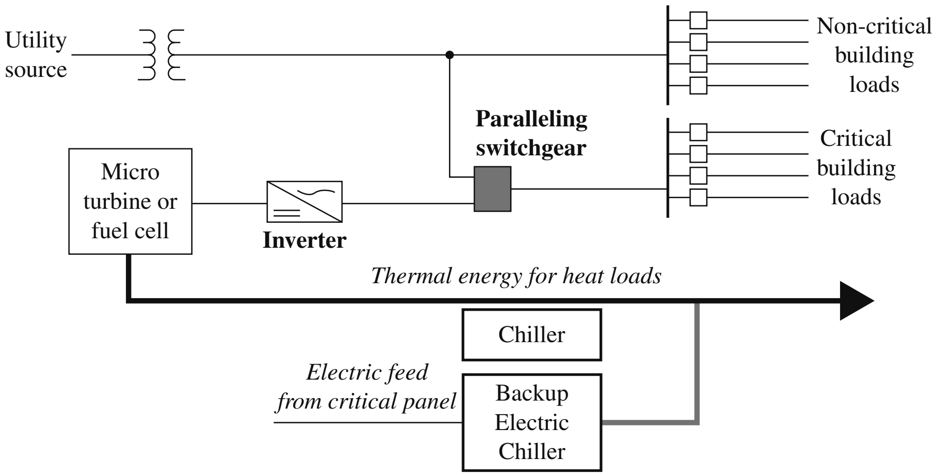
1.5 BEST PRACTICES AND EMERGING TECHNOLOGIES

Although designing energy-efficient data centers is still evolving, many best practices could be applied whether you are designing a small server room or a large data center. The European Commission published a comprehensive “2013 Best Practices for the EU Code of Conduct on Data Centres.” The U.S. Department of Energy’s Federal Energy Management Program published “Best Practices Guide for Energy-Efficient Data Center Design.” Both, and many other publications, could be referred to when preparing a data center design specification. Here is a short list of best practices and emerging technologies:

- Increase server inlet temperature (Fig. 1.5) and humidity adjustments [20]
- Hot- and cold-aisle configuration
- Hot and cold air containments
- Air management (to avoid bypass, hot and cold air mixing, and recirculation)
- Free cooling using air-side economizer or water-side economizer
- High-efficiency UPS
- Variable speed drives
- Rack-level direct liquid cooling
- Combined heat and power (CHP) in data centers (Fig. 1.6) [21]
- Fuel cell technology [22]
- Direct current power distribution

1.6 OPERATIONS MANAGEMENT AND DISASTER MANAGEMENT

Some of the best practices in operations management include applying ISO standards, air management, cable management, preventive and predictive maintenance, 5S, disaster management, and training.



Note: Generic schematic only, not a specific Tier Classification topology

FIGURE 1.6 CHP System Layout for Data Center.

1.6.1 ISO Standards

To better manage your data centers, operations management adheres to international standards, so to "practice what you preach." Applicable ISO standards include the following:

- ISO 9000: Quality management
- ISO 14000: Environmental management
- OHSAS 18001: Occupation Health and Safety Management Standards
- ISO 26000: Social responsibility
- ISO 27001: Information security management
- ISO 50001: Energy management
- ISO 20121: Sustainable events

1.6.2 Computerized Maintenance Management Systems

Redundancy alone will not prevent failure and preserve reliability. Computerized maintenance management system (CMMS) is a proven tool, enhanced with mobile, QR/barcoding, or voice recognition capabilities, mainly used for managing and upkeeping data center facility equipment, scheduling maintenance work orders, controlling inventory, and purchasing service parts. ICT asset could be managed by DCiM as well as Enterprise Asset Management System. CMMS can be expanded and interfaced with DCiM, BMS, or Supervisory Control and Data Acquisition (SCADA) to monitor and improve Mean Time between Failure and Mean Time to Failure, both closely relating to dependability or reliability of a data center. Generally, CMMS encompasses the following modules:

- Asset management (Mechanical, Electrical, and Plumbing equipment)
- Equipment life cycle and cost management
- Spare parts inventory management
- Work order scheduling (man, machine, materials, method, and tools):
  - Preventive Maintenance (e.g., based on historical data and meter reading)
  - Predictive Maintenance (based on noise, vibration, temperature, particle count, pressure, and airflow)
  - Unplanned or emergency services
- Depository for Operations and Maintenance manual and maintenance/repair history

CMMS can earn points in LEED certification through preventive maintenance that oversees HVAC system more closely.

1.6.3 Cable Management

Cabling system may seem to be of little importance, but it makes a big impact and is long lasting, costly, and difficult to replace [23]. It should be planned, structured, and installed per network topology and cable distribution requirements as specified in TIA-942-A and ANSI/TIA/EIA-568 standards. The cable should be organized so that the connections are traceable for code compliance and other regulatory requirements. Poor cable management [24] could create electromagnetic interference due to the induction between cable and equipment electrical cables. To improve maintenance and serviceability, cabling should be placed in such a way that it could be disconnected to reach a piece of equipment for adjustments or changes. Pulling, stretching, or bending the radii of cables beyond specified ranges should be avoided. Ensure cable management "discipline" to avoid "out of control, leading to chaos [24]" in data centers.

1.6.4 The 5S Pillars [25]

5S is a lean method that organizations implement to optimize productivity through maintaining an orderly workplace.[6] 5S is a cyclical methodology including the following:

- Sort: eliminate unnecessary items from the workplace.
- Set in order: create a workplace so that items are easy to find and put away.
- Shine: thoroughly clean the work area.
- Standardize: create a consistent approach with which tasks and procedures are done.
- Sustain: make a habit to maintain the procedure.

1.6.5 Training and Certification

Planning and training play a vital role in energy-efficient design and the effective operation of data centers. The U.S. Department of Energy offers many useful training and tools.

The Federal Energy Management Program offers free interactive online "First Thursday Semin@rs" and "eTraining.[7]" Data center owners can use Data Center Energy Profiler (DC Pro) Software[8] to profile, evaluate, and identify potential areas for energy efficiency improvements. Data Center Energy Practitioner (DCEP) Program [26] offers data center practitioners with different certification programs.

1.7 BUSINESS CONTINUITY AND DISASTER RECOVERY

In addition to natural disasters, terrorist attack to the Internet's physical infrastructure is vulnerable and could be devastating. Also, statistics show that over 70% of all data centers was brought down by human errors such as improper executing procedures or maintenance. It is imperative to have detailed business continuity (BC) and disaster recovery (DR) plans well prepared and executed. BC at data centers should consider design beyond requirements per building codes and standards. The International Building Code (IBC) and other codes generally concern about life safety of occupants but with little regard to property or functional losses. To sustain data center operations after a natural disaster, the design of data center building structural and nonstructural components (mechanical equipment [27], electrical equipment [28], duct and pipe [29]) must be toughened considering BC.

Many lessons were learned on DR from two natural disasters: the Great East Japan Tsunami (March 2011) [30] and the eastern U.S. Superstorm *Sandy* (October 2012). "Many of Japan's data centers—apart from the rolling brownouts—were well prepared for the Japanese tsunami and earthquake. Being constructed in a zone known for high levels of seismic activity, most already had strong measures in place [31]."

Key lessons learned from the aforementioned natural disasters are highlighted as follows:

- Detailed crisis management procedure and communication command line.
- Conduct drills regularly by emergency response team using established procedures.
- Regularly maintain and test run standby generators and critical infrastructure in a data center.
- Have contract with multiple diesel oil suppliers to ensure diesel fuel deliveries.
- Fly in staff from nonaffected offices. Stock up food, drinking water, sleeping bags, etc.
- Have different communication mechanisms such as social networking, web, and satellite phones.
- Get required equipment on-site readily accessible (e.g., flashlight, portable generator, fuel and containers, hoses, and extension cords).
- Brace for the worst—preplan with your customers on communication during disaster and a controlled shutdown and DR plan.

Other lessons learned include using combined diesel fuel and natural gas generator, fuel cell technology, and submersed fuel pump and that "a cloud computing-like environment can be very useful [32]." "Too many risk response manuals will serve as a 'tranquilizer' for the organization. Instead, implement a risk management framework that can serve you well in preparing and responding to a disaster."

1.8 CONCLUSION

This chapter describes energy use that accelerates global warming and results in climate changes, flood, drought, and food shortage. Strategic planning of data centers applying best practices in design and operations was introduced. Rapidly increasing electricity demand by data centers for information processing and mobile communications outpaces improvements in energy efficiency. Lessons learned from natural disasters were addressed. Training plays a vital role in successful energy-efficient design and safe operations. By collective effort, we can apply best practices to radically accelerate speed of innovation (Fig. 1.7) to plan, design, build, and operate data centers efficiently and sustainably.

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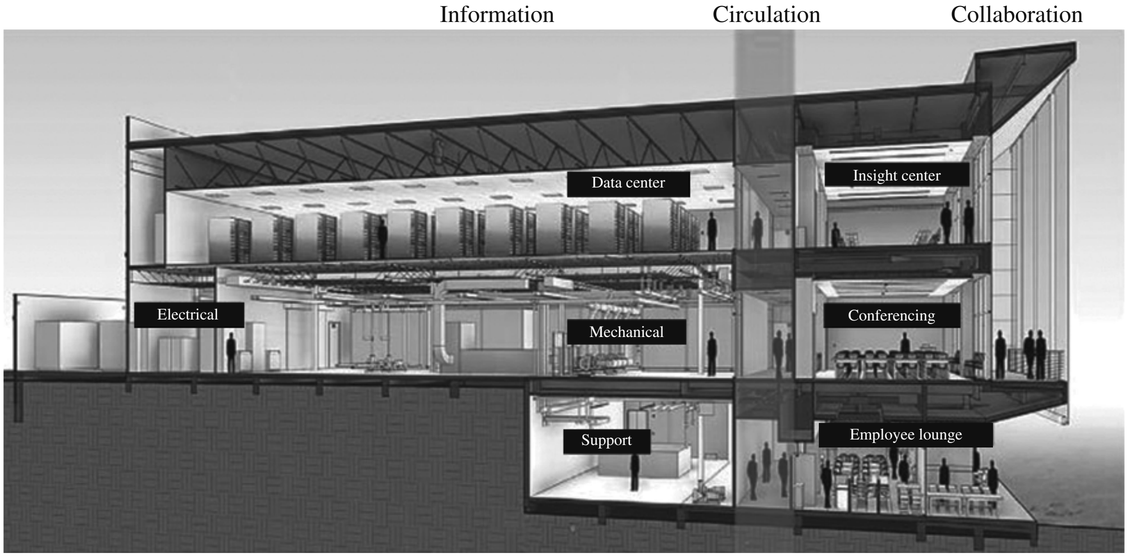
[6] "Lean Thinking and Methods," the U.S. Environmental Protection Agency.

[7] http://apps1.eere.energy.gov/femp/training/first_thursday_seminars.cfm

[8] http://www1.eere.energy.gov/manufacturing/datacenters/software.html



Cross section view into the ESIF HPC data center. *Illustration from SmithGroupJJR*

FIGURE 1.7 ESIF's high-performance computing data center—innovative cooling design with PUE at 1.06 [33].

REFERENCES

[1] IPCC. Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group l to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge/New York: Cambridge University Press; 2013.

[2] Turn down the heat: why a 4°C warmer world must be avoid. Washington, DC: The World Bank; November 18, 2012.

[3] Koomey J. Growth in data center electricity use 2005 to 2010. Analytics Press; August 2011.

[4] EMC/IDC (International Data Corporation). Extracting value from chaos; June 2011.

[5] Gartner. The top 10 strategic technology trends for 2012; November 2011.

[6] Ebbers M, Archibald M, Fonseca C, Griffel M, Para V, Searcy M. *Smart Data Centers, Achieving Greater Efficiency*. 2nd ed. IBM Redpaper; 2011.

[7] Best Practices Guide for Energy-Efficient Data Center Design. Federal Energy Management Program, U.S. Department of Energy; March 2011.

[8] Mell P, Grance T. The NIST definition of cloud computing. NIST, U.S. Department of Commerce; September 2011.

[9] Sigmon D. What is the difference between SDDC and cloud?. InFocus; August 2013.

[10] VMware. Delivering on the promise of the software-defined data center; 2013.

[11] Vision and roadmap: routing telecom and data centers toward efficient energy use. Sponsored by: Emerson Network Power, Silicon Valley Leadership Group, TIA, Yahoo Inc., U.S. Department of Energy; May 13, 2009.

[12] Porter ME. How competitive forces shape strategy. Harvard Bus Rev 1980;57(2):137–145.

[13] Geng H. Strategic planning process. Amica Association; 2012.

[14] Geng H. Data centers plan, design, construction and operations. Datacenter Dynamics Conference, Shanghai; September 2013.

[15] Bell MA. Use best practices to design data center facilities. Gartner Publication; April 22, 2005.

[16] Top 10 business practices for environmentally sustainable data centers. Microsoft; August 2012.

[17] Dunlap K, Rasmussen N. Choosing between room, row, and rack-based cooling for data centers. White Paper 130, Rev. 2, Schneider Electric Corporation.

[18] Rasmussen N, Torell W. Data center projects: establishing a floor plan. APC White Paper #144; 2007.

[19] Telecommunications Infrastructure Standard for Data Centers. Telecommunications Industry Association; August 2012.

[20] Server Inlet Temperature and Humidity Adjustments. Available at http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_inlet_temp. Accessed on May 6, 2014.

[21] Darrow K, Hedman B. Opportunities for combined heat and power in data centers. Arlington: ICF International, Oak Ridge National Laboratory; March 2009.

[22] 2010 hydrogen and fuel cell global commercialization & development update. International Partnership for Hydrogen and Fuel Cells in the Economy; November 2010.

[23] Best Practices Guides: Cabling the Data Center. Brocade; 2007.

[24] Apply proper cable management in IT racks—a guide for planning, deployment and growth. Emerson Network Power; 2012.

[25] Productivity Press Development Team. *5S for Operators: 5 Pillars of the Visual Workplace*. Portland: Productivity Press; 1996.

[26] DCEP program energy training-assessment process manual. LBNL and ANCIS Inc.; 2010.

[27] Installing seismic restraints for mechanical equipment. FEMA; December 2002.

[28] Installing seismic restraints for electrical equipment. FEMA; January 2004.

[29] Installing seismic restraints for duct and pipe. FEMA; January 2004.

[30] Yamanaka A, Kishimoto Z. The realities of disaster recovery: how the Japan Data Center Council is successfully operating in the aftermath of the earthquake. JDCC, Alta Terra Research; June 2011.

[31] Jones P. The after effect of the Japanese earthquake. Tokyo: Datacenter Dynamics; December 2012.

[32] Kajimoto M. One year later: lessons learned from the Japanese tsunami. ISACA; March 2012.

[33] High performance computing data center. National Renewable Energy Laboratory, U.S. Department of Energy; August 2012.

FURTHER READING

2011 Thermal Guidelines for Data Processing Environments. ASHRAE TC 9.9; 2011.

Al Gillen, et al., The software-defined datacenter: what it means to the CIO. IDC; July 2012.

A New Approach to Industrialized IT. HP Flexible Data Center; November 2012.

Annual Energy Outlook 2013 with Projections to 2040. U.S. Energy Information Administration; April 2013.

Avelar V, Azevedo D, French A. PUE™: a comprehensive examination of the metric. The Green Grid; 2012.

Brey T, Lembke P, et al. Case study: the ROI of cooling system energy efficiency upgrades. White Pager #39, the Green Grid; 2011.

Create a Project Plan-Cops, U.S. Dept. of Justice. Available at http://www.itl.nist.gov/div898/handbook/index.htm. Accessed on May 6, 2014.

Coles H, Han T, Price P, Gadgil A, Tschudi W. Assessing corrosion risk from outside-air cooling: are coupons a useful indicator? LBNL; March 2011.

eBay Data Center Retrofits: The Costs and Benefits of Ultrasonic Humidification and Variable Speed Drive. Energy Star Program, the U.S. EPA and DOE; March 2012. Available at http://www.energystar.gov/ia/products/power_mgt/downloads/Energy_Star_fact_sheet.pdf?0efd-83df. Accessed on May 6, 2014.

EU energy trends to 2030. European Commission; 2009.

European Code of Conduct on Data Centre Energy Efficiency, introductory guide for applicants 2013. European Commission; 2013.

Gartner IT Glossary. 2012. Available at http://www.gartner.com/itglossary/data-center/. Accessed on May 6, 2014.

Geary J. Who protects the internet? Popular Science; March 2009.

Gens F. Top 10 predictions, IDC predictions 2013: competing on the 3rd platform. IDC; November 2012.

Govindan S, Wang D, Chen L, Sivasubramaniam A, Urgaonkar B. Modeling and Analysis of Availability of Datacenter Power Infrastructure. Department of Computer Science and Engineering, The Pennsylvania State University, IBM Research Zurich. Technical Report. CSE 10-006.

Green Google. Available at http://www.google.com/green/. Accessed on May 6, 2014.

Hickins M. Companies test backup plans, and learn some lessons. Wall Street Journal, October 37, 2012.

Iyengar M, Schmidt RR. *Energy Consumption of Information Technology Data Centers*. Electronics Cooling Magazine, Publisher: ITEM Media, Plymouth Meeting, PA; December 2010.

Joshi Y, Kumar P. *Energy Efficient Thermal Management of Data Centers*. New York: Springer; 2012.

LaFontaine WR. Global technology outlook 2013. IBM Research; April 2013.

Newcombe L, et al. 2013 Best Practices for the EU Code of Conduct on Data Centers. European Commission; 2013.

Pitt Turner IV W, Brill K. Cost model: dollars per kW plus dollars per square foot of computer floor. White Paper, Uptime Institute; 2008.

Planning guide: getting started with big data. Intel; 2013.

Polar ice melt is accelerating. The Wall Street Journal, November 30, 2012.

Porter M. *Competitive Strategy: Techniques for Analyzing Industries and Competitors*. New York: Free Press, Harvard University; 1980.

Prescription for server room growth: Design a Scalable Modular Data Center. IBM Global Services; August 2009.

Report to Congress on server and data center energy efficiency. U.S. Environmental Protection, Agency Energy Star Program; August 2007.

Rodgers TL. Critical facilities: reliability and availability. Facility Net; August 2013.

Salim M, Tozer R. Data Center Air Management Metrics-Practical Approach. Hewlett-Packard, EYP MCF.

Sawyer R. Calculating total power requirements for data centers. APC; 2004.

Trick MA. *Network Optimization*. Carnegie Mellon University; 1996.

U.S. Energy Information Administration. Available at http://www.eia.gov/todayinenergy/. Accessed on May 6, 2014.

VanDenBerg S. Cable pathways: a data center design guide and best practices. Data Center Knowledge, Industry Perspectives; October 2013.

Wenning T, MacDonald M. High performance computing data center metering protocol. Federal Energy Management Program, U.S. Department of Energy; 2010.