



# ASHRAE DATACOM BOOK SERIES

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## INTRODUCTION

The IT industry continues to experience higher and higher electronic equipment power densities, resulting in a significant impact on facility cooling infrastructures. In addition, the mission-critical nature of today's computing environment has sensitized businesses to the importance of maintaining the long-term health of their data centers. These combined effects have made it imperative that data center managers, facilities operators, and equipment manufacturers be well-aligned to ensure efficient, effective, and reliable operation of mission-critical computing environments.



The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Technical Committee (TC) 9.9, "Mission-Critical Facilities, Technology Spaces, and Electronic Equipment," has published a series of environmental books for datacom applications. These books bridge the technology gaps between IT and facilities, providing a holistic view of data centers and insight into solutions that address current and future issues. The mission of TC 9.9 is "To be recognized by all areas of the datacom industry as the unbiased engineering leader in the subject of HVAC and an effective provider of technical information." The members of TC 9.9 consist of manufacturers, consultants, and end users from the datacom industry.

The Green Grid's Technology and Strategy Work Group established its Thermal Management Task Force to review and summarize recent ASHRAE TC 9.9 books.

This paper presents summaries of the following seven ASHRAE books, in order of publication date:

1. 90431 Thermal Guidelines for Data Processing Environments (2004)
2. 90427 Datacom Equipment Power Trends and Cooling Applications (2005)
3. 90437 Design Considerations for Datacom Equipment Centers (2005)
4. 90430 Liquid Cooling Guidelines for Datacom Equipment Centers (2006)
5. 90438 Best Practices for Datacom Facility Energy Efficiency (2008)
6. 90429 Structural and Vibration Guidelines for Datacom Equipment Centers (2008)
7. 90441 High Density Data Centers - Case Studies and Best Practices (2008)

The Green Grid intends to review and publish summaries on additional ASHRAE Datacom series books as they become available.

The intent of this paper is to introduce these important publications to IT management, beyond the traditional facilities audience, and provide a summary overview to enable the reader to efficiently locate the book(s) of interest. It is important to note that The Green Grid does not necessarily endorse the content of the ASHRAE publications.

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## I. BOOK 1: THERMAL GUIDELINES FOR DATA PROCESSING ENVIRONMENTS



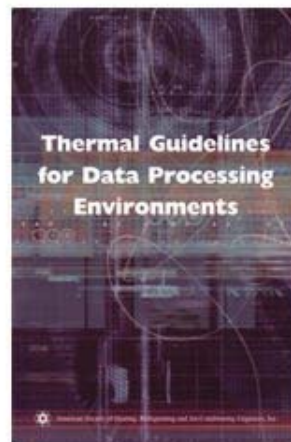
**CHAPTER 1:** This book presents guidelines developed for data center facility operators and equipment manufacturers on common environmental conditions. Included are suggested methods for evaluating and testing the operational health of the data center and the environmental characteristics of a computer system. ASHRAE developed the book because traditional processes for sizing cooling resources were not keeping up with environmental needs for IT reliability given the increasing IT power density. The book also is meant to address the significant amount of over-sizing and over-cooling that takes place due to misunderstanding the environmental conditions needed by the equipment. Current management methods also were forcing cooling resource capital and operational expenditures to outpace IT expenditures.

### CHAPTER 2: EQUIPMENT ENVIRONMENT SPECIFICATIONS

Setting the same operating parameters for all types of IT equipment drives facility capital and operational expenses. This chapter seeks to define various classes of IT and their recommended and allowable humidity and temperature conditions, with data centers typically categorized as Class 1.

#### CLASS DEFINITIONS: (Source: ASHRAE-D-94037-20080606)

- Class 1 – Typically a datacom facility with tightly controlled environmental parameters (dew point, temperature, and relative humidity) and mission-critical operations. Product types typically designed for this environment include enterprise servers and storage products.
- Class 2 – Typically a datacom space or office or lab environment with some control of environmental parameters (dew point, temperature, and relative humidity). Product types typically designed for this environment include small servers, storage products, personal computers, and workstations.
- Class 3 – Typically an office, home, or transportable environment with little control of environmental parameters (temperature only). Product types typically designed for this environment include personal computers, workstations, laptops, and printers.
- Class 4 – Typically a point-of-sale or light industrial or factory environment with weather protection, sufficient winter heating, and ventilation. Product types typically designed for this environment include point-of-sale equipment, ruggedized controllers or computers, and PDAs.



|              |   |
|--------------|---|
| Title        | Thermal Guidelines for Data Processing Environments |
| Page Count   | 62  |
| Date         | 2004  |
| Price        | \$43  |
| Part numbers | 90431 (printed) D-90431 (electronic - PDF)          |

- NEBS – According to Telcordia Technologies “GR-63-CORE” (Issue 2, April 2002) and “GR 3028-CORE” (Issue 1, December 2001), typically a telecommunications central office with some control of environmental parameters (dew point, temperature, and relative humidity). Product types typically designed for this environment include switches, transport equipment, and routers.

Since Class 3 and 4 environments are primarily not designed for datacom equipment, they are not covered further in this chapter. Please refer to ASHRAE’s Thermal Guidelines book for further information (ASHRAE 2004h).



Table 2.1 below from the book is a specifications overview, and the book comes with a quick reference card carrying the same information. Chapter 2 also describes ratings for altitude and discusses acoustic concerns. The appendices show graphical representations of temperature, humidity, and altitude comparisons of the various classes. Major IT manufacturers and ASHRAE have agreed on the operating limits, measured at the equipment inlet. Table 2.1 data was updated at the ASHRAE Summer Annual Meeting in Salt Lake City in June 2008. The new data is shown in Table 2.1a.

| ASHRAE Thermal Guidelines for Data Processing Environments                 |                         |                           |                               |                                 |
|--|-------------------------|---------------------------|-------------------------------|---------------------------------|
| Table 2.1 Equipment Environment Specifications                             |                         |                           |                               |                                 |
| Class  | Allowable Dry Bulb (°C) | Recommended Dry Bulb (°C) | Allowable % Relative Humidity | Recommended % Relative Humidity |
| 1  | 15 to 32                | 20 to 25                  | 20 to 80                      | 40 to 55                        |
| 2  | 10 to 35                | 20 to 25                  | 20 to 80                      | 40 to 55                        |
| 3  | 5 to 35                 | NA                        | 8 to 80                       | NA                              |
| 4  | 5 to 40                 | NA                        | 8 to 80                       | NA                              |
| Max. Altitude = 10,000 feet with dry bulb de-rating applied in some cases. |                         |                           |                               |                                 |
| Courtesy of ASHRAE   |                         |                           |                               |                                 |

**TABLE 2.1: ORIGINAL (2004) FACILITY TEMPERATURE AND HUMIDITY MEASUREMENTS ©2004 ASHRAE**

Note: ASHRAE has published an update to the operating ranges described in Table 2.1 that can be found at: [http://tc99.ashraetcs.org/documents/ASHRAE\\_Extended\\_Environmental\\_Envelope\\_Final\\_Aug\\_1\\_2008.pdf](http://tc99.ashraetcs.org/documents/ASHRAE_Extended_Environmental_Envelope_Final_Aug_1_2008.pdf)



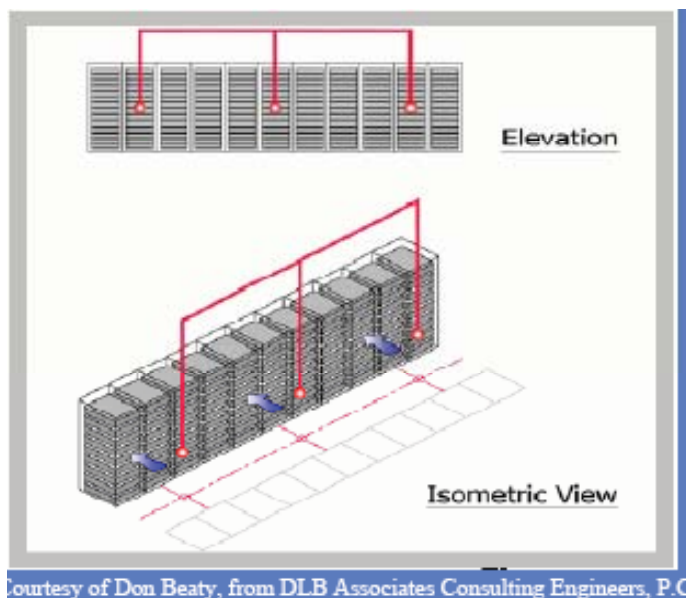
Key changes in the revised table below are shown in bold.

| Class  | Allowable Dry Bulb (°C) | Recommended Dry Bulb (°C) | Allowable % Relative Humidity | Recommended % Relative Humidity                       |
|--|-------------------------|---------------------------|-------------------------------|---|
| 1  | 15 to 32                | <b>18 TO 27</b>           | 20 to 80                      | <b>5.5 °C DEW POINT TO 15 °C DEW POINT AND 60% RH</b> |
| 2  | 10 to 35                | 20 to 25                  | 20 to 80                      | 40 to 55  |
| 3  | 5 to 35                 | NA                        | 8 to 80                       | NA  |
| 4  | 5 to 40                 | NA                        | 8 to 80                       | NA  |
| Max. Altitude = 10,000 feet with dry bulb de-rating applied in some cases. |                         |                           |                               |   |
| Courtesy of ASHRAE   |                         |                           |                               |   |

**TABLE 2.1A: NEW RECOMMENDED ENVIRONMENTAL GUIDELINES, UPDATED AT THE ASHRAE SUMMER ANNUAL MEETING IN SALT LAKE CITY IN JUNE 2008 AND APPROVED BY ASHRAE**

The objective of the specifications above is to ensure that a facility's aisle temperature and humidity levels all are being maintained within the operating conditions recommended for its environment class. Any equipment inlet temperature and/or humidity measurements found to be outside the recommended operating range for the class environment should be investigated and corrected.

Even though facility cooling may be sized to accommodate larger than the total IT thermal load, often some of the IT devices report thermal issues due to local temperature variation in the data center. Chapter 3 defines temperature locations and humidity measurements—both in IT and at the facility level—to help troubleshoot this issue. (See the book's Figure 3.2 below.)



**FIGURE 3.2: TEMPERATURE AND HUMIDITY MEASUREMENT LOCATIONS ©2004 ASHRAE**

**CHAPTER 4: EQUIPMENT PLACEMENT AND AIRFLOW PATTERNS**

An imbalance in airflow throughout the space can cause additional temperature problems, even when facility cooling equipment is appropriately sized for the thermal load. This chapter provides layout and protocol suggestions for IT equipment cabinet airflow. It also suggests best practices for facility layout of IT aisles and air conditioners/handlers, including cabinets with dissimilar airflow patterns, to optimize airflow effectiveness.


**CHAPTER 5: EQUIPMENT MANUFACTURERS HEAT AND AIRFLOW REPORTING**

This section provides guidelines for IT reporting of power and the resulting heat load and airflow. It is critical that facility designers size mechanical and electrical systems for actual and future environmental set points. The chapter suggests a method of obtaining data sheets with typical minimum and full load information from the IT supplier. This is in contrast to the common but inaccurate method of using power supply name plate ratings to determine requirements. A sample of a report based on a manufacturer data sheet is shown below in Figure 3.3 from the book.



| IBM Server Model 520 - Rack Mounted Drawer |   |         |                      |     |                     |        |    |   |                 |
|--|---|---------|----------------------|-----|---------------------|--------|----|---|-----------------|
| Configuration                              | Condition                               |         |                      |     |                     |        |    |   |                 |
|  | Typical Heat Release<br>(Voltage 110 V) | Airflow |                      |     |                     | Weight |    | Overall System Dimensions <sup>b</sup><br>(W x D x H) |                 |
|  |   |         | Nominal <sup>a</sup> |     | Maximum at 35°C     |        |    |   |                 |
|  | watts                                   | cfm     | (m <sup>3</sup> /h)  | cfm | (m <sup>3</sup> /h) | lbs    | kg | in.   | mm              |
| Minimum                                    | 420                                     | 26      | 44                   | 40  | 68                  | 117    | 53 | 25 x 37 x 23  | 630 x 933 x 584 |
| Full                                       | 600                                     | 30      | 51                   | 45  | 76                  | 117    | 53 | 25 x 37 x 23  | 630 x 933 x 584 |
| Typical                                    | 450                                     | 26      | 44                   | 40  | 68                  | 117    | 53 | 25 x 37 x 23  | 630 x 933 x 584 |

| ASHRAE Class | Airflow Diagram Rack-mount Cooling scheme F-R<br> | Configuration |   |
|--------------|--|---------------|---|
|              |  | Description   | Model                                     |
| 3            |  | Minimum       | 1-way, 1.5 GHz processor, 18 GB memory    |
|              |  | Full          | 2-way, 1.85 GHz processor, maximum memory |
|              |  | Typical       | 1-way, 1.85 GHz processor, 18 GB memory   |

a. The airflow values are for an air density of 1.2 kg/m<sup>3</sup> (0.075 lb/ft<sup>3</sup>). This corresponds to air at 20°C (68°F), 101.3 kPa (14.7 psia), & 50% relative humidity.  
 b. Footprint does not include service clearance or cable management, which is zero on the sides, 46 in. (1168 mm) in front, & 40 in. (1016 mm) in the rear.

**FIGURE 3.3: TYPICAL MANUFACTURER’S HEAT AND AIRFLOW TABLE ©2004 ASHRAE**

## II. BOOK 2: DATACOM EQUIPMENT POWER TRENDS AND COOLING APPLICATIONS



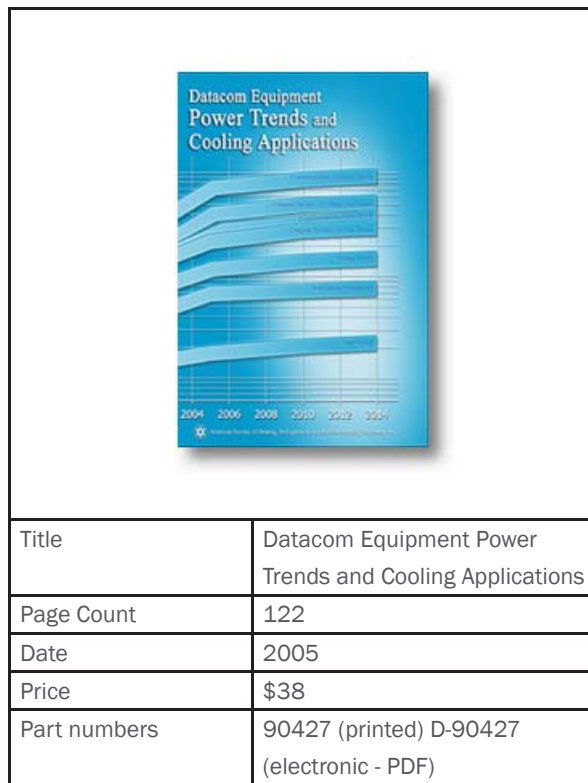
A critical aspect of designing and maintaining all data centers is the ability to efficiently and effectively plan the IT equipment power and cooling requirements—both for today and for growth over time. The book provides datacom equipment power trend charts that give IT staff, facilities, architects, engineers, planners, and operations managers an improved means of forecasting, designing, maintaining, and provisioning new and existing datacom equipment load requirements. It also provides trends to aid in predicting growth in power costs due to increased infrastructure load.

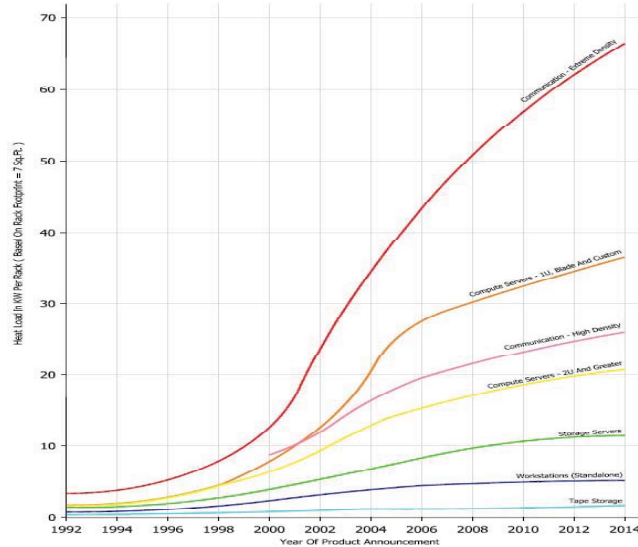
Careful planning of datacom power and cooling facilities is needed because they have a much longer product life cycle than the computer equipment they support. Datacom/IT equipment typically has a product life cycle of 3 to 5 years, whereas a building's cooling and power distribution systems can last 10 to 25 years.

This discrepancy can lead to inefficiencies due to over- or under-design capacity. Therefore, accurate capacity forecasting is essential. The design and operation of a building's power and cooling systems must accommodate multiple computer equipment deployments and prevent costly and disruptive infrastructure upgrades, premature obsolescence, and inefficient datacom facility operation.

In 2000, as defined by the Thermal Management Consortium, the Uptime Institute published the broadly referenced datacom equipment power density trend chart that covers 1992 through 2010. Since that time, ASHRAE has identified some misapplications of the chart, further clarified some of the chart's assumptions and applications, and extended the projections to 2014.

The following is an exemplary chart from the book that projects to 2014 the typical heat load in KW per rack—based on a 7-square-foot rack—for extreme-density communication equipment, compute servers (1U blade and custom, high-density communication compute servers along with 2U and greater compute servers), storage servers, workstations (standalone), and tape storage devices. ASHRAE also felt that new form factor computers showed higher power densities than more traditional computers. Similarly, communications equipment branched into two trend lines between high and extreme densities.





**FIGURE B-4: NEW POWER TREND CHART (NON-LOG SCALE, KW PER RACK), UPDATED AND EXPANDED BY ASHRAE ©2005 ASHRAE**

In addition to the charts, the book contains key aspects of facility planning. It stresses the importance of strong collaboration between the building facilities and information technology personnel and of provisioning for future loads to include system growth components and necessary spatial allocation.

#### **CHAPTER 1: INTRODUCTION**

This chapter describes the book's purpose, which is to provide power trends for datacom (data center and telecommunication) equipment, describe how those trends affect critical decisions on facility cooling system infrastructure requirements, and highlight the importance of collaboration between IT and facilities personnel.

#### **CHAPTER 2: BACKGROUND**

This section describes the five key planning aspects of a datacom facility, with an example that illustrates how the reader can implement the planning process. It also includes a discussion on the use of a power density metric.

#### **CHAPTER 3: LOAD TRENDS AND THEIR APPLICATION**

Chapter 3 contains updated datacom equipment power information, historical and projected power dissipation trend charts for various classes of equipment, a trend evolution overview grouped by various datacom equipment types, and a discussion regarding how to apply the load trend charts for capacity and provisioning when planning a new facility.

#### **CHAPTER 4: AIR COOLING OF COMPUTER EQUIPMENT**

This section provides a definition and overview of the various air cooling systems, including underfloor, overhead distribution, managed supply and return airflow, and local distribution configurations and equipment.

#### **CHAPTER 5: LIQUID COOLING OF COMPUTER EQUIPMENT**

Chapter 5 gives a definition and overview of the various liquid cooling systems associated at the cabinet

level. It discusses the reasons behind the re-emergence of liquid cooling and supplies details on the types of liquid used for enhanced heat transfer. The chapter intentionally excludes component and board-level cooling technologies. The three basic transport liquid strategies discussed in the chapter are:

- Heat rejection by air cooling the heat transport liquid from the electronic equipment
- Heat rejection by liquid cooling the heat transport liquid from the electronic equipment
- Heat rejection by extending the heat transport liquid from the electronic equipment to a remote location far from the rack/cabinet

This chapter also describes the three types of liquid cooling loops and some of the factors that must be considered when choosing a cooling methodology.



**APPENDICES:** The book includes a collection of useful appendices to supplement the chapters.

- Appendix A – Collection of Terms contains a useful list of standard industry terms and high-level definitions for easy reference.
- Appendix B – Additional Trend Chart Information/Data contains the trend charts in SI units. It also offers versions of the trend charts without logarithmic scales for power density to provide a better understanding of the loads escalation. Also included are trend values in a tabular version and kW per rack and W/ft<sup>2</sup> trend graphs.
- Appendix C – Electronics, Semiconductors, Microprocessors, International Roadmap for Semiconductors provides some semiconductor industry history as well as the semiconductor ITRS roadmap information.
- Appendix D – A Micro-Macro Overview of Datacom Equipment Packaging provides a high-level graphical overview of datacom packaging. It also includes a glossary that clarifies terms used by both the data processing and telecommunications industries.

## III. BOOK 3: DESIGN CONSIDERATIONS FOR DATACOM EQUIPMENT CENTERS

### CHAPTER 1: INTRODUCTION

For the purposes of this book, “datacom” refers to the data and communications industry, whereas “data center” refers to the portion of a building that is dedicated to housing data and communications equipment. Datacom equipment centers are unique in terms of their increased power and thermal densities and with regard to their high-availability requirements. They can be several times greater than the specifications for office buildings and equipment support spaces. In addition, these environments often require special environmental conditions such as humidification and air purification.

This book is not meant to be a comprehensive guide to datacom data center design concepts. Rather, it provides an augmentation to existing data center design standards in order to achieve the basic standards of datacom equipment centers.

### CHAPTER 2: DESIGN CRITERIA

The primary focus of this chapter is to cover all of the environmental features, such as temperature, humidity, human comfort issues, and air filtration.

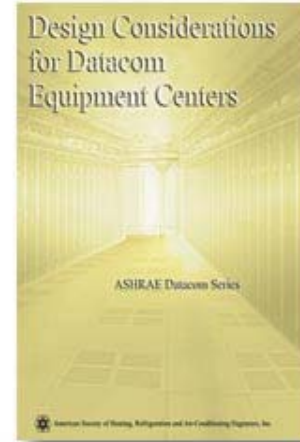
A consortium of equipment manufacturers in the industry has established an agreed-upon set of standardized conditions (Classes 1-4). A definition of these classes can be found in the ASHRAE publication, Thermal Guidelines of Data Processing Environments (ASHRAE 2004h). Further classifications are defined in the Network Equipment-Building Systems (NEBS). NEBS-3 is the most current standard.

The rest of Chapter 2 contains valuable graphs and charts that identify operational factors and conditions for datacom centers based on altitude and environmental conditions that include humidification, filtration of contaminants, ventilation, vapor containment, pressurization, materials usage, and human safety and comfort factors.

### CHAPTER 3: HVAC LOAD CONSIDERATIONS

This chapter focuses on high-density power and thermal loads, with specifications that allow for electrical loads of 30kW+/rack. Given the dynamic nature of load calculations, the publication Datacom Equipment Power Trends and Cooling Applications (ASHRAE 2005i) serves as a useful guide. Specific equipment such as tape storage, workstations, storage, and compute/server load estimates is provided.

Chapter 3 covers heat implications for lighting, people, envelope (exposure to radiant heat from outside sources), and transmission heat gain. It also addresses the use of reheat coils to control humidification.



|              |   |
|--------------|---|
| Title        | Design Considerations for Datacom Equipment Centers |
| Page Count   | 208   |
| Date         | 2005  |
| Price        | \$38  |
| Part numbers | 90437 (printed) D-90437 (electronic - PDF)          |



#### CHAPTER 4: COMPUTER ROOM COOLING OVERVIEW

This chapter covers the basics for cooling infrastructure and designs, yet does not provide specific design recommendations due to the wide variety of computer room designs and applications. It reviews Computer Room Air Conditioner (CRAC) and cooling types (Direct Expansion [DX]) versus chilled water) and discusses CRAC locations in general, yet leaves them to computational fluid dynamics (CFD) analysis for detailed designs.

Chapter 4 analyzes the use of variable-speed fans, also referred to as variable-air-volume (VAV) equipment, to minimize operating costs through reduced fan power consumption at less than full design loads. Such equipment requires careful CFD analysis to apply properly.

Chilled water distribution systems remain the most common method of cooling design because they provide an efficient mechanism for heat removal and also allow for highly efficient heat rejection systems that utilize cooling water towers and/or wet-side economizers.

This chapter also goes into more detail on chiller design, piping, humidification systems, controls, and monitoring.

#### CHAPTER 5: AIR DISTRIBUTION

Air distribution is perhaps one of the least-understood areas of data center design. Yet it can have a significant impact on operational efficiency, energy consumption, and cost effectiveness. Due to increased equipment densities, more sophisticated airflow designs are critical and require advanced CFD tools and knowledge. OEMs publish recommended temperatures and humidity standards, and local recommendations are published in the telecom central offices (Telcordia 2001) and data centers (ASHRAE 2004h).

Chapter 5 discusses basic principles of airflow dynamics, such as the implementation of a hot-aisle/cold-aisle configuration. It also covers various rack flow designs and includes specific recommendations on the placement of floor tiles and CRACs and ways to eliminate floor leakage of the cold air supply. The chapter makes recommendations regarding the use of various perforated tile types.

This chapter also compares vertical under floor (VUF) cold air delivery designs to vertical overhead (VOF) designs. Each design has its unique strengths, weaknesses, and limitations. Supplemental cooling options are discussed in more detail in Chapter 4 of *Datacom Equipment Power Trends and Applications* (ASHRAE 2005i). Supplemental systems can be very useful when higher cooling requirements are needed for specific racks or areas of a data center.

#### CHAPTER 6: LIQUID COOLING

As mentioned, virtually all equipment is cooled with cold air. However, the means by which heat energy is rejected can differ. In air cooling, conditioned air supplied to rack and equipment inlets uses convection cooling to remove heat from the components within the rack. Liquid cooling utilizes conditioned liquids that are fed to the rack or server to remove heat directly from the rack components. The actual heat removal from the CPU or other components could still be via cold air, but the heat-rejection medium to the building's cooling infrastructure outside the rack is liquid.

Chapter 6 also discusses the thermal properties of water and refrigerants in more detail, including reliability, availability, and operational cost implications.



## CHAPTER 7: ANCILLARY SPACES

Within any data center design, the computer room floor is only one of several areas required for normal data center operations. Other areas include UPS room, electro-mechanical rooms, battery room, network entrance room, network operations center (NOC), equipment test and burn-in room, possible rooms for generators, and storage spaces.

## CHAPTER 8: CONTAMINATION

This chapter addresses the sources of particulate matter and other sources of airborne contaminants that can affect performance and/or mean time before failure (MTBF). These can include anything from dust to zinc whiskers to chemical contaminants such as gasses and pollutants.

Also covered are the basic characteristics of corrosive gases and more detail regarding methods of removal and risk mitigation for each contaminant type. The chapter also provides valuable information on how to detect various contaminants along with Telcordia GR-63-CORE limits for each chemical. The types of contaminants included are not uncommon, and air quality tests should be a standard part of data center and facilities operations.

Chapter 8 does a good job covering the basic data center design components of the suppression systems and designs for fire detection; raised-floor designs; component selection for ceiling panels, floor tiles, temperature, and humidity controls; air filtration systems and standards; pressurization; IT equipment installation; operational strategies; and site surveys.

## CHAPTER 9: ACOUSTICAL NOISE EMISSIONS

Noise emissions are regulated by OSHA, with different limits applied to different components in a data center. Until recently, noise levels were not a concern, but with increased power loads, the increased cooling requirements have driven noise levels up, primarily as a result of fan noise. For guidelines, refer to the "Sound and Vibration" chapter of the ASHRAE Fundamentals (ASHRAE 2005c). For more information, refer to ISO 7574, ISO 7779, and ISO 9296 standards. OSHA limits are defined in the USDOL 1991 document and the EU Directives (EU 2003). Basically, sound pressure levels are not to exceed 90dB(A) for the US and 87dB(A) for the EU. Most datacom providers set limits closer to 80db(A).

## CHAPTER 10: STRUCTURAL AND SEISMIC

One of the major issues for high-density computing environments, including datacom equipment centers, is weight distribution for floors above ground floor. Chapter 10 provides examples that show how rack loads are distributed, although professional engineering studies are recommended.

The chapter does a good job covering the four basic load factors: concentrated load, uniform load, ultimate load, and rolling load. These factors affect building floor loads and floor tile loading. In addition, it covers the pedestal design element. Lateral stresses are addressed under the seismic loading section, but it should be mentioned that the use of stringers is not optional: a lack of stringers can result in equipment damage if enough consecutive tiles are removed.

## CHAPTER 11: FIRE DETECTION AND SUPPRESSION

This section defines and discusses various types of sensors, including heat sensors, radiant-energy sensors, and smoke sensors. In addition, it outlines the various spaces and zones along with assorted interfaces to



the building maintenance system (BMS) and alert systems. Fire suppression systems have evolved over time to include carbon dioxide (CO<sub>2</sub>) systems, which minimize residuals that may affect equipment. Chapter 11 describes and assesses FM-200 and HFC-227. A more advanced extinguishing system is Inergen, designed to suppress several types of flammable sources. Water-based (wet pipe and dry pipe) systems are discussed, as well as deluge and pre-action sprinkler systems. The chapter also covers a design called water mist (depending on the age and level of contaminants and particulate matter), which uses dielectric fluids that have non-conductive electrical properties.



## CHAPTER 12: COMMISSIONING

Commissioning is a process of load testing mission-critical systems following either data center construction or installation of a major component or subsystem. Refer to the 2003 ASHRAE Handbook – HVAC Applications, chapter 42, “New Building Commissioning” (ASHRAE 2003d).

There are five levels of commissioning, outlined in the book in Table 12.1:

- Level 1 – product testing prior to shipment to the site
- Level 2 – file component verification upon receipt
- Level 3 – field inspections and certifications
- Level 4 – site acceptance testing
- Level 5 – integrated systems testing

## CHAPTER 13: AVAILABILITY AND REDUNDANCY

Datacom equipment centers by design are highly available environments. Their basic design tenants require high levels of power, network, and equipment redundancy. Regarding HVAC systems, very specific designs are required to ensure systems can be properly cooled, particularly during site-level failures.

Due to the high-availability requirements of datacom equipment centers, requirements for fault-tolerant operation have major implications on the facility design and architecture, as well as on its ongoing management. Consequently, discussions around designs that are compliant with NEBS Tier 1 – Tier 4 are a central theme in this book.

Failure mode and effects analysis (FMEA) is a precise process for analyzing system failure modes. This chapter covers well the subject of resource redundancy, with a focus on the cooling infrastructure.

Diversity refers to the use of geographically diverse locations for critical resource delivery such as power and network. Dual feeds alone are not enough to ensure redundancy. With diversity of location, increased levels of availability can be achieved. While all of the above methods are beneficial, human error still remains a great risk.

## CHAPTER 14: ENERGY EFFICIENCY

This chapter covers four basic energy usage metrics: environmental criteria, generation, distribution, and “other measures.” Refer to ASHRAE’s 90.1 (ASHRAE 2004i) for minimum requirements for energy efficiency for almost all non-residential facilities, including data centers. Chapter 2 of ASHRAE’s Thermal Guidelines for Data Processing Environments (ASHRAE 2004h) defines temperature and humidity guidelines.

However, the following relaxation of these guidelines, properly implemented, can provide certain energy efficiency increases:

- Increase thermodynamic efficiency of vapor compression cycles
- Decrease humidification load
- Decrease dehumidification load

This book reviews energy efficiency design considerations related to chilled-water plants, chilled-water pumps, cooling towers, and controls leading to the optimization of CRAC components, CRAC designs, fans, pumps, variable-speed drives, humidification, dehumidification, water-side economizers, and air-side economizers.



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## IV. BOOK 4: LIQUID COOLING GUIDELINES FOR DATACOM EQUIPMENT CENTERS

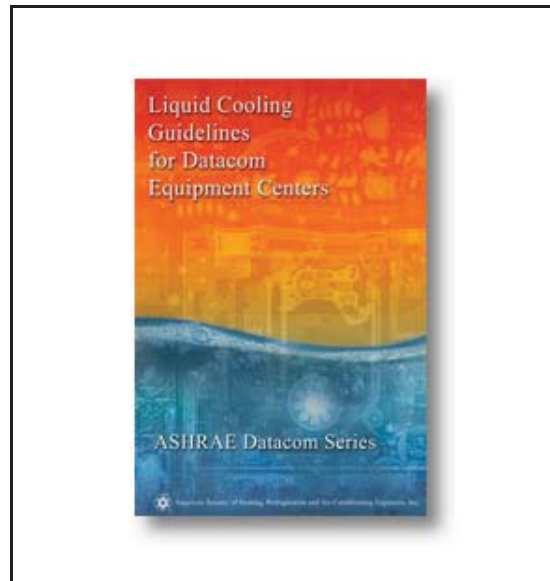


This book provides insight to liquid cooling deployments, from the cooling tower up to and including liquid-cooled IT equipment. It offers guidance, general definitions, and descriptions for various methods of cooling IT equipment using liquid. Many of the practices described in the book may be new to readers who were exposed to the previous generation of liquid-cooled mainframes. Significant content of this book is dedicated to differentiation among the various methods adopted for liquid cooling equipment.

### CHAPTER 1: INTRODUCTION

The reader is introduced to the challenges associated with air cooling and possible benefits derived from liquid cooling. The chapter offers definitions of what is and what is not liquid-cooled IT equipment. It also provides brief descriptions of the various fluid loops of datacom equipment cooling systems (DECS), technology cooling systems (TCS), chilled-water systems (CHWS), and condenser-water systems (CWS). The CHWS and CWS have relevance beyond liquid-cooled IT equipment since they are typical of most chilled water-based cooling systems.

The figure below, found in Chapter 1, describes the various components that comprise one scenario for the thermal transport chain of a liquid cooling architecture.



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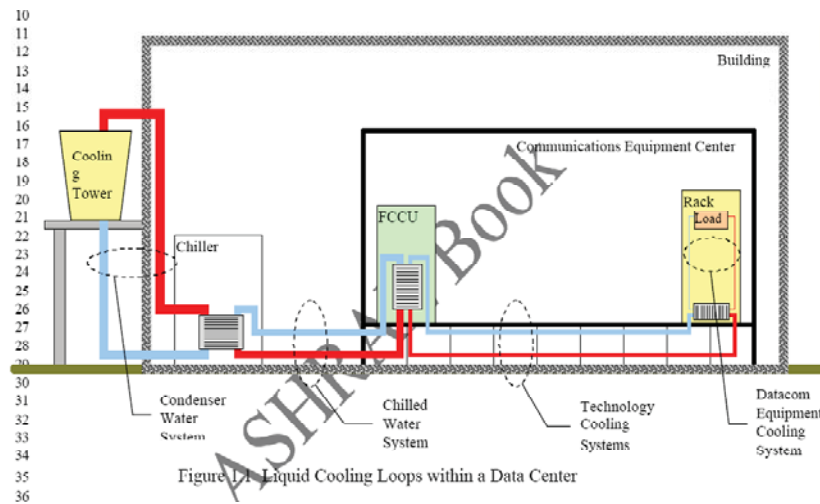


FIGURE 1.1 LIQUID COOLING SYSTEMS/LOOPS WITHIN A DATA CENTER ©2006 ASHRAE

## CHAPTER 2: FACILITY COOLING EQUIPMENT

This chapter discusses key design consideration for data center cooling systems, including flexibility, scalability, ease of installation, commissioning, operation, ease of maintenance/troubleshooting, availability, and reliability. It also offers overviews of chillers, cooling towers, pumps, and energy recovery equipment. The depth of coverage on these topics is limited but may prove beneficial to those who are not already familiar with the various components that make up a mechanical chilled-water plant.



## CHAPTER 3: FACILITY PIPING DESIGN

Chapter 3 discusses piping primarily from a facility-planning perspective. Subject matter for this chapter is divided into five sections: Spatial Consideration, Piping Architecture, Piping Arrangements, Water Treatment and Earthquake Protection. The majority of this chapter is devoted to piping architectures and arrangements. A comprehensive overview of the various piping schemas deployed within commercial chilled-water distribution systems is provided. Sections on water treatment and earthquake protection are adequate to make the reader aware of such considerations but are less comprehensive.

## CHAPTER 4: LIQUID COOLING IMPLEMENTATION FOR DATACOM EQUIPMENT

This chapter discusses a variety of physical and thermal arrangements for the various methods of liquid cooling datacom equipment. Methods covered include traditional air-cooled, hybrid (air- and liquid-cooled), and completely liquid-cooled. The text is complemented with a variety of figures that clearly illustrate key attributes of the various methods. The final section of this chapter introduces the coolant distribution unit (CDU) and clearly establishes its operation and benefits (water volume, temperature, pressure, and quality).

## CHAPTER 5: LIQUID COOLING INFRASTRUCTURE REQUIREMENTS FOR CHILLED-WATER SYSTEMS

In Chapter 5, the reader is introduced to the concept of demarcation between the facility side and the IT side of the liquid cooling solution. Accordingly, this chapter is primarily devoted to the facility side of the demarcation point. It discusses water-quality issues, including velocity, fouling, water chemistry, and biological and wetted material compatibility, along with some quantitative tables. It also depicts idealized piping layouts to promote architectures that facilitate ease of connecting liquid-cooled IT equipment. This chapter also discusses the effects of various subsystems such as pumps, fans, controls, and heat exchangers on reliability and availability. A brief overview of a non-chilled-water-based solution for liquid cooling of IT equipment is given at the end of the chapter. The reader is exposed to the use of refrigerant-based, direct expansion (DX) as a possible alternative to chilled water to support TCS and DECS.

## CHAPTER 6: LIQUID COOLING INFRASTRUCTURE REQUIREMENTS FOR TECHNOLOGY COOLING SYSTEMS

This chapter covers general consideration for TCS, focused primarily on field piping between the CDU and datacom equipment. Many of the considerations from Chapter 5 are repeated, but with an IT perspective.

**APPENDIX:** The appendix summarizes key water-quality attributes collected from a number of datacom facilities. It is noted that all facilities surveyed were able to achieve desired water quality after implementation of a water-treatment program.

## V. BOOK 5: BEST PRACTICES FOR DATACOM FACILITY ENERGY EFFICIENCY



This book provides detailed information on the design of datacom facilities to maximize energy efficiency. It covers many aspects of datacom facility energy efficiency, including environmental criteria, mechanical equipment and systems, economizer cycles, airflow distribution, HVAC controls and energy management, electrical distribution equipment, datacom equipment efficiency, liquid cooling, total cost of ownership (TCO), and emerging technologies. The appendices discuss facility commissioning, operations and maintenance, and the telecom facility experience.

### CHAPTER 1: INTRODUCTION

This chapter states the purpose/objective of the book, defines key terms, and includes a brief overview of the chapters.

### CHAPTER 2: ENVIRONMENTAL CRITERIA

The environmental conditions inside and outside a facility have a significant impact on the choice of an energy-efficient cooling system. This chapter provides an overview of data center design conditions and compares these conditions to ASHRAE criteria to demonstrate how following the criteria can result in increased energy efficiency. It also describes recommendations that have the greatest impact on datacom facility energy consumption.

### CHAPTER 3: MECHANICAL EQUIPMENT AND SYSTEMS

This chapter reviews cooling and humidity control equipment and systems, and it summarizes pertinent design considerations to aid in the selection of energy-efficient systems. Types of equipment covered include chillers, CRAC units, humidification equipment, and heat-rejection equipment. Types of systems covered include air-cooled, water-cooled, and evaporative-cooled systems.

### CHAPTER 4: ECONOMIZERS

Chapter 4 discusses economizer cycles and how they can be used for substantial energy savings and increased TCO in datacom facilities. The chapter also includes discussions of both outdoor air economizer cycles and water economizer cycles, as well as things to consider when choosing an economizer.

### CHAPTER 5: AIRFLOW DISTRIBUTION

The air distribution design in a data center is non-trivial. A substantial percentage of energy costs in an air-cooled data center is associated with air distribution. This chapter identifies air distribution parameters affecting energy consumption and discusses ways to increase energy efficiency. Among the topics covered are best practices methods of airflow delivery, the effect of supply air temperatures, airflow within racks, leakage, and airflow optimization.

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**CHAPTER 6: CONTROLS AND ENERGY MANAGEMENT**

Control and energy management systems are key components of an energy-efficient data center. This chapter covers control systems that have an impact on energy-efficient operations. Subjects include control system architecture, the risks and benefits of using economizers, increasing the chilled-water supply and/or air temperatures, and developing an efficient part-load operation sequence for the central cooling plant.

**CHAPTER 7: ELECTRICAL DISTRIBUTION EQUIPMENT**

Studies have identified electrical distribution systems as a significant source of energy loss. This chapter identifies these losses and discusses approaches that can increase the efficiency of electrical distribution. The chapter starts with a brief discussion of utility generation and continues with facility distribution, including an AC and DC overview. Also included are distribution paths, energy efficiency options such as reduction in amperage and harmonics, and component efficiencies of uninterruptible power supplies (UPSs) and transformers.

**CHAPTER 8: DATACOM EQUIPMENT EFFICIENCY**

This chapter discusses many issues related to datacom equipment energy efficiency. Datacom equipment is continuing to become more energy efficient via more efficient power supplies and voltage regulators, lower-power processors, and increasingly sophisticated power management. Since datacom equipment needs electrical distribution and cooling infrastructure to support the resulting heat load, efficiency improvements at this base level also will reduce energy use in the distribution system and mechanical plant.

**CHAPTER 9: LIQUID COOLING**

Liquid cooling equipment and installations are becoming more common, primarily in response to increasing power density and the need to provide a compact cooling infrastructure. This chapter reviews the energy efficiency and TCO of liquid cooling. It discusses considerations related to open- or closed-cooling architecture, water, refrigerant or dielectric cooling fluid, and TCO.

**CHAPTER 10: TCO**

Total cost of ownership is a broad tool that can be used to design datacom facilities in an efficient and cost-effective manner. This chapter starts by defining TCO and then discusses its applicability for making design decisions in the datacom industry. It discusses the most important capital and operational components of a TCO model and provides advice on what to include in models.

**CHAPTER 11: EMERGING TECHNOLOGIES AND FUTURE RESEARCH**

This chapter presents a listing of some emerging technologies that may have an impact on energy efficiency in datacom facilities. It also makes suggestions for future research.



## VI. BOOK 6: STRUCTURAL AND VIBRATION GUIDELINES FOR DATACOM EQUIPMENT CENTERS



This book discusses, in a holistic way, the structural aspects of housing the servers, storage, tape drives, and network equipment (datacom equipment) within the datacom equipment center. Datacom equipment center engineers must consider the structural and vibration performance of the facility, the building infrastructure, and the contents (datacom equipment). As the datacom equipment density increases (compaction), the datacom power and cooling infrastructure becomes larger, heavier, and inherently more structurally challenging.

With the datacom equipment itself becoming heavier and expectations growing that the facility will house more datacom equipment, the structural and vibration performance of the facility is becoming more and more important. Increased structural resistance against high wind, snow, and seismic loads may be required.

The typical replacement rate of servers, storage, tape drives, and network equipment (datacom equipment) is often 3 to 5 years, while the anticipated lifespan of the supporting mechanical and electrical infrastructure is 15 to 20 years. Consequently, the datacom building structure may house many vintages of datacom equipment over its lifetime. Structural design criteria must consider future requirements.

High-performance data center facilities accommodate a variety of complex and sensitive datacom equipment that is vulnerable to internal and external sources of shock and vibration. Shock and vibration are unwanted forces found at some level in most datacom facilities. Over time, they can degrade both facilities and equipment. Isolation design and techniques typically require assumptions as to ground-motion amplitudes, frequencies, and additional space for the device displacement.

This book describes guidelines for monitoring the level of vibration within the datacom facility and methods for mitigating vibration's effect on the datacom equipment. For example, it discusses numerical simulation, which is one method for evaluating the structural requirements for datacom equipment itself. The book also examines efforts to resist seismic loads, such as systems that anchor datacom equipment to the datacom center as well as techniques to stiffen the datacom equipment.

The intended audience for this publication includes both technical and nontechnical readers. Those involved in the design, construction, commission, operation, implementation, and maintenance of datacom equipment centers all can benefit from this book. In addition, equipment operators, IT departments, chief information



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officers, and those who develop and/or design electronic, cooling, and other infrastructure equipment will benefit from its guidelines.

This book is divided into four parts. Part 1 includes an overview of the book and a summary of the best practices. Part 2, Building Structure, includes chapters on new and existing building structures as well as types of building structures. In Part 3, Building Infrastructure, raised-access floor systems and vibration sources and control are discussed in detail. Part 4, Datacom Equipment, includes chapters on shock and vibration testing, seismic anchorage, and analysis of such systems. For datacom professionals, this book will provide basic guidelines on which seismic anchorage should be used for datacom equipment. The book's appendices provide guidelines for floor loading calculations as well as what type of operational vibration is expected in a data center.



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## VII. BOOK 7: HIGH DENSITY DATA CENTERS - CASE STUDIES AND BEST PRACTICES

This book reviews the seven primary ventilation schemes commonly used in data centers. The measured data in this book's case studies can be used by data center planners and managers to do theoretical construction and modeling for benchmarking against other data centers and to assist in the planning process. The strategy for using this book in a new data center is to start a Thermal Profile around the concepts and recommendations provided as the data center is being built.



### CHAPTER 1: INTRODUCTION

The introduction provides a quick overview and easy-to-understand diagrams of seven different ventilation schemes. For each scheme described, there are several real-world case studies from live data centers in which the scheme was tested for airflow, power, and temperature. The results of each case study are presented in a uniform format to make comparisons with the other studies as accurate as possible.

### CHAPTER 2: RAISED-ACCESS FLOOR CASE STUDIES

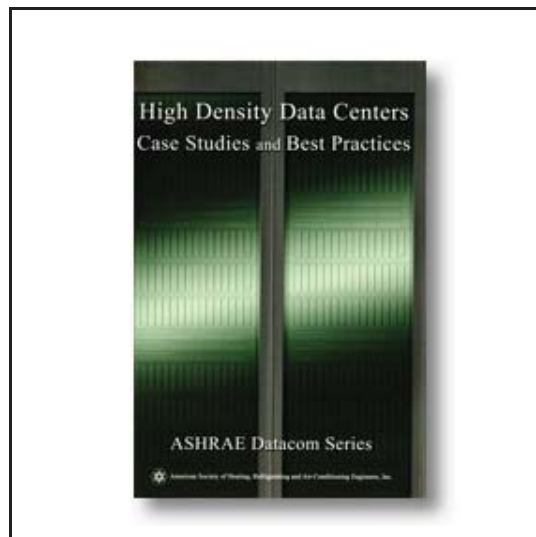
Chapter 2 includes discussions on perimeter CRAC cooling schemes where CRAC units are located within the data center space and on the outside walls and where they deliver conditioned air through a raised floor. For each of the case studies presented, this chapter extensively explains all of the environmental measurements captured, the tools and processes used, and when estimation by other means was used. According to the book, the key IT equipment health indicator is the inlet temperature; the majority of the studies included focus on this point. At the end of each case study, there is a Thermal Profile for the data center that provides the reader with an excellent tool for comparisons between data centers.

This chapter discusses the following cooling schemes:

- Raised-Access Floor with Air-Handling Units (AHUs) on Subfloor
- Raised-Access Floor Supply/Ceiling Return
- Raised-Access Floor with Heat Exchangers Adjacent to Server Racks
- Cooling within the In-Row Rack
- Raised-Access Floor with Heat Exchangers Over Server Racks
- Raised-Access Floor with Underfloor Supply/Ducted Ceiling Return

### CHAPTER 3: NON-RAISED-ACCESS FLOOR CASE STUDIES

These two case studies do not compare the pros and cons of raised-floor versus non-raised-floor cooling schemes; rather, they offer some best practice suggestions for non-raised-floor environments. Then, for comparative purposes, readers are encouraged to develop their own profiles, using the performance data



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and suggested practices to enhance the efficiency of their own data center environments. One configuration utilizes up-flow CRACs with constant-speed AHUs supplied and chilled water from a chiller plant. Another configuration described is ceiling-mounted fan coil units (FCUs) with chilled water from the chiller plant and an overhead duct and grill system.

#### **CHAPTER 4: BEST PRACTICES**

This chapter covers data center design best practices. To meet IT needs and future growth plans, data center managers are encouraged to carefully evaluate the available options and to know what questions to ask to complete a thorough evaluation—before selecting a cooling scheme. The chapter provides recommended basic questions and today’s best practices to consider when designing a data center.



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## CREDITS

The Technology and Strategy Work Group of The Green Grid would like to acknowledge contributions from the following individuals in the creation of this document: John Bean, Ron Bednar, Rich Jones, Robb Jones, Phil Morris, Budy Notohardjono, Mike Patterson, Wade Vinson, and John Wallerich. The Green Grid also wishes to acknowledge the help of ASHRAE's TC9.9 in reviewing this document.

## ABOUT THE GREEN GRID™



The Green Grid is a global consortium of companies dedicated to advancing energy efficiency in data centers and computing ecosystems. The Green Grid does not endorse any vendor-specific products or solutions, and will seek to provide industry-wide recommendations on best practices, metrics and technologies that will improve overall data center energy efficiencies. Membership is open to companies interested in data center operational efficiency at the Contributing or General Member level. General members attend and participate in general meetings of The Green Grid, review proposals for specifications and have access to specifications for test suites and design guidelines and IP licensing. Additional benefits for contributor members include participation and voting rights in committees and working groups. Additional information is available at [www.thegreengrid.org](http://www.thegreengrid.org)