

SECOND EDITION

# DATA CENTER HANDBOOK

PLAN, DESIGN, BUILD, AND OPERATIONS OF A SMART DATA CENTER

HWAIYU GENG P.E



WILEY



# **DATA CENTER HANDBOOK**



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## Plan, Design, Build, and Operations of a Smart Data Center

Second Edition

**HWAIYU GENG, P.E.**

Amica Research

Palo Alto, California, United States of America

**WILEY**

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*To “Our Mothers Who Cradle the World” and To “Our Earth Who Gives Us Life.”*





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# FOREWORD (1)

The digitalization of our economy requires data centers to continue to innovate to meet the new needs for connectivity, growth, security, innovation, and respect for the environment demanded by organizations. Every phase of life is putting increased pressure on data centers to innovate at a rapid pace. Explosive growth of data driven by 5G, Internet of Things (IoT), and Artificial Intelligence (AI) is changing the way data is stored, managed, and transferred. As this volume grows, data and applications are pulled together, requiring more and more computing and storage resources. The question facing data center designers and operators is how to plan for the future that accomplishes the *security, flexibility, scalability, adaptability, and sustainability needed* to support business requirements.

With this explosion of data, companies need to think more carefully and strategically about how and where their data is stored, and the security risks involved in moving data. The sheer volume of data creates additional challenges in protecting it from intrusions. This is probably one of the most important concerns of the industry – how to protect data from being hacked and being compromised in a way that would be extremely damaging to their core business and the trust of their clients.

Traditional data centers must deliver a degree of *scalability* to accommodate usage needs. With newer technologies and applications coming out daily, it is important to be able to morph the data center into the needs of the business. It is equally important to be able to integrate these technologies in a timely manner that does not compromise the strategic plans of the business. With server racks getting denser every few years, the rest of the facility must be prepared to support an ever increasing power draw. A data center built over the next decade must be expandable to accommodate for future technologies, or risk running out of room for support

infrastructure. Server rooms might have more computing power in the same area, but they will also need more power and cooling to match. Institutions are also moving to install advanced applications and workloads related to AI, which requires high-performance computing. To date, these racks represent a very small percentage of total racks, but they nevertheless can present unfamiliar power and cooling challenges that must be addressed. The increasing interest in direct liquid cooling is in response to high-performance computing demands.

5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices. It will require more bandwidth, faster speeds, and lower latency, and the data center infrastructure must be *flexible and adaptable* in order to accommodate these demands. With the need to bring computing power closer to the point of connectivity, the end user is driving demand for edge data centers. Analyzing the data where it is created rather than sending it across various networks and data centers helps to reduce response latency, thereby removing a bottleneck from the decision-making process. In most cases, these data centers will be, remotely managed and unstaffed data centers. Machine learning will enable real-time adjustments to be made to the infrastructure without the need for human interaction.

With data growing exponentially, data centers may be impacted by significant increases in energy usage and carbon footprint. Hyperscalers have realized this and have increasingly used more and more *sustainable* technologies. This trend will cause others to follow and adopt some of the building technologies and use of renewables for their own data centers. The growing mandate for corporations to shift to a greener energy footprint lays the groundwork for new approaches to data center power.

The rapid innovations that are occurring inside (edge computing, liquid cooling, etc.) and outside (5G, IoT, etc.) of data centers will require careful and thoughtful analysis to design and operate a data center for the future that will serve the strategic imperatives of the business it supports. To help address the complex environment with competing forces, this second edition of the Data Center Handbook has assembled by leaders in the industry and academia to share

their latest thinking on these issues. This handbook is the most comprehensive guide available to data center practitioners as well as academia.

Roger R. Schmidt, Ph.D.  
Member, National Academy of Engineering  
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## FOREWORD (2)

A key driver of innovation in modern industrial societies in the past two centuries is the application of what researchers call “general purpose technologies,” which have far-ranging effects on the way the economy produces value. Some important examples include the steam engine, the telegraph, the electric power grid, the internal combustion engine, and most recently, computers and related information and communications technologies (ICTs).

ICTs represent the most powerful general-purpose technologies humanity has ever created. The pace of innovation across virtually all industries is accelerating, which is a direct result of the application of ICTs to increase efficiency, enhance organizational effectiveness, and reduce costs of manufacturing products. Services provided by data centers enable virtually all ICTs to function better.

This volume presents a comprehensive look at the current state of the data center industry. It is an essential resource for those working in the industry, and for those who want to understand where it is headed.

The importance of the data center industry has led to many misconceptions, the most common of which involves inflated estimates of how much electricity data centers use. The latest credible estimates for global electricity use of data centers are for 2018, from our article in *Science Magazine* in February 2020 (Masanet et al. 2020).

According to this analysis, data centers used about 0.9% of the world’s electricity consumption in 2018 (down from 1.1%

in 2010). Electricity use grew only 6% even as the number of compute instances, data transfers, and total data storage capacity grew to be 6.5 times, 11 times, and 26 times as large in 2018 as each was in 2010, respectively.

The industry was able to keep data center electricity use almost flat in absolute terms from 2010 to 2018 because of the adoption of best practices outlined in more detail in this volume. The most consequential of these best practices was the rapid adoption of hyperscale data centers, known colloquially as cloud computing. Computing output and data transfers increased rapidly, but efficiency also increased rapidly, almost completely offsetting growth in demand for computing services.

For those new to the world of data centers and information technology, this lesson is surprising. Even though data centers are increasingly important to the global economy, they don’t use a lot of electricity in total, because innovation has rapidly increased their efficiency over time. If the industry aggressively adopts the advanced technologies and practices described in this volume, they needn’t use a lot of electricity in the future, either.

I hope analysts and practitioners around the world find this volume useful. I surely will!

Jonathan Koomey, Ph.D.,  
President, Koomey Analytics  
Bay Area, California



## FOREWORD (3)

The data center industry changes faster than any publication can keep up with. So why the “Data Center Handbook”? There are many reasons, but three stand out. First, fundamentals have not changed. Computing equipment may have dramatically transformed in processing power and form factor since the first mainframes appeared, but it is still housed in secure rooms, it still uses electricity, it still produces heat, it must still be cooled, it must still be protected from fire, it must still be connected to its users, and it must still be managed by humans who possess an unusual range of knowledge and an incredible ability to adapt to fast changing requirements and conditions. Second, new people are constantly entering what, to them, is this brave new world. They benefit from having grown up with a computer (i.e., “smart phone”) in their hands, but are missing the contextual background behind how it came to be and what is needed to keep it working. Whether they are engineers designing their first enterprise, edge computing, hyperscale or liquid cooled facility, or IT professionals given their first facility or system management assignment within it, or are students trying to grasp the enormity of this industry, having a single reference book is far more efficient than plowing through the hundreds of articles published in multiple places every month. Third, and perhaps even more valuable in an industry that changes so rapidly, is having a volume that also directs you to the best industry resources when more or newer information is needed.

The world can no longer function without the computing industry. It’s not regulated like gas and electric, but it’s as critical as any utility, making it even more important for the IT industry to maintain itself reliably. When IT services fail, we are even more lost than in a power outage. We can use candles to see, and perhaps light a fireplace to stay warm. We can even make our own entertainment! But if we can’t get critical news, can’t pay a bill on time, or can’t even make a critical phone call, the world as we now know it comes to a

standstill. And that’s just the personal side. Reliable, flexible, and highly adaptable computing facilities are now necessary to our very existence. Businesses have gone bankrupt after computing failures. In health care and public safety, the availability of those systems can literally spell life or death.

In this book you will find chapters on virtually every topic you could encounter in designing and operating a data center – each chapter written by a recognized expert in the field, highly experienced in the challenges, complexities, and eccentricities of data center systems and their supporting infrastructures. Each section has been brought up-to-date from the previous edition of this book as of the time of publication. But as this book was being assembled, the COVID 19 pandemic occurred, putting unprecedented demands on computing systems overnight. The industry reacted, proving beyond question its ability to respond to a crisis, adapt its operating practices to unusual conditions, and meet the inordinate demands that quickly appeared from every industry, government, and individual. A version of the famous Niels Bohr quote goes, “An expert is one who, through his own painful experience, has learned all the mistakes in a given narrow field.” Adherence to the principles and practices set down by the authors of this book, in most cases gained over decades through their own personal and often painful experiences, enabled the computing industry to respond to that crisis. It will be the continued adherence to those principles, honed as the industry continues to change and mature, that will empower it to respond to the next critical situation. The industry should be grateful that the knowledge of so many experts has been assembled into one volume from which everyone in this industry can gain new knowledge.

Robert E. McFarlane  
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# PREFACE DATA CENTER HANDBOOK (SECOND EDITION, 2021)

As Internet of Things, data analytics, artificial intelligence, 5G, and other emerging technologies revolutionize the services and products companies, the demand for computing power grows along the value chain between edge and cloud. Data centers need to improve and advance continuously to fulfill this demand.

To meet the megatrends of globalization, urbanization, demographic changes, technology advancements, and sustainability concerns, C-suite executives and technologists must work together in preparing strategic plans for deploying data centers around the world. Workforce developments and the redundancy of infrastructures required between edge and cloud need to be considered in building and positioning data centers globally.

Whether as a data center designer, user, manager, researcher, professor, or student, we all face increasing challenges in a cross-functional environment. For each data center project, we should ask, what are the goals, and work out “How to Solve It.”<sup>1</sup> To do this, we can employ a 5W1H<sup>2</sup> approach applying data analytics and nurture the creativity that is needed for invention and innovation. Additionally, a good understanding of the anatomy, ecosystem, and taxonomy, of a data center will help us master and solve this complex problem.

The goal of this *Data Center Handbook* is to provide readers with the essential knowledge that is needed to plan, build, and operate a data center. This handbook embraces

both emerging technologies and best practices. The handbook is divided into four parts:

Part I: *Data Center Overview and Strategic Planning* that provides an overview of data center strategic planning, while considering the impact of emerging technologies. This section also addresses energy demands, sustainability, edge to cloud computing, financial analysis, and managing data center risks.

Part II: *Data Center Technologies* that covers technologies applicable to data centers. These include software-defined applications, infrastructure, resource management, ASHRAE<sup>3</sup> thermal guidelines, design of energy-efficient IT equipment, wireless sensor network, telecommunication, rack level and server level cooling, data center corrosion and contamination control, cabling, cybersecurity, and data center microgrids.

Part III: *Data Center Design and Construction* that discusses plan, design, and construction of a data center that includes site selection, facility layout and rack floor plan, mechanical design, electrical design, structural design, fire protection, computational fluid dynamics, and project management for construction.

Part IV: *Data Center Operations* that covers data center benchmarking, data center infrastructure management (DCIM), energy efficiency assessment, and AI applications for data centers. This section also reviews lessons imparted from disasters, and includes mitigation strategies to ensure business continuity.

<sup>1</sup> Polya, G. *How to Solve It*. Princeton: Princeton University Press; 1973.

<sup>2</sup> The 5W1H are “Who, What, When, Where, Why, and How.”

<sup>3</sup> ASHRAE is the American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Containing 453 figures, 101 tables and 17 pages in the index section, this second edition of *Data Center Handbook* is a single-volume, comprehensive guide to this field. The handbook covers the breadth and depth of data center technologies, and includes the latest updates from this fast-changing field. It is meant to be a relevant, practical, and

enlightening resource for global data center practitioners, and will be a useful reference book for anyone whose work requires data centers.

Hwaiyu Geng, CMfgE, P.E.  
Palo Alto, California, United States of America



# PREFACE DATA CENTER HANDBOOK (FIRST EDITION, 2015)

Designing and operating a sustainable data center (DC) requires technical knowledge and skills from strategic planning, complex technologies, available best practices, optimum operating efficiency, disaster recovery, and more.

Engineers and managers all face challenges operating across functionalities, for example, facilities, IT, engineering, and business departments. For a mission-critical, sustainable DC project, we must consider the following:

- What are the goals?
- What are the givens?
- What are the constraints?
- What are the unknowns?
- Which are the feasible solutions?
- How is the solution validated?

How does one apply technical and business knowledge to develop an optimum solution plan that considers emerging technologies, availability, scalability, sustainability, agility, resilience, best practices, and rapid time to value? The list can go on and on. Our challenges may be as follows:

- To prepare a strategic location plan
- To design and build a mission-critical DC with energy-efficient infrastructure
- To apply best practices thus consuming less energy
- To apply IT technologies such as cloud and virtualization and
- To manage DC operations thus reducing costs and carbon footprint

A good understanding of DC components, IT technologies, and DC operations will enable one to plan, design, and imple-

ment mission-critical DC projects successfully. The goal of this handbook is to provide DC practitioners with essential knowledge needed to implement DC design and construction, apply IT technologies, and continually improve DC operations. This handbook embraces both conventional and emerging technologies, as well as best practices that are being used in the DC industry. By applying the information contained in the handbook, we can accelerate the pace of innovations to reduce energy consumption and carbon emissions and to “Save Our Earth Who Gives Us Life.”

The handbook covers the following topics:

- DC strategic planning
- Hosting, colocation, site selection, and economic justifications
- Plan, design, and implement a mission-critical facility
- IT technologies including virtualization, cloud, SDN, and SDDC
- DC rack layout and MEP design
- Proven and emerging energy efficiency technologies
- DC project management and commissioning
- DC operations
- Disaster recovery and business continuity

Each chapter includes essential principles, design, and operations considerations, best practices, future trends, and further readings. The principles cover fundamentals of a technology and its applications. Design and operational considerations include system design, operations, safety, security, environment issues, maintenance, economy, and best practices. There are useful tips for planning, implementing, and controlling operational processes. The future trends and further reading sections provide visionary views

and lists of relevant books, technical papers, and websites for additional reading.

This *Data Center Handbook* is specifically designed to provide technical knowledge for those who are responsible for the design, construction, and operation of DCs. It is also useful for DC decision makers who are responsible for strategic decisions regarding capacity planning and technology investments. The following professionals and managers will find this handbook to be a useful and enlightening resource:

- C-level Executives (Chief Information Officer, Chief Technology Officer, Chief Operating Officer, Chief Financial Officer)
- Data Center Managers and Directors
- Data Center Project Managers
- Data Center Consultants
- Information Technology and Infrastructure Managers
- Network Operations Center and Security Operations Center Managers
- Network, Cabling, and Communication Engineers
- Server, Storage, and Application Managers
- IT Project Managers
- IT Consultants
- Architects and MEP Consultants
- Facilities Managers and Engineers
- Real Estate Portfolio Managers
- Finance Managers

This *Data Center Handbook* is prepared by more than 50 world-class professionals from eight countries around the world. It covers the breadth and depth of DC planning, designing, construction, and operating enterprise, government, telecommunication, or R&D Data Centers. This *Data Center Handbook* is sure to be the most comprehensive single-source guide ever published in its field.

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# ACKNOWLEDGEMENTS

## DATA CENTER HANDBOOK (SECOND EDITION, 2021)

*The Data Center Handbook* is a collective representation of an international community with scientists and professionals comprising 58 experts from six countries around the world.

I am very grateful to the members of the Technical Advisory Board for their diligent reviews of this handbook, confirming technical accuracy while contributing their unique perspectives. Their guidance has been invaluable to ensure that the handbook can meet the needs of a broad audience.

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- Data Center Dynamics
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- European Commission Code of Conduct
- Federal Energy Management Program (the U.S. Dept. of Energy)
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- IDC (International Data Corporation)
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- McKinsey Global Institute
- Mission Critical Magazine
- NIST (the U.S. Dept. of Commerce, National Institute of Standards and Technology)

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## DATA CENTER HANDBOOK (FIRST EDITION, 2015)

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