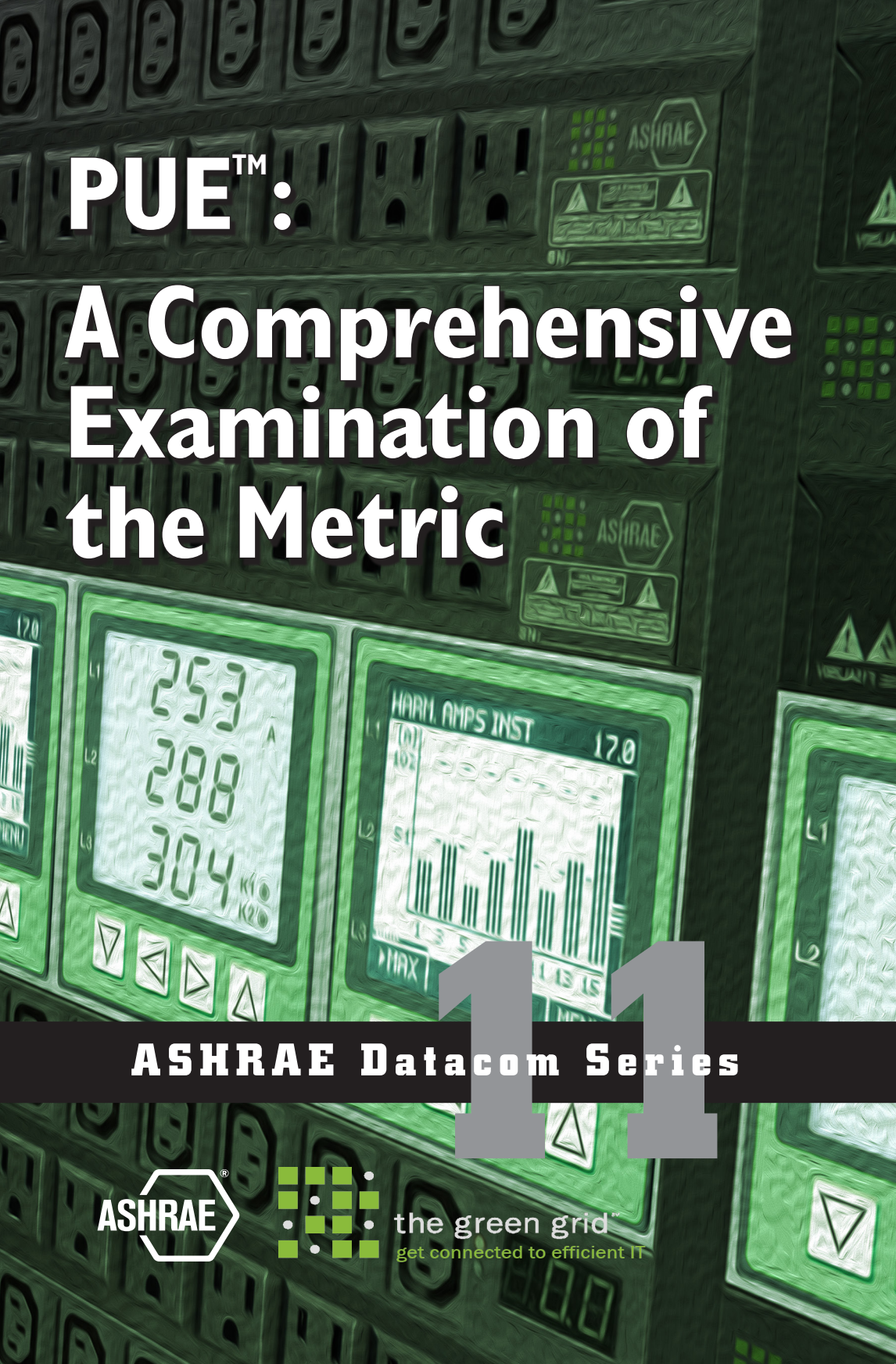

PUE™:
A Comprehensive Examination of the Metric
ASHRAE Datacom Series
11
ASHRAE
the green grid
get connected to efficient IT

PUE™: A Comprehensive Examination of the Metric

This publication was prepared by The Green Grid Association and ASHRAE TC 9.9, Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment.

For more information on the ASHRAE Datacom Series, visit
www.ashrae.org/datacenterefficiency.

Any updates/errata to this publication will be posted on the ASHRAE website at www.ashrae.org/publicationupdates.

PUE™: A Comprehensive Examination of the Metric

ASHRAE Datacom Series
Book 11

1791 Tullie Circle, NE
Atlanta, GA 30329
www.ashrae.org

3855 SW 153rd Drive
Beaverton, OR 97006
www.thegreengrid.org

ISBN 978-1-936504-60-2

© 2014 ASHRAE and The Green Grid
1791 Tullie Circle, NE
Atlanta, GA 30329
www.ashrae.org

All rights reserved.
Printed in the United States of America

Cover image by Joe Lombardo of DLB Associates.

ASHRAE is a registered trademark in the U.S. Patent and Trademark Office, owned by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE has compiled this publication with care, but ASHRAE has not investigated, and ASHRAE expressly disclaims any duty to investigate, any product, service, process, procedure, design, or the like that may be described herein. The appearance of any technical data or editorial material in this publication does not constitute endorsement, warranty, or guaranty by ASHRAE of any product, service, process, procedure, design, or the like. ASHRAE does not warrant that the information in the publication is free of errors, and ASHRAE does not necessarily agree with any statement or opinion in this publication. The entire risk of the use of any information in this publication is assumed by the user.

No part of this publication may be reproduced without permission in writing from ASHRAE, except by a reviewer who may quote brief passages or reproduce illustrations in a review with appropriate credit, nor may any part of this publication be reproduced, stored in a retrieval system, or transmitted in any way or by any means—electronic, photocopying, recording, or other—without permission in writing from ASHRAE. Requests for permission should be submitted at www.ashrae.org/permissions.

Library of Congress Cataloging-in-Publication Data

PUE : a comprehensive examination of the metric.
pages cm -- (ASHRAE datacom series ; book 11)
Includes bibliographical references.
Summary: "Simplifies the absorption and use of the PUE metric and allows executives to gain understanding of the concepts surrounding PUE, while providing application knowledge and resources to those implementing and reporting data center metrics"-- Provided by publisher.
ISBN 978-1-936504-60-2 (softcover)
1. Data processing service centers--Energy consumption--Measurement. I. American Society of Heating, Refrigerating and Air-Conditioning Engineers. II. Title: Power usage effectiveness.
TJ163.5.D38P84 2013
658.2'7--dc23

2013041943

ASHRAE Staff

Special Publications
Mark S. Owen, *Editor/Group Manager of Handbook and Special Publications*
Cindy Sheffield Michaels, *Managing Editor*
James Madison Walker, *Associate Editor*
Roberta Hirschbuehler, *Assistant Editor*
Sarah Boyle, *Assistant Editor*
Michshell Phillips, *Editorial Coordinator*

Publishing Services
David Soltis, *Group Manager of Publishing Services and Electronic Communications*
Jayne Jackson, *Publication Traffic Administrator*
Tracy Becker, Graphics Specialist

Publisher
W. Stephen Comstock

Contributors

ABOUT THE GREEN GRID

The Green Grid Association is a nonprofit, open industry consortium of end users, policy makers, technology providers, facility architects, and utility companies that work to improve the resource efficiency of information technology and data centers throughout the world. With its member organizations around the world, The Green Grid seeks to unite global industry efforts, create a common set of metrics, and develop technical resources and educational tools to further its goals. Additional information is available at www.thegreengrid.org.

ABOUT ASHRAE TECHNICAL COMMITTEE (TC) 9.9

ASHRAE TC 9.9, Mission Critical Facilities, Data Centers, Technology Spaces and Electronic Equipment is concerned with the design, operations, maintenance, and efficient energy usage of modern data centers and technology spaces. Along with the explosive growth of connected technologies (e.g., the Internet, mobile phones, etc.), the high-power density of electronic equipment has also been steadily increasing in recent years. In addition, the mission-critical nature of computing has sensitized businesses to the health of their data centers. The combination of these effects has made it obvious that better alignment is needed between equipment manufacturers and facility operations personnel to ensure proper and fault tolerant operation within mission critical environments.

To address these concerns, TC 9.9 was formed. The committee is composed of a wide range of industry representatives including equipment manufacturers, consulting engineers, data center operators, academics, testing laboratory workers, government officials, and others, all of whom are committed to increasing and sharing the body of knowledge related to data centers. Additional information is available at www.ashrae.org.

The Green Grid Association would like to thank the following people for contributing to this and other PUE-related materials over the last several years.

Hugh Barrass
Cisco

Christian Belady
Microsoft

Stephen Berard
Microsoft

Mark Bramfitt
PG&E

Tahir Cader
Hewlett-Packard

Henry Coles
Lawrence Berkeley
National Laboratory

Jud Cooley
Oracle

Tommy Darby
TI

John Pflueger
Dell

Jamie Froedge
Emerson Network Power

Nick Gruendler
IBM

Jon Haas
Intel

Eric Jewitt
Nationwide

Christine Long
APC

Bob MacArthur
EMC

Phil Morris
Sun Microsystems

Zeydy Ortiz
IBM

Andy Rawson
AMD

Jim Simonelli
APC

Harkeeret Singh
BT

Roger Tipley
Hewlett-Packard

Robert Tozer
Hewlett-Packard

Gary Verdun
Dell

John Wallerich
Intel

Randall Wofford
Dell

Lex Coors
Interxion

ASHRAE TC 9.9 would like to thank the following people for contributing to this publication.

Don Beaty
DLB Associates

David Quirk
Tieche Engineered Systems

Robin Steinbrecher
Intel

Roger Schmidt
IBM

Greg Jeffers
McKenney's Inc.

Jack Glass
Citigroup

Editors

Victor Avelar
Schneider Electric

Dan Azevedo
Walt Disney Comany

Alan French
Emerson Netowork Power

Contents

Contributors v

Preface ix

Chapter 1 Introduction 1

Chapter 2 Metric List and Intended Use 5

Chapter 3 An Overview of PUE 7

3.1 PUE Definition 7

Chapter 4 More about PUE 9

4.1 PUE Calculation Considerations 10
4.2 PUE Measurement Levels 11
4.3 Component Classification 14
4.4 Measuring Energy Usage 14
4.5 Factors Affecting PUE 21
4.6 Sometimes PUE Seems to Go the Wrong Way 23
4.7 Improving PUE 23
4.8 Participants in and Influences on the Development of PUE 24
4.9 Source Energy 25
4.10 Energy or Power 26

Chapter 5 Example Calculations—How to Measure PUE 29

5.1 How to Measure PUE in a Dedicated Data Center Facility 29
5.2 How to Measure PUE in a Mixed-Use Building 34

Chapter 6 How to Report PUE 41

6.1 Requirements for the Acknowledgement or Registration of PUE Results 42
6.2 PUE Nomenclature 43

6.3 Supporting Data Required for Reported, Registered, and Certified PUE Measurements 45
6.4 Additional Details on Pue Reporting Guidelines 47
6.5 Reporting Results to TGG 47
6.6 Common Issues with Reporting or Interpreting PUE. 48

Chapter 7 Partial PUE. 51

7.1 Definition of Partial PUE 52
7.2 Mathematical Relationship to PUE 53

Chapter 8 PUE Scalability and Statistical Analysis. 61

8.1 Proportional Data Center Power Scalability 61
8.2 Determining Actual PUE Scalability 62
8.3 Statistical Analyses Of Data 63
8.4 PUE Scalability 66
8.5 Interpreting PUE Scalability. 68

Chapter 9 Conclusion 71

Glossary of Terms 73

References and Bibliography 77

Preface

Power usage effectiveness (PUE™) has become the industry-preferred metric for measuring infrastructure energy efficiency for data centers. The PUE metric is an end-user tool that helps boost energy efficiency in data center operations. It was developed by The Green Grid Association, a nonprofit, open industry consortium of end users, policy makers, technology providers, facility architects, and utility companies working to improve the resource efficiency of information technology and data centers throughout the world. Since its original publication in 2007, PUE has been globally adopted by the industry. Over the years, The Green Grid has (TGG) continued to refine the metric measurement methodology with collaborative industry feedback. This collective work has been brought together here to simplify the absorption and use of the PUE metric. *PUE™: A Comprehensive Examination of the Metric* supersedes prior white papers, consolidates all things that TGG has developed and published relating to PUE, and adds new material. As such, this book is recommended by TGG and ASHRAE TC 9.9 to those implementing, using, and reporting PUE. Access to various levels of information is provided via the websites listed throughout the book. This book allows executives to gain a high level of understanding of the concepts surrounding PUE, while providing in-depth application knowledge and resources to those implementing and reporting data center metrics.

1

Introduction

The Green Grid Association (TGG) works to improve the resource efficiency of information technology (IT) and data centers throughout the world. In 2007, TGG published two self-help data center energy efficiency metrics for end users: power usage effectiveness (PUE™) and its inverse, data center infrastructure efficiency (DCiE™). Since the original publications, PUE has surpassed DCiE in industry adoption. In fact, PUE is currently viewed as the industry-preferred metric for measuring infrastructure energy efficiency in data centers, for either guiding new facility design or monitoring existing facility operations management.

In 2009, TGG, in collaboration with organizations around the globe, began driving toward a set of metrics and indices that can be formally adopted by all participating organizations to improve worldwide data center energy efficiency. As a result, global agreement has been reached that affirms PUE as the industry's preferred DCiE. The following are the two task forces and supporting organizations that have agreed on the PUE metric, measurement methodology, and reporting convention (TGG 2009a):

- Data Center Metrics Coordination Task Force (U.S. Regional Task Force)
    - 7×24 Exchange
    - ASHRAE TC 9.9
    - TGG
    - Silicon Valley Leadership Group
    - Uptime Institute
    - U.S. Department of Energy Save Energy Now and Federal Energy Management Programs
    - U.S. Environmental Protection Agency's ENERGY STAR® Program
    - U.S. Green Building Council

- Global Harmonization of Data Center Efficiency Metrics Task Force (Global Task Force)
    - European Commission: Joint Research Center Data Centers Code of Conduct
    - TGG
    - Green IT Promotion Council, Japan
    - Ministry of Economy, Trade, and Industry, Japan
    - U.S. Department of Energy Save Energy Now and Federal Energy Management Programs
    - U.S. Environmental Protection Agency's ENERGY STAR Program

PUE is an excellent metric for understanding how well a data center is delivering energy to its IT equipment. The metric is best applied when looking at trends in an individual facility over time and when measuring the effects of different design and operational decisions within a specific facility. For example, improvements to the efficiency of the mechanical or electrical infrastructure will result in a lower PUE value.

No two data centers have exactly the same operating characteristics, such as infrastructure or IT loads. Therefore, the comparison of two data centers based on public reports of their PUE results was not initially recommended because many attributes of data center design, engineering, implementation, and operations affect PUE. However, since the original publications, the industry has globally adopted the PUE metric and begun to compare PUEs among data centers, raising further questions about how to interpret individual results, how to compare different results for the same data center, and how to compare results across different data centers. As there are various ways to calculate PUE, stakeholders in the industry have expressed concerns around the consistency and repeatability of publicly-reported measurements. In response, TGG has published a set of rules and guidelines regarding the process that organizations should follow when making public claims regarding their data centers' PUE measurements and has provided a free PUE reporting tool (TGG 2009c). Chapter 6 of this book outlines the PUE reporting requirements and also includes the definition of standard nomenclature that will enable individual claimants to communicate key information about their measurements.

Standardized PUE nomenclature, proper and transparent public reporting guidelines, and the availability of key information about reported results will enhance both the credibility and usefulness of the PUE metric. To further enable equitable comparison of PUE results among data centers, additional attributes such as age, geographic location, capacity loading, size of facility, infrastructure resiliency, and the like, should be taken into consideration.

Provided the measurement guidelines, reporting guidelines, and the additional data attributes (as mentioned above) are obtained, TGG and ASHRAE TC 9.9 believe PUE can be used to compare DCiE.

The PUE metric is associated with the data center infrastructure. PUE is not a data center productivity metric, nor is it a stand-alone, comprehensive efficiency metric. PUE measures the relationship between the total facility energy consumed and the IT equipment energy consumed. When viewed in the proper context, PUE provides strong guidance for and useful insight into the design of efficient power and cooling infrastructure architectures, the deployment of equipment within those architectures, and the day-to-day operation of that equipment.

Changes in PUE are most meaningful when they are seen as the data center's response to changes in infrastructure equipment or infrastructure operations. Studies investigating the effect of PUE on changes in infrastructure equipment or operations should ensure that any changes occurring in the IT load over the study's period of time are properly accounted.

This book provides guidelines for determining the PUE of a dedicated data center and that of a mixed-use facility or specialized facility, along with results, scalability analyses, and case studies. It also outlines the approach to reuse waste heat. Issues such as availability of equipment and the productivity of the data center require different metrics and different analyses.

Data centers are complex systems. Frequently, changing certain aspects of the facility (e.g., commissioning a new class of server) can produce apparent changes in PUE results for another aspect of the facility. TGG and ASHRAE TC 9.9 advise data center owners and operators to take the greatest care around issues of availability. If an action or initiative taken to improve PUE has a negative effect on the availability of the IT equipment in the data center, owners and operators should review the potential impact on the data center and determine whether or not to proceed any further with that action or initiative.

In addition, PUE does not provide any guidance or insight into the operation or productivity of IT equipment. TGG is currently investigating additional metrics and approaches to provide guidance and insight into these areas (TGG 2009b). It is also possible, even likely, that changes in the deployment or operation of IT equipment will affect PUE results. For example, organizations implementing virtualization in their data centers may reduce overall IT load but see an increase in PUE. In these instances, the fixed overhead for power distribution and cooling has not changed, but the reduction in IT load delivers a seemingly poorer PUE result. PUE metric users should not become overly concerned when changes in one area affect results in another, but rather consider the factors that contributed to the PUE increase as further opportunities for improvements.

Source energy represents the total amount of raw fuel that is required to operate the data center and includes transmission, delivery, and production losses. A source energy based PUE must be used when energy sources other than electricity are delivered to the data center. TGG and ASHRAE TC 9.9's recommended approach for measuring and calculating PUE by source energy will yield the same output as an all-electric data center calculating a site-based PUE. Please see Section 4.9 Source Energy for more information.

Numerous internal references have been incorporated into this book with the goal of maintaining an executive overview of each metric and key topic, while enabling end users and operators to obtain more detailed information, including implementation data, lessons learned, and best practices. These references also allows those in particular verticals (e.g., government or healthcare) and business areas (e.g., executive management, marketing, sales) to pull the level of information required in a quick and efficient manner. This is intended to enhance the use of this book and of PUE-related metrics.

2

Metric List and Intended Use

PUE for a dedicated building is the total facility energy divided by the IT equipment energy. PUE is an end-user metric used to help improve energy efficiency in data center infrastructure and operations. (Please see Section 5.1 for more information.)

PUE for a data center in a mixed-use facility is highlighted in this book due to the need voiced throughout the industry to better define the contributions of data center total energy within a mixed-use facility. This refers to a data center that is located within a larger building that may support other functions. For example, a data center may occupy a single floor within a larger office building that contains some combination of non-IT operations, such as general administrative office space. A mixed-use facility may have its own dedicated infrastructure (including uninterruptible power supply [UPS] and cooling systems) or may have shared infrastructure. Because the majority of data centers are within mixed-use facilities, this chapter of the book provides practical guidelines on how to measure the PUE contribution of shared infrastructure resources. (Please see Section 5.2 for a more in-depth discussion.)

Partial PUE (pPUE™) allows a data center manager to focus on the energy efficiency of a particular portion of the data center or mixed-use facility. This may be needed because some measurements of the total data center energy are unobtainable (because of a leasing arrangement, for example). Partial PUE is the total energy inside a boundary divided by the IT equipment energy inside the boundary. (Please see Chapter 7 for details.)

The PUE scalability and statistical analysis metrics provide scalability metrics associated with changes in IT loads typically seen in the data center. PUE scalability is used to show how well a data center's total energy consumption scales with changes in its IT equipment loads. (These metrics are described in Chapter 8.)

Data center infrastructure efficiency (DCiE) is the inverse of PUE: it is IT equipment energy divided by total facility energy. Since TGG's introduction of these two metrics, PUE has surpassed DCiE in industry adoption. Moving forward, TGG and ASHRAE TC 9.9 will use PUE and view it as the industry-preferred metric for measuring infrastructure energy efficiency in data centers.

3

An Overview of PUE

TGG and ASHRAE TC 9.9 believe that metrics can help data center owners and operators better understand and improve the energy efficiency of their existing data centers, as well as help them make better decisions on new data center deployments. With standardized PUE nomenclature, proper and transparent public reporting guidelines, and the availability of key information about reported results, both the credibility and usefulness of the PUE metric will be enhanced. To further enable equitable comparison of PUE results among data centers, attributes such as age, geographic location, capacity loading, size of facility, and the like should be taken into consideration. Provided the measurement guidelines, reporting guidelines, and the additional data attributes (as mentioned above) are obtained, TGG and ASHRAE TC 9.9 believe PUE can be used to compare data center infrastructure efficiency.

Why the need for greater energy efficiency? Because data center power and cooling are two of the biggest issues facing IT organizations today, and growing companies need a way to control these costs while enabling future expansion. Many traditional businesses are migrating their data to digital form and leveraging technology as a key business enabler. With more efficient data centers, IT organizations can better manage increased computing, network, and storage demands; cut energy costs; and reduce total cost of ownership (TCO)—all while remaining competitive and able to meet future business needs (Patterson et al. 2007).

TGG and ASHRAE TC 9.9 recognize the importance of establishing metrics for data center efficiency and offer guidance on technologies that claim to improve performance-per-watt. Ideally, these metrics, tools, and associated processes will help organizations determine if an existing data center can be optimized before a new data center is needed.

3.1 PUE DEFINITION

PUE is defined as the ratio of total facilities energy to IT equipment energy, as shown in Equation 3.1.

$$\text{PUE} = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}} \tag{3.1}$$

Total facility energy is defined as the energy dedicated solely to the data center (e.g., the energy measured at the utility meter of a dedicated data center facility or at the meter for a data center or data room in a mixed-use facility). The IT equipment energy is defined as the energy consumed by equipment that is used to manage, process, store, or route data within the compute space.