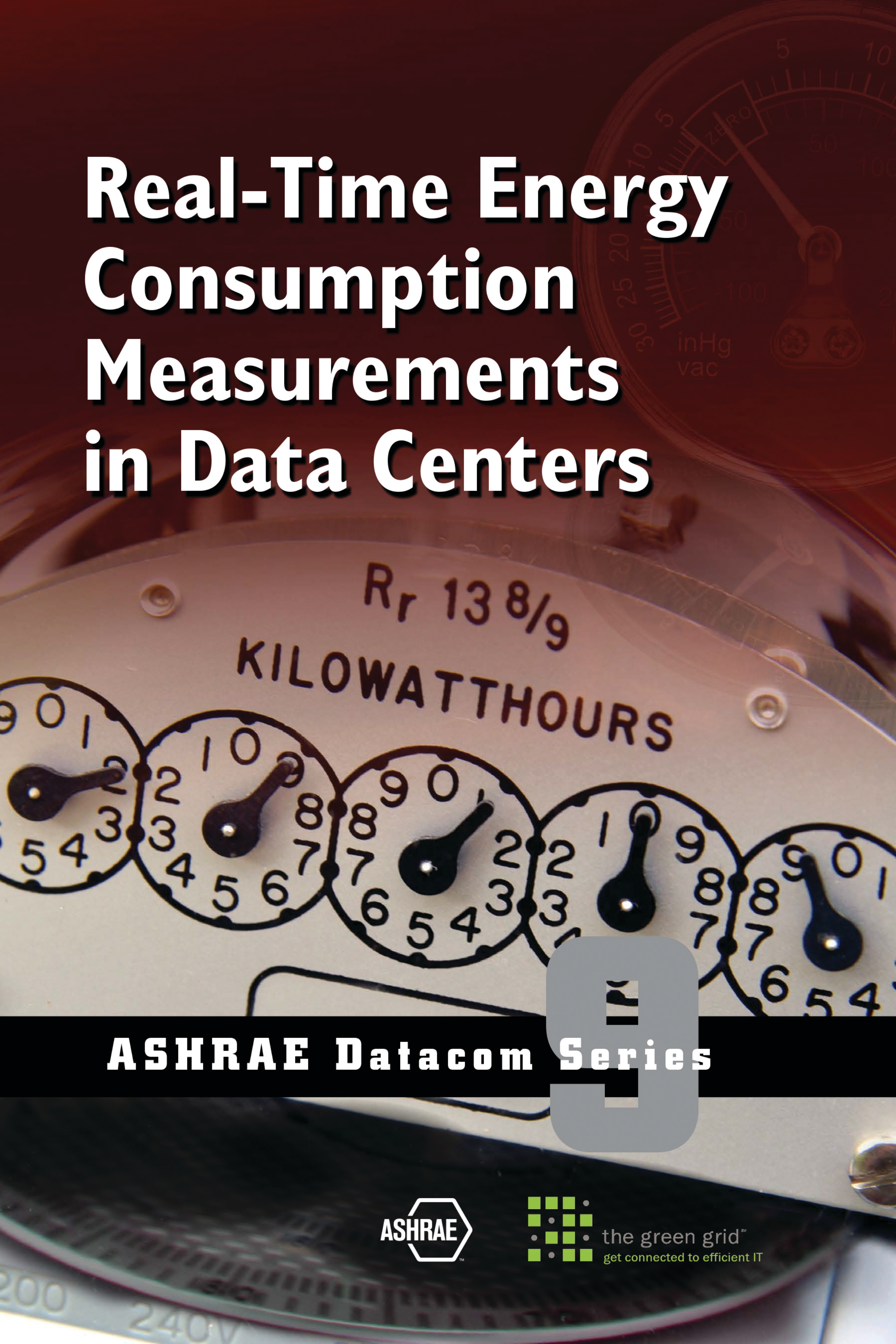
Real-Time Energy Consumption Measurements in Data Centers



ASHRAE Datacom Series

9

ASHRAE

the green grid™
get connected to efficient IT

Real-Time Energy Consumption Measurements in Data Centers

This book, coauthored by ASHRAE with The Green Grid's Data Collection and Analysis Work Group, is the ninth in a series of datacom books by ASHRAE TC 9.9, Mission Critical Facilities, Technology Spaces and Electronic Equipment.

About ASHRAE

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), founded in 1894, is an international organization of some 50,000 members. ASHRAE is the world's foremost technical society in the fields of heating, ventilation, air conditioning, and refrigeration. ASHRAE fulfills its mission of advancing heating, ventilation, air conditioning, and refrigeration to serve humanity and promote a sustainable world through research, standards writing, publishing, and continuing education. The result of these efforts is that engineers are better able to keep indoor environments safe and productive while protecting and preserving the outdoors for generations to come. For information about ASHRAE or to become a member, visit www.ashrae.org.

About The Green Grid

The Green Grid is a global consortium of end-users, technology providers and government agencies seeking to improve energy efficiency in data centers and business computing ecosystems around the globe. Through data collection and analysis, assessment of emerging technologies, and devising best practices for data center operators, The Green Grid is unifying global efforts to standardize on a common set of metrics, processes and measurement standards for executives and end-users anywhere in the world to determine the efficiency of their specific data centers. More information on the organization, including membership opportunities, can be found at www.thegreengrid.org.

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

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ASHRAE™

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Lead editor / author – Tahir Cader, HP (formerly SprayCool)
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Chapter 1 – Tahir Cader[a,b], HP (lead)
Chapter 2 – Tahir Cader[a,b], HP (lead); Mike Mangan, DLB Associates; Jeff Jaworksi, DLB Associates
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Chapter 4 – Ken Uhlman[b], Eaton (lead); Harry Rogers[b], Microsoft
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Chapter 6 – Jeff Trower[a], DataAire (lead); Cliff Federspiel, Federspiel Controls
Chapter 7 – John Bean[a,b], APC/Schneider (lead)
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Chapter 9 – Jonathan Spreeman[a], Trane (lead); Tahir Cader[a,b], HP
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Chapter 16 – Kevin Engelbert[a,b], Cisco (lead)
Chapter 17 – Kevin Wyman[a], Carrier Corporation (lead); Greg Palmer[b], HP (formerly UTC Power) (lead);

Appendix A – John Bean[a,b], APC/Schneider (lead)
Appendix B – Jonathan Spreeman[a], Trane (lead)
Appendix C – Tahir Cader[a,b], HP (lead); Jonathan Spreeman[a], Trane

Appendix D – Steve McCluer[a,b], APC/Schneider (lead); Bill Campbell[a], Emerson Network Power; John Messer[b], Emerson Network Power
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[a] Member ASHRAE TC 9.9
[b] Member The Green Grid

PART 1

BASICS

CHAPTER 1
INTRODUCTION

Over the last several years, energy consumption by data centers in the US as well as worldwide has become a topic of intense discussion within the Information and Communication Technologies (ICT) world. There are numerous publications presenting statistics on the impact of data center power consumption on the supply of electricity. One of the more comprehensive studies was that requested by the US Congress in Public Law 109-431, in which the EPA was mandated to quantify the electricity usage by US data centers, resulting in *Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431*, 2007. The key finding of this study is that in 2006, US data centers consumed 1.5% of all electricity used in the US and that according to historical trends, this consumption would rise to 2.9% by 2011. The 1.5% electricity usage included servers and the infrastructure to support servers, but did not include network or storage equipment. A graph of the findings is shown in Figure 1.1.

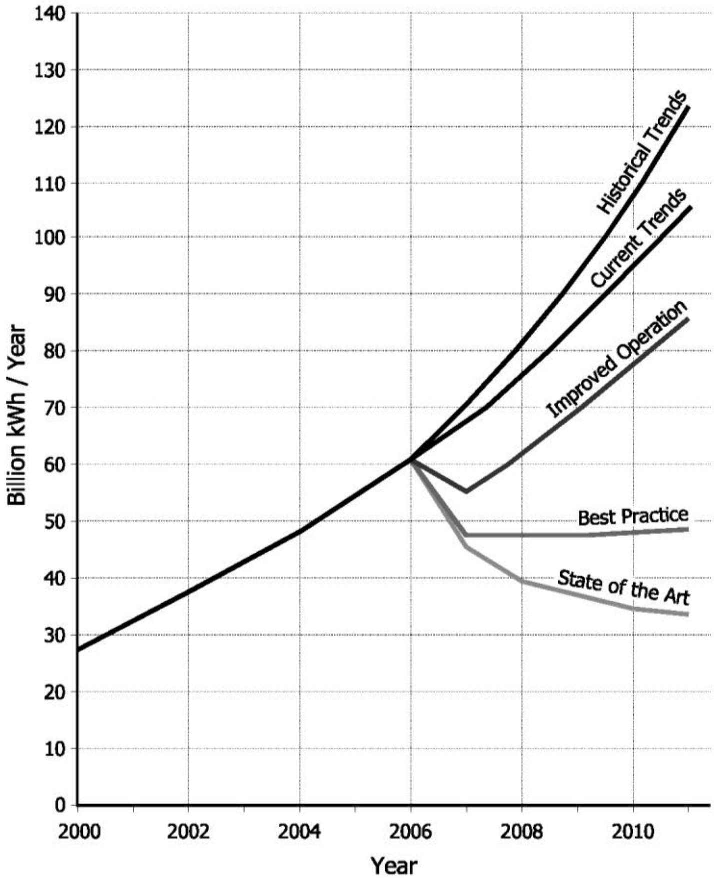

Figure 1.1 - Projected data center energy use scenarios (EPA, 2007)

The alarming trend of escalating electricity consumption in US data centers has spurred the ICT industry to aggressively increase energy efficiency in order to dramatically reduce power consumption in data centers. Together, the DOE and The Green Grid have stated that a goal for 2011 is to achieve a reduction of energy to 100B kWh / year instead of the current projection of 120B kWh / year for 2011. One of the key ways in which the industry can achieve the state-of-the-art curve is via real-time energy efficiency, which is achievable only through the use of real-time energy consumption data using energy efficiency and productivity metrics. An example of a real-time energy efficiency metric is the real-time version of the Power Utilization Effectiveness (PUE) metric as proposed by The Green Grid (*Green Grid Data Center Power Efficiency Metrics: PUE And DCiE*, 2008). This metric is defined and discussed further in Chapter 2. The focus of this book is real-time energy consumption measurements, with the resulting data to be used in all the relevant energy efficiency and productivity metrics.

Real-time energy consumption measurements are only possible if all key subsystems are appropriately instrumented and properly communicating through use of data center level software. Existing data centers have varying levels of instrumentation, ranging from very poor to excellent. For this book, three approaches to instrumentation and measurement for any given subsystem will be followed. The following loose guidelines are provided:

- Minimum Practical Measurement
- Best Practical Measurement
- State-of-the-Art Measurement

When deciding what level of measurement to target, a data center owner / operator needs to keep in mind key items such as capital cost, data accuracy and resolution, and end-use of the data. These factors will be dealt with in further detail in subsequent chapters. The following guidelines, summarized in Table 1.1, are suggested:

- Minimum Practical Measurement – This will require some level of human activity to perform periodic measurements. This approach will require zero to limited infrastructure upgrades, and zero to limited investment in instrumentation. This approach may rely more heavily on staff (most likely existing) to manually record data, and will also rely on manufacturers' equipment data.

- Best Practical Measurement – This will require a lower level of human activity than the minimum case in order to manually record data. For this case, it is anticipated that data will be logged in real-time with extensive trending possible. The instrumentation used may not necessarily be of the highest accuracy nor will it likely be the most extensive, with the more difficult to instrument parts of the facility remaining uninstrumented. Limited modification to infrastructure should be expected, and some tasks may be beyond the competency of the existing staff. Less reliance on manufacturers' data is expected.

- State-of-the-Art Measurement – This will not require human activity to gather and record data. Data will be collected by automated systems in real-time and will support extensive trending and analysis. The instrumentation will be of accuracy suitable for revenue grade. There will likely be a requirement to upgrade the existing infrastructure, and it is very likely some level of contractor or consultant support will be needed for the implementation.

Table 1.1 Measurement Implementation Level Overview

Topic	Minimum Practical	Best Practical	State-of-the-Art
Human Activity	Periodic Measurements & Recording, Mostly Manual	Some Manual Recording, Some Automation	Automated
Measurement Equipment	Manual	Semi-Manual	Automated

Mixed-use facilities offer the greatest challenge in which to quantify real time energy consumption. Figures 1.2 through 1.4 show a generic layout in a mixed-use facility. These figures are schematic in nature and are not intended to be fully representative of all possible configurations. Figure 1.2 shows a schematic representation of the electrical distribution system in a mixed-use data center, while Figure 1.3 shows the mechanical layout of the same data center type.

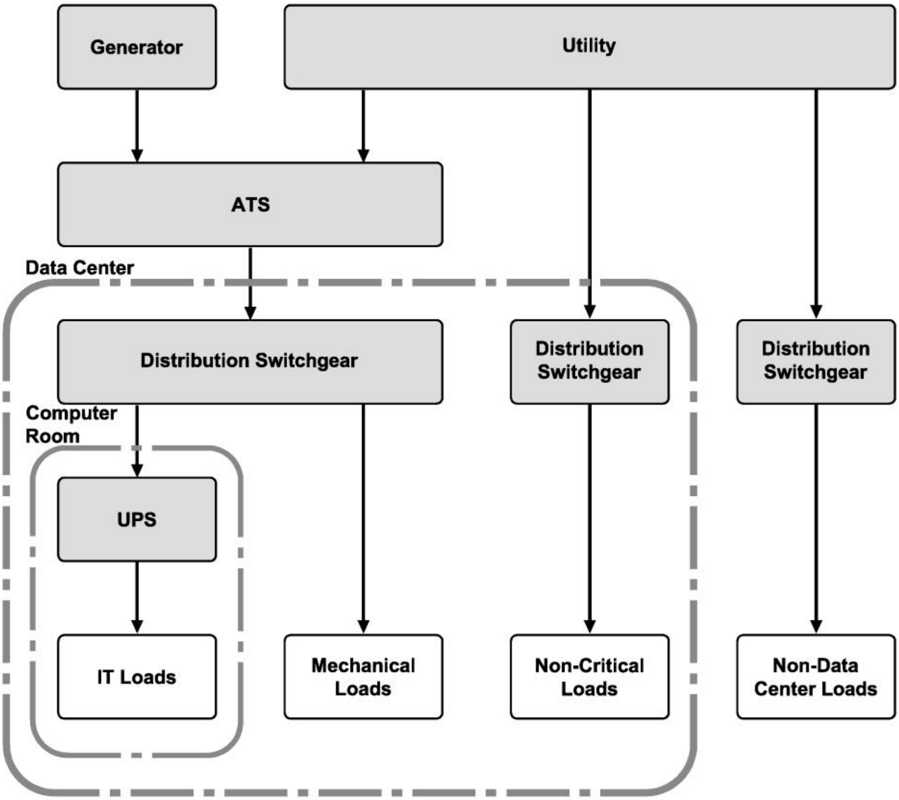

Figure 1.2 - Schematic representation of the electrical system in a mixed-use facility

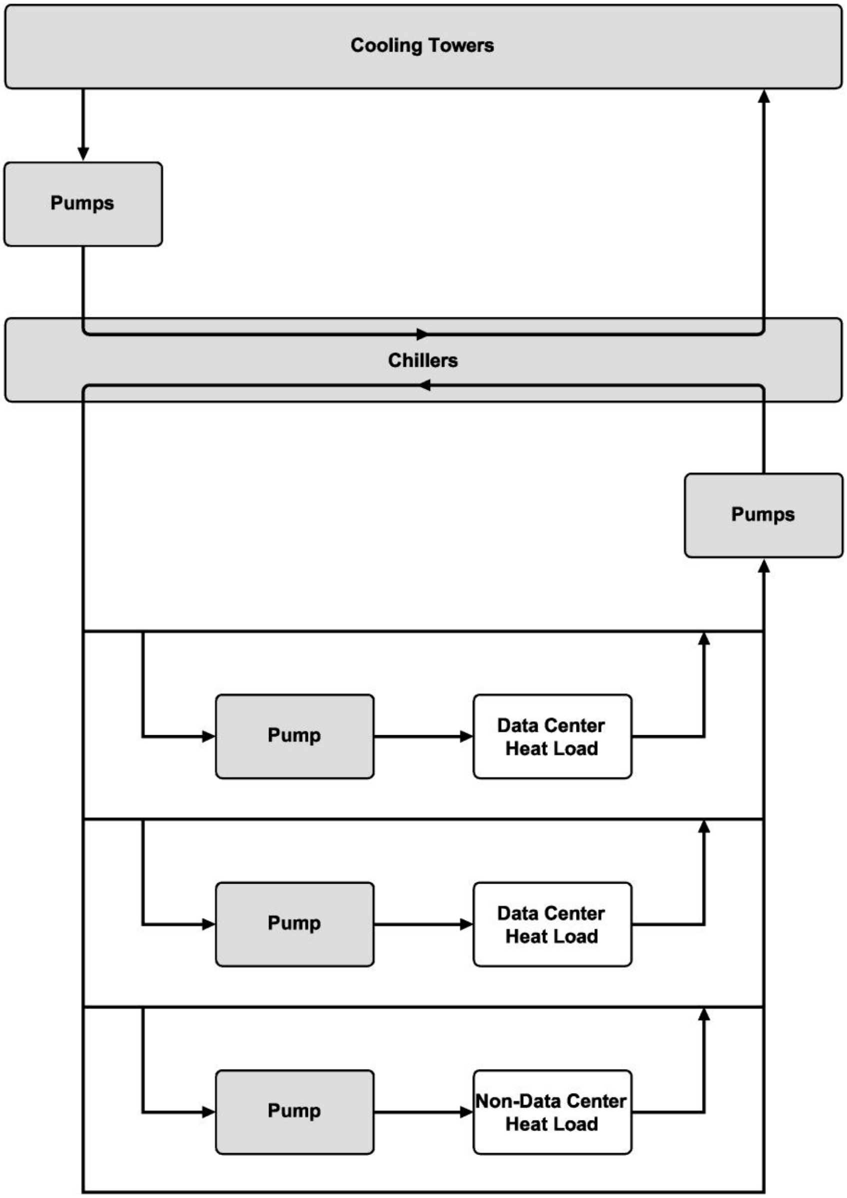

Figure 1.3 - Schematic representation of the mechanical layout of a data center housed in a mixed-use facility

Figure 1.4 is a simple graphic representing the key metering locations in a typical data center. The meters acquire power consumption data from all the electrical and mechanical subsystems shown in Figures 1.2 and 1.3, respectively. Each metering location is associated with its own hardware and software protocols, and in many cases hardware and software is provided by multiple vendors. These systems generally do not communicate with each other, which creates a significant issue in progressing toward the display of real-time energy and productivity metrics. The subsequent chapters will discuss these issues in further detail.

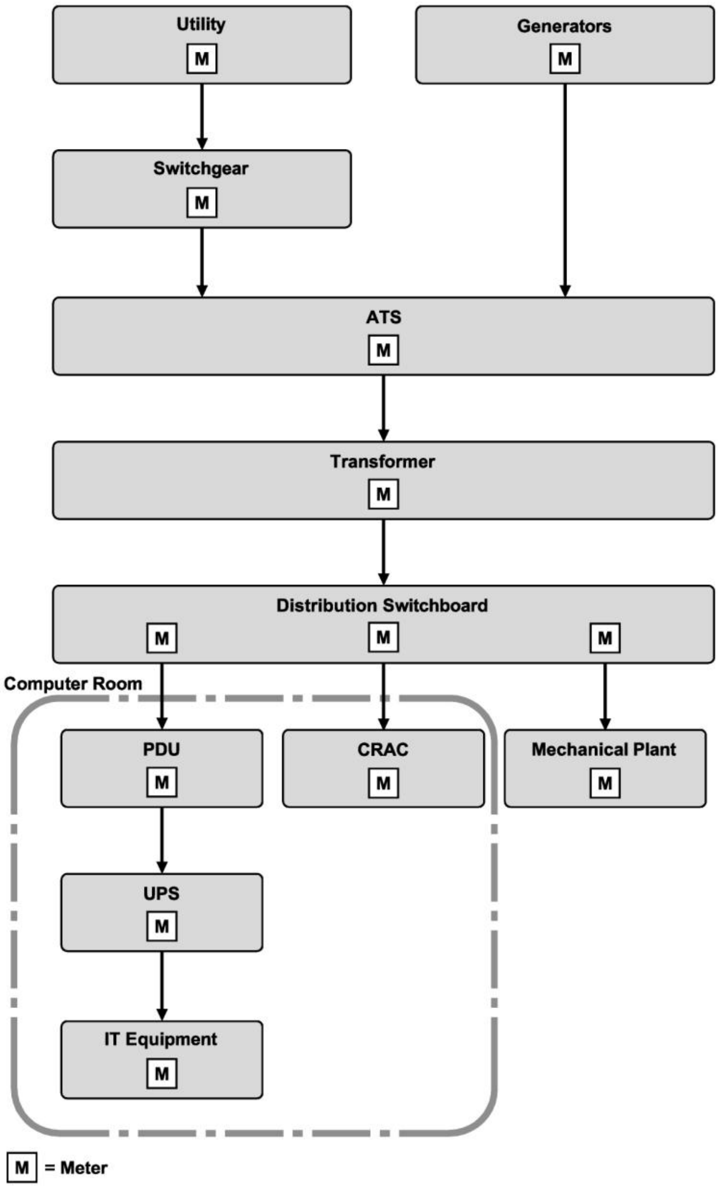

Figure 1.4 - Key metering locations in a data center

1.1 OBJECTIVES FOR THIS BOOK

The following are key objectives for the book:

- Provide an overview of the state of real-time energy consumption measurements in the data center. The book will cover both legacy as well as state-of-the-art data centers.
- Discuss the minimum and best practical levels of measurement, as well as state-of-the-art measurement for real-time energy consumption measurements (see Chapter 1 – Introduction).
- Provide a detailed discussion of how the measured real-time data will be used, and in particular how this information will be turned into knowledge that can lead to actionable items. This will cover the latest industry data center productivity and energy efficiency metrics from organizations such as The Green Grid and ASHRAE TC9.9. Emphasis will also be placed on quantifying the data center's power consumption for a data center housed in a mixed-use facility.

The idea behind the state-of-the-art measurement is that the industry will eventually arrive at the "plug and play" data center. Such a data center will rely on the widespread availability of network-enabled equipment. For example, at some point in the future, a data center owner / operator can expect to "plug in" a key subsystem such as a pump and have the data center's operating system recognize the pump in real-time. This will be followed shortly thereafter by real-time reporting of energy consumption measurements, and in turn real-time data center productivity and energy efficiency metrics.

This book will focus on monitoring and control for optimization of data center energy efficiency. There are, in fact, other benefits that may arise from real-time monitoring and control. One key benefit includes predicting the health of the infrastructure by tracking performance trends.

Additionally, while the book presents several examples using the Power Usage Effectiveness (PUE) metric from The Green Grid, use of any specific metric such as the DOE's Energy Usage Effectiveness (EUE), or The Green Grid's Data Center Energy Productivity (DCeP) is left entirely up to the data center owner / operator.

1.2 HOW TO USE THIS BOOK

While it is recommended that this book be read in its entirety, it is possible to benefit from reading only parts of the book. For the benefit of the reader, the book has been divided into five parts, each containing chapters dedicated to key components or subsystems. The five parts included are:

Part 1 Basics
Part 2 Cooling Systems – Air Measurements
Part 3 Cooling Systems – Hydronic Measurements
Part 4 Power Systems Measurements
Part 5 IT Systems Measurements

Part 1 will provide an overview of the book including measurement devices and software. Chapter 1 sets the stage for the book. Chapter 2 will focus on How, What & Where To Measure. Chapter 3, the Measurement Devices chapter, will provide an overview of the various sensor types available. The chapter will provide an overview of sensors for all electrical (e.g., voltage, current, etc.) and mechanical (e.g., pressure, temperature, flow, etc.) systems in the data center. Chapter 4, the Measurements Collection Systems chapter, will cover the business objectives that will guide a data center owner / operator to a given level of instrumentation (i.e., minimum practical, best practical, or state-of-the-art level of measurement). This chapter will also provide an overview of the various standards and protocols to facilitate communication with IT equipment and facilities equipment. The objective of such protocols is to acquire the real-time power consumption data and make it readily available to the data center owner / operator. Finally, this chapter will provide some discussion of how the acquired and reduced data can be turned into knowledge and subsequent actionable items that affect the business.

Parts 2 and 3 will provide an overview of the various cooling systems and subsystem types (e.g., chillers) that are deployed today. Each chapter will focus on the single most widely deployed subsystem type and provide a more detailed discussion of the three levels of instrumentation. The reader will be shown a high level discussion (not a detailed description) of how to, at each level of instrumentation, use measured data and manufacturer's data to quantify the power consumption of the specific subsystem type. Special attention is given, where appropriate, to show the reader how to quantify that part of the subsystem's power consumption that is attributable to a data center housed in a mixed-use facility. For example, in mixed-use facilities, the cooling towers, chillers, and pumps typically support all parts of the facility, including the data center.

Part 4 will focus on the power delivery path from the point of entry into the facility, to the point of delivery to the IT equipment. Specific attention is paid to Uninterruptible Power Supplies (UPS) and transformers. As with the other chapters, an overview is provided with emphasis on the most widely deployed UPSs and transformers.

Part 5 will provide a description of the servers, storage, and networking equipment deployed in data centers. The three levels of instrumentation will be discussed, and the reader will be shown how to roll the total IT equipment power consumption into a single power consumption number for later use by the data center owner / operator.

There are also Appendices meant to provide additional information or detail for different subsystems or components. Appendix A provides additional information for calculating real-time pump efficiency. Appendix B describes additional methods for quantifying chiller efficiency. Appendix C focuses on a specific example for calculations within a mixed-use facility. Appendix D provides additional information on Uninterruptible Power Supply efficiency measurements. Some rule-of-thumb calculations are also provided to enable the reader to perform calculations on power conversion losses. Appendix E, Onsite Combined Cooling, Heat, and Power (CCHP), describes in some detail the specifics of CCHP and waste heat recovery. An important feature of the chapter is the description of how to accommodate CCHP within the calculation of energy efficiency metrics such as PUE for data centers. Appendix F lists the nomenclature in the book.

A references section is located at the end of the book.

CHAPTER 2
HOW, WHAT, & WHERE TO MEASURE

2.1 OVERVIEW

Understanding the overall goals for measurements is as important as implementing the measurement system and obtaining measurements within the data center. While accuracy of the measurement devices can be critical, benefits can be realized through simply obtaining useful data. Depending on what, where, and how measurements are taken, varying levels of accuracy of the devices may be implemented.

Potential uses for measured data can include understanding energy usage as a whole, trending over time, understanding the instantaneous power consumption of key pieces of equipment, billing, or calculating energy efficiency using one of the metrics described in this book. Depending on the purpose, different factors may be paramount for the collected data. Assuming that a fixed budget exists for obtaining a set of measurements or calculating a metric, the owner / operator may need to balance measurement accuracy with frequency, sensor quantity and location. These decisions ultimately need to be made in accordance with understanding how, what, and where to measure.

Common to all systems is the opportunity to measure the real-time power consumption for each subsystem. The real-time energy consumption can be measured directly via current and voltage measurements, or accurately via the measurement of power. For purely electrical equipment such as UPSs and transformers, the only choice of accounting for power consumption (losses in the case of this type of equipment) is via direct measurements of current and voltage or power.

For mechanical subsystems such as pumps, compressors, and blowers, estimated power consumption can be indirectly calculated via the measurement of temperature, flow rate, and pressure drop. Power consumption can also be obtained through direct measurements on each subsystem. The measured data can then be used in conjunction with manufacturers' performance data in order to determine efficiency. It is instructive for the user to consult ASHRAE Guideline 22-2008 for some guidance with respect to instrumentation of the chilled-water plant (includes cooling towers, condenser water pumps, chillers, and chilled water pumps). It is important to note, however, that the level of instrumentation required for isolating the real-time power consumption of a data center housed in a mixed-use facility is higher than that shown in ASHRAE Guideline 22-2008.

For facilities using air side economizers it is important to understand the condition of the air external to the data center to properly react to changing external conditions. Particulate and gaseous contamination will not be discussed in this book, however, more information can be found in ASHRAE's "Particulate and Gaseous Contamination in Datacom Environments".

Measurements can be taken either manually or automatically. The specific device installed will dictate which option can be used. Generally, manual readings will be the minimum practical measurement, while automatic readings will occur in the best practical, and state-of-the art data center. Automated readings can be stored electronically and trended over time. Trending can also be achieved with manual readings, but will take more time and effort to produce.

The decision whether to use minimum practical, best practical, or state-of-the-art measurements is ultimately a function of the facility and its stakeholders. This book will introduce a multitude of measurement devices, locations, and techniques to understand the energy consumption of common components of a data center. Obtaining the most useful data should always dictate the techniques employed.

2.2 QUANTIFYING ENERGY EFFICIENCY METRICS

The Green Grid recently proposed Power Utilization Effectiveness (PUE) as an energy efficiency metric (Data Center infrastructure Efficiency (DCiE) is the reciprocal of PUE). This metric highlights the amount of power that is consumed in total by the data center, including IT loads, and the amount for IT and physical infrastructure to support the IT. Figure 2.1 shows a simple schematic detailing the key data center subsystems that are accounted for in PUE or DCiE.

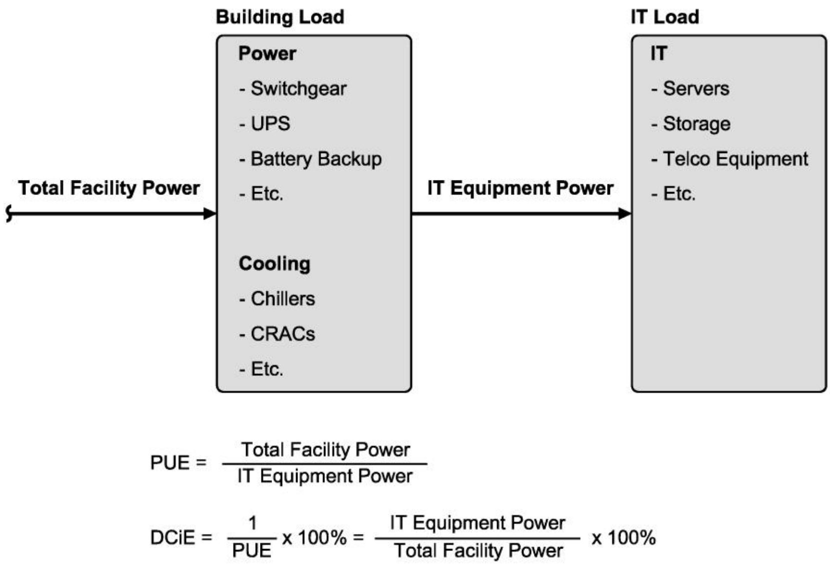

Figure 2.1 - Data center energy efficiency metrics

In keeping with the discussion of each of the data center subsystems covered in the remainder of the book, Power Utilization Effectiveness (PUE) is defined as:

$$PUE = \frac{P_{fac}}{P_{IT}} \qquad (2.1)$$