Better Buildings®
U.S. DEPARTMENT OF ENERGY

Data Center Metering and Resource Guide

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U.S. DEPARTMENT OF ENERGY

Contents

1. Introduction

Data centers constitute a large and growing sector of energy use. By one estimate, they consume about 2 percent of U.S. electricity, and the sector is increasing energy use by about 1 percent each year (Shehabi et al 2016). Inefficiencies in the power and cooling systems of the data center infrastructure often give data center owners and operators significant opportunities for energy-efficiency measures. Taking advantage of such opportunities typically is very cost-effective, reducing the operating costs, and can also improve data center reliability.

Managing and assessing energy performance requires the use of established data center energy performance metrics, and metering is needed to provide the data for such metrics. Tracking and managing data can inform decision makers in the following ways:

1. It helps organizations identify abnormally low- or high-energy usage and potential causes, supporting such practices as peak-shaving. It also facilitates capacity planning around space and power utilization and helps with carbon accounting and greenhouse gas (GHG) reporting.
2. It helps organizations track and manage energy costs, verify energy bills, and prioritize, validate, and reduce energy costs through improved energy efficiency and energy management.
3. It allows organizations to quantitatively assess data center performance and to benchmark it across a level playing field. Benchmarking evaluates the organization's position relative to the rest of the market (cross-sectional benchmarking) or over time in one data center (longitudinal benchmarking). This enables engagement with senior management and other stakeholders to participate in continuous improvement of the organization's energy performance.
4. It helps organizations develop and validate energy-efficiency strategies and identify opportunities to improve energy efficiency by lowering energy and operational costs. These strategies include identifying large energy users and establishing performance metrics (cooling plant kilowatts/ton, air-handling watts/cubic foot per minute, etc.) for monitoring and tracking.
5. Energy performance metrics can also be used to commission and detect faults in physical systems and diagnose their causes.

This Guide intends to help data center owners and operators implement a metering system that allows their organizations to gather the necessary data for effective decision-making and energy-efficiency improvements. It also provides metering guidance to organizations considering participation and to those already participating in the Better Buildings Data Center Challenge or Accelerator Partnerships. A successful participation as a Better Buildings Partner requires data submission that is fully metered; partial metering or other estimates are only appropriate for baseline data. For information on how to baseline energy use without sub-metering, see Appendix B: Data Center Profiler (DC Pro) Tools.

The following list describes the sections in this Guide:

- Section 2, Definitions, includes the Power Usage Effectiveness (PUE) metric and describes its value to users, as well as levels of PUE measurement. At a minimum, Better Buildings Partners should implement metering consistent with PUE Level 1, the basic metering defined by The Green Grid (TGG). This Guide provides guidance for partners focusing on PUE Level 1.
- Section 3, Implementation, discusses data center types (especially stand-alone and embedded types), estimates PUE for various metering scenarios, planning for and installing the meters, and the importance of commissioning. This Guide will focus on embedded data centers with incomplete metering.
- Section 4, Anticipated Scenarios, covers anticipated scenarios of metering systems and how they integrate with data center types.
- Section 5, General, discusses metering methods, including leveraging existing meters, starting from scratch, and meter types.
- Section 6, Challenges to Meter Installation and Possible Solutions, deals with challenges to installing and gathering data from electrical and thermal meters and how to overcome these challenges.
- Section 7, Metering Costs, covers order-of-magnitude metering costs and associated variables.
- The Appendix provides references and additional resources for readings and training.

2. Definitions

2.1. PUE as a Metric

2.1.1. Definition

Power Usage Effectiveness, or PUE, is a measure of how efficiently a computer data center infrastructure uses energy. Specifically, it is the ratio of total energy use to that of information technology (IT) equipment.

$$PUE = \frac{Total\ Facility\ Annual\ Energy\ Use}{IT\ Equipment\ Annual\ Energy\ Use}$$

IT equipment energy includes the energy associated with all of the IT equipment (e.g., compute, storage, and network equipment). Total facility energy includes all IT equipment energy as described above, plus everything that supports the IT equipment using energy, such as:

- Power delivery components, including uninterruptible power supply (UPS) systems, on-site switchgear, transformers, generators, power distribution units (PDUs), batteries, and distribution losses external to the IT equipment.
- Cooling system components, such as chillers, cooling towers, pumps, computer room air handlers (CRAHs), computer room air conditioners (CRACs), and direct expansion air handler (DX) units.
- Lighting.z

2.1.2. What PUE is good for (infrastructure overhead)

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

2.2. Levels of PUE (1 through 3) per The Green Grid (TGG)

The Green Grid defines a three-level approach for measuring PUE, which includes basic, intermediate, and advanced measurement levels. This guide focuses on PUE Level 1, which is the basic-level measurement. PUE Level 1 is the minimum requirement for Better Buildings Challenge partners to measure and manage their data centers. For context, PUE Level 2 and PUE Level 3 are briefly described below.

Level 1: Basic Metering

The IT load is measured at the output of the UPS equipment and can be read from the UPS front panel, through a meter on the UPS output, or, in cases of multiple UPS modules, through a single meter on the common UPS output bus. Note that any transformers and other electrical distribution losses between the UPS and the IT equipment are counted as IT load when using PUE Level 1.

Level 2: Intermediate Metering

Level 2 metering counts losses from the power distribution units (PDUs) as part of infrastructure and not IT. Level 2 is typically a hybrid metering solution, where most of the metered points are automatically recorded and some are recorded manually. This is different from Level 1, Basic Metering, where typically the majority or all of the points are manually read. Level 2 metering is done at the data center level and at some selected system-level points. In addition to the minimum meters in Level 1, Level 2 may include certain additional manual recording and automated metering, such as a chiller plant meter and metering of outside air temperature through a control system.

In Level 2 metering, in addition to utility and switch gear meters that provide continuous and accumulated data on the center’s energy use, there are meters at the chilled water plant and heating, ventilation, and air conditioning (HVAC) fans. The UPS and PDU displays can provide instantaneous data. Electrical distribution loss, which is an important factor in data center energy efficiency, can be calculated by observing the UPS and PDU displays. In this case, the derived metrics are presented as a good estimate. There are also temperature readings for chilled water and CRAC/CRAH (CRAC/H) air. With these data, possible measures can be implemented to improve chiller efficiency in the chiller plant and air management inside the data center. It should be noted that UPS and PDU metering is typically less accurate (within a few percent of reading) than utility meters (within 1 percent).

Level 3: Advanced Metering

In Level 3 monitoring, all points are automatically metered, with minimum dependency on potentially inaccurate equipment display values and manual recording. At this level, the accuracy of the metrics depends on the accuracy of the meters. The values are metered over time as opposed to being estimated from the product specifications or taken from manual meter readings. In this case, meters are installed to determine energy end use, and they provide continuous and accumulated data on data center energy use. In the chiller plant, power use by chillers, pumps, and fans are metered. Electrical distribution is metered at each step, down to the UPS, PDU, and IT equipment. Power use by HVAC equipment, generator block heaters, and cooling and lighting for support rooms is metered.

In Level 3 monitoring, the derived metrics are presented as a precise value. There are also temperature readings for chilled water, CRAC/H supply air, and rack intake air temperature. These more extensive data help to identify more measures that can be implemented to improve chiller plant efficiency and air management inside the data center.

Figure 1 illustrates the different metering levels and meter locations.

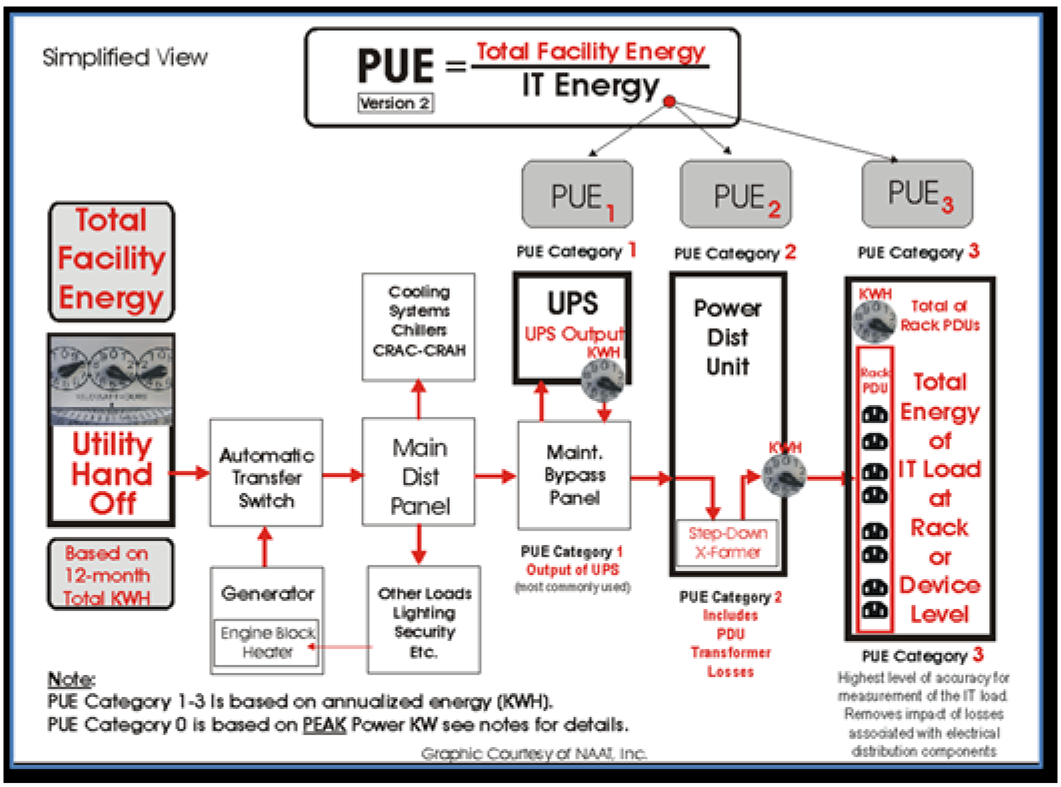


Figure 1 - Different Levels of PUE (Source: NAAT, Inc.)

3. Metering Implementation

3.1. Data Center Type

While this guide discusses two types of data centers—stand-alone and embedded—it focuses on embedded data centers.

At a stand-alone data center, the incoming energy is measured from the utility electrical service entrance that feeds all of the electrical and mechanical equipment used to power, cool, and condition the center. If the stand-alone data center does not have its own meter, one needs to be added.

In either type of data center, the power to the IT equipment is measured at the UPS output (or if there is no UPS, at the panels serving only the IT loads in the data center).

When a data center is embedded in a building and served by a shared chilled-water plant, the cooling energy is measured using thermal meters, or calculated if measurement is not possible. Thermal meters are installed on the chilled water pipes serving the data center HVAC system. If the data center is served by a stand-alone cooling system (e.g. Computer Room Air Conditioners (CRACs), the CRACs should be electrically submetered, but again the cooling energy can be estimated. In a PUE Level 1 calculation, electrical distribution system losses can be estimated. A typical number may be 10 percent of energy measured at the UPS output (which is the assumed IT energy use).

Basic monitoring requires, at a minimum, the collection of energy measurements once a month.

3.2. Energy vs. Power

Energy is a measure of the ability to do work, and is a ***quantity***. The most common unit for measuring electrical energy is the kilowatt-hour (kWh); one kWh is the quantity of energy that results from one kW of electrical power used for one hour. Power is the ***rate*** at which energy is generated or used; the kilowatt (kW) is the most common unit for measuring electrical power.

3.3. PUE Estimation

Figure 2 below is a representative diagram for Level 1 metering. This is a relatively inexpensive solution that typically relies on existing meters; however, the level of data availability and accuracy is low for derived metrics. M1 is for utility readings. M2 is UPS output. For stand-alone data centers, PUE Level 1 = M1/M2.

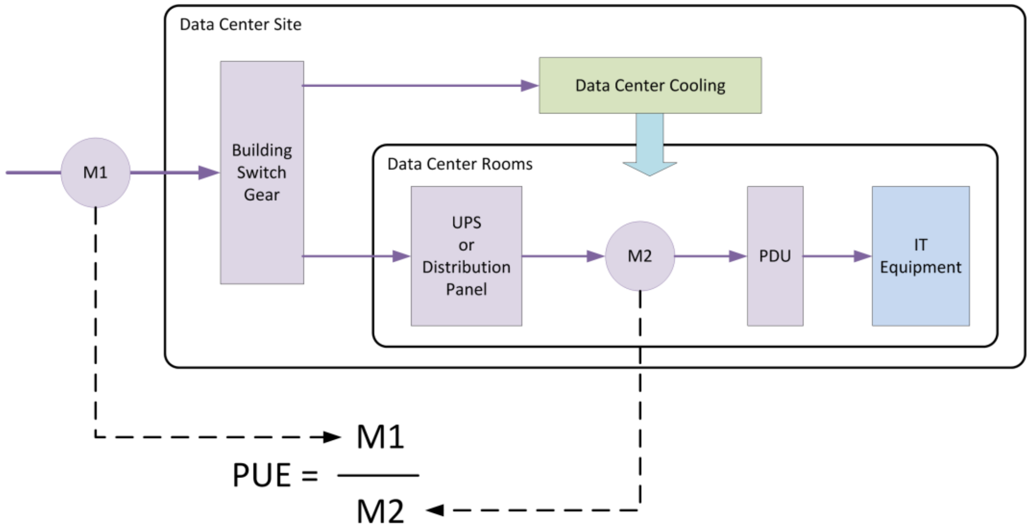


Figure 2 - Representative Diagram for Level 1: Basic Metering

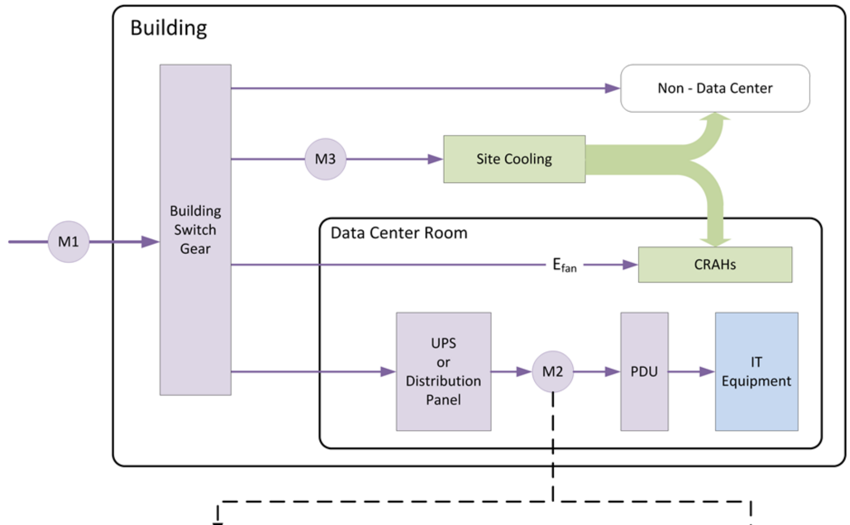
Note that for PUE calculations, some of the infrastructure-related loads such as lighting and standby generator energy use were not considered to have significant value. Lighting energy is usually less than 1 percent of the total energy and generator energy use, assuming weekly no-load and quarterly full-load test runs are less that 0.5 percent of the total energy use.

Table 1 and the corresponding Figures 3 through 8 exhibit different cases and the corresponding PUE calculation for embedded data centers where some metering (more advanced than that required by PUE Level 1) is available or can feasibly be installed. We recommend that the total electrical load to the data center and the thermal load imposed by the data center be measured if possible. Note that any PUE estimate based on assumptions about cooling and power distribution efficiencies, while acceptable as a baseline, will be less accurate and will be difficult to adjust when efficiency improvements are made to these infrastructure systems.

TABLE 1 – PUE CALCULATION GUIDE FOR CASES WITH ADDITIONAL METERING (IN ADDITION TO UPS OUTPUT)

Case	Additional Metering	PUE Calculation
Central chilled water plant with or without economizer plus CRAH units in the data center	Chiller plant input energy M3 See Figure 3.	PUE = $[((M2/0.9) + E_{fan})$ X $(1+ (0.285$ X $Eff))]/M2$
Central chilled water plant with or without economizer plus CRAH units in the data center	Thermal energy to data center T_1 is metered See Figure 4.	PUE = $[(M2/0.9) + E_{fan} + (T_1$ X $Eff)]/M2$ Eff = (Chiller efficiency + 0.2) kW/ton, where chiller efficiency can be obtained from Table 3 and 0.2 represents typical additional load of chilled water and condenser water pumps and cooling tower fans.
Central chilled water plant with or without economizer plus CRAH units in the data center	Chiller plant energy M3 UPS energy input is metered M4 See Figure 5.	PUE = $[((M4$ X $1.03) + E_{fan})$ X $(1+ (0.285$ X $Eff)]/M2$
CRAC units in the data center	CRAC and condenser energy M5 See Figure 6.	PUE = [M5 + (M2/0.9)]/M2
CRAC units in the data center	CRAC and condenser energy M5 and UPS energy input M4 See Figure 7.	PUE = [(M5 + M4) X 1.03]/M2
Central chilled water plant with or without economizer plus CRAH units in the data center	Thermal energy to data center T_1; chiller plant input M3, and chiller plant output T. See Figure 8.	PUE = $[(M3/T)$ X $T_1 + (M2/0.9) + E_{fan}]/M2$

Notes:
1. *M3 i*s chiller plant energy (kWh) (includes the energy use of chillers, pumps and cooling tower fans).
2. *M2* is UPS output (kWh).
3. *M2/.9* is based on an assumption of 10 percent loss in electrical distribution.
4. E_{fan} is the energy used by the CRAH fans (kWh). It can be estimated using motor nameplate. Use motor horsepower x 0.746 kW/hp x 0.75 load factor x operating hours /motor efficiency. Actual energy measurement is preferred, especially for fans with variable-speed drives.
5. *Eff* is chiller plant performance in kWh/integrated chiller plant load in ton-hours; overall units are kW/ton.
   The chiller plant load (in tons) is shown on the chiller display or (chilled water flow in gallons per minute (gpm) X ΔT in °F)/24, then converted to ton-hours by multiplying by the number of hours at each load. Using the equation in the table, this plant efficiency is then applied to the data center load to obtain the share of the plant electricity attributed to the data center.
6. *0.285* is used to convert kW of heat rejection to tons of heat rejection.
7. *M4* is UPS input (kWh). It does not include upstream losses (utility transformer, etc.). Include losses if the data are available, otherwise, an addition of 3 percent to the M4 reading provides an estimate of distribution losses upstream of the UPS.
8. *M5* is DX compressor + evaporator fan power + condenser fan power (kWh) (for equipment that serves only the data center).
9. T_1 is the thermal output of the chilled water supplied to the data center, in units of ton-hours. *T* is the total thermal output of the chilled water plant, in units of ton-hours.

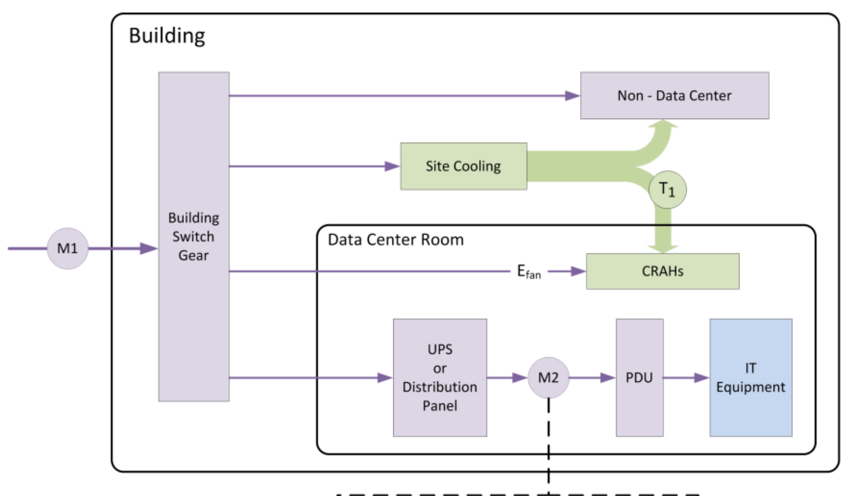


$$\text{PUE} = \frac{((M2/.9) + E_{fan}) \text{ X } (1+ (0.285 \text{ X } Eff))}{M2}$$

Where E_{fan}= CRAH fan energy use
Eff = average chiller plant efficiency in kW/ton

(M3 is used to calculate: see Table 1.)

Figure 3. Embedded Data Center with Additional Metering: Chiller Plant input M3.



$$\text{PUE} = \frac{(M2/0.9) + E_{fan} + (T_1 \text{ x } Eff)}{M2}$$

Eff = (Chiller efficiency + 0.2) kW/ton, where chiller efficiency can be obtained from Chiller Efficiency Table and 0.2 represents typical additional load of chilled water/condenser water pumps and cooling tower fans.

Figure 4. Embedded Data Center with Additional Metering: Chiller Plant output to Data Center T1.

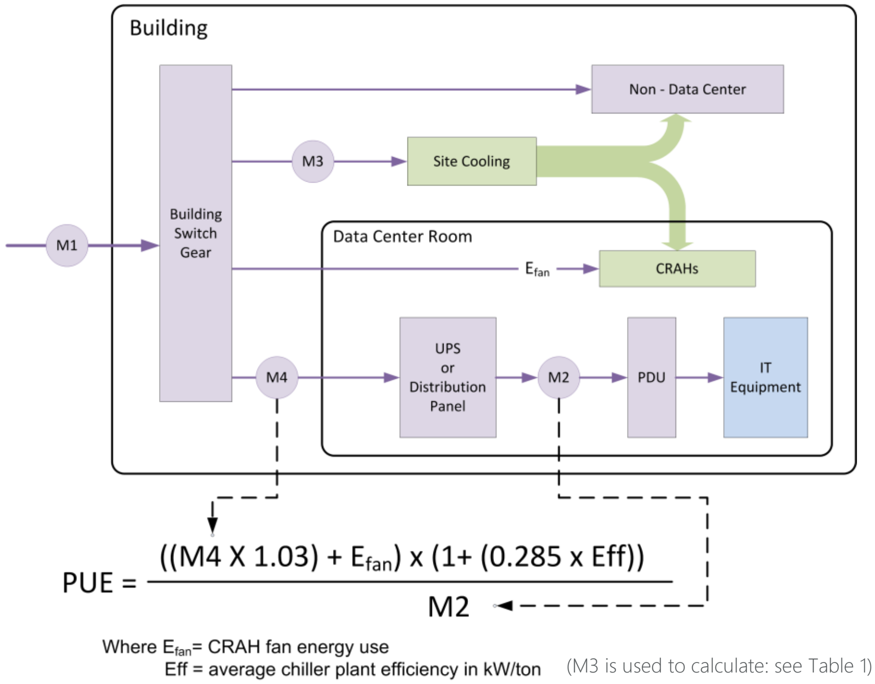


Figure 5. Embedded Data Center with Additional Metering: Chiller Plant input M3 and UPS input M4.

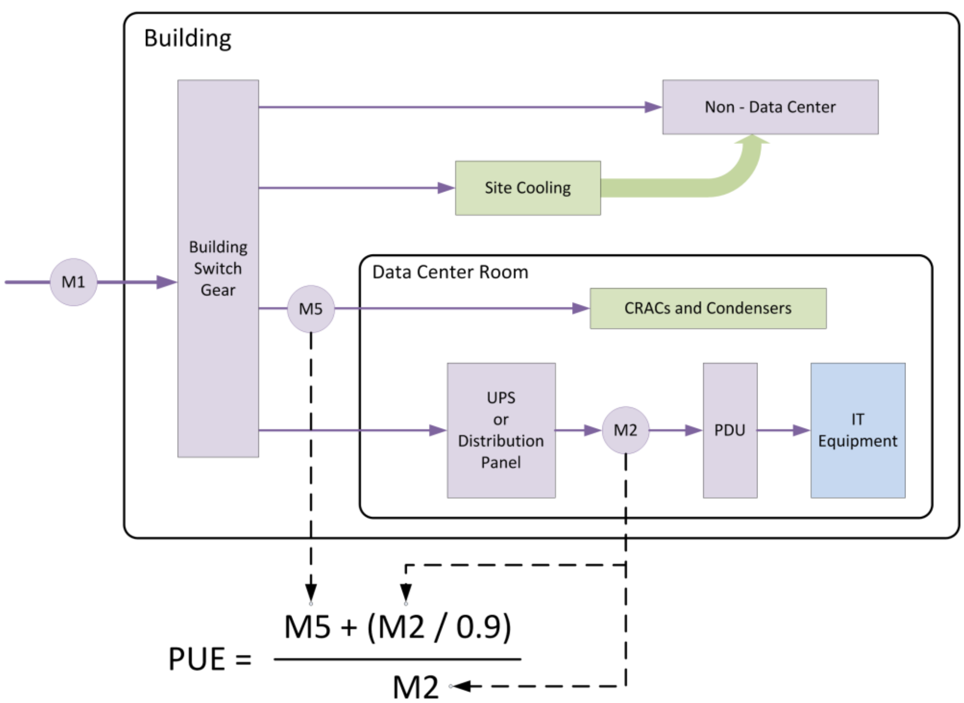


Figure 6. Embedded Data Center with Additional Metering: CRACs and Condensers input M5.

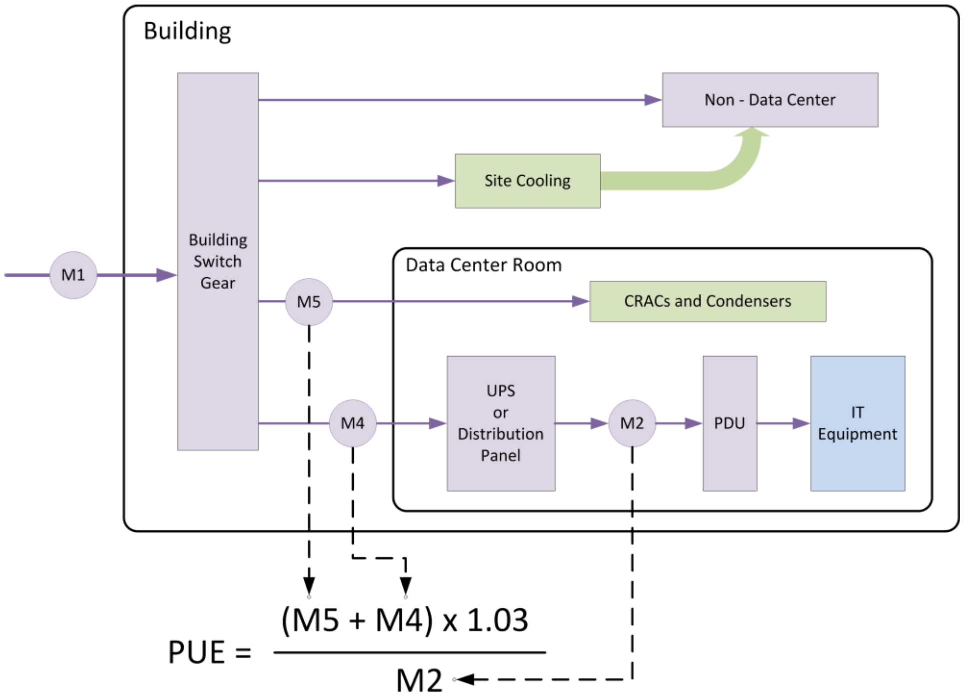


Figure 7. Embedded Data Center with Additional Metering: CRACs and Condensers input M5 and UPS input M4.

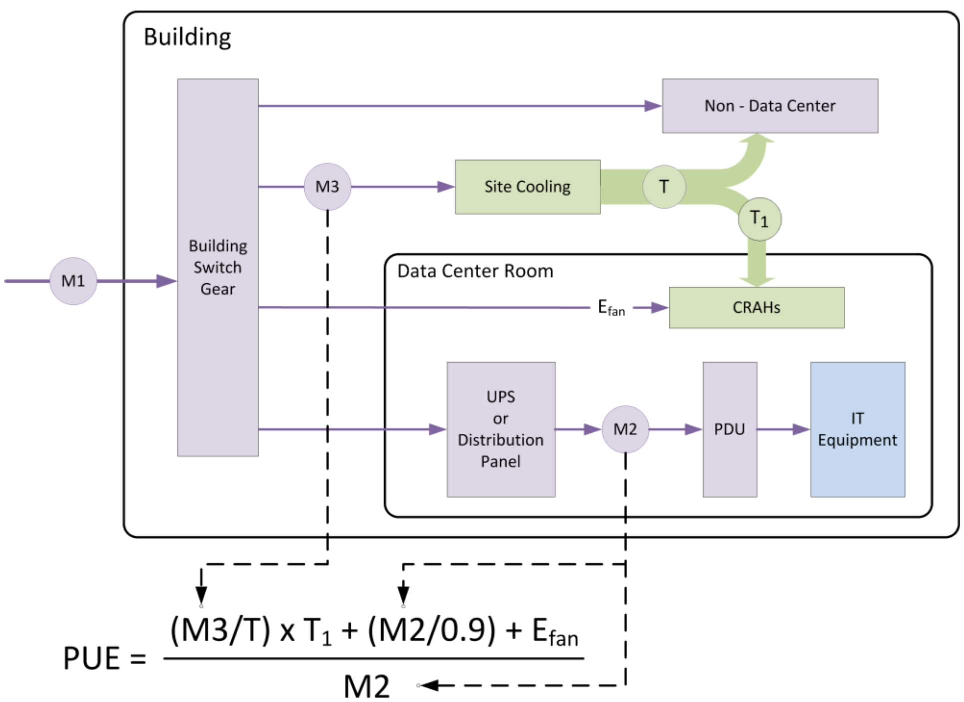


Figure 8. Embedded Data Center with Additional Metering: Chiller Plant input M3, Chiller Plant total output T, and Thermal input to Data Center T1.

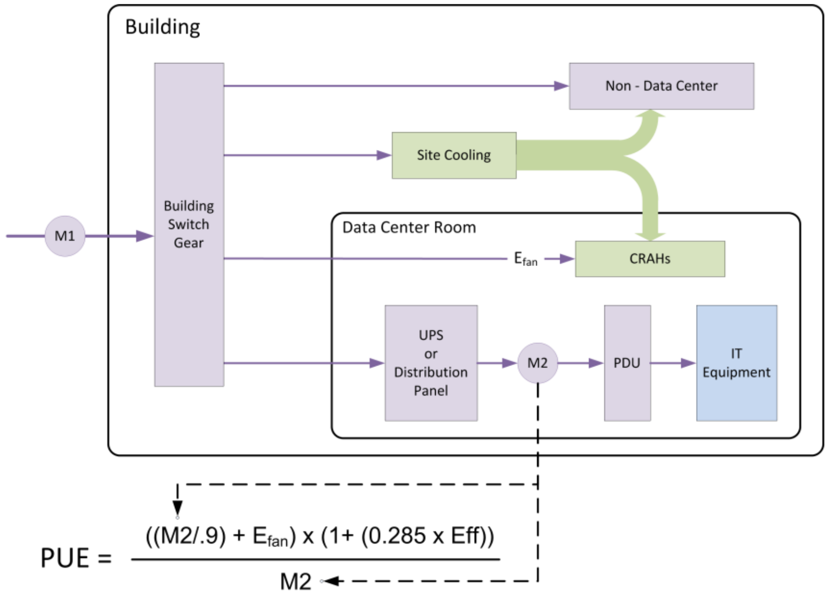
For data centers that only have UPS output energy available, it is still possible to estimate PUE as shown in Table 2 and corresponding Figures 9 through 12. Again, because several assumptions must be used for such estimates, users are strongly encouraged to install additional metering to obtain more-accurate data and generate easily trackable metrics.

TABLE 2 – PUE CALCULATION GUIDE FOR EMBEDDED DATA CENTERS WITHOUT ADDITIONAL METERING BEYOND UPS OUTPUT

Case	PUE Calculation
Water-cooled central chilled water plant plus CRAH units in the data center. See Figure 9.	PUE = $[((M2/0.9) + E_{fan}) \times (1+ (0.285 \times Eff))]/M2$ In this case, Eff = (Chiller efficiency + 0.2) kW/ton, where chiller efficiency can be obtained from Table 3 and 0.2 represents a typical additional load of chilled water and condenser water pumps and cooling tower fans.
Air-cooled central chilled water plant plus CRAH units in the data center. See Figure 10.	PUE = $[((M2/0.9) + E_{fan}) \times (1+ (0.285 \times Eff))]/M2$ In this case, Eff = (chiller efficiency + 0.1) kW/ton, where chiller efficiency can be obtained from Table 3 and 0.1 represents a typical additional load of chilled water pumps.
CRAC units in the data center, with air-cooled condensers. See Figure 11.	PUE = $[(M2/0.9) \times (1+ (0.285 \times 1.45))]/M2$ In this case, 1.45 kW/ton represents typical air-cooled CRAC efficiency, including fans.
Water-cooled chiller water plus CRAH units in the data center and a water-side economizer, or Air-cooled chilled water plant plus CRAH units in the data center and a water-side economizer. See Figure 12.	Treat the hours in the year that chiller is operating like the water-cooled chillers or air-cooled chiller discussed in the top two rows of this table. For hours in the year that the economizer is in active use: PUE = $[((M2/0.9) + E_{fan}) \times (1+ (0.285 \times 0.25))]/M2$ Where 0.25 kW/ton represents cooling system efficiency during economizer operation.

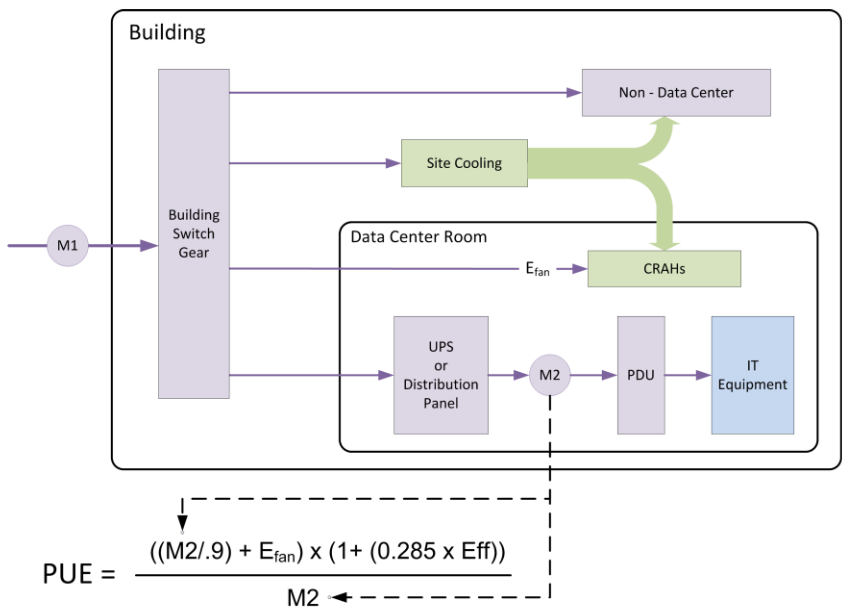
Notes:

1. *M2* is UPS output (kWh) from meter readings.
2. *M2/0.9* is based on assumption of 10 percent loss in electrical distribution upstream of the M2 measurement.
3. E_{fan} is the energy used by the CRAH fans (kWh). It can be estimated using motor nameplate. E_{fan} = (motor horsepower x 0.746 kW/hp x 0.75 assumed load factor x operating hours)/motor efficiency. Actual energy measurement is preferred, especially for fans with variable-speed drives (VSDs); many VSDs have built-in energy and power meters, which can be read at the same intervals as the UPS meters. Depending on power distribution to the CRAC or CRAH fans, a few central points can often be used to spot-check all of the units; one such power measurement is then assumed to be typical for the year.



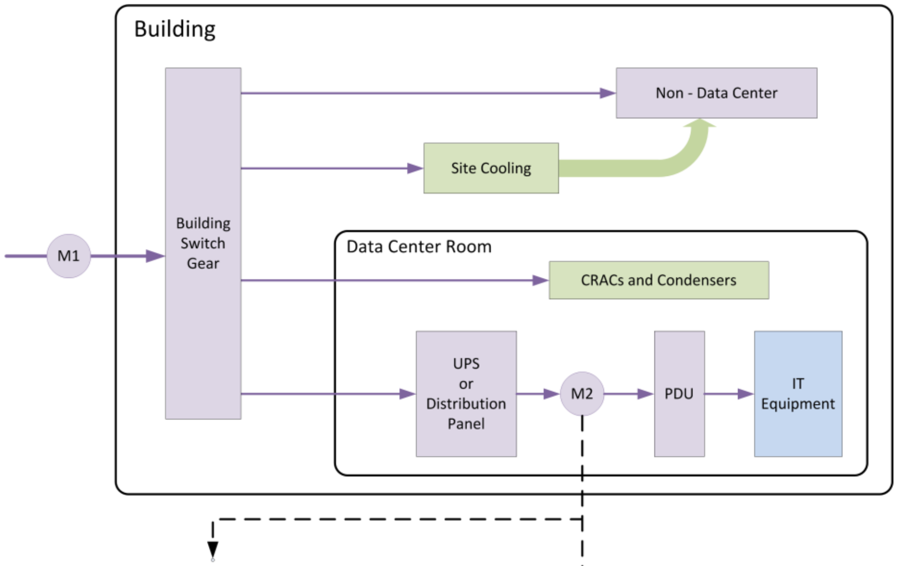
Eff = (Chiller efficiency + 0.2) kW/ton, where chiller efficiency can be obtained from Chiller Efficiency Table and 0.2 represents typical additional load of chilled water/condenser water pumps and cooling tower fans.

Figure 9. Embedded Data Center with No Additional Metering: Water-Cooled Chiller Plant with CRAHs.



Eff = (Chiller efficiency + 0.1) kW/ton, where chiller efficiency can be obtained from Chiller Efficiency Table and 0.1 represents typical additional load of chilled water pumps.

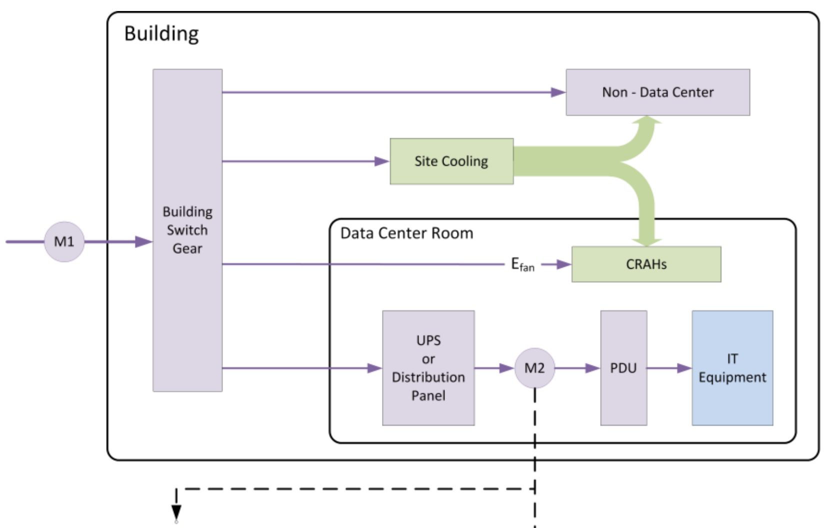
Figure 10. Embedded Data Center with No Additional Metering: Air-Cooled Chiller Plant with CRAHs.



$$\text{PUE} = \frac{(M2/.9) \times (1 + (0.285 \times 1.45))}{M2}$$

1.45 kW/ton represents typical air-cooled CRAC efficiency including fans.

Figure 11. Embedded Data Center with No Additional Metering: CRACs with Air-Cooled Condensers.



$$\text{PUE} = \frac{((M2/.9) + E_{fan}) \times (1 + (0.285 \times 0.25))}{M2}$$

0.25 kW/ton represents typical cooling plant efficiency during economizer operation.
Use this equation for economizer operating hours and otherwise-applicable equation for non-economizer hours.

Figure 12. Embedded Data Center with No Additional Metering: Water- or Air-cooled Chiller Plant with Water-Side Economizer (WSE).

Table 3 illustrates minimum efficiency for chillers as required by ASHRAE 90.1-2010 (edited from Table 6.8.1C). Note that mostly we are interested in Integrated Part-Load Value (IPLV) numbers, since they are a better indicator of the part-load conditions under which data center cooling plants typically operate. Note that these numbers are a good starting point for estimation, assuming there is a lack of more exact numbers for a particular plant, but they will typically underestimate the energy used by plants older than 2010.

TABLE 3 – CHILLER EFFICIENCY (EDITED FROM TABLE 6.8.1C – ASHRAE 90.1-2010)

Equipment Type	Size Category	Minimum Efficiency (kW/ton-IPLV)
Air-Cooled Chillers	< 150 ton	≤ .960
	> 150 ton	≤ .941
Water-Cooled Chillers Positive Displacement	< 75 ton	≤ .630
	≥ 75 ton and < 150 ton	≤ .615
	≥ 150 ton and < 300 ton	≤ .580
	≥ 300 ton	≤ .540
Water-Cooled Chillers Positive Displacement	< 300 ton	≤ .596
	≥ 300 ton and < 600 ton	≤ .549
	≥ 600 ton	≤ .539

Generally, Level 1 PUE calculations are performed using (homegrown) spreadsheet models used to manipulate the data. Data collection and communication are limited to manually acquired data—for instance, spot measurements may be taken monthly or weekly. Results can be displayed in spreadsheets or basic charts and graphs. The quality and extent of the reports mostly depends on the operator's knowledge base and level of effort. Some operators create homemade tools to do analytics and present the results. Unfortunately, the accuracy of these results is relatively low, considering the potential errors in recording the data from displays and meters, and the manual calculations and the time variability of the values. However, this level may be applicable for a site where savings opportunities are lower and extensive metering is not worthwhile.

3.4. Planning

Invite input from facility and IT managers on their needs and expectations. This information will help to ensure that all needs are being considered from the outset.

Select the assessment team. The chosen internal or external resource should be experienced and should demonstrate an ability to understand the specific needs and challenges. The resource also should be willing to engage in a consultation process to properly establish how their specific solution can integrate with your system, address your needs, and maximize new opportunities.

Create a metering plan to achieve the objective of measurement and reporting of PUE to show progress for the Better Buildings Challenge. The process will depend partly on the capabilities of the in-house or hired resource, as well as on your facility's specific needs, challenges, and data center type. It is important to have a plan for implementing the metering system before beginning the implementation process.

3.5. Collection of Information to Determine System Type

Once the data center type is determined (see 3.1. above), the power distribution and cooling system types must be reviewed in order to establish the necessary metering.

3.5.1. Drawings

System drawings of relevance include those for the electrical, mechanical, and control systems. The most important are the electrical "single line" drawings and the mechanical schedules and flow diagrams (also known as *piping diagrams* or *process and instrumentation diagrams*, or "P and ID"), e.g., for chilled water.

Electrical single-line drawings show the electrical distribution system for the building and show existing metering. Meters to look for include: main feeder(s) to the data center and for input to the IT equipment (meters might be built into the UPS output or PDU output). In stand-alone centers, these two numbers are all that is needed to determine the PUE. Note that per Energy Star Portfolio Manager instructions, to receive a score, UPS measurements must be used rather than PDU measurements unless there is a sufficiently high non-IT related load on the UPSs (lighting, CRACS, etc. greater than 10% of load), in which case measurements must be used to determine the equivalent of UPS output to the IT load. (Energy Star Portfolio Manager, 2016).

If the data center is embedded in a larger building with a shared cooling system (or is stand-alone but with chilled water fed from a central plant), mechanical drawings showing the configuration of the chilled water piping are most important. Piping diagrams are used to determine where thermal metering can be installed to determine the chilled water load for the data center, and potentially where metering can be installed to determine the overall chiller plant efficiency.

Drawings (including "As-Built" or "Record" ones) are notorious for being inaccurate, especially for older data centers, so a site visit is needed to verify actual conditions.

3.5.2. Interviews / Site visit

Interviewing the site infrastructure personnel can supply both general information (whether stand-alone or embedded data center type) and specifics (e.g., what meters are already in place). To determine actual site conditions, an inspection is needed of the electrical and mechanical systems, as well as operating conditions. If skilled personnel are working at the site, they can perform the inspection and pass on the information. Otherwise, a site visit by a knowledgeable person will be needed. Ideally, the site visit would merely confirm information made available through the drawings. Often the drawings only become available at the site visit, or no drawings are available, so the assessor needs to adapt to the available information and establish or verify appropriate metering locations.

3.6. Determination of Implementation Method

Regardless of who does the work, key implementation phases typically include:

- Project initiation,
- Defining needs and expectations,
- Obtaining buy-in from all stakeholders,
- Design (including review cycles),
- Installation,
- Integration and configuration,
- Commissioning, and
- Training.

Implementation needs a roadmap and a process to execute. For instance, practical concerns such as avoiding a shutdown of the data center operations while the metering system is being installed may be one worth planning around. Automating monitoring that was or could have been done manually is the first step. Power monitoring is usually the first monitoring phase, and thermal heat transfer metering is the second phase. The third phase is environmental (temperature, humidity, pressure) monitoring in the data center that will help operators explore energy-efficiency opportunities related to air management and environmental conditions.

Three methods of implementing a metering project are contracted, internal, or hybrid.

3.6.1. Contracted

In data centers with little or no internal capability to perform metering installation themselves, contracting the job is the best method. If the internal management team is able to write a tight set of project design requirements, a design-build contract can be the preferred method. Otherwise, a consultant can be hired to either write the requirements for a design-build contractor or create drawings and specifications for a construction contractor (the “design-bid-build” process).

3.6.2. Internal

In data centers with sufficient internal capability to perform metering installation themselves (e.g., multiple electricians or plumbers on staff), typically the best method is an internal (in-house) one. Someone needs to specify and order the proper metering equipment; this could be done internally if there is sufficient in-house engineering expertise. Otherwise an engineering consultant can be retained.

3.6.3. Hybrid

In some data centers, there is a mixture of capabilities that may differ considerably between the construction trades and engineering disciplines. In that case, a hybrid approach—where some work and/or design is done in-house and some is done by contractors—is optimal.

3.7. Commissioning

Commissioning is a well-planned, documented, and managed engineering approach to verify construction, start-up, and turnover of building systems, to ensure that all the installed systems meet design requirements and stakeholder expectations. The likelihood of success of the commissioning process is enhanced when the process begins early in the design phase. This document focuses on metering systems, where commissioning entails an end-to-end check, from sensors, to gateway, to server, and to visualization. System performance should be validated to be in acceptable ranges. Commissioning may be the hardest part of the implementation process. Every monitoring system on the site that is connected to the new metering needs to be recommissioned. In general, the commissioning process consists of the integrated application of a set of engineering techniques and procedures to check, inspect, and test every operational component of the project. This ranges from individual functions, such as instruments and equipment, up to complex amalgamations such as modules, subsystems, and systems. The key goal is to enable communications between sensors and gateways, and then to servers and monitoring/control consoles. Considering that the time stamp is different from one system to another, converting the data to information is the next key factor. Data center owners who do not have in-house expertise in commissioning should retain the services of a commissioning agent.

3.7.1. End-to-end check

The only way to ensure that a metering system is working properly is to perform an end-to-end check. This check uses portable metering to parallel the installed metering, and the readout of the portable meter must be compared to the final readout (e.g., on a remote computer screen) of the installed metering. Nearly any problem with the meter installation, setup, programming, networking, or display configuration will be revealed by this check. Problems with accumulation (e.g., converting kW to kWh) will not be revealed this way, unless the portable meter is left in place over time and is set to integrate the power into energy, which would be very time consuming. A separate test to confirm that the integration is being performed properly is thus typically needed.

3.7.2. Sum checking where possible

Another way to check metering is to compare the sums of sub-meters against the main meter that serves the sub-meters. In an ideal installation, everything would be sub-metered, the sum of the sub-meters could be compared against the main meter, and any discrepancy tracked down and repaired. This ideal is seldom realized, but there is often more metering than the minimum needed, and downstream meters can be used as at least a partial check on the upstream meters.

4. Anticipated Scenarios

4.1. Stand-alone Data Center

Stand-alone data centers typically have the best options for monitoring. Total power use can be calculated by using utility bills or meters. The UPS numbers can be read from the UPS display. The PUE Level 1 then can be calculated by dividing building energy use by UPS energy output (assumed as IT energy use). If the UPS serves other equipment beside the IT, such as CRACs, then it will be necessary to find a way to read the UPSs, PDUs, or distribution panel(s) that only serve the IT input power.

If the UPS reading is not available, as an example, a Modbus card can typically be installed to read the UPS output and report to a server. Consult with the vendor on different options in reading and reporting the UPS power output.

If there is no UPS, the total energy input to the PDUs serving the IT equipment should be used. If no display is available, metering needs to be installed at the panel(s) serving the PDUs. The problem with installing meters is that in most facilities, panels are not accessible while they are “hot” (energized and in use), so in many cases, meter installation should be planned to take place during a scheduled shutdown. See Section 6 for tips on how to address this and other installation challenges. Figure 2 above illustrates meter locations in a stand-alone data center. In addition to the main switch gear meter, the UPS or panel(s) serving IT is metered.

Note that for large standalone data centers, it is often the case that a small area of supporting office space is included in the total building measurement, and it is acceptable to ignore the energy use associated with these offices. Typically such space makes up only a few percent of total energy use.

4.2. Embedded Data Center

Power Usage Effectiveness calculations in embedded data centers are more complex than those in stand-alone data centers. Different scenarios for calculating PUE are used, depending on the different cooling system and metering architectures.

Some data centers have metering installed beyond UPS output. See Section 3.3, Table 1, and associated Figures 3 through 8 (above) for more details on the calculations when data from various meters are available, and for estimating power distribution losses.

Other data centers have no metering besides UPS output. In this case, additional estimation is required. See Section 3.3, Table 2, and associated Figures 9 through 12 (above) for instructions on estimating PUE in this scenario.

If there is no UPS, then the total PDU energy input is considered as IT energy. If no display is available, then install meters at the panel serving the PDUs.

4.3. Existing Metering System Types

Typically, a facility's existing metering consists of built-in power meters in the UPS output(s), supplied by the UPS manufacturer, and meter(s) for the whole data center, which are typically watt-hour meters supplied by the utility.

In an embedded data center, it is less likely that there is an electric meter just for the data center. There is typically a UPS output meter available, but it often only reads power (kilowatts) and not energy (kilowatt-hours). If there is heat rejection to a shared chilled water system, that heat is typically not metered for the data center.

Data centers with metering beyond PUE Level 1 requirements are likely candidates for Level 2 or 3 PUE. They are not covered in detail here, but more information is available; see The Green Grid and ASHRAE references.

5. Metering Method Options

5.1. General

As is shown in Figures 3 through 8 and as discussed above, there are certain points in the electrical and cooling distribution where meters can be installed to collect data so that PUE and other performance metrics can be calculated. The idea is to measure energy used by the IT system and the cooling system serving the IT, as well as electrical distribution losses. This approach ensures that PUE, cooling efficiency, and electrical distribution efficiency are identified.

5.2. Extending/Leveraging Existing Meters

In many data centers, there are already meters in some locations. Before planning an upgrade, to facilitate the performance metrics calculations, the existing system needs to be evaluated. The best approach is to first prepare a plan for metering that is suitable for the site and then evaluate the additional hardware and software needed to upgrade the existing system to comply with the plan. The main goal is to network the system so that it delivers data from all the related meters to one location for evaluation, calculation, and visualization.

5.3. Determining Metering When No Meters Are on Site

When there are no meters on site, the best approach is to first prepare a metering plan that suits the site and then evaluate the hardware and software that are needed. The scope of work depends on the level of metering that the stakeholders (data center management and operation) agree to. As was mentioned, PUE Level 1 metering requires a UPS output energy measurement and preferably cooling energy measurement, although a cooling energy estimation based on the cooling plant's efficiency is also acceptable. Refer to Section 3 for more details on different measurement levels and their requirements for hardware and software, including metering and estimating schemes when the data center is cooled by CRACs rather than a chilled water plant. A key goal at any level is to network the systems to get data from all the related meters to one location for evaluation, calculation, and visualization.

5.3.1. Meter types

Table 4 presents information on a variety of meters. The first part relates to power meters; the second part relates to thermal meters (a flow meter and a matched pair of temperature sensors); the third part relates to possible environmental monitoring.

TABLE 4 – METER TYPES AND THEIR USES

Measurement Equipment	Type	Accuracy (% of reading)	Cost Level
Part 1: Electrical Power			
Electrical Power	Solid-State	0.2–0.5	$$$
	Portable	0.5–2	$
Part 2: Thermal Meters			
Liquid Flow	Paddle Wheel	0.5–5	$
	Turbine Wheel	0.3–2	$$
	Venturi	0.5–2	$
	Ultrasonic	1–5	$$
	Variable Area	0.5–5	$
Part 3: Environmental Monitoring			
Temperature	Thermocouple	1.0–5.0	$
	Thermistors	0.1–2.0	$$
	RTDs	0.01–1.0	$$$
Pressure in Pipe	Bourdon	0.25–0.5	$$
	Strain Gauge	0.1–1	$$

6. Challenges to Meter Installation and Possible Solutions

6.1. Need for Shutdowns to Install Metering

6.1.1. Electrical metering: Shut down one system at a time in N+x systems

In order to install metering safely, the system being metered must typically be de-energized (see NFPA 70E). Many data centers are equipped with dual-fed power systems for redundancy; likewise, UPS systems are often modular. Turning off one system (or sub-system) at a time to install metering allows the data center to keep operating on the remaining system(s).

6.1.2. Electrical metering: Wait for system maintenance

Another approach, especially appropriate in data centers without redundant power systems, is to wait for a scheduled shutdown (typically done at least once a year for routine maintenance) and perform the meter installation at that time.

6.1.3. Thermal metering: Use hot-taps or ultrasonic meters

For thermal metering, which requires that the flow and temperature difference in chilled water systems be measured, there is a commonly used technique known as *hot-tapping,* whereby ports for the flow meter and temperature sensors can be installed safely on fully operational systems with only negligible water loss. This method is more expensive than an installation on a new piping system under construction, but the savings in time on existing piping to shut down, drain, refill, pressure test, and treat the water typically make hot tapping very cost-effective. Another technique for measuring water flows is through use of an ultrasonic meter, which clamps onto the outside of the pipe and uses ultrasonic signals to determine flow velocity and thus, for a given pipe size, volumetric flow. To read accurately, flow meters must be placed on a straight length of pipe of sufficient length.

6.2. Multiple Metering Systems: Utility, In-house Electrical, Building Automation Systems (BAS), Data Center Infrastructure Management (DCIM)

6.2.1. Manual assembly of data

Often a basic level of homegrown spreadsheet models is used to manipulate data. Data collection and communication may be limited to manually acquired data—for instance, spot measurements may be taken monthly or weekly. Results can be displayed in spreadsheets or basic charts and graphs. For the stand-alone case, utility or switch gear meters provide continuous and accumulated data on the center's total energy use. The UPS readings (manual or automatic) produce the IT energy use data. Where there is an embedded data center with a chilled water plant shared with other loads, a BTU meter can be used to measure the cooling energy use of the data center. If a BTU meter is not available, then cooling energy use should be estimated with the following data: chillers usually show power use (instantaneous) on a display; and for pumps and fans, nameplate readings can be used to estimate power use. Instantaneous chilled water temperatures can be read from the chiller display(s). See Section 3.3 for calculation details. Assembly of data in most cases is manual and through spreadsheets. By using certain applications, the time stamp of the different data can be manipulated to be the same, which simplifies presentation of the energy use trending and graphing.

The minimum requirement for the ENERGY STAR Portfolio Manager is annual total kilowatt-hours for the IT load, using UPS output (or equivalent where there is no UPS), and annual total kilowatt-hours for the data center total energy. Where the latter is not directly available from metering, the calculations in Section 3.3 can be used to get PUE, then the data center total = PUE x IT.

6.2.2. Automated assembly of data

For the PUE 1 case, in addition to a UPS display that may provide instantaneous data in a continuous and accumulated format, there may be BTU meters and HVAC fan energy data. The data from such disparate sources can be assembled automatically. Typically this assembly happens at a central location with an application to address different time stamps, units of measure, etc., so that the data can be presented whenever and however a user desires.

6.2.3. Commercial dashboard and database

Dashboard/database packages are commercially available and can facilitate the use of metered data from data centers, including:

- Display the most important performance indicators and performance measures that are being monitored; these are usually user-defined, user-friendly, and easy to understand.
- Display content that can include different kinds of charts and measured or calculated numbers presented graphically.
- Provide information for key stakeholders (owners, operators, and managers).
- Provide visual data that fits on a single computer screen. Different screens can be used to display different energy parameters.
- Update displayed data automatically.
- Support interactivity—filtering, drilling down, or customizing the screens to meet the needs of various stakeholders.
- Store data and generate reports on various goals of energy use, as needed or defined by the stakeholders.

6.2.3.1 In-house solution

An in-house solution is the most cost-effective approach for estimating the performance metrics (chiller plant kW/ton, fan W/cfm, etc.), even though it may lack the accuracy of commercially available metering and management systems.

Cooling power use is calculated considering the IT load and theoretical cooling load, air handler fan power use (nameplate), and cooling system efficiency. See Section 3.3, Table 2 for more information. This calculation works for both stand-alone and embedded data centers. Now that power use is calculated, homemade spreadsheets can be set up for energy calculations. This document can be as simple as multiplying all the power data by annual use hours (8,760 hours for 24 X 7 data centers) or any other period of use hours. Better accuracy can be achieved by using more complex data entry, such as adjusting IT load and cooling efficiency data by time of the day (showing that servers are busier during working hours and the cooling system is more efficient under a higher load factor) and season (showing that cooling systems are more efficient during cooler weather).

7. Metering Costs

7.1. Rough Order of Magnitude Cost

The cost of a monitoring and metering package will depend on the scope and design of the specific system and other competitive factors. For a rough estimate, the cost of metering can be $150–$1,500 per point (a point can be an analog or digital signal). Wireless monitoring points are in the range of $150–$400, and wired monitoring points are in the range of $500–$1,500 per point. The cost of a permanent reliable power meter with good accuracy, for example, can be as low as $3,000 and as high as $10,000.

7.2. Variables

One of the major cost variables is the location of the work to be performed. For example, labor is generally less expensive in the South than the Northeast, and the transportation expense to Hawaii drives up material costs there.

7.2.1. Scope

The biggest cost variable for a metering project is the scope, i.e., how many meters will be included and what type they will be. One source (Modius, 2014) estimates that metering needed for PUE metering scenarios ranges from about $3,000 (for integration of existing meters) to $17,000 (for main power meter, adding communication to existing UPS, and adding BTU meter to the cooling). The following sections provide some additional detail.

7.2.2. How much metering is already present

The extent of the existing metering relative to what is required is the most important cost variable. Some data centers already have the necessary metering, others have none, and many are in between.

- Stand-alone power and thermal meters: Stand-alone meters (i.e., those that are not built into other equipment) are somewhat common in data centers (especially at the utility service entrance). Such meters can be an integral part of the PUE metering system.
- Integrated meters on plant and electrical distribution equipment: Some electrical distribution equipment, especially UPS and PDU equipment, has built-in metering. Often this metering reads in power (kilowatts) only and not energy (kilowatt-hours), but often an option is available to convert such meters to display kilowatt-hours. Such meters, especially those metering UPS output, can be an important part of the PUE metering.
- Integrated meters in IT equipment: Each Energy Star IT product (servers, storage, and networking gear) can report input power with an accuracy of +/- 5%. Power (as well as inlet temperature and average CPU utilization) is sampled at least once every 10 seconds, and most implementations include timestamping the ability to pull data using any third party management software. This data

availability is more relevant to Level 3 than Level 1 PUE, and security concerns may restrict networking to gather these data, but it can be a valuable and inexpensive source of data.

- Extent of networking of existing meters: While networked meters are not required in order to measure PUE, having the meters networked so they can be read and recorded remotely greatly facilitates real-time tracking. Such tracking also allows troubleshooting and tuning in the data center and the power and cooling systems serving it. Different scenarios require different approaches:
- *No networking exists; all meters are manually read:* This scenario, where none of the meters are networked, is the most expensive to convert to a fully networked system.
- *Meters are on multiple networks:* It is common to have some meters on one network (typically electrical meters on a supervisory control and data acquisition (SCADA)-type system) and other meters (typically thermal meters on the building automation systems [BAS]). Both can be read remotely but are not on a fully integrated system. This scenario can be no cost if access to the data is acceptable, or relatively low cost if the data need to be on a single network.
- *Meters are on one network:* The least common scenario is for all necessary meters to be on a single network already. In this case, no additional expense is needed to get all of the data in one place where it is locally or remotely available.

References

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- Shehabi, A., S. Smith, D. Sartor, R. Brown, M. Herrlin, J. Koomey, E. Masanet, N. Horner, I. Azevado, and W. Lintner. 2016. "United States Data Center Energy Usage Report". Lawrence Berkeley National Laboratory. https://datacenters.lbl.gov/sites/all/files/DCEnergyUseReport_2016.pdf

Annotated References

No	Title	Publisher and issue date	Summary and Link
1	PUE™: A Comprehensive Examination of the Metric	ASHRAE-TGG 2014 TGG 2012	This book consolidates all previously published material in TGG and ASHRAE related to PUE and includes some new material. It is about reporting on data center energy use metrics and making decisions based on them. Available for purchase at: http://www.techstreet.com/ashrae/products/1869497?ashrae_auth_token This white paper is a good guide for all who implement, report on, and make decisions based on data center energy use metrics. Available at no cost at: http://www.thegreengrid.org/en/Global/Content/white-papers/WP49-PUEAComprehensiveExaminationoftheMetric
2	EIS Guide	LBNL 2014	The purpose of this document is to provide structured guidance to data center owners, operators, and designers, to empower them with information on how to specify and procure data center energy information systems (EIS) for managing the energy utilization of their data centers. Available at no cost at: https://datacenters.lbl.gov/resources/guidelines-data-center-energy
3	Data Center Energy Efficiency Measurement	LBNL 2014	The purpose of this document is to provide structured guidance to data center owners and operators, to empower them with information on the importance of

	Assessment Kit Guide and Specification		energy assessment and how a portable, temporary wireless mesh assessment kit can be used to speed the process and reduce the costs of a data center energy use assessment and overcome issues with respect to shutdowns. Available at no cost at: https://datacenters.lbl.gov/resources/data-center-energy-efficiency
4	Harmonizing Global Metrics for Data Center Energy Efficiency	TGG March 2014 Global Taskforce 2012	This guidance is published to drive a common understanding of energy-efficiency metrics. Available for TGG members at: https://www.thegreengrid.org/Global/Content/Regulatory-Activities/HarmonizingGlobalMetricsForDataCenterEnergyEfficiency_DCeP The purpose of this paper is to provide recommendations on measuring and publishing values for PUE at data centers. Available at no cost at: https://www.thegreengrid.org/~/media/WhitePapers/HarmonizingGlobalMetricsforDataCenterEnergyEfficiency2011-02-28.pdf?lang=en
5	Real-Time Energy Consumption in Data Centers	ASHRAE, TGG 2010	This book is designed to: ▶ Provide an overview of the state of energy consumption measurements in the data center. ▶ Educate the data center owner/operator with respect to making real-time energy consumption measurements in the data center. ▶ Demonstrate how to consolidate energy consumption data into a single energy-efficiency value, e.g., PUE. A slide presentation is available to TGG members at: http://www.thegreengrid.org/en/Global/Content/TechnicalForumPresentation/RealTimeEnergyConsumptionMeasurementsinDataCentershttp://www.thegreengrid.org/en/Global/Content/TechnicalForumPresentation/RealTimeEnergyConsumptionMeasurementsinDataCenters The book is available on Amazon: http://www.amazon.com/Real-Time-Energy-Consumption-Measurements-Centers/dp/1933742739

6	General Recommendations for a Federal Data Center Energy Management Dashboard Display	LBNL 2014	Dashboards help to track energy use and inform decisions for taking corrective action, and can be used to track the performance of energy-efficiency improvements once they have been implemented. This guide discusses some typical dashboard content that is useful for energy management. Available at: https://datacenters.lbl.gov/resources/femp-dashboard-guide
7	High Performance Computing Data Center Metering Protocol	ORNL for DOE 2010	This report is part of DOE effort to develop methods for measurement in high-performance computing data center facilities and document system strategies that have been used in data centers to increase data center energy efficiency. Available at: https://datacenters.lbl.gov/resources/high-performance-computing-data-center-metering-protocol

Additional Resources

- Energy Efficient High Performance Computing Power Measurement Methodology. No date. Energy Efficient High Performance Computing Working Group. http://www.green500.org/sites/default/files/eehpcwg/EEHPCWG_PowerMeasurementMethodology.pdf
- 2013 Best Practices for the EU Code of Conduct on Data Centres. European Commission 2013. http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/best_practices_v4_0_5-r1.pdf
- DPPE: Holistic Framework for Data Center Energy Efficiency - KPIs for Infrastructure, IT Equipment, Operation (and Renewable Energy). August 2012. http://home.jeita.or.jp/greenit-pc/topics/release/pdf/dppe_e_20120824.pdf

Appendix A: Data Center Energy Practitioner (DCEP) Program

DCEP description

The U.S. Department of Energy (DOE) partnered with industry to develop a Data Center Energy Practitioner (DCEP) certificate training program to accelerate energy savings in the dynamic and energy-intensive marketplace of data centers.

The DCEP program was defined, designed, and implemented by working closely with industry stakeholders. Presently there are more than 400 qualified practitioners. Significant knowledge, training, and skills are required to perform accurate energy assessments in data centers. DCEPs:

- Are qualified to identify and evaluate energy-efficiency opportunities in data centers.
- Demonstrate proficiency in the use of DOE's Data Center Profiler (DC Pro) Tool: https://datacenters.lbl.gov/dcpro.
- Address energy opportunities in electrical systems, air management, HVAC, and IT equipment.
- Meet academic/work experience requirements (pre-qualifications).
- Receive training on conducting data center assessments.
- Are required to pass an exam.

Property management companies, engineering consulting firms, service companies, data center operators, state energy agencies, and utilities benefit from the expertise provided by DCEPs.

Link to DCEP program

The direct link to the DCEP program is https://datacenters.lbl.gov/dcep

Link to practitioners

https://datacenters.lbl.gov/resources/dcep-program-developers-instructors-and

Appendix B: Data Center Profiler (DC Pro) Tools

DC Pro Tools description

The Data Center Profiler (DC Pro) Tools are “early stage” assessment tools that help data center operators estimate PUE without sub-metering. The current DC Pro Tools include DC Pro, which estimates PUE and provides tailored recommendations for improvement, and the simplified PUE Estimator. Results from both tools can be exported to PDF or Microsoft Excel to be used as a stand-alone report or included in other reporting material. Guidance on data collection is built into the tool, but additional guidance and information on how the tools estimate PUE is available in the user’s manuals.

DC Pro

- Estimates current and potential PUE and energy use distribution
- Provides tailored recommended actions to start an improvement process
- Requires a login and saves data

PUE Estimator

- Quick, simplified version of DC Pro
- Only asks questions that affect PUE
- Does not provide potential PUE or recommended actions
- No login and doesn’t save data

Link to DC Pro Tools

https://datacenters.lbl.gov/dcpro