

Recommendations for Measuring and Reporting Overall Data Center Efficiency

Version 2 – Measuring PUE for Data Centers

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Recommendations for Measuring and Reporting Overall Data Center Efficiency

Version 2 – Measuring PUE for Data Centers

1 Introduction

1.1 Purpose – Recommendations for Measuring and Publishing PUE at All Data Centers

The purpose of this document is to provide recommendations on measuring and publishing values for PUE at data centers. These recommendations represent the collective work of a task force representing 7x24 Exchange, ASHRAE, The Green Grid, Silicon Valley Leadership Group, U.S. Department of Energy Save Energy Now Program, U.S. Environmental Protection Agency's ENERGY STAR Program, United States Green Building Council, and Uptime Institute. The recommendations are prepared in accordance with the guiding principles, presented in the following section.

1.2 Background – Guiding Principles for Data Center Efficiency Metrics

As business demands and energy costs for data centers rise, owners and operators have focused on the energy efficiency of the data center as a whole, frequently using energy efficiency metrics. However, the metrics are not always applied clearly and consistently. To address these inconsistencies, a group of leaders from across the industry met on January 13, 2010 to agree on data center energy efficiency measurements, metrics, and reporting conventions. Organizations represented included the 7x24 Exchange, ASHRAE, The Green Grid, Silicon Valley Leadership Group, 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, and Uptime Institute.

The following guiding principles were agreed to:

- Power Usage Effectiveness (PUE) using source energy consumption is the preferred energy efficiency metric for data centers. PUE is a measurement of the total energy of the data center divided by the IT energy consumption.
- When calculating PUE, IT energy consumption should, at a minimum, be measured at the output of the uninterruptible power supply (UPS). However, the industry should progressively improve measurement capabilities over time so that measurement of IT energy consumption directly at the IT load (e.g., servers, storage, network, etc.) becomes the common practice.
- For a Dedicated Data Center, the total energy in the PUE equation will include all energy sources at the point of utility handoff to the data center owner or operator. For a Mixed-Use Data Center, the total energy will be all energy required to operate the data center, similar to a Dedicated Data Center, and should include cooling, lighting, and support infrastructure for the data center operations.

This guidance is meant to help the industry have a common understanding of energy efficiency metrics that can generate dialogue to improve data center efficiencies and reduce energy consumption. Member organizations are committed to applying and promoting these guidelines to their programs.

A task force was created to further refine these metrics and to identify a roadmap for the future. The group also aspires to address IT productivity and carbon accounting in the future.

1.3 Scope of Recommendations

The purpose of this document is to provide recommendations from this task force on how to measure and publish overall data center infrastructure energy efficiency, based on the agreed upon guiding principles. This document does not address IT efficiency. It also does not directly address system-level metrics for cooling or heat rejection, air flow management, power distribution, lighting, etc.

The task force recognizes that many data center operators may not currently have the capability to measure all energy consuming components within their data center accurately. The task force therefore recommends four (4) categories of measurement, which represent a subset of The Green Grid's (TGG) measurement methods¹. These categories range from relatively simple measurements that provide a performance snapshot to more sophisticated measurement means that provide highly detailed performance data.

The intent is to encourage operators with limited measurement equipment to participate while also defining a framework that allows operators to add additional measurement points to increase the accuracy of their measurement program. The goal is to recommend a consistent and repeatable measurement strategy that allows data center operators to monitor and improve the energy efficiency of their data center. A consistent measurement approach will also facilitate communication of PUE among data center owners and operators. It should be noted that caution must be exercised when an organization wishes to use PUE to compare different data centers, as it is necessary to first conduct appropriate data analyses to ensure that other factors such as levels of reliability and climate are not impacting the PUE.

These recommendations can also be used in the planning phase for a new data center or a major renovation of an existing building to assist in the placement and number of measurement points and monitoring equipment.

This document provides an overview of how to measure and report PUE per this task force's recommendations. This document is not intended to serve as a detailed technical reference. Further specific details and requirements on how to measure PUE are available in The Green Grid white papers (<http://www.thegreengrid.org/>).

2 Definitions

Ancillary Services: This term refers to services that may be part of any data center. While they do not directly provide infrastructure or power, they are typical building services that will be present within the data center boundary and should be included in the total energy. Ancillary services include bathrooms, lobbies, kitchenettes, offices, conference rooms.

Data Center in Mixed-Use Building (Mixed-Use Data Center): This refers to a data center that is located within a larger building that may support other functions. For example, a data center located on a single floor within a larger office building. In this case the larger building contains some combination of non-IT operations, such as general administrative office space. A Mixed-Use Data Center may have its own dedicated infrastructure (UPS and cooling) or may have shared infrastructure. Refer to the discussion of boundaries in Section 3.1. The Mixed-Use Data Center recommendations covered herein apply to data centers that have dedicated infrastructure (power and cooling).

Dedicated Data Center: In this context, a Dedicated Data Center is a free standing building in which all the spaces and supporting infrastructure (HVAC, lighting, electrical) are directly associated with the operation of the data center. Dedicated Data Centers are stand alone buildings whose exclusive purpose is IT operations and their support functions.

IT annual energy is calculated as annual electrical consumption of the IT. IT includes all IT equipment, servers, networking and storage as well as telecom equipment typically installed in telecom data centers.

¹ The Green Grid nomenclature and supporting information: <http://www.thegreengrid.org/en/Global/Content/white-papers/Usage%20and%20Public%20Reporting%20Guidelines%20for%20PUE%20DCiE>

Peak IT electric demand (kW) is the annual peak electric demand for the IT load.

Peak Total electric demand (kW) is the annual peak electric demand for the entire data center including IT and supporting infrastructure measured at the data center boundary (e.g. point of electric feed for Mixed-Use Data Centers or utility meters for Dedicated Data Centers).

PDU Output is defined as the output of the PDU that serves IT loads. PDU output does not include efficiency losses of any transformation that occurs within the PDU but may include downstream non-IT ancillary devices installed in IT racks such as fans. If there is non-IT equipment supported by the PDU system, (e.g., CRAC, CRAH, In-row coolers, etc.) it must be metered and subtracted from the PDU Output reading (the metering approach should be consistent with the metering required for the PUE category e.g. continuous consumption metering for PUE categories 1,2 and 3).

IT equipment input is defined as the IT load as measured at the point of connection of the IT device to the electrical power system, e.g., the power receptacle(s). *IT equipment* input captures the actual power load of the IT device exclusive of any power distribution losses and non-IT loads such as rack mounted fans.

Supporting infrastructure includes the following:

- Power systems: Transfer switch, UPS, DC batteries/rectifiers (non UPS – telco nodes), generator, transformer (step down), power distribution unit (PDU), rack distribution unit (RDU), breaker panels, distribution wiring, lighting.
- HVAC systems: Systems, equipment and control strategies including cooling towers, condenser water pumps, chillers, chilled water pumps, computer room air conditioners (CRAC's), computer room air handlers (CRAH's), dry cooler, supply fans, return fans, direct and indirect air economizer, direct and indirect evaporative cooling, water-side economizer, humidifier, in-row, in-rack, & in-chassis cooling solutions.
- Physical security: Fire suppression, water detection, physical security servers/ devices.
- Building management systems: computer-based control system that control and monitor the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems.

Total annual energy is calculated as the weighted sum of the annual energy consumption for all energy types serving the data center at the data center boundary. In a Dedicated Data Center building, this will include all energy captured on utility bills; for a Mixed-Use Data Center, all the same fuels must be sub-metered if they cross into the data center boundary. This includes electricity, natural gas, fuel oil, and district utilities such as supplied chilled water or condenser water. All energy types must be converted into the same units before they are summed. Total annual energy must include supporting infrastructure and dedicated ancillary services (see definitions above). Section 3.3 describes how to weight different energy types. (Note that weighting only applies for data centers that have energy types in addition to electricity.)

UPS Output is defined as the output of the UPS that serves IT equipment loads. UPS output does not include efficiency losses from the UPS system but does include losses from downstream electrical distribution components such as PDU's. It may include non-IT ancillary devices installed in IT racks such as fans. If there is non-IT equipment supported by the UPS system, (e.g., CRAC, CRAH, In-row coolers, etc.) it must be metered and subtracted from the UPS Output reading (the metering approach should be consistent with the metering required for the PUE category e.g. continuous consumption metering for PUE categories 1,2 and 3).

3 PUE Metric Calculation

Power Usage Effectiveness (PUE) is the recommended metric for characterizing and reporting overall data center infrastructure efficiency. The task force strongly recommends annual energy consumption (kWh) for all energy types as the unit of measure for PUE calculation. However an entry level measurement category has been included in the recommendations to allow operators that do not have consumption measurement capability to utilize demand based power readings.

PUE is defined by the following formula:

$$\text{PUE} = (\text{Total data center energy consumption or power} / \text{IT energy consumption or power})$$

The following sections detail boundary considerations for both Dedicated Data Centers and Mixed-Use Data Centers, describe the four recommended PUE categories for data centers, and address calculation details associated with proper accounting of all fuels and on-site systems.

3.1 Data Center Boundaries

The PUE calculation guidelines presented in this document address two data center configurations:

- Dedicated Data Center i.e. the data center is a free-standing building. (see definition)
- Mixed-Use Data Center with dedicated infrastructure i.e. the data center is within a larger building that has other uses, but the data center has dedicated HVAC and electrical systems. (see definition)

The PUE calculation approach presented below is the same for both these configurations. However, there are some minor differences in how the boundary for total energy use is defined for each configuration, as shown in Figure 1:

- In Dedicated Data Centers, the boundary is the building boundary i.e. all energy uses within in the building are included.
- In Mixed-Use Data Centers, shared ancillary services such as common lobbies, common bathrooms and elevators may be excluded from the energy use boundary. However, ancillary services that are dedicated to the data center must be included (e.g. lobby, bathrooms, office spaces that are dedicated to the data center operation).

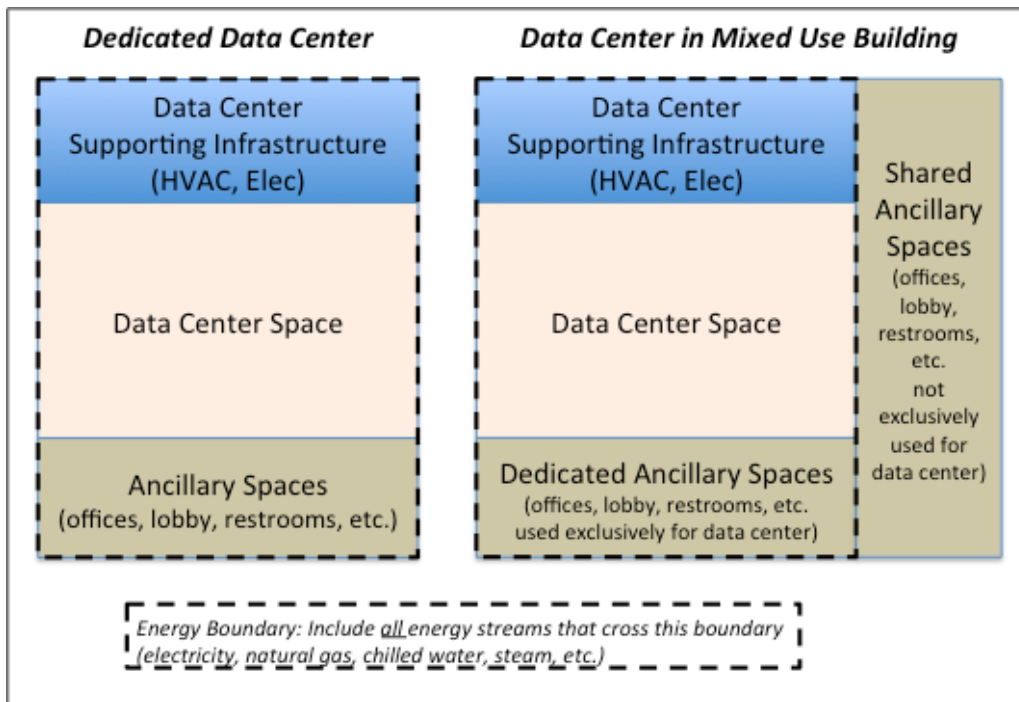


Figure 1: Energy use boundaries for Dedicated Data Centers and Mixed-Use Data Centers.

3.2 PUE Categories

The task force recommends four (4) measurement categories for the measurement of PUE within a data center:

PUE Category 0

This is a demand based calculation representing the peak load during a 12-month measurement period. IT power is represented by the demand (kW) reading of the UPS system output (or sum of outputs if more than one UPS system is installed) as measured during peak IT equipment utilization. Total data center power is measured at the data center boundary (e.g. point of electric feed for Mixed-Use Data Centers or utility meters for Dedicated Data Centers) and is typically reported as demand kW. As this is a snapshot measurement, the true impact of fluctuating IT or mechanical loads can be missed. However consistent measurement can still provide valuable data that can assist in managing energy efficiency. PUE category 0 may only be used for all-electric data centers i.e. it cannot be used for data centers that also use other types of energy (e.g. natural gas, district chilled water, etc.).

PUE Category 1

This is a consumption based calculation. The IT load is represented by a 12-month total kWh reading of the UPS system output (or sum of outputs if more than one UPS system is installed). This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points. The total energy must include all fuel types that enter the data center boundary (electricity, natural gas, chilled water, etc). In a Dedicated Data Center building, this will include all energy captured on utility bills; for a Mixed-Use Data Center, all the same fuels must be sub-metered if they cross into the data center boundary. Annual reading should reflect 12 consecutive months of energy data. This measurement method captures the impact of fluctuating IT and cooling loads and therefore provides a more accurate overall performance picture than PUE Category 0.

PUE Category 2

This is a consumption based calculation. The IT load is represented by a 12-month total kWh reading taken at the output of the PDU's supporting IT loads (or sum of outputs if more than one PDU is installed). This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points. The total energy is determined in the same way as Category 1. This measurement method provides additional accuracy of the IT load reading by removing the impact of losses associated with PDU transformers and static switches.

PUE Category 3

This is a consumption based calculation. The IT load is represented by a 12 month total kWh reading taken at the point of connection of the IT devices to the electrical system. This is a cumulative measurement and requires the use of kWh consumption meters at all measurement points. The total energy is determined in the same way as Category 1. This measurement method provides the highest level of accuracy for measurement of the IT load reading by removing all impact of losses associated with electrical distribution components and non-IT related devices, e.g., rack mounted fans, etc.

Table 1 summarizes the four categories.

Table 1: PUE measurement categories recommended by this task force.

	PUE Category 0*	PUE Category 1	PUE Category 2	PUE Category 3
IT energy measurement location	UPS output	UPS output	PDU output	IT equipment input
Definition of IT energy	Peak IT electric demand	IT annual energy	IT annual energy	IT annual energy
Definition of Total energy	Peak Total electric demand	Total annual energy	Total annual energy	Total annual energy

*For PUE Category 0 the measurements are electric demand (kW).

3.3 Weighting of Energy Types Based on Source Energy

For data centers that have electricity as well as other energy types, the different energy types must be weighted according to their source energy. Source energy represents the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses, thereby enabling a complete assessment of energy efficiency in a building. Table 2 provides the weighting factors for each energy type, normalized to electricity. These weighting factors are based on national average source factors used by EPA in their building energy benchmarking.

Weighted energy for each energy type = (Annual energy use X source energy weighting factor).

Note that all energy types must be converted into the same units before they are summed². For example, if electricity is in kWh and natural gas is in kBtu, both must be converted to a common unit.

Table 2: Source energy weighting factors³

Energy Type	Weighting Factor
Electricity	1.0
Natural gas	0.31
Fuel oil	0.30
Other fuels	0.30
District chilled water	0.31
District hot water	0.40
District steam	0.43
Condenser water	0.03

Appendix A has an example of PUE calculation using source energy Weighting Factors.

3.4 Renewable Energy Sources

Electricity from renewable energy (RE) sources should be included in the total energy or power and assigned the same source factor as grid electricity. In other words, RE sources are outside the PUE calculation boundary (Figure 2). Therefore, the installation of RE sources does not change the PUE (i.e. an all-grid building and all-RE building would have the same PUE). The rationale for this is that the purpose of the PUE is to evaluate how efficiently energy is used in the data center, regardless of the energy supply. Renewable energy in this context includes solar and wind power.

² For conversion factors, see:

http://www.energystar.gov/ia/business/tools_resources/target_finder/help/Energy_Units_Conversion_Table.htm

³ The EPA source energy factor methodology for all energy types except condenser water is available at:

http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf. The weighting factors presented in this recommendation document are obtained by dividing each EPA source factor by the reference source factor for electricity, 3.34. The factor for condenser water was calculated assuming 20 gpm/hp, 3 gpm/ton and 1% line losses.

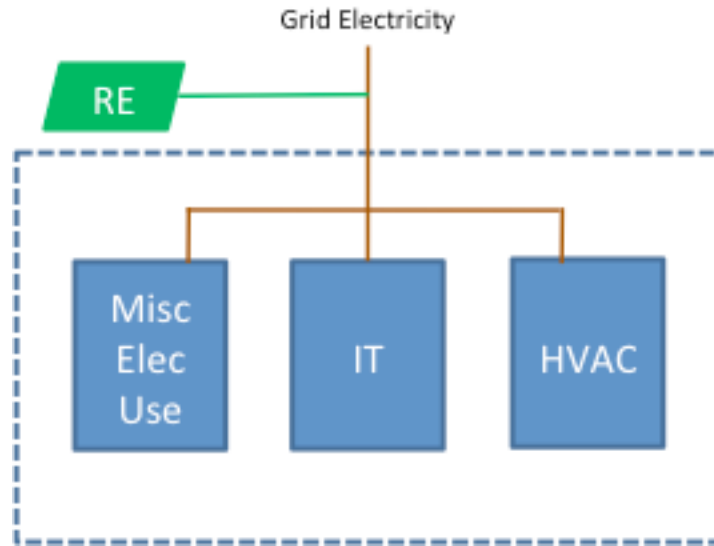


Figure 2: Data center PUE calculation boundary with renewable energy

3.5 Combined Heat and Power Plants

If the data center has a dedicated combined heat and power (CHP) plant, the inputs to the CHP should be included in the total energy or power (Figure 3) and assigned the same source factors as those shown in table 1. The outputs from the CHP should not be included in the total energy or power. The use of CHP (like the use of more efficient cooling or other equipment) should lower the PUE. The rationale for this is that CHP is considered to be an efficiency measure rather than an alternative source of energy.

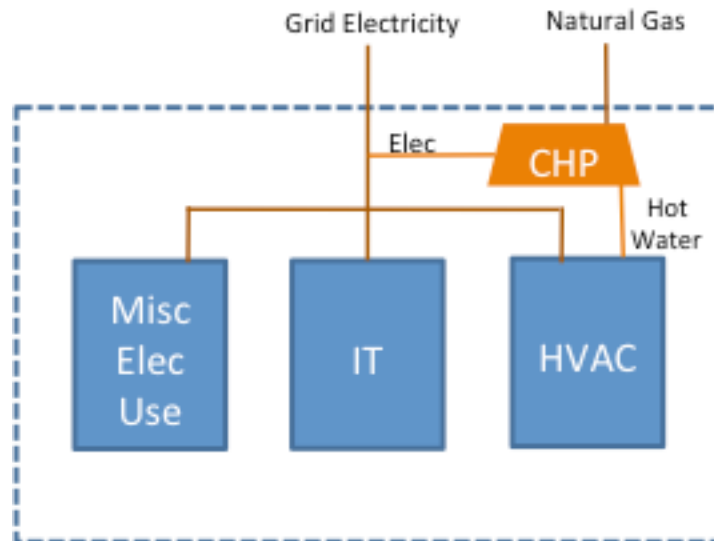


Figure 3: Data center PUE calculation boundary with CHP.

To enable equitable PUE calculations in data center designs that operate on-site electric generation two topics need to be explained:

- IT Source Energy Conversion Factor
 - To ensure the PUE calculations for a design including on-site electric generation and a design excluding on-site electric generation are equitable, the taskforce uses an IT Source Energy Factor (Figure 4). The IT Source Energy Factor enables the data center owner / operator to include the efficiencies of generating chilled water (as in all calculations for PUE), but exclude the efficiencies of generating electricity (as in all calculations for PUE). PUE is not a metric to reward or penalize the efficiencies of how electricity is brought to the data center, it is a metric to identify how efficient the electricity is used from the data center boundary to the IT Equipment.

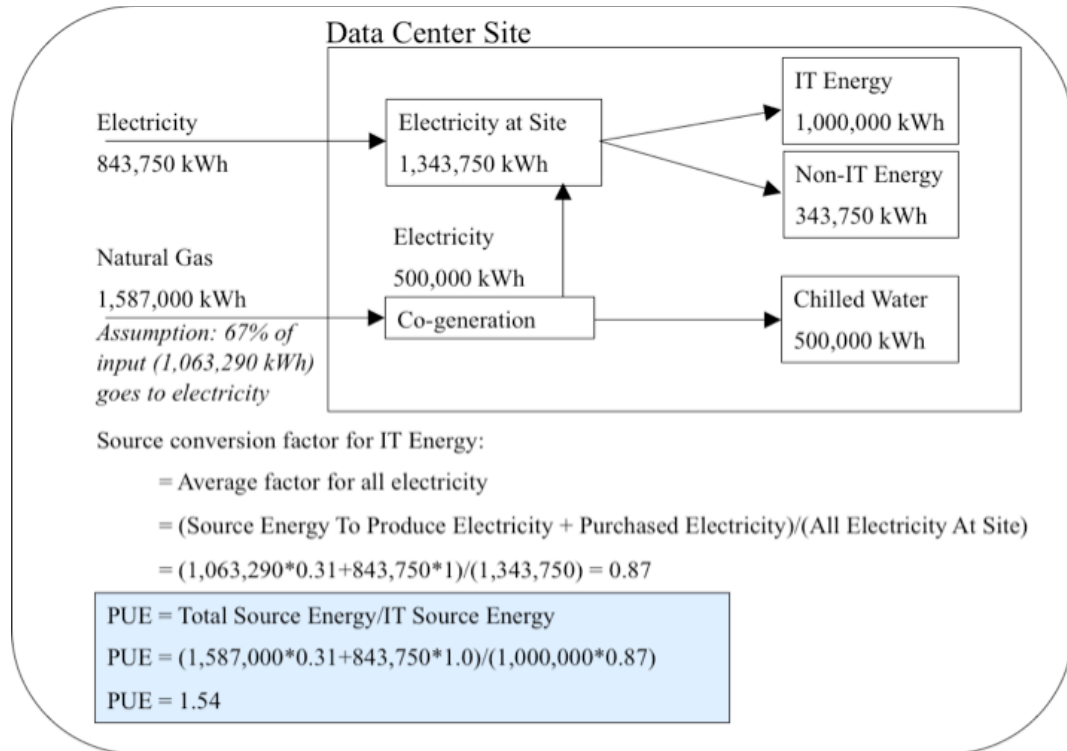


Figure 4: Data center with electric and natural gas (Co-generation) purchase

- Cogeneration Input Fuel Assumption
 - This taskforce has adopted the assumption that 67% of a cogeneration plants' input fuel is allocated to the primary form of generation (electricity in the provided example) and respectively 33% of the primary input fuel is allocated to the secondary form of generation (chilled water in the provided example).
 - This assumption is based on a similar steam based cogeneration study from the U.S. Environmental Protection Agency's Energy Star Program. Differences do exist between the two scenarios, but to solidify the methodology of calculating PUE and to drive consistent and equitable calculations for all design types, this taskforce is proceeding with the recommendation to adopt this approach. As further data specific to cogeneration examples are provided, the data will be taken into consideration. Provided there is a material change in calculations, the taskforce will consider updating the recommendations specific to this assumption.

3.6 Reused Data Center Energy

The concept of reusing waste energy (generally in the form of heat) is receiving a lot of study as part of an overall effort to improve energy efficiency. The value of this energy may or may not affect PUE, depending on the location of the re-use.

- If the energy is reused within the datacenter, the value of the reused energy will already be contained within the PUE calculation and needs no special consideration. An example will be reusing waste heat to warm a battery space in a cool climate. The PUE would generally be lower because the HVAC system does not have to add as much energy to heat that battery space, thereby reducing the PUE when energy is measured and PUE calculated.
- If the energy is reused outside the data center (e.g. re-using heat to warm a lab that is not part of the data center), the PUE of the data center is not affected. While the effort to conserve energy is laudable, it cannot be accounted for in the calculation of the data center PUE due to the strict definition of PUE used in these recommendations. Currently there are on-going industry efforts to define a metric that could be used to account for this beneficial use, but it is specifically excluded from PUE.

4 Publishing Format and Related Resources

When publishing PUE, the category must clearly be indicated using a subscript e.g. PUE₀, PUE₁, PUE₂, PUE₃. A PUE reported without the subscript is not considered to be in compliance with these recommendations.

Note that PUE₀ may only be used for all-electric data centers. It cannot be used for data centers that also use other types of energy (e.g. natural gas, district chilled water, etc.). An all-electric data center can utilize any of the PUE categories.

When publishing PUE calculated in accordance with these guidelines, users may state that “PUE was calculated in accordance with the recommendations of the Data Center Metrics Coordination Taskforce, sponsored by 7x24 Exchange, ASHRAE, The Green Grid, Silicon Valley Leadership Group, U.S. Department of Energy Save Energy Now Program, U.S. Environmental Protection Agency’s ENREGY STAR Program, United States Green Building Council, and Uptime Institute.”

4.1 Related Resources and Tools

The Green Grid (TGG) white paper #22⁴ provides a range of options for calculating PUE, as well as an annotation system to indicate how PUE was calculated. The recommendations of this task force are essentially a subset of the options in TGG framework, as shown in Table 3, and are therefore consistent with TGG framework.

Table 3: Mapping of PUE categories to TGG framework

PUE category	TGG annotation
PUE ₀	PUE _{L1,Y--}
PUE ₁	PUE _{L1,YC}
PUE ₂	PUE _{L2,YC}
PUE ₃	PUE _{L3,YC}

The U.S. EPA Energy Star Portfolio Manager tool will be incorporating PUE calculations that are consistent with PUE₁.

The U.S. DOE’s DC Pro tool will be incorporating PUE calculations that are consistent with PUE₂.

The US Green Building Council’s forthcoming LEED credit adaptations for data centers has information related to the amount and type of monitoring equipment that are either prerequisites or for achieving additional points in the monitoring and verification credit category. The PUE definition used is consistent with PUE₂.

⁴ The Green Grid nomenclature and supporting information: <http://www.thegreengrid.org/en/Global/Content/white-papers/Usage%20and%20Public%20Reporting%20Guidelines%20for%20PUE%20DCiE>

5 Next Steps

This document (Version 2) provides guidance for PUE measurement and publication for Dedicated Data Centers and Mixed-Use Data Centers with dedicated infrastructure. Following the release of this document each participating organization will work to disseminate this information and promote measurement and reporting of PUE across the IT industry.

At the same time, all participating organizations will reconvene to discuss the important next steps to continue to move the industry towards effective energy efficiency metrics, including metrics of IT productivity. The organizations will continue to work together, and may establish new task forces as necessary to help provide consistent guidance to the industry.

Appendix A. Example PUE Calculation Using Source Energy Weighting Factors

PUE should be based upon Source Energy as described in Section 2.2 of this document as well as the EPA source energy factor methodology as described in:

http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf.

Table 2 from the main document is reproduced here for convenience

<i>Energy Type</i>	<i>Weighting Factor</i>
Electricity	1.0
Natural gas	0.31
Fuel Oil	0.30
Other fuels	0.30
District chilled water	0.31
District hot water	0.40
District steam	0.43
Condenser water	0.03

Each component of the PUE calculation needs to be multiplied by the appropriate Weighting Factor.

Recall the definition of PUE: Total Energy divided by IT Energy.

$$PUE = \frac{TotalEnergy}{ITEnergy}$$

Total energy should include all fuel sources. For an example data center that purchases electricity and district chilled water, the equation can be expressed as:

$$PUE = \frac{Electricity + DistrictChilled\ Water}{IT\ Energy}$$

To compute a PUE in accordance with these recommendations it is critical to include all fuels. For illustrative purposes, consider two fictitious data centers: Case A is an all electric data center, while Case B purchases chilled water from a local utility. The following tables show the input fuels, the end uses, and the approximate energy use for each end use. In order to compute the PUE it is not necessary to have the energy for each end use separately. The total energy is simply summed across all energy inputs to the data center (at the data center boundary). The IT energy is the only end use that must be sub-metered within the building.

Case A – All Electric Data Center

<i>Energy Input to Data Center</i>	<i>End-use</i>	<i>Energy Use</i>
Electricity (1,705,000 kWh total)	IT Load	1,000,000 kWh
	Power delivery loss	250,000 kWh
	Lighting	50,000 kWh
	Cooling	400,000 kWh
	Other	5,000 kWh

The PUE for Case A would be computed as:

$$PUE = \frac{1,705,000 * (1.0)}{1,000,000 * (1.0)} = 1.70$$

Case B – Data Center with District Chilled Water

<i>Energy Input to Data Center</i>	<i>End-use</i>	<i>Energy Use</i>
Electricity (1,305,000 kWh total)	IT	1,000,000 kWh
	Power system loss	250,000 kWh
	Lighting	50,000 kWh
	Other	5,000 kWh
District Chilled water (1,300,000 kWh total)	Cooling	1,300,000 kWh (4.44 M BTUs)

In Case B, district chilled water is used to provide cooling (remove excess heat). The PUE for Case B would be computed as:

$$PUE = \frac{1,305,000*(1.0)+1,300,000*0.31}{1,000,000*(1.0)} = 1.70$$

It is informative to consider that the PUE for each case is 1.70. The implication of this is that the efficiency of the cooling system in the all electric data center is identical to the efficiency with which the District Chilled Water is produced. If the Case A's cooling system was more efficient, then it would have required less than the 400,000 kWh in the example and the PUE would be lower. If Case A's cooling system is less efficient then it would have used more than the 400,000 kWh to cool the data center (including distribution losses and lighting) and the PUE would be higher.