



THE GREEN GRID METRICS: DATA CENTER INFRASTRUCTURE EFFICIENCY (DCIE) DETAILED ANALYSIS

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EXECUTIVE SUMMARY

The Green Grid previously published THE GREEN GRID METRICS: DESCRIBING DATACENTER POWER EFFICIENCY white paper. The following is detailed analysis to support and strengthen the Data Center infrastructure Efficiency (DCiE) metric. The intent is to enable data center managers collectively to derive and use DCiE as a global standard metric.



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INTRODUCTION

Previously, The Green Grid published a white paper entitled “The Green Grid Metrics: Describing Data Center Power Efficiency”. The white paper discussed the need for a finite number of industry-accepted metrics that describe the effectiveness and efficiency of data centers around the world. The white paper also provided an overview of a proposed metric called the “Data Center infrastructure Efficiency” (DCiE).

A phased approach will be adopted as The Green Grid provides increasingly detailed information with respect to quantification of the DCiE. Table 1 provides a graphical representation of the approach. This White Paper represents the first in a series of White Papers that will provide a more detailed analysis of the DCiE metric, and represents the “Basic” level in Table 1.



	<u>Level 1 (Basic)</u>	<u>Level 2 (Intermediate)</u>	<u>Level 3 (Advanced)</u>
<u>IT Equipment Power</u>	<u>UPS</u>	<u>PDU</u>	<u>Server...</u>
<u>Total Facility Power Where</u>	<u>Data Center input power</u>	<u>Data Center input power less shared HVAC</u>	<u>Data Center input power less shared HVAC plus building lighting, security</u>
<u>Minimum Measurement Interval</u>	<u>1month / 1Week</u>	<u>Daily</u>	<u>Continuous (XX min)</u>

Level 1(Basic) involves collecting power measurements on at least a monthly basis from the UPS equipment within the data center (the IT Load) and from the Main Distribution panel feeding all of the mechanical equipment used to cool and condition the data center.

Level 2 (Intermediate) would involve collecting data on at least a daily basis using measurements taken at the PDUs within the data center and from the distribution system used to power each of the pieces of equipment that make up the “Facility” equipment.

Level 3 (Advanced) would involve collecting data from each individual piece of IT equipment within the data center and from each individual piece of facility’s equipment on a continuous basis.

For the “Basic” and “Intermediate” measurement processes, it is recommended that the measurements be taken at approximately the same time of day and when the loading in the data center is as consistent as possible with prior measurements. When making week to week comparisons, the day of the week should also be kept constant for comparable measurements.

This White Paper starts with an overview of the DCiE, and includes a graphical representation of the subsystems included in the DCiE, a discussion of how to obtain the required data and a description of, and suggestions for, obtaining DCiE in multi-use facilities. The overriding goal of this and all subsequent papers is to educate data center operators on how to collect the necessary data and interpret the metric in order to drive a given facility to a higher level of effectiveness and efficiency, i.e., a higher DCiE.

BACKGROUND AND ASSUMPTIONS

The recommendations below are based upon a dedicated data center facility. If working with a multiuse facility (ex. office space and data center space combined) see Multiuse Facilities section later in this document to assist with the additional calculations. It is recommended that DCiE be monitored over a period of one year with ongoing measurements in order to compensate for peak and nominal loading changes that occur within the data center. If it’s not possible to monitor power consumption over a full year, select a period

of time not less than one month and verify that the loading within the data center is typical for your particular environment.

It is important to understand the difference between cumulative and instantaneous measurements and the effect of variations (of load, of environment, etc.) on the overall infrastructure efficiency. An instantaneous reading of power for the IT equipment and the total facility power (e.g. in kW) will yield an instantaneous value for DCiE, however it should be expected that this will vary on daily, weekly, monthly or annual cycles depending on load, environment and other factors. More frequent instantaneous measurements will result in a better understanding of this variation and an insight into the factors that most influence the overall facility efficiency. To get a useful single metric for DCiE the cumulative energy use should be measured (e.g. in kWhr) for a period that is longer than the cyclic variation in efficiency, for many facilities this may be a full year.



DCiE OVERVIEW

Equation 1

$$\text{DCiE} = \frac{\text{IT Equipment Power}}{\text{Total Facility Power}}$$

DCiE is defined as the ratio of IT Equipment Power and Total Facilities Power as shown in Equation 1 above. The Total Facility Power is defined as the power measured at the utility meter – the power dedicated solely to the datacenter (this distinction is important in mixed-use buildings that house data centers as one of a number of functions). The IT Equipment Power is defined as the power consumed by equipment that is used to manage, process, store or route data within the compute space.

It is important to understand the components for the loads in the metrics, which can be described as follows:

1. IT Equipment Power:

This includes the load associated with all of the IT equipment, i.e. compute, storage and network equipment, along with supplemental equipment i.e. KVM switches, monitors, and workstations/laptops used to monitor or otherwise control the data center.

2. Total Facility Power:

This includes all IT Equipment power as described in number 1 above plus everything that supports the IT equipment load such as:

- a. Power delivery components i.e. UPS, switch gear, generators, PDUs, batteries and distribution losses external to the IT equipment
- b. Cooling system components i.e. chillers, computer room air conditioning units (CRAC's), direct expansion air handler (DX) units, pumps, and cooling towers
- c. Other miscellaneous component loads such as datacenter lighting

The following diagram (Figure 1) shows a typical data center with indicated measurement points for the proposed levels for measuring DCiE listed in Table 1. These points are indicated by meters in the diagram with associated levels indicated as Level 1 through Level 3 (L1-L3).

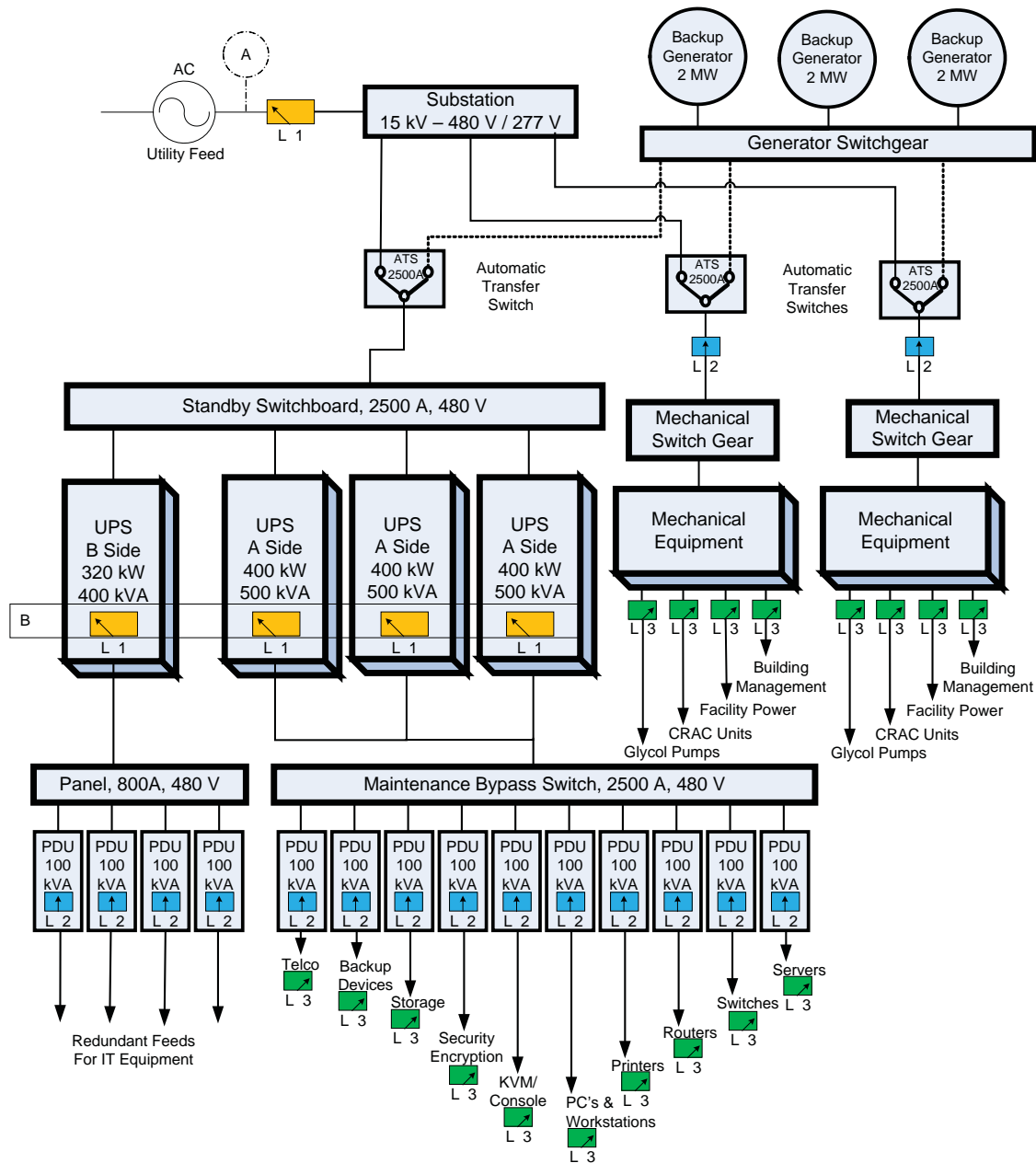


Figure 1

Note: You cannot accurately calculate DCiE using name plate ratings for any of the IT Equipment OR for any of the Mechanical Infrastructure components. Actual power measurements must be collected in order for DCiE to have any correlation to an operational data center.

DCiE SUBCOMPONENTS

In order for DCiE to become a global metric there are two important requirements all must follow:

- 1) Correctly classify each sub-component that comprises the metric's two core contributors
- 2) Obtain the data inputs that create DCiE's two core contributors in the same method, i.e. utilize a consistent method for data capture and always use actual measurements.



DCiE Subcomponents

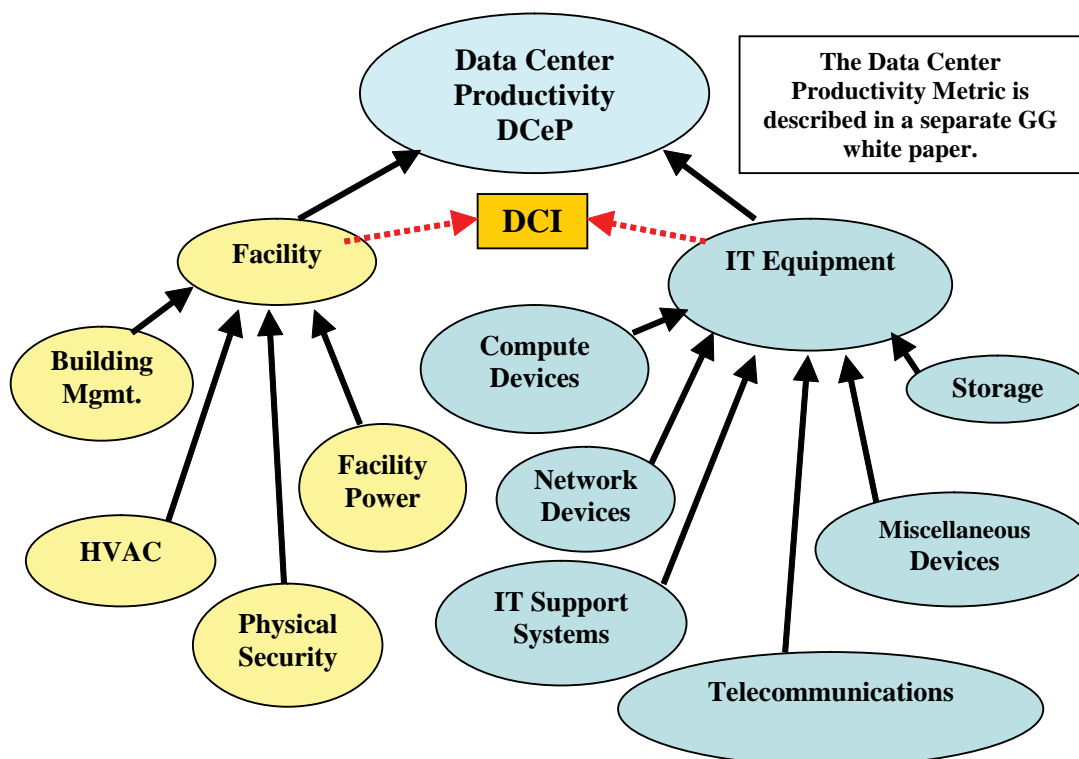


Figure 2

Table 2 below is designed to assist with correctly classifying each sub component:

- Organize the components to map to the “DCiE Subcomponent Drawing” shown in Figure 2
- Organize the components from the largest offender to the smallest offender – this will allow you to easily focus on the area's that need the most improvement in order to improve your DCiE

Table 2

Subcomponent	Core Contributor
Facility	
	Power
	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
	Heating Ventilation & Air Conditioning (HVAC)
	Cooling Tower
	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
	Air Economizer
	Water-side Economizer
	Humidifier
	In-row, In-rack, & In-chassis Cooling Solutions
	Physical Security
	Fire Suppression
	Water Detection
	Physical Security Servers / Devices
	Building Management System
	Server / Devices used to control management of Data Center
	Probes / Sensors





IT Equipment	
	Compute Devices
	Servers
	Network Devices
	Switches
	Routers
	IT Support Systems
	Printers
	PC's / workstations
	Remote Management (KVM / Console/ etc.)
	Miscellaneous Devices
	Security encryption, Storage Encryption, Appliances etc.
	Storage
	Storage Devices- Switches, Storage Array
	Backup Devices – Media Libraries, Virtual Media Libraries
	Telecommunication
	All Telco Devices

OBTAINING REQUIRED DATA

As defined in the Introduction, the DCiE is the ratio of the IT Power and the Total Facility Power. There are two fundamentally different methods for obtaining data necessary to make the DCiE calculation. One can either estimate the power by using available information on the equipment factoring in appropriate operational and ambient properties, or one can measure the actual power consumption of the required components.

ESTIMATING POWER CONSUMPTION

Power consumption for the various components necessary to populate the DCiE equation can be obtained using estimates such as efficiency curves and estimated loading conditions. The Green Grid envisions this method to be useful in estimating expected DCiE and evaluating alternatives during design and planning stages for future data centers. The Green Grid does not recommend this approach for operational data centers and strongly recommends one of the following approaches.

MEASURING POWER CONSUMPTION

The Green Grid recommended approach for obtaining the data necessary to calculate DCiE is to measure actual power consumption for the entire data center and IT equipment. TGG recognizes that obtaining actual measurement is not a trivial task especially in existing data centers that do not have adequate instrumentation to collect the data. The minimum required measurement data would consist of two measurements one being total facility power (Point A in Figure 1) and IT equipment power (Point B in Figure 1). Although this would be adequate to calculate DCiE, The Green Grid believes that more data would be necessary to assess areas for potential improvements and evaluating changes intended to improve DCiE within a data center.

POWER METERING REQUIREMENTS



The typical specifications of power meters include the terms accuracy, resolution, crest factor and bandwidth, but most important to measuring the power use of equipment is requiring a suitable watt meter that reports the “true” power, via the simultaneous measurement of the input voltage, current and power factor (note that kVa, the product of voltage and current alone is not an accurate representation of the power used). Many watt meters also have the capability to report energy usage which is the measurement of power over time (kWatt hours or Joules).

Accuracy is specified in terms of percent error in the measurement. While a low error is desirable and often needed, one must note the specified range over which the accuracy is stated and whether or not it is specified as the accuracy of full scale. Having a uniform percentage error over the full range of operation is more important. Measurements with a maximum of $\pm 5\%$ error can be useful in determining overall power usage trends for level 1 measurement, but it is recommended that meters used have at least a $\pm 2\%$ accuracy.

Resolution is the term used for number of significant digits that carry meaning contributing to the accuracy and often will vary with the measurement range. A 0.1 Watt resolution is recommended for the measurement of a single piece of IT equipment. This level is not obtainable for the meter of a multi-megawatt data center utility feed. An acceptable meter resolution for level one measurements is 0.05% of full scale.

Crest factor of an AC current waveform is equal to the ratio of the peak current to the RMS current. The meter selected must be able to handle the equipment’s crest factor without introducing distortion in the measurement due to the top of waveforms being “clipped”. Normally a full range rating of 3 is sufficient, though lighter loading of single equipment meters may require crest factors in the range of 6 to 8.

Bandwidth is a measure of the meters’ capability to handle measurements that contain high frequency harmonics created by the power converters in the data center equipment (both IT and infrastructure). A minimum bandwidth of 3kHz is recommended.

Other considerations for power metering include choices impacting the ease of installation and of data collection. Power measurement systems generally implement contactless current sensors rather than shunts, because the latter cause power losses as well as installation and safety issues. The current transducers are normally transformers through which the electrical feed passes. Two common designs are solid and split-core transducers. A solid core sensor is less expensive and more accurate and the best choice for new permanent installations, while the split-core design is the more common choice for existing installations. Split-core transformers are designed for the ability to be retrofitted into a live installation without disturbance (as opposed to a solid core transformer which would require the power cabling to be disconnected to be installed). Automatic Meter Reading (AMR) or Remote Meter Reading (RMR) allow users to have the equipment communicate the measurements and not have someone physically read a display or download a data file. AMR or RMR may be “smart” meters incorporating additional functions to report data in greater detail, such as power quality, outages and the ability to communicate data and alerts over a network smart meters will be needed to automate the measurement and calculation of DCiE.

Note: DCiE and PUE can be represented using either power or energy. When it is calculated using power, it represents an instantaneous DCiE or PUE. When it is calculated using energy, it represents an average DCiE or PUE over the time period of the measurement.

FACTORS AFFECTING DCiE

The intent of DCiE is to assist decision makers for data center operations, IT or facilities in the effort to improve data center efficiency. As with any data point, this is only one part of the entire data center picture. DCiE is valuable to monitor changes in one data center at an aggregated level. It can also help to identify large differences in efficiency in similar data centers, though further investigation is required to understand why these variations exist. It is the first step to better understand a data center's efficiency. Subsequent investigation is required to determine the best approach for additional improvement in data center's efficiency.



DYNAMIC DATA CENTER

Today's data center is in constant flux. Applications, as well as the IT equipment and infrastructure that support them, are continually evolving to better meet the business needs of the corporation. Therefore, the initial design of the data center is obsolete the day after the installation and commissioning is complete. Often, energy efficiency calculations are based on a static design instead of the dynamic data center configuration. The designed (static) versus actual (dynamic) nature of a data center must be considered. Improvements will come through incremental step changes in infrastructure over time. Also, it is important to keep in mind that as the load changes in the data center, the operating point of the subcomponents on their efficiency curves will change.

Measurements should not be taken if maintenance is being performed within the data center. This could negatively impact the DCiE measurement and provide unrealistic measurements.

TYPE OF DATA CENTER

The type of processing done in a data center can greatly impact the DCiE metric. The Green Grid is also working on a companion paper, *Data Center Segmentation*, to help various types of data centers compare DCiE to similar data centers. Is the data center primarily for testing, production, internal processes, networking? What is the primary business supported by the data center – financial, healthcare, telecom? What Tier level is required to support this business? Another aspect to consider is if the data center operations scheme includes disaster recovery, which would certainly affect efficiency.

Similarly, the physical attributes of the data center will impact DCiE. What is the typical temperature and humidity kept at in the data center? What type of cooling system is used and does it include free cooling? How old is the data center and the subcomponents in it? Was the building intended to be a data center, or was it retrofitted to be used as one? How far is the data center from its power source?

Many infrastructure subcomponents and IT equipments currently support energy reduction features – are these employed in the data center? And are they effective? Are alternate energy sources being used? Are dummy loads being run, and if so, why and when?

CLIMATE AND LOCATION

Where a data center is located can have significant impact on energy efficiency achievability. The efficiency of identical mechanical system can be drastically different depending on the climate the system is operating

in. The climate and location of the data center also impacts the hours of free cooling available. Free cooling implies the ability to provide cooling to IT equipment by leveraging local ambient conditions in order to reduce energy use. Similarly, some mechanical systems are just not practical in some climates or locations. Location has a significant impact on utility rates and even energy availability.

DATA CENTER DESIGN AND OPERATION



The design of the data center infrastructure cannot be underestimated in its impact on energy efficiency. IT equipment density, power distribution architecture, cooling architectures, redundancy levels and floor layouts, to name a few, all have major impacts on efficiency. Many of these topics will be further addressed in depth in other The Green Grid White Papers. Even the best design can result in poorer than designed efficiency as operation changes take place. For example, increasing the density in a single rack above the specified design value may result in air conditioners cooling the new hot spot. As a result, the cooling system is no longer in balance and is less efficient.

MEASUREMENT PERIOD

Hourly, daily, weekly, monthly, and seasonal variances effect DCiE. To truly understand and successfully manage a data center's efficiency, continuous real time monitoring should be used so that historical trending and statistical analysis can be done to determine where efficiencies can be gained. However, this is not always practical or economically justifiable, but some form of repeatable, defined process should be in place to capture DCiE as often as possible for comparison purposes.

Measurements should not be taken if maintenance is being performed within the data center. This could have a negative impact and provide unrealistic DCiE measurements.

The Green Grid recommends automated, real-time monitoring with data captured every quarter hour. The quoted DCiE number is the average over a one year period. For data centers without real-time monitoring, DCiE is collected according to Table 1 per the intended level of implementation.

SOMETIMES DCiE SEEMS TO GO THE WRONG WAY

The common goal is reduce energy consumption, not defraud a metric. In some real world situations, the DCiE metric may go down if total power provided to a data center is not adjusted accordingly to a drop in IT power. It is important to remember to reduce the infrastructure subcomponent power consumption.

Unlike other measures, there are no credits or percentage points awarded for generating energy, waste heat recovery, etc. While important, these are not the focus of the DCiE metric. The maximum DCiE is 100%, the minimum 0%.

DCiE needs to be considered with total data center energy consumption in mind. The total energy consumption of a data center may go down, but DCiE may not reflect an improvement. Similarly, total energy costs may increase, but per unit cost may decrease.

DRIVING DCiE EFFICIENCY

The purpose for collecting the required information and calculating a DCiE for any data center is to provide a means by which to compare one data center to another similar data center and more importantly to determine the effectiveness of any changes made within a given data center in terms of infrastructure power efficiency.

DCiE provides an indication of how much power is consumed by the facility infrastructure in order to distribute this power to the IT equipment, provide necessary cooling to the IT equipment and provide stability and redundancy in power delivery to the IT equipment.



Currently, in typical data centers it is expected that DCiE will likely vary with levels of IT load. In order to improve DCiE and the energy efficiency of a data center, it is necessary to make changes that affect the energy consumed by non-IT equipment in the support of the IT equipment.

Implementation of Level 1 in Table 1 is sufficient to measure the DCiE of a facility and will provide the necessary data to determine the effectiveness of changes made to a data center. The added information provided in Levels 2 and 3 may be necessary, either all or in part, in order to identify those changes most likely to provide improvements.

Changes made to improve DCiE should be made in the following order:

1. Follow best practices found in other The Green Grid White Papers
2. Increase granularity of power measurements such that power losses can be ranked by subsystems
3. Rank loss contributors by magnitude and investigate opportunities to make changes that will lower the energy consumed in these subsystems and still support the requirements of the IT equipment.

DCiE AND FUTURE TECHNOLOGY ADVANCEMENTS

The Green Grid will continually review and revise DCiE as advancements are made in technology and in data center design. It is assumed that things will change, and this metric will be updated to reflect these changes. Other metrics may be added to assist in optimizing the efficiency of a data center. For example, it would be helpful to know what percentage of the current data center capacity is currently being used. Similarly, graphing and reporting DCiE and other metrics could provide easy access to relevant data for operators.

MULTIUSE FACILITIES

The assumption at the beginning of this paper was that the data center was standalone and easily isolated. However, this is often not the case. Often, a data center is part of a larger building or structure that includes other functions. In these multiuse facilities, the applicable portion of the power used in the data center must be determined. If possible, a demarcation point for data center versus non-data center needs to be established. This should be straightforward for the electrical distribution path, but may be more challenging for the HVAC subcomponents. Ideally it would be possible to determine the exact portion of the HVAC power required by IT equipment vs. the rest of facility. Realistically this is not always possible to do. When the mechanical systems are shared, some method to allocate HVAC power between the data center or IT equipment and the rest of building is required.

Industry estimates for HVAC power in a data center range from 20% to 45% of total data center consumption.¹ For basic level DCiE analysis it is expected that estimation is required. One method of doing this is using the ratio of IT equipment power to the total facility power multiplied by the total HVAC power to estimate the IT equipment HVAC power requirements.

Using the same data center layout from Figure 1, the basic method for estimating HVAC power allocated to the data center is shown in Figure 3.

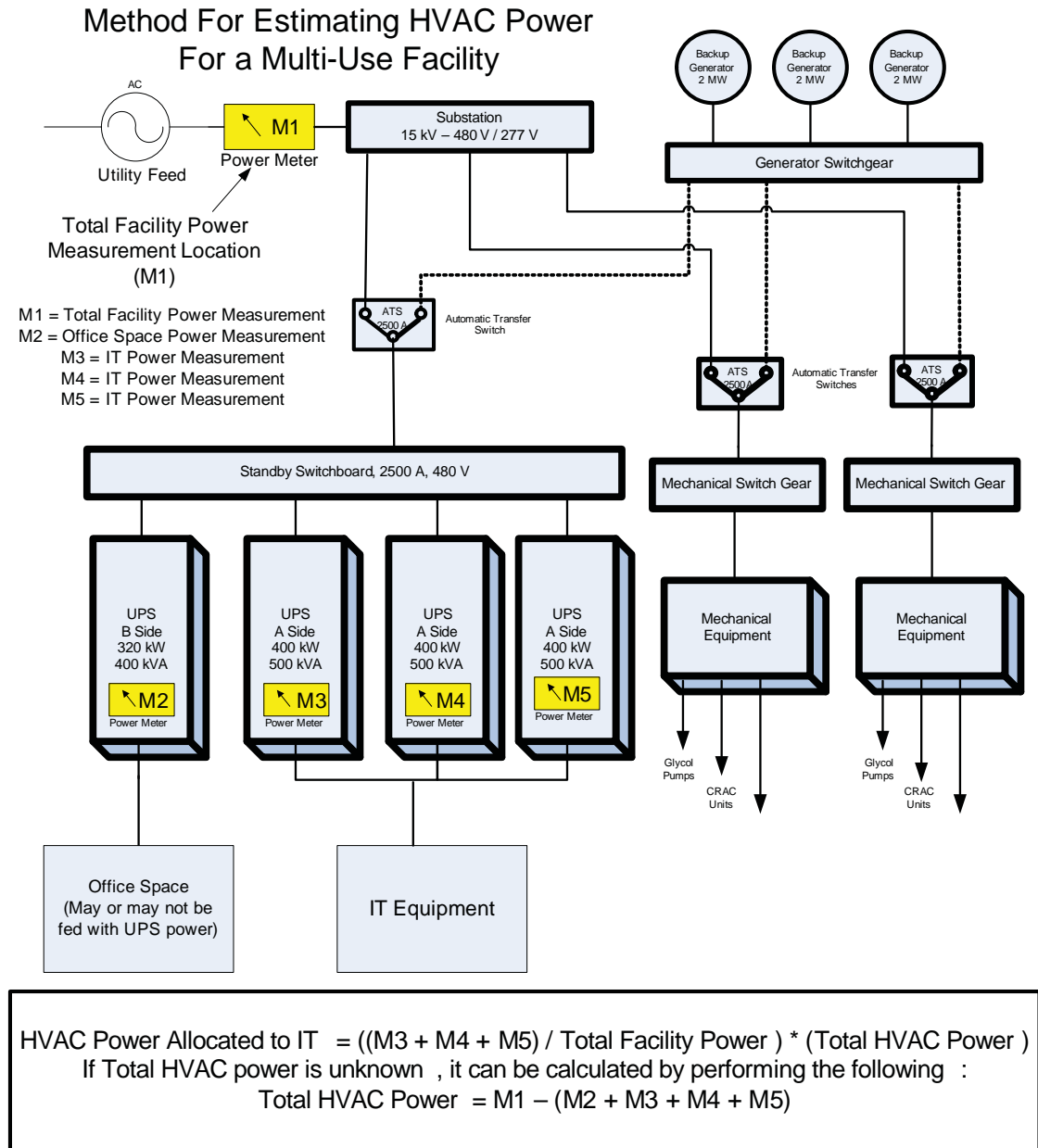


Figure 3

For intermediate DCiE analysis, the HVAC component can be calculated based on information collected from the HVAC components. The portion of cooling directed to the data center is determined by the percentage based on flow rate of heat transfer medium, number of cooling units, and size of cooling units. This will provide a more accurate estimation of the power dedicated to cooling the data center.

For advanced DCiE analysis, the individual HVAC components supporting the data center would be instrumented to measure the actual power consumption.



SUMMARY

- This paper provides information and guidelines necessary for end users to apply DCiE in their facilities. Areas addressed include the following:
 - Multiple levels of DCiE Implementation are described which allow a phased approach to instrumenting data centers for DCiE data collection and calculation. This allows IT operators the ability to begin collecting data and using DCiE without the costs and time required to implement a fully instrumented data center
 - Power Metering locations described for each of these implementation levels in a typical data center providing a phased approach to instrumentation and effort required to collect data and compute DCiE
 - All expected equipment in data center is categorized as IT equipment or not IT Equipment providing clarity as to components should be categorized as infrastructure vs. IT equipment
 - Methods of obtaining data to populate DCiE discussed describing usefulness and limitations of the methods
 - Power Metering requirements are described to provide guidance in selecting appropriate power measuring equipment
 - Factors affecting the DCiE value are discussed to provide a better understanding of what items affect DCiE. This knowledge can help identify sources of changes in DCiE and also provide guidance on potential areas for improvement
 - Methods of addressing DCiE measurements in Multi-Use facilities are described in order to provide guidance in instrumenting multi-use facilities for DCiE measurement

CONCLUSION

The DCiE metric provides a very useful tool for evaluating and measuring the energy usage and efficiency of the infrastructure equipment supporting IT equipment within a data center. This allows data center operators to address and reduce the energy usage related to the supporting infrastructure within a data center. Much of the detail in this paper addresses the Basic level of implementation for DCiE measurement. This level is specifically tailored to address the capabilities of existing equipment in data centers. The intent is to provide the capability to measure DCiE with the minimum amount of changes to existing data centers. Future white papers shall provide more detail on requirements and use of DCiE for intermediate and advanced levels of implementation.

REFERENCES

ⁱ LBNL Energy Efficient Data Centers Power Chain Efficiency, December 11, 2006 William Tschudi, APC white paper #144 & #154

