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FEDERAL ENERGY MANAGEMENT PROGRAM

Guidelines for Data Center Energy Information Systems

Prepared for the U.S. Department of Energy Federal Energy Management Program

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DRAFT

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1. Introduction

Purpose

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 study, specify and procure data center energy information systems (EIS) for managing the energy utilization of their data centers.

Data centers are typically energy-intensive facilities that can consume up to 100 times more energy per unit area than a standard office building (FEMP 2013). This guidance facilitates "data-driven decision making," which will be enabled by following the approach outlined in the guide. This will bring speed, clarity, and objectivity to any energy or asset management decisions because of the ability to monitor and track an energy management project's performance.

An EIS is a key component of managing operations and reducing energy use and cost in data centers. It is broadly defined as performance monitoring software, data acquisition hardware, and communication systems used to store, analyze, and display building operational and energy data (Granderson 2009). Given the heightened awareness around data center energy utilization, many EIS products in the market provide a range of capabilities. Data center owners, operators, and designers need to consider their organization's specific priorities and context (e.g., knowledge base, skill, resources) to determine the appropriate solution for them.

This document provides vendor-neutral guidance focused on energy monitoring and performance tracking in a data center. The energy performance tracking (EPT) could be a stand-alone package, or be a subset of a larger data center infrastructure management (DCIM) package. However, this guide does not include other asset or infrastructure management aspects of DCIM, and its focus is entirely energy-centric.

By using this guideline, the user will be able to specify and install off-the-shelf, currently available products and packages. The guidelines could be used as a basis for a request for proposals (RFP) for EIS vendors, or for doing the job in-house.

The guide helps to answer these critical questions:

1. What are the business drivers and related metrics for energy information systems?
2. What are the metering requirements (e.g., what sensors and meters at which points and at what frequency of measurements)?
3. What are the software tool requirements (including communication platform, analysis, and visualization)?
4. What is the optimum level of energy monitoring and performance tracking (i.e., Basic, Intermediate, or Advanced tracking package)?
5. How should one acquire, install, and use an EIS package?

These five questions convey a deliberate, exhaustive process for selecting an appropriate EPT package. Users who are well-versed with metering and tools may elect to do a quicker read, moving directly to section 7 and beyond, and iterating back to previous sections if more detail is required.

Note that by design, this guide exposes the reader to various levels of energy performance-tracking packages before they get to best practice EIS. Not every step defined will lead to an EIS. The EIS as defined in this guide is an advanced EPT system as defined in section 7 and 8; and its procurement, installation and use described in section 9.

These guidelines are pertinent for new construction and retrofits, as well as for integrated or stand-alone data center buildings. Existing data centers may have constraints that can preclude certain EIS options as being impractical or costprohibitive. Wireless EPT packages are easier to install and less costly than wired solutions, especially for retrofit projects.

Finally, this guide's long-term objective is to provide a basis for a packaged, scalable EIS solution for data center and commercial building energy management that will be cost-effective and rapidly deployable.

Audience

The primary audiences for this guide are stakeholders with an interest in specifying, installing, and using a data center EIS; especially first-time users such as:

- Engineers and designers of new data centers
- Data center owners
- Data center facility managers
- Data center information technology (IT) managers

Secondary audiences are energy services companies (ESCOs) and performance contractors, as well as vendors of data center EIS products and software developers who wish to deliver appropriate EIS solutions to informed clients.

2. Context

Data centers constitute a large and rapidly growing sector of energy use. By one estimate, they consumed 0.97 percent of the world's electricity in 2005, at an aggregate cost of 7.2 billion USD, and this is growing by 15 percent each year (Koomey 2008). Data centers can consume up to 100 times more energy per unit area than a standard office building. Often, only around 15 percent of original source energy is used for the IT equipment within a data center. Figure 1 outlines typical data center energy consumption ratios (FEMP 2013).

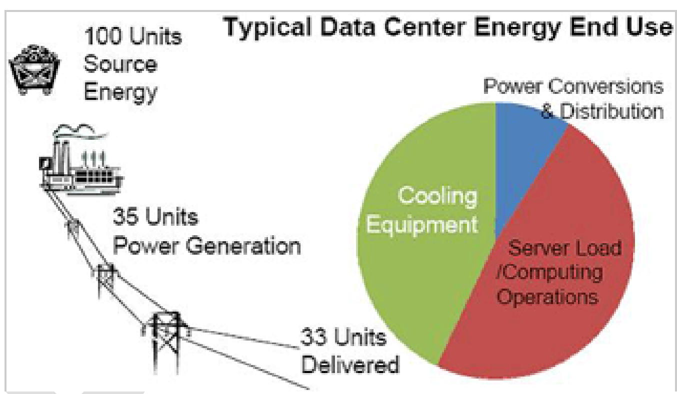

Figure 1: Illustrative End-Use Breakdown of Data Center Energy Consumption (Source: FEMP 2013)

In the United States, from 2000–2006, computing performance increased 25 times, but energy efficiency increased only 8 times. The amount of power consumed per server increased 4 times (Koomey 2011). The cost of electricity and supporting infrastructure is currently surpassing the capital cost of IT equipment. Figure 2 illustrates the increase in electricity consumption in U.S. data centers. Currently, some of the best metrics reported among U.S. data centers is a power usage effectives (PUE) of 1.1, as reported for a Facebook data center in Oregon (Facebook 2010) and by Google as their average PUE (Google 2013).

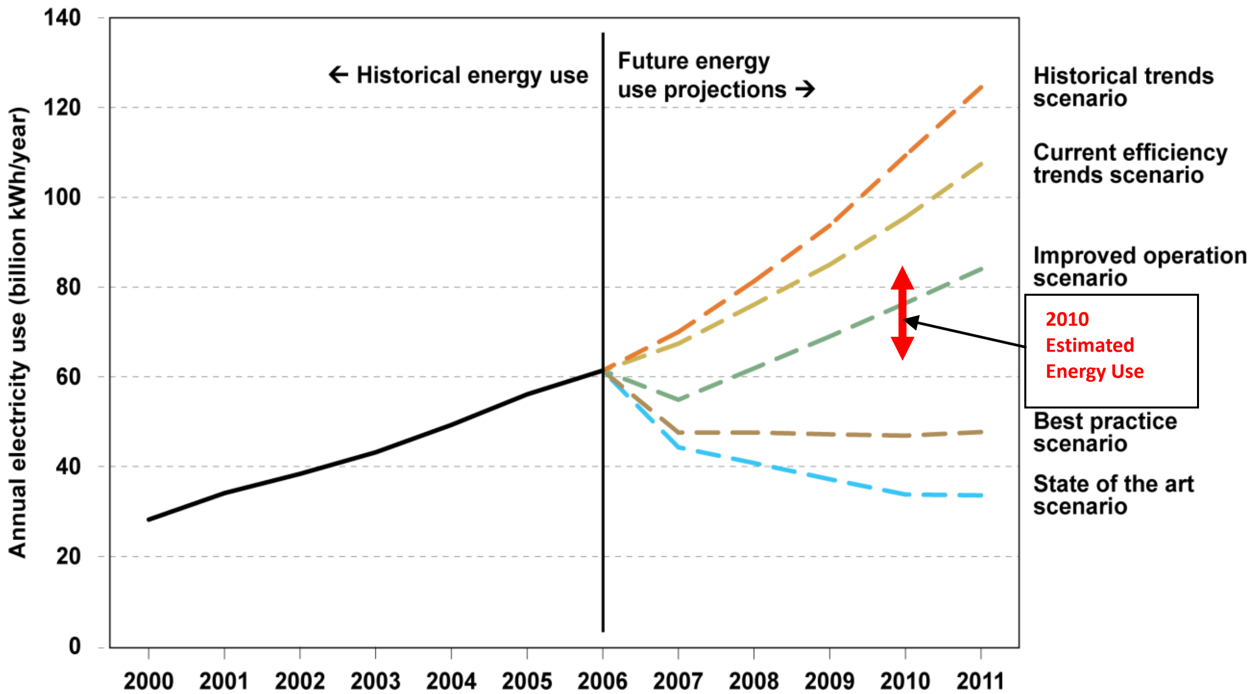

Figure 2 Energy Use by Data Centers in US (EPA Report to Congress 2007 and Koomey 2011)

Since data center operator awareness of energy efficiency is increasing, there is an increased demand for energy-efficiency products, which has expanded the market increasing the number of suppliers and products. However, this quantitative increase does not necessarily translate to quality, and hence it becomes important to provide practical recommendations. This document provides a set of guidelines that users can employ to help analyze and manage energy across the whole spectrum of energy-efficient strategies for data centers. The guidelines are applicable to various EISs.

3. Data Center Energy Use Breakdown

Figure 3 is a schematic of the typical electricity flow in most data centers. Power is provided by utility, or alternatively, by an onsite generator. Data center IT power runs through a UPS. Power is also fed to the mechanical plant and offices.

In the diagram, from left, a photo shows a utility power station, an automatic transfer switch, and a generator feeding it. The automatic transfer switch(ATS) feeds to HVAC system, to support office and lighting, and to the power distribution, including the UPS, PDU, computer racks, and finally, the computer equipment itself.
Consider the electrical side of efficiency opportunities in the data center. Power enters at a high voltage; it is stepped down in voltage, enters a UPS, and is converted from AC to DC power. The UPS then converts it back from DC to AC. It then travels through the data center where it goes to power distribution units that typically reduce the voltage to that required by the IT equipment.
The IT equipment's power supply again converts AC to DC, the voltage is increased to 380 volts DC, and it is then stepped down to a variety of DC voltages depending on the needs of the equipment. Overall, there are many conversions from AC to DC and DC to AC, and changes in voltages. Each of those transitions results in energy losses and heat, which in turn must be removed by the cooling system.

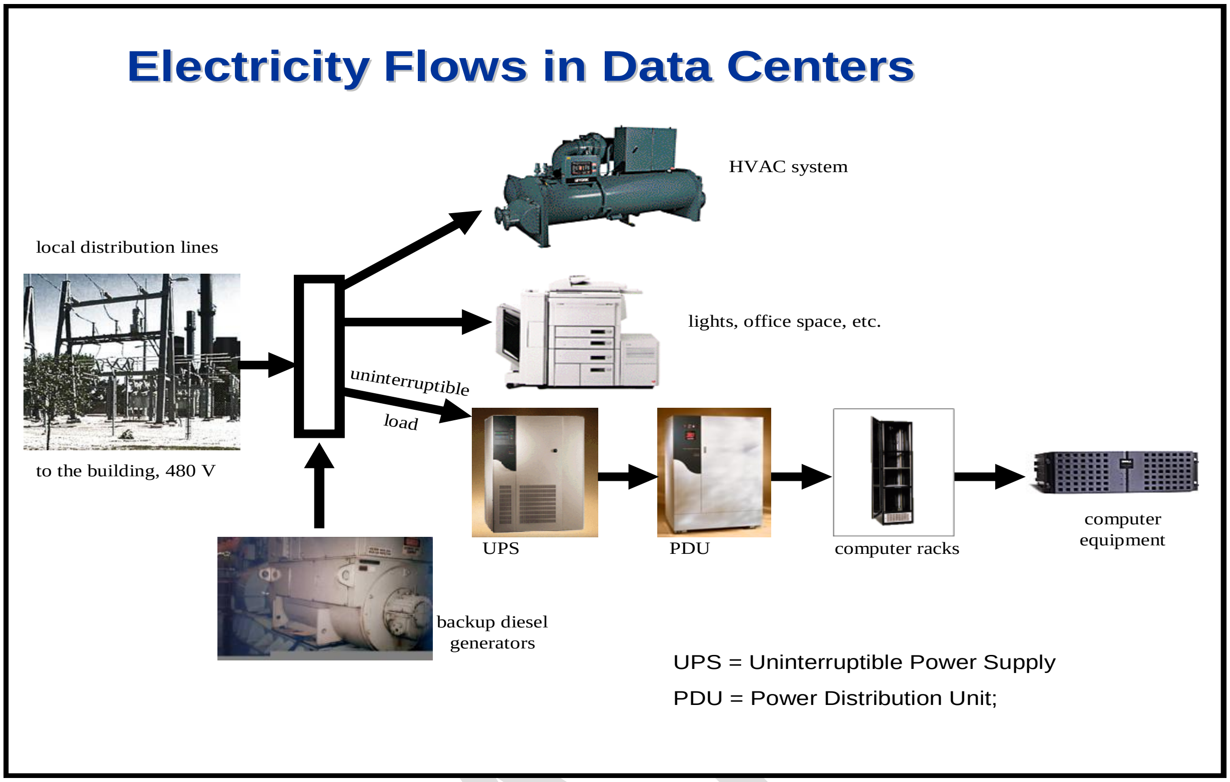

Figure 3: Electricity Flow in Data Centers

4. Drivers for Measurement

The first step to monitoring is to identify and prioritize why and how the monitoring solutions will be used. The type of monitoring solution will be derived from current and future business drivers that require tracking and reporting of energy information.

Business Drivers

The user should begin by prioritizing the following five business drivers:

1. **Track and manage energy consumption** to collect energy use data at building or end-use levels to inform the organization about how it uses energy, where it is used, and what drives its energy use. Tracking helps to identify abnormally low or high-energy usage and potential causes, and it supports emergency responses, such as load-shedding events. It also facilitates capacity planning around space and power utilization and helps with carbon accounting and green house gas (GHG) reporting.
2. **Track and manage energy cost** to predict energy cost, verify energy bills, and prioritize and validate energy costs through improved energy efficiency and energy management. Cost tracking can improve your organization's bottom line by enabling a high return on investment.
3. **Benchmark** to quantitatively assess data center performance and to compare them across a level playing field. Benchmarking evaluates your 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 in the organization's energy performance.
4. **Develop and validate energy-efficiency strategies** to identify opportunities for increasing energy use efficiency by lowering energy and operational costs. These strategies can also be used for commissioning and detecting faults in physical systems and diagnosing their causes.
5. **Manage demand response (DR)** to determine peak, critical, and non- critical load trends; and to verify energy savings from demand response at peak energy times. The opportunity for DR in datacenters depends on

redundancy requirements and criticality of the mission of the datacenter. For instance, energy use may be curbed by increasing the air intake or ambient temperature, or using site generators as the main power source.

Table 1 is a summary of relation between business drives and metrics. A definition of each of these business drivers and a table detailing the relationship between business drivers and metrics are provided in Appendix 1.

Characterization Matrix of Business Drivers vs. Measurements and Metrics	**Whole Building Measurements**	**End Use Measurements**	**Derived Metrics**
Track and Manage Energy Consumption	x	x	
Track and Manage Energy Cost	x	x	
Benchmarking			x
Develop and validate Energy Efficiency Projects	x	x	x
Manage Demand (Demand Response)	x	x	

Table 1: Characterization Matrix of Business Drivers and Metrics

5. Key Metrics

Each of these business drivers has various metrics associated with it that include measurements and derived metrics, ranging across whole building (data center) and end-use levels.

The following are standard derived metrics used to understand and manage the efficiency of data center energy consumption. (Also, see Appendix 2 for further details on derived metrics.)

1. Total Energy Usage: energy used by all of the different systems in a data center.

2. Power Usage Effectiveness or PUE (index): a measure of how efficiently a computer data center uses energy; specifically, the ratio of total energy use to that of information technology (IT) equipment , i.e.,

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

3. **Electrical Distribution Efficiency, or Electrical Power Distribution Efficiency (avg. percent):** efficiency of the power distribution that usually consists of a utility transformer, automatic transfer switch, back-up generator, distribution switch gear, uninterruptable power supply (UPS), and the downstream power distribution units (PDUs), providing power to the IT equipment cabinets. Other distribution losses are incurred by the infrastructure systems as well.

4. **Cooling System Efficiency (avg. kW/ton):** efficiency of the cooling system in a data center that represents the major part of facility-related energy usage in the data center, outside of the actual IT load itself.

5. **IT Utilization**: percent of the utilized portion of IT capacity. An idle server can use as much as 50 percent of the energy it would use when it is 100 percent utilized.

6. **IT Efficiency (product/W):** In computing, performance per watt is a metric of the energy efficiency of particular computer architecture or computer hardware. Specifically, it measures the rate of computation that can be delivered by a computer for every watt of power consumed. FLOPS (floating-point operations per second) per watt are a common measure. Another performance-based metric is transactions/watt/sec.

7. **Carbon Dioxide (CO_2) Emissions:** energy-related CO_2 emissions released at the location of the consumption of the fuel; in this case, electricity.

6. Measurement

Level of Metering, Measurement:

We define three levels of metering. The user can choose from these three levels, based on budget, needs, the extent and accuracy of the measurements and the potential analysis.

Select one of the following three levels of metering for your specific data center needs.

Level 1: Basic Metering

At Level 1, Basic Metering, only some of the highest-level points are metered at the campus or larger building (and usually not at the data center) level. This is done primarily through manual readings, although for some of meters, such as electric utility meter and switchgear meter, there may be automated readings. Any other potential points beyond those are manually recorded from the display of the equipment, such as the UPS display, chiller display, or read from sensors such as data center air temperature and chilled water temperature. Since the readings are manual, the frequency tends to be low—monthly, or in some cases weekly.

See Figure 4 below for a representative diagram for Level 1 metering. This is a relatively inexpensive solution that relies mainly on existing meters; however, the level of data availability and accuracy is low for derived metrics. For instance, the level of uncertainty for PUE measurement can be as high as $\pm$30 percent.

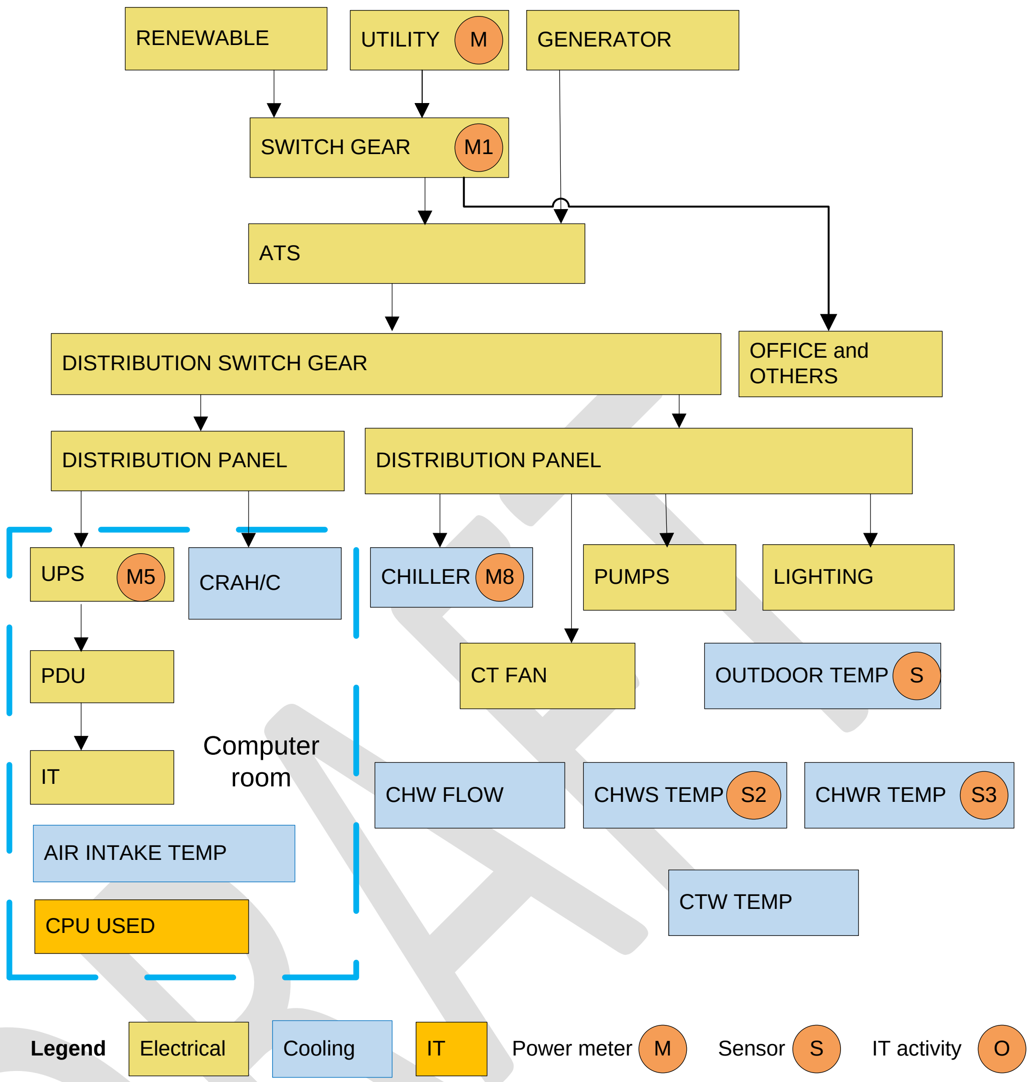

Figure 4: Representative Diagram for Level 1: Basic Metering

In this case, meters at utility and switchgear provide continuous and accumulated data on data center energy use. Chillers usually show power use (instantaneous) on display. For pumps and fans, nameplate can be utilized to estimate power use. Instantaneous chilled water temperature and air temperature can be read from chiller and CRAC/H display. The derived metrics are presented only as a rough estimate. See Table 7 in Appendix 1 for more details on Level 1 metering and what metrics it helps to measure.

Level 2: Intermediate Metering

Level 2, Intermediate Metering, is a hybrid metering solution, where some of the points are metered and some are recorded manually. This is different from Level 1, Basic Metering, where the majority or all of the points are manually read; although in a few cases, some may be automated. 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 the chiller plant meter and outside air temperature through a control system.

See Figure 5 below for a representative diagram for Level 2 metering. Additional monitoring can provide a better estimate of end-use or component-level usage patterns. In this case, the estimated PUE can be off by ±15 percent. The hybrid of manually collected and automatically collected data can vary. It also may be possible to get some level of historical information for trending.

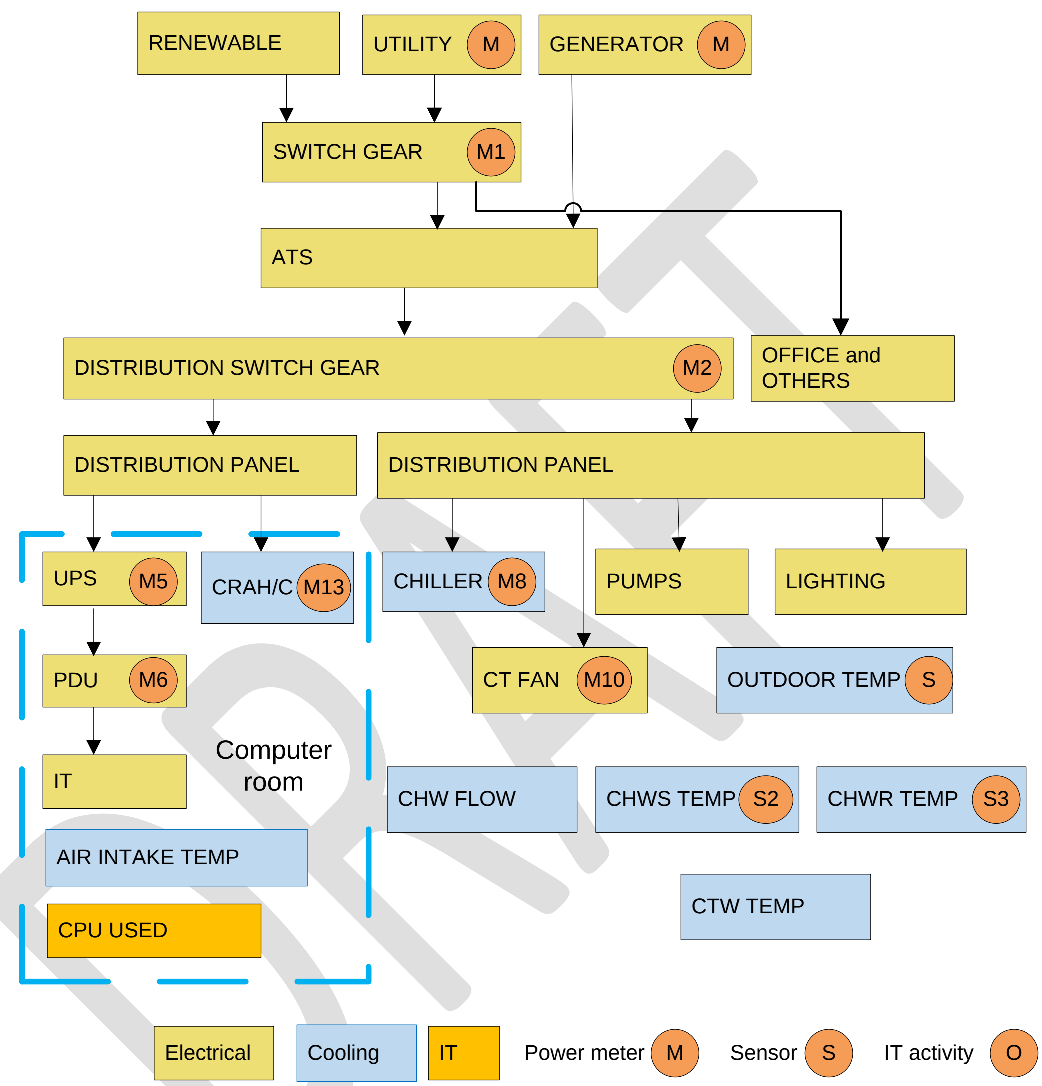

Figure 5: Representative Diagram for Level 2: intermediate Metering

In this case in addition to meters at utility and switchgear that provide continuous and accumulated data on data center energy use, there are meters at the chilled water plant and HVAC fans. UPS and PDU displays can provide instantaneous data. Electrical distribution loss that is an important factor in data center energy efficiency can be calculated by observing UPS and PDU display. In this case, the derived metrics are presented as a good estimate. There are also temperature readings for chilled water and CRAC/H air. With these data, possible measures can be implemented to improve chiller efficiency in chiller plant and air management inside data center. See Table 8 in Appendix 1 for more details on Level 2 metering and what metrics it helps to measure.

Level 3: Advanced Metering

In Level 3, Deep Metering, all the 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 meters' accuracy. The values are metered over time as opposed to being estimated from the product specifications or taken from manual meter readings. The PUE estimate can be as close as ±5 percent. This is the most expensive metering level, but it results in extensive measurements, comprehensive data collection, analytics, customized trending, and user-friendly visualization for meeting the drivers as defined in Table 5, Appendix 1. See Figure 6 below for a representative diagram for Level 3 metering. See Table 9 for details on Level 3 metering.

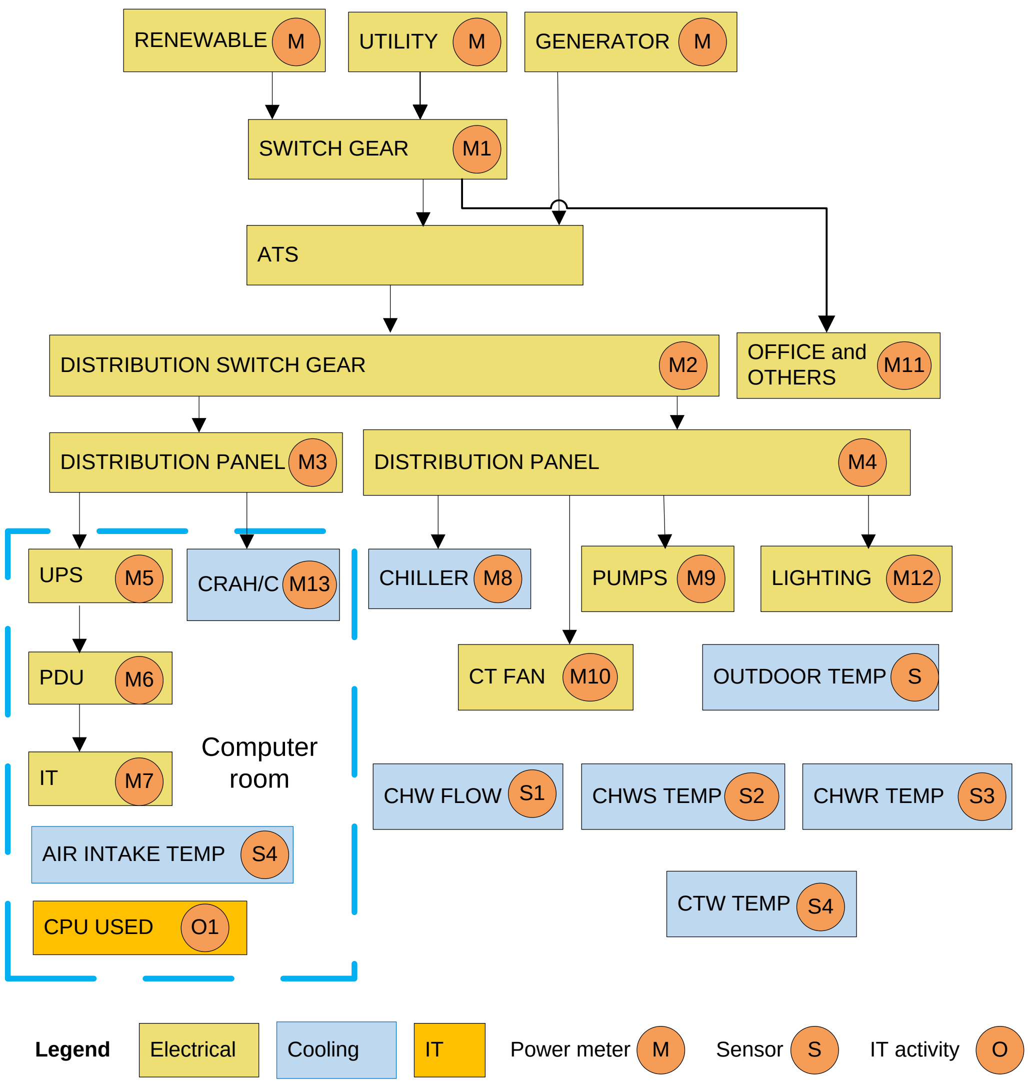

Figure 6: Diagram showing Level 3 Advanced Metering

In this case, meters are installed in almost all power users. The meters provide continuous and accumulated data on data center energy use. In the chiller plant, power use by chiller, pumps, and fans are metered. Electrical distribution is metered at each step including down to UPS, PDU, and IT equipment. Power use by HVAC equipment, generator block heater, and cooling and lighting for support rooms is metered. In this case, the derived metrics are presented as a precise value. There are also temperature readings for chilled water, CRAC/H supply air, and racks' intake air temperature. With these data, more measures can be implemented to improve chiller plant efficiency and air management inside the data center. See Table 9 in Appendix 1 for more details on Level 3 metering and what metrics it helps to measure.

Key Metrics and the Meters

Table 2 summarizes the relation between metrics and meter readings for three measure levels. This table needs to be reviewed in conjunction with Figure 6 above.

Metrics	Measure level 1	Measure level 2	Measure level 3
PUE_1	(M1-estimated office load)/M5	NA	NA
PUE_2	NA	M2/M6	NA
PUE_3	NA	NA	M2/M7
Elec. Dist. Loss	Estimated based on UPS type and load factor	M5-M6	M3+M13-M7
Cooling Efficiency kW/ton	Estimated based on cooling type	Estimated chilled water plant load/M6x0.285	(M4-M12) /(500xS1x (S3-S2))/12000
IT Efficiency	NA	NA	O1x1000/M7

Table 2: Metrics, Meters, and Measure Levels

Estimated Cost of Metering

The cost of a monitoring and metering package will depend on the scope and design of the desired specific system. For a rough estimate, the cost of metering can be estimated at $150–$1,000 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–$1,000 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.

Consider this example for Level 3 metering in a typical data center. The sample data center includes 100 racks, 20 servers per rack (average), 2 UPS units, 5 PDUs, 10 computer room air handlers (CRAHs), 2 chillers, 2 towers, 4 pumps, and 2 generators. Metering scope includes 600 rack temperature points, 10 PDU power metering points, 4 UPS power metering points, 10 CRAH fan power metering points, 2 chillers power metering points, 2 cooling tower fan power metering points, 4 pump power metering points, 2 generator power metering points, 5 panel power metering points, and about 60 temperature monitoring points for CRAHs and cooling equipment. The cost of metering equipment can be about $150,000, including installation. Software, commissioning, and training are not considered in the estimate.

At the end of this section, determine your desired level of metering, and proceed to the next section.

7. Levels of Tracking

Identify the energy performance tracking (EPT) package required. Prioritize the package most suited for the purpose, with respect to business needs and cost. The user should then develop a specification based on their particular needs.

A monitoring approach consists of a combination of metering/sensing hardware, data collection/communications software, and a pre-defined analysis and visualization interface. The user can use one of the three described below as a starting point and then.

Levels of Energy Performance Tracking (EPT) Packages

There are three levels of EPT approaches, from which the user can select the one most relevant to their data center. Each level of metering hardware, software, and data acquisition should be prioritized according to the business drivers, and will be influenced by the available budget.

These three levels correspond to ASHRAE guidelines, *Real Time Energy Consumption Measurements in Data Centers.* Issued in 2010, it defined three levels of measurements: minimum practical (Level 1), best practical (Level 2), and state-of-the art (Level 3) as illustrated in Table 4.

Measurement Level	1 Minimum Practical	2 Best Practical	3 State-of-the-Art
Human activity	Periodic measurement and recording manual	Some manual recording and some automated	Automated recording
Measurement equipment	Manual	Semi-manual	Automated
Reliance on manufacturer data	High	Less	None
Extend of infrastructure upgrade	Very low	Limited, less expensive upgrades are done	High
Reports	Manual, no trending is possible, no training is needed	Limited trending, existing staff should be able to handle	All types of reports, consultant/vendor assistance needed for implementation
Dashboards	None	Limited	Extensive

Table 3: Comparison of Three Levels of EPT Packages Based on ASHRAE Guidelines

The following is a description of each EPT package level.

Level 1: Basic EPT Package

Level 1 Basic EPT Package = Level 1 Basic metering + Level 1 Spreadsheet tools + simple, hand-drawn charts for visualization

The Level 1 Basic EPT Package requires no, or limited, infrastructure upgrades and investment in instrumentation. Homegrown spreadsheets for this level of measurement may be utilized for analysis. Even with minimal instrumentation and data logging, a data center owner/operator can perform analysis on the data to observe trends. For example, PUE can be calculated just by dividing total power load (assuming that the meter measures just power to the data center and support rooms/systems) by UPS output power (shown on UPS display). This is a snapshot of PUE. Annual PUE is equal to total annual energy use divided by annual IT energy use.

In a Level 1 measurement scenario, the organization most probably would not have an online data acquisition system, so a documented process should be established to ensure that the metered data from key subsystems are read on a consistent and timely basis, and that the data are reviewed for consistency and are accurately entered into the spreadsheet software. Notes should also be included to account for any anomalies such as new acquisitions, new equipment installed, or new applications installed in the data center to help normalize the data.

The Basic EPT package may be used for site/portfolio purposes, for gauging financial, energy, and carbon performance. For example, utility billing information that does not require interval meter data may be used. For some purposes, such as simple tracking, utility cost accounting, monthly cross-sectional benchmarking at the whole-building level, and carbon accounting, the Level 1 Basic EPT package may suffice.

Level 2: Intermediate EPT Package

Level 2 Intermediate EPT Package = Level 1 Basic or level 2 Intermediate metering + Level 2 equipment-specific tools and reports/ charts for visualization

The Level 2 Intermediate EPT Package assumes a combination of manual and automated measurements. For the automated measurements, a data acquisition system is provided to gather and store the subsystem metering data. Some human intervention may be required periodically. A Level 2 measurement should provide an organization with the information needed to operate its facilities systems in real-time to support the IT and the organization.

The Intermediate EPT Package may be used at the whole-building (data center) or selected end-use level. It requires a certain amount of interval meter data or other time-series data, such as temperatures. With some well-prioritized meters, one can analyze and reveal energy waste and opportunities for energy-efficiency projects at the whole building, and some extent, the system level. For purposes such as longitudinal building benchmarking (which looks at the same metric over a period of time) beyond that available through Level 1, interval data-based load profiling, and broad-brush analysis, the Level 2 package may suffice.

Level 3: Advanced EPT Package

Level 3 Advanced EPT Package = Automated inputs from Level 1 Basic or Level 2 Intermediate or optimum Level 3 Deep metering and Advanced software and dashboard + potential interoperability with DCIM.

The Level 3 Advanced EPT package instrumentation, including automatic data collection and logging software, is required at key measurement points throughout the data center and facilities. With this level of instrumentation, it is more practical to support proactive control of the IT and facility loads linked with electric utilities.

More savings are associated with advanced metering, as it provides more information for the EPT to analyze. However, there can be a degree of flexibility as to whether an EIS should be used only with advanced metering. Since an EIS can be used to fulfill various business drivers, such as energy-efficiency opportunity identification, benchmarking, measurement and verification (M&V), and utility bill analysis, all of these functions do not necessarily require advanced metering. For example, an EPT can detect abnormal energy behavior by comparing the daily whole-building energy consumption profiles using certain statistical models. In addition, an EPT can also determine the project savings with whole-building energy use. Therefore, an EPT can also use basic metering and still bring savings. Simple tools and metering can be helpful if the level of detail of the results is well matched to the facility's size. For a site where savings opportunities are lower, extensive metering is probably not worthwhile. However, an EPT is designed with a high capability to glean and process information, so it is adequately matched to higher levels of metering and the potential for higher savings. Hence, there is flexibility when choosing a software approach for different metering levels.

Facility software has historically focused on power and cooling systems, and IT software has focused on storage, network, and computing systems. Organizations typically focusing on the power and cooling systems for the data centers may have sensors installed at various locations with monitoring systems for facilities personnel. In most organizations, IT monitors its equipment on a network that may or may not be separate from the facilities network. Using IT-equipment-based sensors, data center power and thermal metrics can be gathered and used for real-time control of data center thermal profiles and real-time power provisioning. Since the sensors are integrated into equipment, configuration errors and correlation of IT equipment to power supply units are reduced. Facilities management is a real-time process, and therefore requires localized monitoring and control in order to affect a workable control loop. Information technology equipment is deployed at a very large scale, and therefore requires localized monitoring to cope with the volume of data produced by a large number of computing and networking devices. Both facilities and IT equipment rely on local monitoring for consolidating local data to be logged to a central management database. In this Level 3 case, organizations are able to display facilities information to IT and vice versa, thereby linking the organizations. While the IT and facility software systems may not be fully integrated, having the key metrics available to each team in real-time helps optimize the overall data center system.

The advanced EIS monitoring approach may be used seamlessly across the portfolio, whole building (data center), and end-use levels. All the business drivers and the metrics associated with can be precisely determined. This information makes for a much more effective data-driven energy management platform.

8. Data Manipulation and Presentation

Data Manipulation

Before embarking on selecting the appropriate tools, the user should take stock of existing information sources such as:

- Operations, schedules, services, and in-house skills.
- Trend-logging integration options from existing monitoring systems, including the building automation system (BAS) and electrical monitoring system.

It is important to identify and utilize any existing information systems and then select the level of software tools from the following three levels. Also, note that the level of tools will be also correlated to the level of metering.

Level 1: Spreadsheet Tools

Level 1 tools utilization is at the basic level of (homegrown) spreadsheet models used to manipulate the data. Data collection and communication is 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. Considering the possible errors in recording of the data from displays and meters and manual calculations and the time variability of the values, the accuracy of the result is generally low. However this level may be applicable for a site where savings opportunities are lower, and extensive metering is not worthwhile.

Table 4 illustrates an example. Using the display of UPS units, the IT power was recorded each month over the course of seven months, and chiller loads and electrical equipment (EE) loss (UPS input minus UPS output) was noted. Then an estimate of other loads was added to the analysis, and the PUE was calculated (Figure 7). The result showed that the PUE improved when IT load was higher and outdoor temperature was lower. The information represented in Table 4 was manually collected through monthly spot measurements. However, spot measurements tend to introduce error, due to load fluctuations, and can introduce bias error, depending on when measurements were collected. Some loads may be estimated rather than measured, introducing additional uncertainty. The granularity of data is coarse, and the level of analysis and accuracy is correspondingly limited. The result is a high-level capability to ascertain the data center metrics and calibrate to business drivers such as whole-building benchmarking. The numbers shown in Table 4 are the real-time kilowatt (kW) power draw for each system.

	Fan 1	Chiller 1	UPS 1	EE loss	Fan 2	Chiller 2	UPS 2	EE loss	Lighting, cooling	PUE
3-Jan	26	0	348	24	104	110	388	27	100	1.53
1-Feb	32	55	350	24	48	65	357	25	100	1.50
1-Mar	0	66	415	29	44	0	453	32	110	1.32
3-Apr	41	60	456	32	65	57	455	32	120	1.45
1-May	30	32	394	28	35	72	401	28	130	1.45
1-Jun	0	0	402	28	32	83	401	28	140	1.39
2-Jul	31	113	381	27	0	115	442	31	150	1.57

Table 4: Example of Level 1 Tool-Based Data Collection Note: All units are in kilowatts.

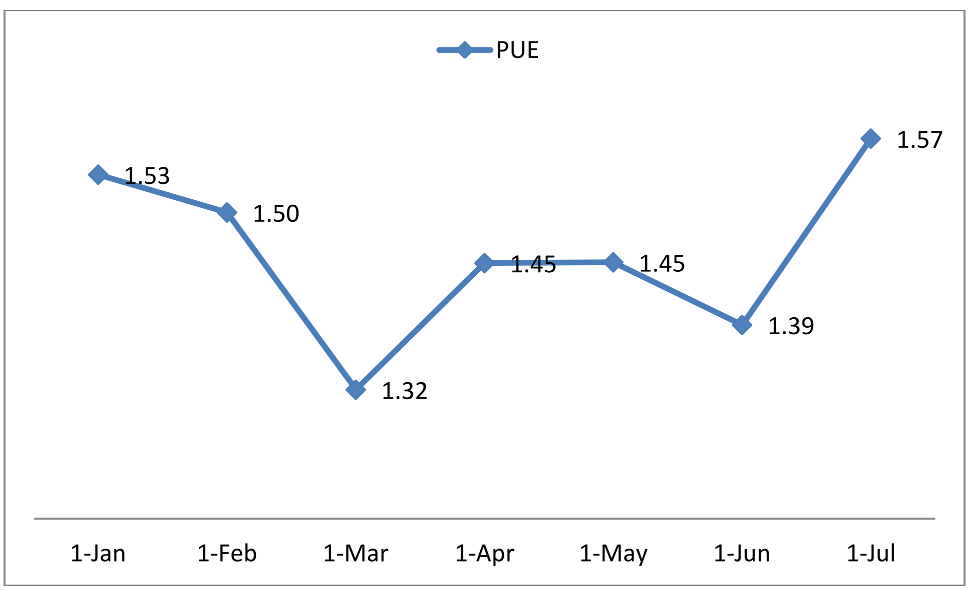

Figure 7: Example of Results from Using Level 1 Tool-Based Data Visualization

Level 2: Equipment-Specific Software Approach

The Level 2 software approach involves a combination of manual and automated data collection. This approach implies selected continuous data collection streams through priortized meters, while other data are collected from spot readings. The focus is on certain areas for partial metering and partial automated data collection. Various equipment vendors separately provide tools, such as software for the smart card for UPS meter and UPS utilization. Spreadsheets are still used for energy calculations.

This hybrid of manually collected and automatically collected data can be used to provide more granularity of analysis and information than the Level 1 tools provide. In terms of analysis, it may be possible to get some level of historical information and do trending. The quality and extent of the reports depends on the knowledge base and level of effort of the operators of the available meters. Considering the possible errors of those recording of the data from displays and meters and some manual calculations, the accuracy is more granular than that of level 1 tools, but still not optimal lacking the presision of level 3..

An example is where PDU reading is used (instead of UPS) and some of the other loads are actually measured (which is better than estimating). The difference here is that the numbers are closer to the actuals, and accuracy is more reliable than that in Level 1 tools. A better report can be created based on the greater amount of data collected.

Using a Level 2 software approach, some high-level assumptions can be made, such as monthly benchmarking and an estimated PUE based on spot checks on a monthly, daily, or hourly basis. One can execute prioritized metering, but with a ±15 percent accuracy. Some training in the software is required.

Level 3: EIS Software Approach

Level 3 software approach entails an EIS, full-functionality software that enables true data-driven energy decision making. This approach encompasses the broad range of business drivers as identified in Table 1 and in Appendix 1. There are two aspects to EIS software:

1. Integration and Communication
2. Analytics and Visualization

Details about each are provided below.

Integration and Communications

Ideally, EIS solutions should integrate with building management systems (BMS) that work toward managing the entire building, including lighting, cooling, power, and security—a concept known as *Data Center Infrastructure Management* (DCIM). See Appendix 2 for more information about DCIM.

It is of great benefit if the EIS modules are interoperable with other enterprise resource management/BMS/energy management system (EMS) platforms. For instance, integration with the building automation system (BAS) for fault detection and diagnosis (FDD), and integration with automated system optimization (ASO), a tool to dynamically change heating, ventilating, and air conditioning (HVAC) BAS settings for optimizing energy use. The EIS should also integrate with modules that perform capacity management and change management, and ideally should be virtually interoperable with IT. Given all the points of integration highlighted above, the EIS should operate smoothly across all of those currently disparate systems. In addition, the EIS should monitor power (UPS, PDU), cooling (chillers, CRACs), generators, and servers using multiple protocols (BACnet, Modbus, and simple network management protocol [SNMP]). Given this integration and its familiarity with the facilities side of the house, EIS should provide the capability to actually alter certain actions within the data center based on pre-set, user-set thresholds. For example, if a large workload moves to a different CRAH zone on the data center floor, EIS should automatically work with the variable frequency drive in that CRAH to adjust the fan speed as required by the zone, and/or adjust the cooling level.

Analytics and Visualization

Standardization of dashboards and reports associated with Level 3 is based on analyses, in order to:

- 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.

Recommended Standardized Dashboards

Figure 8 illustrates the dashboard that is built around the main metrics and can be used by different levels of stakeholders, including senior management. Power is the amount of energy used per unit time.

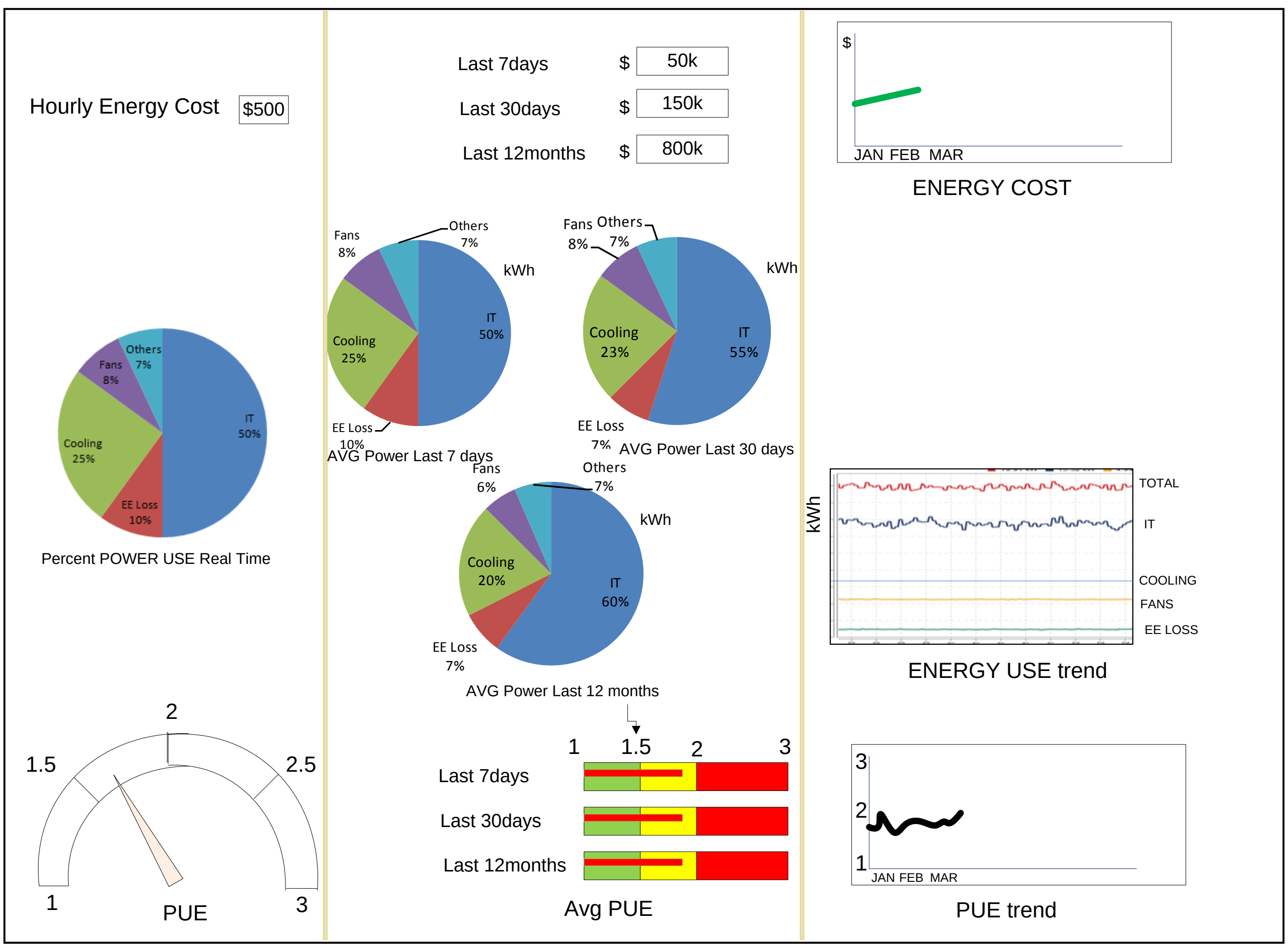

Figure 8: Dashboard View of Interest for Different Users (Level 3 Tools)

The dashboard is arranged in three columns. The first column illustrates the real-time figures for energy cost, energy by use (kilowatt-hours [kWh]/hour), and instantaneous PUE. The second column illustrates the average figures during last 7 days, last 30 days, and last 12 months for the same performance metrics. The third column illustrates the trending capabilities of the dashboard for the same metrics. The examples shown are for trending from the beginning of the year. By moving the cursor on the graph, the user can define trending by any start/finish (date/hour) with whatever granularity is desired.

Figure 9 illustrates the dashboard that can best serve the IT manager in addition to the above dashboard. The IT manager will see the same dashboard as the director, but in addition a second window will assist with the observation of IT utilization.

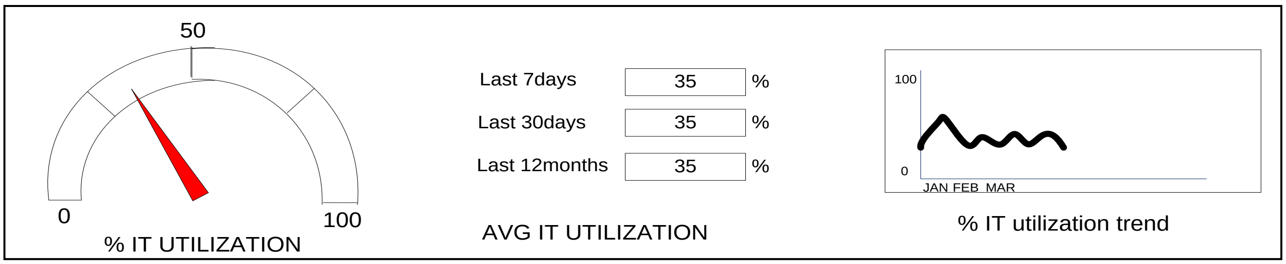

Figure 9: IT Manager's Second Dashboard Using a Level 3 tools Approach

The first column illustrates real-time IT utilization. The second column illustrates the average IT utilization during the last 7 days, last 30 days, and last 12 months for IT utilization. Finally, the third column graph is used for trending. By moving the cursor on the graph, you can define trending by any start/finish (date/hour) with whatever granularity is desired.

Figure 10 illustrates the dashboard that can be added to the previous dashboards to best serve a facility manager. The facility manager will see the same dashboard as the director but in addition a second window will help the manager observe the electrical distribution efficiency, the cooling efficiency, and a thermal map of the data center.

Examples are shown for trending from the beginning of the year. In the actual case, by moving the cursor on the graph, the user can define trending based on any start/finish (date/hour) and with any granularity desired (e.g., a few hours, few days, or weeks). A thermal map also can be defined for any time/date as the user wishes. In addition, a movie can be set up by defining the start and end point so that changes can be observed for any period of time in the past.

In summary, the benefits of Level 3 EIS Software include: the removal of manual errors, customized analytics, and visualization at all user levels to access and use the data as needed. Some levels of automatic control (i.e., the ability to communicate with other systems such as BAS) can help users simultaneously read three to four metrics to provide automatic control signals (e.g., when the temperature in a data center lowers, an automatic control to turn off the chilled water valve).

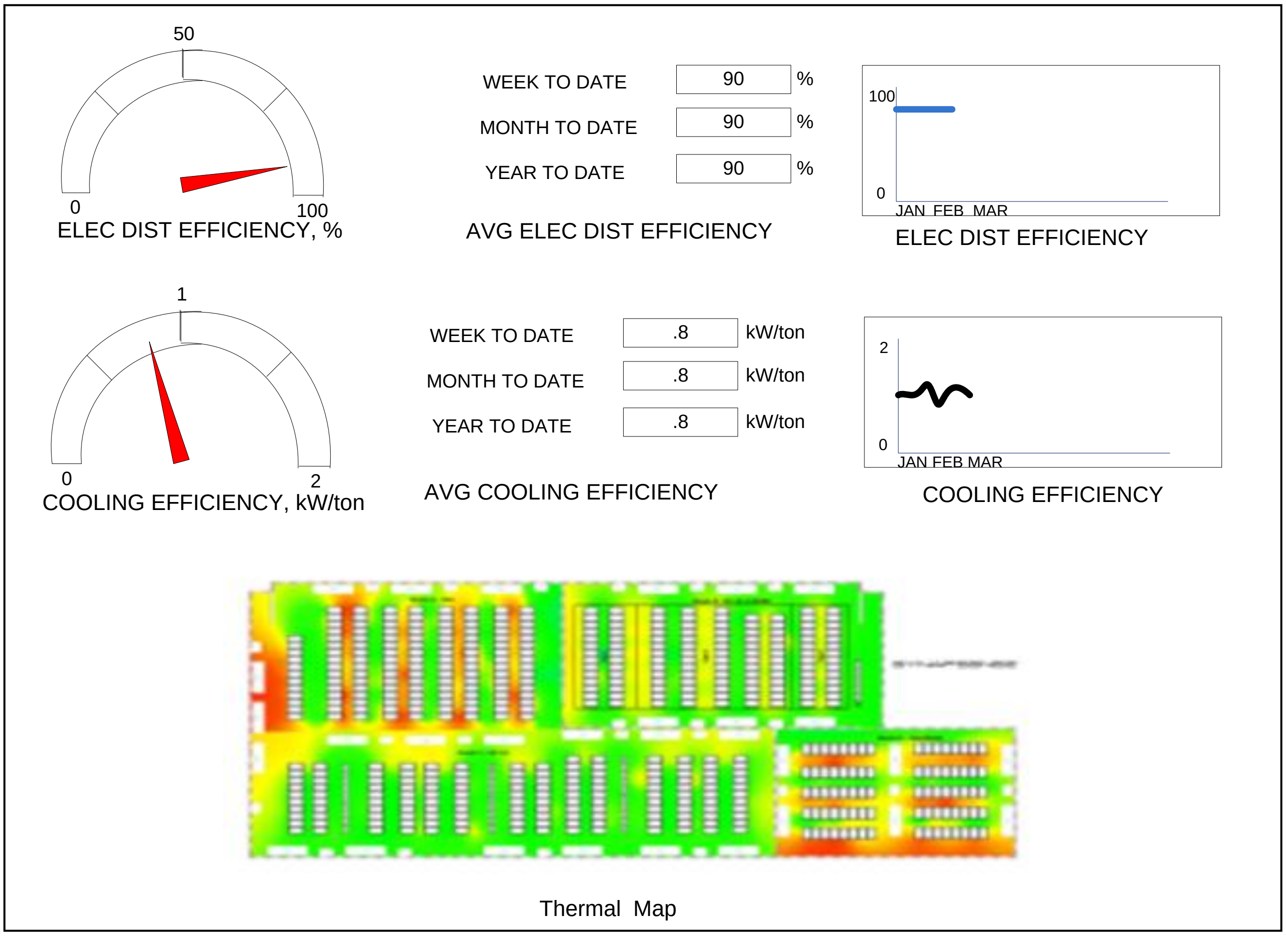

Figure 10: Facility Manager's Dashboard Using Level 3 Tools Approach

At the end of this section, the user should be able to determine their desired level of tools and software for data acquisition, communication, analysis, and visualization.

9. Acquiring M&M

This final step involves the selection, installation, commissioning of the EIS and conducting training for the selected monitoring package.

In the following section, although a description has been provided for Level 3 (Advanced EIS Monitoring approach), the user could also take a Level 1 or 2 approach.

The Process of Acquiring, Installing, and Using the EIS

Planning

To plan this final step, conduct the following activities:

- **Invite input from facility/IT managers on needs and expectations.** This information will help to ensure that all needs are being considered from the outset.
- **Select a vendor.** The chosen EIS solutions vendor should be experienced and should demonstrate an ability to understand your specific needs and challenges. The vendor should be willing to engage with you in a long consultancy process to properly establish how their specific solution can integrate with your system, address your needs, and maximize new opportunities.

- **Create an EIS Roadmap, using the process described above, to achieve the business objectives.** The process will depend partly on the capabilities of the EIS vendor, as well as your facility's specific needs, challenges, and data center type. It is important to have a roadmap for implementing the EIS before beginning the implementation process. Develop the implementation roadmap in conjunction with EIS vendor partners, and establish key implementation milestones and ways of measuring them.
- **Issue a Request for Proposal (RFP) to the short-listed vendors.** See sample specifications language provided in Appendix 4. Modify the sample specification to meet your facility's specific requirements.

Implementation

Key implementation phases typically include project initiation, defining needs and expectations, obtaining buy-in from all stakeholders, design including review cycles, implementation, 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 monitoring system is being installed may be a 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 environmental monitoring is the second phase.

Commissioning

Commissioning may be the hardest part of the implementation process. Every monitoring system on the site that is connected to the new EIS needs to be recommissioned. The presence of IT and facilities operators during commissioning is strongly recommended. In general, the commissioning process comprises the integrated application of a set of engineering techniques and procedures to check, inspect, and test every operational component of the EIS 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 data to information is the next key factor.

Training

The goal of training should be to increase awareness and create user-friendliness with the EIS package. This starts with assessing training needs, developing training materials focused on the key energy-efficiency performance metrics, and presenting workshops for all levels of data center stakeholders. Training should be used to influence behavioral change and enhance collaborative efforts between management, technology, and facilities staff. To this end, vendors should provide comprehensive training to the operators.

At the end of section, you should be confident about procuring and operating an EPT package for optimum use in your data center.

10. Summary

These guidelines have described three packages for Energy Performance Tracking (EPT). The user should select the relevant package for their purpose after reading this guideline.

In summary:

Level 1 Basic EPT Package =
Level 1 Basic metering + Level 1 Spreadsheet tools and simple hand-drawn charts visualization

Level 2 Intermediate EPT Package
= Level 1 Basic or 2 Intermediate metering
+ Level 2 equipment-specific tools and reports/ charts visualization

Level 3 Advanced EIS Package
= Automated inputs from Level 1 Basic or Level 2 Intermediate or, ideally Level 3 Deep metering
+ Advanced software and dashboard
+ potential interoperability with DCIM

These EPT packages, to varying degrees, help to fulfill the current and future business drivers that require tracking and reporting of energy information. The authors guidance about the relevance of the packages to the drivers is as follows:

1. **Track and manage energy consumption:** This is a high-level measurement of energy use. Usually the building utility meter and display of switchgear provide adequate information to estimate energy use. As identified in Table 1, whole-building metrics mostly satisfy this driver. Homemade spreadsheets and some end-use measurements can provide energy-use tracking and even basic capacity management. Level 1 and Level 2 EPT packages would be sufficient for this driver.
2. **Track and manage energy cost:** This directly relates to the energy use driver. The complexity may increase when the utility has variable rates and higher rates for peak loads. At this point, more data, including end-use metrics, are needed to track cost. Verifying reduced energy costs through improved energy efficiency and energy management is also important. Hence, a Level 3 EIS package would be most appropriate for tracking and managing energy costs.
3. **Energy-efficiency benchmarking:** Benchmarking is done with peers and/or through comparison to the same site before and after retrofits. Benchmarking usually is based on energy-efficiency measures and relies on derived metrics. Again, the higher the level of monitoring and analytics, the more precise the benchmarking. Through benchmarking, stakeholders can make meaningful conclusions from the collected data. For this, a Level 3 EIS package is recommended.
4. **Develop and validate energy efficiency strategies:** This is the most important driver. Here a full-functionality Level 3 EIS package is needed to comfortably address deficiencies and plan energy-efficiency measures.
5. **To avoid unwanted and business disruptive shutdowns, and manage demand response:** Onsite generation and load shedding are mostly employed, but monitoring and predictive measures are needed to achieve a secure and efficient demand-response process. It is essential to use point monitoring and trending for this driver, so at a minimum a Level 2 EPT and preferably a Level 3 EIS is recommended.

Figure 11 summarizes the mapping of business drivers to EPT package levels.

Package Levels \ Business Drivers	1. Track and Manage Energy Consumption	2. Track and Manage Energy Cost	3. Benchmarking	4. Develop and Validate Energy Efficiency Projects	5. Manage Demand (Demand Response)
Level 1 Basic Energy Performance Tracking package	Partially relevant	Partially relevant	Not relevant	Not relevant	Not relevant
Level 2 Intermediate Energy Performance Tracking package	Highly relevant	Partially relevant	Partially relevant	Partially relevant	Partially relevant
Level 3 Advanced EIS package	Highly relevant	Highly relevant	Highly relevant	Highly relevant	Partially relevant

Not relevant Partially relevant Highly relevant

Figure 11: Mapping of Business Drivers to EPT Package Levels

Figure 12 shows, on a sliding scale, the benefits and costs of the three levels of EPT. If possible, the budget should be allocated toward a Level 3 Advanced EIS package to enable a data-driven approach to data center energy management.

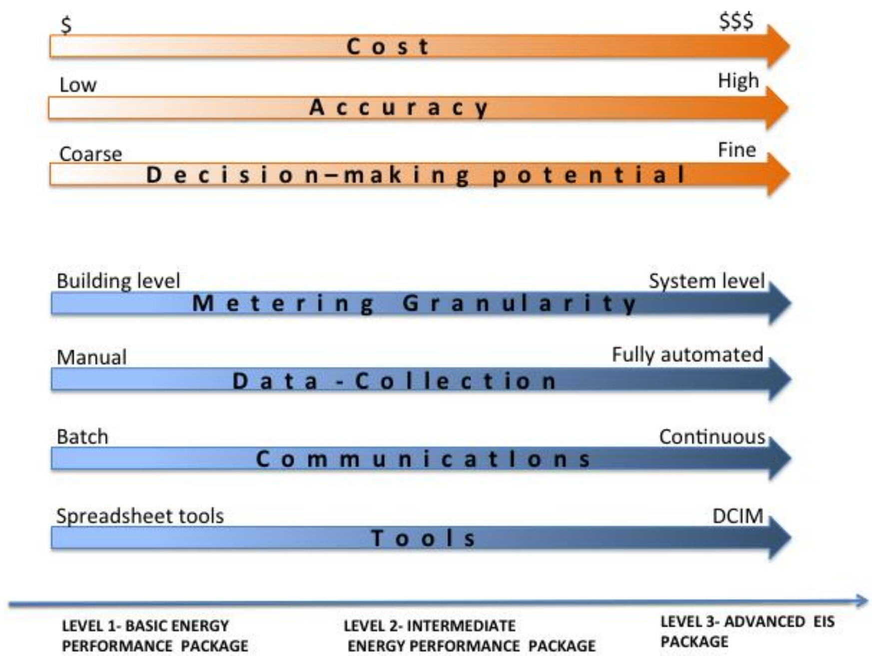

Figure 12: Comparison of the Three Levels of Energy Performance Tracking

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Appendix 1: Details on Business Drivers, Metrics and Related Factors

The following table provides definitions for each of the business drivers from Table 1. Several of these are standard definitions from the Energy Information Handbook.

1. Track and manage energy consumption	
1.1 Identification of baseline energy consumption	This metric is used to determine current energy consumption (the baseline). The baseline is a standard or typical energy performance metric, used for comparisons. Baselines may be expressed according to a variety of metrics, and to compare with consumption after energy-efficiency measures are implemented. The baseline can be at a certain point in time, or at a particular level of energy efficiency.
1.2 Measurement of real-time energy consumption for a specified time series at whole data-center and end-use level	The purposes of real-time measurements are to study the status of different equipment and systems and to detect anomalies. This is a window to the health of operations.
1.3 Simple tracking of energy use to monitor for anomalies	This is the most basic form of energy consumption accounting. Energy use from one period to another is inspected for decreases or increases, or for long-term downward or upward trends. A diversion from predicted value initiates an alert informing the operators of anomalies from expected use in the system's operation. Simple tracking relies on energy use total, and does not include normalization.
1.4 Tracking of emergency responses	This involves tracking emergency response such as a load-shedding event or as a part of fault diagnostics.
1.5 Optimization across various possible energy sources	Available power from different sources is analyzed and those at a lower carbon footprint and lower cost, such as a smart power distribution system, are selected.
1.6 Capacity management through space planning, cooling, and power load capacity planning	Part of predictive measurement is to have data on available capacity of space for future rack/servers, available power (from site, from PDU, etc.), and available cooling needed for the future IT equipment.
1.7 Carbon accounting	This accounting is used to quantify greenhouse gas (GHG) emissions associated with data center energy consumption. Carbon is typically reported at the building or portfolio level, but it may also be tracked at the system or component level.
2. Track and manage energy cost	
2.1 Prediction of energy cost, allocation	This method converts energy consumption into billed costs, so that information can be used in budgets and financial projections.
2.2 Verification of billing/metering accuracy and discrepancy identification	Bills are verified with respect to metered energy, to avoid surprises.
2.3 Estimation of cost	By creating the baseline and comparing the impact of energy-efficiency

saving	measures, savings can be estimated. Energy savings performance of energy efficiency measures (EEMs) can be determined using baseline models, with regression being the most common approach.
3. Benchmarking	
3.1 Cross-sectional benchmarking: Comparison of energy use with other facilities in the portfolio or peer group	By comparing your data center's energy performance to that of a comparable group of data centers, you can rank your facility's performance with that of similar facilities.
3.2 Longitudinal benchmarking: Comparison of energy use across time	By comparing your data center's current energy performance to past performance, you can identify energy trends and opportunities for improvement.
4. Develop and validate energy-efficiency projects	
4.1 Setting performance goals and identification of improvement opportunities for energy savings and/or retrofits	After benchmarking is complete, performance goals can be set that compare benchmark values with peers. Opportunities can then be discovered for energy efficiency.
4.2 Monitoring-based commissioning	This process verifies and documents the performance of building equipment to ensure that operational needs and design intent are satisfied. The monitoring process is required for a complete and thorough commissioning.
4.3 Diagnosing problems during operations (fault detection and diagnostics)	Through these diagnostics, equipment and hardware faults can be identified and treated.
4.4 Verification of energy savings from energy-improvement projects to reduce overall consumption and peak demand	This process quantifies the total energy savings associated with an efficiency improvement. Monitoring is a tool to verify the savings, both in peak load reduction and energy reduction.
5. Manage Demand (demand response, or DR)	
5.1 Determination of peak, critical, and non-critical load trends	Changes in electric usage by customers in response to changes in the price of electricity over time or when system reliability is jeopardized. A plan can be created for load shedding when the energy consumption trend is known.
5.2 Verification of energy and cost savings from DR	With monitoring, the savings can be evaluated and verified for DR.

Table 5: List and definition of the drivers

		Whole-building (data center) measurements						End-use measurements						Derived metrics					
		Energy Use: All sources (KWh)	Energy Use: Utility (KWh)	Energy Use: Generator (KWh)	Energy Use-: Other source CHP., RE (KWh)	Building Load (kW)	Annual Energy Cost (INR or $)	IT Energy Use (KWh)	Cooling load (KWh)	Fans energy Use (KWh)	Elec Distr. energy loss (KWh)	Lighting and other plugs energy use (KWh)	Environ-mental Temp, Hum., Press.	Annual CO2 metric ton	Power Usage Effectiveness (PUE)	Electrical chain efficiency (Avg percent)	Cooling system efficiency (Avg kW/ton)	IT Utilization (e.g. CPU utilization)	IT Efficiency (Product/W)
Drivers	**1. Track and manage energy consumption**																		
	1.1 Identify baseline energy consumption	x	x	x	x														
	1.2 Monitor real time energy consumption	x	x	x	x	x		x	x	x	x	x							
	1.3 Anomaly detection	x						x	x	x	x	x							
	1.4 Track emergency response e.g load shed events	x	x	x		x		x	x	x	x	x							
	1.5 Optimize across various possible sources of energy	x	x	x	x														
	1.6 Capacity management viz. space planning, cooling and power load capacity planning	x				x		x	x	x	x								
	1.7 Carbon accounting	x																	
	2. Track and manage energy cost																		
	2.1 Predict energy cost, allocation	x	x				x	x	x	x	x	x							
	2.2 Verify billing/ metering accuracy; identify discrepancies	x	x	x	x	x	x	x	x	x	x	x							
	2.3 Estimate savings	x	x	x	x	x	x	x	x	x	x	x							
	3. Benchmarking																		
	3.1 Cross-sectional benchmarking													x	x	x	x	x	x
	3.2 Longitudinal benchmarking													x	x	x	x	x	x
	4. Develop and validate energy efficiency projects																		
	4.1 Set performance goals and Identify improvement opportunities for energy savings and/or retrofit	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
	4.2 Monitoring-based commissioning	x	x	x	x	x		x	x	x	x	x	x		x	x	x	x	x
	4.3 Fault detection and diagnostics	x	x	x	x	x		x	x	x	x	x	x		x	x	x	x	x
	4.4 Verify savings from energy improvement	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x
	5. Manage Demand (Demand Response)																		
	5.1 Determine peak, critical and non-critical load trends	x	x	x	x	x		x	x	x	x	x	x						
	5.2 Verify savings from DR	x	x	x	x	x	x	x	x	x	x	x							

Table 6: Characterization Matrix of Business Drivers and Metrics

Meters	Energy Use: All sources (KWh)	Energy Use: Utility (KWh)	Energy Use: Generator (KWh)	Energy Use: Other source CHP, RE (KWh)	Building Load (kW)	Annual Energy Cost (INR or $)	IT Energy Use (KWh)	Cooling Load (KWh)	Fan Energy Use (KWh)	Elec Distr. energy loss (KWh)	Lighting and Other Energy Use (e.g., generator heater) (KWh)	Environ-mental Temp., Hum., Press.	Annual CO2 metric ton	Power Usage Effective. (PUE)	Electrical Chain Effic. (Avg percent)	Cooling System Efficiency (Avg kW/ton)	IT Utilization (e.g., CPU Utiliz.)	IT Efficiency (Product/W)
	Metrics																	
	Whole-building (data center) measurements						**End-use measurements**							**Derived metrics**				
Electric meter at utility	**M**	**M**			**M**								rough estimate					
Electric meter at generator	**M**		**M**															
On-site renewable energy meter																		
Electric meter at distribution panels																		
UPS meter							display							rough estimate	rough estimate			
PDU meter																		
IT energy meter																		
Product meter																		
Chiller plant meter								display										
CRAH meter								nameplate										
CRAC meter								nameplate										
Pump meter								nameplate or display if VFD										
Fan meter								nameplate or display if VFD										
Lighting meter																		
Chilled water flow meter																		
Air flow meter																		
Data center air temp												CRAH temp display						
Air distribution pressure (ducted/ underfloor)																		
Chilled water temp												display						
Cooling tower fan																		
Outside air temperature																		

Measured time series data

Instantaneous values

M Meters with automated data collection

Table 7: Metrics and Pertinent Meters Associated With Level 1 (basic) Metering. This Level of Metering Allows for Rough Estimates of Some of the Derived Metrics.

	Whole-building (data center) measurements						End-use measurements							Derived metrics				
	Energy Use: All sources (KWh)	Energy Use: Utility (KWh)	Energy Use: Generator (KWh)	Energy Use: Other source CHP, RE (KWh)	Building Load (kW)	Annual Energy Cost (INR or $)	IT Energy Use (KWh)	Cooling Load (KWh)	Fan Energy Use (KWh)	Elec Distr. Energy Loss (KWh)	Lighting and Other Energy Use (e.g., generator heater) (KWh)	Environ-mental Temp, Hum, Press.	Annual CO2 metric ton	Power Usage Effective. (PUE)	Electrical Chain Efficiency (Avg percent)	Cooling System Effic. (Avg kW/ton)	IT Utilization (e.g., CPU utiliz.)	IT Efficiency (Product/W)
Electric meter at utility	**M**	**M**			**M**	**M**							**estimate**	**estimate**				
Electric meter at generator	**M**		**M**			**M**												
On-site renewable energy meter	**M**			**M**														
Electric meter at distribution panels																		
UPS meter							**EM**							**estimate**	**estimate**			
PDU meter							**EM**											
IT energy meter																		
Product meter																		
Chiller plant meter								**M**						**estimate**		**estimate**		
CRAH meter									**M**									
CRAC meter																		
Pump meter																		
Fan meter																		
Lighting meter																		
Chilled water flow meter																		
Air flow meter																		
Data center air temp												**S**						
Air distribution pressure (ducted/ underfloor)																		
Chilled water temp																		
Cooling tower fan												**S**						
Outside air temperature								**S**				**S**						

(orange)	Measured time series data
(blue)	Instantaneous values
S	Sensor with manually recorded information
M	Meter with automated data collection
EM	Equipment meter to be manually recorded

Table 8: Metrics and Pertinent Meters Associated with Level 2, Intermediate Metering. This Level of Metering Allows for Estimates of Many of the "Derived metrics"

	Whole-building (data center) measurements						End-use measurements							Derived metrics				
Meters	Energy Use- All sources (KWh)	Energy Use- Utility (KWh)	Energy Use- Generator (KWh)	Energy Use- Other source CHP., RE (KWh)	Building Load (kW)	Annual Energy Cost (INR or $)	IT Energy Use (KWh)	Cooling load (KWh)	Fans energy Use (KWh)	Elec Distr. energy loss (KWh)	Lighting and other energy use (e.g. generator heater)(KWh)	Environ-mental factors Temp, Hum, Press.	Annual CO2 metric ton	Power Usage Effectiveness (PUE)	Electrical chain efficiency (Avg percent)	Cooling system efficiency (Avg kW/ton)	IT Utilization (e.g. CPU utilization)	IT Efficiency (Product/W)
Electric meter at utility	**M**	**M**			**M**	**M**								Precise	Precise			
Electric meter at generator	**M**		**M**			**M**								Precise	Precise			
On-site Renewable energy meter	**M**			**M**										Precise	Precise			
Electric meter at distribution panels							**M**							Precise	Precise			
UPS meter							**M**			**M**				Precise	Precise			
PDU meter							**M**			**M**				Precise				
IT energy meter							**M**			**M**				Precise	Precise		Precise	
Product meter							**M**							Precise				Precise
Chiller plant meter								**M**	**M**					Precise		Precise		
CRAH meter								**M**						Precise		Precise		
CRAC meter								**M**						Precise		Precise		
Pump meter								**M**						Precise		Precise		
Fan meter								**M**	**M**					Precise		Precise		
Lighting meter											**M**			Precise		Precise		
Chilled water flow meter								**M**								Precise		
Air flow meter												**M**						
Data center air temp												**S**						
Air distribution pressure (ducted/ underfloor)												**S**						
Chilled water temp												**S**				Precise		
Cooling tower fan								**M**								Precise		
Outside Air Temperature								**S**				**S**				Precise		

[orange box] Measured time series data

[blue box] Instantaneous values

S Sensor
M Meter with automated software data collection
EM Equipment meter to be manually recorded

Table 9: Metrics and Pertinent Meters associated with Level 3 Advanced Metering. This Level Provides the Most Precise Accuracy for all The Derived Metrics

Appendix 2: Glossary of Terms

Cooling Systems

These systems generally fall into two categories: the Computer Room Air Conditioner (CRAC), wherein each unit has its own internal compressor, and Computer Room Air Handler (CRAH), which is primarily a coil and a fan, which requires externally supplied chilled water. From an energy-efficiency viewpoint, the CRAH, which is usually supplied by a water-cooled central chilled water plant, is more efficient than an air-cooled CRAC unit is. However, the air-cooled CRAC unit has one advantage over a centralized chiller system; it is all autonomous and therefore offers inherent redundancy and fault tolerance, in that there are fewer failure modes (other than power failure). Data centers have historically maintained very tight environmental conditions, to help ensure the reliability of the IT equipment. This was originally driven by older equipment's susceptibility to temperature and humidity changes, as well as a very narrow range of "recommended" environmental conditions mandated by the equipment manufacturers themselves.

Demand Response

According to Wiki, demand response (DR) is defined as: "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." It includes all intentional modifications to consumption patterns of electricity of end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption. It is expected that demand-response programs will be designed to decrease electricity consumption or shift it from on-peak to off-peak periods, depending on consumers' preferences and lifestyles. Demand response activities are also defined as "actions voluntarily taken by a consumer to adjust the amount or timing of his energy consumption." Demand response is a reduction in demand designed to reduce peak demand or avoid system emergencies. Hence, DR can be a more cost-effective alternative than adding generation capabilities to meet the peak and or occasional demand spikes. Its underlying objective is to actively engage customers in modifying their consumption in response to pricing and/or abnormality signals. This all is possible through end-use monitoring of energy consumption, which is best made possible by a Level 3 monitoring.

Derived Metrics

The following are standard data center-derived metrics used in order to understand and manage energy consumption.

1. **Carbon Dioxide (CO_2) Emissions (metric tons per capita):** energy-related CO_2 emissions released at the location of the consumption of the fuel; in this case, at the power plant(s) generating the electricity used at the data center.

2. **Power Usage Effectiveness or PUE (index):** a measure of how efficiently a computer data center uses energy; specifically, how much energy is used by the computing equipment (in contrast to cooling and other overhead)

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

Hypothetically, a perfectly efficient data center would have a PUE of 1, so the closer to that number, the more efficient the data center is. The average PUE for U.S. data centers is about 2. There are efficient data centers that have PUEs of about 1.2 and even 1.1.

Different values can be obtained depending on where the IT power measurement is done. Figure 14 illustrates the three assigned values for PUE based on meter location. The organization GreenGrid has defined three degrees of accuracy for PUE. If the measurement at UPS is used as IT energy to calculate PUE, it is called PUE_1. See Figure 14 for meter location. If measurement is done at PDU, then power loss in the UPS is considered infrastructure energy—that is called PUE_2. If the measurement is taken at the server, then a more realistic PUE, called PUE_3, is obtained, since all the power distribution losses are considered in the infrastructure portion of the energy used, and not in the IT portion.

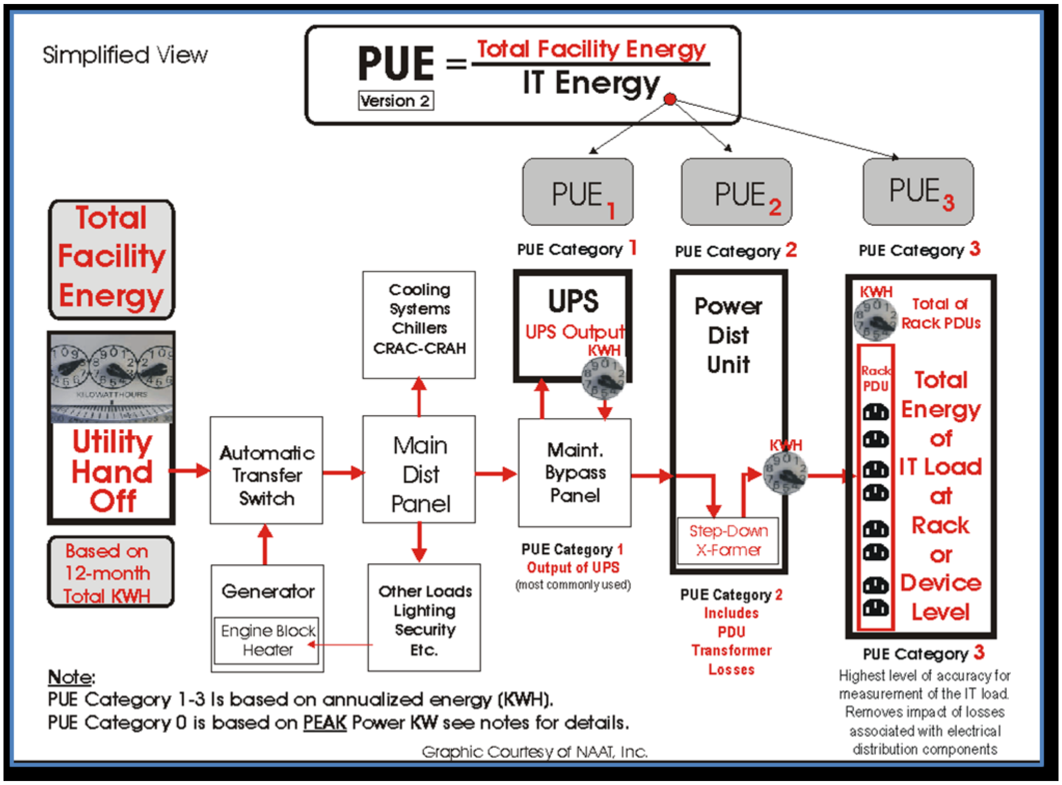

Figure 13: Different Versions of PUE (Source: NAAT, Inc.)

3. **Electrical power chain efficiency (avg. percent):** Efficiency of a power chain that usually consists of a utility transformer, automatic transfer switch, back-up generator, distribution switchgear, uninterruptable power supply (UPS), and the downstream power distribution system going to the IT equipment cabinets.

4. **Cooling system efficiency (avg. kW/ton):** Efficiency of the cooling system in a data center that represents the majority of facility-related energy usage in the data center, outside of the actual IT load itself.

5. **IT Utilization (e.g., CPU utilization)**: In computing, performance per watt is a measure of the energy efficiency of particular computer architecture or computer hardware. Literally, it measures the rate of computation that can be delivered by a computer for every watt of power consumed. FLOPS (floating-point operations per second) per watt is a common measure. While each of the components in the power chain incur a relatively small loss, the overall efficiency in of the power system is primarily affected by the efficiency of the uninterruptible power system (UPS), as well the overall smaller downstream power distribution losses.

6. **Data Center IT Power Density (W/unit area):** This metric indicates the IT power load per unit area. For instance, legacy data centers run at 20 to 100 watts/square foot (sf). Newer data centers are designed for 100 to 500 watts/sf.

Data Center Infrastructure Management (DCIM)

In general, *data center infrastructure management* (DCIM) is a category of solutions created by the information technology (IT) industry to extend the traditional data center management function to include all physical assets and resources in the facilities and IT domains. It extends the traditional data center management function to include all physical assets and resources in the facilities and IT domains, to integrate all critical aspects of a data center's systems. Metrics provide the foundation of the DCIM system used to manage the data center.

DCIM deployments over time will integrate IT and facilities management disciplines to centralize monitoring, management, and intelligent capacity planning of a data center's critical systems. In general:

- DCIM is a central data repository for multiple pieces of information, delivering a consolidated source of data for all infrastructure variables such as energy use, location, asset life cycle, environmental conditions, capacity, connectivity, and configuration.
- DCIM tools aggregate data from multiple sources and present the data to decision makers in a meaningful, actionable way; mostly graphical.
- DCIM solutions need to support strong change planning and management processes.
- Some DCIM solutions can be used to design proposed infrastructure, allowing facilities and IT to model proposed changes and capacities.
- To identify energy-efficiency opportunities, data needs to be converted to actionable information, including cost and payback, which DCIM can provide.
- Although staff time and commitment is needed to review and act on information, EIS process automation can minimize labor time and labor cost.
- It provides real-time resource utilization data which makes capacity management possible.
- It provides better electrical, cooling, floor, rack, and IT capacity planning.
- As the result of DCIM implementation and integration, through providing a common platform for monitoring and managing data center resources, DCIM produces greater harmonies between management, technology, and facilities personnel. This includes managing cooling and electrical systems together more cost effectively and energy efficiently. Although these personnel share the common goal of maintaining the health of the data center, in many cases they continue to operate in physical and cultural silos.

At a minimum, DCIM should be capable of the following:

- Communicate with the other sites and facilities' monitoring and control systems. This requires open protocol capability (e.g., SNMP, Modbus, BACnet, and over TCP).
- Provide customization of the dashboard with different components and for different users.
- Provide customization of real-time and historical reporting.
- Provide central monitoring and control for multiple sites.
- Provide access to resources such as a library of IT and infrastructure equipment and components (as well as websites such as those related to weather, utilities, and other factors).

Appendix 3: Types of Meters

The following is a list of types of types of meters.

Measurement Equipment	Type	Accuracy %	Cost level	Notes
Temperature	Thermocouple	1.0–5.0	$	Stable, durable
Temperature	Thermistors	0.1–2.0	$$	Retains characteristics
Temperature	RTDs	0.01–1.0	$$$	Stable output, ease of calibration
Pressure in pipe	Burdon	0.25–0.5	$$	Used for speed variable pumps
Pressure in pipe	Strain gauge	0.1–1	$$	Used for speed variable pumps
Liquid Flow	Paddle wheel	0.5–5	$	Water quality impact
Liquid Flow	Turbine Wheel	0.3–2	$$	Water quality impact
Liquid Flow	Venturi	0.5–2	$	Shut down needed
Liquid Flow	Ultrasonic	1–5	$$	No shut down is required to install
Liquid Flow	Variable area	0.5–5	$	Shut down needed
Liquid Flow	Coriolis mass	0.1–0.5	$$$	Too accurate for this application
Air flow	Hot wire Anemometer	1.0–5.0	$	For air handler and perf tile
Power	Electromechanic	0.5–1.5		Not recommended
Power	Electronic	0.2–0.5	$$$	Very good
Power	Solid-State	0.2–0.5	$$$	Best
Power	Portable	0.5-–2	$	Range of quality

Table 10: Types of Meters

Appendix 4: Sample Data Center EIS Specifications

The following are two sample EIS-related specification documents.
The first specification is a general specification for monitoring and control as part of an EIS for a data center. It is a typical construction specification and shall be regarded as a sample.
The second is a guide/specification for a wireless monitoring as part of EIS. It is specific to wireless systems.
The specifications language for EIS should be selected, tailored, and modified to suit each user's purpose and preferences based on the information's provided in the guidance document.

I. SAMPLE: EIS General Specifications

This specification covers general requirement for an EIS and is the main part for an EIS. An EIS also addresses demand-response management, which is not addressed here.

PRODUCTS

The intent of this section is not to cover all the components of an EIS system. This is only a sample specification. The Owner needs to decide on the level of monitoring and management and provide the contractor with the specification and scope of work.

EIS

A. The EIS shall be a microprocessor-based, fully integrated, modular system, wireless granular mesh network.

B. The system shall include, but not be limited to, the following:

1. The system shall be easily expandable by the user in both capacity and functionality.
2. To maintain reliability, each stand-alone controller shall be capable of operating, controlling, or monitoring without a host computer.
3. Each stand-alone controller shall be capable of performing the basic direct digital control (DDC) functions with proportional integral derivative (PID) loop control, time scheduling, duty cycling, temperature override, start and stop time optimization, outside air optimization, and user-defined programs to meet the sequences of operation.
4. The controllers shall be connected by a high-speed network to allow for data communication between controllers and other parts of the system.
5. The network shall be fault-tolerant and any stand-alone controller detecting an error in its operation shall disconnect itself from the network to allow the remaining controllers to continue normal operations. The only loss of data shall be the data supplied by the failed controller panel. The network panel shall automatically regenerate the token after a failed panel removes itself from the network or on start-up of the system.
6. The network shall be able to pass analog point values and binary point status conditions. A minimum amount of points shall be definable as "global" points for interchanging pertinent data between stand-alone controller panels or for initiating alarm sequences.
7. Provide automatic clock synchronization between all stand-alone controllers on the network and any supervisory computer workstations.
8. The system shall be fully programmable by the user to allow adding, deleting, and changing points and to write custom control sequences without vendor assistance.
9. The system shall have full proportional, integral, and derivative control of control loops to minimize offset and maintain tight control to assigned set points.

10. Start/Stop Function: The system shall enable starting and stopping of remote devices either by operator or built-in clock function.
11. Pre-programmed standard functions for HVAC control and energy management shall be provided in each stand-alone controller for:
    a. Time of day scheduling.
    b. Daylight-savings time adjustments.
    c. Holiday scheduling.
    d. Temperature compensated duty cycling.
    e. Electrical demand limiting.
    f. Start and stop time optimization.
    g. Controlling start/stop interlock schedules.
    h. Minimum on/maximum off timers.
    i. Temperature override.
    j. Outside air enthalpy optimization.
    k. Maintenance messages.
    l. Direct Digital Control (PID).
    m. Power failure/auto restart.
    n. User-defined programming.
    o. Data logging.
    p. Self diagnostics with service alarm buffer.
12. The system shall provide for automatic restart after a power failure or upon initialization of the system. Controlled loads shall have a user programmable delay between successive starts to limit demand peaks.
13. The stand-alone controllers' and distributed control modules' database shall be stored on disk memory at the supervisory computer for backup and restore operation. The controller shall up-line load any entered attribute changes made at the panel by a manual command from the supervisory computer.
14. Each stand-alone controller shall contain self-diagnostics that continuously monitor the proper operation of the unit. A malfunction of the controller, any distributed control module, or associated communication link shall be reported automatically to display the condition of failure along with time and date.
15. The system shall include data logging, storage, and trending capabilities.

TEMPERATURE SENSORS

A. Temperature sensors shall be as required to meet the control tolerances specified.

HUMIDITY SENSORS/TRANSMITTERS

A. Furnish electronic humidity transmitters complying with following minimum specifications:
    1. Sensing range 10% to 90% RH
    2. Operating range 20% to 80%RH
    3. Accuracy - plus/minus 3% RH over operating range including non-linearity, hysteresis, and repeatability.
    4. Drift - maximum 5% of full scale per year.

B. 4-20 mA Output signal as suitable for interfacing to analogue to digital converter input of DDC controller.

DIFFERENTIAL PRESSURE TRANSMITTERS

A. Differential pressure transmitters shall be provided as necessary to meet the control tolerances specified. The transmitters shall include zero adjust and averaging output (debounce).

HOST COMPUTER AND PERIPHERALS

A. Owner will provide the computer workstation. EIS contractor shall install provide and install the required software for proper operation.

B. The system shall include all necessary operating system software.

C. Provide all required connectors and cables for complete connection of all Host and Local Command Device connections to peripherals.

CURRENT TRANSMITTERS

A. AC current transmitters shall be self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4-20 mA two-wire output. Full-scale unit ranges shall be 10 A, 20 A, 50 A, 100 A, 150 A, and 200 A, with internal zero and span adjustment. Unit accuracy shall be ±1% full-scale at 500 ohm maximum burden.

B. Transmitter shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA recognized.
C. Unit shall be split-core type for clamp-on installation on existing wiring.

VOLTAGE TRANSFORMERS

A. AC voltage transformers shall be UL/CSA recognized, 600 Vac rated, and shall have built-in fuse protection.

B. Transformers shall be suitable for ambient temperatures of 4°C–55°C (40°F–130°F) and shall provide ±0.5% accuracy at 24 Vac and 5 VA load.

C. Windings (except for terminals) shall be completely enclosed with metal or plastic.

POWER MONITORS

A. Power monitors shall be three-phase type and shall have three-phase disconnect and shorting switch assembly, UL-listed voltage transformers, and UL-listed split-core current transformers.

B. Power monitors shall provide selectable output: rate pulse for kWh reading or 4-20 mA for kW reading. Power monitors shall operate with 5 A current inputs and maximum error of ±2% at 1.0 power factor or ±2.5% at 0.5 power factor.

CURRENT SWITCHES

Current-operated switches shall be self-powered, solid-state with adjustable trip current. Select switches to match application current and DDC system output requirements.

DIFFERENTIAL PRESSURE SWITCHES

Differential pressure switches (air or water service) shall be UL-listed, SPDT snap-acting, pilot-duty rated (125 VA minimum) and shall have scale range and differential suitable for intended application and NEMA 1 enclosure unless otherwise specified.

LIQUID FLOW TRANSMITTER

A. Flow meter with associated installation kit or approved equal with local display. This is for Chilled water application only.

II. SAMPLE: Wireless Network Specification for Data Center EIS

The two primary motivations for choosing a wireless network over a wired approach are the flexibility and the cost-savings associated with eliminating cables and wires. With no wires or cables to route, a wireless monitoring system is inherently more flexible than a traditional network. You are not locked into a fixed network topology or system setup, leaving open the possibility for additions, upgrades, extensions, and so on. This convenience means there is less overhead associated with setting up a measurement, and less overhead means more opportunity for taking additional measurements for added insight into your system. Wireless also extends the portability of your data acquisition. Field measurements can be time-consuming and costly. With wireless sensors, setup time is significantly reduced. The flexibility of wireless remote monitoring systems can translate into large cost savings. Cost savings can be achieved at two levels: reduced downtime and installation labor. Table 2 illustrates a summary of benefits and features. (Courtesy of Wireless Sensors)

Driver	Benefit	Feature Required to Deliver Benefit
Reduce Op Ex	▪ Optimize cooling distribution system	▪ Granular temp measurements at low deployment costs
	▪ Optimize CRAC	▪ CRAC supply and return temperature ▪ CRAC chilled water supply return temp ▪ CRAC thermal performance
Reduce Cap Ex	▪ Wireless devices non-invasive installation reduces TCO of monitoring systems	▪ Scalable, low cost, easy to deploy with long battery life ▪ Stand alone system or integrate with existing third party systems and applications
Prevent Failures	▪ Alert excessive ambient conditions	▪ Granular temperature measurements
	▪ Alert access intrusion	▪ Sense room access
	▪ Alert anomaly in air distribution system	▪ Granular temperature measurements

Table 11: Summary of benefits and features

DESCRIPTION

A wireless mesh network (WMN) is a communications network made up of radio nodes organized in a mesh topology. Wireless mesh networks often consist of mesh clients, mesh routers and gateways. The mesh clients are often laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways, which may but need not connect to the Internet. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. Access to this mesh cloud is dependent on the radio nodes working in harmony with each other to create a radio network. A mesh network is reliable and offers redundancy. When one node can no longer operate, the rest of the nodes can still communicate with each other, directly or through one or more intermediate nodes. Wireless mesh networks can be implemented with various wireless technology including 802.11, 802.15, 802.16, cellular technologies or combinations of more than one type.

ARCHITECTURE REQUIREMENTS

Wireless mesh architectures infrastructure is, in effect, a router network minus the cabling between nodes. It should be built of peer radio devices that don't have to be cabled to a wired port. Mesh architecture should sustain signal strength by breaking long distances into a series of shorter hops. Intermediate nodes not only should boost the signal, but cooperatively make forwarding decisions based on their knowledge of the network, i.e. perform routing. Architecture should provide high bandwidth, spectral efficiency, and economic advantage over the coverage area.

Wireless mesh networks should have a relatively stable topology except for the occasional failure of nodes or addition of new nodes. The path of traffic, generated from a large number of end users, should change infrequently. Practically all the traffic in an infrastructure mesh network should either forwarded to or from a gateway.

The sensor nodes should collect temperature and other environmental parameters and power readings. The manager (gateway) should coordinate routing, aggregates packets of data, collect network statistics, and handle all data transfers. Again, gateway communication with its mesh network is required to be wireless. The server should communicate with the gateway through an Ethernet connection. A typical mesh network is illustrated in figure 14. (Courtesy of Wireless Sensors)

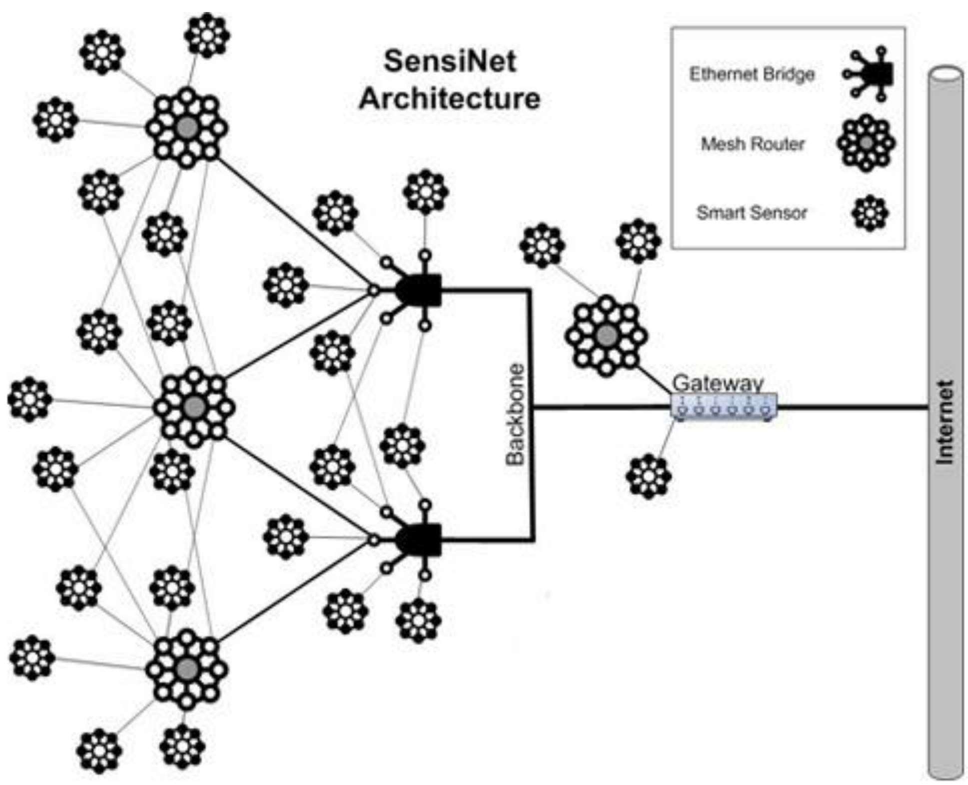

Figure 14: Typical Mesh Network

COMPONENTS AND FEATURES SPECIFICATIONS

The monitoring and metering shall be a microprocessor-based, fully integrated, modular, wireless granular mesh network. The system shall include, but not be limited to, the following features:

- The system shall be easily expandable by the user in both capacity and functionality.
- The network shall be fault tolerant.

Following are requirements for typical components:

Gateway

While main power supply is the house 120V. The gateway shall have a minimum of 72-hour battery back-up in case of power failure. It should have lights showing if it is powered by battery. Also lights should demonstrate if the gateway is communication with the nodes. The system shall have complete alarm handling, logging, prioritizing, and acknowledge capabilities. It shall include data logging, storage, dashboard, and trending.

Rack thermal node

Temperature node shall gather data from multiple sensors installed on the air intake and air exhaust of the racks and transfer temperature and humidity data to the nodes. Temperature nodes wired to those sensing points should communicate with the gateway through wireless mesh network. It is preferred that the same node collect relative humidity data from sensors without need for additional nodes. Accuracy of equal or better than ±0.6°F is required. The time between each data release (communication with gateway) should not exceed 5 minutes. Nodes should have lights showing that they are on, communicating, or initializing.

CRAH/C Thermal

Each unit comes with two thermal nodes, one for supply air and one for return air. Having multiple sensors at the return, usually a 3 foot by 8 foot area, will provide a more accurate temperature reading but is optional. Accuracy of equal or better than ±0.6°F is required. The time between each data release (communication with gateway) should not exceed 5 minutes. Nodes should have lights showing that they are on, communicating, or initializing.

Dew point Sensors/ Transmitters

These can be integrated parts of the rack and CRAC thermal nodes listed above to make the installation faster and easier or provided separately. Required accuracy is ±0.9°F. The time between each data release (communication with gateway) should not exceed 5 minutes. Nodes should have lights showing that they are on, communicating, or initializing.

Differential Pressure Transmitters

Differential pressure transmitters should be provided as necessary to meet the control tolerances specified. Differential Pressure Range should be from -1.0 to 2.0 in H_2O. Zero point accuracy should be equal or better than: ±0.002 in H_2O. The time between each data release (communication with gateway) should not exceed 5 minutes. Nodes should have lights showing that they are on, communicating, or initializing.

Current Transmitters
AC current transmitters should be a self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4-20 milliamp (mA) two-wire output. Full-scale unit ranges shall be 10 amps (A) to 1000 A, with internal zero and span adjustment. Unit accuracy shall be ±1% full-scale at a 500 ohm maximum burden. The transmitter shall meet or exceed ANSI/ISA S50.1 requirements and shall be UL/CSA recognized. The unit shall be a split-core type, for clamp-on installation on existing wiring. Nodes should have lights showing that they are on, communicating, or initializing.

Voltage Transformers
AC voltage transformers shall be UL/CSA recognized, 600 Vac rated, and shall have built-in fuse protection. Transformers shall provide ±0.5% accuracy at 24 Vac and 5 VA load. Windings (except for terminals) shall be completely enclosed with metal or plastic.

Other Components
There might be requirement for other components such as btu meter (combination of water flow meter and two temperature sensors) for chilled water system, or others. These meters are not part of wireless mesh network but should be able to communicate with the monitoring server through Modbus, Bacnet, SNMP or other communication protocols.

Battery Life
The network should let battery powered devices sleep for minutes at a time, reducing battery use. The duty cycle of battery powered nodes within a network should be designed to be very low, offering even more energy efficiency and greater battery life. Batteries should last for four years at a minimum.

Operational Interference
Data center environments typically have a large amount of radio frequency (RF) noise. This noise is created by servers, UPS inverters and building systems, and other wireless communications, such as Wi-Fi and mobile phones, all of which create interference that can significantly degrade network performance. To overcome operational interference (noise), the network nodes should be ultra low-power wireless transceivers that transfer data to and from integrated sensors or controllers, using an on-board radio to send the packets to neighboring nodes. Each node should pass the packet on to other nodes, in a series of “hops” that deliver data to their destination. Preconfigured nodes should be able to be added to or removed from the network without disrupting communications. In addition, wireless monitoring devices should not cause any problems with the operation of the existing communicating devices in the data center; therefore, they should have low-power transmissions (< 3 mW), low data transmission rate (< 3%), and non-overlapping frequency range.

Security
Wireless sensor, router, and gateway devices should not support any Internet-protocol (IP)-based protocols. To avoid any security threats, they should not provide any support for IP connection initiation, connection establishment, data initiation, or data transfer. In addition, the wireless networks shall use encryption, to ensure that external agents cannot snoop the context of the communication on the network.

Data Latency
Wireless network providers should identify their data latency in their bid. This includes propagation, the time that it takes for a packet to travel between one place and another, and transmission speed, considering the medium itself introduces some delay.
The data reliability of the wireless network should be on the order of 99.999%, at least. The wireless network also should be able to accommodate feedback (i.e., data flow from upstream back).

If communication with a vendor's server is necessary, the mechanism, ease of use, and security features need to be defined and approved by the data center managers.

SCOPE OF WORK

The following bullets outline the scope of work. Note that the responsibility for each item should be well defined in the contract between the owner and contractor(s).

- Provide all of the design, labor, equipment, and materials that are required to result in a complete and properly operating monitoring and metering installation.
- Furnish all remote field devices (sensors, gateways, transmitters, power supplies, etc.) to assure a complete and operating system.
- Provide a server for the monitoring and metering contractor to install their operating program(s) on. The contractor is responsible for coordination of software versions and implementation.
- Provide complete start up, check out, and commissioning of related monitoring and metering systems.
- Provide complete on-site instruction to the Owner in the proper operation of the system and all devices.
- Provide all wiring, terminations, enclosures, network devices, software installation, and commissioning for monitoring of typical electrical systems such as CRAH or/and CRAC units.

List of Abbreviations

AC	alternating current
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASO	automated system optimization
ATS	automatic transfer switch
AVG	average
BAS	building automation system
BMS	building management systems
Btu	British thermal unit
CHP	combined heat and power
CHW	chilled water
CO_2	carbon dioxide
CRAC	computer room air conditioner
CRAH	computer room air handler
CSA	Canadian Standards Association
CT	cooling tower
CTW	cooling tower water
DC	direct current
DCIM	data center infrastructure management
DDC	direct digital control
DR	demand response
ECM	energy conservation measures
EE Loss	Electrical distribution energy loss
EIS	Energy Information System
EM	equipment meter
EMS	energy management system
EPT	Energy Performance Tracking
ESCO	energy services company
FDD	fault detection and diagnosis
FEMP	Federal Energy Management Program
FLOPS	floating point operations per second
GHG	greenhouse gas
HVAC	heating, ventilating, and air conditioning
Hz	hertz
ISA	International Society of Automation
IT	information technology
kW	kilowatt
kWh	kilowatt-hour
LCD	liquid-crystal display
LED	light-emitting diode
M	power meter
M&V	measurement and verification
mV	millivolt

PC	personal computer
PDU	power distribution unit
PEC	Pacific Energy Center
PID	proportional integral derivative
PSU	power supply unit
PUE	Power Usage Effectiveness
RE	renewable energy
RF	radio frequency
RFP	request for proposal
RH	relative humidity
RMS	root mean square
RTD	resistance temperature detector
S	sensor
sf	square foot
SNMP	simple network management protocol
TCP	transmission control protocol
THD	total harmonic distortion
UL	underwriters laboratories
UPS	uninterruptable power supply
USD	United States dollars
VAC	voltage alternating current
WMN	wireless mesh network
W	watt

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