Lawrence Berkeley National Laboratory
Recent Work

Title
Guidelines for Datacenter Energy Information System

Permalink
https://escholarship.org/uc/item/0sr9t9mp

Authors
Singh, Reshma
Mahdavi, Rod
Mathew, Paul
et al.

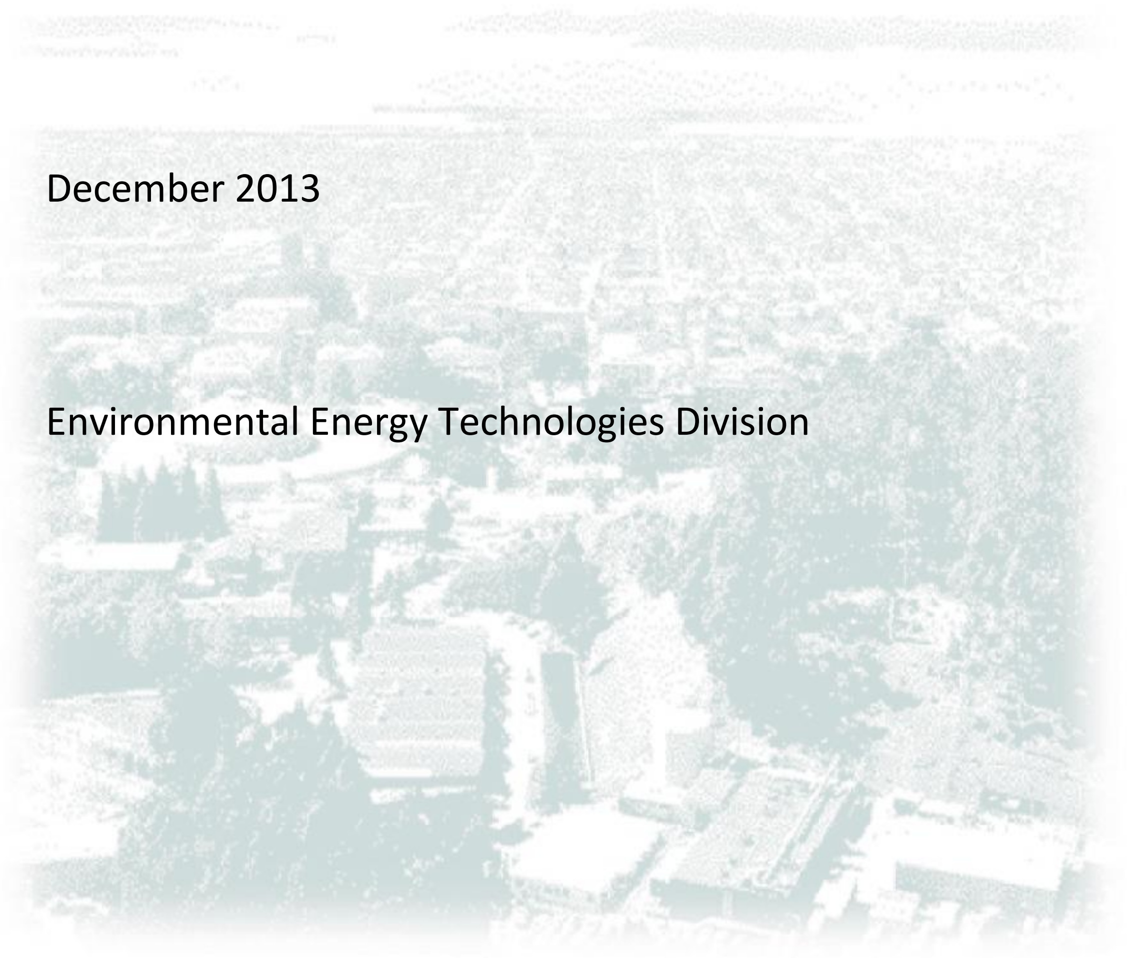
Publication Date
2013-12-01

eScholarship.org
Powered by the California Digital Library
University of California

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Guidelines for Datacenter Energy Information System

Reshma Singh, Rod Mahdavi, Paul A. Mathew,
Jessica Granderson, Lawrence Berkeley National Laboratory;
Yash Shukla, CEPT University



December 2013

Environmental Energy Technologies Division

U.S.-India Joint Center for Building Energy Research and Development (CBERD)

Guidelines for Data Center Energy Information Systems

Reshma Singh, Rod Mahdavi, Paul Mathew, Jessica Granderson,
Lawrence Berkeley National Laboratory

and Yash Shukla,
CEPT University

Acknowledgements

The U.S. Department of Energy (DOE) and the Department of Science and Technology (DST), Government of India (GOI) provided joint funding for work under the U.S.–India Partnership to Advance Clean Energy Research (PACE-R) program's "U.S.–India Joint Center for Building Energy Research and Development" (CBERD) project. The Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology of the U.S. DOE under Contract No. DE-AC02-05CH11231 supports the U.S. CBERD activity. The DST, GOI, administered by Indo-U.S. Science and Technology Forum, supports the Indian CBERD activity.

The authors acknowledge the assistance and thank all the reviewers, in particular, Raju Pandey of SynapSense Corporation; Satish Kumar and Aalok Deshmukh of Schneider Electric; and Ankur Thareja of Wipro Limited, for their advice and continued support. Also thank you to Bill Tschudi, Dale Sartor, Erin Hult and Guanjing Lin at Lawrence Berkeley National Lab for their insightful reviews.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or The Regents of the University of California.

Guidelines for Data Center Energy Information Systems

Authors

CBERD US Team:

Reshma Singh, Rod Mahdavi, Paul Mathew, Jessica Granderson

Lawrence Berkeley National Laboratory

CBERD India Team:

Yash Shukla

CEPT University

December 31, 2013

Table of Contents

1. Introduction 1

Audience........ 2

2. Context 2

3. Five Steps to Data Center EIS 4

Step 1: Define Drivers and Metrics 6

Business Drivers........ 6

Metrics 7

Step 2: Select Metering 10

Levels of Metering 10

Key Metrics and the Meters 19

Table 5 summarizes the relation between metrics and meter readings for three measure levels........19

Estimated Cost of Metering........19

Step 3: Identify Tools/Software 19

Levels of Software and Tools 20

Step 4: Determine Monitoring Approach and Energy Performance Tracking Package 26

Levels of Energy Performance Tracking (EPT) Packages 26

Step 5: Procure, Install and Use the EIS 29

The Process of Acquiring, Installing, and Using the EIS........30

4. Conclusions 31

5. References 35

Appendix 1: Details on Business Drivers 37

Appendix 2: Glossary of Terms 40

Appendix 3: Types of Meters........44

Appendix 4: Examples of Meters 45

Appendix 5: Sample Data Center EIS Specifications 59

I. SAMPLE: EIS General Specifications........59

II. SAMPLE: Wireless Network Specification for Data Center EIS 66

List of Acronyms 73

Introduction

The purpose of this document is to provide structured guidance to data center owners, operators, and designers, to empower them with information on how to specify and procure data center energy information systems (EIS) for managing the energy utilization of their data centers. 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, there are many EIS products in the market that 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 the five-step guidance provided in this document, the user will be able to specify and install off-the-shelf, currently available products and packages. The specification 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's five steps help 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 [EIS] 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 from Step 1 to Steps 4 and 5, and iterating back to Steps 2 and 3 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 in Section 3 will lead to an EIS. The EIS as defined in this guide is an advanced EPT system as defined in Step 4; and its procurement, installation and use described in Step 5.

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 cost-prohibitive. Generally speaking, 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 in both India and the United States.

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.

Context

Data centers constitute a large and rapidly growing sector of energy use. By one estimate, they consumed 0.5 percent of the world's electricity in 2005, at an aggregate cost of 7.2 billion USD, and this is growing by 16 percent each year (Koomey 2008). Although the net consumption of data centers in India has yet to be quantified, the IT-heavy nature of the country's tertiary economy suggests relative data center energy consumption in India may exceed the global average (Sartor 2010). 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).

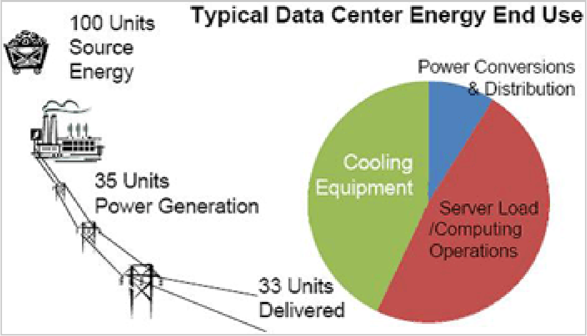


Figure 1: Illustrative end-use breakdown of data center energy consumption (Source: FEMP 2013)

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 2a illustrates the increase in electricity consumption in U.S. data centers.

The influx of IT activities, a renewed banking sector, an expanding Internet population, and the second largest wireless network have led to data explosion and the increased need for data centers in India. The data center market in India is expected to grow at a rapid pace for both captive and hosted data center space. Figure 2b illustrates the increase in footprint of Indian data centers.

While the availability of reliable power is the biggest challenge for the growth of data centers in India, efficiency is also a concern: the Power Usage Effectiveness (PUE)[1] of Indian data centers ranges from 1.4 (best) to a high of 3.0 (worst) (CII 2013). By comparison, the best U.S. data center PUE is 1.1, as reported for a Facebook data center in Oregon (Facebook 2010) and by Google as their average PUE (Google 2013).

a

---

[1] Power Usage Effectiveness is a metric of data center energy efficiency. It is defined in Appendix 2.

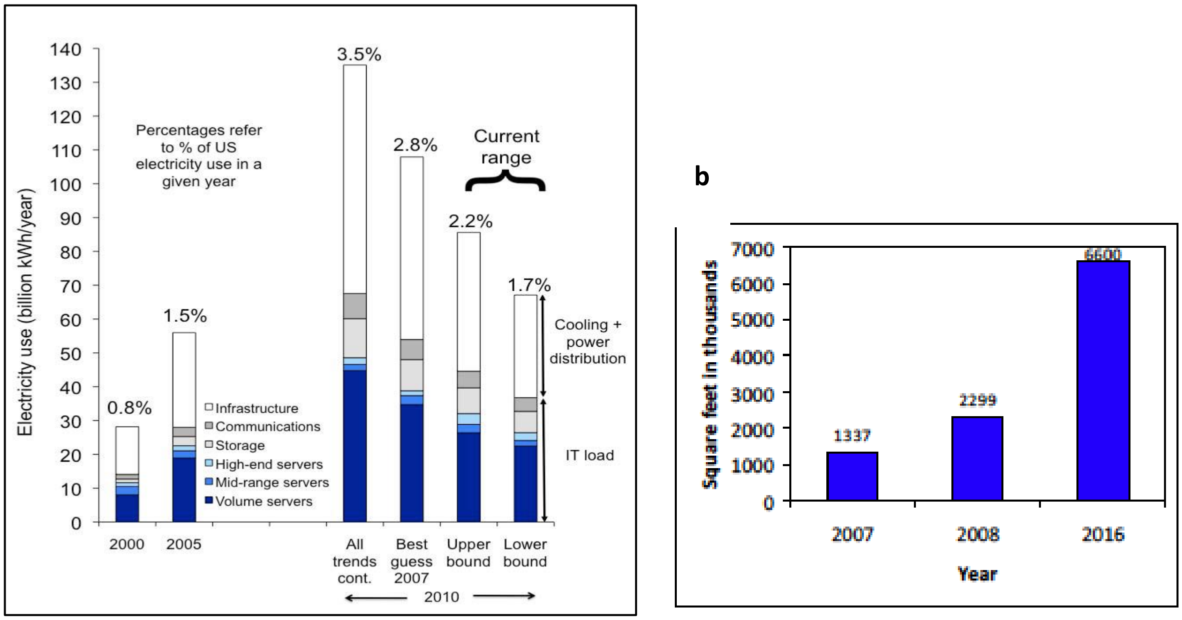


Figure 2: (a) U.S. data center historical energy use data. U.S. data centers use 2 percent of all electricity in the country (Source: Koomey 2011). (b) Growth projection for data centers in India. The data center footprint in India will almost triple from a 2008 baseline to 6.6 million square feet (sf) in 2016. Note that this footprint does not include the numerous under-1,000 sf data centers. (Source: CII 2013).

Since data center operator awareness of energy efficiency is increasing, there is an increased demand for energy-efficiency products, which has expanded the market and increased 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 EIS.

Five Steps to Data Center EIS

Data center owners interested in monitoring their data center’s energy use should develop a well-informed plan or roadmap based on the specific targeted energy-monitoring and performance-tracking goals. The goals are in turn dependent on the enterprise’s business drivers. Setting these goals early in the process will help ensure that the equipment and software tools are incorporated into the design early enough to minimize costs, reduce issues during construction coordination, and maximize monitoring system expansion capability. The plan or roadmap should be started during the development of design and construction documents and updated as necessary to reflect changes that occur.

The data center energy-monitoring and performance-tracking plan should address how the results of the energy monitoring will be used. Depending on the target audience for the results (e.g., building operator, owner, or engineer), the design team can adjust the monitoring system and performance-tracking software tool requirements. Building size and complexity will also influence the goals and objectives of energy monitoring, as well as how the energy consumption data are collected.

This document follows a five-step plan, as illustrated in Figure 3 below and listed here. An Energy Performance Tracking (EPT) plan should follow these five steps:

1. **Define drivers and metrics:** Articulate the business drivers for energy management and reporting, and clearly define a set of energy-related metrics based on those drivers.
2. **Select metering:** Select the level of metering and sensor hardware for the project (i.e., whole-building, system, or end-use). This process should include identification of the level of monitoring required for the future metering system build-out or data center modification or expansion.
3. **Identify tools/software:** Identify tools and software required for data acquisition, communication, analysis, and visualization.
4. **Determine the monitoring approach and energy performance tracking package:** Determine which energy-monitoring and performance-tracking package takes into account the three aspects listed above. Also consider accuracy/cost information for monitoring equipment and performance-tracking tools.
5. **Procure, install, and use the EIS:** Procure, install, and operate the solution. Include training for building operations staff and develop a corrective action plan for addressing problems and operational issues.

Figure 3 below summarizes the step-by-step guidelines for specifying the monitoring solution.

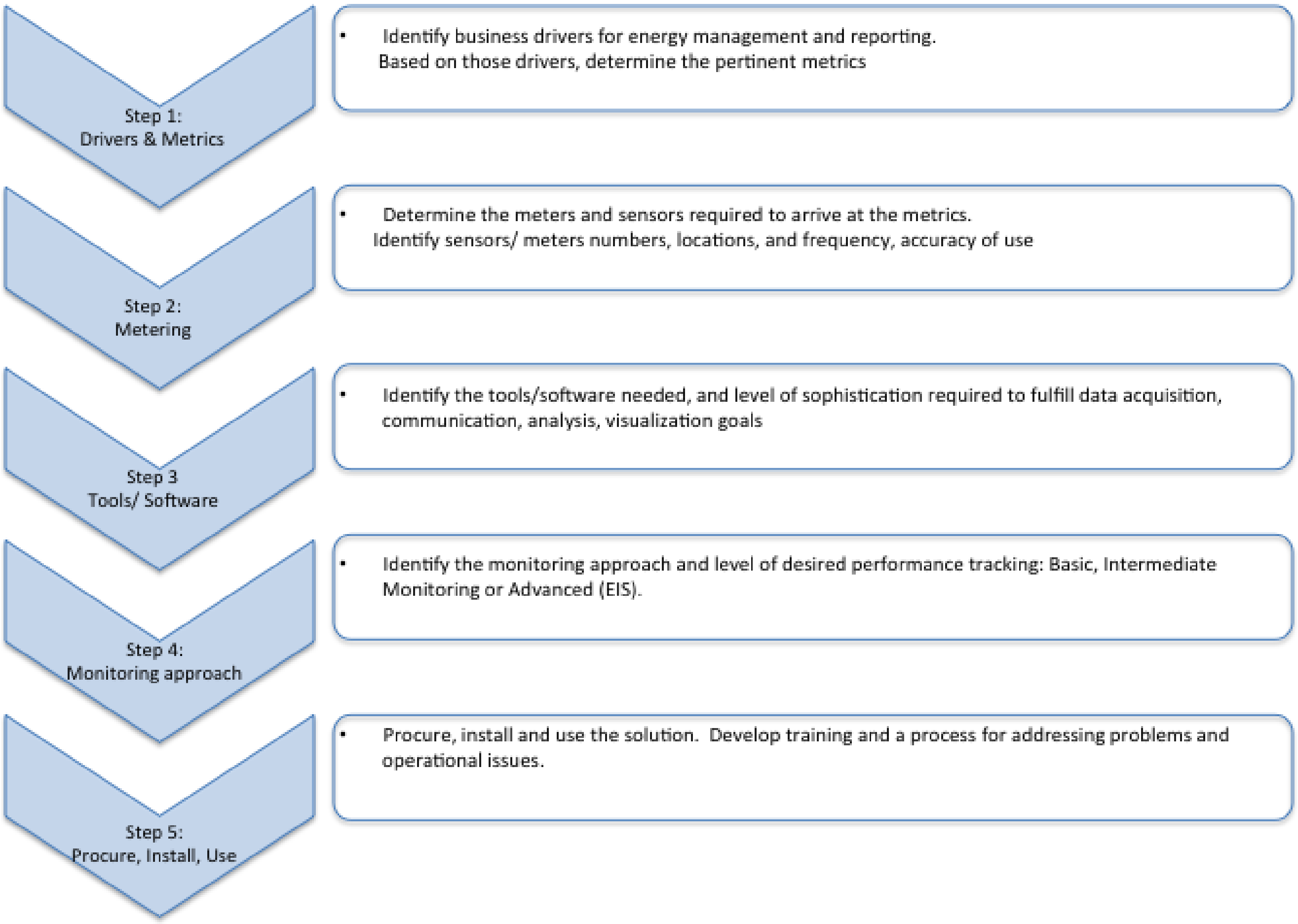


Figure 3: The five-step process for developing data center EIS specifications

The following sections provide a detailed description of each of the five steps.

Step 1: Define Drivers and Metrics

The first step is to identify and prioritize why and how the user will use their monitoring solution. 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 also supports emergency responses, such as load-shedding events. It also facilitates capacity planning around space and power utilization and helps with carbon accounting and greenhouse 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 profitability 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.

A definition of each of these business drivers is provided in Appendix 1. These drivers form the Y-axis of Table 1, Characterization matrix of business drivers and metrics.

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. 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, electricity.

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)

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

3. **Electrical Chain Efficiency, or Electrical Power Distribution Efficiency (avg. percent):** efficiency of a power chain 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 system (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 majority 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 is a common measure. Another performance-based metric is transactions/watt.

Metrics along the X-axis of Table 1 include both measurements and derived metrics. The user can review Table 1 below as a checklist to determine their prioritized business drivers, and hence what metrics (measurements and derived metrics) would be associated with them. The metrics define the data requirements that will enable decision-making around the business accountability goals. The data requirements can be met through meters that are defined further in Step 2.

The next few sections elaborate Steps 2 through 4, with the objective of fulfilling the business drivers to various stages of granularity.

At the end of Step 1, the user should be able to determine their desired metrics based on the business drivers, and then proceed to Step 2. Then use the output from Step 1 as a reference point to the remaining Steps 2 through 5, so that the final Energy Performance Tracking strategy is guided by the core business drivers. As mentioned earlier, users who are well-versed with metering and tools may elect to move directly from Step 1 to Steps 4 and 5 (which discuss the EPT packages and their implementation, respectively), and iterate back to Step 2 and Step 3 if more detail is required.

		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 1: Characterization matrix of business drivers and metrics

Step 2: Select Metering

Once the user has identified the prioritized metrics, the second step is to identify what points need to be metered, what kind of metering equipment to use, and how frequent to take readings and collect data.

Levels of Metering

We define three levels of metering. The user can choose from these three levels, based on the extent and accuracy of the measurements and the potential analysis. Appendix 3 and Appendix 4 provide details about the meters that can be used in a data center.

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 couple of meters, such as electric utility meter and switch-gear 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 chiller 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 accuracy for PUE measurement can be as high as ±30 percent.

See Table 2 for details on Level 1 metering, and what metrics it helps to measure.

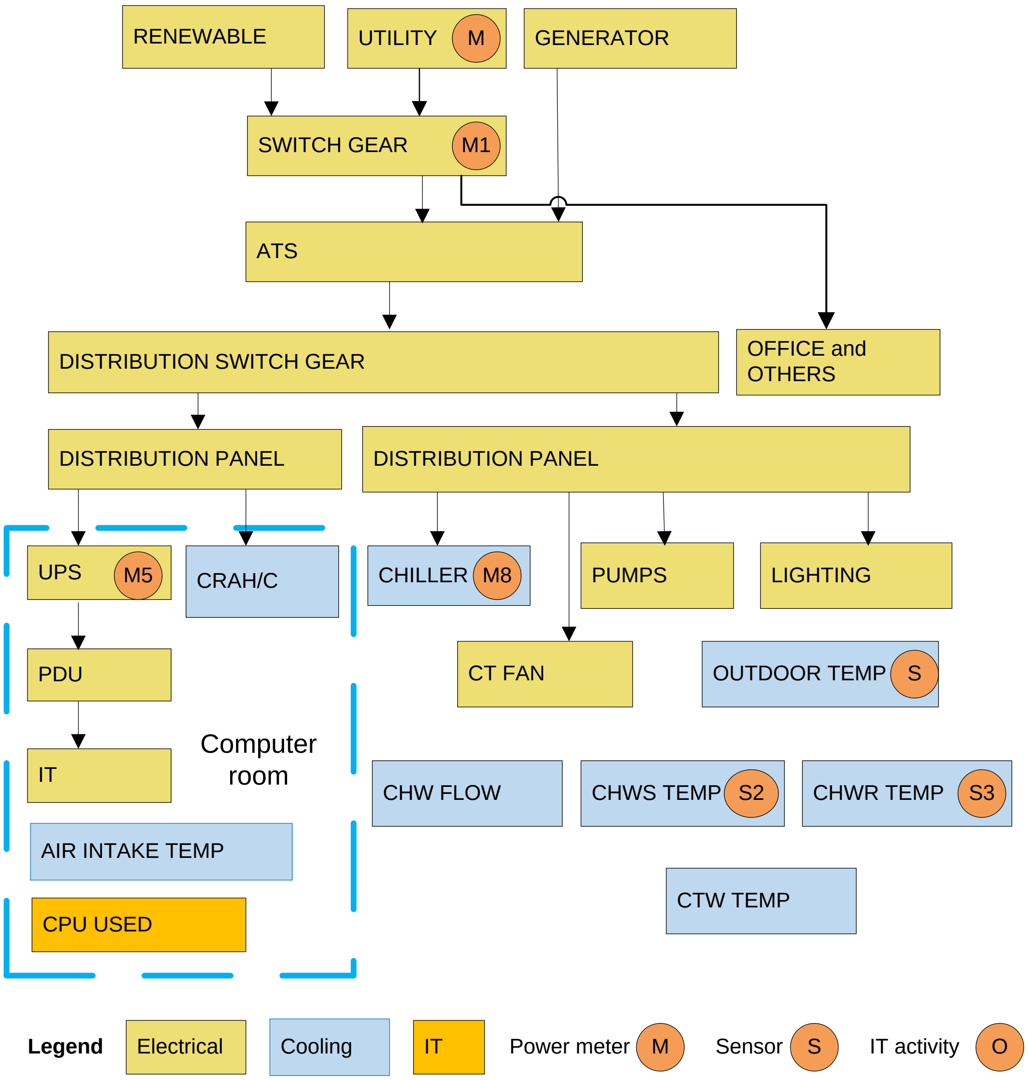


Figure 4: Representative diagram for Level 1: Basic metering (mainly utility metering)

		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 Effic. (Avg percent)	Cooling System Efficiency (Avg kW/ton)	IT Utilization (e.g., CPU Utiliz.)	IT Efficiency (Product/ W)
Meters	🟧 **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										
	Fan meter								nameplate										
	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 2: Metrics and pertinent meters associated with Level 1 (basic) metering. This level of metering allows for rough estimates of some of the derived metrics.

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 a couple 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 weather station.

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 PUE can be off by ±15 percent. The hybrid of manually collected and automatically collected data can be varied. It also may be possible to get some level of historical information and do trending.

See Table 3 for more details on Level 2 metering and what metrics it helps to measure.

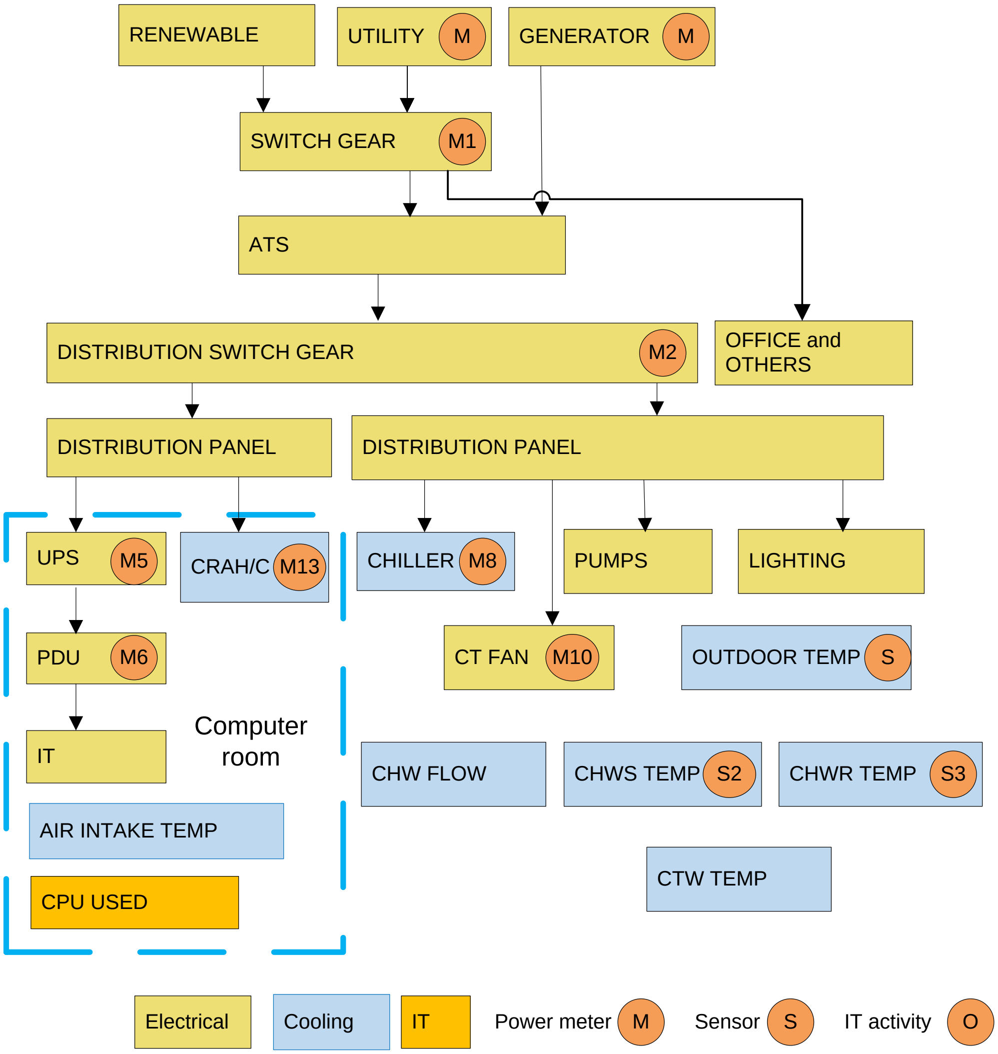


Figure 5: Representative diagram for Level 2 (intermediate) metering of power chain and cooling system

	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**						

🟧	Measured time series data
🟦	Instantaneous values
S	Sensor with manually recorded information
M	Meter with automated data collection
EM	Equipment meter to be manually recorded

Table 3: Metrics and pertinent meters associated with Level 2, intermediate metering. This level of metering allows for estimates of many of the "derived metrics"

Level 3: Deep 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 a single manual meter reading. The PUE measurement accuracy can be as high 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 1.

See Figure 6 below for a representative diagram for Level 3 metering. See Table 4 for details on Level 3 metering.

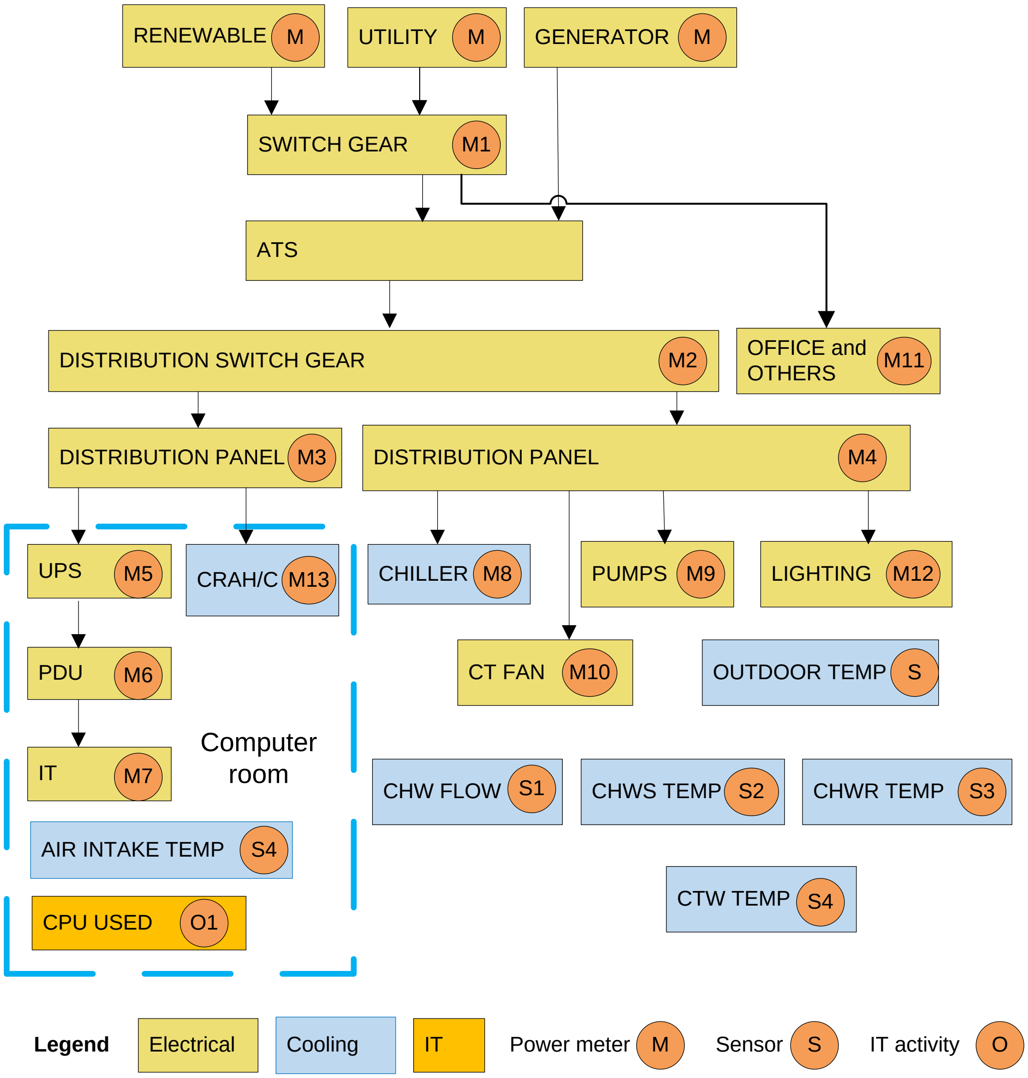


Figure 6: Diagram showing Level 3 (deep) metering recommended standardization for meter locations. This includes locations of measurable points for cooling, power chain, and IT equipment.

		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)	Fans energy Use (KWh)	Elec Distr. energy loss (KWh)	Lighting and other energy use (e.g. generator heater)(KWh)	Environ-mental factors	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)
Meters	**Electric meter at utility**	**M**	**M**			**M**									Precise	Precise			
	Electric meter at generator	**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**						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		

🟧	Measured time series data
🟦	Instantaneous values
S	Sensor
M	Meter with automated software data collection
EM	Equipment meter to be manually recorded

Table 4: Metrics associated with Level 3 (deep) metering, that provides the most precise accuracy for all the derived metrics

Key Metrics and the Meters

Table 5 summarizes the relation between metrics and meter readings for three measure levels.

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

Table 5- 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 analogue or digital signal). Wireless monitoring points are in the range of $150–$300, 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 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 cabinets, 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 in the United States, including installation. For a similar sample data center in India, the cost of metering and installation can be about $100,000. Software, commissioning, and training will be extra.

At the end of Step 2, determine your desired level of metering, and proceed to Step 3.

Step 3: Identify Tools/Software

The third step is to determine the appropriate software tools and packages. Software tools provide platforms for data collection, communication, analytics, visualization, and potentially, interoperability.

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).

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, as identified in Step 2.

Levels of Software and Tools

Level 1 Software Approach: 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 (Figure 7). 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, 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 5 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 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 5 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 6 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

Note: All units are in kilowatts.

Table 6: Example of Level 1 tool-based data collection

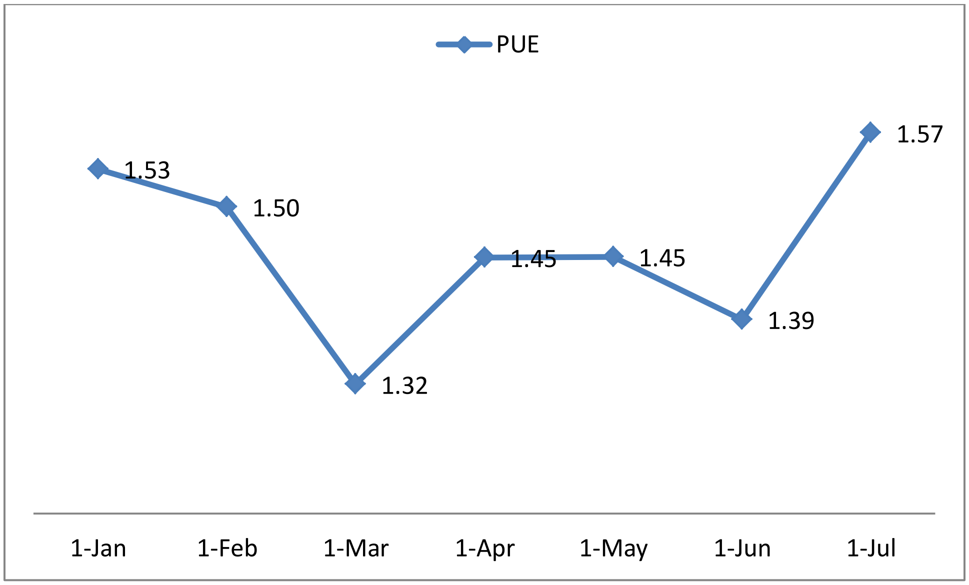


Figure 7: Example of results from using Level 1 tool-based data visualization

Level 2 Software Approach: Equipment-Specific Software

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. Tools, such as software for the smart card for UPS meter and UPS utilization, are separately provided by various equipment vendors. 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.

An example is provided below, 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 number 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 spots 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 Software Approach: EIS Software

Level 3 softwrae approach enatils 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.

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, servers, and sensors 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 or automate 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, DCIM 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 in 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 in one hour.

Figure 8: Dashboard view of interest for different users using 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 instantanious 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 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.

This image cannot currently be displayed.

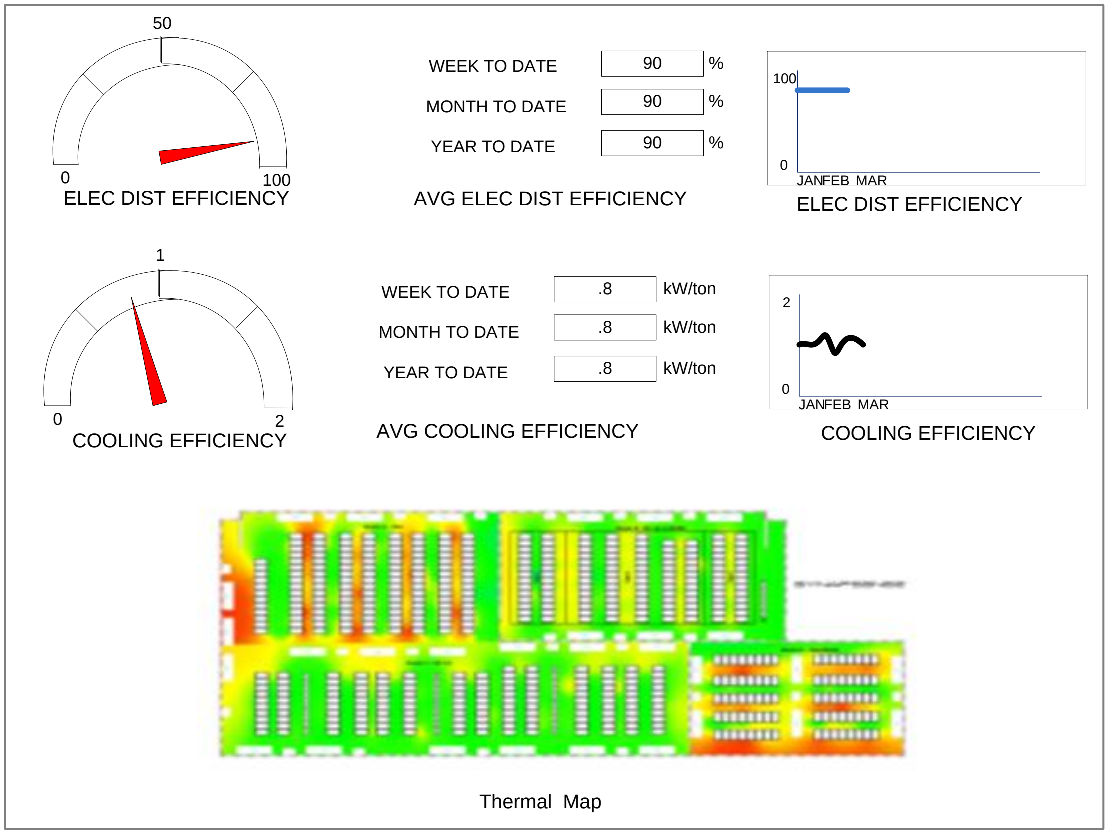
Figure 9: IT manager’s second dashboard using a Level 3 tools approach

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 beginning of the year. In the actual case, by moving the cursor on the graph, you 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 arrors, customized analytics, and visualization at all user levels to access and use the data as needed. 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).



WEEK TO DATE 90 %
MONTH TO DATE 90 %
YEAR TO DATE 90 %

WEEK TO DATE .8 kW/ton
MONTH TO DATE .8 kW/ton
YEAR TO DATE .8 kW/ton

Figure 10: Facility manager’s dashboard using a Level 3 tools approach

At the end of Step 3, the user should be able to determine their desired level of tools and software for data acquisition, communication, analysis, and visualization, and proceed to Step 4.

Step 4: Determine Monitoring Approach and Energy Performance Tracking Package

Identify the energy performance tracking (EPT) package required, as gleaned from Steps 2 and 3 above. Prioritize the package most suited for the purpose, with respect to business needs and cost. Iterate back to Steps 2 and 3 as necessary. 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 customize based on the outputs from steps 1, 2, and 3.

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 also 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) (See Table 7).

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
Infrastructure upgrade	Very low	Limited, less expensive upgrades is 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 7: Comparison of three levels of EPT packages based on ASHRAE guidelines

The following is a description of each package:

Level 1: Basic EPT Package

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

Level 2: Intermediate EPT Package

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 temperature. With some well-prioritized meters, one can analyze and reveal energy waste and opportunities for energy-efficiency projects at the whole-building, and to a small 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 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

The Level 3 Advanced EIS 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.

Deep savings are associated with deep metering, as deep metering provides more information for the EIS to analyze. But there can be a degree of flexibility as to whether an EIS should be used only with deep 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 deep metering. For example, an EIS can detect abnormal energy behavior by comparing the daily whole-building energy consumption profiles using certain statistical models. In addition, an EIS can also determine the project savings with whole-building energy use. Therefore, an EIS can also use shallow 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 EIS 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 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 them in Step 1 can be precisely determined. This information makes for a much more effective data-driven energy management platform.

Level 3 Advanced EIS 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.

At the end of Step 4, the user should be able to determine the desired level of their EPT package and then proceed to Step 5.

Step 5: Procure, Install and Use the EIS

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 processes 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 in Steps 2–4, to achieve the business objectives defined in Step 1.** 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 5. 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, 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 the usually 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 Step 5, you should be confident about procuring and operating an EPT package for optimum use in your data center.

Conclusions

These guidelines have described three packages for Energy Performance Tracking (EPT). The user should select the relevant package for their purpose after going through Steps 1 through 5, with iterative loops as required.

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

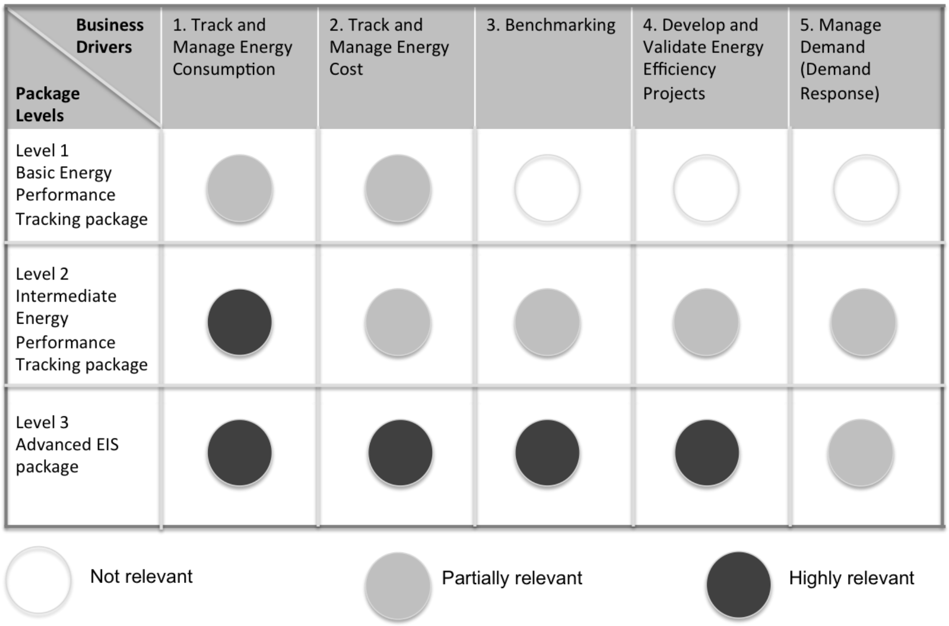
+ Advanced software and dashboard

+ 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 switch gear 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.



Business Drivers / Package Levels	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	◐	◐	○	○	○
Level 2 Intermediate Energy Performance Tracking package	●	◐	◐	◐	◐
Level 3 Advanced EIS package	●	●	●	●	◐

○ 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.

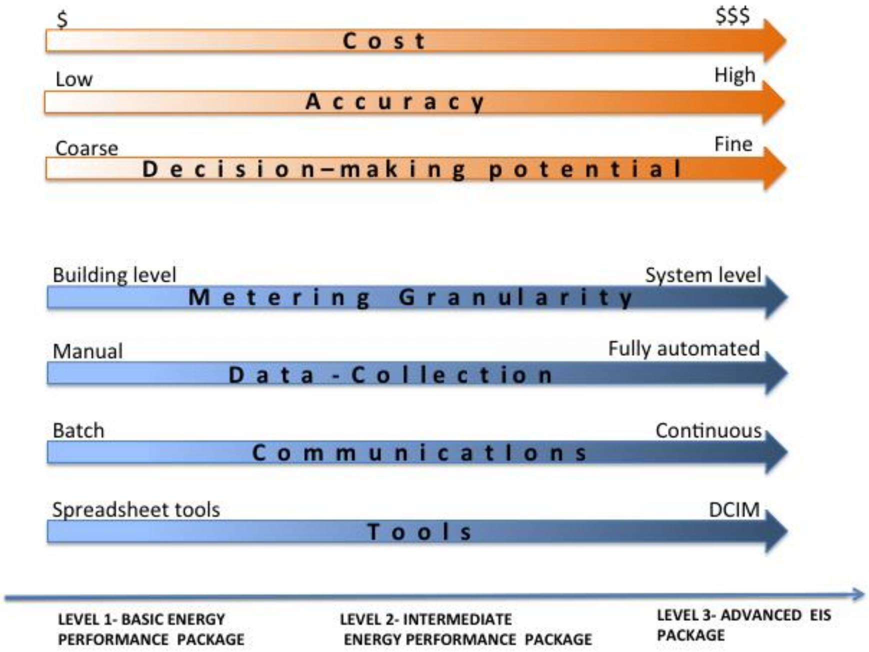


Figure 12: Comparison of the three levels of Energy Performance Tracking

References

CII (Confederation of Indian Industry). 2013. Energy Efficiency in Indian Data Centers: Present Trends and Future Opportunities.

Energy Trust of Oregon. 2011. Monitoring & Reporting Applications Guide. Developed with support from PAE Consulting Engineers. Accessed in December 2013 from http://energytrust.org/library/forms/NBE_MR_Applications_Guide_v01.pdf.

Facebook Data Center FAQ. 2010. Accessed in December 2013 from http://www.datacenterknowledge.com/the-facebook-data-center-faq/.

FEMP (Federal Energy Management Program). No date. U.S. Department of Energy: Energy Efficiency and Renewable Energy. Federal Energy Management Program website. Accessed in October 213 from http://www1.eere.energy.gov/femp/program/dc_energy_consumption.html

Google. 2013. Efficiency: How We Do It. Google datacenters. Accessed in November 2013 from https://www.google.com/about/datacenters/efficiency/internal/.

Granderson, J., M. A. Piette, G. Ghatikar, and P. Price. 2009. Building Energy Information Systems: State of the Technology and User Case Studies. Lawrence Berkeley National Laboratory. LBNL-2899E.

Granderson, J., M. A. Piette, B. Rosenblum, and L. Hu. 2011. Energy Information Handbook: Applications for Energy-Efficient Building Operations. Lawrence Berkeley National Laboratory. LBNL-5727E.

Koomey, Jonathan. 2011. Growth in Data Center Electricity Use 2005 to 2010. Accessed in December 2013 from http://www.analyticspress.com/datacenters.html.

Koomey, Jonathan. 2008. Worldwide Electricity Used in Data Centers. Lawrence Berkeley National Laboratory. Accessed in December 2013 from http://iopscience.iop.org/1748-9326/3/3/034008/pdf/1748-9326_3_3_034008.pdf.

North American Access Technologies (NAAT). No date. Network Services Division. Accessed in December 2013 from http://www.naat.com/

Sartor, D., K. Kircher, S. Kumar, and M. Kamath. 2010. Benchmarking Energy Consumption in Indian Data Centers. http://bijlee.lbl.gov/sites/default/files/India-DataCenters-Benchmarking.pdf.

Appendix 1: Details on Business Drivers

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. (Granderson 2011).

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 also 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 time 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 saving	By creating the baseline and comparing the impact of energy-efficiency measures, savings can be estimated. Energy savings performance of energy conservation measures (ECMs) 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	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.

consumption and peak demand	
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.

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. 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 is no single point of failure (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

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, electricity.

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)

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

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 PUE of about 1.2 and even 1.1.

Different values can be obtained depending on where the IT power measurement is done. Figure14 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.

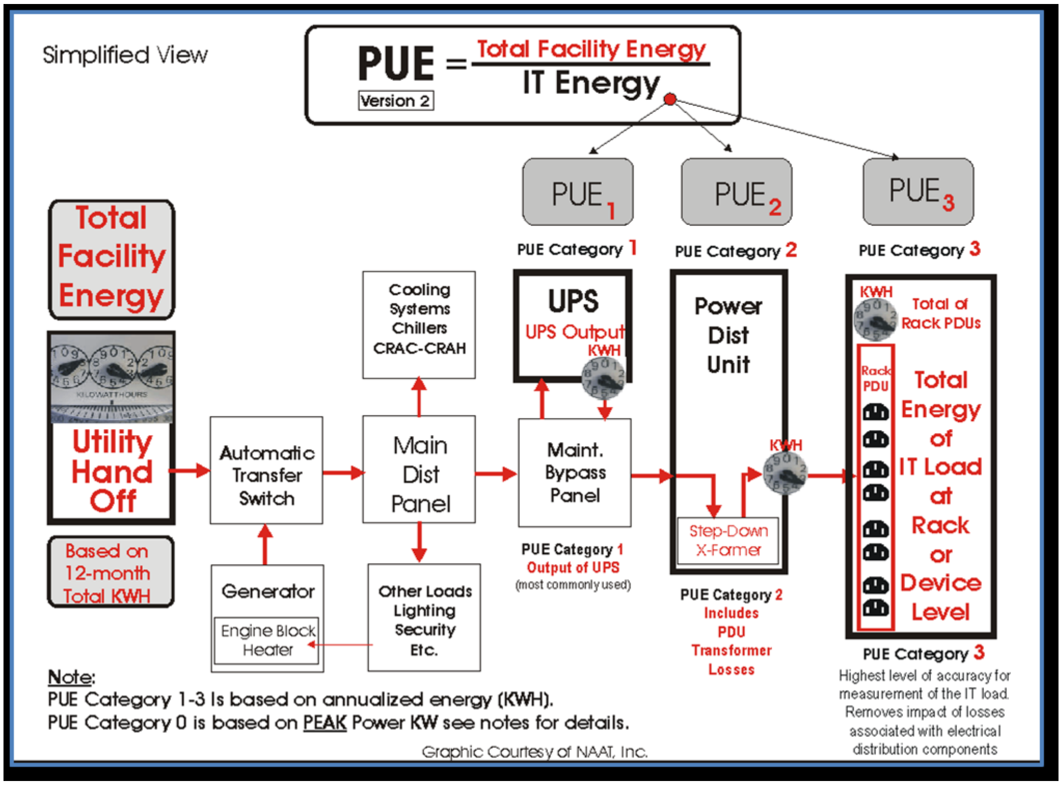


Figure 14: Different versions of PUE (Source: NAAT, Inc.)

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 switch gear, 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 makes capacity management possible, which provides real-time resource utilization data.
- It provides better electrical, cooling, floor, cabinet, 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, 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 meters pertinent to data centers.

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

Appendix 4: Examples of Meters

Measurement Equipment

The following is a list of equipment that may be useful in collecting measurement data for a data center. The equipment specifications and photos were provided by the Pacific Energy Center (PEC). Further information and additional equipment can be found on the PEC website (http://www.pge.com/pec/) under “Performance Measurement Tools.”

This list is provided as sample measurement equipment, and this document does not make any warranty, expressed or implied, toward the applicability or effectiveness of a specific measuring tool toward a specific system or facility. We recommend that for any metering equipment that you procure, you should obtain the measures, accuracy, resolution and memory and fit it to your requirements.

Sample meters are provided below:

Power Meters

Dent Instruments

Elite Pro, Line Powered, Extended Memory
Model: EPUHPSDC
Measures: Power, Current, Voltage, Power Factor
Description: Poly phase recording power meter with 4 integrated voltage references. Uses 333mV current transducers. Logger uses a PC serial interface for data transfer and real time readings. Models with extended memory (store 100k records) and modems also available. Logger dimension: 3 in x 6 in x 2 in.
Sensor: Range (Accuracy):
- Current: 0 to 6000 Amps (0.5% typical, meter only)
- Volts: 0 to 600V AC or DC
- Frequency: 50 or 60 Hz

Resolution: 12 bit
Memory/Records: 100,000 recs

Dent Instruments

ElitePro Logger
Measures: Power, Current, Voltage, Power Factor
Description: Poly phase recording power meter with 4 integrated voltage references. Uses 333mV current transducers. Logger uses a PC serial interface

for data transfer and real time readings. Models with extended memory (store 100k records) and modems also available. Logger dimension: 3 in x 6 in x 2 in.

Sensor: Range (Accuracy):

- Current: 0 to 6000 Amps (0.5% typical, meter only)
- Volts: 0 to 600V AC or DC
- Frequency: 50 or 60 Hz

Resolution: 12 bit

Memory/Records: 25,000 records

Summit Technology

Power Quality Analyzer PS4000

Model: PS4000

Measures: AC Voltage, Amps, AC Current, Kilowatt, Kilowatt/Hour, Power Factor, Harmonics, Transients, Swells and Sags.

Description: True RMS power quality analyzer with 1000 amp current probes and voltage references for 3-phase loads. Capable of swell, sag, inrush, high-speed transient, and harmonic analysis. Meter has a LCD display for real-time readings and button interface. Stand alone logger uses a PC serial interface for data transfer. Logger dimension: 4 in x 8 in x 1.5 in.

Sensor: Range (Accuracy):

- AC Voltage 1 to 600 VRMS (0.1%)
- AC Current: 0.01 to 5000 Amps (0.1% of readings plus accuracy of probes)
- Harmonic (THD): Thru 25th or 1800 Hz (To within 1% of fundamental)

Memory/Records: 4 Megabyte

Summit Technology

PS250 True RMS Energy Analyzer

Model: PS 250

Measures: AC Voltage, Amps, AC Current, Kilowatt, Kilowatt/Hours, Power Factor, Harmonics

Description: Stand alone true RMS, data logging, polyphase power meter can measure up to 140 measurement parameters. Four voltage clips and three proprietary 1000 Amp CT clamps are included with meter. Meter has LCD display for real-time readings and uses a PC serial interface for data transfer. Logger dimension: 4 in x 8 in x 1.5 in.

Sensor: Range (Accuracy):

- Voltage: 1 to 600 VRMS (± 0.5%)
- AC Current: 0.01 - 5000 Amps (± 0.5% plus accuracy of current probe)
- Harmonic (THD): through 50th or 3000 Hz (± 1% of fundamental)

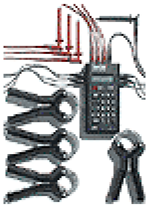
Memory/Records: Standard Mem: 1,044 Records with 53 Variables, Extended Mem: 4,540 Records with 53 Variables

Summit Technology

Single Phase Adapter Box
Model: 120ADP
Measures: AC Current
Description: Single-phase receptacle with voltage and current leads to be used with the Powersight Energy Analyzer. Allows user to get power and waveform information on plug-loads.
Sensor: Range (Accuracy):
- AC Current: 0 to 15 Amps (+/-0.5%)
- AC Power: 0 to 120 VAC (+/-1%)

Compatible Data Loggers:
Powersight 250
Powersight 3000
Powersight 4000

Summit Technology



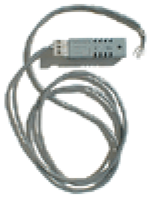
True RMS Energy Analyzer PS-3000
Model: PS-3000
Measures: AC Voltage, AC Current, Kilowatt, Kilowatt/Hour, Power Factor, Harmonics
Description: True RMS energy analyzer with 1000 amp current probes and voltage references for 3-phase loads. Meter has an LCD display for real-time readings and a keypad interface. Stand alone logger uses a PC serial interface for data transfer. Logger dimension: 4 in x 8 in x 1.5 in.
Sensor: Range (Accuracy):
- Voltage: 1 to 600 Volts rms (± 0.5%)
- Frequency: 45 to 3000 Hz (± 0.5%)
- AC Current: 0.01 to 6000 Amps (± 0.5% plus accuracy of probe)
- Power: 1 Watt to 60 Megawatts (± 1% + accuracy of probe)
- Power Factor: 0 to 1 (± 1% + accuracy of probe)
- Energy & Cost: (± 1% + accuracy of probe)
- Harmonic (THD): through 50th or 3000 Hz (± 1% of fundamental)

Memory/Records: Standard Mem: 1,044 Records with 53 Variables, Extended Mem: 4,540 Records with 53 Variables

Temperature/Relative Humidity Probes/Sensors and Data Loggers

ACR Systems

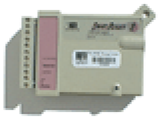
External Temp/RH Sensor for ACR
Model: EH-010A
Measures: Temperature, Relative Humidity
Description: External temperature and relative humidity sensor with 3 foot lead length.



For use with the ACR SmartReader 2.
Sensor: Range (Accuracy):
- RH: 10% to 95% (± 5%)
- Temp: - 4° to 104° F

Compatible Data Loggers:
ACR SmartReader 2

ACR Systems



Smart Reader 2
Model: SR-002
Measures: Temperature, Relative Humidity
Description: Temperature and relative humidity logger with four channels; one internal temperature, one internal RH, two channels for optional external temperature and RH sensors. Logger uses a PC serial interface for data transfer and real time readings. Logger dimension: 4.2 in x 2.9 in x 0.9 in.
Sensor: Range (Accuracy):
- Internal Temp: - 40° to 158° F (± 0.3° F)
- Internal RH: 0% to 95% (± 4%)

Resolution: 8 bit
Memory/Records: 32,768 readings

ACR Systems

Smart Reader Plus 2
Model: SRP-2
Description: Temperature and relative humidity logger. 128 KB mem., 12 bit
Sensor: Range (Accuracy):
0 to 95 % RH (non-condensing)
+/- 3% RH from 10 to 90 % RH
Resolution: 12 Bit
Memory/Records: 128 KB

ACR Systems

Smart Reader Plus 4
Model: SRP-004
Measures: Pressure and temperature.
Description: Pressure and temperature logger (used for very precise low differential pressure measurements).
Sensor: Range (Accuracy):
-40 to 158 F operating temperature range
+/-0.05"for.5",1.0" and 2.0" ranges- calibrated
+/-1.0" for5.0" and 10.0" ranges- calibrated
Thermal : +/-0.5%FS(over compensated range)
Memory/Records: 32 KB

ACR Systems

Smart Reader Plus 4 LPD
Model: SRP-004-LPD-10-32K

Measures: gauge and differential pressures plus/minus 10"WC
Description: differential pressure and temperature logger
Sensor: Range (Accuracy):
plus/minus 10"WC
Resolution: 12 bit
Memory/Records: 32Kb
Related Application Note(s):

ACR Systems

Smart Reader Plus 6
Model: SRP-006-1.5M 7
Measures: Temperature
Description: Eight channel logger with one internal temperature channel, and seven thermocouple input channels. Uses ACR thermocouple wires, or any J, K, S, T, and E type thermocouples. Logger uses a PC serial interface for data transfer and real time readings. Logger dimension: 4.2 in x 2.9 in x 0.9 in.
Sensor: Range (Accuracy):
- Internal Temp: - 40° to 158° F (± 0.2 to 0.3° F)
Resolution: 12 bit
Memory/Records: 1,048,000 readings

Architectural Energy Corp.

12 inch Temperature Probe
Model: Temp-02-2-t05-016
Measures: Temperature
Description: Air duct temperature sensor for use with the AEC MicroDataLogger. 12 inch temperature probe with 16 foot long cable and an attached prewired MicroDatalogger module.
Sensor: Range (Accuracy):
- Temperature: - 40° to 254° F (± 0.9° F)
Compatible Data Loggers:
AEC MicroDataLogger

Architectural Energy Corp.

Air Temperature Module
Model: TEMP-02-1-T01
Measures: temperature
Description: Air temperature sensor directly mounted on a pre-wired module with no cable. For use with the AEC MicroDataLogger.
Sensor: Range (Accuracy):
- Temperature: - 40° to 254° F (± 0.9° F)
Compatible Data Loggers:
AEC MicroDataLogger

Architectural Energy Corp.

Weather Station
Model: in-house
Measures: Temperature, Relative Humidity

Description: Portable weather station with relative humidity sensor and ambient temperature sensor in radiation shield. Watertight enclosure to be used with the AEC MicroDataLogger. The weather station can also be configured for use with wind speed, wind direction and radiation sensors.
Sensor: Range (Accuracy):
- Relative Humidity: 0 to 90% (± 3%)
- Air Temperature: - 40° to 254° F (± 0.9° F)
Compatible Data Loggers:
AEC MicroDataLogger

Campbell Scientific

Temperature & RH probe
Model: 207 #7059
Measures: Temperature, Relative Humidity
Description: Temperature and relative humidity sensor with radiation shield. Sensor requires 3 VAC excitation, and measures across a 150mV range to calculate the RH based on the temperature. For use with Campbell Scientific data loggers.
Sensor: Range (Accuracy):
- Temperature: - 40° to 140° (± 0.72° F)
- Relative Humidity: 12% to 100% (± 5%)
Compatible Data Loggers:
Campbell CR10

Measurement Computing Corp.

IQ-Temp
Model: IQ-Temp
Measures: temperature
Description: Ambient temperature logger with LED light indicator showing different status levels. Logger uses a PC serial interface for data transfer and real time readings.
Sensor: Range (Accuracy):
- Temperature: - 40° to 185° F (± 0.9° F)
Resolution: 12 bit
Memory/Records: 21,280 records

Measurement Computing Corp.

IQ-VmA
Model: IQ-Vma
Measures: Temperature, Milliamp, Millivolt and Voltage Signals
Description: Voltage/milliamp input data logger with nine voltage input ranges, a current input range and an internal temperature sensor. Logger uses a PC 9 serial interface for data transfer and real time readings.
Sensor: Range (Accuracy):
- Temperature: - 40° to 185° F (± 0.9°F)
- Inputs: - 0 to 333 mV, 0 to 1.2 V, 0 to 5 V, 0 to 10 V, 0 to 30 V, 0 to 20 mA (± 0.3%)
Resolution: 12 bit
Memory/Records: 21,280 records

Dickson **Pro Series Temperature & RH logger**

Model: TP120
Measures: Temperature, Relative Humidity
Description: Two channel data logger with internal temperature and relative humidity sensors. Logger uses a PC serial interface for data transfer and real time readings. Logger dimension: 3.1 in x 2.1 in x 0.9 in.
Sensor: Range (Accuracy):
- Temperature: - 40° to 176° F (± 1.8° F between + 14° to 176° F)
- Relative Humidity: 0 to 95% (± 2%)

Resolution: 0.1° F, 0.1% RH
Memory/Records: 32,512 records

Dickson

TH Trace
Model: TL 120
Measures: Temperature, Relative Humidity
Description: Compact temperature and relative humidity logger. Logger uses a PC serial interface for data transfer and real time readings.
Sensor: Range (Accuracy):
- Temperature: - 40° to 176° F
- Relative Humidity: 25% to 95% (± 5%)

Resolution: 0.9° F; 0.19% RH
Memory/Records: 7680 records

Omega Engineering

Type K Thermocouple Probe
Model: TJ240-CASS-ISU-8
Measures: Temperature
Description: Wide-range Type K Thermocouple with 12 ft. lead with transition joint and 8" stainless steel probe.
Sensor: Range (Accuracy):
- Temperature: - 454° to 1600° F (± 1.98° F or ± 4.4% whichever is greater)

Compatible Data Loggers:
ACR SmartReader Plus 6

Omega Engineering

Type T Thermocouple Wire
Model: TT-T-20
Measures: Temperature
Description: Type T Thermocouple wire uses two metals, copper and constantan, to produce a current proportional to temperature. This non-linear signal needs a reference meter to provide an accurate reading.
Sensor: Range (Accuracy):
- Temperature: - 450 to 500º F

Compatible Data Loggers:
ACR SmartReader Plus 6
Campbell 21X
Campbell CR10

Hobo Type T Thermocouple

Onset Computer Corp.

HOBO Pro RH/TEMP

Model: H08-032-08

Measures: Relative Humidity, Temperature

Description: This high accuracy, two channel weatherproof data logger can be installed in outdoor environments. Logger uses a PC serial interface for data transfer and real time readings.

Sensor: Range (Accuracy):

- Temperature: - 22° to 122° F (± 0.33° F at 70° F)
- Relative Humidity: 0 to 100% (± 3%, ± 4% in condensing environments)

Resolution: 8 bit or 12 bit (2 modes)

Memory/Records: 64k records

Onset Computer Corp.

HOBO Pro Temp/Ext. Temp

Model: H08-031-08

Measures: Temperature

Description: High accuracy, two channel, weather-proof, temperature data logger. The exterior temperature sensor has a 6' lead. Logger uses a PC serial interface for data transfer and real time readings.

Sensor: Range (Accuracy):

- Internal Temperature: - 22° to 122° F (± 0.33° F at 70 °F)
- External Temperature: - 40° to 212° F (± 0.33° F at 70° F)

Resolution: 8 or 12 bit (2 modes)

Memory/Records: 64k records

Onset Computer Corp.

HOBO RH/Temp/Light/Ext

Model: H08-004-02

Measures: Temperature, Relative Humidity, Light Intensity, AC Current and External Temperature with proprietary sensors, Low DC Voltage Signals

Description: Stand-alone four channel data logger with internal sensors for monitoring relative light levels, temperature, relative humidity, and one external channel for proprietary temperature thermistors and current transducers and non-proprietary DC voltage signals. The logger uses an RS232 interface for data transfer and real time readings.in.

Sensor: Range (Accuracy):

- Temperature: - 4° to 158° F (± 1.27° F at 70° F)
- Relative Humidity: 25 to 95% (± 5%)
- Light Intensity: 2 to 600 footcandles typical, maximum varies from 300 to 900 footcandles
- Voltage Signal: 0 to 2.5 DC volts (±10 mV ±3% of reading)

Resolution: 8 bit

Memory/Records: 7943 records

Onset Computer Corp.

HOBO TEMP
Model: HO8-001-02
Measures: Temperature
Description: Stand-alone single channel temperature logger with internal thermistor and non-volatile memory. Blinking LED confirms operation. Logger uses a PC serial interface for data transfer and real time readings.
Sensor: Range (Accuracy):
- Temperature: - 4° to 158° F (± 1.27° F at 70° F)
Resolution: 8 bit
Memory/Records: 7944 readings

Onset Computer Corp.

HOBO Temp External
Model: H08-002-02
Measures: Temperature, External Proprietary Sensors: Temperature, Current, Voltage
Description: Two channel data logger has an internal temperature sensor and an input channel for external proprietary sensors for temperature, AC current and non-proprietary DC voltage signals. Logger uses a PC serial interface for data transfer and real time readings. Logger dimension: 2.4 in x 1.9 in x 0.8 in.
Sensor: Range (Accuracy):
- Temperature: - 4° to 158° F (± 1.27° F at 70° F)
- Milliamp Signal: 4 to 20 mA
- Voltage Signal: 0 to 2.5 DC volts
Resolution: 8 bit
Memory/Records: 7943 records

Onset Computer Corp.

HOBO Type T Thermocouple Logger
Model: H12-003
Measures: Temperature
Description: These loggers accept Type T thermocouple probes with plug-in subminiature connectors. Two software-selectable measurement ranges available for optimal accuracy and resolution. There is also an internal ambient temperature sensor. Logger uses a PC serial interface for data transfer and real time readings.
Sensor: Range (Accuracy):
- Internal Temperature: 32° to 122° F (± 1.3° F at 70° F)
- Type T Thermocouple: - 328° to +122° F (± 7.2° F at - 103° F), - 94° to +356° F (± 5.4° F at 131° F)
Resolution: Int: 0.7° F at 70° F, Ext: 1.8° to 11°F, and 1.8 to 5.4°F
Memory/Records: 32,530 records

Onset Computer Corp.

HOBO U12 J,K,S,T Thermocouple Logger
Model: U12-014
Measures: Temperature

Description: Thermocouple logger with two temperature channels. Channel 1 is for external Type J, K, S or T thermocouples. Channel two is the logger's internal temperature sensor for cold-junction compensation of the thermocouple output. Compatible with standard thermocouples with standard subminiature connectors. Logger uses a direct USB connection. Logger dimension: 2.3 in x 2.9 in x 0.85 in.
Sensor: Range (Accuracy):
- Internal Temperature: 32º to 122º F (± 0.63º F)

Resolution: 12-bit
Memory/Records: 43,000 measurements

Onset Computer Corp.

HOBO U12 RH/Temp/Light/Ext Datalogger
Model: U12-012
Measures: Temperature, Relative Humidity, Light; 0 to 2.5 VDC input for external sensors: Temperature, Current, Voltage
Description: Stand-alone four channel data logger with internal sensors for monitoring relative light levels, temperature, relative humidity, and one external channel for proprietary temperature thermistors and current transducers and non-proprietary DC voltage signals. The logger uses a USB interface for data transfer and real time readings. Logger dimension: 2.3 in x 2.9 in x 0.85 in.
Sensor: Range (Accuracy):
- Temperature: - 4° to 158° F (± 0.63° F)
- Relative Humidity: 5 to 95% (± 2.5%)
- Light Intensity: 1 to 3000 footcandles typical
- Voltage Signal: 0 to 2.5 DC volts (±10 mV ±3% of reading)

Resolution: 12 bit
Memory/Records: 43,000 records

Onset Computer Corp.

Narrow Range Temperature Sensor
Model: TMC6-HB
Measures: Temperature
Description: Narrow range external temperature sensor for Hobo data loggers. 6 foot cable and 0.3 inch diameter sensor; fits in 3/16 inch holes.
Sensor: Range (Accuracy):
- Temperature: 32° to 110° F (± 0.7° F with H8, ± 0.45° F with U12 at 68° F)

Compatible Data Loggers:
Hobo 4-channel External
Hobo RH/Temp/2 External
Hobo RH/Temp/Light/External
Hobo U-12 Temp/RH/Light/External
Resolution: 0.3° F at 68° F with H8, 0.025° F at 68° with U12

Onset Computer Corp.

RH, Temp, 2 External Channel HOBO
Model: H08-007-02
Measures: Relative Humidity, Temperature, 0 to 2.5 VDC with External sensors:

Temperature, Current, Voltage
Description: Stand-alone four channel data logger with one internal relative humidity sensor, one internal temperature sensor, and two external channels for proprietary sensors for temperature, AC current and non-proprietary low voltage signal input. Logger uses a PC serial interface for data transfer and real time readings. Logger dimension: 2.4 in x 1.9 in x 0.8 in.
Sensor: Range (Accuracy):
- Temperature: - 4° to 158° F (± 1.27° F at 70° F)
- Relative Humidity: 25% to 95% (± 5%)
- Voltage Signal: 0 to 2.5 DC volts (±10 mV ±3% of reading)
- Milliamp Signal: 4 to 20 mA (±10 mV ±3% of reading)

Resolution: 8 bit
Memory/Records: 7943 records

Onset Computer Corp.

Temperature Sensor
Model: TMC6-HA
Measures: Temperature
Description: Wide range external temperature sensor for Hobo data loggers. 6 foot cable and a sensor diameter of 0.2 inch.
Sensor: Range (Accuracy):
- Temperature: - 40° to +212° F (± 0.9° F with H8, ± 0.45° with U12 at 68° F)

Compatible Data Loggers:
Hobo 4-channel External
Hobo RH/Temp/2 External
Hobo RH/Temp/Light/External
Hobo U-12 Temp/RH/Light/External
Resolution: ± 0.7°F at 68°F with H8, ± 0.05° F at 68° F with U12

Pace Scientific

PT907 Temperature Probe
Model: PT907
Measures: Temperature
Description: Proprietary Pace Scientific temperature probe with epoxy tip and 4' lead. Not for continuous immersion in water (mineral or silicon oil ok).
Sensor: Range (Accuracy):
- Temperature: -58 to 221°F (± 0.27° F from 32° to 104° F, better than ±0.54° F from -13° to 185° F)

Compatible Data Loggers:
Pace Pocket Logger
Pace XR5 Logger

Pace Scientific

PT916 Temp Probe
Model: PT916
Measures: Temperature
Description: Pace Scientific proprietary probe has closed end stainless steel tube, suitable

for liquid or gaseous immersion, refrigerant (insert into a Pete's Plug) and general temperature applications. 1/8 inch sensor diameter with 4 foot long cable.

Sensor: Range (Accuracy):

- Temperature: -58° to 248° F continuous duty, or intermittent max temp: 302° F (± 0.27° F from 32° to 104° F, better than ± 0.54° F from -13° to 185° F)

Compatible Data Loggers:

Pace Pocket Logger

Pace Scientific

PT940 Temperature Probe

Model: PT940

Measures: Temperature

Description: Proprietary temperature probe with closed end stainless steel tube in a moisture-proof jacket, suitable for wet environments for use with the Pace Scientific data loggers. 3/16 inch sensor diameter with 20 foot cable.

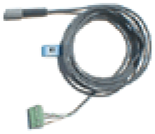
Sensor: Range (Accuracy):

- Temperature: - 58° to 221° F (± 0.27° F from 32° to 104° F, better than ± 0.54° F from - 13° to 185° F)

Compatible Data Loggers:

Pace Pocket Logger
Pace XR5 Logger

Pace Scientific



Temperature & RH Probe

Model: TRH-100-10FT

Measures: Temperature, Relative Humidity

Description: Proprietary temperature & RH probe for the Pace Logger. Probe's lead length in 10 feet and 0.5 inches in sensor diameter.

Sensor: Range (Accuracy):

- Relative Humidity: 0 to 95% (± 2%)
- Temperature: - 13° to 185° F (± 0.27° F from 32° to 104° , ± 0.55° F below 32° F and above 104° F)

Compatible Data Loggers:

Pace Pocket Logger
Pace XR5 Logger

Hydronic Flow Meters

Controlotron

Dual Channel Submersible Flow Computer

Model: 1010WDP1

Measures: Liquid Flow

Description: Portable ultrasonic flow meter with clamp-on transducers for non-intrusive liquid flow monitoring. Kit includes a variety of transducer sizes for use on pipe diameters ranging from 0.75 inches to 24 inches. The transducers can be used on pipe temperatures up to 250° F. Instantaneous readings are output via graphic display screen. Logger uses a PC 9-pin serial

interface for data transfer.
Sensor: Range (Accuracy):
- Flow: 1 to 40 ft/sec (± 0.5%)
Resolution: 12 bit
Memory/Records: 200 Kilobytes of Memory

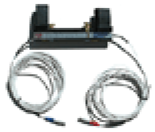
GE Panametrics

Dual Channel Flow Meter - 2PT868
Model: 2PT868
Measures: Liquid Flow
Description: Non-intrusive, portable, 2-channel, transit time ultrasonic flowmeter for chilled and hot liquid applications with continuous calculation of the sum, average and difference of the two channels. Meter has an LCD display and keypad for instantaneous readings and PC serial interface for data transfer. Standard transducers ranging for pipes ranging from 2.0" to 200" OD used for measuring flow for liquids with temperatures ranging from -4 to 122°F. Kit includes ultrasonic thickness gage for measuring pipe thickness.
Sensor: Range (Accuracy):
- Flow: 0.1 to 40 feet/sec (± 2% for pipe diameter less than 6 inches; ± 2% to 5% for pipe diameter greater than or equal to 6 inches)
Memory/Records: 40,000 records

GE Panametrics

Mid-Range Ultrasonic Transducers
Model: C-PT-10-M-B-00
Measures: Flow (liquid)
Description: Mid Range ultrasonic transducers for the Panametrics Ultrasonic Flow Meter for pipes ranging from 2.0 to 200 inches for liquids with temperatures ranging from -4° to 270° F.

GE Panametrics



Small Pipe Transducers and Clamping Fixtures
Model: CF-LP-2EM40NM-1
Measures: Liquid Flow
Description: Small pipe transducers and clamping fixture for the Panametrics flow meters for pipe sizes ranging from 0.5" to 2.0" OD. For measuring flow for liquids with temperatures ranging from -40 to 248°F.
Sensor: Range (Accuracy):
- Flow: (± 0.5 nanosecond)

Onicon

Dual turbine flow sensor
Model: F-1200
Measures: Flow
Description: Insertion sensor for measuring flow of water-based liquid. Fits schedule 40, 4 inch pipe size. Liquid temperature range up to 180° F continuous and 200° F at peak. Sensor has a 400 psi maximum operating pressure and 18 pulses per gallon. Sensor output is 15 VDC signal.
Sensor: Range (Accuracy):

- Flow: 2.5 to 60,900 GPM, depending on pipe size (± 2% or better, depending on range)

Compatible Data Loggers:

AEC MicroDataLogger

SeaMetrics

Paddle Wheel Flow Sensor

Model: IP101B

Measures: Liquid Flow

Description: Brass insertion meter with paddle wheel flow sensor. Fits pipes ranging from 2" to 10". Used with AO55 analog transmitter to transmit 4-20 mA signal.

Sensor: Range (Accuracy):

- Liquid Flow: 0.1 to 9 Meters/Sec (± 1.5% Full Scale)

Compatible Data Loggers:

AEC MicroDataLogger

Pace Pocket Logger

Appendix 5: 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 steps 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.

PART 1 – GENERAL

1.1 RESPONSIBILITY

A. The final responsibility for providing all the necessary EIS components and for the proper operation of the systems as described, except where directly excluded or listed as work not included, shall be by the EIS Contractor. Nothing in this specification is intended to override this responsibility.

B. The EIS Contractor shall have the responsibility as the expert in the proper application of his systems. The final design, installation, and operation of the system is the responsibility of this Contractor. The Contractor shall make additions and/or modifications to the design as required at no additional cost.

C. The Contractor is responsible for including the proper settings of each loop (set point, throttling range, integral, and derivative) as necessary to achieve system stability and control accuracy.

1.2 GENERAL CRITERIA

A. The final design, installation, and operation of the systems in accordance with the sequence of operation are the responsibility of the Contractor and he shall make additions and/or modifications to the design, as required, to produce the required function at no additional cost.

B. The final responsibility for providing all the necessary monitoring and control components and for the proper operation of the control systems, as described herein, shall be by this Contractor. Nothing in this specification is intended to override this responsibility.

C. The Contractor shall have the responsibility as the expert in the proper application of his monitoring and control components to input, review, and correct the design such that the control system shall function as intended.

1.4 DESCRIPTION

A. General: The control system shall consist of a high-speed web-based operator interface. Operators shall be able to perform normal operator functions through the web browser interface.

B. The system shall directly monitor and control specified IT, cooling, and electrical equipment. This includes all aspect of the project with regard to energy use.

1.5 SCOPE OF WORK

A. Provide design, labor, equipment (hardware and software), and materials that are required to result in a complete installation and properly operating EIS as described herein.

B. Furnish all remote field devices, except those specifically excluded, to assure a complete and operating system (sensors, gateways, transmitters, power supplies, etc.).

C. The control output signals and thus, the control of the final devices (motors, valves, dampers, etc.) shall be electric.

D. Owner will provide a server to install their operating program(s) on. Contractor is responsible for coordination of software versions and implementation.

E. Provide complete engineering/detailed control drawings showing all devices, terminal numbers, schedules, legends, labels, etc., as required to properly display the system to be installed and to allow easy trouble-shooting in the future. The diagrams shall also indicate set points, throttling range, ratios, and all other switch settings and adjustments.

F. Provide a detailed written sequence of operation that specifically describes the system operation in terms easily understandable by the Owner's representative and describes how the Contractor's specific equipment will accomplish making the system operate as intended. This shall be more detailed than the engineers sequence and specifically describe the operation of each device.

G. Provide complete start up, check out, and commissioning of related building control systems.

H. Provide complete start-up and field calibration of the control system. This Contractor must set the controls at the proper values to assure that all systems are stable, hold the required conditions, and function as intended.

I. Provide complete on-site Owner instruction in the proper operation of the system and all devices. Training should be provided and video taped for later use. Training should include operation of equipment, programming, set point adjustments, etc.

J. Provide complete operating and maintenance instruction booklets in hardcover binders that are fully indexed and include a complete parts listing.

K. Control systems shall provide for manual operation in case automatic operations fail where designed into the system.

L. Control systems shall interconnect via network. Provide BACnet, SNMP, and/or Modbus interface as necessary to monitor/control equipment connected via serial interface. Coordinate as necessary with equipment suppliers to insure proper interface.

M. Immediately following the acceptance of the EIS submittals, the contractor shall submit the system programming/logic flow diagrams. In addition, this contractor shall include at this time the system checkout checklist used to verify system performance and interaction.

N. This contractor shall have the system trending activated for the following system points as indicated on the attached points list. Trending shall begin one week prior to this contractor demonstrating the functional performance test required by the commissioning firm and continue on for a minimum of one week or longer based on the owner’s facility management and after system demonstration and acceptance.

O. Provide all wiring, terminations, enclosures, network devices, software installation, alarm programming, and commissioning for monitoring of typical electrical systems, including but not limited to the following:

1. Generators
2. Power distribution units (PDU)
3. Power transformers
4. Medium voltage switchgear
5. UPS modules
6. Battery diagnostic/monitoring systems
7. Lighting controls

PART 2 – 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.

2.1 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.

2.2 TEMPERATURE SENSORS

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

2.7 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.

2.8 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).

2.9 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.

2.10 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.

2.11 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.

2.12 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.

2.13 CURRENT SWITCHES

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

2.14 DIFFERENTIAL PRESSURE SWITCHES

A. 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.

2.15 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

This section covers the wireless monitoring of data center environmental conditions (temperature, humidity, and pressure) and CRAH/C power use. The purpose of providing this section is to inform the owners of cost saving that can be resulted in use of wireless sensors in lieu of wired ones.

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 do not 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 (Figure 1) should have a relatively stable topology except for the occasional failure of nodes or addition of new nodes. The path of traffic, being aggregated from a large number of end users, should change infrequently. Practically all the traffic in an infrastructure mesh network should either be 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, aggregate 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.

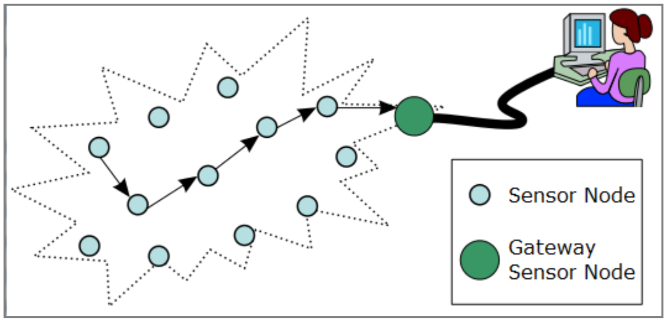


Figure 1. Wireless Mesh Network Architecture

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 the 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 communicating 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

The 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 the wireless mesh network. It is preferred that the same node collect relative humidity data from sensors without a 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 CRAH/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 1,000 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 the 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 and/or CRAC units.

Figure 2 shows a typical wireless EIS. On the left a thermal node, a pressure node, and a gateway are shown, and on the right the green dots identify sensor placement.

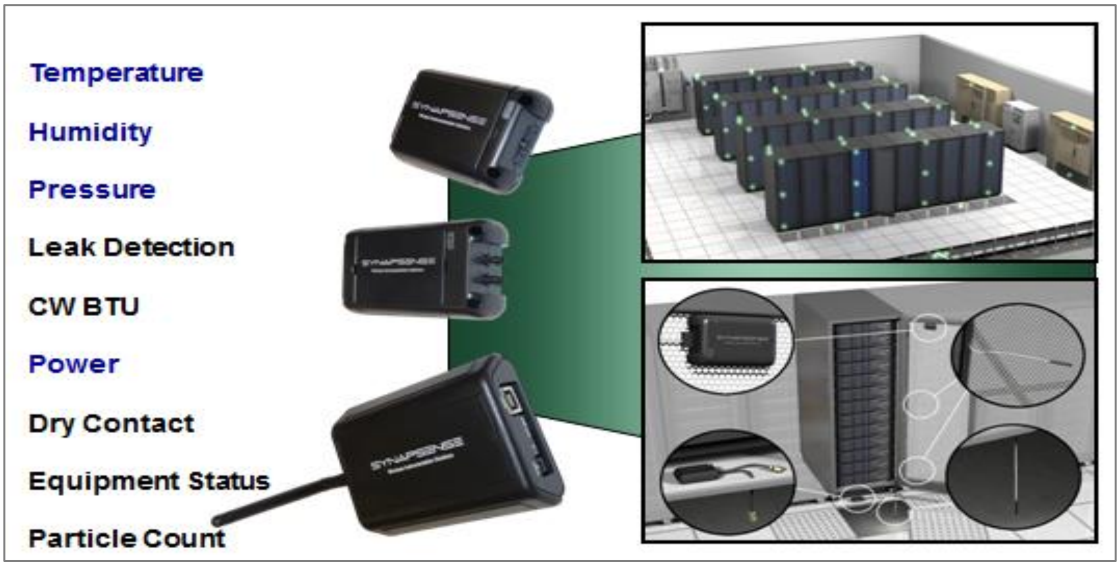


Figure 2: Typical Monitoring Solutions (Courtesy of SynapSense Corporation)

PURPOSE

The main purpose of this work is to use the monitoring to improve the robustness of the energy-efficiency assessment. This application helps to create an accurate understanding of data center operation, evaluation of air management in the data center (locating hot and cold spots and air leaks, etc.), and calculation of PUE. Air flow distribution can be optimized through trial and trending (sealing openings, floor tile tuning, etc.). After each trial, trending can immediately show the impact of the changes, which can encourage additional trials. The purpose of the trials is to identify the effect on the separation of cold and hot air, potentials for increasing room temperature set point, and expanding relative humidity set-point range or disabling humidity control.

SYSTEM DATA PRESENTATION

The important data should be accessible through a server interface in the form of dashboard, snapshots, maps, tables, and graphs. Rack temperature and humidity, supply air pressure, and CRAC/CRAH power use should be accessible directly. Databases of information should be created that users can utilize to create different reports for diagnostic, management, or planning purposes. For example, a user should be able to superimpose rack air intake temperature on the data center map, or tabulate it to compare with other data, or graph it to exhibit the changes of the parameter in a pre-defined period of time. Power usage effectiveness is not expected as a direct output of the assessment kit. It is computed using electrical component readings, estimation of power use by the cooling system (assuming certain efficiencies), estimation of lighting power use, and information from CRAC/CRAH power measurement.

REFERENCES

Assessment Protocol:

http://www1.eere.energy.gov/industry/datacenters/pdfs/data_center_assessment_process.pdf

Metering Protocol:

http://www1.eere.energy.gov/femp/pdfs/hpc_metering_protocol.pdf

Data Collection Protocol:

http://www1.eere.energy.gov/femp/pdfs/datacollectionprotocol.pdf

Self-Benchmarking Guide for Data Center Infrastructure: Metrics, Benchmarks, Actions

http://hightech.lbl.gov/benchmarking-guides/data.html

List of Acronyms

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
CII	Confederation of Indian Industry
CO_2	carbon dioxide
CRAC	computer room air conditioning
CRAH	computer room air handling
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
INR	Indian rupees
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