



Data Center Energy Efficiency Measurement Assessment Kit Guide and Specification

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Summary

A portable and temporary wireless mesh assessment kit can be used to speed up and reduce the costs of a data center energy use assessment and overcome the issues with respect to shutdowns. The assessment kit is comprised of temperature, relative humidity, and pressure sensors. Also included are power meters that can be installed on computer room air conditioners (CRACs) without intrusive interruption of data center operations. The assessment kit produces data required for a detailed energy assessment of the data center. Its design incorporates the following considerations:

- Measurement of environmental parameters (temperature, humidity, pressure) and power through a non-intrusive, non-interruptive process.
- These parameters (temperature, dew point) at server intakes are recognized by ASHRAE for standardization of server cooling performance.
- Air management improvement will provide grounds for increasing data center temperature closer to ASHRAE recommended or allowable numbers.
- Graphical reports (maps) for different parameters provide an accurate understanding of data center operation

This kind of study and report can cost much more and take much longer if conventional wired technologies are used. For comparison, a sensing point for the wireless network can cost \$100-\$150. A similar wired sensing point can cost \$500 to \$1,000.

Guide and Specification Scope

Target Audience

This guide is primarily intended for personnel including Information Technology (IT) and facilities managers who are responsible for managing data center energy use.

What This Guide Does

This guide introduces an assessment kit for data center assessment, and presents its advantages and limitations. Additionally, the guide describes the assessment kit's components, specifies the requirements of the assessment kit and its components, guides the user through the assessment kit's installation, and lists and describes the data required for computing the proposed metrics used to determine power usage effectiveness (PUE).

What This Guide Does Not Do

This guide does not address IT efficiency and productivity metrics. While the energy efficiency measurement approach described in this guide can be used to identify potential efficiency opportunities in HVAC and electrical systems, this guide does not constitute a detailed energy audit procedure or checklist. However, the results may be used by a trained energy auditor as part of an energy audit procedure, or to help prioritize areas for more in-depth audits. This guide does not describe the opportunities that result from the assessments or how to calculate savings from the potential actions identified. The owners of data centers are encouraged to hire trained energy auditors with data center experience to conduct their audits. The Department of Energy has established a data center energy practitioner program to train and certify such auditors.

Data Center Monitoring

Background

Monitoring data centers for energy efficiency is an important factor in their efficient operation. Environmental monitoring can provide a map of cooling system performance that can be used to help detect and address deficiencies. Other monitoring can segregate the power used by various components and systems, as well as reveal data center power distribution losses. Many sensing points are required to create a reasonable map of data center energy usage performance. This is a granular monitoring approach that monitors both environmental parameters such as temperature, dew point, pressure, and power in the data center at many locations and levels.

Granular monitoring should help data center stakeholders accomplish the following:

- Identify baseline energy usage and improvement opportunities
- Measure real-time power usage and estimate PUE, which is calculated by dividing total estimated annual energy used by estimated IT equipment annual energy use
- Interpret temperature, humidity, and sub-floor pressure differential data from hundreds of sense points into intuitive live imaging maps

- Monitor environmental conditions to stay within specified recommended and/or allowable ASHRAE ranges and provide alerts when boundaries are exceeded.

This monitoring should consist of three basic components: the wireless network, a console application, and a browser-based user interface.

The principal objective of this work is to use the assessment kit's capability to improve the robustness of the assessment. This process helps to create an accurate understanding of data center operation, evaluate air management in the data center, and calculate PUE.

Data Center Supporting Infrastructure Efficiency Metrics

Principal Parameters

As described in *Self-Benchmarking Guide for Data Center Infrastructure: Metrics, Benchmarks, Actions*, issued in 2010, the principal parameters for measuring/affecting energy use include the following (this list has been modified for this guide):

- Power Usage Effectiveness (PUE), percent of total used energy to IT used energy
- Air Supply Temperature at IT intake (degF)
- Relative Humidity Range at IT Intake (percent)
- Return Temperature Index (RTI) (percent)
- Data Center Cooling System Efficiency (kW/ton)
- Airflow Efficiency (watts per cubic feet per minute, W/cfm)
- Data Center Power Distribution System Efficiency (percent)
- Data Center Lighting Power Density (watts per square foot, W/sf)

Wireless technology should enable measurements that are essential for the computation of the above metrics.

Air Cooling Efficiency Metrics

Air cooling efficiency metrics indicate how effectively cooling resources are being employed. The monitoring system should calculate and display, at a minimum, the following metrics, which have been developed by industry consensus:

- Rack Cooling Index (RCI), which is a measure of the cooling effectiveness of the IT equipment racks to ASHRAE levels
- Return Temperature Index (RTI), which is a measure of CRAH/CRAC air flow versus Rack air flow by measuring temperature differential across computer room air handler (CRAH)/CRAC and racks.

Airflow Management

- By utilizing wireless mesh network monitoring system, data center operators should be able to visualize air mixing, observe trends, and identify hot spots. In addition, high-sensitivity sub-floor grids of pressure sensors target poor flow areas and floor leaks. Airflow management problems can then be resolved by addressing the hot and cold spots and leaks.

Power Utilization Effectiveness

- PUE can be computed by measurement of the four basic components of power utilization including IT power, cooling power, other infrastructure losses, and lighting.

Data Center Visual Trending

Visual trending should provide thermal, pressure differential, humidity, and dew point mapping using real-time data at multiple levels of the data center.

With the amount of the sensors in a wireless mesh network monitoring system, operators will be able to see hot spots and direct airflow to avoid over-heating or air mixing. Also, pressure mapping should enable operators to balance the sub-plenum/ductwork pressure differential. Visual trending should provide:

- An integrated view of the data center environment, and a record of anomalies
- Real-time visibility of the impact of data center changes
- Information to assist in identifying data center energy efficiency improvement opportunities such as rack intake and exhaust
- Information to assist in identifying available data center cooling for increased CPU density and footprint reclaim
- Information to assist in identifying potential energy savings, operational savings, and data center resiliency
- Data center cooling capacity management by depicting real-time impact of changes

Wireless Network Specification

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

Wireless mesh networks should have a relatively stable topology except for the occasional failure of nodes or addition of new nodes. The path of traffic, 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.

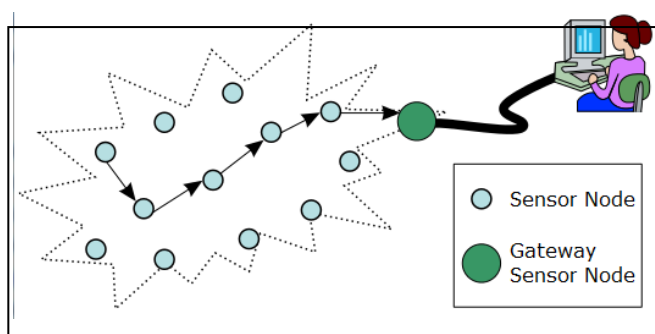


Figure 1 – Wireless Mesh Network Architecture

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 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 acknowledging capabilities. It shall include data logging, storage, dashboard, and trending.

Rack Thermal Node

Temperature nodes shall gather data from multiple sensors installed on the air intake and air exhaust of the racks and transfer temperature and humidity data to the nodes. Temperature nodes wired to those sensing points should communicate with the gateway through wireless mesh network. It is preferred that the same node collect relative humidity data from sensors without need for additional nodes. Accuracy of equal or better than $\pm 0.6^{\circ}\text{F}$ 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 to or better than $\pm 0.6^{\circ}\text{F}$ 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 $\pm 0.9^{\circ}\text{F}$. The time between each data release (communication with gateway) should not exceed 5 minutes. Nodes should have lights showing that they are on, communicating, or initializing.

Differential Pressure Transmitters

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

Current Transmitters

AC current transmitters should be a self-powered, combination split-core current transformer type with built-in rectifier and high-gain servo amplifier with 4-20 milliamp (mA) two-wire output. Full-scale unit ranges shall be 10 amps (A) to 1000 A, with internal zero and span adjustment. Unit accuracy shall be $\pm 1\%$ 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 $\pm 0.5\%$ accuracy at 24 Vac and 5 VA load. Windings (except for terminals) shall be completely enclosed with metal or plastic.

Other Components

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

Battery Life

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

Operational Interference

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

Security

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

Data Latency

Wireless network providers should identify their data latency in their bid. This includes propagation, the time that it takes for a packet to travel between one place and another, and transmission speed, considering the medium itself introduces some delay.

The data reliability of the wireless network should be on the order of 99.999%, at least. The wireless network also should be able to accommodate feedback (i.e., data flow from upstream back).

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

Scope of Work

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

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

Assessment Kit

The following sections outline the specifications of the equipment that comprises the assessment kit that was used by LBNL. The components for the kit came from one manufacturer. Similar equipment from different manufacturers/vendors should be considered as well.

Thermal rack nodes and temperature sensors – 20 units

- Each node comes with seven temperature sensors and one humidity sensor.

Thermal rack nodes and 6 row temperature sensors set – 3 intake/exhaust units

- For network and other low-density racks, a thermal node with six intake and six exhaust sensors is included. It makes the work easier and more racks are covered by the sensors.

CRAC/CRAH thermal nodes measuring temperature and humidity – 10 units

- 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.

Dew point sensors/ transmitters- 30 units

- These can be integrated parts of the rack and CRAH/CRAC thermal nodes listed above to make the installation faster and easier.

Differential pressure transmitters – 6 units

- The assessment kit has six pressure sensors capable of covering 3,000 square feet of white space.

Current transmitters – 4 sets

- The assessment kit can be complemented by more current meters if there are more than three CRAC units in the zone of the data center that being assessed. Note that for constant speed fans CRAH units, continuous monitoring is not required since the power use is the same throughout the day. This is assuming there is no reheat in place.

Voltage transformers – 4 Units

- See above under current transmitters.

A typical monitoring assessment kit is shown in Figure 2. On the left a thermal node, a pressure node, and gateway are shown and on the right the green dots identify the placement of the sensors.

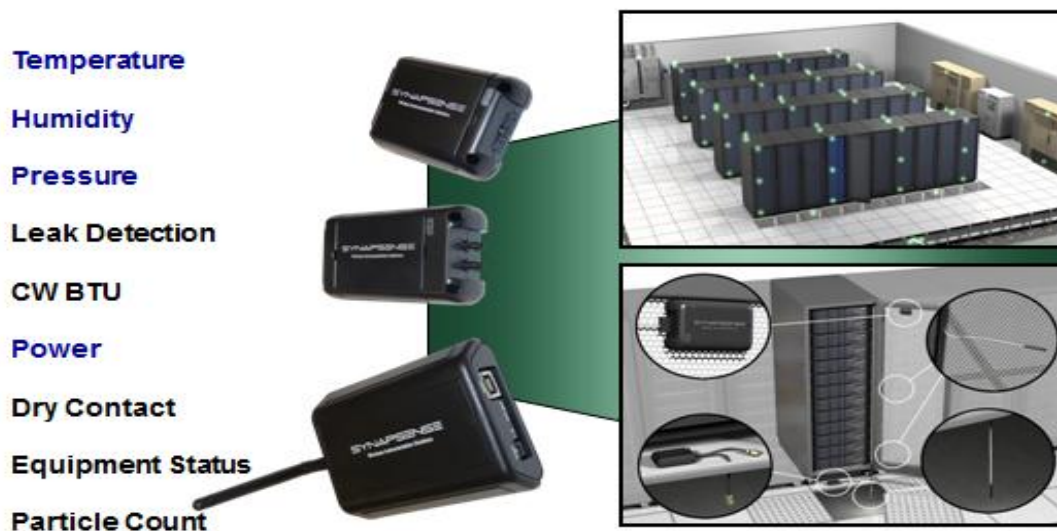


Figure 2: Typical Monitoring Solutions (Courtesy of SynapSense Corporation)

Assessment Kit Installation and Commissioning

Purpose

The main purpose of this work is to use the monitoring to improve the robustness of the energy efficiency assessment. The main goal of introducing the assessment kit was to combine the measured data with calculations and produce meaningful information that otherwise would have required a lot of equipment. The results are close to those from more extensive alternatives that cost more and take longer to install and commission. 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, locating the air leaks, etc.), and calculating 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.

Process

The process begins with installation of the system, including sensors, routers, and a gateway for environmental monitoring. The following bullets outline the steps necessary to install and operate the system.

1. Arrange access to the data center and coordinate the activities. Many data centers have extensive change control and access procedures, and it is critical that these procedures be followed and accounted for in the assessment plan. Observe all safety procedures in order to maintain the safety of personnel, protect equipment, and ensure continuous operation of the data center.
2. Generally, the installation of the environmental sensors is not intrusive and does not interrupt data center operations. However, this is not the case if power meters are planned for installation because shutdowns are required to install power meters on panels, and those will interrupt the data center operation. It can take a long time to install the meters, and it can be costly. This is the reason the assessment kit estimates power usage in lieu of metering in those instances.
3. Set up the equipment. First, the server and the gateway need power. The gateway needs to be set up in a central location in white space with good access to wireless components such as thermal nodes, with no major obstruction (such as a full height walls) between the gateway and the nodes. After the gateway and server are set, the nodes and sensors need to be installed as planned. When all of the equipment is installed, the software can be activated to start the data-logging process.
4. Where consistent with the plan, start logging the computer room conditions of the computer room air conditioners, computer room air handlers, or other air-handling units serving the data center. This may be either through energy management control systems (EMCS) or with assessment kit power meters. The supply and return air conditions (both temperature and relative humidity) are monitored over time. Be aware of stratification at

the point of measurement; it is possible for the air temperature to vary several degrees between the top and bottom of supply air ducts. To meter the power, an amp meter and volt meter should be installed. Note that power is required for these meters, and the communication between these meters and gateway is wireless. The meters are especially useful for metering CRAC units, since the power use is variable (i.e., the compressor stages on and off). For a constant volume CRAH unit while the humidification/dehumidification is disabled (that is, neither reheat nor electronic humidifier are in operation), calculation would be easier than measurement.

5. Measure pressure by locating the differential pressure sensor tubes under the raised floor and above (or inside the ductwork and the data center space). Here data can be presented by a pressure map or different tables or graphs. Reducing pressure to around 0.03inch can result in reduced airflow, thus saving energy.
6. Measure rack air intake and exhaust temperatures and relative humidity by installing sensors in the front and back of the racks. Considering the coverage of each node, usually a thermal node is installed on every third rack in the row.
7. To monitor the fan power for constant speed fans, nominal cfm from the equipment data sheet can be used along with the estimated pressure loss. The preferred option is to do a spot measure of the power using the kit current/voltage meters. This will require the shutdown of one unit, installation of the meter, and turning the unit back up. Shut down should be repeated when meter needs to be removed. For CRAC units and CRAH units with VFD, power meters need to be installed on all the operating units. If not enough power meters exist then the meters should be installed on temporary basis and move from one unit to another until all are covered.
8. To calculate PUE, the cooling needs to be estimated since the assessment kit does not include flow meters and power meters for chiller plant or other cooling systems monitoring. Knowing the IT load, one can estimate required cooling (0.285ton per kW). By estimating the other cooling loads such as electrical equipment cooling, lighting, and possible envelope loads one can then calculate total cooling in tons. The power needed to provide that amount of cooling then depends of the cooling system components and their efficiencies.

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. Data bases of information should be created that can be utilized by the user to create different reports for diagnostic, management, or planning purposes. For example, 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 the 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 cooling system assuming certain efficiencies, estimation of lighting power use, and information resulted 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>

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