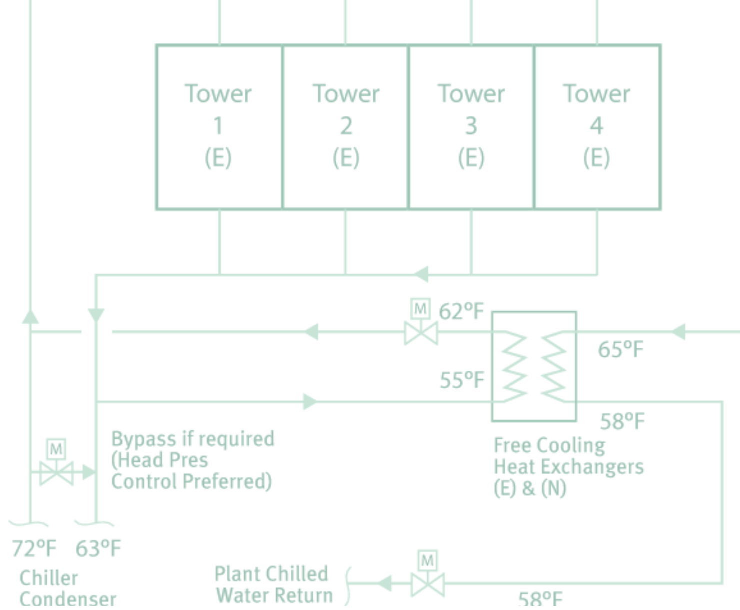
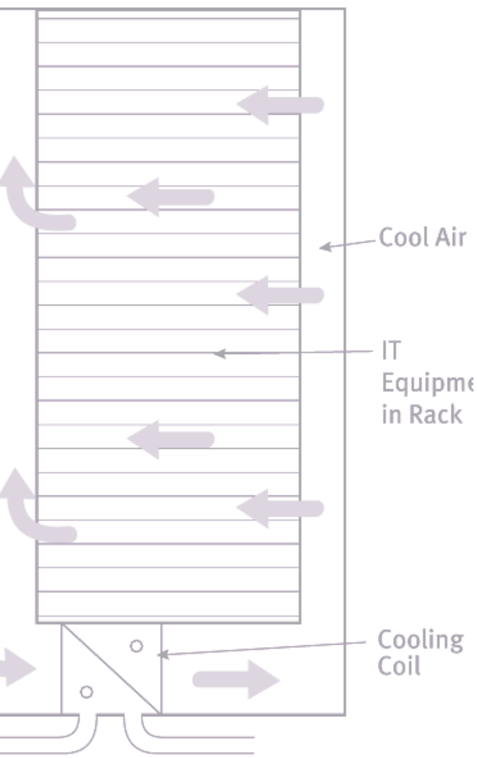
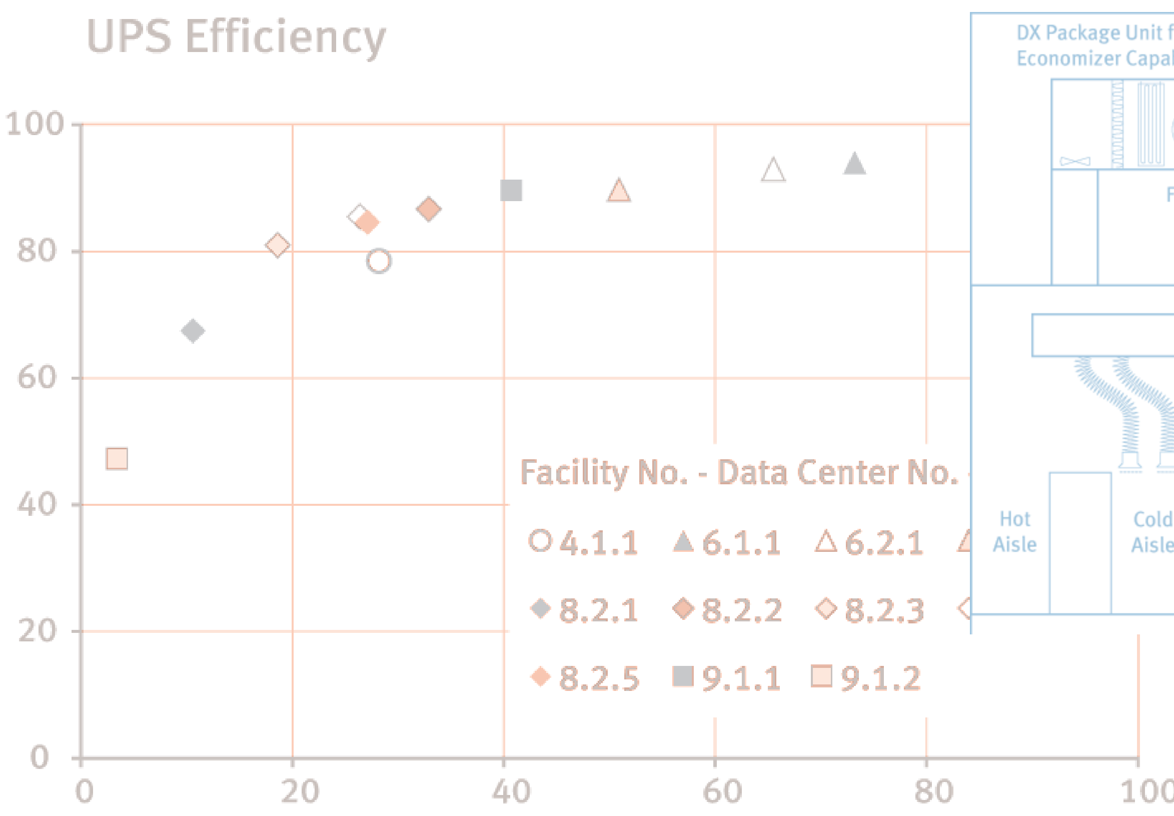


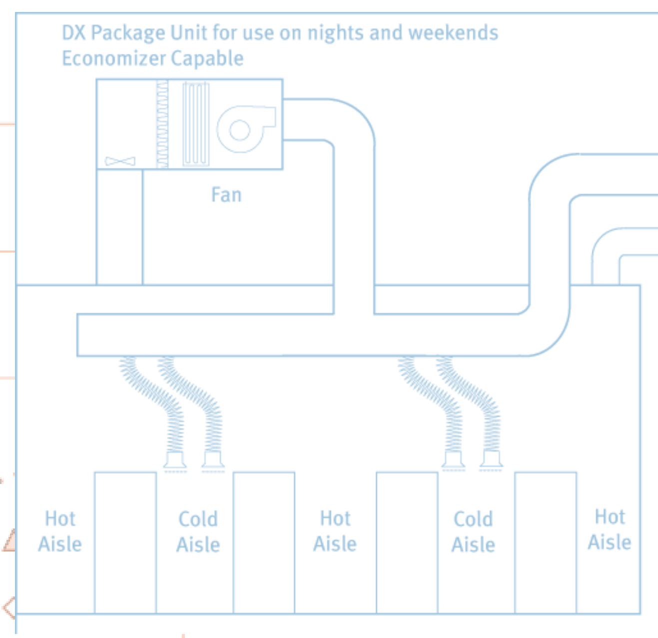


Self Benchmarking Guide for Data Center Energy Performance

Version 1.0

Ernest Orlando Lawrence
Berkeley National Laboratory





Self Benchmarking Guide for Data Center Energy Performance Version 1.0

Ernest Orlando Lawrence Berkeley National Laboratory

May, 2006

Authors:

Steve Greenberg, William Tschudi,
LBNL

John Weale,
Rumsey Engineers

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Introduction

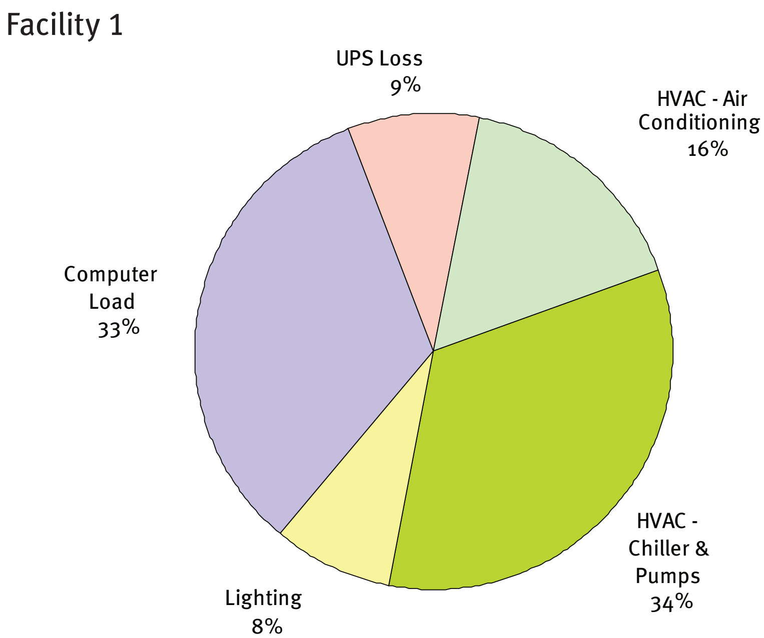
In order to optimize any system, or combination of systems working together such as those found in a typical data center, it is crucial to accurately assess its current performance. This guide is intended to show data center operators, or their contractors, how to perform a comprehensive measurement, or benchmarking, of their own facilities' energy use.

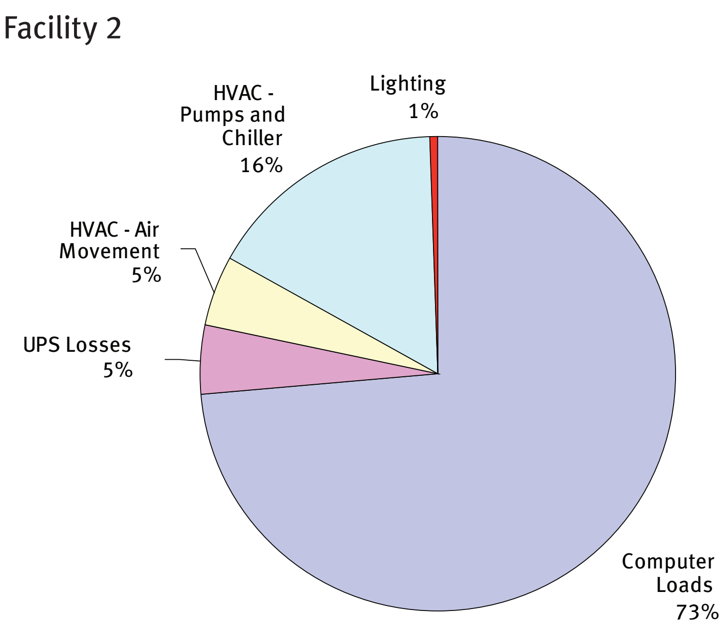
Energy benchmarking offers a very effective way to evaluate the performance of a data center facility and compare it to similar facilities. Comparisons are a quick and easy way to identify poorly operating areas, which typically have the highest potential for economical modifications that reduce operating cost and/or increase the load capacity of a data center. Benchmarking is particularly valuable as a precursor to an expansion of a facility, because increases in system capacity and identification of best practice design approaches can be used to reduce the cost and increase the energy efficiency of new space.

The following steps guide the operator through the benchmarking process, from the initial definition of the scope of the benchmarking through the initial evaluation of the results. Widely used by most manufacturing industries to improve product quality, benchmarking is also a powerful tool for improving the quality, reliability, and performance of data center facilities. Once the magnitude of power use is identified on a system basis, limited resources can be prioritized for the areas where the greatest savings can be achieved.

The charts below are part of the results of benchmarking performed on typical datacenter facilities. They show the large differences that can occur between systems supporting the same space requirements. Since the conditioning requirements of data centers are usually similar, with roughly equivalent loads and setpoints, large discrepancies between auxiliary equipment energy costs can clearly identify system designs and/or operations that are inefficient and good targets for improvements in cost and energy use.

Figure 1: Comparison of actual benchmarking data from two data centers showing breakdown of total electricity use per watt of server. Facility 2 uses less than half as much power on infrastructure.





1. Getting started- Identify Benchmarking Goals

The first step in benchmarking your facility is to determine the scope and overall business objectives of the benchmarking project. There are many reasons to benchmark a data center. A few common ones are:

• Establishing a base line performance as a diagnostic tool
Comparing trends data over time to baseline performance can help predict and avoid equipment failure, improving long-term reliability. Efficiency can also benefit by identifying and therefore allowing the correction of typical performance decay that occurs as systems age and calibrations are lost.

• Identifying operational or maintenance issues
In particular, to assist in diagnosing the root cause of hot spots, heat related equipment failure, lack of overall capacity, and other common operational problems. Due to the critical nature of data center environments, such problems are often addressed in a very non-optimal, Band-Aid manner due to the need for an immediate fix. Benchmarking can identify those "quick fixes" that should be revisited in the interests of lower operating cost or long-term reliability.

• Helping to plan future improvements
The areas that show the poorest performance relative to other data center facilities usually offer the greatest, most economical opportunity for energy cost savings. Improvements can range from simply changing setpoints in order to realize an immediate payback, to replacing full systems in order to realize energy savings that will show payback over the course of a few years.

• Developing design standards for future facilities
Benchmarking performed over many facilities in recent years has suggested there are some "best practice" design approaches that offer fundamentally lower cost, more efficient facilities. Benchmarking can help identify: 1.) Company-specific best practices that should be duplicated to reduce the cost of future facilities; and 2.) Less efficient design approaches that should be avoided.

• Improving management
The cliché, "You can't manage what you don't measure" applies to data centers. For example, knowing the relationship between server wattage requirements and mechanical cooling costs can help in determining the value of purchasing slightly more expensive but much more efficient server power supplies and IT equipment. Also, operating costs of double-conversion UPSs can be compared to those of line-reactive units to determine if the (possibly unnecessary) additional conditioning is financially justifiable.

An attainable scope for the benchmarking should be defined. For example, if the goal is to establish a benchmarking team within a company with several data centers, it would be useful to start with a relatively smaller and simpler data center known to have good documentation. Centers with high absolute or system energy costs, known performance concerns, or "Band-Aid" fixes might be good candidates as well since they are most likely to produce quick payback (or "low hanging fruit") opportunities. At this point in the process the goals of the benchmarking should be established to help guide the study. A review of the metrics in the appendix of this document can help in selecting the areas that are typically addressed in data center benchmarking (and where significant comparison data is available).

2. Orient the IT and Facilities staff

The next step is to engage Information Technology and Facilities personnel at the data center. Benchmarking is often motivated by facilities staff, who must monitor operations, identify and resolve trouble spots and ensure smooth operation; however, it's also important to involve IT staff so that the data center's mechanical infrastructure and IT equipment can be considered as a whole system. This is best achieved through meetings involving IT and Facilities staff, where the benchmarking process and its benefits can be explained; each group can be informed of the documentation and access they need to provide during benchmarking; and the expected results can be identified and communicated to the group.

For example, purchasing more energy efficient IT equipment, such as servers that use "80 plus" certified higher performing power supplies, would at least reduce long-term power costs. Quantifying the savings to the operational budget can justify a minor increase in the equipment infrastructure budget that will result in valuable efficiency gains.

Another issue is airflow management, which requires close control of the layout of equipment in the racks and the exhaust flow configuration of the equipment. While air management has a very large impact on the efficiency of mechanical systems, it can also directly impact IT personnel through reliability improvement, or its opposite, increased heat-related failure rates. The most economical and long-term way to achieve optimal performance is to view and treat the data center infrastructure and the IT equipment in the way it actually operates in real-time: as an integrated, whole system.

There are also significant benefits to the operational facilities staff. Benchmarking can also identify easily corrected problems that can increase the heat density capacity of a space without requiring additional cooling equipment. While useful at nearly all points in a data center's life cycle, benchmarking can be most useful and cost-effective before expansion to identify the most efficient systems and facilitate optimal Return on Investment decisions.

3. Obtain documentation

The process starts with gathering information on utility bills. This could simply be a quick snapshot- looking at the latest bills - but a longer load (and cost) history is useful in evaluating growth trends. Ideally, a year or more of utility bills should be obtained and displayed graphically. The Energy Monitoring and Control System (EMCS) and Supervisory Control and Data Acquisition (SCADA) systems can provide much of the benchmark data for both snapshots of current operation and historical performance, if trend data is available. Where this data is available, it can be used to minimize the cost of additional monitoring equipment.

Other resources include drawings of the facility, Test, Adjust, and Balance (TAB) reports, and commissioning or retro-commissioning reports. These documents will be essential to understanding system performance and efficiency opportunities and will provide much of the benchmark design or previously measured performance information. This will enable comparisons of current measured performance (determined by direct measurement or through building management systems) to the original design, or to latest measured performance.

Facilities and IT personnel should review the current data center configuration and operation to better understand its current performance and opportunities for improvement. Documentation of the electrical and mechanical systems is useful in understanding the data center and creating a monitoring plan. Available documentation varies greatly, from the ideal case of up-to-date as-built drawings, reports and lists, to the worst case of no documentation. Typically, there will be substantial documentation available, but it will often be incomplete and imperfect and require some physical verification. The following documents tend to be available and useful to the process.

1) Floor plans
Floor plans of the center will show the location of the IT equipment racks, computer room air conditioners (CRACs) or computer room air handlers (CRAHs), power distribution units (PDUs), uninterruptible power supplies (UPSs), etc.

2) One-line electrical drawings
These will show the main power distribution configuration, including utility power feed, transformers, switchgear, UPS systems, and distribution to major loads and panels.

3) Mechanical piping and duct work drawings
These show configurations, locations, sizes, and design flows for air and water systems.

4) Mechanical equipment schedules
These are comprised of one or more drawings with tables, typically showing the manufacturer and model numbers of the mechanical equipment, as well as design loads, temperatures, flows, pressure drops, etc.

5) Controls drawings
In particular, a "P&ID" drawing shows a schematic of the mechanical systems being controlled as well as the control points for those systems. The sequence of operations (how the control system is programmed) may be found on the control drawings, in the Specifications, or in a Maintenance Manual submittal.

6) Utility bills
Ideally, at least one year of monthly electricity, gas, and water bills should be obtained. If the site does not have ready access to them, the Utility can usually provide them upon request by the Utility customer. It is also useful to get several years' data if available in order to trend the center's overall usage over time (as the IT equipment load changes).

7) EMCS and SCADA system points lists
The Energy Monitoring and Control System and Supervisory Control and Data Acquisition system often monitor equipment and systems that are relevant to the benchmarking process. Get a list of the available monitoring points from the system operator(s). Also verify that the points can be logged (or "trended") and that it is reasonably easy to get the data from the system as a spreadsheet or equivalent (comma separated value or csv, e.g.) file.

8) Air and water balance and commissioning reports
These are done by balancing and commissioning contractors and show (for balance reports) air and water flows and temperatures for mechanical equipment and systems. Commissioning reports tend to also show system performance data at real-time operating conditions rather than design conditions. Where systems cannot be easily measured in the operating center, such reports provide the best data; otherwise design data must be used.

4. Create the site-specific monitoring plan

Using all of the information collected in step 3, a center specific monitoring plan can be developed. Once the plan is established and agreed to by the IT and Facilities staff, data collection can be done by taking measurements, recording information from EMCS systems and using monitoring equipment temporarily installed in the building.

1) Select Metrics

Use the LBNL template or create a site-specific list of metrics (several lists of monitoring points and metrics used for prior benchmarking studies are provided in Appendix A and Appendix B). Areas of interest can be selected from the overall list, if needed, to assign priority in the common situation where access and resources are limited. Three key parameters are recommended as fundamental for defining the space: 1.) IT equipment total power and power density, 2.) The ratio of IT energy to HVAC energy (since that is key to determining how efficiently the IT equipment is cooled-see Figure 2), and 3.) The ratio of IT energy to total energy (since it is key to the overall efficiency of the center). Additional metrics should be selected to target specific systems, known problem areas, or to prepare for specific future work. It is common to select at least a few high-level metrics, such as kW/ton for chilled water systems, to serve as a check for gross efficiency or operational problems. Additional measurements are often included during the benchmarking process to identify the cause of unusual measurements as they are taken.

$$\text{HVAC Performance Index (\%)} = \frac{\text{kW}_{\text{HVAC}}}{\text{kW}_{\text{UPS Output}}}$$

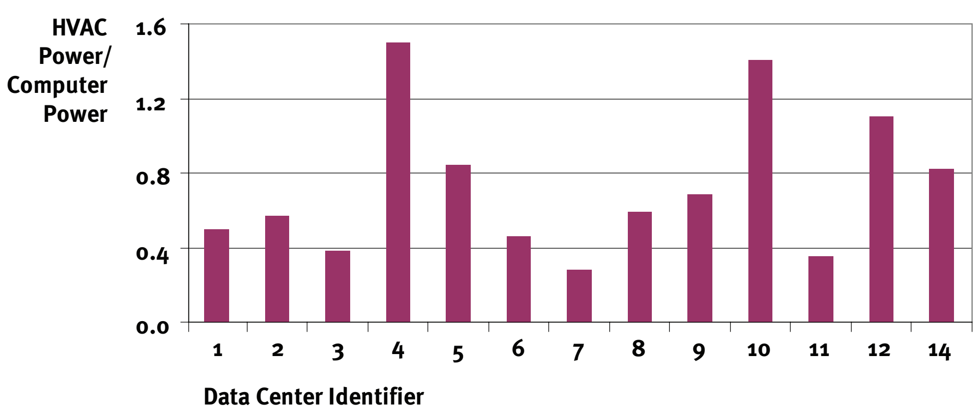


Figure 2: HVAC performance index. By comparing the energy used for cooling the data center (HVAC power in kW) to the UPS output, (which should closely resemble the computer loads) an indicator of HVAC system performance is obtained. The graph shows a comparison of data for 14 system configurations, indicating wide variation in system design and energy efficiency.

2) List data required for metrics

List specific points to spot check for spot measurement trending with EMCS or SCADA system, or use measurements with data loggers. Based on past experience, some of the measurements vary little over time, so they only need to be checked once (see Appendix). Spot checks can be done with either portable instrumentation or by observing instruments that are part of the existing system (thermometers, gauges, control panels, or EMCS/SCADA screens). For more critical spot checks, installed gauges and sensors should have their calibration checked or be compared against a portable calibrated instrument once in order to verify their accuracy. Other items need to be trended over time in order to properly identify operational performance: this can be done with either the EMCS or SCADA, if they have the capability, or with portable data logging equipment.

3) List monitoring equipment needed to collect data

Depending on the scope of the study, the number of systems and pieces of equipment, and how much instrumentation is built into the center, a wide range of monitoring equipment may be needed to complete the benchmarking. For each point, determine how the measurements will be taken and whether the equipment is available in-house. One important point to consider for the power measurements is the size of the current sensors (often referred to as “CTs” even when they are not technically current transformers) needed, both in current rating and physical size (will they be going around multiple large conductors, bus bars, etc.).

5. Obtain monitoring equipment

From the list generated in the previous step, determine how the monitoring equipment will be obtained. Ideally the benchmarking process will become an ongoing part of the management of the data center. In this event it may be advantageous to purchase the monitoring equipment needed for the study. Equipment can also be rented. Other possible sources include consultants or public utilities. For instance, California public utilities provide free monitoring equipment loans through tool lending libraries such as Pacific Gas and Electric Company’s at http://www.pge.com/003_save_energy/003c_edu_train/pec/toolbox/tll/tll_home.shtml.

The accuracy of the monitoring equipment should be assessed, including calibration status. Calibration accuracy should support the desired accuracy of results expected from the benchmarking. The measurement range should be carefully considered when determining minimum sensor accuracy. For example, a pair of +/-1.5 F degree temperature sensors are almost useless for determining the waterside dT across a typical chiller, which under normal operation may be as low as 5 F degrees.

6. Install monitoring equipment

Access to the data center and coordination must be arranged. Many centers have extensive change control and access procedures: it is critical that these be followed and accounted for in the benchmarking plan. Most power measurements are made on live panels due to the impracticality of any power interruption to the data center, so an electrician needs to be available to place monitoring equipment in or around live electrical panels. Observe all safety procedures, particularly “hot work” requirements, in order to maintain the safety of personnel, protect equipment, and ensure continuous operation of the data-center. If electrical panels cannot be fully closed due to the placement of temporary logging equipment, the area must be blocked off with appropriate signage and caution tape, or as otherwise required by the site, for the duration of the required trending period.

1) Set up data logging equipment

Ideally, this step is as simple as configuring trends on the control system. In cases where temporary loggers are used in place of permanent control system sensors, configure the loggers as needed to take the planned measurements. Data loggers vary in their configuration procedures, but typically there is software that runs on a Windows-based PC that allows the recording interval, type of circuit, and other parameters to be set up in the logger.

The trending interval is of particular importance. It should be set as short as is practical, with one minute being the ideal. Longer intervals are often required due to limited logger memory, and will still provide a great deal of valuable information; however, shorter intervals tend to be required in order to identify control problems, such as a control valve cycling from open to closed once every 2 minutes (which may be caused by a PID tuning or sizing issue), or a system switching from humidification to dehumidification every minute (which may be caused by a bad sensor, inappropriate humidifier type, or unrealistically tight control band setting). Setting all loggers that measure related parameters to the same interval can simplify data analysis and facilitate combining collected data into a single spreadsheet.

Logging equipment setup can be done in the field; however, prior setup can help staff to familiarize themselves with the equipment and afford the opportunity to make test runs to verify that the equipment gathers data and records it back to the computer. Ensure that self-powered loggers have fresh batteries, that sufficient memory is available for the desired durations, and that appropriate size connectors are available. While familiarizing the team with the equipment, create a simple checklist for the logger connections that will be performed at each point (see Appendix B). The checklist should include common quality checks, such as downloading a five minute trend to verify proper operation. Trended data is most valuable when taken simultaneously; the loss of a single point can necessitate repeating many others in order to achieve a complete picture of the data center operation.

For points that will be monitored from the EMCS or SCADA system, verify that the logging and data download capabilities are well understood.

See the Sample Monitoring Setup Checklists in Appendix B for a useful checklist for setup.

2) Logging at CRACs/CRAHs/AHUs

Where consistent with the plan, start logging the computer room conditions of the air conditioners, computer room air handlers, or other air-handling units serving the data center. This may be either through use of the EMCS or with portable instrumentation. The supply and return air conditions (both temperature and relative humidity) are typically 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. Air flow measurement at the units may be taken or flow from an existing test and balance (TAB) report can be used if available. As a last resort, the design airflow can be assumed.

3) Monitor temperature and relative humidity in the data center

One or more loggers can be used to determine the space temperature and humidity conditions. Logger placement depends upon the goals of the study; hot spots at IT equipment inlets; effectiveness of the hot aisle/cold aisle configuration (return air temperature to the cooling unit); bypasses; and mixing. Any EMCS sensors (including those accessible at the CRAC or air handler intakes) should also be trended. In particular, the temperature difference, ΔT, at the CRAC units and the temperature at the outlet of the CRAC units or air handling units should be recorded since this directly indicates the capacity capability and the airflow utilization efficiency of the entire system. Monitoring points may be determined as suggested in the *ASHRAE Thermal Guidelines for Data Center Environments Book*.

4) Inventory Datacenter Equipment

To get average rack power, count the number of racks in the data center, and assign a percentage full for each rack. The percentage full may appear to be somewhat arbitrary, but it can be very useful when the same team is used to estimate future data center loads. If desired, a complete inventory of the IT equipment could be obtained, or a partial inventory of 'typical' equipment. This inventory can be useful in tracking load growth trends and planning for future expansions.

5) Select racks for individual monitoring

There are several types of racks that may be of interest. Selecting a typical rack allows for projections of total rack load and load density, while selecting a peak load rack offers guidance as to the airflow distribution required for cooling. At a minimum, measure a rack with a typical mixture of equipment to get a sense of the variability of the power requirement. The rack needs to have its own electrical circuit and preferably has just one electrical circuit feeding it. If different types of servers are used, select a rack with the most common type of server.

6) kW monitoring at panel supplying rack

Unless there are built-in meters on the rack-feed circuit, install a portable kW logger at the feed to the rack. If using a built-in meter, start trend log in monitoring software. A significant length of trend time (usually a week) is required to capture data if there are any processing task load impacts on the overall data center power usage.

7) Check kW monitor with one-time reading

Using a portable kW meter, verify the reading on the data logger. This step is generally applicable to any kW logging, whether by portable loggers, EMCS, or SCADA system. If there are significant differences, check the logger or system setup (voltage setting, range, multiplier, etc.). Power meters are a very mature technology, so highly accurate results are to be expected.

8) Determine computer floor area and support areas.

A.) Total. This is the total computer room floor area, whether occupied by equipment or not.
B.) Electrically Active IT Equipment Footprint. This space consists of computers and telecommunications equipment including communication frames, servers, rack-mounted equipment, DASD, and tapes.

9) Obtain raised floor and ceiling height

The distance from the top of the sub floor to the top of the raised floor, the thickness of the raised floor tile (height of plenum blocked by tile and frame) and the ceiling height above the floor containing the IT equipment should be recorded. These measurements are useful for characterizing the data center and getting an idea of the power density it can support. While taking the raised floor measurement, look around under the floor in a few places and note the extent to which the spaces, particularly the plenum spaces used to move air, are constricted by cabling, piping, and conduits. Such observations can be very valuable when identifying and troubleshooting based on benchmarking and should be collected in a single place – useful information formats can range from a three-ring binder section for small projects all the way up to a spreadsheet with fields to sort by system, area, noted digital pictures taken, locations of documentation, and other information, for larger multi-building projects.

10) Check CRACs, CRAHs, or AHUs for status

Status for these types of equipment means whether they are cooling, heating, humidifying, or dehumidifying. Determine the status of all units at approximately the same time and record. This activity should be repeated several times at different times of day during the benchmarking to look for abnormal operation. In particular, note the humidification operation of units serving the same space.

11) Check CRACs, CRAHs, or AHUs for control setpoints and deadbands

Check and record the temperature and humidity setpoints and deadbands (minimum and maximum numbers for both). These may be at the units (typical for CRACs and CRAHs) or the EMCS programming for AHUs. Also note:
1.) Whether the system can humidify (and if so how: steam or electric ultrasonic, infrared, boiling), and 2.) If there is reheat and whether it is electric, steam, or hot water.

12) Measure PDU electrical power loss

To determine electrical power losses in the Power Distribution Units (or equivalent distribution transformers in systems without PDUs), measure the input and output power at the same time. Some PDUs are equipped with internal meters to allow this, though they should be checked with portable meters to assess their accuracy. Note that kVA (or the product of voltage and current) is not a reliable substitute for kW. Design data can be substituted if there's no easy access for power measurements.

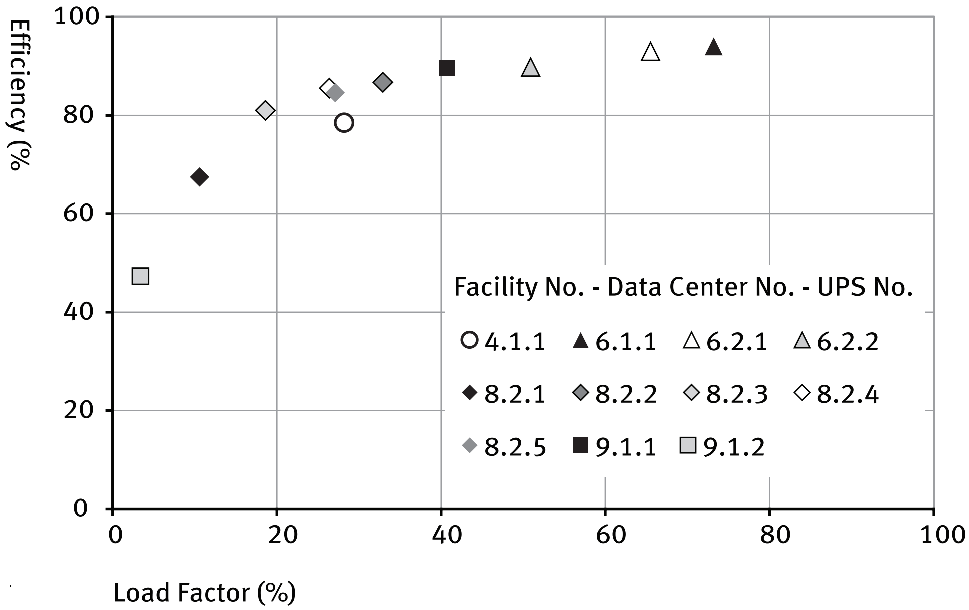


Figure 3: UPS efficiency at different benchmarked data center facilities.

13) Measure UPS electrical power loss

To determine electrical power losses in Uninterruptible Power Supplies, measure input and output power at the same time. Some UPSs are equipped with internal meters that display this, though they should be checked with portable meters to verify their accuracy. Note that kVA (or the product of voltage and current) is not a reliable substitute for true kW meters, which measure the sometimes significant impact of power factor on the total power used. Determine and record the input power and the rated maximum for the UPS and calculate the percent load factor by dividing the input load by the rated maximum. The load factor has a significant impact on the measured UPS efficiency. The graph in Figure 3 summarizes UPS efficiency at different benchmarked sites. The exact shape of the partload curve varies by manufacturer, but a drop at low load factors is a common characteristic of battery-based systems. Similar model-specific performance at part-load information should be available for all major UPS systems.

14) Measure Standby generator electrical power loss

Losses in standby generators include jacket heaters and battery chargers. Measure and log these electrical power loads and the ambient temperature at the generator(s). Also note the jacket water temperature setpoint and measure the temperature (one reading is adequate).

15) Measure Full data center IT equipment electrical power

In order to reduce the number of points required to determine the total IT equipment electrical load, use the most upstream feeders available and feasible to access, serving only IT equipment. If measured upstream of UPSs and PDUs, be sure to subtract off these losses in the data reduction phase (see #9). Typically, a single meter can be used to capture the power usage of many racks or even a whole (small) data center.

16) HVAC equipment measurement

A.) Chiller plant. The chiller plant includes the chiller(s), cooling tower(s), and pump(s). Sometimes it is easiest to monitor the entire motor control center feeding the chiller plant as one kW point, and any other loads on it can be monitored for subtraction (or, if constant, can be read with a one-time reading for subtraction). Pumps without VFD drives can be spot checked or trended for a short time and assumed to be constant power devices. The chiller and cooling tower systems tend to have high variations in load over time and should be trended. Variable speed pumps should also be trended.

In order to optimize the chiller plant, each component should be logged separately, as well as chilled water and condenser water supply and return temperatures and chilled water flow to allow for the determination of tons of cooling supplied. An accurate tonnage measurement requires highly accurate temperature and flow sensors. The difference between the supply and return temperatures (dT) is often 5-10 degrees, or less. Use of non-matched, typical temperature sensors that are only accurate to +/-1 could introduce an uncertainty of almost 50% into the dT measurement, rendering it useless. Flow can be determined by clamp-on ultrasonic or by an installed meter, which would allow for continuous monitoring. Care should be taken when selecting a flow meter for installation to select a unit with minimal chance of fouling and calibration drift.
Ideally, plant cooling load will be measured simultaneously with load in the data center.

Plant tonnage can be determined from the following equation (valid for lower temperature water, 40 – 100 F deg):

$$\text{Tons} = \frac{(\text{Return Temperature } ^\circ\text{F} - \text{Supply Temperature } ^\circ\text{F}) \times \text{Flow}}{24}$$

B.) CRAC/Direct expansion cooler measurement. Each air conditioning unit should be monitored for power use simultaneously with the equipment load in the room served. Monitor power usage of both the inside fan unit and the external compressor and condenser units. Where water cooled condenser systems that locate the compressor indoors with the supply fan (as opposed to an outdoor compressor/condenser unit) are used, note that it may not be feasible to isolate the fan power energy from the cooler energy.

C.) Air handling equipment. Aside from the temperatures and flows noted above, log the input power to this equipment. It can be done in aggregate if the electrical system configuration is suitable. Note that for most air cooled CRAC units, the interior unit power usage should be assigned to fan power.

D.) Boiler plant (where usage is non-negligible). The boiler plant includes the boiler(s) and pump(s). Log the input electrical power to these as well as the supply and return temperatures. Significant boiler plant usage generally indicates a lower efficiency isothermal humidification system (as opposed to an adiabatic evaporative system, similar in operation principle to the simple "swamp cooler").

17) Measure lighting power

For the lighting in the data center, measure and log the electrical power consumption. Often this can be done at a single lighting feeder. Make a note of any lighting controls present and their settings (approximate lumens setting, sensor sensitivity, or schedule).

7. Collect data and remove monitoring equipment

Using portable equipment, gather the one-time reads per the monitoring plan. Let the logging and trending run for at least a full week. "At the end of the week, download all trends for analysis. Collect data from any central control system trends in an appropriate format (ascii, comma delimited, .xls, etc) and store it with the stand-alone trending equipment data."

Using the same personnel and safety procedures, gather and record the data from the data loggers, EMCS, and SCADA system. Verify that the data are complete. Remove loggers, and let the facilities personnel know that they can stop trending the points that were set up for the study.

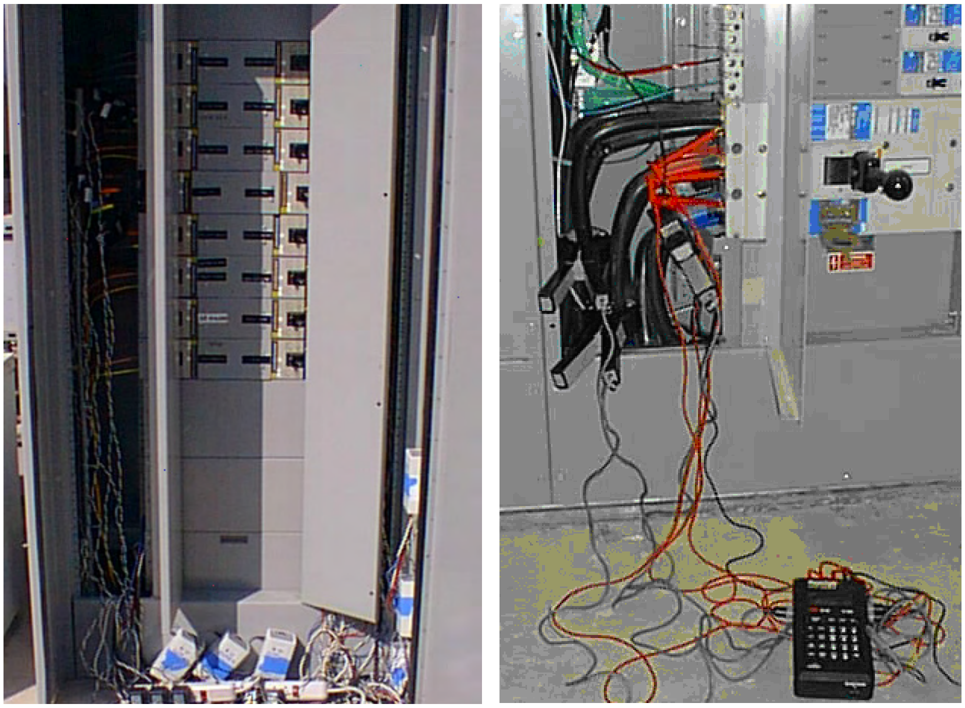


Figure 4: Two kinds of power meters deployed to trend panels (five circuits on right, one on left). Note: safety tape and barriers are not shown.

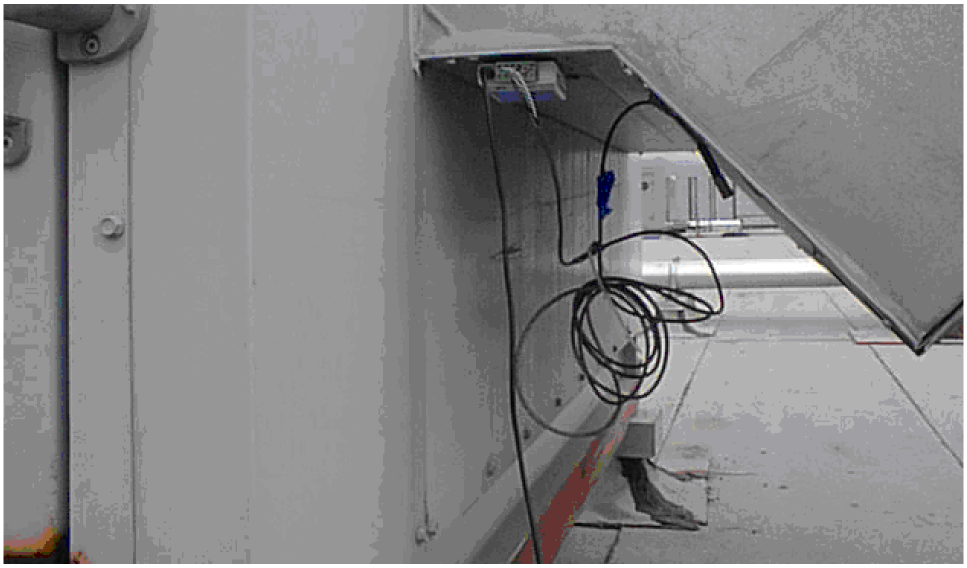


Figure 5: Outside air temperature and humidity logger and sensor deployed in shaded area under outside air intake hood (same sensor and logger can be deployed inside data center).

Figure 6: Ultrasonic 'strap-on' temporary flow meters

Figure 7: Water temperature sensor installed in test port ("Pete's plug") with logger; note masking tape on logger used to field note time of installation, removal time, sensor used and measurement point name.

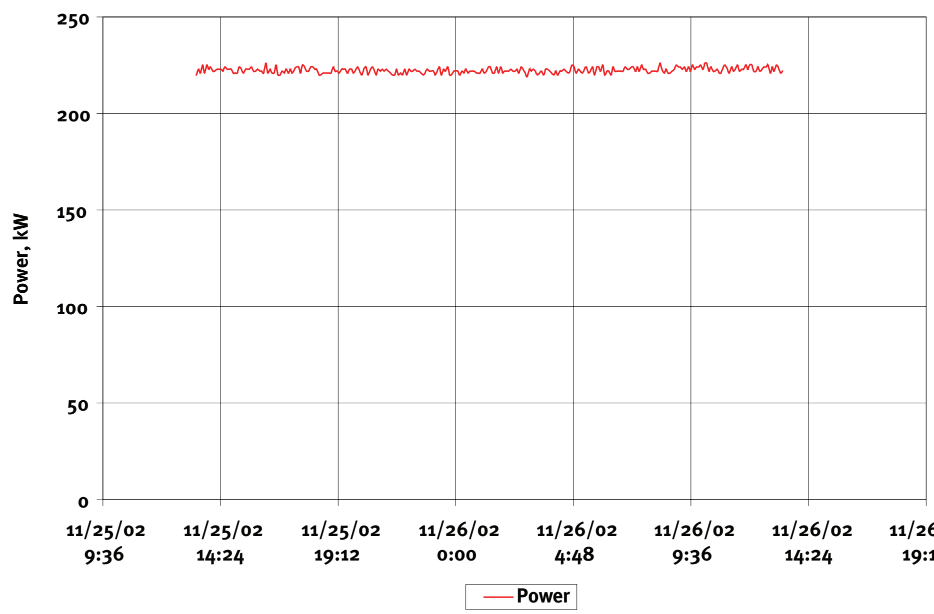
8. Analyze and reduce data

After a period of gathering data (defined in the plan), the monitoring equipment is removed, and the data are analyzed to create an end-use breakdown of the data center's energy use.

Using spreadsheets, convert the raw data collected into useful end-use data, consistent with the goals of the survey. Again, three very useful benchmarks are: 1.) The W/sf of IT equipment, 2.) The ratio of IT energy to HVAC energy, and 3.) The ratio of IT energy to total energy. Also commonly included are the cooling plant performance (e.g. overall kW/ton for the chillers, towers, and pumps) and an end-use breakdown for the data center, i.e. lighting, HVAC, IT equipment, and losses in the PDUs, UPSs, and standby generators. Other common benchmarks are listed in the Appendix.

Trends of data should be graphed for examination. In particular, check for rapidly cycling loads, fan operation or humidification/dehumidification operation. These are signs of poor control loop tuning or system sizing that can lead to premature equipment failure, poorer control resolution, and significant energy waste. The temperature trends in the computer room should be relatively flat, with the temperature at the intake of the computer the key control parameter: temperatures 'behind' the racks in the hot aisle do not impact the equipment and should be significantly higher than at the intakes. Essentially all of the trended data is most easily and valuably interpreted graphically: control signals to valves, cycling of compressors, fan speed, and power usage of racks.

Figure 8: Sample whole-facility data center load variation over 24 hours



After analyzing the benchmarking results, staff can meet to identify opportunities and determine appropriate next steps to correct problems found, immediately implement low or no-cost system improvements; and document any future design or IT equipment acquisition guidelines and optimization projects.

9. Compare findings to existing benchmarks

Once the data are reduced and the benchmark numbers determined, one can compare the benchmarks to those of other data centers, both within the company and for data centers previously studied. If the LBNL template was followed, comparisons to other benchmark data collected by LBNL is now possible. Any significant deviations from the normal comparison data should be investigated and identified. Significantly greater energy use usually indicates a very good opportunity for savings, while significantly lower energy use indicates a potential best practice approach that should be emulated in associated and future data centers. (A spreadsheet of basic benchmarking data for prior data centers available on the internet at http://hightech.lbl.gov/benchmarking_dc.html).

Beyond simply allowing the comparison of system efficiency, often operational problems are recognized. For example, the graph in Figure 9 suggests a control problem causing unnecessary compressor cycling - a reliability and efficiency concern.

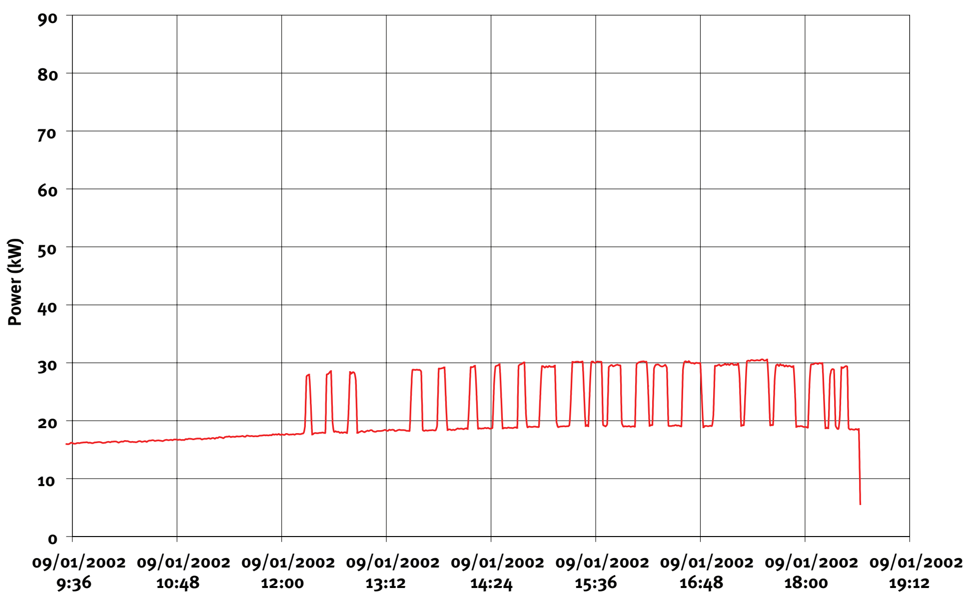
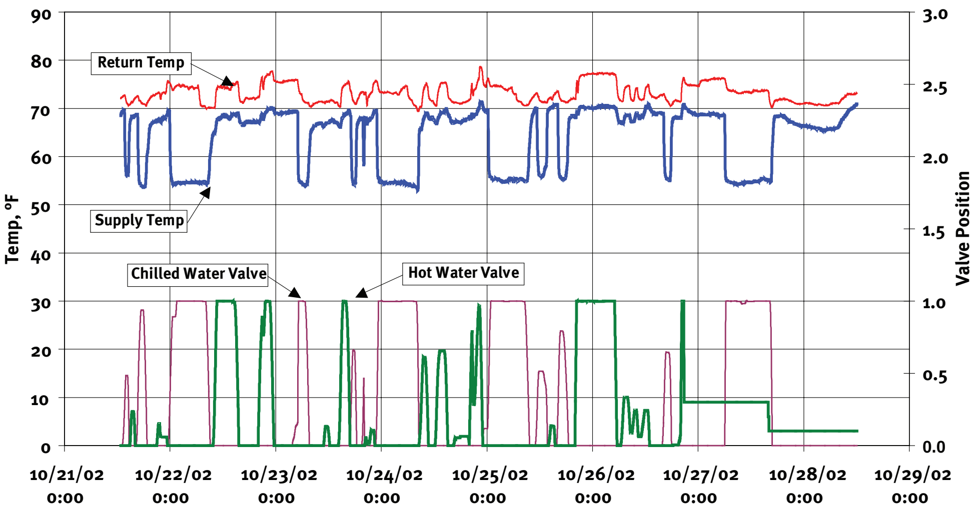


Figure 9: Facility A data center 1 Chiller 1 power

Air handler coil control loops often show control loops that have not been tuned for the specific conditions of datacenter use. The chart in Figure 10 shows the results of monitoring an air handler where the chilled water and hot water coil are cycling excessively considering the near-constant datacenter load they serve. Unstable control behavior from the systems serving a stable datacenter load are inefficient at best and instigators of equipment failure and/or loss of space control at worst.

Figure 10: Data Center Facility 5 AHU-2 Conditions



10. Compare data center to best practices

Several Design Guides based upon observed best practices have been prepared for Pacific Gas and Electric Company and are available through their Energy Design Resources website. Technologies include:

1) Air And Water-Side Economizers/Free Cooling
2) Cooling Source And Distribution Systems
3) Optimized Centralized Air Handling
4) Chiller Plant Optimization
5) Air Flow Management
6) Temperature Setpoints For Chilled Water And Supply Air
7) Humidity Controls
8) Evaporative Cooling
9) Reduced Losses In UPSs
10) On-Site Cogeneration
11) Efficient Lighting Sources And Controls
12) Reduced Losses In Standby Generators
13) Efficient Power Supplies And Power Distribution
14) Direct Liquid Cooling Of It Equipment Opportunities

11. Share results

Consider sharing your results, or an anonymous version of your report with the data center community. At the very least, anonymous contribution of measured benchmarks helps the benchmarking resource to continue to grow. Design best practices are continuously and incrementally improved as the quantity and quality of available data grows. Sharing of best practices helps innovative ideas come from a variety of sources, and helps energy efficient design standards and technologies to evolve.

Conclusion

Optimizing a complex system such as a data center in order to minimize operating costs and maximize capacity and reliability requires that its performance be measured. The benchmarking procedure described in this guide has shown a simple approach to making a detailed measurement of data center performance.

The snapshot of data center performance provided by the benchmarking procedure described here allows a facility's efficiency to be determined and compared against similar facilities on a system-by-system basis. Improved performance and cost savings can be realized by identifying and duplicating the most efficient systems and equipment in the future, and by correcting inefficient systems and equipment. Also, this procedure is intended to convey the sense of the data center as a whole system, rather than a collection of diverse pieces of equipment. Specific metrics and design strategies can contribute to as well as shape this whole system perception.

In the rapidly maturing data center field, benchmarking allows facilities operators to evolve beyond the crude rule-of-thumb design practice of "if its cool, its good enough" to optimize their systems for maximum reliability, minimum first costs and lower operating costs – all while maintaining a "Much-better-than-good-enough" critical environment.

Appendix A: Data Center Benchmarking Data Tables

The following data tables will guide the data collection process. Proxy data from design documents or testing results may be used for data points for which direct measurement is not possible.

All time series data for each site can be compiled into a single spreadsheet workbook. Trended data can be reported with in-service average, minimum, and maximum values.

I. Data Center Metrics

All metrics will be calculated using data collected below.

Description	Units
AHU Efficiency	KW/cfm
Annual Fuel Usage	MBtu/sf/yr
Annual Electricity Usage	kWh/sf/yr
Annual Energy Usage	Mbtu/sf/yr
Cooling Load Density	sf/ton
IT Equipment Power Density	W/sf
Lighting Power Density	W/sf

Data Center Data Points

Target	Units	Data Source (circle one)	Duration
Total Recirculation Fan (Total CRAC) Usage	kW	From electrical panels	Spot (trended where possible)
Total Make-Up Air Handler Usage	kW	From electrical panels	Spot
Total IT equipment Power Usage	kW	From electrical panels	Spot (trended where possible)
Chilled Water Plant (if chilled water plant is on same meter or in same building as data center that is being measured)	kW	From electrical panel or from chilled water plant measurements	1 week
Rack power usage, 1 typical	kW	From electrical panels	1 week
Number of racks	number	Observation	Spot
Rack power usage, average	kW	Calculated	N/A
Other Power Usage	kW	From electrical panels	Spot
Data Center Temperatures (Approx. 6, located to identify range of temperatures and air distribution issues)	Deg F	Temperature Sensor	1 week
Humidity Conditions	R.H.	Humidity Sensor	1 week
Annual Electricity Use, one year	kWh/yr	Utility bills	N/A
Annual Fuel Use, one year	Therm/yr	Utility bills	N/A
Annual Electricity Use, 3 prior years	kWh/yr	Utility bills	N/A
Annual Fuel Use, 3 prior years	Therm/yr	Utility bills	N/A
Peak Power	kW	Utility bills	N/A
Average Power Factor	%	Utility bills	N/A
Facility (Total Building) Area	sf	Drawings	N/A
Data center Area ("Electrically Active Floor Space")	sf	Drawings	N/A
Fraction of Data Center in use (Fullness factor; taking into account available floor space and available space within existing racks)	%	Area measurements and rack observations	Spot
Extrapolated IT equipment Power Usage for Fully Utilized Data Center	kW	Calculated	N/A

CRAC Metrics

All metrics will be calculated using data collected below.

Description	Units
Fan Efficiency	KW/CFM
Cooling Efficiency	KW/Ton
System ΔT (Return T - Supply T)	˚F

CRAC Unit Data Points

Measure a minimum of 3 sampling CRAC units or air handlers per data center.

Target	Units	Data Source	Duration
Air Flow	cfm	(Designed, TAB report)	N/A
Fan Power	kW	3Φ True Power	Spot
VFD Speed	Hz	VFD	Spot
Setpoint Temperature	Deg F	Control System	Spot
Return Air Temperature	Deg F	10k Thermistor	1 week
Supply Air Temperature	Deg F	10k Thermistor	1 week
RH Setpoint	RH	Control System	Spot
Supply RH	RH	RH Sensor	1 week
Return RH	RH	RH Sensor	1 week
Status (cooling, heating, humidifying, dehumidifying)	Misc.	Observation (trend if on-site monitoring in place)	Spot (One week trend if possible)
Cooling Load	Tons	Calculated	N/A

II. Chiller Metrics

All metrics will be calculated using data collected below.

Description	Units
Chiller Efficiency	kW/ton
Tower Efficiency	kW/ton
Condenser Water Pumps Efficiency	kW/ton
Chilled Water Pumps Efficiency	kW/ton
Total Chilled Water Plant Efficiency	kW/ton
Plant Efficiency While Free Cooling	kW/ton

Chiller Data Points

Target	Units	Data Source	Duration
Chiller Power	kW	3Φ True Power	1 week
Primary Chilled Water Pump Power	kW	3Φ True Power	Spot
Secondary Chilled Water Pump Power	kW	3Φ True Power	1 week
Chilled Water Supply Temperature	Deg F	10k Thermistor	1 week
Chilled Water Return Temperature	Deg F	10k Thermistor	1 week
Chilled Water Pump Head (ΔP)	Feet of head	Pressure Transducer or single gauge	Spot
Chilled Water Flow	gpm	Ultrasonic Flow	1 week
Cooling Tower Power	kW	3Φ True Power	1 week
Condenser Water Pump Head	Feet of head	Pressure Transducer or single gauge	Spot
Condenser Water Pump Power	kW	3Φ True Power	Spot
Condenser Water Supply Temperature	Deg F	10k Thermistor	1 week
Chiller Cooling Load	Tons	Calculated	N/A

Boiler Plant Metrics

All metrics will be calculated using data collected below.

Description	Units
Hot Water Pumping Efficiency	kW/MBtu

Boiler Plant Data Points

Target	Units	Data Source	Duration
Hot Water Supply Temperature	Deg F	10k Thermistor	1 week
Hot Water Return Temperature	Deg F	10k Thermistor	1 week
Hot Water Pumping Power	kW	3Φ True Power	Spot
Hot Water Flow	gpm	Ultrasonic Flow	1 week
Boiler Gas Input	CFH	From Gas Meter (if available)	1 week
Boiler Efficiency	%	Design	N/A
Total Gas Use	Therms	Calculated	N/A

III. Other Metrics

Description	Units
Standby Generator Losses	kW loss / kVA rating of generator
UPS Losses	kW loss/ kW Usage
Lighting	W/sf
Height of raised floor	inches

Utilities Data Points

Target	Units	Data Source	Duration
Backup generator(s) size(s)	kVA	Label Observation	N/A
Backup generator standby loss (heaters, chargers, fuel system, controls)	kW	Power Measurement	1 week
Backup generator ambient temp	Deg F	Temp Sensor	1 week
Backup generator heater setpoint	Deg F	Observation	Spot
Backup generator water jacket temperature	Deg F	Temp Sensor	1 week
Backup generator test consumption	Gallons of Diesel?	Site records or measured during a test	
UPS Load	kW	UPS Interface Panel	Spot
UPS Rating	kVA	Label observation	Spot
UPS Loss	kW	UPS interface panel or measurement	Spot
PDU Load	kW	PDU Interface Panel	Spot
PDU Rating	kVA	Label observation	Spot
PDU Loss	kW	PDU interface panel or measurement	Spot

Weather Data Points

Target	Units	Data Source	Duration
Outside Air Dry Bulb Temperature	Deg F	Temp/RH Sensor	1 week
Outside Air Wet Bulb Temperature	Deg F	Temp/RH Sensor	1 week

Appendix B: Checklists and Data Collection Forms

Sample Monitoring Setup Checklists

PowerSight Power Measurement

__ Verify that the three phases of current are approximately equal. Verify the three phases of voltage are approximately equal. A significant imbalance suggests a poor CT or voltage probe connection. A significant imbalance can also be a (generally undesirable) property of the electrical system (VFD, supply, etc.).

__ Verify monitoring recording is begun and will not end until after the desired time.

__ Verify monitoring mode is recording correct parameters (True Power) and is set to end when full (not 'overwrite when full' or 'continue until stopped').

__ Verify unit is plugged in and receiving outlet power for long trends (top LED).

Temperature and RH with Pace XR440 Pocket Logger

__ Verify channels are set to the correct sensor type

__ Verify the linear scale for the RH logging is set to values on the RH wire's tag.

__ Verify the channels are set on

__ Verify the channel names are correct. It is difficult to change these names and they are likely to appear in any graphs of the data included in the final report.

__ Verify monitoring recording is begun and will not end until after the desired time.

Elite Pro Power Logger

__ Verify white lead is (+) and black lead is (-).

__ Verify clock is synchronized with PC clock.

__ Verify "memory type" is set to linear.

__ Verify CT arrows are facing against the flow of current.

__ Verify white alligator clip is connected to a good ground.

__ Verify unit is plugged into outlet.

__ Verify unit is logging; LED will blink ~ once every 5 seconds.

__ Verify equipment is yielding reasonable data on a real time reading.

__ Verify unit is labeled with equipment ID, time, and panel #.

Generic Data Center Data Collection Form

Date: ____________

Team Member(s): ____________________________

Electric Panel No. & Designation	Category (Data Center Cooling, Office Conditioning, etc.)	Measured Watts (kW)	Power Factor	Voltage Va / Vb / Vc	Measured Amps Ia / Ib / Ic / (In)	Circuit Rating (Amp)	Notes