U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Case Study: Opportunities to Improve Energy Efficiency in Three Federal Data Centers

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

Prepared By Lawrence Berkeley National Laboratory

Rod Mahdavi, P.E. LEED AP

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Contacts

Rod Mahdavi
Lawrence Berkeley National Laboratory
1 Cyclotron Road
Berkeley, CA 94720
Phone: (510) 495-2259
E-mail: RMahdavi@lbl.gov

For more information on the Federal Energy Management Program, please contact:

William Lintner
Federal Energy Management Program
U.S. Department of Energy EE-2L
1000 Independence Ave., S.W.
Washington, D.C. 20585-0121
Phone: (202) 586-3120
E-mail: William.lintner@ee.doe.gov

Abbreviations and Acronyms

BMS	Building Management System
BTU	British Thermal Unit
CRAH	Control Room Air Handler
DC	Data Center
EEM	Energy Efficiency Measure
Genset	Standby Generator
GHG	Greenhouse gas
IT	Information Technology
kW	Kilowatt
LBNL	Lawrence Berkeley National Laboratory
MWh	Megawatt-hours
PDU	Protocol Data Unit
PUE	Power Usage Effectiveness
UPS	Uninterruptable Power Supply

Contents

Executive Summary 5

Introduction 6

Assessment Process 7

Observations 7

Analysis 9

Challenges 9

Energy Efficiency Measures for the Federal Data Centers 9

Forecasted Results 9

Lessons Learned 11

Next Steps and Recommendations 11

List of Figures

Figure 1. Power Usage in the Data Centers 6

Figure 2. DC1 Hot Aisle Containment 7

Figure 3. DC3 Openings in Racks Figure 4. DC3 PDU Open Skirts 8

Figure 5. Air Recirculation Under the Racks Figure 6. DC2 Lighting, and Perforated Tiles 8

Figure 7. Data Center EEMs 10

Figure 8. Power Usage Savings Based on Implementation of EEMs 11

Figure 9. Electricity Flows in Data Centers 12

List of Tables

Table 1. Data Centers Potential Energy, GHG, and Cost Savings 5

Table 2. Summary of Power, Losses, Current and Potential PUE 6

Executive Summary

Lawrence Berkeley National Laboratory (LBNL) evaluated three data centers for potential energy efficiency improvements during the summer of 2012. Geographic location, facility layouts, data center spatial configuration, Information Technology (IT) power supply and demands, mechanical, and electrical and cooling system equipment varied among the three sites. The data centers also contained a variety of new and old infrastructure support equipment; dynamic, growing IT platforms; and, thousands of computing, storage, and data transport servers and devices.

Table 1 illustrates the results of the three data center (DC) assessments, including potential energy savings, potential greenhouse gas (GHG) emission reductions, and average payback periods for completing recommended projects at each data center. Total estimated potential energy savings were 11,500 Megawatt-hours (MWh). This potential energy savings is equivalent to an annual GHG emission reduction of 10,800 tons. In addition to reduced fuel consumption and GHG reductions are annual energy cost savings of approximately $700,000. All of the referenced savings are attainable by implementing LBNL-identified energy efficiency measures (EEM). These measures have an average payback period of approximately 2 years.

LBNL's conclusion was that annual cost savings can be achieved by aligning IT rack units and equipment rows into hot and cold aisles. Containment of the hot aisle air flow will result in substantial reductions in cooling energy expenditures, as well as increased efficiency and lowered costs. In DC1, most of the hot aisles were contained. In DC3, high density racks were enclosed and hot air was exhausted through chimneys directly to the ceiling plenum. The most ubiquitous and significant findings involved increasing the data center supply air temperatures and increased use of a waterside economizer. Increasing the room temperature also reduces the need for cooling provided by computer room air handlers (CRAH), allowing many to be turned off. In addition, sufficient cooling could be provided with higher temperature-chilled water supply, thus reducing the number of hours of compressor-based cooling.

Site	Estimated Payback, Years	Estimated Annual Energy Saving, MWh	Estimated Annual GHG Emission Reduction, Ton	Estimated Cost Savings	Estimated EEMs Implementation Cost
DC1	1.9	3,300	3,000	$200,000	$380,000
DC2	2.4	1,900	1,800	$115,000	$276,000
DC3	2	6,300	6,000	$385,000	$770,000

Table 1. Data Centers Potential Energy, GHG, and Cost Savings

Introduction

The Office of Energy Efficiency and Renewable Energy tasked Lawrence Berkeley National Laboratory (LBNL) to provide measurements of energy usage, and total building energy consumption. LBNL also evaluated data center and IT systems and devices, and building systems that automate and regulate energy management and affect energy consumption. Included in the task was a request for recommendations to monitor and improve energy consumption, balance and optimize equipment, and to develop a plan to avoid energy and cost savings erosion over time. This case study includes the results of 3 data center assessments, lessons learned, and recommended EEMs. Table 2 identifies IT equipment power density, end-use power breakdown, and power usage effectiveness (PUE) for the 3 data centers during the evaluation period. The potential PUE as the result of implementation of the recommended energy efficiency measures is also illustrated.

Sites	Current IT Load W/ sqft	Current IT Load kW	Elec Dist. Loss kW	Cooling Load kW	Fan Load kW	Other Users kW	Total DC kW	Current PUE	Potential PUE
DC1	33	1,100	160	411	174	142	1,987	1.80	1.45
DC2	50	420	87	192	90	80	870	2.07	1.55
DC3	62	1,824	356	525	330	210	3,245	1.78	1.38

Table 2. Summary of Power, Losses, Current and Potential PUE

Figure 1 illustrates the power use relationships in the 3 data centers during the summer of 2012. DC1 consumes 33%, DC2 consumes 14%, and DC3 consumes 53% of the overall power consumed.

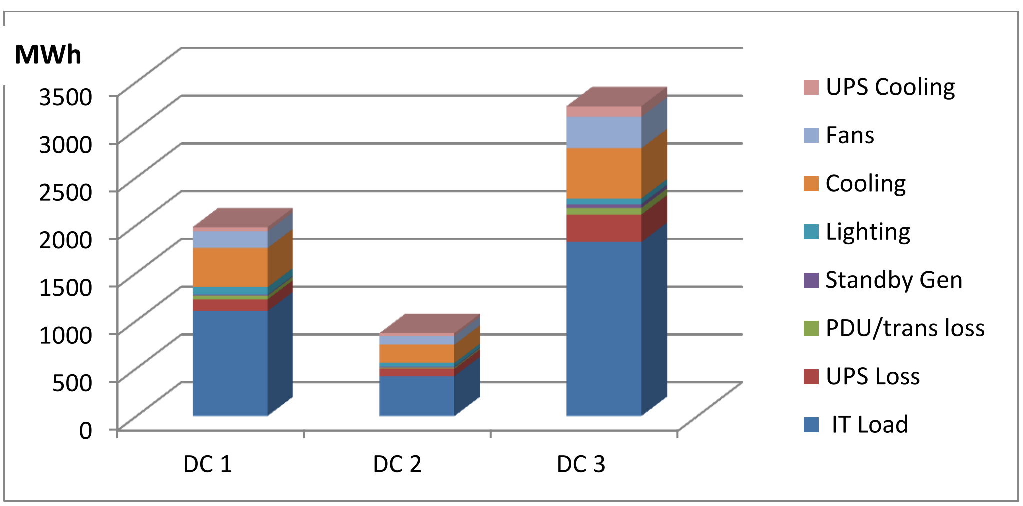

Figure 1. Power Usage in the Data Centers

Assessment Process

LBNL used a portable wireless monitoring kit to baseline the environmental conditions (temperature, humidity, airflow ranges) in the data centers. For those data centers where the monitoring kit was used, the following environmental sensors and points of measurement are described:

Temperature sensors were installed at all CRAHs air supply and return. No intrusive sampling of devices occurred inside racks. Exterior placements were made on the front of IT racks (top, middle, and bottom), on the back of the rack (top and middle), and in the sub-floor space. Humidity was also measured by the same thermal nodes. Pressure sensors were installed to measure sub-floor pressure. Power measurements were also obtained from equipment display such as switch gear, uninterruptable power supply units (UPS), and power distribution units. Power measurements were also taken from selected electrical panel locations using power logging devices. In some cases that a direct power measurement was not possible, power usage was conservatively estimated to calculate PUE. Loss in the electrical power chain was either measured or estimated while considering efficiency of the UPS units based on their load factor. Lighting power usage was calculated by counting the fixtures. Determining the cooling power measurement, including chiller power usage, was a challenge. Assessors used BTU and power meters. However, if direct power measurements or readings from the control panels were not available, then calculations based on theoretical plant efficiency were applied. While use of specifications for CRAHs with constant speed fans provided sufficient information, it was more advantageous to have building management system (BMS) log reports as was the case for DC3.

Observations

The data centers' stakeholders were concerned about high-energy use. In one DC2, the agency installed low cost hot aisle containment, and provided weekly manual logging of the temperatures on every rack. DC1 had some hot aisles contained, as illustrated in Figure 2. This data center also had a rack cooling system for higher power density racks. DC2 had two out of twelve CRAHs turned off.

Figure 2. DC1 Hot Aisle Containment

DC3 had installed a wireless monitoring system. This center also had two chilled water loops, with the warmer loop serving the CRAHs. In the same center, a water side economizer was installed. Unfortunately, the waterside economizer was not integrated into the chilled water loop, which minimizes its active hours. Efficiencies associated with air management included closing openings in the floor, between and within racks (Figure 3), and closing openings around the Protocol data unit (PDU) by applying solid skirts to stop the escape of cool air into the room (Figure 4).

Figure 3. DC3 Openings in Racks

Figure 4. DC3 PDU Open Skirts

When inefficient air flow issues were observed, recommendations were provided to optimize equipment use and to improve and balance air flow. Once these energy opportunities were identified, efficiencies were immediately gained by quick fixes such as re-arranging 98 floor tiles at one location. Hot air re-circulation through the bottom of the racks was another issue, as illustrated in Figure 5. In this case supply air from the perforated tile was 62^{o} F, though the depicted temperature sensor illustrates 75^{o} F just above the frame. Figure 6 illustrates excessive lighting in DC2. Tiles were installed in areas other than in front of the racks (cold aisle).

Figure 5. Air Recirculation Under the Racks

Figure 6. DC2 Lighting, and Perforated Tiles

Analysis

The collected data included empirical measurements of recirculation and by-pass air mixing, and cooling system efficiency. The assessment established the data center's baseline energy utilization, identified relevant EEMs and potential energy savings benefits. Operational procedures were also examined, actions were taken during the assessment, and their impacts observed in real time. For instance, in DC3, 35% of the CRAHs were turned off with no impact on the operations. No considerable change in IT equipment air intake temperatures were observed by turning off the CRAH units. Actual annual saving (associated with turning off the CRAHs) was 1,300 MWh or $75,000 annually.

Challenges

Site and data center observations occurred during a two-week period. The LBNL assessment team was initially challenged by security requirements and restricted site access. These challenges existed because LBNL assessors did not have appropriate security clearances. However, with the assistance of Site Security personnel, access was not a major impediment to evaluating infrastructure or the data center. Widespread cooperation and the use of security escorts resulted in dynamic understandings and daily progress. A second challenge involved the potential risk of disrupting mission critical activities. Eventually, working with the host and as a team these obstacles subsided.

Energy Efficiency Measures for the Federal Data Centers

Several EEMs were both common and applicable at each data center. These efficiency measures along with their rough cost estimates are described generally in Figure 7 (next page).

Estimated Savings for 3 data Centers

Figure 8 illustrates estimated power savings achievable in the 3 data centers if the recommended EEMs are fully implemented. The waterside economizer will have the most beneficial impact in DC1 and DC2 while fan power savings can be optimized in DC3. Although the total savings are proportional to the data center IT load or data center square feet, different levels of impact are associated with each specific EEM.

Improve UPS Load Factor

Offline UPS units by transferring its load to the online units thus increase load factor

Typical Cost of this package is $30-$70/kW of IT power. A typical payback is 1.9 years.

UPS Rooms Cooling and Genset Block Heater

- Minimize cooling by widening temperature range
- Minimize cooling and fan energy by running CRAH with VFDs
- Minimize energy use by standby generator block heater

Typical Cost of this package is $20-$40/kW of IT power. A typical simple payback is 2.5 years.

Full Lighting Retrofit

- Reposition light fixtures from above racks to above aisles
- Reduce lighting
- Install occupancy sensors to control fixtures, install multiple circuits for large areas

Typical Cost of this package is $2-$6/sf of data center. A typical payback is around 2.2 years.

Chilled Water Plant

Install/integrate waterside economizer

Typical Cost of this package is $130-$360/kW of IT power. A typical payback is 2.3 years.

Air Management Adjustment

- Seal all floor leaks including that from floor mounted electrical panels
- Rearrange the perforated floor tiles locating them only in cold aisles
- Contain hot air to avoid mixing with cold air as it was done in one center
- Utilize contained racks with exhaust chimneys as it was done in one of the centers
- Seal spaces between and within racks
- Raise the supply air temperature (SAT)
- Install variable frequency drives (VFD) for CRAHs fan and control fan speed by air plenum pressure
- Convert computer room air handler return air temperature control to rack inlet air temperature control
- Raise the chilled water supply temperature thus saving energy through better chiller efficiency

Typical Cost of this package is $80-$220/kW of IT power. A typical payback is around 2 years.

Figure 7. Data Center EEMs

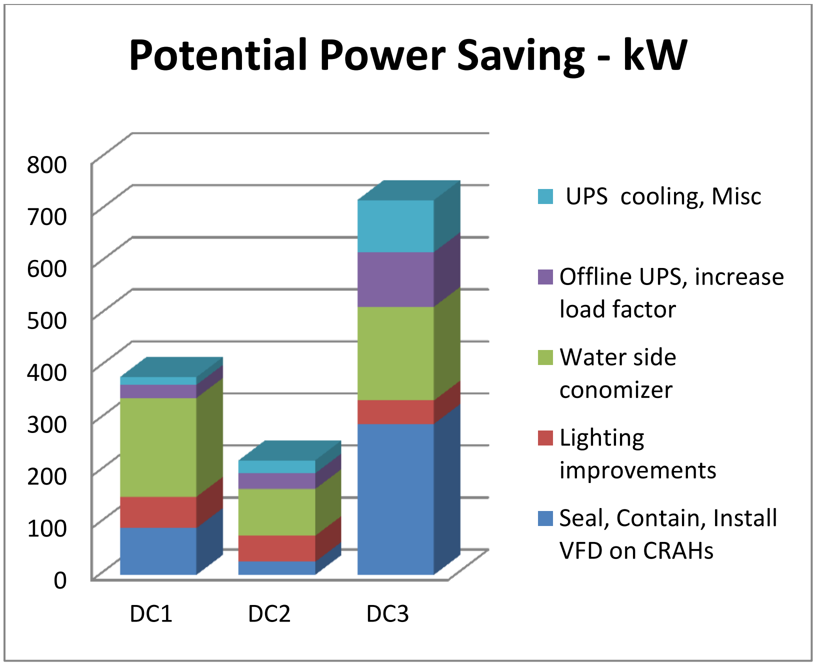

Figure 8. Power Usage Savings Based on Implementation of EEMs

Lessons Learned

- The main barrier for increasing the supply air temperature is the IT equipment maximum temperature limitations specified by the vendors.
- Rack unit monitoring enables real time temperature measurements at the server level allowing the implementation of EEMs without concerns for interrupting data center operations.
- Monitoring at the rack level yields real time visualization and enables corrective action if needed.
- Chilled water supply temperature set-point optimization can result in additional large energy savings.
- LBNL recommended against procurement of air-cooled chillers in lieu of water cooled chillers in DC1.

Next Steps and Recommendations

To implement the remaining EEMs, LBNL recommends that an investment-grade verification be performed, for a favorable return on investment, by a design/build contractor experienced in data center efficiency improvements. Opportunities exist in other spaces beyond data centers. Those can be combined with the data center EEMs to make a more attractive case for energy savings performance contracts. In addition, it is recommended that metering and monitoring systems be installed, along with a comprehensive dashboard to present the environmental data and the energy efficiency related data, including end use power breakdown by the various IT components, power chain, and infrastructure. Figure 9 illustrates the suggested metering location. Of course, multiple meters might be required for certain areas because of electrical distribution layout. The use of direct liquid cooling to the chip and application of increased temperatures (the upper side of ASHRAE Standard 90.9 (2011)) can lead to major reductions in energy use because of the higher energy carrying capacity found in liquids compared with air. This should be planned to future procurement of IT equipment.

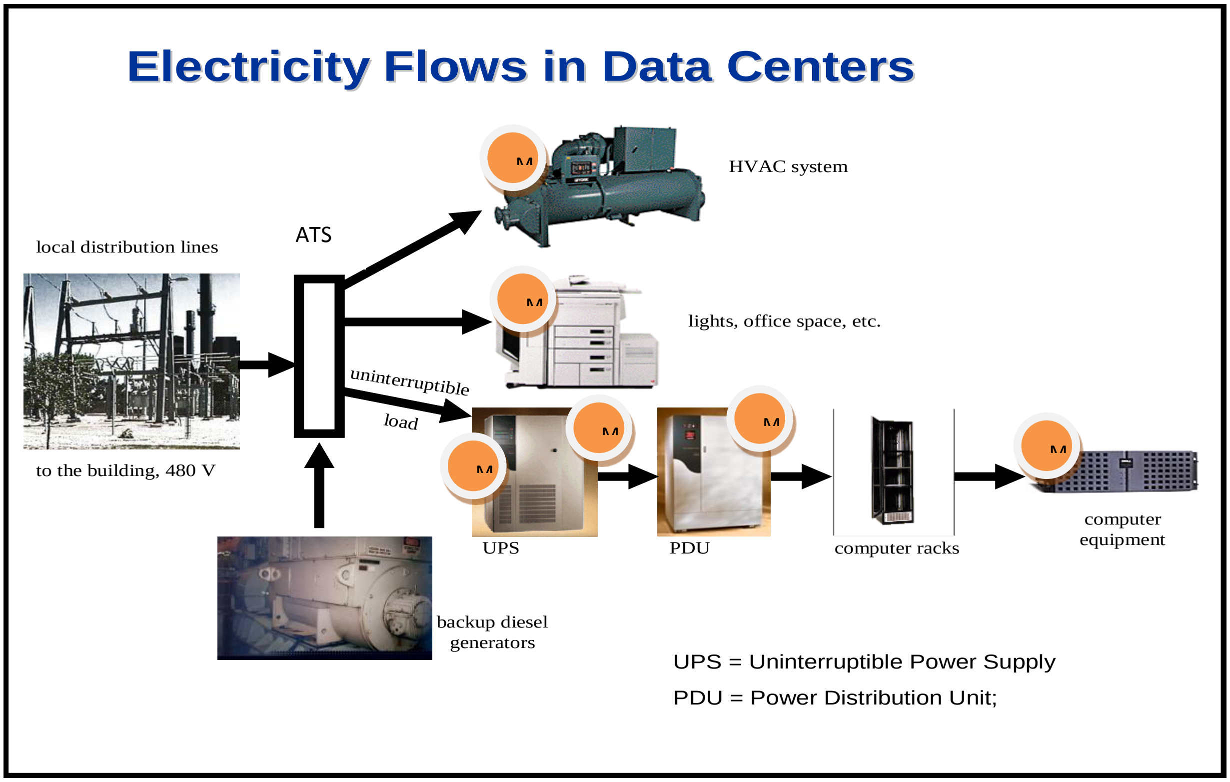

Figure 9. Electricity Flows in Data Centers

The dashboard will assist data center operators and facility managers to make real time changes and optimize energy efficiency. A dashboard is defined as a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single or multiple screens so the information relevant to each user can be observed at a glance. In other words, dashboard provides quick access to actionable visual data. The recommended dashboard:

- Displays the most important performance indicators and performance measures that are being monitored; these are usually user defined, user friendly and easy to understand.
- Displayed content includes different kinds of charts, measured or calculated numbers mostly presented in a graphical manner

- Provides information for all stakeholders.
- Supports interactivity – filtering, drilling down, or customizing screens to meet the needs of stakeholders.
- Stores data and generates reports on various aspects of energy, as needed or defined by the stakeholders.

LBNL also recommends that future purchases of IT equipment and cooling systems include a preference for water cooled systems. If air cooled systems are procured, at a minimum, the IT equipment should be capable of operating at more than a 90^0F supply air intake temperature (ASHRAE class A2). Regardless of cooling options, the servers should be powered at a high voltage (480V is preferred), and equipped with variable speed server fans controlled by the server core temperature. For new data centers use of direct current in lieu of alternate power is recommended since the power loss due to multiple conversions and inversions are avoided.

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