Title
Data Center Energy Benchmarking: Part 2 - Case Studies on Two Co-location Network Data Centers (No. 18 and 19)

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Final Report

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Final Report prepared by

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1 Executive Summary

Two data centers in this study were within a co-location facility located on the sixth floor of a multi-story building in downtown Los Angeles, California. The facility had 37,758 gross square feet floor area with 2-foot raised-floors in the data services area. The two data centers were designated as the west data center (DC #18) and the east data center (DC #19).

The study found that 56% of the overall electric power was consumed by sixth floor critical loads in both data centers, 33% of the power was consumed by HVAC systems, 3% of the power was consumed by UPS units, 3% of the power was for generator losses, and the remaining 5% was used by lighting and miscellaneous loads in the building.

The power density of installed computer loads (rack load) in the two data centers was 20 W/ft^2 and 56 W/ft^2, respectively. The power density was relatively lower in DC #18 compared to other data centers previously studied. In addition, HVAC to IT power demand ratio was 0.6 in DC #18 in this study, and was 0.4 in DC #19.

Two out of three chillers were running at a low partial load, making the operation very energy inefficient. The operation and control of the chillers and air-handling units should be optimized while providing sufficient cooling to the data centers. Although arranging hot aisle/cold aisle design to separate airflow streams would be difficult in such a co-location data center, optimizing air distribution should be pursued.

General recommendations for improving overall data center energy efficiency include improving the design, operation, and control of mechanical systems serving the data centers with various critical loads in place. This includes chiller operation, chilled water system, AHUs, airflow management and control in data centers. Additional specific recommendations or considerations to improve energy efficiency are provided in this report.

2 Review of Site Characteristics

Data Centers # 18 and #19 were located on the sixth floor in a multi-story building in Downtown Los Angeles, California. The data center facility had a total floor area of 37,758 gross square feet (ft^2) with 2-foot raised-floors in the data services area. The data centers were designed to provide co-location data services in areas that are environmentally controlled and monitored. The data center space on the sixth floor was divided into east and west sections, each conditioned by five separate air-handling units. The air-handling units(AHUs) were controlled in unison to cool their respective sections. Chilled water was produced by three 315-ton air-cooled chillers and distributed via primary and secondary pumping water systems.

Energy monitoring was performed during the time of the study conducted between October 27 and November 3, 2004, Data Center #18 (west section) and Data Center #19 (east section) were in operation. Both data centers operated 24 hours per day year-round. The users of the data centers had 24-hour full access to and from their caged spaces. Security requirement was very high. Electric power for both data centers was supplied through three 5,000A, 480V main buses, each with a 750 kVA uninterruptible power supply (UPS).

2.1 Electrical Equipment and Backup Power System

Data Centers # 18 and #19 were served by LA Department of Water and Power and had three main service drops of 5,000A, 480V, 3-phase power to each floor, as shown in Appendix B. Main meter monitoring was not permitted, but the load of the occupied floor was 1,300 kVA.

Each of the service drops fed power to three 750 kVA uninterruptible power supply (UPS) units, which in turn supplied power to the power distribution units (PDUs) feeding the computer racks. There were separate power feeds and generator backup for lighting and HVAC panels. Each power distribution unit was supplied by two UPS feeds. The UPS units were originally designed to operate at 33% capacity but operated at 25% capacity at the time of this study.

2.2 Mechanical System

2.2.1 Chillers

Three Technical System air-cooled chillers (Model # 30A0TSM400) with a cooling capacity of 315-tons each are located on the building roof. The three chillers were designated as CH-1, CH-2 and CH-3. Each chiller had four variable capacity screw compressors. Unloading from 25% to 100% of compressor capacity was via internal slide valves. The chillers had condenser fan staging head pressure control for low ambient conditions down to 20°F. The chillers were sized such that one unit operating at 75% capacity could condition one floor but for normal operation of the plant two chillers were typically operating at partial load. At the time of survey chillers CH-1 and CH-2 were operating, CH-3 was a redundant unit.

2.2.2 Primary Chilled Water Pumps

Primary chilled water was circulated by two centrifugal Bell & Gossett pumps. The primary pumps were identified as (P1P and P2P). Each pump had a motor capacity of 25 HP and a design volume flow rate of 1,040 GPM. Only one primary pump was running at the time of this study. According to the on-site gauges, the primary pump had a discharge pressure of 55 psig and suction pressure of 36 psig with 19 psi of differential pressure.

2.2.3 Secondary Chilled Water Pumps

At the time of the study, secondary chilled water was supplied to the building by two parallel centrifugal pumps rated 40-HP. The pumps were identified as (P1S and P2S) Bell & Gossett fitted with variable speed drives. The pumps variable speed drives were controlled by return water temperature through the building EMCS.

2.2.4 Air Handling Units

The 6th floor space was divided into east (DC #19) and west (DC #18) sections. The east section (DC #19) was more heavily loaded with critical load at the time of the study. Each section was served by five Carrier central station air handling units (Model 39T) that supplied air to ceiling diffusers located above aisles separating the racks. There was no provision of outside air supply nor supply air humidification. There were four reserve air-handling units, as shown in Appendix B.

Each of the air-handling units had a sensible cooling capacity of 600 MBH and was capable of supplying 30,000 cubic feet per minute (ft^3/m). Each air-handling unit included 2” throwaway filters rated at 85% filtration efficiency, a chilled-water cooling coil, and a 30-hp supply-fan motor with a variable speed drive. The five air-handling units were controlled in unison for each section (east and west, respectively). The supply-air fan speed in the air-handling unit was controlled to maintain the static air pressure in the duct. The static pressure was one- to two-inch water columns (or 250-500 Pascal).

The air humidity ranged between 25%RH and 65%RH in both data centers. In the east section (DC #19), the supply air temperature averaged 60°F with 62%RH, while the return air averaged 67°F and 48% RH. In the west section (DC #18), the supply air temperatures averaged 68°F, while the return air averaged 70°F and 44%RH.

3 Electric Power Consumption Characteristics

The following table summarizes the power consumption measured at the facility during this study.

Table 1A. End-Use of Electricity of the Data Center Building

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft^2)	Electric power density (W/ft^2)
Overall Building Load	**1000**	**100%**	**37,758**	**25.6**
Data Center 6th Floor Overall Load Data	**564**	**56%**	**14,850**	**37.9**
6th Fl Critical Load PDU 1	197	20%	14,850	13.3
6th Fl Critical Load PDU 2	162	16%	14,850	10.9
6th Fl Critical Load PDU 3	205	21%	14,850	13.8
HVAC Systems	**331**	**33%**	**14,850**	**22.3**
Air Handlers AHU 1-10	65	7%	14,850	4.4
Pumps P2P and P2S	25	3%	14,850	1.7
Chillers	241	24%	14,850	16.2
Generator Losses	**26**	**3%**	**37,758**	**0.7**
Lighting	**45**	**5%**	**37,758**	**1.2**
UPS Losses	**34**	**3%**	**14,850**	**2.3**

A total building power demand of 1,000 kW was recorded from building instruments. The reading resulted in a power factor of approximately 0.76, suggesting that power factor correction was warranted. From these measurements, 56% of the overall electric power was consumed by sixth floor critical loads in both data centers, 33% of the power was consumed by HVAC systems, 3% of the power was consumed by UPS units, 3% of the power was for generator losses, and the remaining 5% was created by lighting and miscellaneous loads in the building.

The end-use breakdown for both data centers' electric power demand is shown in Table 1B. For both data centers combined, 65% of the overall electric power was the rack critical loads, 28% of the power was consumed by HVAC systems, 4% of the power was consumed by UPS units, 1% of the power was for generator losses, and the remaining 2% was for data center lighting.

Table 1B. End-Use of Electricity of the two Data Centers Only

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft^2)	Electric power density (W/ft^2)
Data Center Rack Power	**564**	**65%**	**14850**	**38**
6 Floor- PDU - 1	197	23%	14850	13.3
6 Floor- PDU - 2	162	19%	14850	10.9
6 Floor- PDU - 3	205	24%	14850	13.8
HVAC Systems	**246**	**28%**	**14850**	**16.6**
Air Handlers	65	7%	14850	4.4
Pumps P2P, P2S	17	2%	14850	1.1
Chillers	164	19%	14850	11
Generator Losses	**10**	**1%**	**14850**	**0.7**
Data Center Lighting	**17**	**2%**	**14850**	**1.2**
UPS Losses	**34**	**4%**	**14850**	**2.3**
Total Data Center (only)	**871**	**100%**	**14850**	**58.7**

The following explains how the energy use was estimated for each data center, individually. Using the frequency of the VFD for each center (44.3 HZ for the east side and 54.6 HZ for the west side), we estimated the airflow circulation, based on fan laws. Knowing the entering and leaving air conditions to the cooling coils allowed an estimate of the cooling load for each individual center. From the cooling load in each center, and the respective energy use of the chiller (1.05 kW/ton), we estimated the chiller electrical load for each individual center. The electrical load for the pumps, generator losses, UPS losses, and PDUs were proportioned according to rack load.

Power demand break-down for each data center is shown in Table 2 and Table 3, respectively. The density of installed computer loads (rack load) in DC#18 and DC#19 was 20 W/ft^{2}and 56 W/ft^2, respectively. The ratios of HVAC to IT power demand in each of the data centers in this study were approximately 0.6 in DC #18 and 0.4 in DC #19.

Table 2. End-Use of Electricity of Data Center 18

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft^2)	Electric power density (W/ft^2)
Data Center Rack Power	148	59%	7425	20
HVAC Systems	82	33%	7425	11
Generator Losses	3	1%	7425	0.4
Data Center Lighting	9	3%	7425	1.1
UPS Losses	9	4%	7425	1.2
Total Data Center 18 (only)	250	100%	7425	33.7

Table 3. End-Use of Electricity of Data Center 19

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft^2)	Electric power density (W/ft^2)
Data Center Rack Power	416	67%	7425	56
HVAC Systems	164	26%	7425	22.1
Generator Losses	7	1%	7425	1
Data Center Lighting	9	1%	7425	1.1
UPS Losses	25	4%	7425	3.4
Total Data Center 19 (only)	621	100%	7425	83.6

An estimate of "rack-cooling load" was calculated based upon the data center critical power load, assuming 100% of the critical power becomes cooling load. For example, using the critical power of 148 kW and 416 kW in each data center, the rack-cooling loads of the data centers #18 and #19 would be approximately 42 tons and 118 tons, respectively.

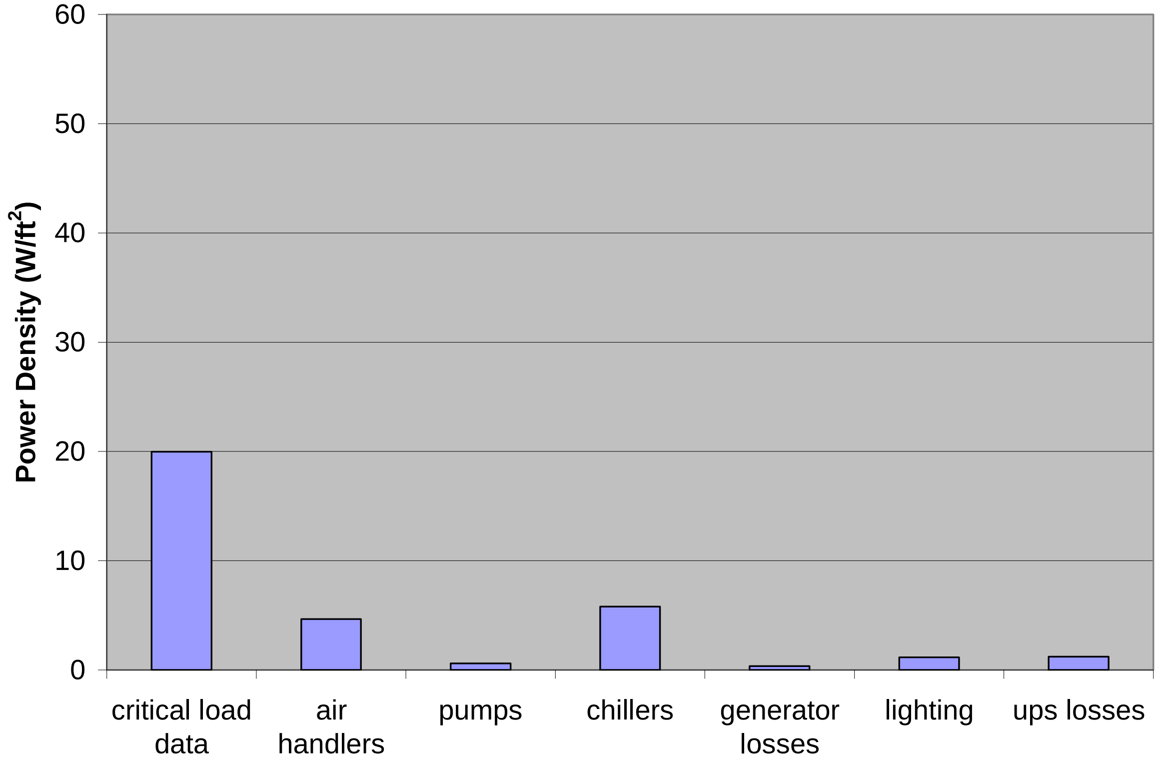

Figure 1. Data Center 18 Power Density

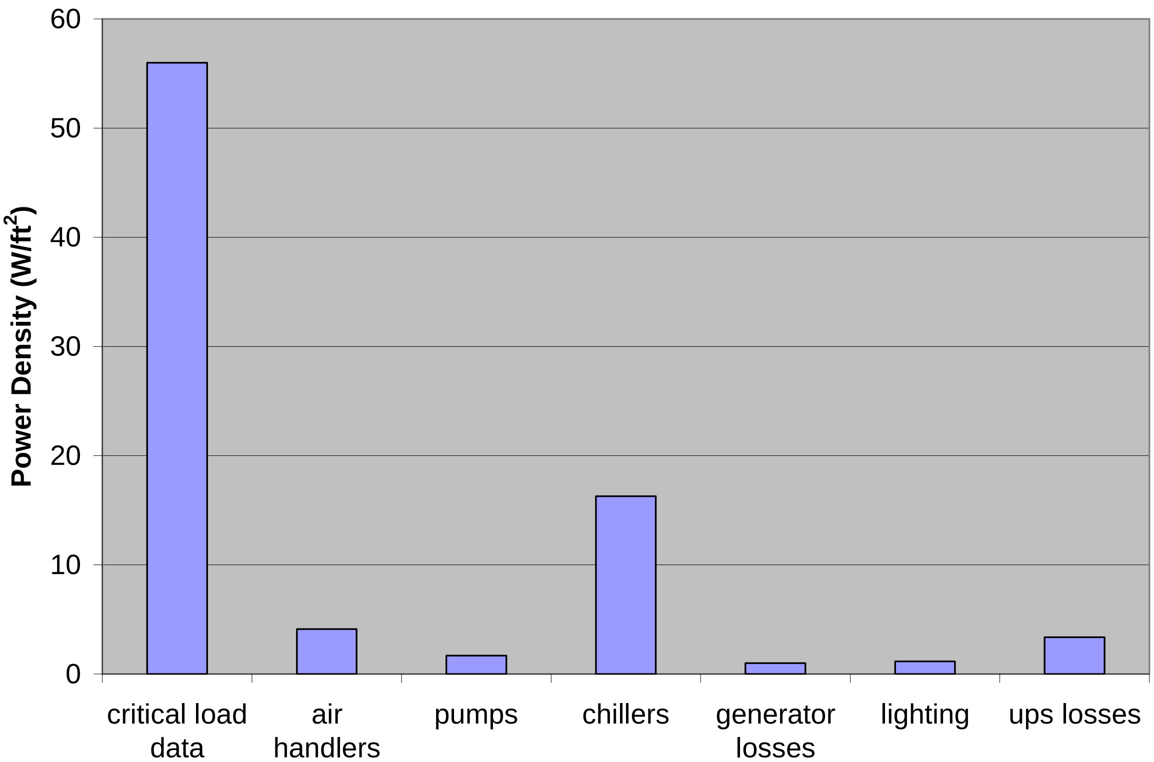

Figure 2. Data Center 19 Power Density

Figures 1&2 show the power density of various components in the facility, including critical power loads, essential mechanical loads, losses from UPS' serving the 6th floor data centers.

3.1 PDU System

Critical electrical power to both data centers on 6th floor was distributed to 12 PDUs fed by UPS 1, UPS 2 and UPS 3.

3.2 Emergency Generators

The three emergency generators had average standby losses of 26 kW during the monitoring period. Emergency generator losses included jacket heat, battery chargers, transformer switches, fuel management system and control.

4 Mechanical System

During the one-week monitoring period, the following HVAC equipment was operating:

- Two Chillers
- Primary chilled water pump P2P, constant speed

- Secondary chilled water pump P2S, on variable speed drive (VSD)
- All ten air handling units (AHUs) with variable speed drives (VSDs): AHU (1-5) west section (DC#18) and AHU (6-10) east section (DC #19).

4.1 Chiller System

Figure 3 shows electric power demand monitored on the two operating chillers for a one week period (October 27 to November 3, 2004). The low chiller power usage around October 28 was the result of alternating operation among the three chillers.

Using the average water temperature rise and the chilled water flow rate, the calculated cooling tonnage was ($Q_{cooling} = \rho GPM C_p \Delta T*60/12000$, in ton). Based on the measured temperatures rise of 7.7°F and averaged water flow rate of 735 GPM, assuming water density ρ of 8.32 lb/gal, the estimated total cooling produced by the chillers was within approximately 235 cooling tons. This was approximately 37 % of the designed cooling capacity of the two chiller at full design load. The portion of actual cooling required for data center rack load was approximately 68% of one chiller.

Chillers' CH-1 and CH-2 power consumption averaged 96 kW and 146 kW respectively during the monitoring period. Therefore, the actual chiller operating efficiency was calculated as approximately 1.0 kW/Ton for the two operating chillers recorded during the monitoring period.

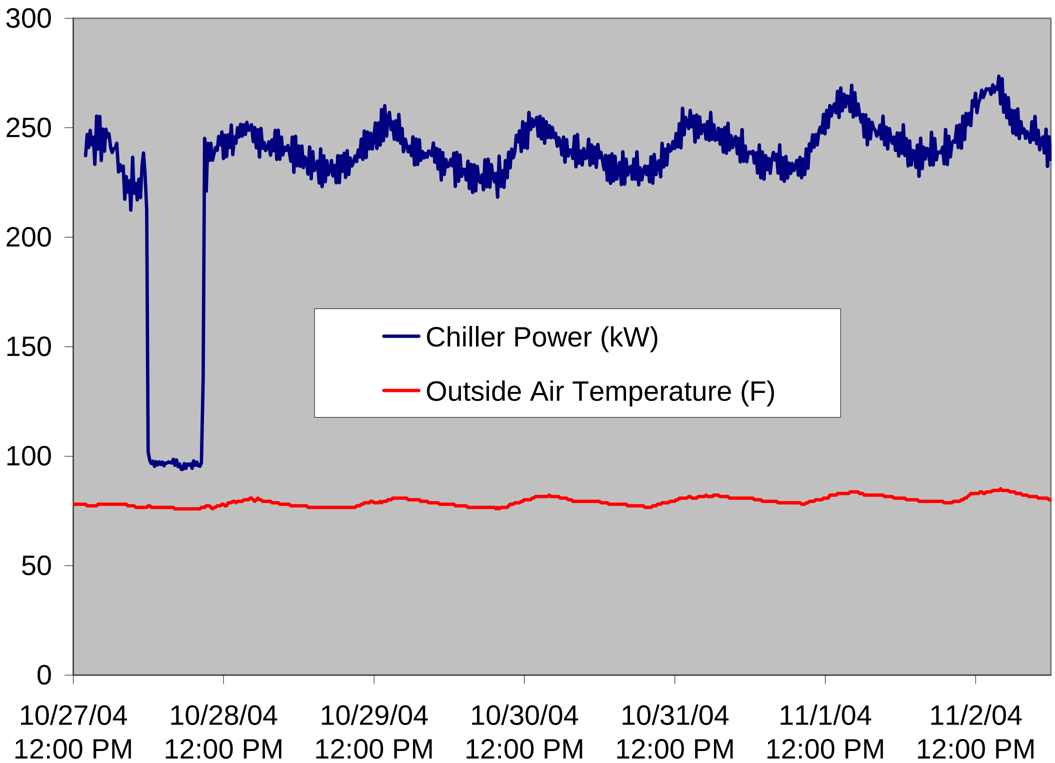

Figure 3. Chiller power demand and outdoor temperature

4.2 Pumping System

Primary chilled water pump P2P and secondary chilled water pump P2S were in operation during the monitoring period. The primary chilled water pump P2P was a constant speed 25-hp pump, and the secondary P2S was a 40-hp pump fitted with a variable speed drive (VSD). The average power consumption for the primary pump (P2P) was 16 kW, while the secondary pump (P2S) was 9 kW. The power consumption for both pumps is shown on Figure 4.

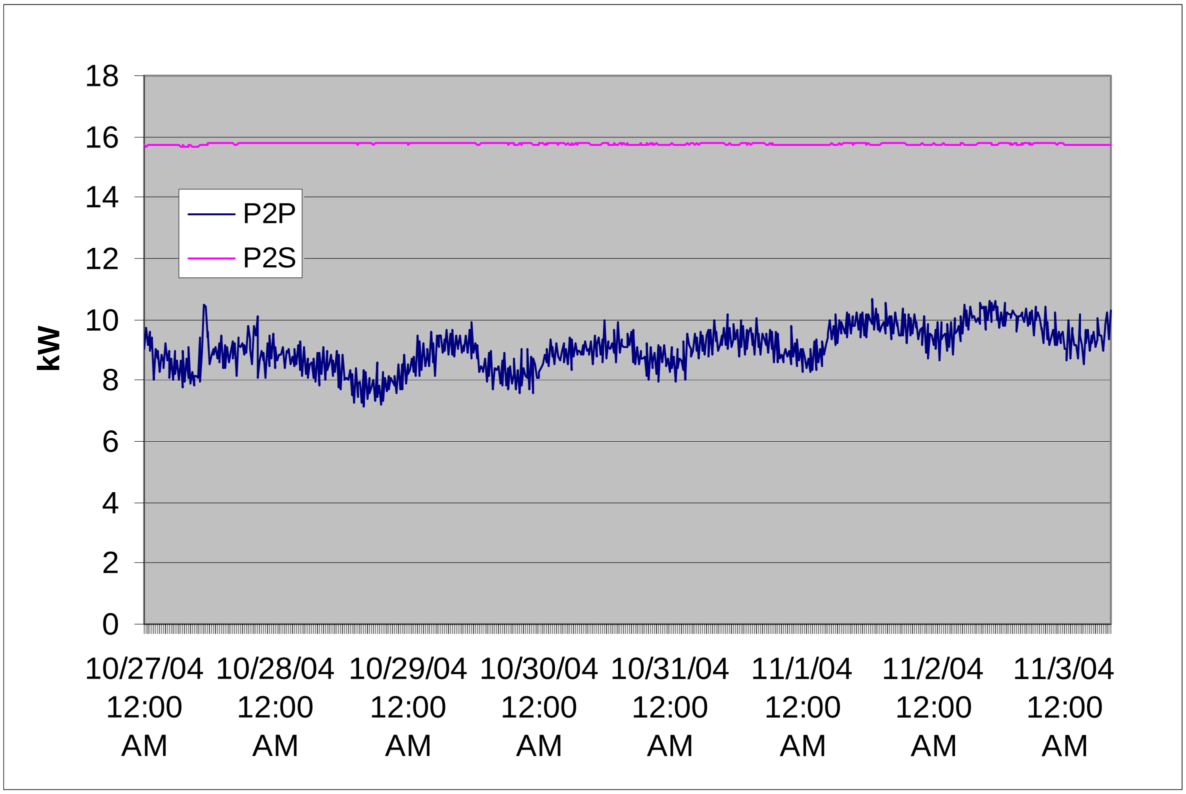

Figure 4. Power Demand for Chilled Water Pumps

4.3 AHU System

The five AHUs (AHU 1-5) serving the west side of the floor (DC #18) were controlled in unison. They were independent from the other five AHUs (AHU 6-10) that were also controlled in unison to serve the east side of the floor (DC #19).

At the time of the survey, EMS printouts of AHU motor operating frequency showed that the west side air handlers were operating at an average of 55 Hz, while the east side air handlers were operating at an average of 44 Hz. AHU 2 served the west side of the 6^{th} floor, and had average power demand of 7 kW with large fluctuations, suggesting a need for tuning the control loop. AHU 10 served the east side of the 6^{th} floor, and had average power demand of 6 kW with little variation.

5 System Operation

5.1 Chilled Water Flow

The total secondary chilled water flow rate was monitored and the results are shown in Figure 5. For the monitoring period, the average flow rate was 735 GPM.

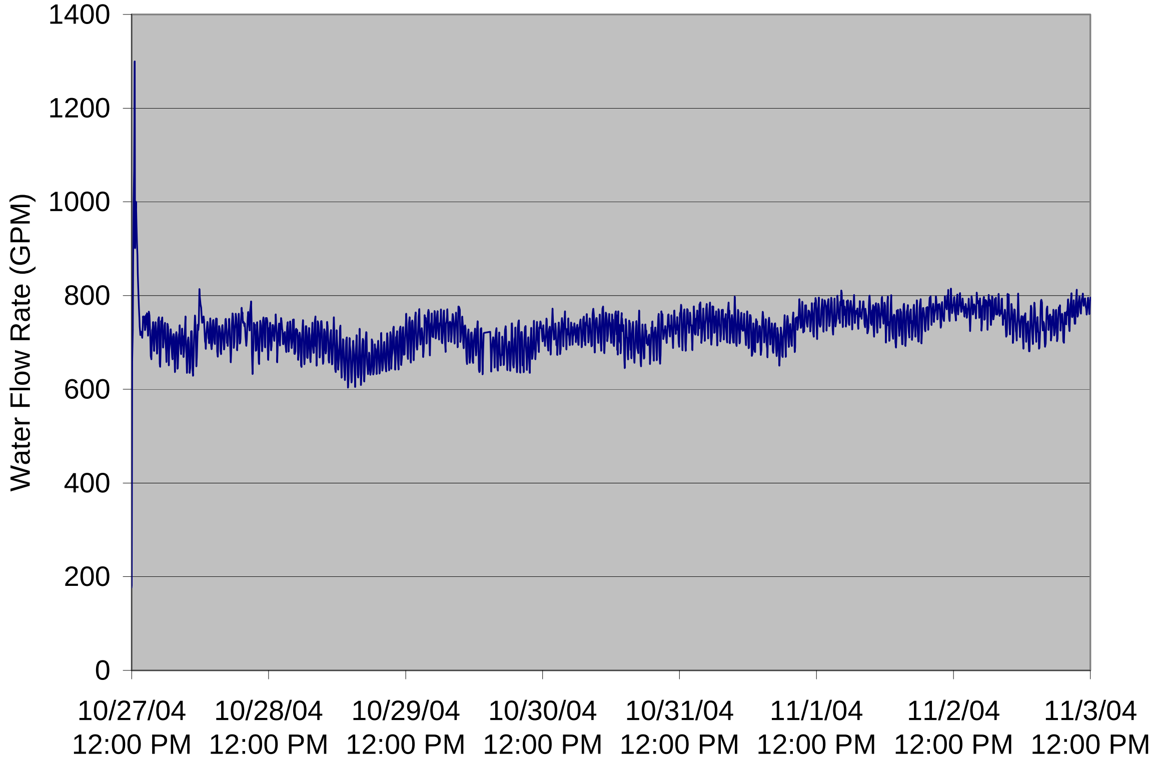

Figure 5 Chilled Water Flow Rate

5.2 Chilled Water Supply and Return Temperatures

The chilled water supply and return temperatures were monitored in the study. For the monitoring period, the average chilled water supply temperature was 44°F, while the average chilled water return temperature was 52°F. The chilled water temperature was controlled by chilled water return temperature set point. This produced an average temperature differential of 7.7°F and an average cooling capacity of 235 tons.

5.3 Air Handler Unit Supply and Return Air

Temperatures and relative humidity for the east and west supply and return air plenums were monitored for a week. In DC #18, average supply and return air temperatures were 68°F and 70°F, respectively. The temperature differential was only 2°F for the period. In DC #19, average supply and return air temperatures were 60°F and 67°F, respectively. The temperature differential was 7°F. The AHU power demand for DC #18 was higher than that for DC #19. This indicates that there was noticeable deficiency in cooling effectiveness induced by operating AHUs for DC #18. Therefore, control of the five AHUs for DC # 18 should be optimized to reduce the power demand for operating the units.

5.4 Generator Jacket Ambient Temperatures

The generator jacket ambient temperatures for Generators 1 and 2 were monitored, as shown in Figure 6. The average ambient temperature was 78°F for generator 1 and 79°F for generator 2.

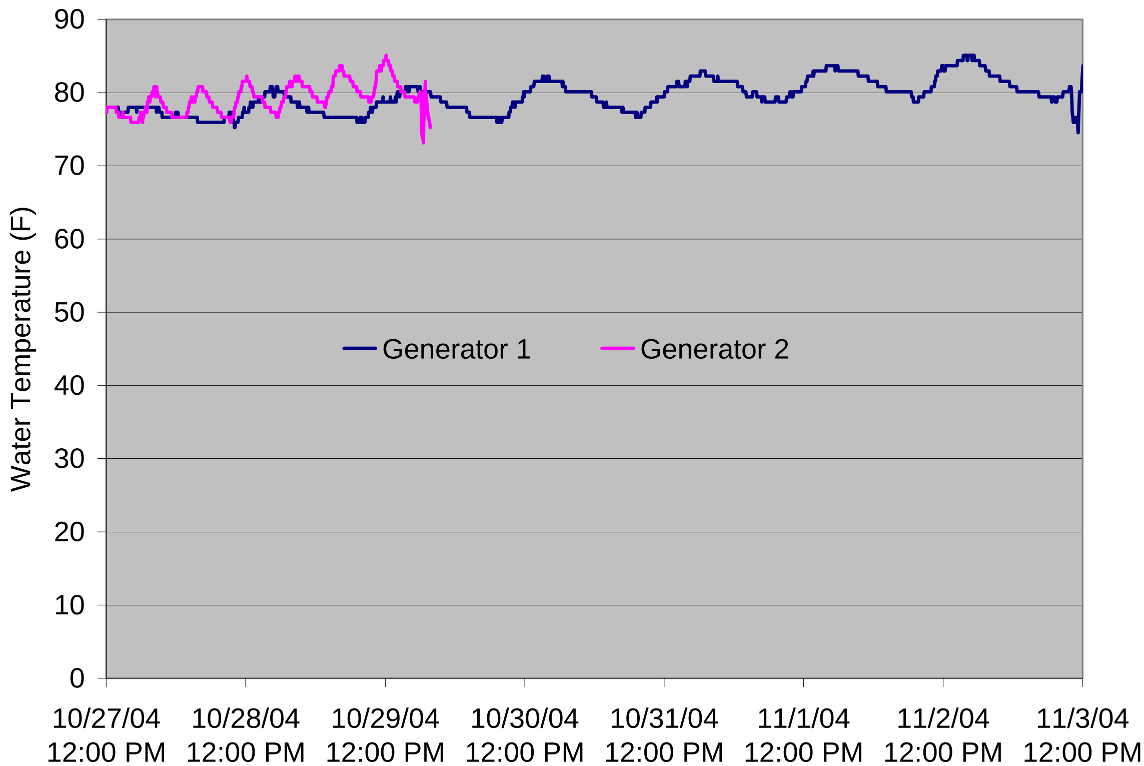

Figure 6 Generator Ambient Temperatures

6 Recommendations

The density of installed computer loads (rack load) in the two data center was 20 and 56 W/ft^2 for DC #18 and DC #19, respectively. The power density of IT equipment in DC #18 was relatively lower compared to other data centers previously studied. In addition, with an HVAC to IT power demand ratio of 0.6 in DC #18 in this study, actual mechanical systems serving the critical load in DC #18 seemed to be oversized and operating less efficiently.

Both chillers were running at a low partial load, making the operation very energy inefficient. Therefore, the operation and control of the chillers and AHUs should be optimized while providing sufficient cooling to the data center. Although arranging hot aisle/cold aisle design to separate airflow streams would be difficult in such a co-location data center, optimizing air distribution should be pursued.

General recommendations for improving overall data center energy efficiency include improving the design, operation, and control of mechanical systems serving the data centers in actual operation. This includes chiller operation, chilled water system, AHUs, airflow management and control in data centers. Additional specific recommendations or considerations are provided in the following.

6.1 Chilled Water System

Consideration should be given towards resetting the chilled water supply temperature to a higher set point. Lower chilled water supply temperatures may lead to dehumidifying the space air, thus requiring additional re-humidification which would cause energy penalty and yet the existing system does not provide humidification. For example, setting the chilled water supply temperature to 50°F or higher may still provide sufficient sensible cooling in the data center. In the meanwhile, chiller energy consumption would be reduced due to improved thermal efficiency. This measure can be implemented in steps, raising the temperature set point by 2°F at a time, while verifying that no hot spots in critical locations. During these steps, the secondary chilled water pump and air handling unit fan speeds should be monitored, while ensuring that chiller energy savings are not offset by greater energy usage of these mechanical components.

Employing evaporative pre-coolers for the air-cooled chiller condensers may significantly increase chiller efficiency, especially at peak conditions. Resetting secondary chilled water pump speed based on AHU valve positions, keeping one valve 90% open may save energy.

Integrating VSD device and operation in chilled water systems can improve the efficiency. This would be more useful, especially when the future cooling load increases. In addition, optimizing water temperature differential and pump head required would collectively contribute to minimizing total power demand for water systems.

6.2 Air System

Optimize the control of supply and/or return air temperatures and airflow rate from the AHUs, and air distribution.

Optimize air distribution through carefully placing perforated tiles, cable pass-through, and equipment layout. The benefits include achieving greater cooling effectiveness. The temperature difference of supply and return air in DC # 18 was 2°F, indicating a rather low cooling load in this zone.

Recommendation should be given to significantly reduce supply airflow rate of the five air-handling units, while optimizing air distribution within the operating data center space. For example, turn off some AHUs and control airflow rates using VFDs. The possibility of providing more efficient air flow within the tenant spaces, through the use of hot aisle/cold aisle arrangement of computer racks, is limited by the architecture of the tenant cages and the desire to allow these tenants flexibility of use within their own spaces.

6.3 Lighting

The on-site Energy control measures should be considered to reduce lighting load in the data center, this measures should include: Installing lighting zones occupancy sensors; and adding task lighting in appropriate areas and disabling portions of overhead lights.

6.4 Metering and Power Conditioning Equipment

EMCS sensors should be checked and calibrated to provide more accurate readings and monitoring. This includes temperature, pressure, humidity, and power sensors. For example, the reading of power input to PDUs from EMCS was lower than the output power. It's necessary to calibrate the power metering device. In addition, power factor correction device should be provided to improve the accuracy of existing power factor output.

7 Acknowledgements

This report on data center energy benchmarking was finalized based upon the field data collection performed by EYP Mission Critical Facilities and Landsberg Engineering and the draft report produced in the course of performing work subcontracted for the Lawrence Berkeley National Laboratory (LBNL).

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8 Appendix A: Data Facility Definitions and Metrics

The following definitions and metrics are used to characterize data centers:

Air Flow Density	The air flow (cfm) in a given area (sf).
Air Handler Efficiency 1	The air flow (cfm) per power used (kW) by the CRAC unit fan.
Air Handler Efficiency 2	The power used (kW), per ton of cooling achieved by the air-handling unit.
Chiller Efficiency	The power used (kW), per ton of cooling produced by the chiller.
Computer Load Density – Rack Footprint	Measured Data Center Server Load in watts (W) divided by the total area that the racks occupy, or the "rack footprint".
Computer Load Density per Rack	Ratio of actual measured Data Center Server Load in watts (W) per rack. This is the average density per rack.
Computer/Server Load Measured Energy Density	Ratio of actual measured Data Center Server Load in watts (W) to the square foot area (sf) of Data Center Floor. Includes vacant space in floor area.
Computer/Server Load Projected Energy Density	Ratio of forecasted Data Center Server Load in watts (W) to the square foot area (sf) of the Data Center Floor if the Data Center Floor were fully occupied. The Data Center Server Load is inflated by the percentage of currently occupied space.
Cooling Load – Tons	A unit used to measure the amount of cooling being done. One ton of cooling is equal to 12,000 British Thermal Units (BTUs) per hour.
Data Center Cooling	Electrical power devoted to cooling equipment for the Data Center Floor space.
Data Center Server/Computer Load	Electrical power devoted to equipment on the Data Center Floor. Typically the power measured upstream of power distribution units or panels. Includes servers, switches, routers, storage equipment, monitors and other equipment.

Data Center Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility.
Data Center Floor/Space	Total footprint area of controlled access space devoted to company/customer equipment. Includes aisle ways, caged space, cooling units electrical panels, fire suppression equipment and other support equipment. Per the Uptime Institute Definitions, this gross floor space is what is typically used by facility engineers in calculating a computer load density (W/sf).
Data Center Occupancy	This is based on a qualitative estimate of how physically loaded the data centers are.
Server Farm Facility	A facility that contains both central communications and equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Data Center Facility. Also defined as a common physical space on the Data Center Floor where server equipment is located (i.e. server farm).

9 Appendix B: Facility Diagrams

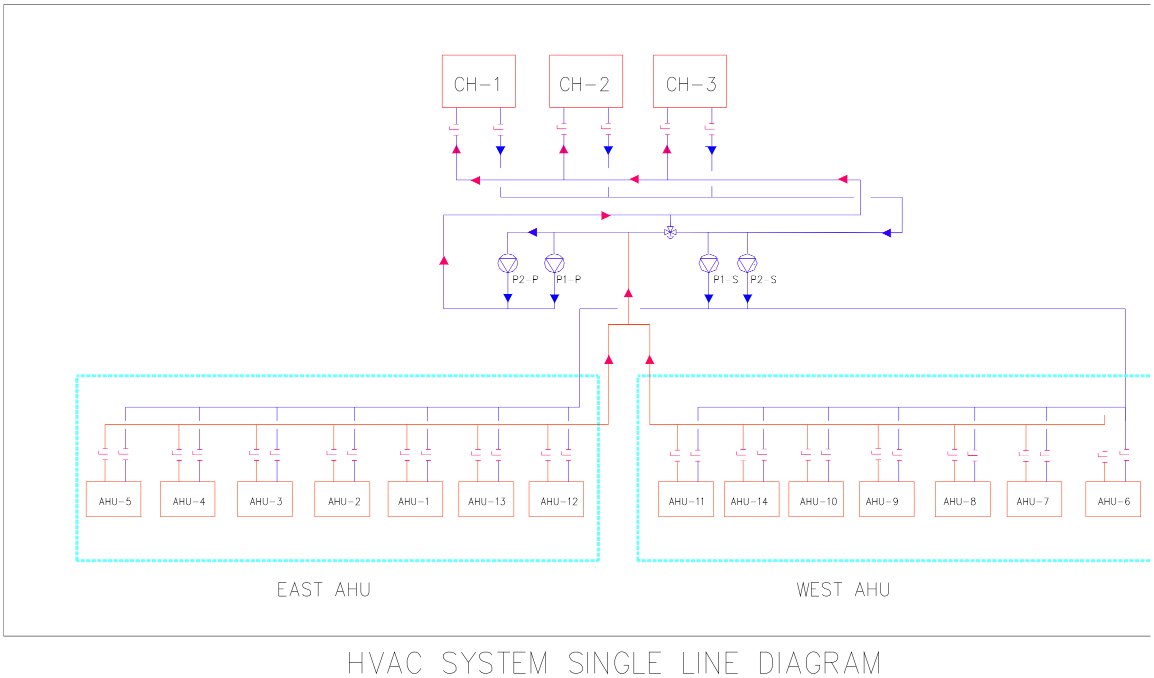
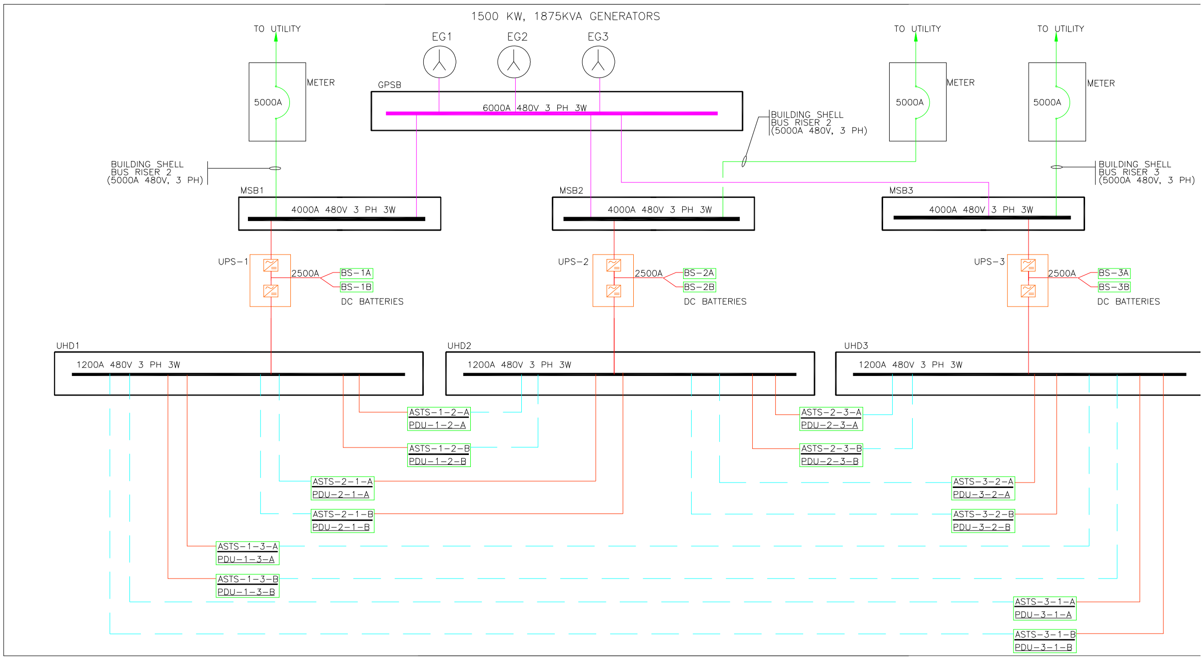


Figure 7 HVAC System



ELECTRICAL SYSTEM SCHEMATIC

Figure 8 Electrical System Schematic