Data Center Energy Benchmarking:

Part 3 - Case Study on an IT Equipment-testing Center (No. 20)

Final Report

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1 Executive Summary

The data center in this study had a total floor area of 3,024 square feet (ft^2) with one-foot raised-floors. It was a rack lab with 147 racks, and was located in a 96,000 ft^2 multi-story office building in San Jose, California. Since the data center was used only for testing equipment, it was not configured as a critical facility in terms of electrical and cooling supply. It did not have a dedicated chiller system but was served by the main building chiller plant and make-up air system. Additionally it was served by only a single electrical supply with no provision for backup power in the event of a power outage. The Data Center operated on a 24 hour per day, year-round cycle, and users had full-hour access to the data center facility.

The study found that data center computer load accounted for 15% of the overall building electrical load, while the total power consumption attributable to the data center including allocated cooling load and lighting was 22% of the total facility load. The density of installed computer loads (rack load) in the data center was 61 W/ft^2. Power consumption density for all data center allocated load (including cooling and lighting) was 88 W/ft^2, approximately eight times the average overall power density in rest of the building (non-data center portion). The building and its data center cooling system was provided with various energy optimizing systems that included the following

- Varying chilled water flowrate through variable speed drives on the primary pumps.
- No energy losses due to nonexistence of UPS or standby generators.
- Minimized under-floor obstruction that affects the delivery efficiency of supply air.
- Elimination of dehumidification/humidification within the CRAH units.

For the data center, 70% of the overall electric power was the rack critical loads, 14% of the power was consumed by chillers, 12% by CRAH units, 2% by lighting system, and about 2% of the power was consumed by chilled water pumps.

General recommendations for improving overall data center energy efficiency include improving the lighting control, airflow optimization, control of mechanical systems serving the data center in actual operation.. This includes chilled water system, airflow management and control in the data center. Additional specific recommendations or considerations to improve energy efficiency are provided in this report.

2 Review of Site Characteristics

The data center (DC #20) in this study had a total floor area of 3,024 square feet (ft^2) with one-foot raised-floors. It was a rack lab with 147 racks, and was located in a 96,000 ft^2 multi-story office building in San Jose, California. Since the data center was used only for testing equipment, it was not configured as a critical facility in terms of electrical and cooling supply. The data center did not have a dedicated chiller system but was served by the main building's chiller plant and make-up air system. Additionally it was served by only a single electrical supply with no provision for backup power in the event of a power outage. The center operated on a 24 hour per day, year-round cycle, and users had full access to the data center facility at all hours.

Electric power was supplied to the office building from the utility to a single 3,000A, 480V main service switchboard (MSB-H). the MSB fed a 2,000A, 480V building electrical distribution system switchboard (SB-1) via current transducer auto metering. Data center computer power is provided directly from SB-1 (via a 225kVA transformer), without the use of Uninterruptible Power Supplies (UPS's) normally associated with typical data centers. In addition, there was no standby generator serving the facility. Communication and power wiring was installed above ceiling. Fire sprinklers were provided under the raised floor and at the ceiling.

Cooling for the data center facility was served by the building's main chiller plant and the make-up air system. The building chilled water system included five air-cooled chillers with chilled water pumps. The cooling system inside the data center included five Computer Room Air Handling (CRAH) units that received chilled water from the chiller plant serving complete building. Three of the CRAH units were monitored in this study. The CRAH's used down-flow type supply for air distribution, and return to the top with or without ducts. Two (Tag numbers CRAH-1.7 and CRAH-1.5) of the three CRAH's monitored used ducted return to the ceiling plenum. Figure 1shows a view of a typical rack lineup in the data center.

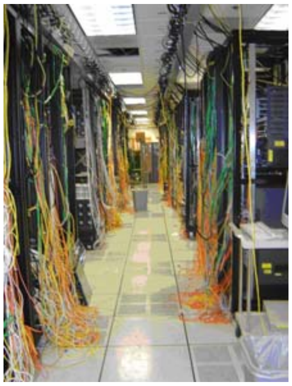

Figure 1   Typical computer rack lineup in the data center

2.1 Electrical Equipment and Backup Power System

Electrical power to Data Center #20 was served by the building electrical distribution system, which received power from Pacific Gas and Electric Company via a three-phase, 480-V, 3000-Ampere main service drop to a main switchboard (MSB-H) as shown on the Electrical System One-line Diagram in Figure 12 of Appendix B.

As part of the study, the overall building power consumption was monitored over a two-week period in December 2004. During that period, the average amount of power consumed in the building during peak usage (workday) periods was 1,238 kW.

The building main switchboard, MSB-H, fed a sub-switchboard SB-1. SB-1 was a three-phase, 480/277-V, four-wire 2,000-Ampere Bus switchboard. The SB-1 switchboard served Data Center #20 through a 225-kVA transformer, identified as HFT7, and three-phase, a 120/208V, four-wire 800-Ampere distribution panel fed by HFT7. All of the server racks received power from the 800-Ampere panel. There was no uninterruptible power supply, static transfer switch, or standby generator serving the data center.

Switchboard SB-1 also fed the building chillers. Power to each chiller was supplied through its own 150-amp circuit breaker located in SB-1. The building chilled water pumps and the CRAH units were fed from a motor control center, H2-MCC1. The H2-MCC1 motor control center received its power directly from main switchboard MSB-H.

The lighting and miscellaneous loads were fed from other electrical panels.

2.2 Mechanical System

2.2.1 Chiller

The data center, along with the remainder of the building, was designed to be cooled by five 60-ton air-cooled chillers. Each chiller had a design power consumption of 0.9 kW per ton of produced refrigeration.

Three chillers were operating during a majority of the monitoring period, with a fourth being placed on-line at no load during a small percentage of the time. Throughout the monitoring period the chillers operated at approximately 49% to 54% of total motor capacity - Chiller #1 carrying 46% of the cooling load, chiller #2 carrying 38%, and chiller #5 carrying about 16%.

2.2.2 Chilled Water Pumps

Primary chilled water was circulated by six parallel in-line Bell & Gossett pumps, each with a motor capacity of 7.5 HP, and a design volume flow rate of 135 GPM. Each pump was sized to provide the flow required for one chiller. The chilled water pumps are identified as CHP-1H through CHP-6H. Each chilled water pump was provided with a variable-speed drive. There was no secondary pump in the building chilled water system.

One of the six pumps, CHP-6H, serves as a redundant pump for backup. CHP-5H and CHP-6H were not in operation at the time of this study. The observed pump discharge pressure (with four pumps in operation) was 50 psig and the suction pressure was 46 psig per the installed pressure gauges. The chilled water pump operation was automatically controlled by the building cooling load demand through the facility's Trane Trace building management system.

2.2.3 Computer Room Air Handling Units

Three out of five package Computer Room Air Handling (CRAH) units were in operation in Data center #20, supplying the data center with cold air from the one-foot raised floor. The CRAH's were Pomona Air Model # PW 3000 units. No reheat coils or humidifiers were included in the CRAH units. The CRAH units had 4-inch throwaway air filters located at the top of the unit, rated at 85% efficiency. Each CRAH unit's internal controls were set to maintain temperature and relative humidity set-points of 70°F and 20% RH, respectively, measured at the unit's return air intake.

Figure 2 below shows a photograph of the CRAH units in data center #20. CAH-1.5 and CAH-1.6 can be seen on the left in the foreground and CAH-1.7 is barely visible at the end of the room. As can be seen in the photo, CAH-1.5 has a ducted return from the ceiling plenum and CAH-1.6 has a non-ducted return and pulls directly from the room.

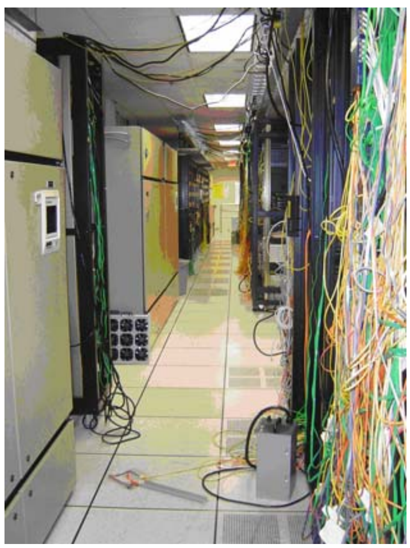

Figure 2 CRAH units in the data center

3 Electric Power Consumption Characteristics

Data center computer power consumption was monitored and shown in Figure 3. The power demand load was fairly steady between 178 and 190 kW, averaging 185 kW for the monitored period, and varying no more than 4% from the average. This data was recorded continuously and shows that there is no discernable cycle in load variation between day and night or between weekdays and weekends (the weekend days were 12/4 & 5 and 12/11 & 12).

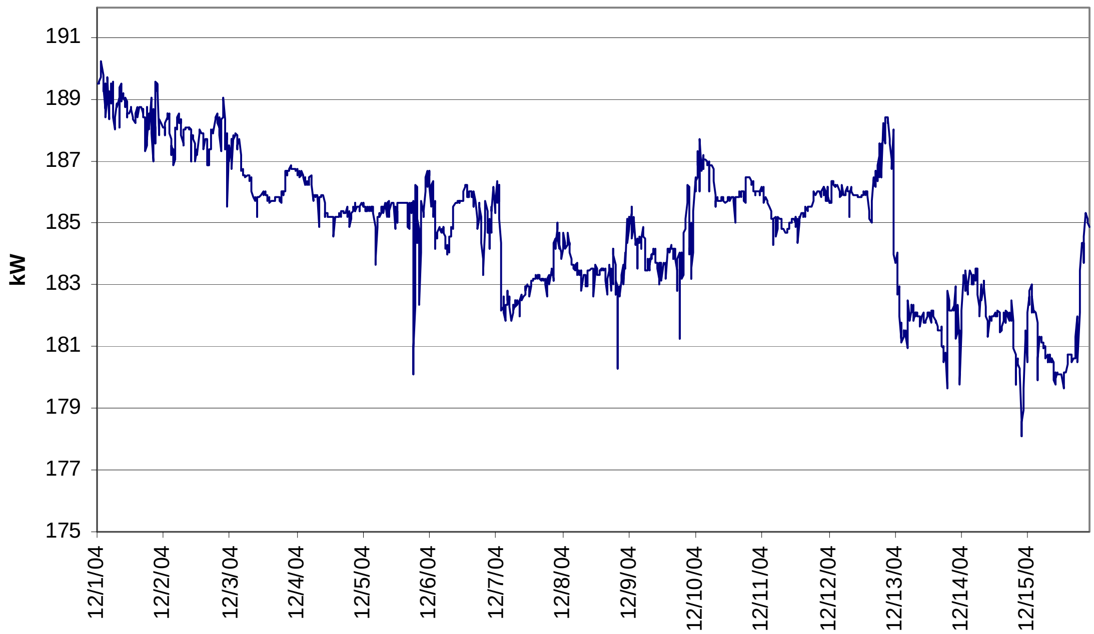

Figure 3 Data center rack power demand over two weeks

Table 1 shows the end-use electricity demand of the building housing the data center in this study. The table shows the power density for the square foot area served by each load. The average building electrical load of 1,238 kW was recorded from building instruments. From the measurements, about 79% of the electrical load was consumed by other areas of the building than the data center, including total cooling systems. For the remaining 22% of power consumption, approximately 15% of the building load was consumed by the data center computer equipment and about 7% of the load was by the CRAH units and the data center allocation of chiller and chilled water pump loads. The density of installed computer loads (rack load) in DC #20 was 61 W/ft^2. Power consumption density for all data center allocated load (including cooling and lighting) was 88 W/ft^2, approximately eight times the average overall power density in rest of the building (non-data center portion).

The ratio of HVAC to IT power demand in the data centers in this study was approximately 0.4. An estimate of "rack-cooling load" was calculated based upon the data center critical power load, assuming 100% of the critical power would become cooling load. For example, using the critical power of 185 kW in the data center, the rack-cooling load of the data center would then be approximately 53 tons. By calculation, the sensible load from the racks, lighting, and CRAH units was about 65 tons. This was used to allocate the portion of the chiller plant serving the data center. The portion of the chilling plant load allocated to the data center was estimated as 42 kW for the chillers and 5 kW for the chilled water pumps.

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

Description	Electric power demand (kW)	Share of electric energy use (%)	Floor Space (ft2)	Electric power density (W/ft2)
Overall Building Load	1238	100%	96,000	13
Chillers – (non Data Center load)	41.5	3.4%	92,976	0.5
CHW Pumps – (non DC load)	4.5	0.4%	92,976	0.1
Building - (other non DC load)	926	74.8%	92,976	10
Total Non-Data Center Load	972	78.5%	92,976	11
Data Center Computer Load	185	14.9%	3,024	61
Data Center CRAH Units	30	2.4%	3,024	10
Chillers – (Data Center load)	41.5	3.4%	3,024	14
CHW Pumps – (Data Center load)	4.5	0.4%	3,024	1
Data Center UPS Losses	0	0.0%	3,024	0
Data Center Lighting	5	0.4%	3,024	2
Total Data Center Load	266	21.5%	3,024	88

The end-use breakdown for the data center's electric power demand is also shown in Table 2. For the data center, 70% of the overall electric power was the rack critical loads, 14% of the power was consumed by chillers, 12% by CRAH units, 2% by lighting system, and about 2% of the power was consumed by pumps.

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

Description	Electric power demand (kW)	Share of electric energy use (%)
Data Center Rack Load	185	70%
Data Center CRAH Units	30	12%
Chillers (DC portion)	41.5	14%
CHW Pumps (DC portion)	4.5	2%
Standby Generator	none	0%
Data Center UPS Losses	none	0%
Data Center Lighting	5	2%
Total Data Center Only	**266**	**100%**

3.1 Chiller System

Electric power demand was monitored for the four operating chillers (CH-1, CH-2, CH-3, and CH-5) within a two-week period. Chiller CH-3 was only operational for three days (at very low loads) and chiller CH-4 never ran. The remaining three chillers operated continually for the monitoring period.

Total average chiller kW for the period was 83 kW, which represented the chilling load of the whole building. CH-1 and CH-2 provided the majority of the cooling load with average kW power consumption of 37.8 and 31.8 respectively. The chiller CH-5 operated with a power consumption of 13.4 kW.

Figure 4 shows the total chiller power demand and outside air temperatures within the two-week period. As the outside air temperature changed, the actual chiller power demand also changed accordingly. In addition, Figure 5 further shows the same data points illustrating the correlation of total chiller power consumption and outside air temperatures. The variations in power demand and air temperatures in both figures indicate that the chiller load was not solely affected by the ambient temperature but also was influenced by other factors.

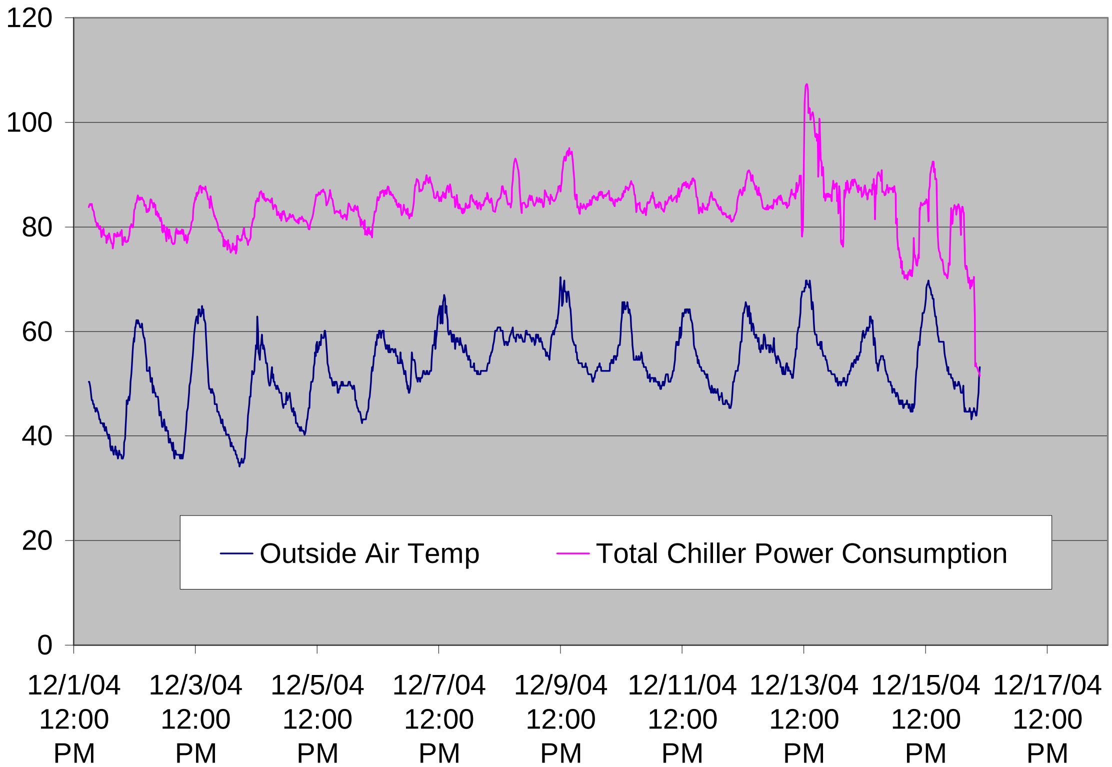

Figure 4 Chiller cooling power and outdoor air temperature

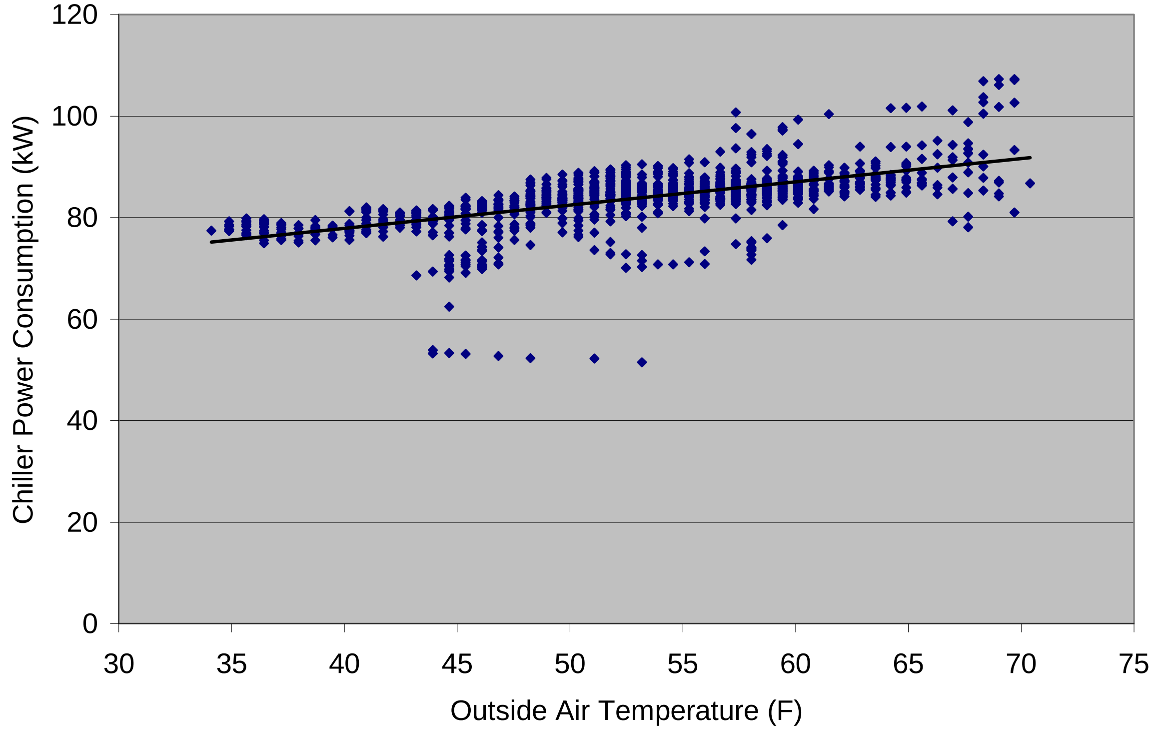

Figure 5 Correlation of chiller cooling power and outdoor air temperature

3.2 Pumping System

The building was served by six 7.5-hp chilled water pumps: CHP-1H through CHP-6H. CHP-1H through 3H were operational at the time of monitoring, while CHP-4H was operational for the first half period of the monitoring. Pumps CHP-5H and CHP-6H were for reserve and were not in operation.

The pumps were fitted with variable speed drives (VSDs) and controlled to modulate from 30HZ to 60HZ. Control sequence was not known. The power consumption of the pumps was monitored and shown in Figure 6. The average total pumps kW for the monitoring period was 9 kW.

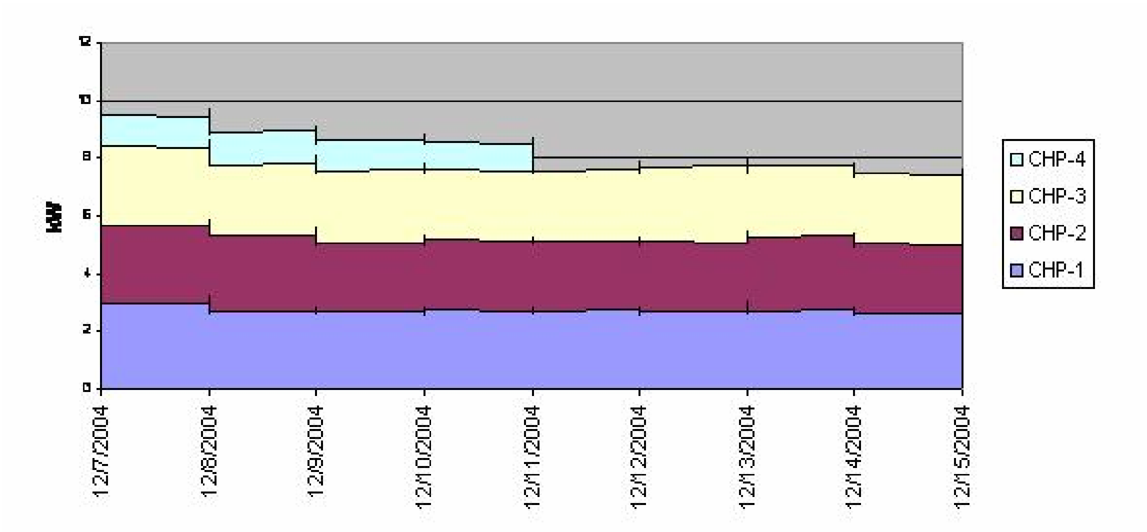

Figure 6 Chilled Water Pumps

3.3 Computer Room Air Handlers

The data center was actively served by three 20-ton CRAH units during the survey period. Each unit had two 7.5-hp constant-speed fan motors.

The power consumption of CRAH unit CAH-1.5 is shown in Figure 7. Based on data taken at the time of the survey, CRAH power consumption was 0.84 watts/cfm. The variation of minimum to maximum power draw was under 4% during the period.

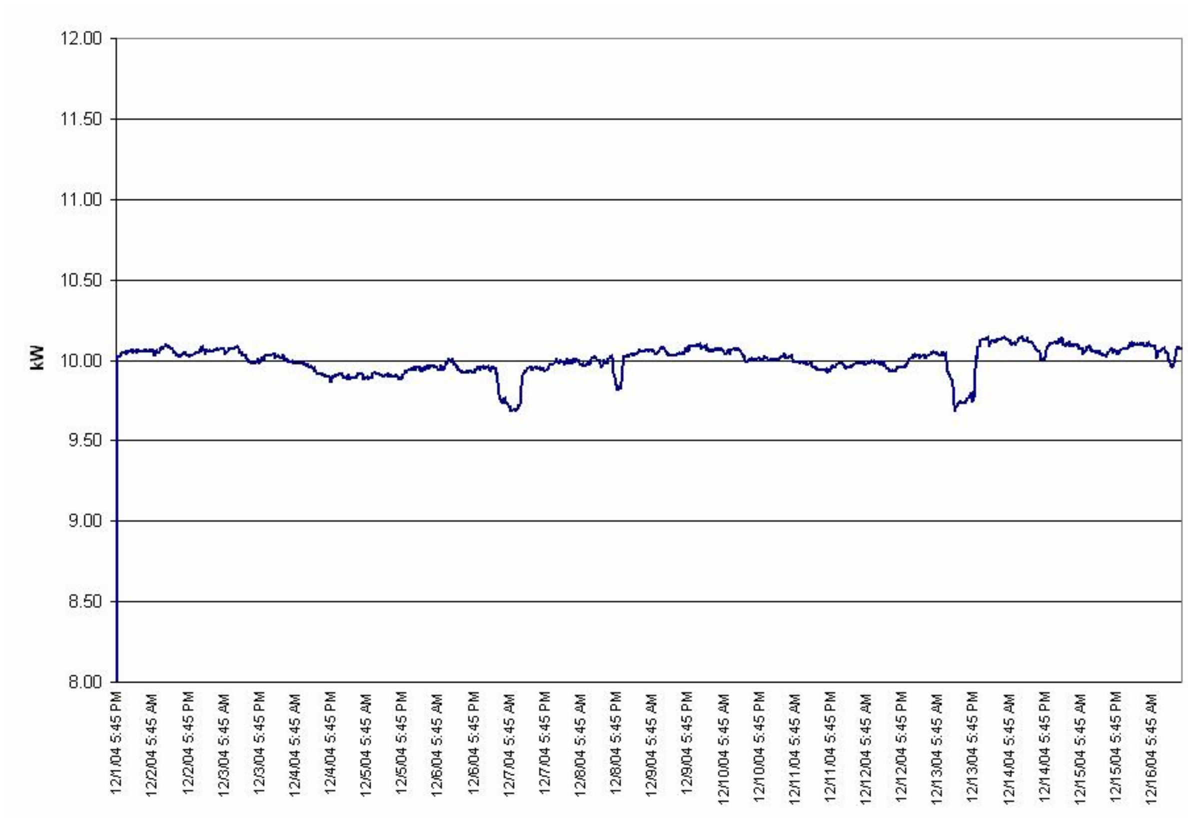

Figure 7 CRAH unit CAH-1.5 Power Consumption

4 System Operation

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

- Chilled water pumps CHP-1H, CHP-2H, CHP-3H, and CHP-4H
- Chillers CH-1, CH-2, CH-3 and CH-5.
- All three monitored CRAH units CAH-1.5, CAH-1.6 and CAH-1.7 were operating, while the other two units were off.

4.1 Chilled Water Supply and Return Temperatures

The chilled water supply and return temperatures were monitored in the study.

The data center branch-chilled water return temperature was shown in Figure 8 along with the corresponding ambient temperature and CRAH supply air temperature (for CAH 1.5). The recorded chilled water supply temperature readings were almost identical to the ambient temperature. In addition, the recorded chilled water supply temperature showed that it rose well above the CRAH supply air temperature every day (which is not possible) in concert with the ambient temperature. It was found that the temperature sensor used for recording chilled water supply temperature was surface-mounted on the piping and was apparently much more influenced by ambient air temperature around the piping than it was by the temperature of the chilled water flowing in the pipe. This indicates that the readings were not right and a verification or calibration should be pursued to correct the error.

The chilled water return temperature correlated with the ambient temperature to some degree. The maximum lows for each day occurred in the morning hours (between 5:00 AM and 8:00 AM) while the peak highs occurred in the early afternoon hours (between 12:00 PM and 3:00 PM). For the monitoring period, the average chilled water return temperature was 71°F, and the average CRAH supply temperature for CAH-1.5 was 55°F.

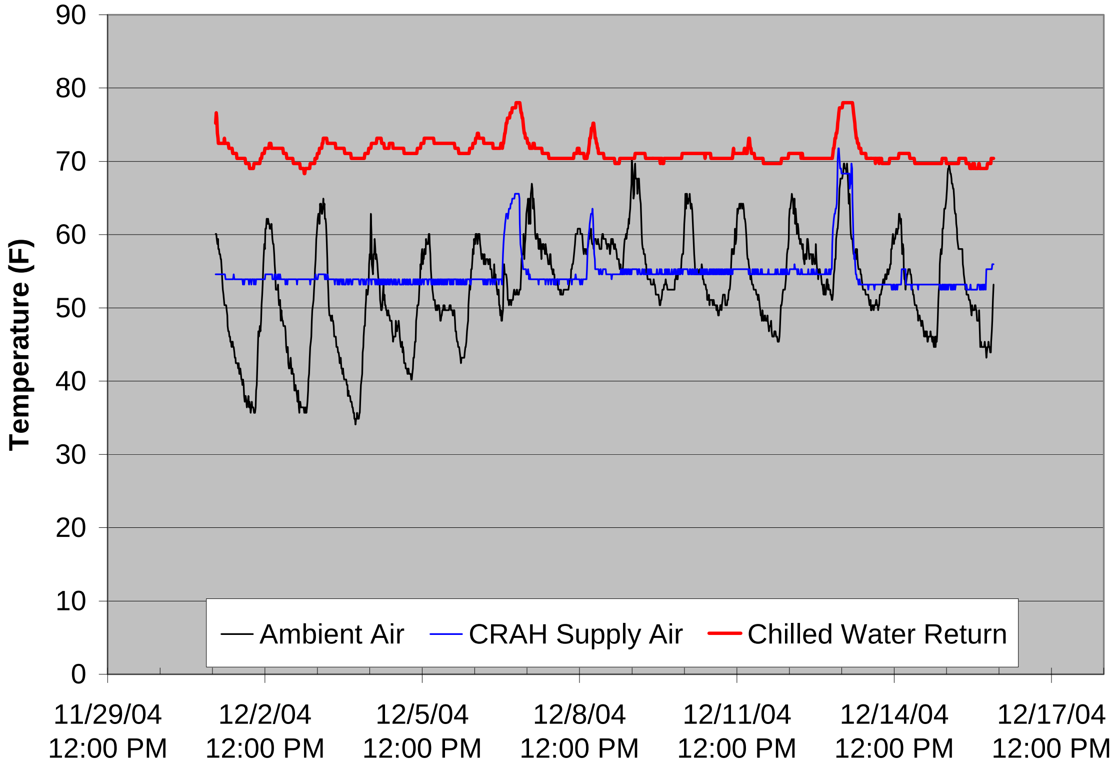

Figure 8. Water and air temperatures

4.2 CRAH Supply and Return Air

Temperatures and relative humidity for the supply and return airflows were monitored for two weeks. Figure 9 shows the supply air temperatures for air handlers CAH-1.5, and CAH-1.6 as well as the return air temperature and relative humidity for CAH-1.7. Supply air temperature excursions were experienced on three different occasions as shown in Figure 9. According to the Building Engineer, the excursions were caused by problems with the modulation of the chilled water control valve. The exact location of the control valve was not known. Therefore, the control valves should be located, checked, and repaired or replaced as needed to ensure stable and reliable control, reducing the power demand for operating the units.

Each CRAH unit was equipped with two 7.5-hp fan motors and was rated to deliver 12,000 ft^3/m (CFM) of cold air to the under floor plenum with a net sensible cooling capacity of 20-tons (after deducting fan heat). During the survey, three operating CRAH's (CAH-1.5, CAH-1.6, and CAH-1.7) were monitored and measured. The average supply temperature for CAH-1.5 was 55°F. CAH-1.6 had an average supply temperature of 58°F and an average supply relative humidity of 51% RH. CAH-1.7 had an average return air temperature of 79°F and an average return relative humidity of 26% RH.

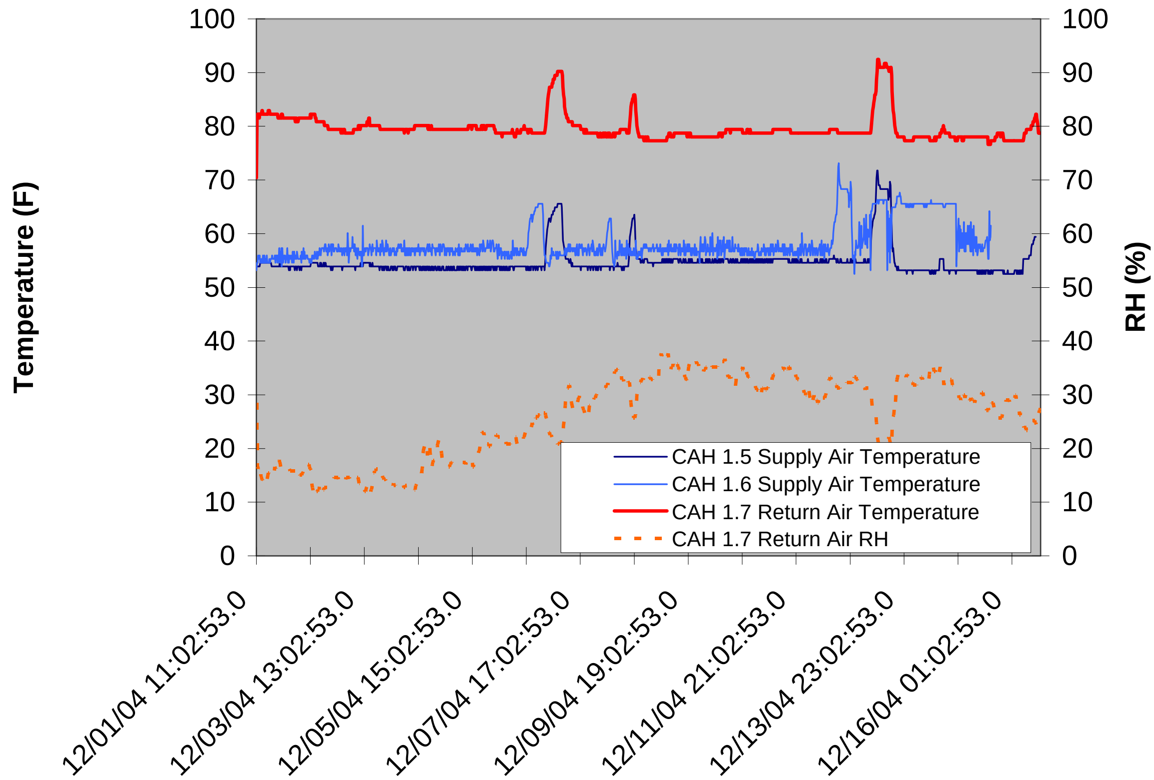

Figure 9 DC Computer Room Air Handling Unit Supply, Return Temperatures and Relative Humidity

4.3 Data Center Space Air Temperature and Relative Humidity

The space temperature and relative humidity were monitored and shown in Figure 10. At one location the average space temperature and relative humidity was 74°F and 32% RH, respectively.

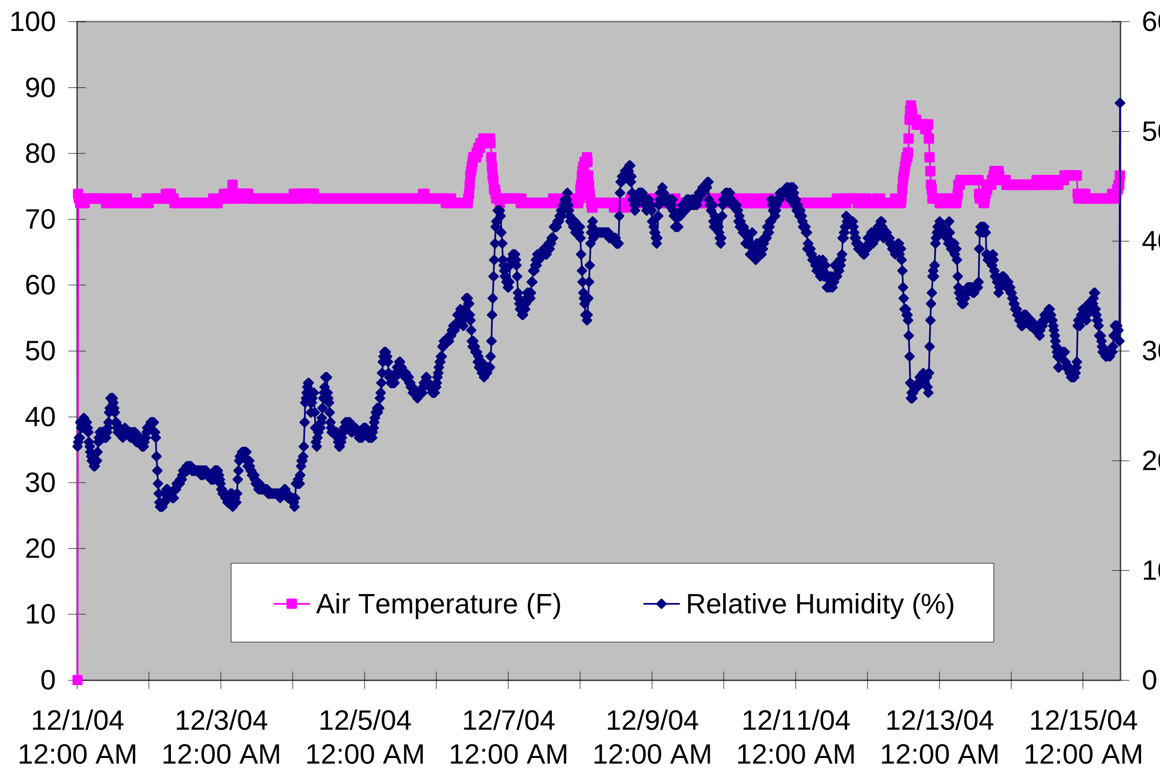

Figure 10 DC air temperature and humidity

5 Recommendations

The density of installed computer loads (rack load) in the data center was 61 W/ft^2. The building and its data center cooling system was provided with various energy optimizing systems that included the following:

- Varying chilled water flow rate through variable speed drives on the primary pumps.
- No energy losses due to nonexistence of UPS or standby generators.
- Minimized under-floor obstruction that affects the delivery efficiency of supply air.
- Elimination of dehumidification/humidification within the CRAH units.

General recommendations for improving overall data center energy efficiency include improving the lighting control, design, operation, and control of mechanical systems serving the data center in actual operation. This includes chilled water system, airflow management and control in data centers. The following additional techniques should result in significant improvements in energy efficiency, effective operation, or both.

5.1 Lighting

The measured lighting load in the Data center was 5 kW with an intensity of $2W/ft^2$. The lighting load can be reduced by considering the following energy control measures: install lighting zone occupancy sensors; and task lighting in appropriate areas and disable portions of overhead lights where light is not needed.

5.2 Airflow Optimization

5.2.1 Floor Tile Rearrangement

Cold air was un-evenly distributed throughout the data center. Either blocking unwanted openings on the raised floor or reducing airflow rates using adjustable dampers (or lower % open perforated tiles) on the areas with excessive air flow would result in a more even air distribution, thus reducing potential hot spots in the data center.

5.2.2 Rack Air Management

A primary recommendation for the rack layout is that cold supply air should flow from the front to the rear of the IT equipment. The study recommends to arrange fronts of equipment on each side of a cold aisle face each other and the backs of equipment in adjacent aisles (hot) facing each other. The cool air entering the front of the computer servers forms a common cold aisle and, warm air discharging at the rear of the servers forming a common hot aisle.

5.2.3 Wiring Configuration

Cables hanging in front of computer racks caused undesirable airflow deviations to cool the rack equipment. These communication cables should be properly managed in front of the server to reduce air circulation restrictions as cold air is drawn through the front of the server to the backside of the server. An additional recommendation would be to utilize a server rack with a bottom opening for cold air and perforated tile in the bottom of the computer server. Adding blank-offs within and between racks could prevent air bypasses and undesired mixing between hot and cold air flows.

5.3 HVAC Controls

The space relative humidity in the data center varies considerably as shown in figures 16 & 17. The CRAH units can be globally controlled by an energy management system through the establishment of temperature set point(s) in the space. This can be created by adding input and output control points at the EMS.

- The current control sequence of chilled water pump was not known. Chilled water pump flow can be improved by providing a control that is based on differential pressure (DP) in the system.

- Check and tune controls and instrumentation for chillers and CRAH's.

- Check the electrical loading on the main and the circuit transducer; in places it appeared to be above the 80% continuous loading allowed by Code.

5.4 Chilled Water System

Consideration should be given towards resetting the chilled water supply temperature to a higher set point. For example, setting the chilled water supply temperature to 50°F may 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 1 or 2°F at a time, while verifying that there is no hot spot in critical locations. In addition, employing evaporative pre-coolers for the air-cooled chiller condensers could increase chiller efficiency, especially at peak conditions.

6 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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7 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).

8 Appendix B: Facility Diagrams

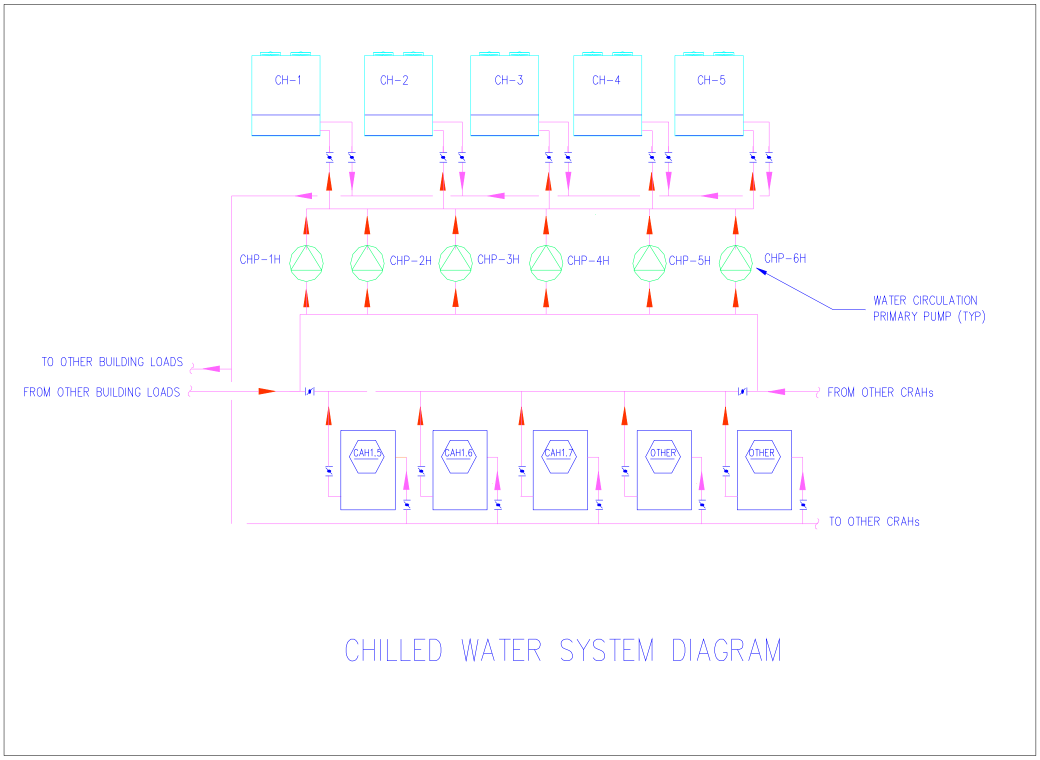
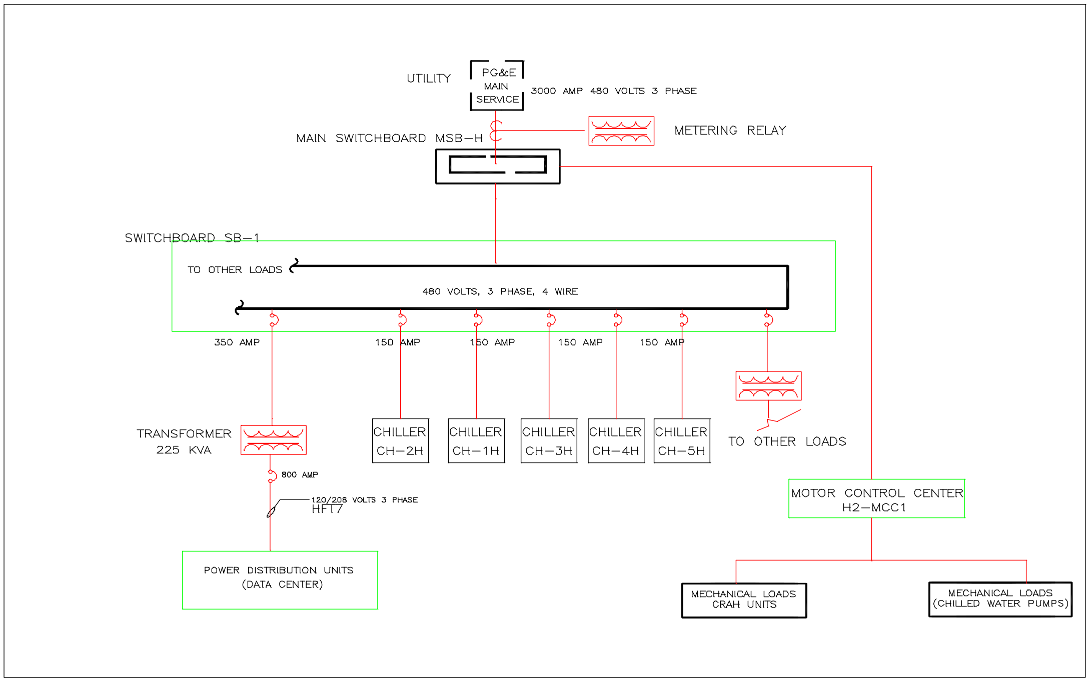


Figure 11 Chilled Water System



ELECTRICAL SYSTEM SCHEMATIC

Figure 12 Electrical System Schematic