

# DATA CENTER ENERGY BENCHMARKING CASE STUDY

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**FACILITY 7**  
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## **Acknowledgements**

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*A -- CHARTS OF MONITORED DATA*

## I. Executive Summary

Rumsey Engineers and the Lawrence Berkeley National Laboratory (LBNL) have teamed up to conduct an energy study as part of LBNL's Data Center Load Characterization and Roadmap Project, under sponsorship by the California Energy Commission (CEC). This study will aid designers to make better decisions about the design and construction of data centers in the near future. Data centers at four different organizations in Northern California were analyzed during the period of September 2002 to December 2002, with the particular aim of determining the end-use of electricity.

This report documents the findings for one of the case studies – termed Facility 7. Additional case studies and benchmark results as they become available will be provided on LBNL's website (<http://datacenters.lbl.gov>). For comparison purposes, the results of a similar benchmarking study completed for the Pacific Gas and Electric Company (PG&E) in 2001 are included in this report.

Facility 7 contains two data centers, in two separate floors, in a large office building. The facility is a financial institution, and has a variety of data equipment, that includes file servers, tape storage robots, and printers. An addition, another floor contains check-processing equipment, which is also served by the critical facility equipment, but for purposes of this study, was excluded where possible. Only a portion of the data center resembles the server farms that became common as a result of the Internet Age.<sup>1</sup> The data center gross area is approximately 74,000 square feet (sf), while the entire building is 1.4 million sf. The data center electricity and the building electricity end use are evaluated.

The whole building and data center are served by a chilled water plant. Primary chilled water directly feeds all the building's main air handlers. A heat exchanger separates the primary chilled water loop from the secondary chilled water loop, which supplies chilled water to the computer room air conditioners (CRAC) units. The CRAC units pressurize a raised floor, and the air handlers supply air through a VAV system overhead.

The current computer energy loads are listed in the table below. A qualitative estimate of the loading of the racks was made, and the future computer energy loads were estimated based on this loading. For comparison purposes the computer loads of another data center studied in this project (CEC funded) and other data centers studied in the PG&E project are also included. The computer loads are also shown graphically.

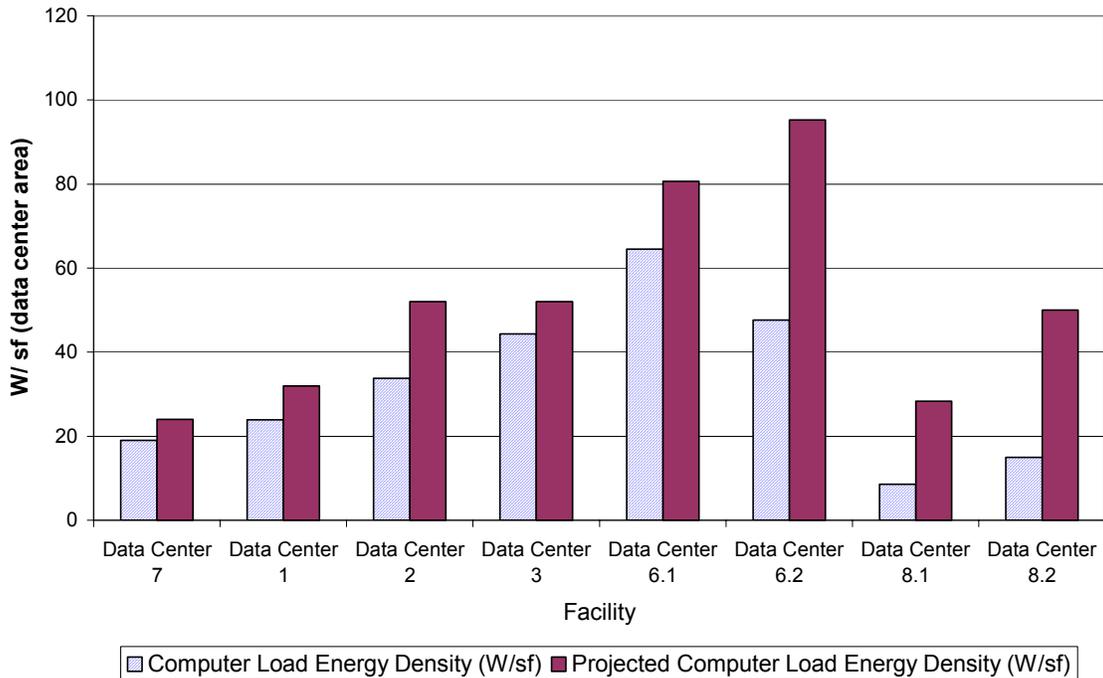
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<sup>1</sup> Based on the rack configuration, high density of computers, and absence of the large mainframe servers that were common in older data centers.

### CURRENT AND FUTURE COMPUTER LOADS

Data Center	Data Center Area (sf)	Computer Load (kW)	Computer Load Energy Density (W/sf)	Occupancy (%)	Projected Computer Load Energy Density (W/sf)
Data Center 7	74,000	1,395	19	80%	24
Data Center 1	62,870	1,500	24	75%	32
Data Center 2	60,400	2,040	34	65%	52
Data Center 3	25,000	1,110	44	85%	52
Data Center 6.1	2,400	155	65	80%	81
Data Center 6.2	2,501	119	48	50%	95
Data Center 8.1	26,200	222	8	30%	27
Data Center 8.2	73,000	1,059	15	30%	50

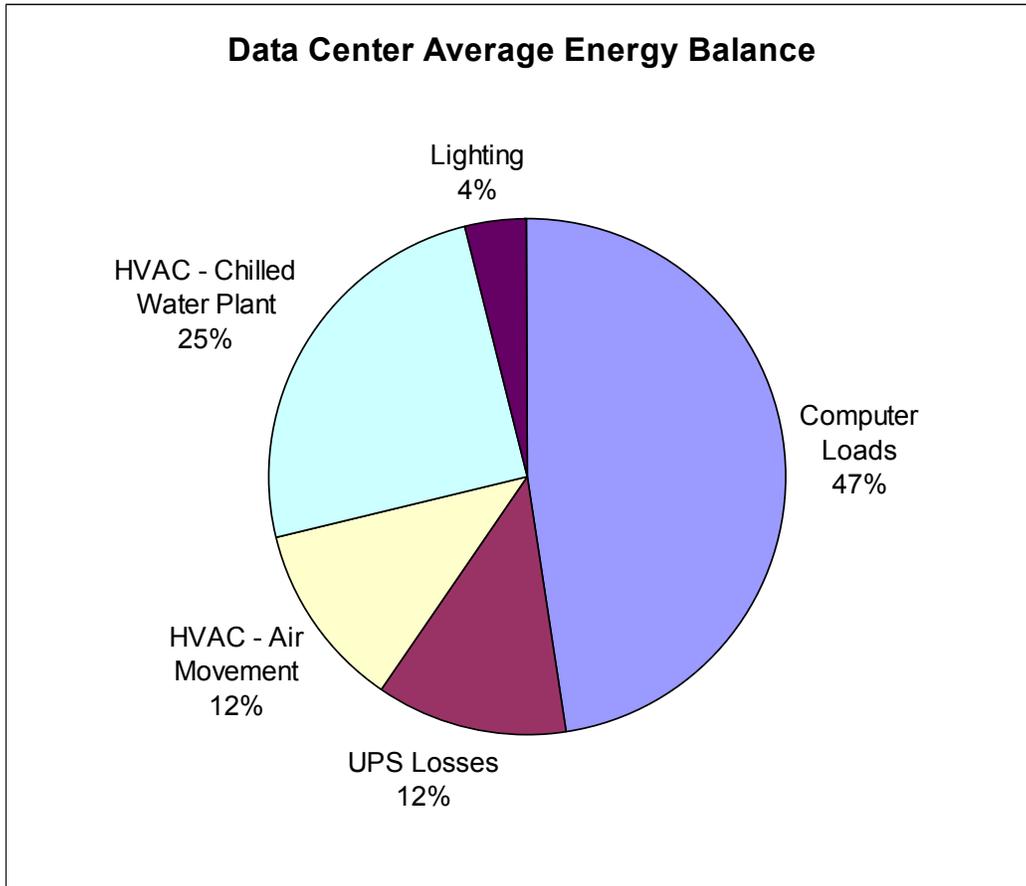
### Computer Energy Loads



The measured computer load densities at Facility 7 are significantly smaller than the computer load densities measured in the previous study. The measurement projects a full occupancy density of 24 W/sf, which is well below all of the full occupancy densities projected for the other data centers.

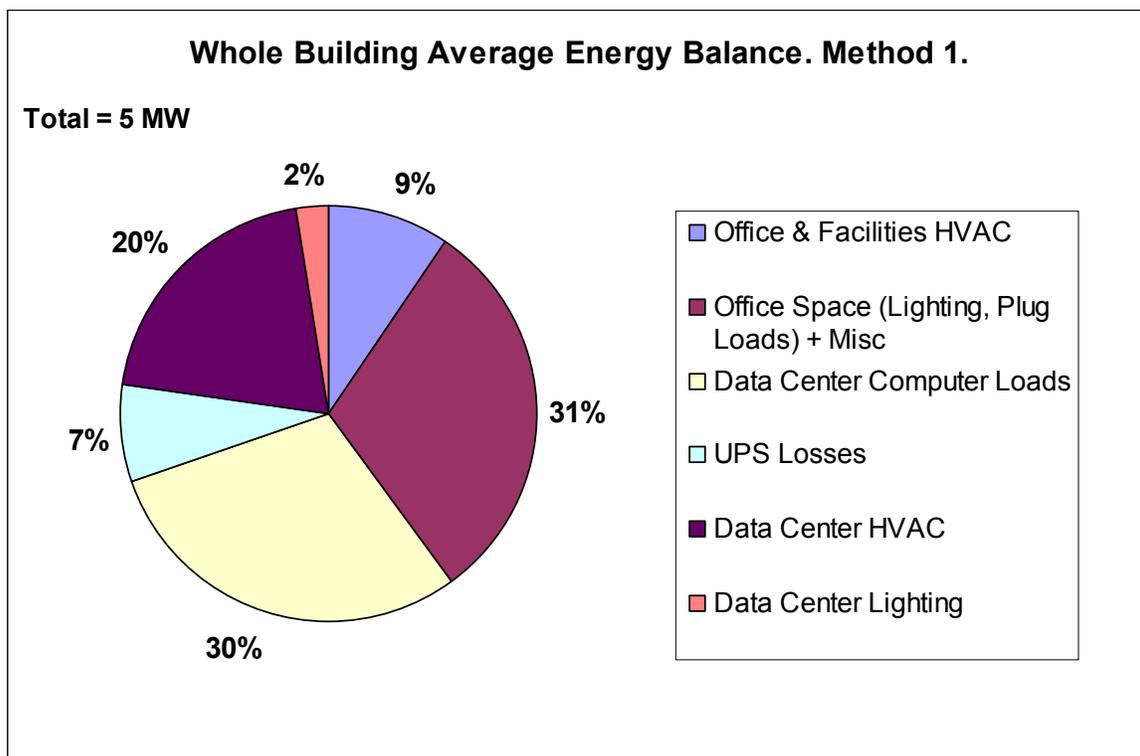
The remaining energy loads of the data center include chiller, and chilled water plant energy (proportioned to the data center load), CRAC unit power, lighting, and uninterruptible power supply inefficiencies. Due to the critical nature of the facility, an efficiency of the UPSs were not obtained, but an efficiency was assumed, based on values observed at another site.

The data center electrical end use is shown below in graphical format, and is listed in tabular format in the report.

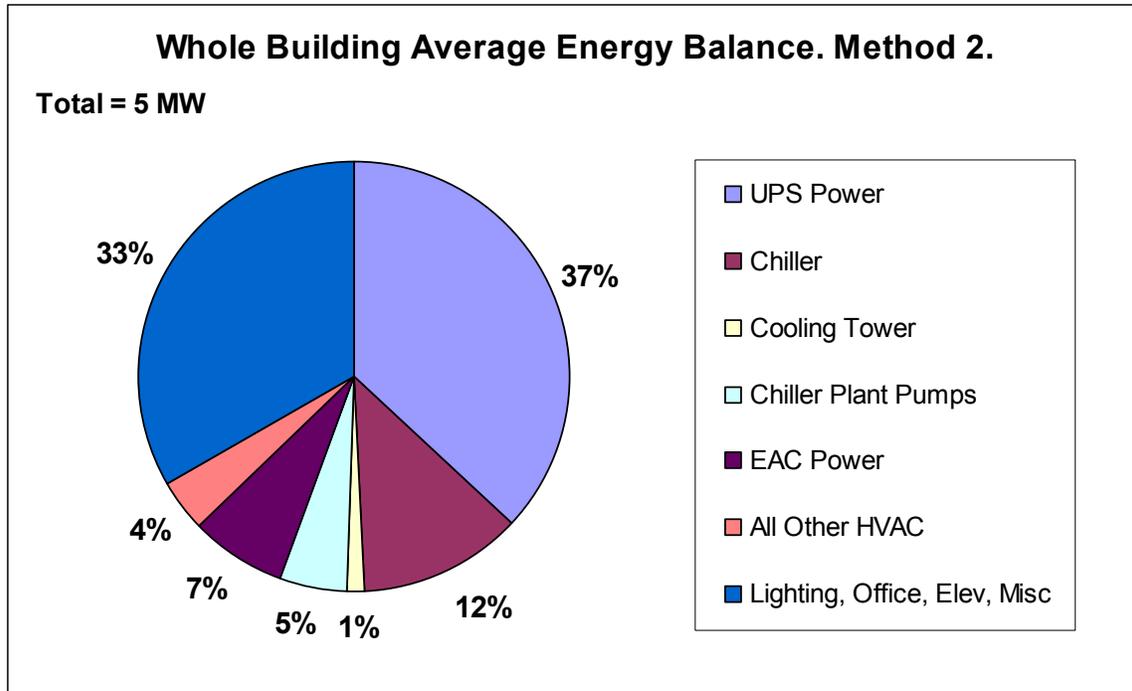


A large percentage, approximately 47%, of the total electrical load is from the computer loads. However, the HVAC loads contribute a significant percentage at 37%. Therefore, efficiency improvements could result in significant energy savings. In addition, the estimated lighting and UPS consumption represent an opportunity for energy savings, where redundancy requirements permit such changes in operation. These are discussed in detail in the report.

The whole building electricity end use was also determined, and is shown in two formats. The first, separates the data center loads from the non-data center loads, and the second is categorized based on major equipment categories. This data is included in tabular format in the report.



The whole building consumes an average of 5 MW of electricity. The major consumers are 1) the data center computer loads, 2) the office plug loads, lighting loads, and miscellaneous loads (which include elevator loads), and 3) the data center HVAC. They are approximately 30%, 30%, and 20%, respectively, or 70% together. The data center alone contributes to 62% of the total building energy.



The largest consumer is the UPS power at approximately 1.9 MW, or 38% for weekend operation, and 33% for weekday operation. The difference between this value, and the computer loads cited in the previous paragraph is due to the UPS losses. The total HVAC power for the whole building is approximately 30% for both scenarios, and the office, lighting, elevators and miscellaneous loads account for 34%. This representation further emphasizes the electrical consumption of HVAC equipment, and the relevance of energy efficiency measures. As shown earlier, approximately 2/3 of the HVAC power can be attributed to the data center cooling exclusively. The category of lighting, office, elevators, and miscellaneous sources emphasizes that lighting, as well as power management within offices is important, though this is not a focus of the study.

The performance of the HVAC system can be evaluated based on energy efficiency metrics. Though the cooling power is represented in W/sf, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. This essentially removes the variable of how tightly packed the computers are. The more traditional metrics of energy per ton of cooling (kW/Ton) are calculated for individual chillers, total chilled water plant (chillers, cooling towers, pumps) and the data center cooling efficiency. The data center cooling efficiency includes the chilled water plant power weighted by the data center load, data center air handler and CRAC unit power.

#### FACILITY 7 EFFICIENCY METRICS

Metric	Value	Units
Building Energy Density	3.6	W/sf
Data Center Computer Power Density	18	W/sf

<b>Metric</b>	<b>Value</b>	<b>Units</b>
Data Center Cooling Power Density	15	W/sf
Non Computer Load Density	21	W/sf
Cooling kW / Computer Load kW	0.7	--
Chiller 3 Efficiency	0.9	kW/ton
Chiller 4 Efficiency	0.6	kW/ton
Chilled Water Plant Efficiency	1.1	kW/ton
Total Data Center HVAC Efficiency	1.7	kW/ton
Theoretical Cooling Load *	553	Tons
Cooling Provided by CRAC Units	520	Tons
Cooling Provided by Air Handlers	121	Tons
Measured Cooling Load	641	Tons

\* Based on computer loads, lighting loads, and fan energy.

The data center computer load density is small, relative to what is observed at other data centers. Hence, the cooling energy density is also small, at 15 W/sf, relative to other facilities. The “cooling efficiency”, which is the efficiency normalized to the computer power is 0.7 Cooling kW/ Computer kW. This means that for 1 kW of energy input, only 1.4 kW of energy is removed. This value is slightly higher than the measured efficiencies of 0.5 kW/kW and 0.6 kW/kW at two other monitored data centers, which utilizes air cooled chillers and fan coil units, and air cooled CRAC units, respectively. Another monitored site has an efficiency of 1.3 kW/kW, which utilizes a water cooled reciprocating chiller and computer room air handlers with humidification and reheat. Though a water cooled chiller plant could operate extremely efficiently, it will not if the fundamental equipment, air delivery and pumping systems are inefficient.

Chiller efficiencies were obtained for chillers 3 and 4, and on average are 0.9 and 0.6 kW/ton, respectively. Both are water cooled, centrifugal constant speed chillers. The efficiency of chiller 4 meets the rated efficiency of 0.6 kW/ton, but the observed efficiency should be better, since the operating conditions are more favourable (at 68 °F entering condenser water temperature).<sup>2</sup>

Several opportunities for energy savings, addressing the chiller plant, and other areas are described in detail in the “Energy Efficiency Recommendations” section of the report.

<sup>2</sup> The rated conditions are: 80 °F entering condenser water temperature, chilled water setpoint of 42 °F. The operating conditions are: 65 °F entering condenser water temperature, chilled water setpoint of 42 °F.

## II. Definitions

<b>Data Center Facility</b>	A facility that contains both central communications equipment, and data storage and processing equipment (servers) associated with a concentration of data cables. Can be used interchangeably with Server Farm Facility
<b>Server Farm Facility</b>	A facility that contains both central communications equipment, and data storage and processing equipment 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)
<b>Data Center Floor / Space</b>	Total footprint area of controlled access space devoted to company/customer equipment. Includes aiseways, 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). <sup>3</sup>
<b>Data Center Occupancy</b>	This is based on a qualitative estimate on how physically loaded the data centers are. For calculations, the facility's assessment of this value is utilized.
<b>Data Center Cooling</b>	Electrical power devoted to cooling equipment for the Data Center Floor space
<b>Data Center Server/Computer Load</b>	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.

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<sup>3</sup> Users look at watts per square foot in a different way. With an entire room full of communication and computer equipment, they are not so much concerned with the power density associated with a specific footprint or floor tile, but with larger areas and perhaps even the entire room. Facilities engineers typically take the actual UPS power output consumed by computer hardware and communication equipment in the room being studied (but not including air handlers, lights, etc.) and divide it by the gross floor space in the room. The gross space of a room will typically include a lot of areas not consuming UPS power such as access aisles, white areas where no computer equipment is installed yet, and space for site infrastructure equipment like Power Distribution Units (PDU) and air handlers. The resulting gross watts per square foot (watt/ft<sup>2</sup>-gross) or gross watts per square meter (watt/m<sup>2</sup>-gross) will be significantly lower than the watts per footprint measured by a hardware manufacturer in a laboratory setting.

<b>Computer/Server Load Measured Energy Density</b>	Ratio of actual measured Data Center Server Load in Watts (W) to the square foot area (ft <sup>2</sup> or sf) of Data Center Floor. Includes vacant space in floor area
<b>Computer Load Density – Rack Footprint</b>	Measured Data Center Server Load in Watts (W) divided by the total area that the racks occupy, or the rack “footprint”.
<b>Computer Load Density per Rack</b>	Ratio of actual measured Data Center Server Load in Watts (W) per rack. This is the average density per rack.
<b>Computer /Server Load Projected Energy Density</b>	Ratio of forecasted Data Center Server Load in Watts (W) to square foot area (ft <sup>2</sup> or 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.
<b>Cooling Load Tons</b>	A unit used to measure the amount of cooling being done. Equivalent to 12,000 British Thermal Units (BTU) per hour.
<b>Chiller Efficiency</b>	The power used (kW), per ton of cooling produced by the chiller.
<b>Air Handler Efficiency 1</b>	The air flow (CFM) per power used (kW) by the CRAC unit fan
<b>Air Handler Efficiency 2</b>	The power used (kW), per ton of cooling achieved (ton) by the air handling unit.
<b>Cooling Load Density</b>	The amount of cooling (tons) in a given area (ft <sup>2</sup> or sf)
<b>Air Flow Density</b>	The air flow (CFM) in a given area (ft <sup>2</sup> or sf)

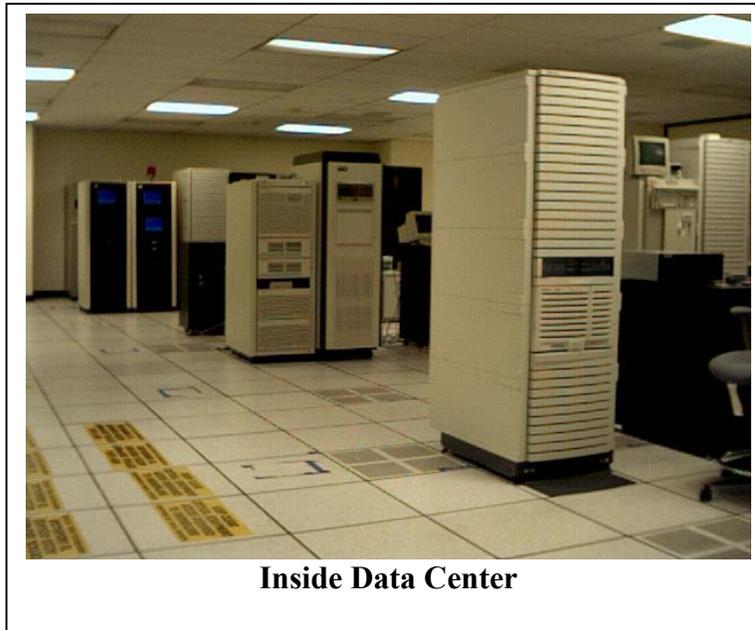
### **III. Introduction**

This report describes the measurement methodology and results obtained for this case study. The facility is a large financial facility that includes office space and data centers. The data centers were measured collectively. Electricity end use for the entire building and data centers is determined. This was achieved through a combination of spot electrical measurements, temperature and flow measurements on various mechanical equipment, spot measurements of utility meters for computer loads, miscellaneous office loads, and trended data on mechanical systems from the Energy Management Control System (EMCS). The computer load density is also determined based on the gross area of the data center, as this number, in watts per square foot (W/sf) is the metric typically used by facility engineers to represent the computer power density. Based on the owner's assessment of the data center occupancy, the computer load density at full occupancy is extrapolated.

Additional information was collected, where necessary, in order to determine the operating efficiencies of the cooling equipment. These efficiencies are compared to the design efficiencies. Opportunities for energy efficiency improvements are described, which are based on observation of the mechanical system design, and measured performance.

## IV. Site Overview

Facility 7 is a large financial institution located in San Francisco, California. The building has a gross area of 1.4 million square feet (sf). It consists of several floors of office area, and three floors that are dedicated to computer equipment, and check processing. The data center gross floor area is approximately 74,000 sf, and consists of approximately 5% of the total building area.<sup>4</sup> The data centers host a variety computer equipment that includes servers and networking equipment, mainframe computers, tape storage robots, and printers. A portion of the data centers is arranged in the typical server farm rack style.



The data centers are operated 24 hours a day. The check processing areas are not considered to be typical data center equipment, and are therefore not included in the majority of the calculations. In order to avoid including this data, weekend measurements were obtained as much as possible during the measurement period.

The data centers are cooled both by an underfloor system and overhead system. The underfloor system is supplied cool air by water-cooled computer room air conditioners (CRACs)<sup>5</sup> and the overhead system by typical office air handlers. The central cooling plant serves the entire building.

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<sup>4</sup> Note, this is not the total floor area of the floors housing the computer rooms, only the computer room area.

<sup>5</sup> Termed “environmental air conditioners” or EACs by the facility.

## V. Energy Use

### ELECTRICAL EQUIPMENT AND BACKUP POWER SYSTEM

The facility utilizes an Exide 2225 kVA uninterruptible power supply (UPS) and a Teledyne 2500 kVA UPS. The UPSs provide a constant supply of power to the data center at constant delivery voltage (480/277 V). The UPS converts AC current and stores it as DC current in multiple battery packs. When the voltage is needed, it is converted back to AC current. In the event of a power loss, four 3 megawatt (MW) Diesel generators can provide power for approximately 8 days at maximum generator load.

Spot power measurements were taken at the UPSs by reading the instantaneous power draw at the utility meters. In order to avoid including the power draw by the check processing equipment, several readings were taken during weekend operation, after confirming with facility personnel that check processing would not be active. The output of the UPSs were not measured, as this would involve an electrical hook up to critical facility equipment. For the purposes of estimating UPS heat losses, an efficiency of 80% was assumed. This was based on experience at other facilities



**Teledyne UPS**

where power measurements were conducted by measuring at the input and output sides of the UPS.<sup>6</sup>

The most commonly used metric among mission critical facilities is the computer load density in watts consumed per square foot (W/sf). However, the square footage is not always consistent between designers. This inconsistency has been a problem.<sup>7</sup> Some data centers use kVA/rack or kW/rack as a design parameter. Our definition of “Data Center Floor Area” includes the gross area of the data center, which includes rack spaces, aisle spaces, and areas that may eventually contain computer equipment. Per the Uptime Institute, the resulting computer load density (W/sf) is consistent with what facility

<sup>6</sup> Measurements at other facilities indicated an efficiency of 78% for an Emerson Accupower 500 kVA installed approximately 20 years ago. The measured UPS was approximately 30% loaded. The UPSs at Facility 7 are also under-loaded at 40%.

<sup>7</sup> See “Data Center Power Requirements: Measurements from Silicon Valley”, by Mitchell-Jackson, Koomey, Nordman, & Blazek, December 2001. It is available on the web at [http://enduse.lbl.gov/Info/Data\\_Center\\_Journal\\_Article2.pdf](http://enduse.lbl.gov/Info/Data_Center_Journal_Article2.pdf).

engineers use, though this is different from the “footprint” energy density that manufacturers use. The data center floor area was estimated from drawings by the in-house mechanical engineering company, and is 74,000 sf, and 104,000 sf when check processing areas are included.<sup>8</sup> The UPS data, estimated UPS losses, and computer densities are listed in the table below.

**TABLE 1. UPS ELECTRICAL MEASUREMENTS**

	<b>Sep 14 (Sat)</b>	<b>Sep 28 (Sat)</b>	<b>Sep 29 (Sun)</b>	<b>Oct 1 (Tue)</b>	<b>Oct 5 (Sat)</b>	<b>Oct 6 (Sun)</b>
UPS 1 Input (Exide)	1056	861	862	1112	976	980
UPS 2 Input (Teledyne)	820	765	780	820	808	808
Total UPS Input (kW)	1876	1626	1642	1932	1784	1788
Calculated UPS Output (kW)	1501	1301	1314	1546	1427	1430
Calculated UPS Losses	375	325	328	386	357	358
Computer Density (W/sf)	20	18	18	15	19	19
Projected Computer Density (W/sf)	24					

The total UPS input power varies from 1626 kW to 1932 kW, with the peak power on a the only weekday measurement. The check processing rooms, which are variable loads are likely to account for this difference between weekday and weekend operation. However, the deviation from weekday to weekend operation is relatively small at 200 kW, or 10%. Note, the weekday measurements were taken during working hours in the early afternoon. This suggests that the check processing is additional load is an insignificant, or is highly variable even during weekday, working hours. The weekend measurements vary between 1626 kW and 1876 kW. The computer load density varies from 15 W/sf to 20 W/sf, with the minimum corresponding to the weekday operation. This value is small compared to measurements made at other facilities, which have computer load densities of 30 – 50 W/sf.

The Data Center Occupancy is a qualitative estimate of how physically full the rooms are. Per a meeting with the facility personnel, the approximate occupancy of each floor was obtained, and a geometrically weighted average occupancy was estimated. Based on this rough occupancy of 80%, the fully loaded computer load density, excluding the check processing areas, is projected on average to be 24 W/sf.<sup>9</sup>

## COOLING SYSTEM

The facility has a central plant that serves both the data centers and office areas. It consists of four constant speed centrifugal chillers. Three of these were installed in 1973

<sup>8</sup> The check processing areas are included for calculating the computer load density for the weekday measurement obtained on October 1.

<sup>9</sup> Occupancy, and square footage data based on estimate given by facility.

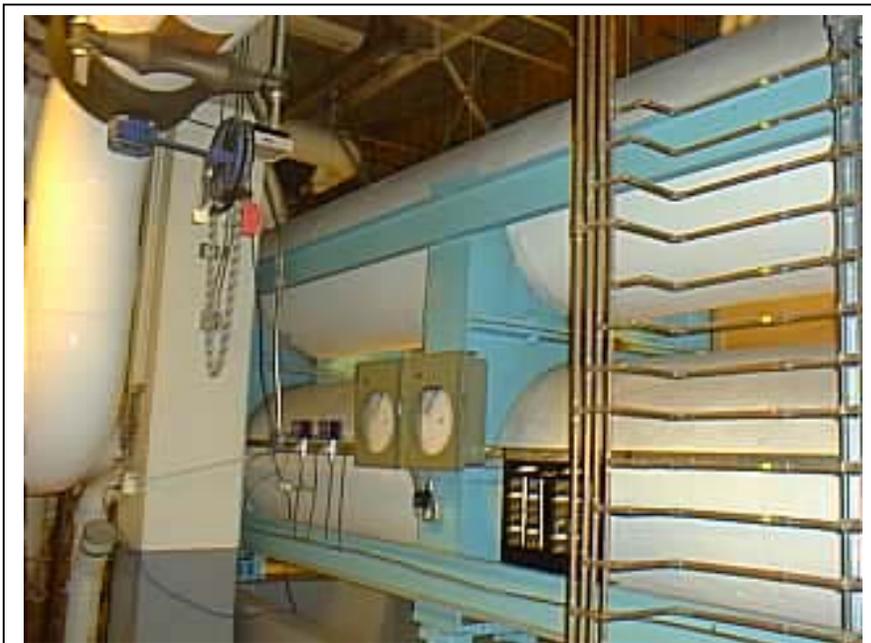
and have a capacity of 1500 tons.<sup>10</sup> During an expansion that occurred in 1994, a fourth chiller was added with a capacity of 1380 tons.<sup>11</sup> The purpose of the expansion was to split the chilled water plant into two side, for redundancy purposes.

The chillers are cooled by eight variable speed drive cooling towers, which are forced draft and are located indoors. These are typically operated in groups of four. The chilled water setpoint is 42 °F, and the condenser water setpoint is 68 °F. The chilled water is supplied in two directions by primary pumps. The main loop is fed to eight large air handlers, and the UPS room CRAC



**Chiller 4**

units. There are four primary pumps, three originally installed, and one of which was installed during the expansion. They are driven by 150 horsepower (hp) and 125 hp



**Intercoolers**

motors. One primary chilled water pump is typically on. There are five condenser water pumps, three older, and two newer, 75 and 60 hp. One condenser pump is typically on. The secondary loop that feeds the CRAC units is separated from the primary loop by two shell and tube heat exchangers.

<sup>10</sup> Per mechanical schedule. Based on a evaporator flow rate of 3000 gpm, entering and leaving chilled water temperatures of 54 °F and 42 °F, respectively.

<sup>11</sup> Per mechanical schedule. Based on a evaporator flow rate of 2756 gpm, entering and leaving chilled water temperatures of 54 °F and 42 °F, respectively.

There are six secondary loop pumps, all 125 hp. A 200,000 gallon thermal storage tank provides backup chilled water if needed, but is typically not used. As mentioned, the chilled water plant is split into two sides that are mirror images. Each side includes two chillers, one shell and tube heat exchanger, two primary chilled water pumps, two/three condenser water pumps, and three secondary loop pumps.

The CRAC units, each have a 20 ton capacity. They are supplied chilled water by the secondary loop. A bypass valve controls flow to maintain a differential pressure in the secondary loop. Each CRAC has two way control valves. The units control to a return temperature setpoint of 70 °F, and relative humidity of 50% ± 5%. Humidity control has been disabled on several of the units. There are two overhead air handlers that supply 55 °F air to the data center areas. Each has an air flow capacity of 170,000 cubic feet per minute (cfm), and cooling capacity of 6,227,000 British Thermal Units per hour (Btu/hr) or 520 tons. The overhead air handlers mix a minimal amount of outdoor air with return air, and do not have motorized dampers for outdoor air economizing. Steam is supplied for humidification.



Spot power measurements were obtained on the pumps, air handler fans, and CRAC units using a power meter (PowerSight). Long term power monitoring was setup on the cooling tower fans, chillers, and CRAC units over a period of four weeks. Since the chiller load serves office air handlers, data center air handlers, and the CRAC units, it was necessary to identify the chilled water supplied solely to the data center, in order to segregate the chiller power consumption due to cooling of the data center only. Consequently, the chilled water supply, return, and flow were monitored to each air handler. When combined with the secondary chilled water load, the total chilled water load to the data

center can be determined. Where possible, data was obtained from the EMCS. This included individual chiller flow, chilled water supply and return temperatures, secondary loop chilled water flow, secondary loop chilled water supply and return temperatures, and chiller current. The monitored chiller current is for one phase, and is converted to power using the monitored power factor. Using this information, the chiller efficiency, total chilled water plant efficiency, and data center cooling efficiencies were determined.

The spot measurements, and average of trended and monitored points are listed in the table below. Please refer to the Appendix for graphs of the measurements over the entire monitored period, and tables with measurements for corresponding to each weekend day of operation during the measurement period. The "Data Center HVAC Pumps, Chiller, Cooling Tower" includes the chiller pump, chiller, and cooling tower power proportioned to the data center cooling load. The "Data Center HVAC Air Movement" power includes the total power for the data center dedicated overhead air handlers, as well as the CRAC units' power. The CRAC units' power proportioned to the data center load, versus non data center CRAC unit load in order to properly determine electrical end use for the data center.<sup>12</sup>

**TABLE 2. COOLING EQUIPMENT ELECTRICAL AND LOAD MEASUREMENTS**

<b>Equipment</b>	<b>Spot / Monitored / Trended</b>	<b>Average Weekend Measurement</b>	<b>Weekday (Oct 1) Measurement</b>	<b>Units</b>
<b>HVAC Equipment Electrical Measurements</b>				
Chiller 4	Monitored, Modified Trended Data	554.6	--	kW
Chiller 3	Monitored, Modified Trended Data	795.9	801.0	kW
Cooling Towers	Monitored	55.1	35.1	kW
Primary Chilled Water Pump (No. 1)	Spot	111.6	--	kW
Condenser Water Pump (No. 23)	Spot	47.8	--	kW
Secondary (Environment) Chilled Water Pump (No. 20)	Spot	91.7	--	kW
Air Handler 4	Spot and Monitored	41.3	--	kW
Air Handler 5	Spot	40.8	--	kW
CRAC Units (EACs) Total	Monitored	350.6	412.2	kW

<sup>12</sup> All CRAC units condition computer room equipment, but for the CRAC unit that conditions the Teledyne UPS room.

<b>Equipment</b>	<b>Spot / Monitored / Trended</b>	<b>Average Weekend Measure- ment</b>	<b>Weekday (Oct 1) Measure- ment</b>	<b>Units</b>
<b>Cooling Load Measurements</b>				
Chiller Tonnage	Trended	861	968	Tons
Cooling Provided by CRACs - Computer Room Cooling	Monitored	511	563	Tons
Cooling Provided by Air Handlers 4 and 5	Monitored	120	126	Tons
Data Center - Total Measured Cooling Load	Monitored	632	689	Tons
<b>Chiller Efficiency</b>				
Chiller 4 Efficiency	Monitored	0.6		kW/Ton
Chiller 3 Efficiency	Monitored	0.9		kW/Ton
<b>Data Center Attributed Electrical Consumption</b>				
Chiller	Calculated from Monitored Data	488	570	kW
Cooling Tower	Calculated from Monitored Data	39	25	kW
Primary Chilled Water Pump	Calculated from Spot Data	82	--	kW
Condenser Water Pump	Calculated from Spot Data	35	--	kW
CRAC Units (EACs) - Computer Room Cooling	Monitored	317	371	kW

The “HVAC Equipment Electrical” lists the measured electrical load for all cooling equipment that contributes to cooling the data center. This includes the chilled water plant components, the air handler units, and CRAC units. Chiller 3 consumes on average 796 kW. Chiller 4, which is the newest chiller, consumes 555 kW. The average efficiency of chiller 4 is superior to Chiller 3’s efficiency. This is discussed in more detail in the HVAC Efficiency Metrics and Energy Efficiency Recommendations Sections. The individual pump power is comparable to the total air handler power, and the cooling tower power. This presents a ripe opportunity for energy savings. The air handler power was monitored over a period of several days, and exhibited little variation during the monitored period. Finally, the CRAC unit power is substantial, and rivals the chiller power. Interestingly, the CRAC unit power did not vary much between weekend and weekday operation. Rumsey confirmed with the Building Operators that all but one CRAC unit were off in the areas serving the check processing. However, the CRAC unit

electrical loads show little decrease between weekday and weekend operation, averaging at 15%. This is consistent with the variation in the UPS input power, which was 10%.

The total chiller tonnage averaged at 860 tons for weekend periods. The CRAC units constituted a large part of this load, at 510 tons. The CRAC unit cooling load increased only slightly for the weekday measurement. On average, the CRAC cooling load showed a decrease of only 8% from weekend to weekday operation. This is consistent with the UPS input and CRAC unit power measurements.

Using the measured electrical consumption of the equipment is combined with the measured cooling loads to determine the portion of the HVAC equipment power accountable to the data center. This data is presented in more detail in the “Data Center Electricity End Use” Section.

## LIGHTING

Lighting to the data centers is provided by T-8 tubular fluorescent lamps. Lighting to the data center floors alone could not be obtained. As a result, for purposes of the computing the data center end use, a lighting density of 1.5 W/sf is used. This assumption is used, since the facility's lighting resembles standard office lighting design.

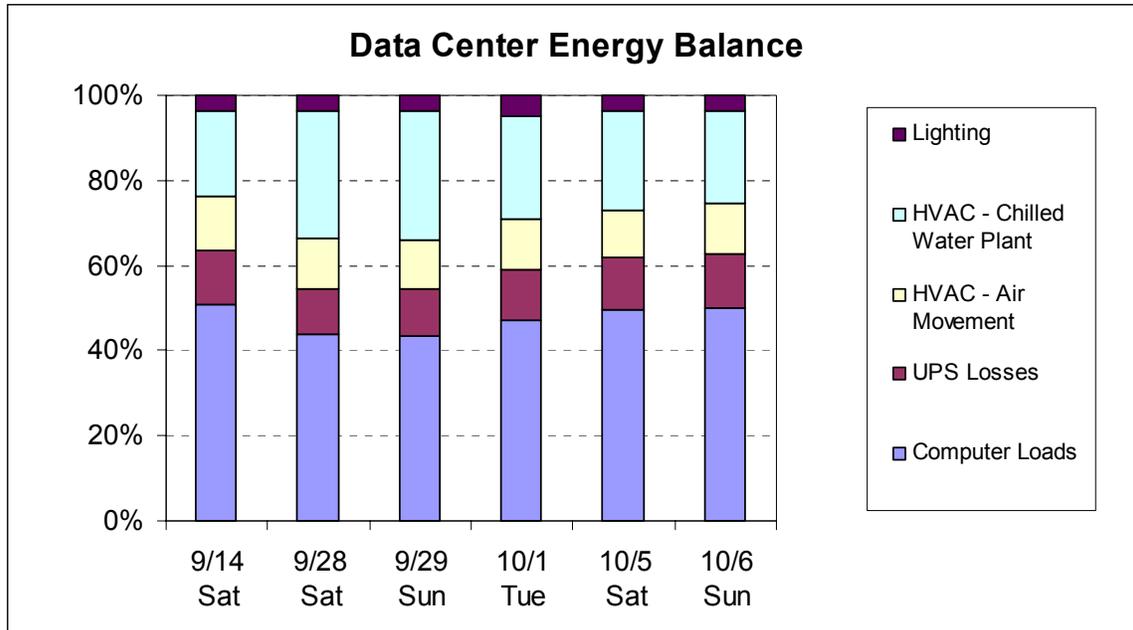
## DATA CENTER ELECTRICITY END USE

The measurements in the preceding sections are used to illustrate the Data Center Electricity End Use. The following table combines the HVAC, lighting, and computer power. The average energy use includes both weekend and weekday measurements. The same data is shown graphically for all measurement days.

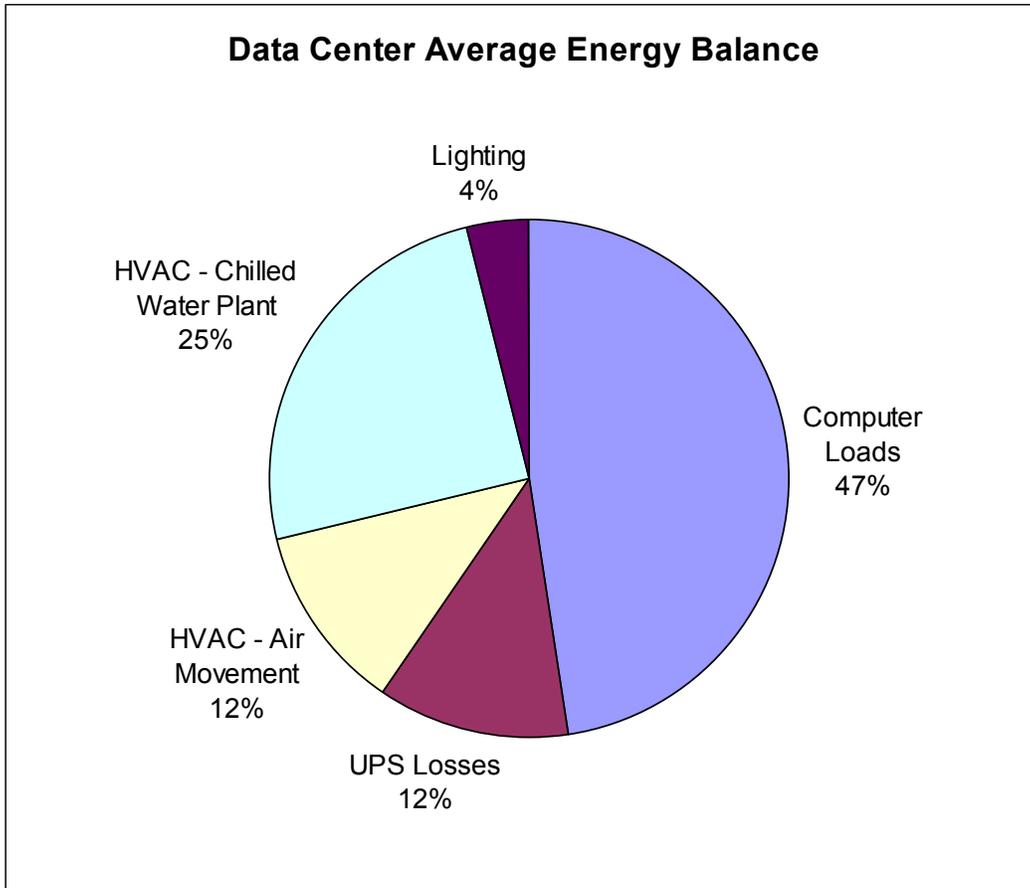
**TABLE 3. DATA CENTER AVERAGE ENERGY USE**

	kW	Percent (%)
Computer Loads	1,420	47%
UPS Losses	355	12%
HVAC – Air Movement	353	12%
HVAC – Pumps & Chiller	747	25%
Lighting	119	4%
Total	2,993	100%

The data is also presented in graphical form below for each monitored day.



The above graph shows that the relative power consumption is fairly constant during the monitored period, with slighter lower computer loads on September 28 and 29. The average power during the monitored period, as a percentage, is shown in the graph below.



The largest data center energy consumer are the computer loads at 47% of the total. The UPS losses, though based on an efficiency estimate, are large even at an accuracy of  $\pm 10\%$  (355 kW  $\pm$  36 kW). The HVAC power consumes  $\sim 1100$  kW, or 37% of the total data center power. This is a substantial amount of power, both in a relative, and absolute sense, and represents an opportunity for energy savings. The lighting loads are relatively small, compared to the other loads, at 119 kW, or 4% of total data center energy use; however, there is an opportunity to reduce lighting levels, and to implement lighting controls.

All the above areas present significant opportunities for energy savings. More details are included in the Energy Efficiency Recommendations Section. A more detailed discussion of efficiency metrics also follows.

### WHOLE BUILDING ELECTRICITY END USE

Energy consumption of the whole building was obtained by taking spot readings of the instantaneous power (kW) from the utility meters. This data was consolidated with the monitored data to develop the end use for the whole building. The data is shown in two ways. The first method shows separates the data center electrical consumption from the office and miscellaneous spaces electrical consumption. The purpose is to illustrate the

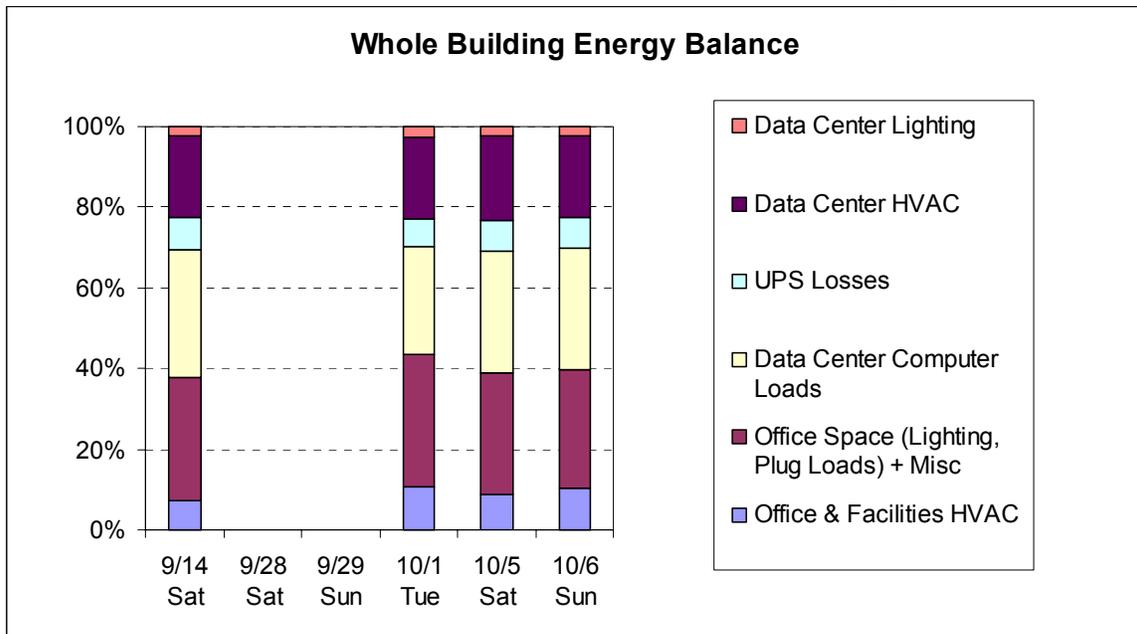
relative contribution of the data center to the whole building power consumption. The table below lists the average whole building electricity consumption.

**TABLE 4. WHOLE BUILDING AVERAGE ELECTRICITY END USE. METHOD 1.**

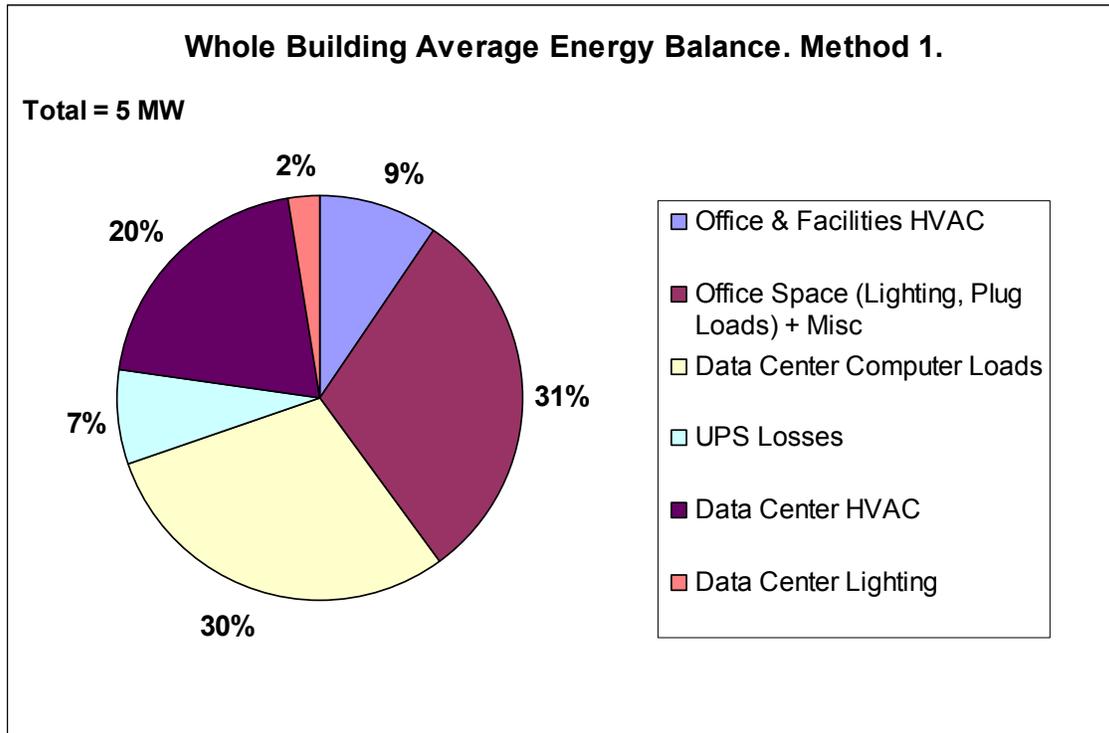
Category	Average, Weekend		Weekday	
	kW	Percent (%)	kW	Percent (%)
Office & Facilities HVAC	423	9%	470	9%
Office Space (Lighting, Plug Loads) + Misc.	1422	30%	1547	31%
Data Center Computer Loads	1453	31%	1476	30%
UPS Losses	363	8%	369	7%
Data Center HVAC	970	20%	1022	20%
Data Center Lighting	111	2%	122	2%
Total Building Load	4742	100%	5007	100%

The whole building consumes an average of 5 MW of electricity. The weekday consumption is approximately 1 MW more than for the weekend, or 20% larger. This increase is seen mainly in the office space and miscellaneous loads, which include elevator loads, and smaller increases in other categories. In both modes of operation, the percentage breakdown of electricity use stays fairly constant. The major consumers are 1) the data center computer loads, 2) the office plug loads, lighting loads, and miscellaneous loads (which include elevator loads), and 3) the data center HVAC. They are approximately 30%, 30%, and 20%, respectively, or 70% together.

Measurements for the electrical consumption for each day are shown graphically below.



The above graph shows that the shift in electrical consumption between weekday and weekend operation is small. The graph below shows the overall average relative consumption in a different format.



The second method of showing the whole building electrical end use, is by the major categories of equipment, per their assignment to the utility meters. The distinction between data center and non-data center consumers is not made.

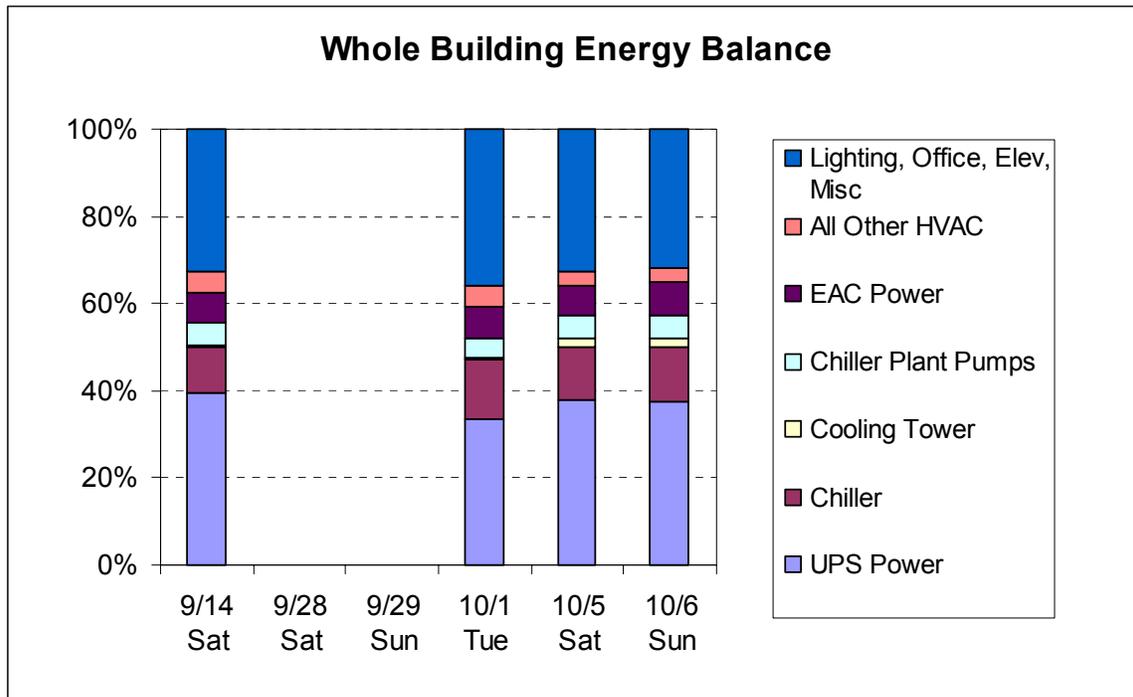
**TABLE 5. WHOLE BUILDING AVERAGE ELECTRICITY END USE. METHOD 2.**

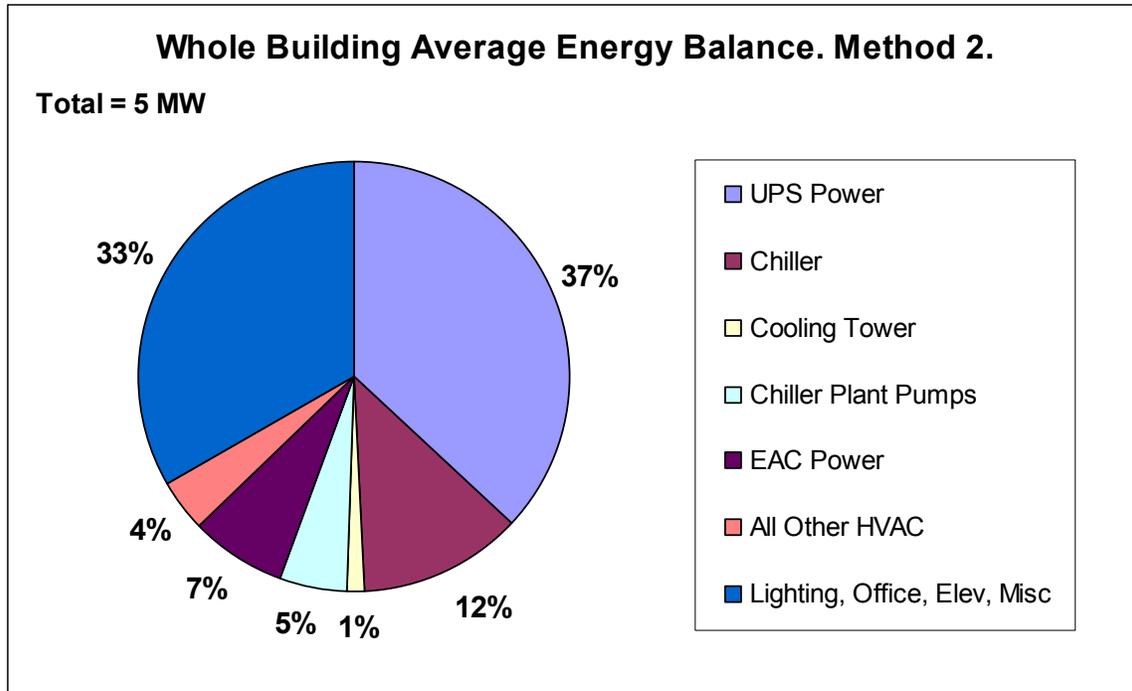
Category	Average, Weekend		Weekday (Oct 1)	
	kW	Percent (%)	kW	Percent (%)
UPS Power	1816	38%	1932	33%
Chiller	555	12%	801	14%
Cooling Tower	69	1%	35	1%
Chiller Plant Pumps	251	5%	251	4%
EAC Power	338	7%	412	7%
All Other HVAC	180	4%	294	5%
Lighting, Office, Elevators, Misc.	1533	32%	2077	36%
Total Building Load	4742	100%	5802	100%

The largest consumer is the UPS power at approximately 1.9 MW, or 38% for weekend operation, and 33% for weekday operation. The difference between this value, and the one cited before is due to the UPS losses. The total HVAC power for the whole building

is approximately 30% for both scenarios, and the office, lighting, elevators and miscellaneous loads account for 34%. This representation further emphasizes the electrical consumption of HVAC equipment, and the relevance of energy efficiency measures. As shown earlier, approximately 2/3 of the HVAC power can be attributed to the data center cooling exclusively. The category of lighting, office, elevators, and miscellaneous sources emphasizes that lighting, as well as power management within offices is important, though this is not a focus of the study.

The relative electrical consumption is shown graphically below, for each day in the monitored period, and for the overall average.





The above graph shows three distinct areas: the UPS power, the lighting, office and miscellaneous loads, and the collection of consumers that make up the HVAC. Notice the chiller consumes approximately 12% of the total building power. Assuming a rough 5 MW of total consumption and \$0.12/kWh, this translates to a yearly cost of roughly \$0.6 million! The chiller plant pumps and CRAC /EAC power are also quite significant, at 5%, and 7%, respectively.

### **HVAC EFFICIENCY METRICS**

The performance of the HVAC system can be evaluated based on energy efficiency metrics. Though the cooling power is represented in W/sf, a more useful metric for evaluating how efficiently the data center is cooled can be represented as a ratio of cooling power to computer power. This essentially removes the variable of how tightly packed the computers are.

The “theoretical cooling load” is the same as the sum of the computer loads, lighting loads, and fan energy. This is a good cross check. Differences can be attributed to the error in estimating UPS losses (which decrease the data center cooling load), duct losses, as well as unaccounted human load.<sup>13</sup> The more traditional metrics of energy per ton of cooling (kW/Ton) are calculated for individual chillers, total chilled water plant (chillers, cooling towers, pumps) and the data center cooling efficiency. The data center cooling efficiency includes the chilled water plant power weighted by the data center load, data center air handler and CRAC unit power.

<sup>13</sup> The fan energy included in the theoretical cooling load, removes an estimate of CRAC unit energy dedicated to the UPS that is cooled by the secondary loop.

**TABLE 6. AVERAGE EFFICIENCY METRICS**

<b>Metric</b>	<b>Value</b>	<b>Units</b>
Building Energy Density	3.6	W/sf
Data Center Computer Power Density	18	W/sf
Data Center Cooling Power Density	15	W/sf
Non Computer Load Density	21	W/sf
Cooling kW / Computer Load kW	0.7	--
Chiller 3 Efficiency	0.9	kW/ton
Chiller 4 Efficiency	0.6	kW/ton
Chilled Water Plant Efficiency	1.1	kW/ton
Total Data Center HVAC Efficiency	1.7	kW/ton
Theoretical Cooling Load *	572	Tons
Cooling Provided by CRAC Units	520	Tons
Cooling Provided by Air Handlers	121	Tons
Measured Cooling Load	641	Tons

\* Based on computer loads, lighting loads, and fan energy.

The “cooling efficiency” is 0.7 Cooling kW/ Computer kW.<sup>14</sup> This means that for 1 kW of energy input, only 1.4 kW of energy is removed. This value is slightly higher than the measured efficiencies of 0.5 kW/kW and 0.6 kW/kW at two other monitored data centers. The former utilizes air cooled chillers, and fan coil units, while the latter utilizes air cooled CRAC units. Both are considerably smaller in size, at 2500 sf, and 8600 sf. Another monitored site has an efficiency of 1.3 kW/kW. This data center utilizes a water cooled reciprocating chiller and computer room air handlers with humidification and reheat. This data center is also smaller at 8900 sf. Without going into details of these sites, it is interesting that a system that could operate efficiently (e.g., water cooled chilled water plant), isn’t necessarily more efficient than the standard air-cooled computer room air conditioners if the fundamental equipment, pumping, and air delivery systems are not efficient.

Chiller efficiencies were obtained for chillers 3 and 4, and on average are 0.9 and 0.6 kW/ton, respectively. This is expected, since chiller 3 was installed as part of the original plant, and chiller 4 was installed in 1994. However, though, Chiller 4 is a fairly new centrifugal chiller, its efficiency is not comparable to what it should be for the actual operating conditions, which are more favourable than the standard conditions at which the unit is rated at.<sup>15</sup>

<sup>14</sup> The “Computer kW” includes the entire Exide UPS input, since the cooling kW is proportioned based on the secondary loop tonnage, which includes chilled water supplied to the Exide UPS CRAC units.

<sup>15</sup> The rated conditions are: 80 °F entering condenser water temperature, chilled water setpoint of 42 °F. The operating conditions are: 68 °F entering condenser water temperature, chilled water setpoint of 42 °F.

The total chilled water plant efficiency, which includes the pumping and cooling tower power is 1.1 kW/ton. To put this in perspective, an efficient chilled water plant, such as all variable speed chilled water plant can operate at efficiencies between 0.5-0.7 kW/ton. The measured efficiency at this facility is comparable to standard chilled water plant efficiencies, with constant speed pumping, and constant speed chillers. These efficiencies typically vary between 0.8-1.2 kW/ton. The total HVAC efficiency, including air handling is 1.7 kW/ton. A standard HVAC design, utilizing similar equipment will typically operate at 1.5 kW/ton, while a range of 0.8-1.0 kW/ton is characteristics of efficient design.

Opportunities for energy savings exist, from simple measures to more complex and longer payback measures. These are described in the next section.

## **VI. Energy Efficiency Recommendations**

### **IN HOUSE ENGINEERING RECOMMENDATIONS**

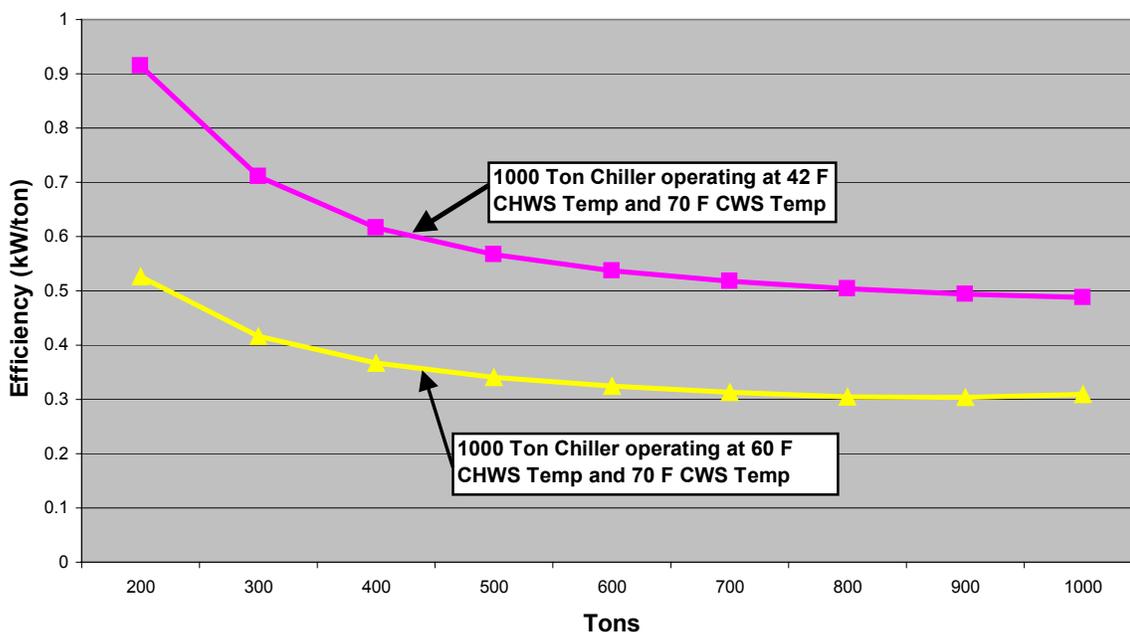
Rumsey was provided with a report titled “Final Report, SFDC Energy Study”, dated October 5, 2001, by the facility’s in-house engineering group. We concur with many of the recommendations, which also addressed the whole building energy. In particular, the replacement, or addition of a dedicated VSD centrifugal chiller, and variable speed pumping on the secondary loop is suggested in this report. Note, however, we have not reviewed the calculation methodologies (as they were not apparent), or the assumptions utilized.

### **DEDICATED CHILLER FOR DATA CENTER, AND/OR OTHER CONTROL MEASURES**

The facility currently utilizes the same chiller for the office cooling and data center cooling. The operating chiller cools water to a temperature of 42 °F, yet, the intercooler maintains a chilled water supply temperature of 48 °F for the CRAC units. The data taken in the monitored period, which includes 5 weekend days, and a 1 weekday, suggests that majority of the chiller load is absorbed by the CRAC unit load dedicated to the computer rooms (hereafter referred to as the CRAC unit load): During the weekend periods, the CRAC unit load averages at 59% of the chiller load, and was 58% of the chiller load on the weekday measurement. If the air handler load that is dedicated to the data center floors is included, then, the total measured data center load on weekend, and weekday operation is 73%, and 71%, respectively.

The chilled water setpoint has a direct correlation on the efficiency of the chiller. The measured efficiencies of chiller 3, and chiller 4 were 0.9 kW/ton, and 0.6 kW/ton, respectively. Greater efficiencies can be achieved if this supply temperature is raised. Though, each individual chiller is unique in terms of its operating characteristics, in general an “energy efficiency” rule of thumb is that the chiller’s efficiency increases by 2% for every 1 °F rise in chilled water setpoint. The graph below, based on measured data illustrates this point.

## Comparison of Low Temperature and Medium Temperature Chillers



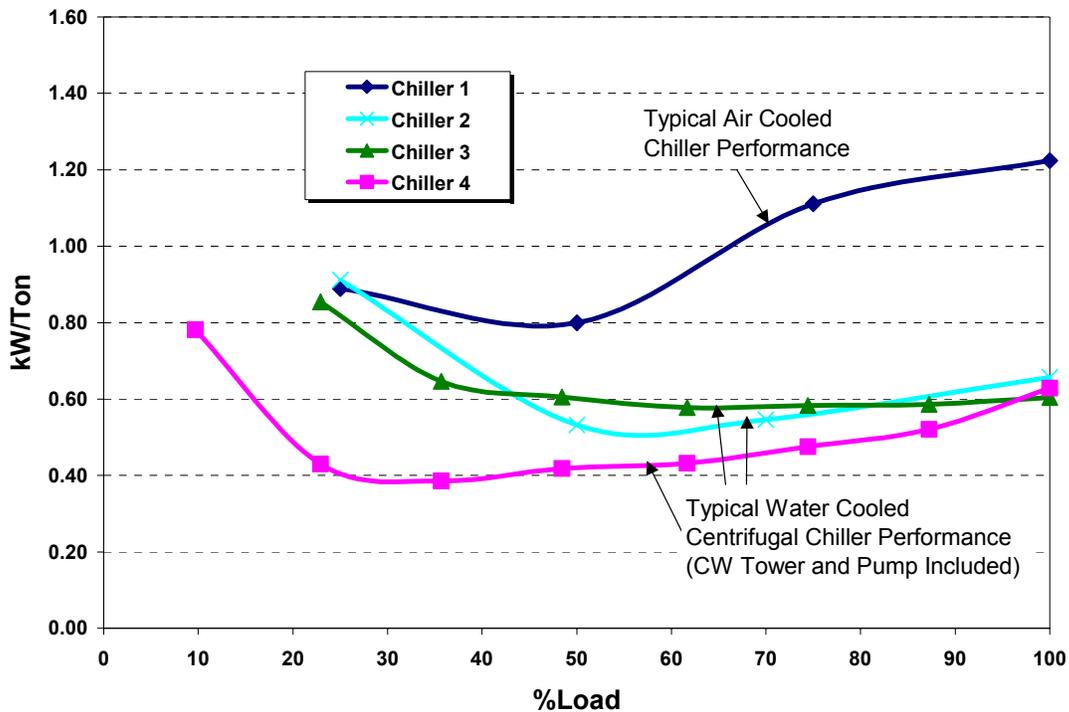
Suppose the Facility operated chiller 4 at a supply temperature of 48 °F, the chiller efficiency will be approximately 0.54 kW/Ton. If chiller 4 is operated instead of operating chiller 3 at a supply temperature of 42 °F, at the average data center load of 660 tons (average of weekend and weekday measurement), 2,081,376 kWh of energy will be saved per year, or approximately \$250,000 at \$0.15/kWh.

It is likely that the temperature is kept so low, because the chilled water flow to the farthest air handler is inadequate, and thus has to be compensated with cooler water. Investigating this problem could also be considered, and if it is possible for the main building air handlers to accept warmer chilled water, then this may be the simplest solution.

The most energy efficient solution is to install a data center dedicated chiller, preferably a centrifugal, variable speed drive (VSD) type. This allows the data center chiller to operate efficiently at part-load, and also allows for expansion in the data center, without concern of having cooling capacity. The existing chillers, including the newest chiller (4), are constant speed centrifugal type chillers. These chillers achieve lower loads, by adjusting inlet guide vanes of the compressor, which causes the refrigerant to swirl, and thus reduces the flow through the refrigerant cycle. A much more efficient mechanism of reducing refrigerant flow, and hence, chiller loading, is to reduce the speed of the motor, that is, install a VSD. The cost of VSDs in general has decreased dramatically in the past couple years, and VSD chillers are becoming more and more common. The graph below compares the typical efficiencies of different chiller types.

Recent conversations with the facility confirm that they are in the process of raising the chilled water setpoint to 48 °F for all chillers, and to 52 °F for the environmental chilled water. The facility is also in the process of installing VFDs on both Chillers 3 and 4. With these changes, the addition of a new, dedicated chiller is not required.

Comparison of Typical Chiller Efficiencies over Load Range



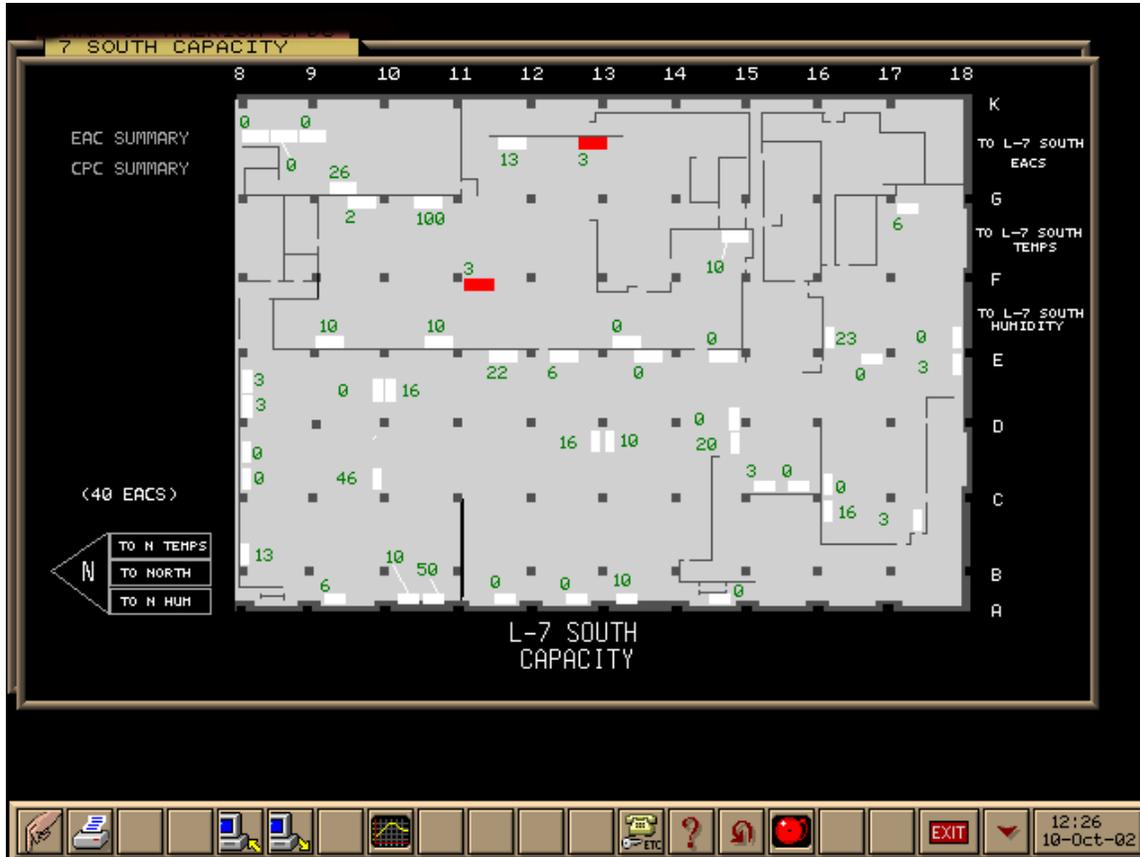
Chiller 1	250-Ton, Screw, Standard Efficiency, Air Cooled
Chiller 2	216 Ton, Screw, Water Cooled
Chiller 3	227-Ton, Centrifugal, Constant Speed, Water Cooled
Chiller 4	227-Ton, Centrifugal, Variable Speed, Water Cooled

The above graph clearly shows the advantage of a constant speed centrifugal VSD chiller over a constant speed centrifugal chiller at part-load conditions. At 35% loading, the VSD chiller is more than 40% more efficient than the constant speed centrifugal chiller. It is our understanding that the facility is contemplating a VSD retrofit of one of the older existing chillers. The facility should also consider a VSD retrofit on Chiller 4, since this chiller is the more efficient chiller.

#### CONVERSION TO VARIABLE SPEED PUMPING ON SECONDARY LOOPS AND OTHER PUMPING SAVINGS

A number of energy efficiency opportunities are available in the pumping of the chiller plant. The most obvious retrofit is to add a VFD to the secondary chilled water loop that serves the data center CRAC units. The system already consists of two-way valves on the

CRAC units, and maintains constant differential pressure in the chilled water supply line by controlling a bypass valve. Even at 48 °F supply temperature, the CRAC units' valves are barely open. The pictures below are snapshots of the CRAC unit monitoring system at the facility.



The picture shows that the CRAC units' valves are at varying positions, though, a majority are less than 20% open. Pumping savings are based on the cube law: pump power is reduced by the cube of the reduction in pump speed, which is directly proportional to the amount of fluid pumped. Assuming an average valve opening of 20%, for simplicity of calculations a linear acting valve, and the measured secondary pump power of 92 kW, a savings of 91 kW would result! This is a direct result of the cube law, and that the current pump is oversized for the existing CRAC units. These savings would amount to approximately 797,160 kWh, or roughly \$100,000/year. Currently, VFDs can be purchased at \$100/hp. The secondary pump's motor is 125 hp. A VFD would cost \$12,500, resulting in a simple payback of 1.5 months, or a return on investment (ROI) of 800%! The bypass valve should be permanently closed with this retrofit.

Premium efficiency motors and high efficiency pumps are recommended. During the retrofit, high efficiency motors were installed, which are more efficient than the motors installed originally. The existing motors should be retrofitted with premium efficiency

motors, and permitting, with VFDs. This would allow for a future retrofit to variable speed pumping on the primary chilled water side.

### **COOLING TOWER STAGING**

These cooling towers have VFDs controlling the speed of the fans. VFDs are very energy efficient on cooling towers, because of the Cube Law savings discussed earlier. This allows the tower fans to modulate, based on varying outdoor air conditions, and to condenser water reset strategies. The facility's condenser water setpoint appears to be 68 °F. This is a fantastic way to achieve energy efficiency from the chillers. Just as chilled water setpoint affects chiller efficiency, lower condenser water temperatures reduce the chiller compressor work. However, the staging of the cooling towers is unclear. During some of the visits to the facility, it appeared that all eight towers were operating, as would be desired much of time. At other visits, it was observed that six towers were operating. The data also suggests that not all eight towers were operating during the monitored period, though, the operators had indicated they were. (The outdoor air conditions didn't change enough for the tower energy per fan to triple. This likely happened from the staging off of tower fans.) The sequencing information observed on the EMCS did not clearly indicate the staging sequence. It is recommended that the staging be based on the principal of operating all towers in parallel, with fewer towers as the fan speed reaches a minimum operating speed. This will ensure that cooling tower fan power is kept at a minimum.

### **REPLACEMENT / ELIMINATION OF INTERCOOLERS**

Currently, the "intercooler" are shell and tube type heat exchangers. If the selection is made appropriately, a plate and frame heat exchangers will have a better approach for less pressure drop. The proper selection will save on pumping energy (if incorporated with the secondary pump VSD recommendation) and will allow the chilled water setpoint to be set to a higher value (currently at 42 °F), which will increase the efficiency of the chiller.

Based on the facility's plan of raising the chilled water setpoint for both building, and data center cooling, the intercooler can be completely eliminated. This unit adds additional pressure drop, and is not required if all systems can receive a common chilled water temperature.

### **ECONOMIZER BASED COOLING**

A significant amount of cooling can be provided by outdoor air, particularly in this climate. Humidity control is often a concern in data center environments when outside air is introduced. This climate, is however, so moderate, that neither high humidity, nor low humidity is concern enough to not take advantage of outdoor air economizing. The air handlers that serve the data centers currently have fixed outside air dampers, and do not do economizing. It is encouraged that in this data center, and in future data centers in a similar climate, strongly consider using outdoor air economizing.

*Recent conversations with the facility indicate that economizing should be possible with these air handlers, though they have not worked properly in the past. The facility has been working with its controls contractors to remedy this problem.*

## **AIR MANAGEMENT**

### **Humidity and Temperature Control**

Over the past several years, the data center community has come to accept that tight humidity control is not an important factor for maintaining reliability of computers. Certainly, very low humidity can promote static electricity, however, tight humidity control, such as  $50\% \pm 2\%$  is certainly unnecessary. It is encouraged, that in non-paper environments, the dehumidification be disabled (this promotes over-cooling, and re-heating) and the humidity control be broadened. (Observation of one of the CRAC units indicated a dead band of  $50\% \pm 5\%$ .) Currently, there are a collection of CRAC units that are permitted to do humidity control, and a number are not. This is in the right direction for saving energy.

### **Turn Off CRAC Units and Replace Perforated Tiles**

The facility appears to be turning off selected CRAC units in areas that no longer have computers. This is certainly in the right direction, and can be pursued, so long as the underfloor is still adequately pressurized. As computers are moved, or removed, the placement of perforated tiles must also be managed. There are sand bags made for data centers that can be placed on perforated tiles.

### **Underfloor – Promote Thermal Stratification**

The standard practice of cooling data centers employs an underfloor system fed by CRAC units. There are a number of potential problems with such systems: an underfloor system works on the basis of thermal stratification. This means that as the cool air is fed from the underfloor, it absorbs energy from the space, warming up as a result, and rises. In order to take advantage of thermal stratification, the return air must be collected at the ceiling level. CRAC units often have low return air grills, and are therefore, simply recirculating cool or moderately warmed air. Even if the grills are located on the top of the unit, the height of the CRAC units is unlikely to be high enough to capture warm air. Furthermore, they are often located along the perimeter of the building, and not dispersed throughout the floor area, where they can more effectively treat warm air. One alternative is to install transfer grills from the ceiling to the return grill.

### **Underfloor – Manage Cabling**

Another common problem with underfloor supply is that the underfloor becomes congested with cabling, increasing the resistance to air flow. This results in an increase in fan energy use. A generous underfloor depth is essential for effective air distribution (We

have seen 3 feet in one facility. See [www.nserc.gov](http://www.nserc.gov)). Also, it is essential that cabling be managed, and that when computers are moved, or removed, the associated cables are also removed.

### **Overhead System Alternative**

An alternative to underfloor air distribution is high velocity overhead supply, combined with ceiling height return. This has been seen to work as efficiently as an underfloor system. A central air handling system can be a very efficient air distribution unit. Design considerations include using VFDs on the fans, low pressure drop filters, and coils.

Another common problem identified with CRAC units is that they are often fighting each other in order to maintain a constant humidity setpoint. Not only is a constant humidity setpoint unnecessary for preventing static electricity (the lower limit is more important), but it uses extra energy. A central air handling unit has a better ability to control overall humidity than distributed CRAC units.

### **Rack Configuration**

Another factor that influences cooling in data centers is the server rack configuration. It is more logical for the aisles to be arranged such that servers' backs are facing each other, and servers' fronts are facing each other. This way, cool air is drawn in through the front, and hot air blown out the back. The Uptime Institute has published documents describing this method for air management.<sup>16</sup> Our observations of the rack type areas of the data centers showed an inconsistent rack configuration. It is suggested that this arrangement be utilized in this data center, and for future data centers.

### **UPS REPLACEMENT**

The UPS efficiency is likely to be poor, particularly, because the UPSs (Exide, and Teledyne) are loaded, on average at 54%, and 40%, respectively. The part load efficiency of the UPS drops dramatically, and observations at a 500 kVA UPS at a facility of comparable age to this facility, exhibited a UPS efficiency of 78%. This UPS was also partly-loaded. It is encouraged that when the new UPS is installed, efficiency is considered, and a gateway installed, so that the UPS can be monitored and trended at the EMCS.

*Recent conversations with the facility indicate that both UPSs are operated such that each UPS should not be loaded by more than 50% for reliability purposes.*

### **COMMISSIONING OF NEW SYSTEMS AND OPTIMIZED CONTROL STRATEGIES**

Many times the predicted energy savings of new and retrofit projects are not fully realized. Often, this is due to poor and/or incomplete implementation of the energy

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<sup>16</sup> <http://www.upsite.com/TUIpages/whitepapers/tuiaisles.html>

efficiency recommendations. Commissioning is the process of ensuring that the building systems perform as they were intended to by the design. Effective commissioning actually begins at the design stage, such that the design strategy is critically reviewed. Either the design engineer can serve as the commissioning agent, or a third party commissioning agent can be hired. Commissioning differentiates from standard start-up testing in that it ensures systems function well relative to each other. In other words, it employs a systems approach.

Many of the problems identified in building systems are often associated with controls. A good controls scheme begins at the design well. In our experience, an effective controls design includes 1) a detailed points list, with accuracy levels, and sensor types, and 2) a detailed sequence of operations. Both of these components are essential for successfully implementing the recommended high efficiency chilled water system described above. Though commissioning is relatively new to the industry, various organizations have developed standards and guidelines. Such guidelines are available through organizations like the Portland Energy Conservation Inc., at [www.peci.org](http://www.peci.org), or ASHRAE, Guideline 1 - 1996.

### **OPTIMIZATION OF EMCS**

The facility currently monitors chilled water flow at each chiller, and in the secondary loop, as well as temperatures. At a minimum, the chiller kW/ton, tonnage of the chiller, and in the secondary loop could be calculated and displayed on the EMCS. Though this is easy to calculate, having the value as a point and displaying it is valuable. If a correlation is made between the tower fan Hz, and power, (once the data for one point is made, then power is known at all speeds, since power is directly proportional to motor speed), then the variable portion of the electrical consumption by the entire chilled water plant is known. If the secondary pump is retrofitted with a VFD, then its consumption can also be added to this total kW/ton.

Another observation by the monitoring team is that the retrieval and transfer of Trend data to a remote computer can be performed easily using a copy and paste to clipboard function. Therefore, past data from the EMCS can be retrieved and analyzed on a continual basis quite easily, which will facilitate making controls and energy efficiency recommendations. Though the operations personnel view trend data and graphs on a continual basis *at* the EMCS, this functionality may help design engineers and non-operations personnel in making engineering decisions.

### **LIGHTING CONTROLS**

The observed lighting appeared to be much larger than what is needed for data centers. In addition, all computer rooms that appeared to be unoccupied were fully illuminated. Lighting controls, such as occupancy sensors may be appropriate for areas that are infrequently, or irregularly occupied. If 24 hour lighting is desired for security reasons,

scarce lighting can be provided at all hours, with additional lighting being provided for occupied periods. The estimated lighting consumption for the data center is at 119 kW.<sup>17</sup>

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<sup>17</sup> Assuming 1.5 W/sf, and the data center gross areas, as obtained from facility's engineers.

# **APPENDICES – MONITORED DATA – FACILITY 7**

**CHILLED WATER PLANT GRAPHS**

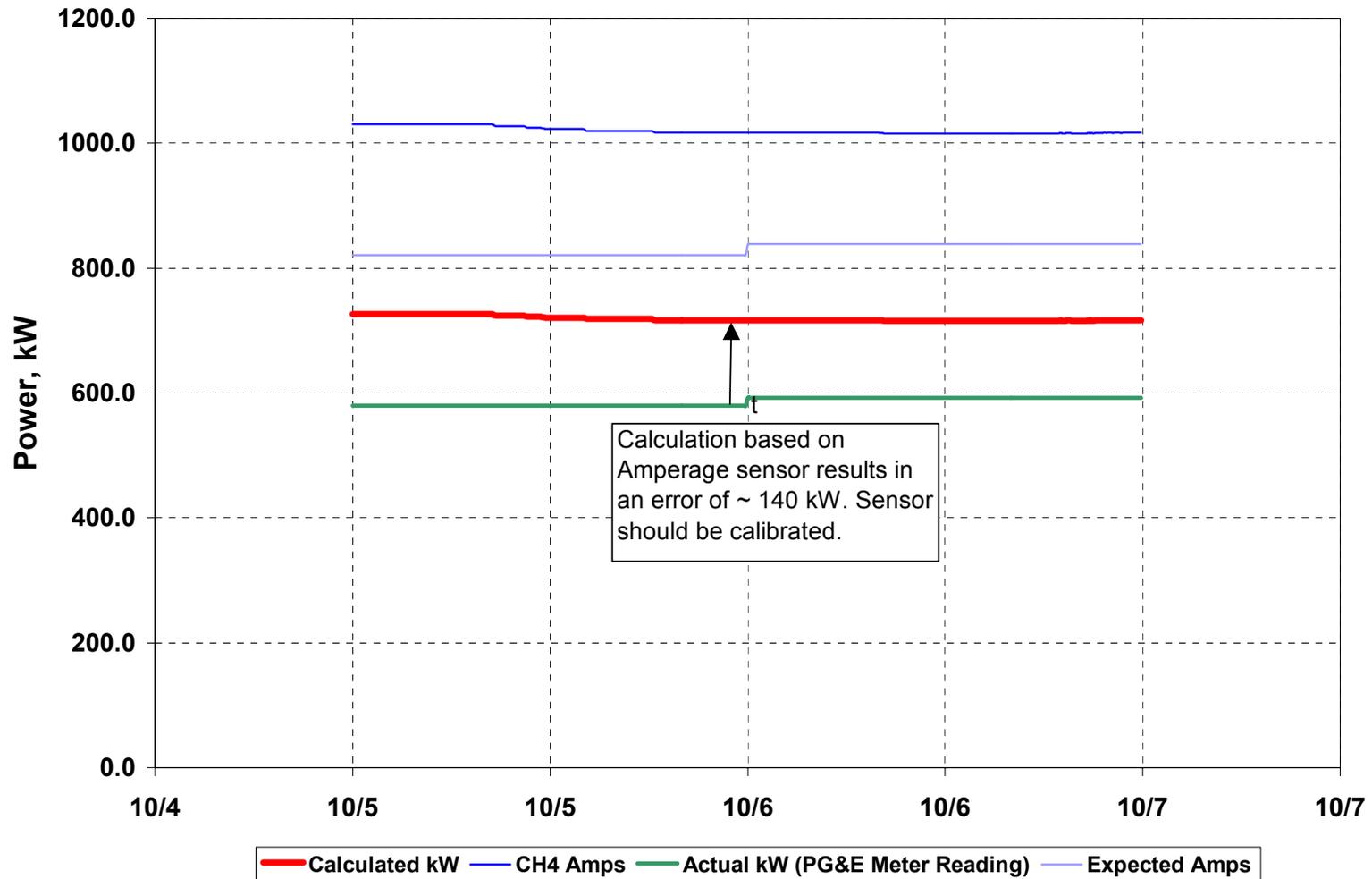
**AIR HANDLER GRAPHS**

**CRAC UNIT / EAC GRAPHS**

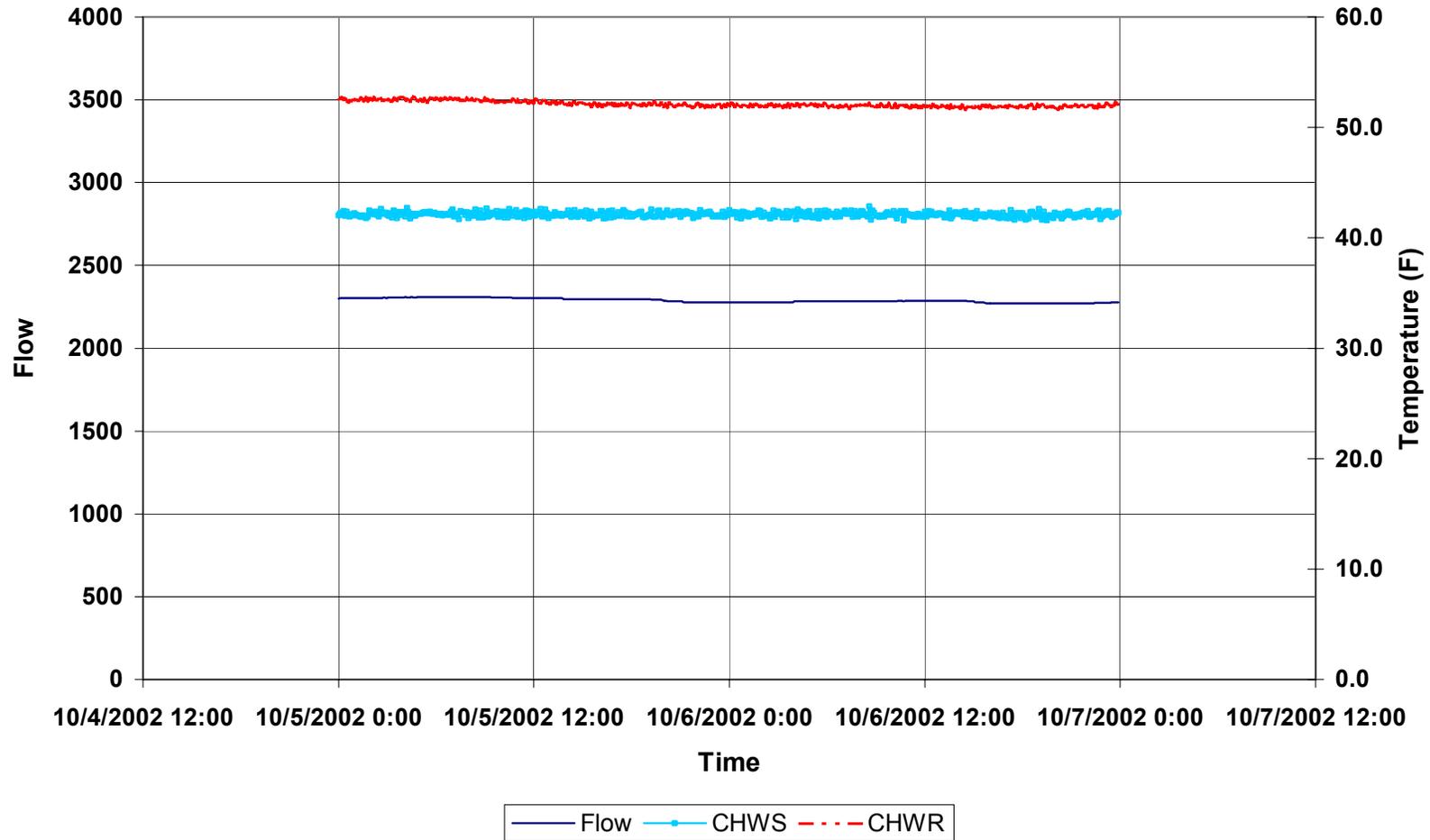
### Facility B Data Center Chiller 4 Measured Power



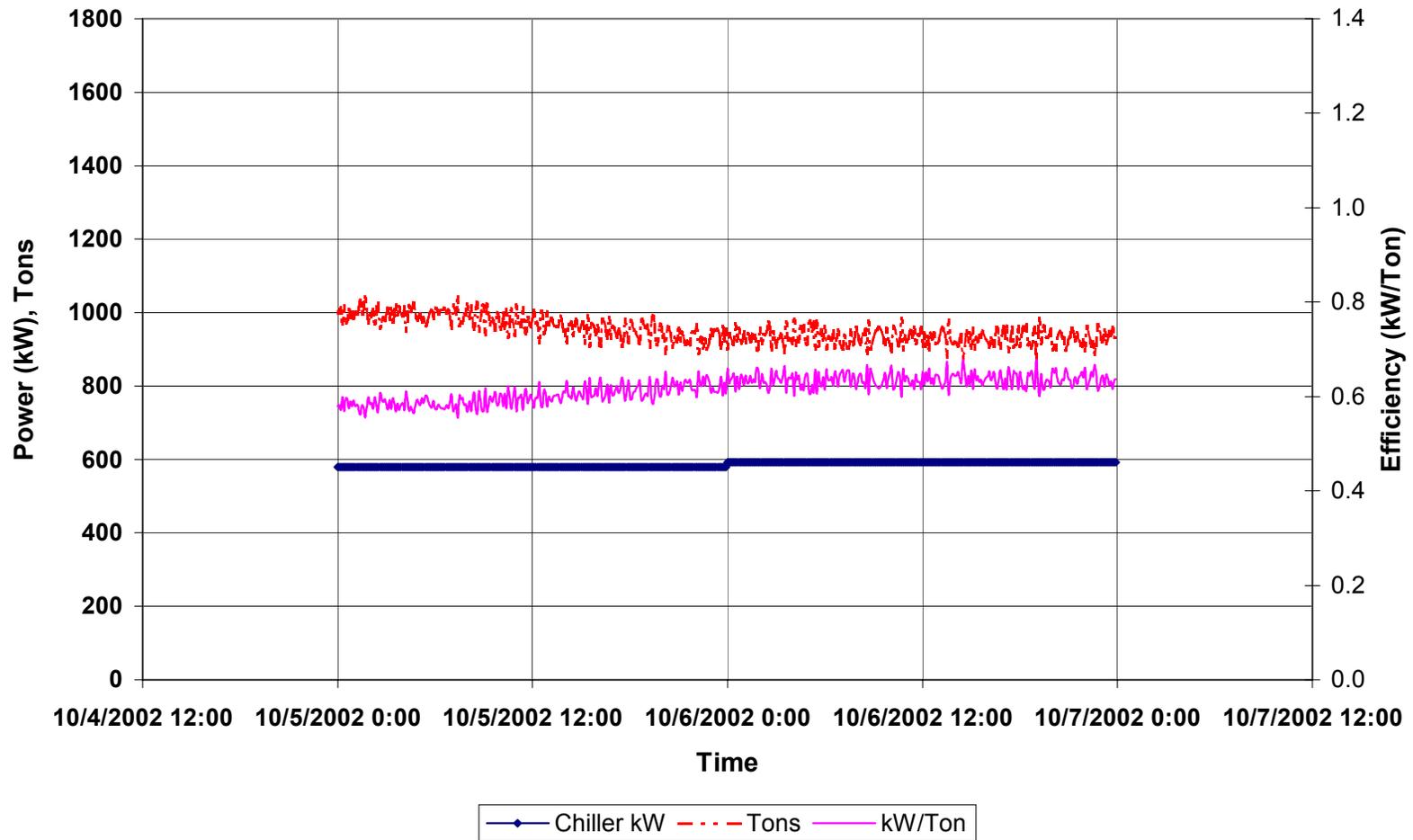
## Facility B Data Center Chiller 4 - Amps Sensor Error



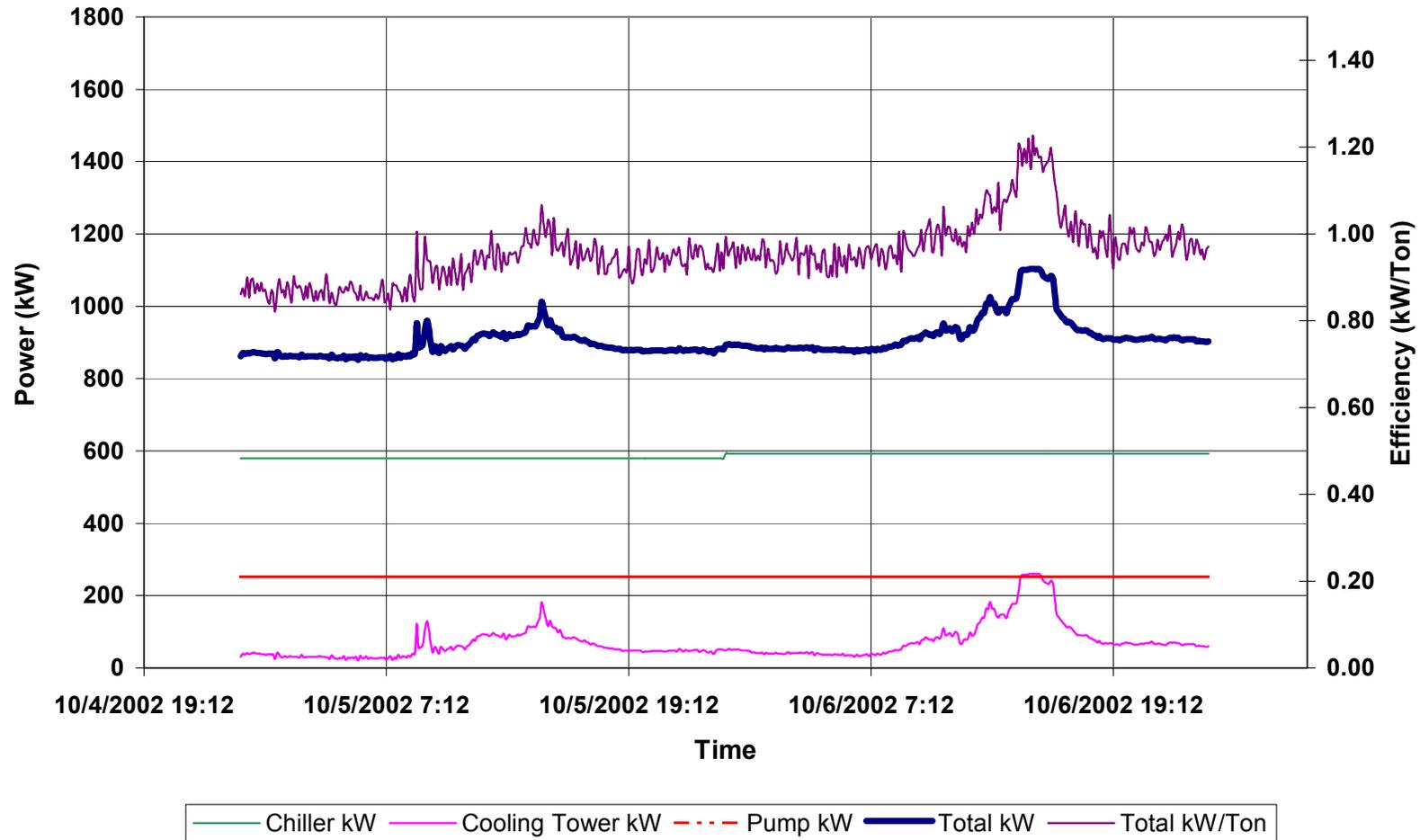
## Facility B Data Center Chiller 4 Flow and Temperature - Oct 5 and 6



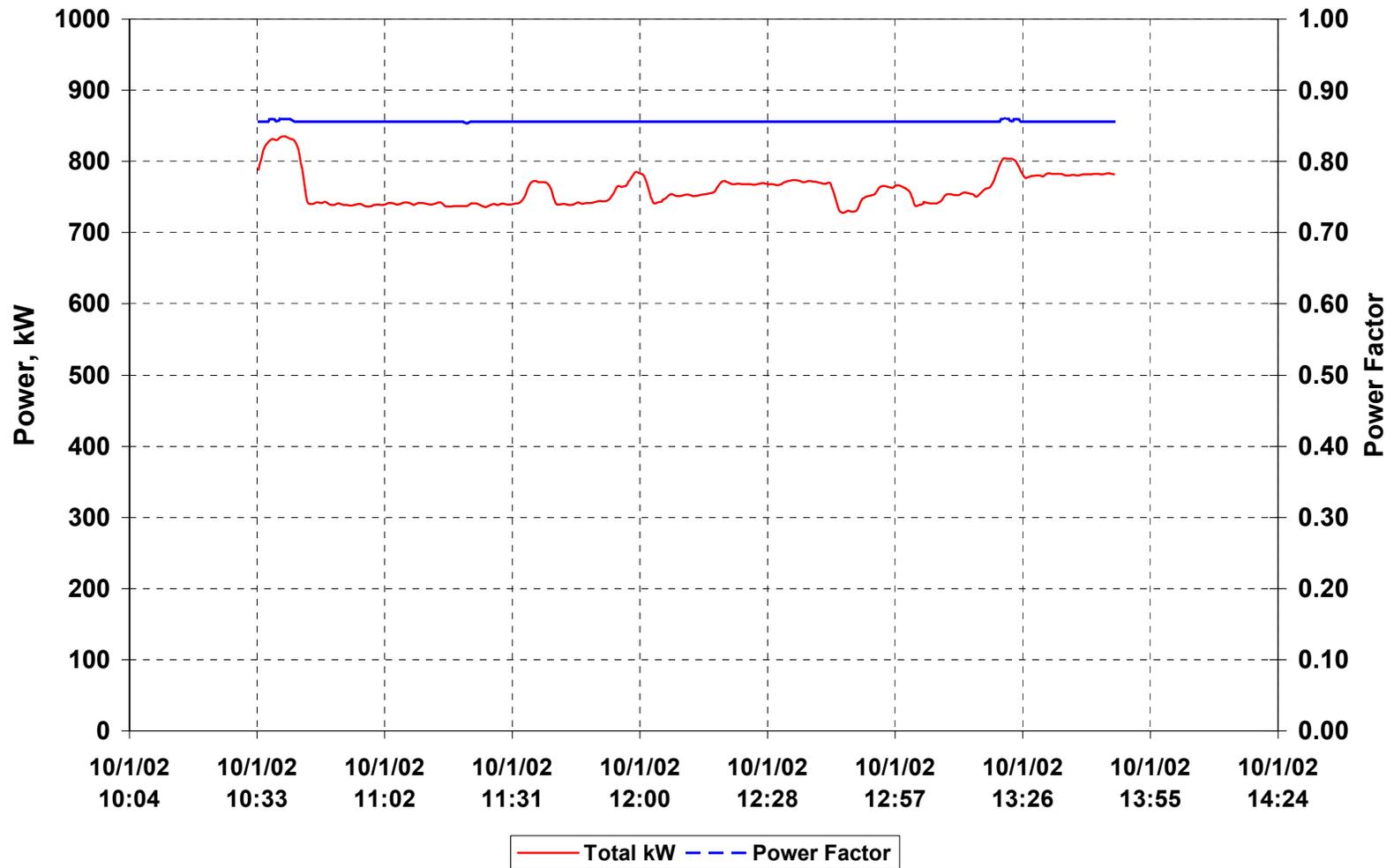
# Facility B Data Center Chiller 4 Power, Load and Efficiency - Oct 5 and 6



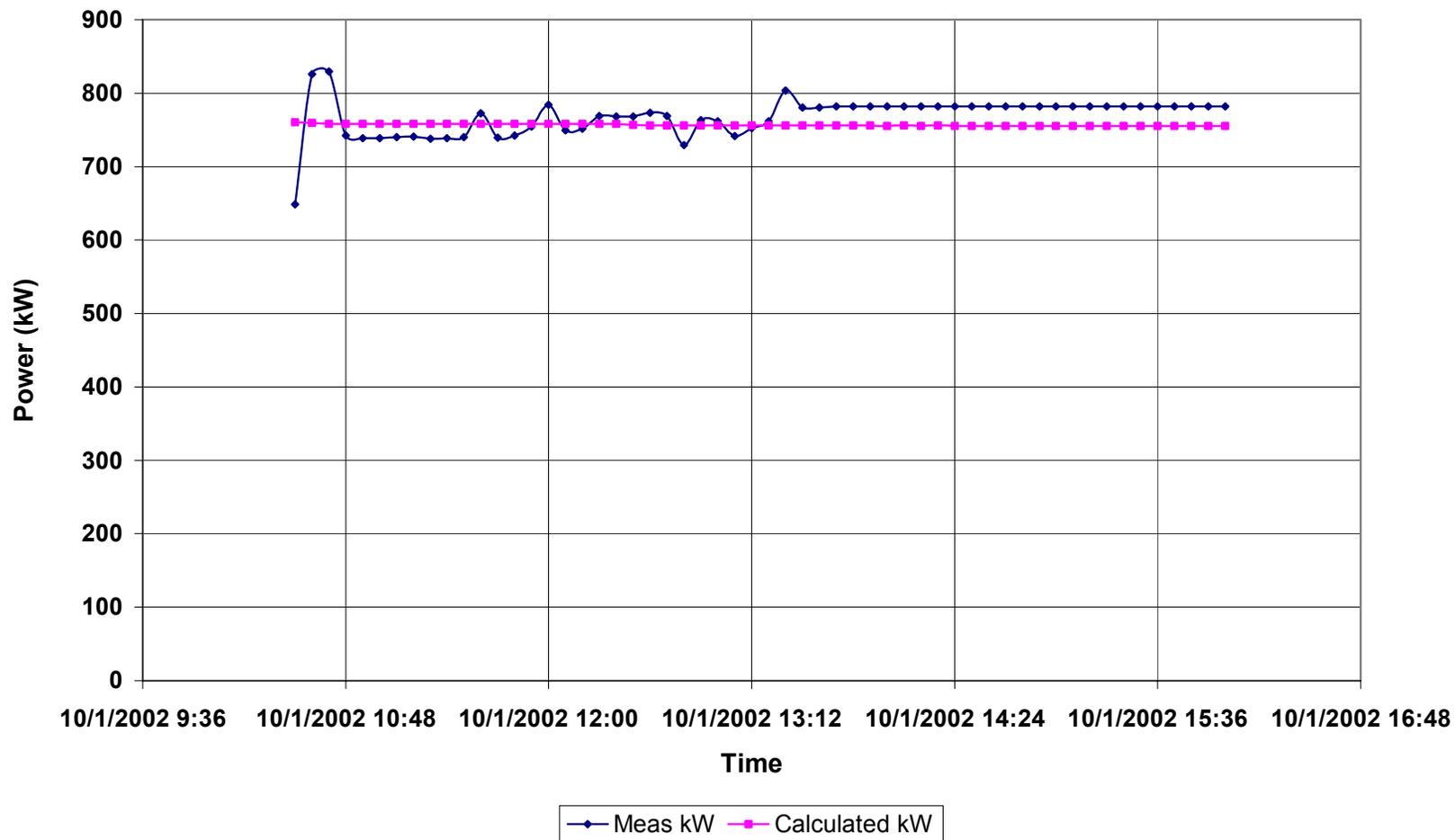
## Facility B Data Center Total Chilled Water Plant Efficiency (Ch4) - Oct 5 and 6



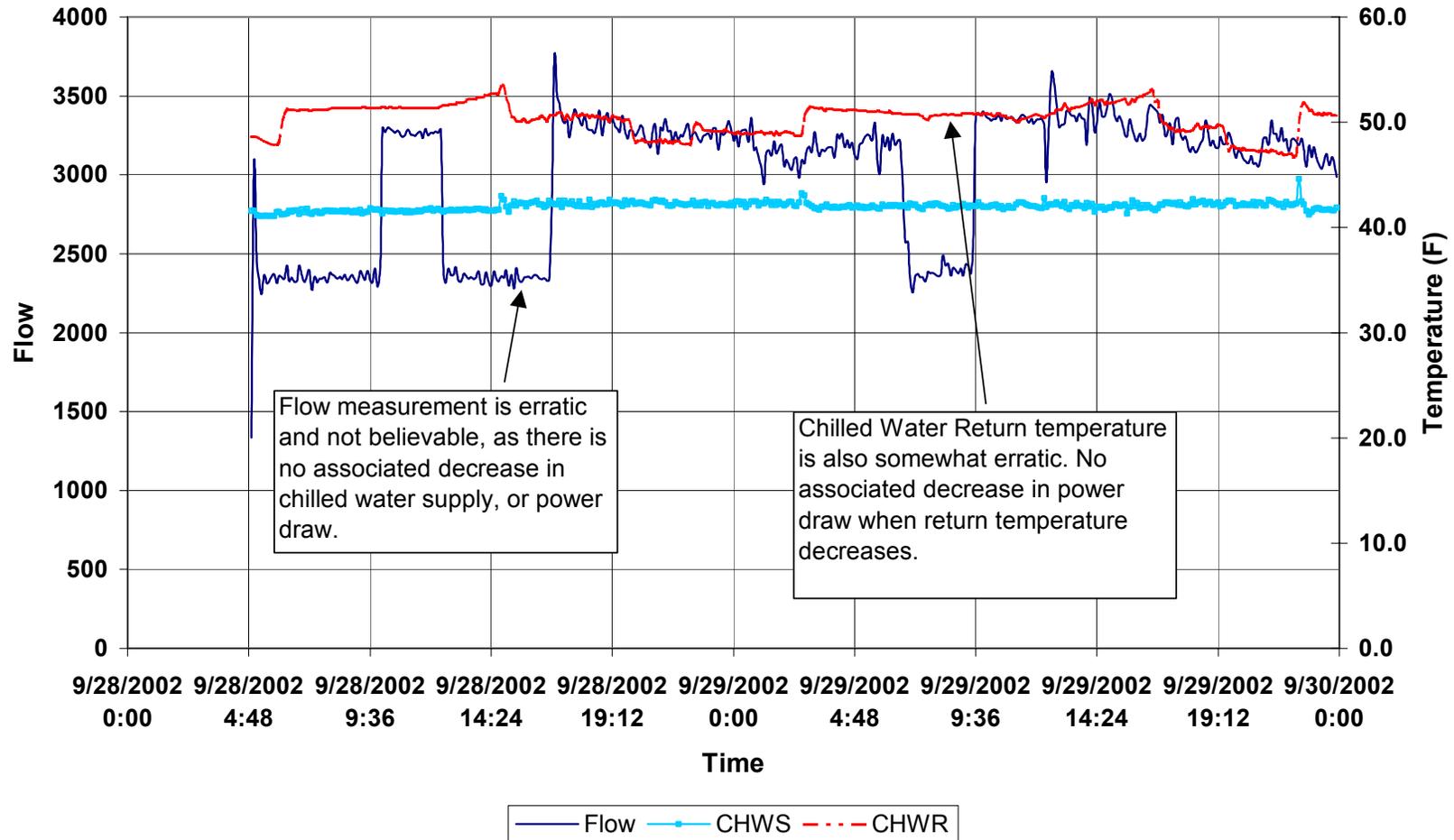
### Facility B Data Center Chiller 3 Measured Power



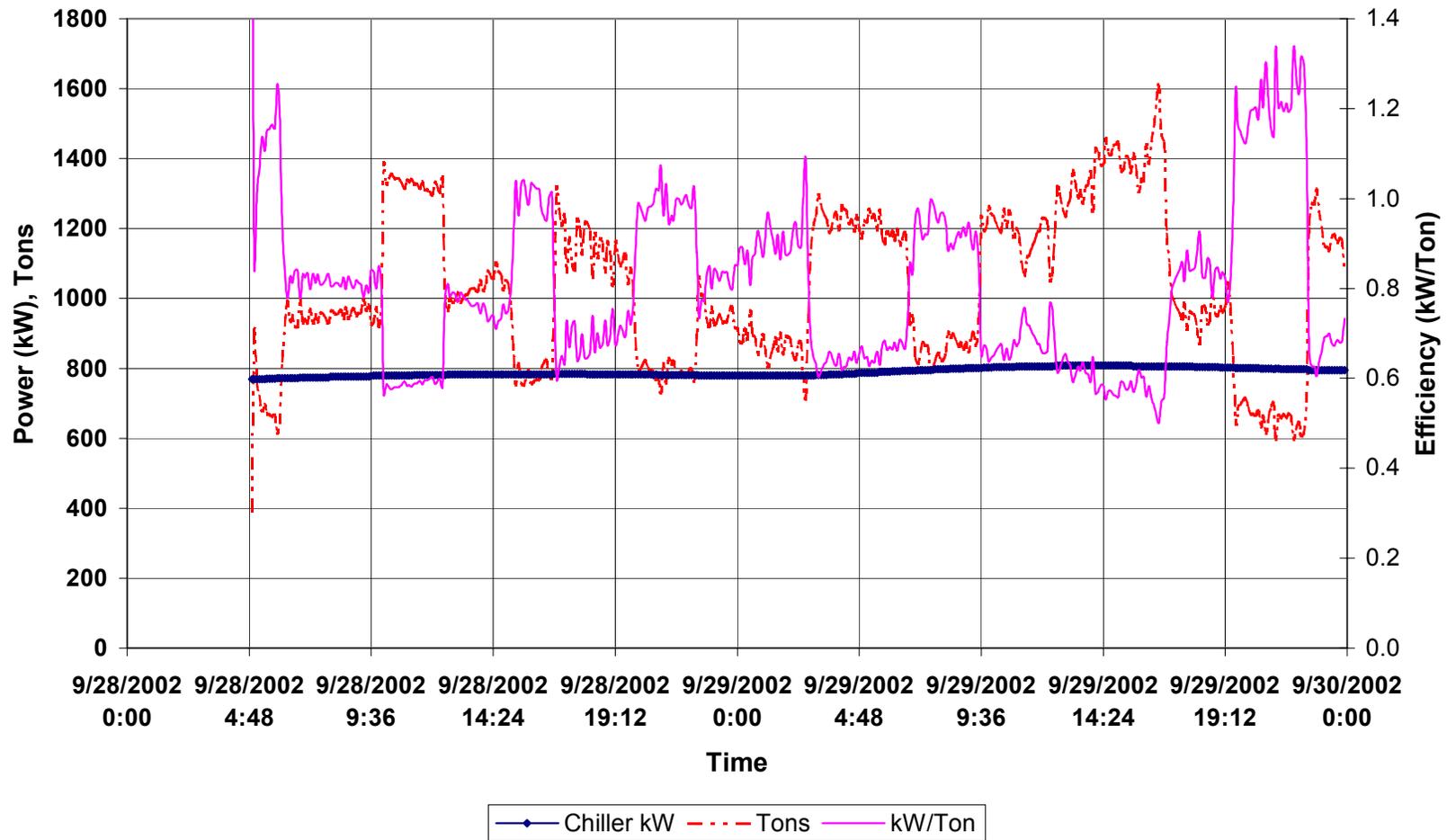
## Facility B Data Center Chiller 3: Calculated Vs. Measured



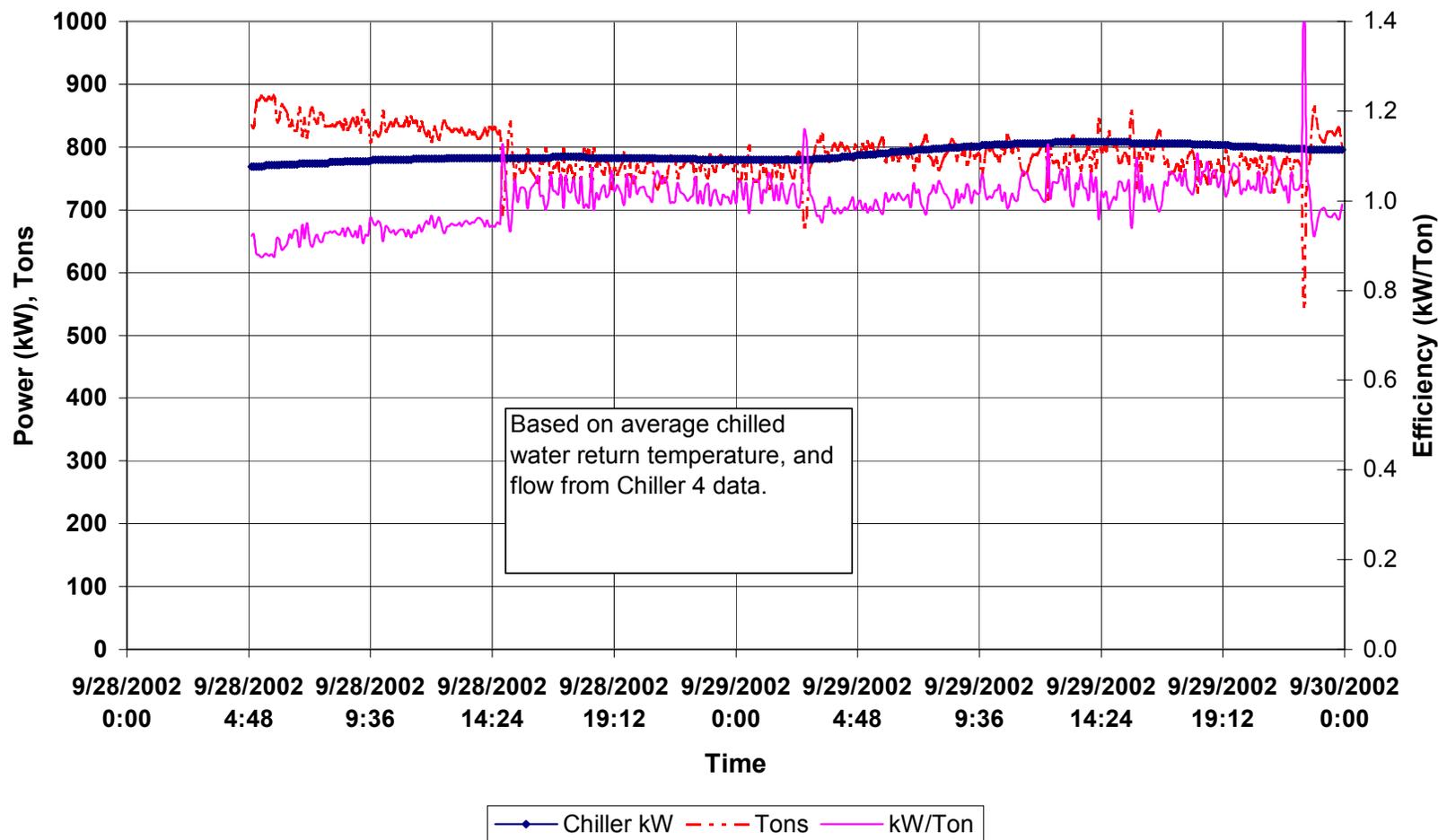
## Facility B Data Center Chiller 3 Flow and Temperature - Sep 28 and Sep 29



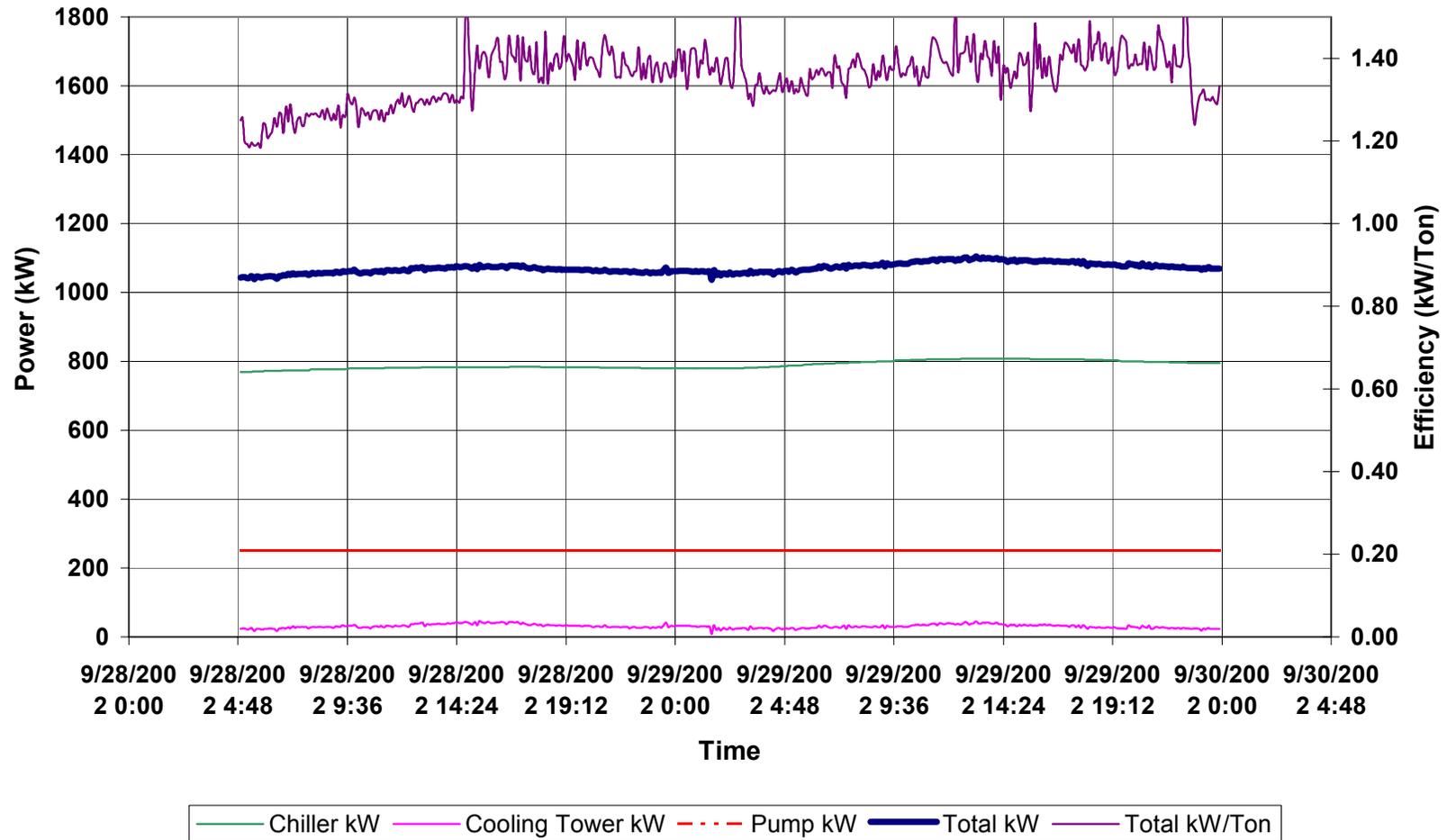
## Facility B Data Center Chiller 3 Power, Load and Efficiency - Sep 28 and 29



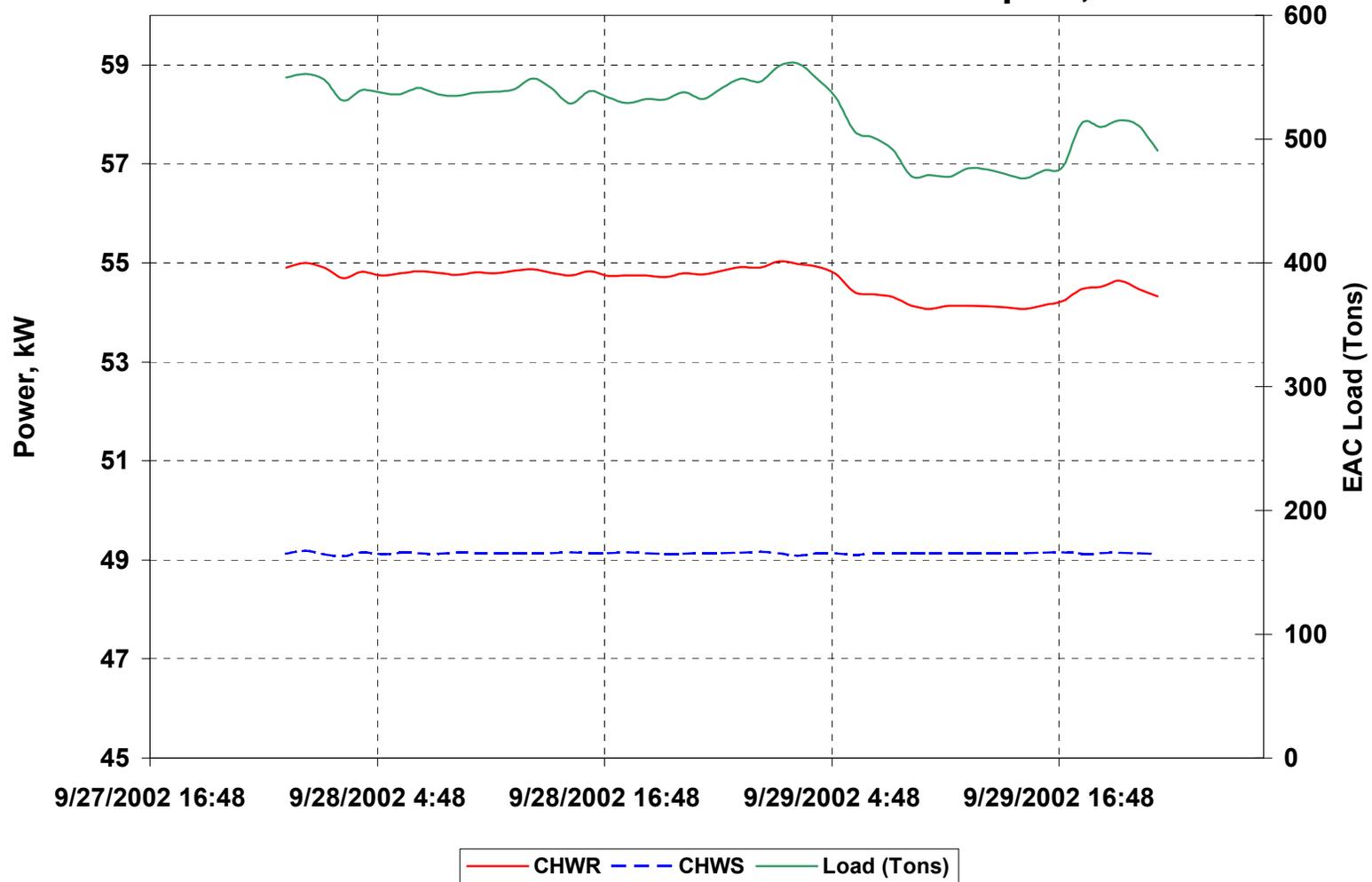
## Facility B Data Center Chiller 3 Power, Load and Efficiency - Sep 28 and 29



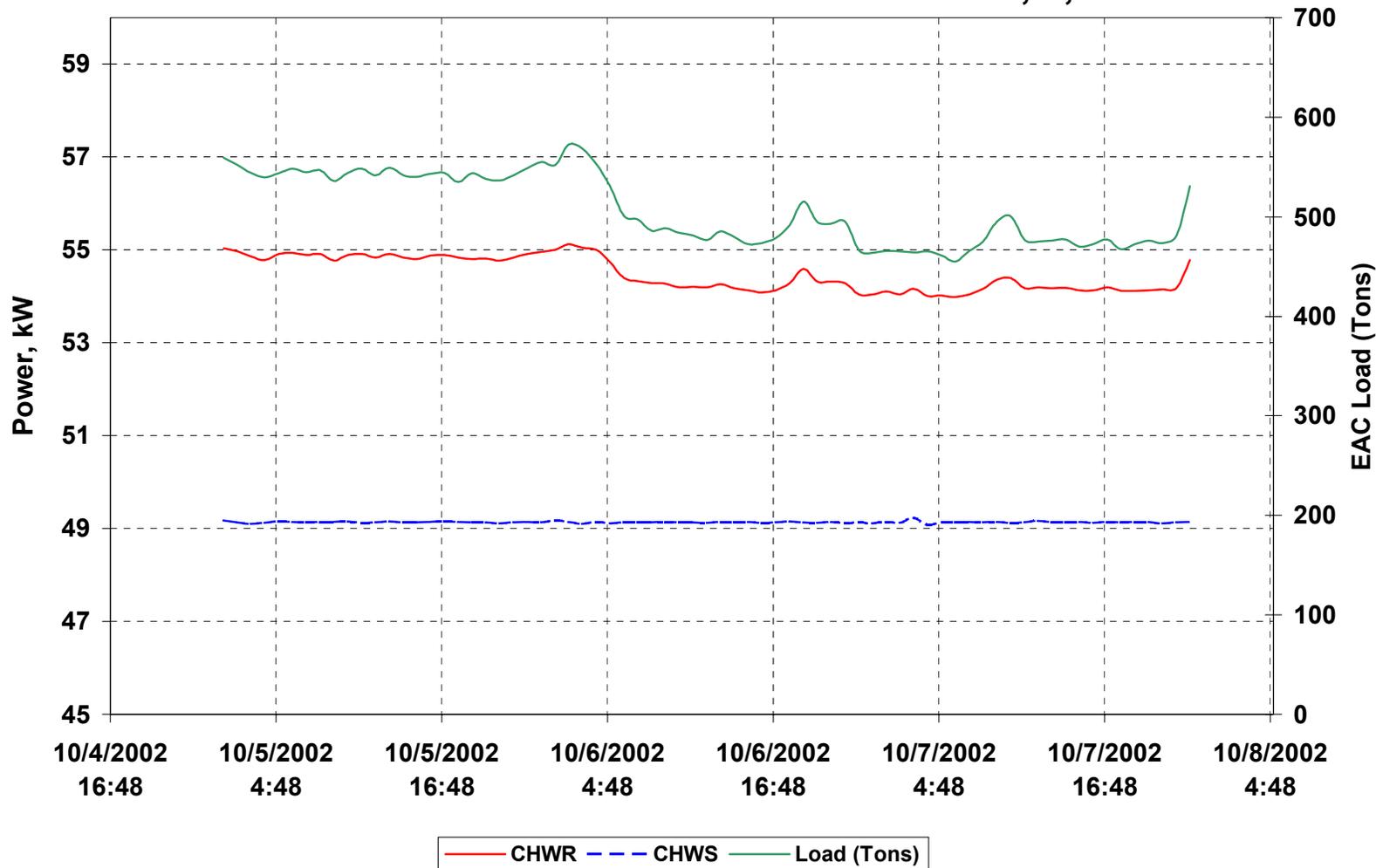
## Facility B Data Center Total Chilled Water Plant Efficiency (Ch3) - Sep 28 and 29



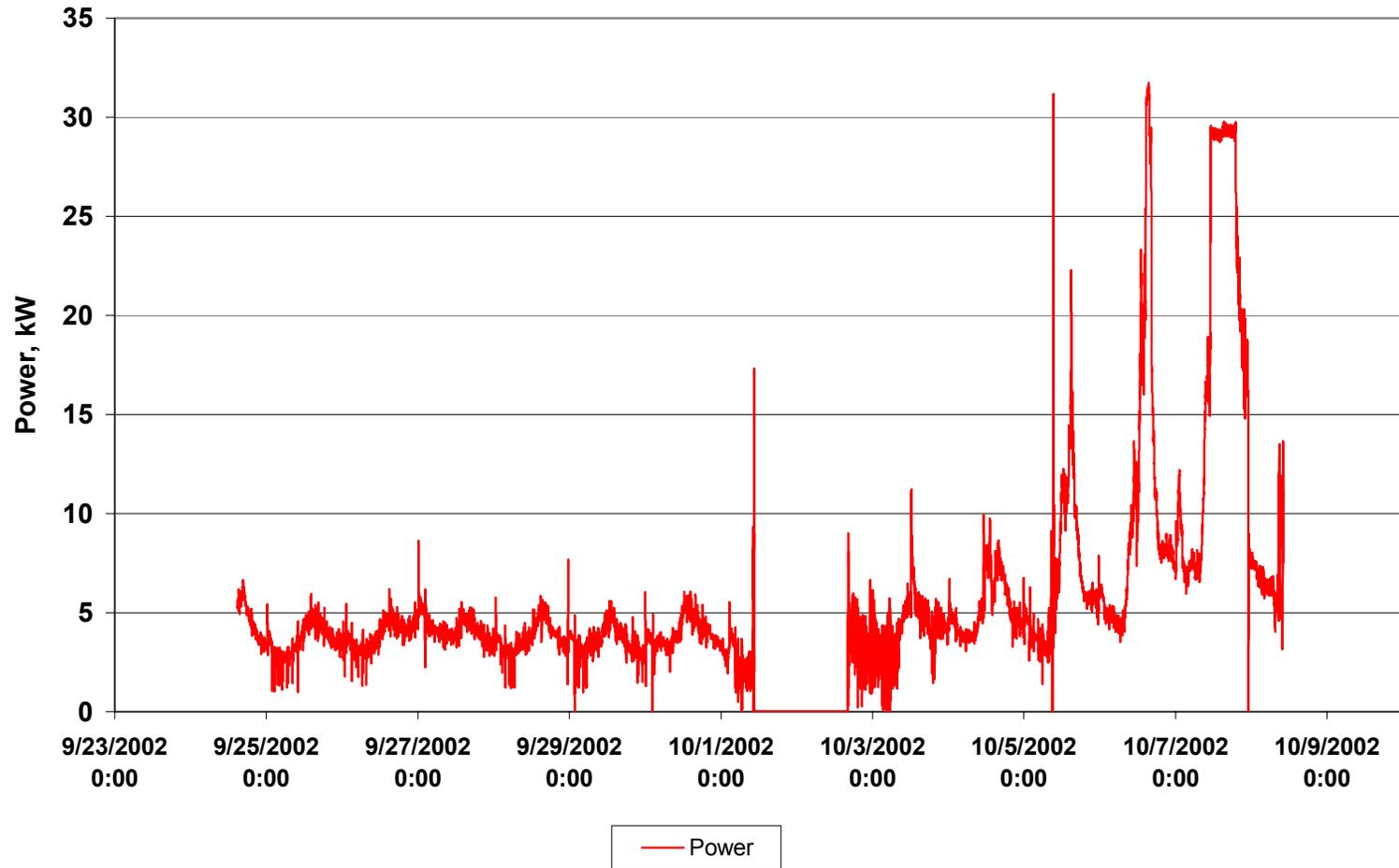
## Facility B Data Center Environmental Chilled Water Load - Sep 28, 29



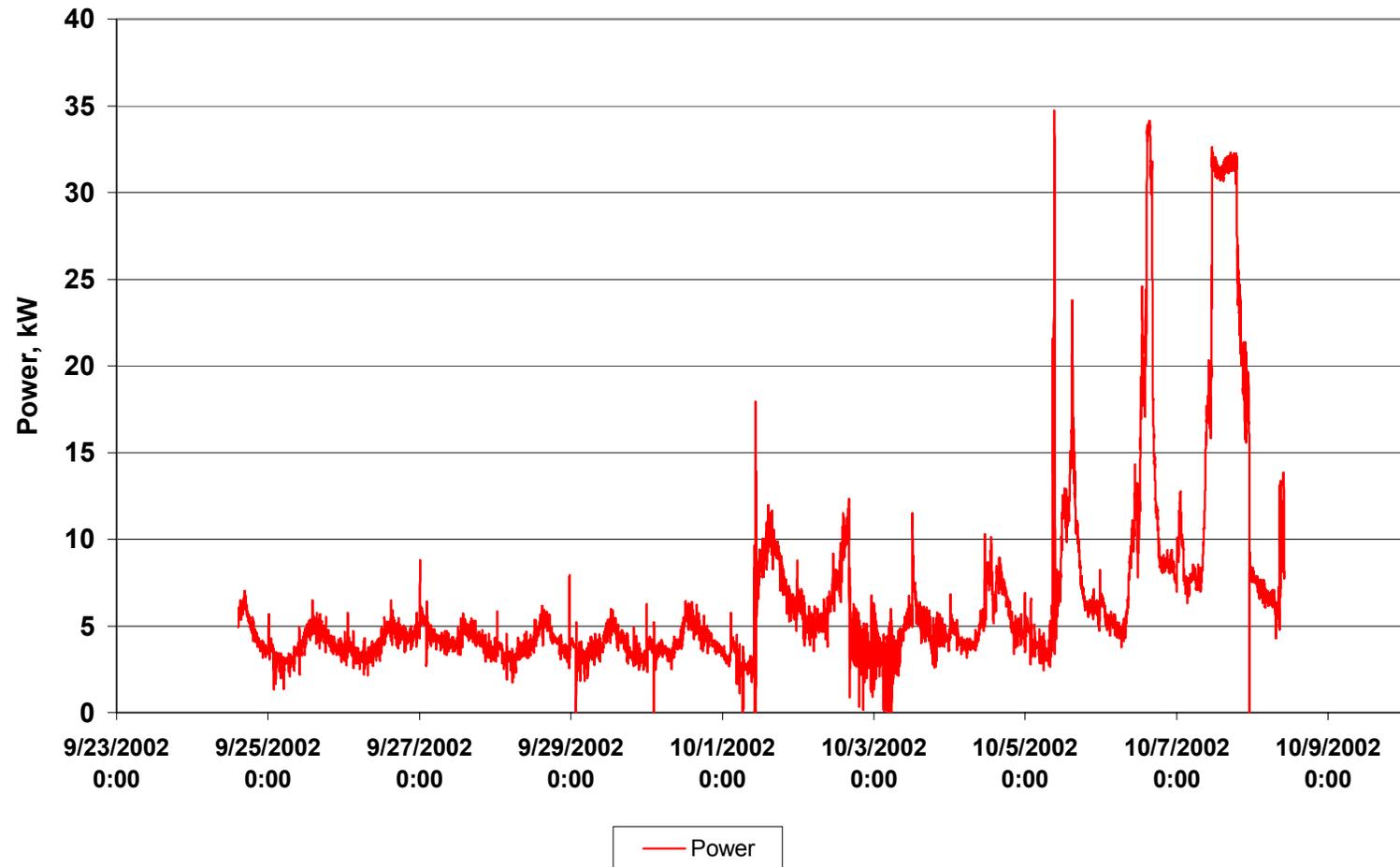
## Facility B Data Center Environmental Chilled Water Load - Oct 5, 6, 7



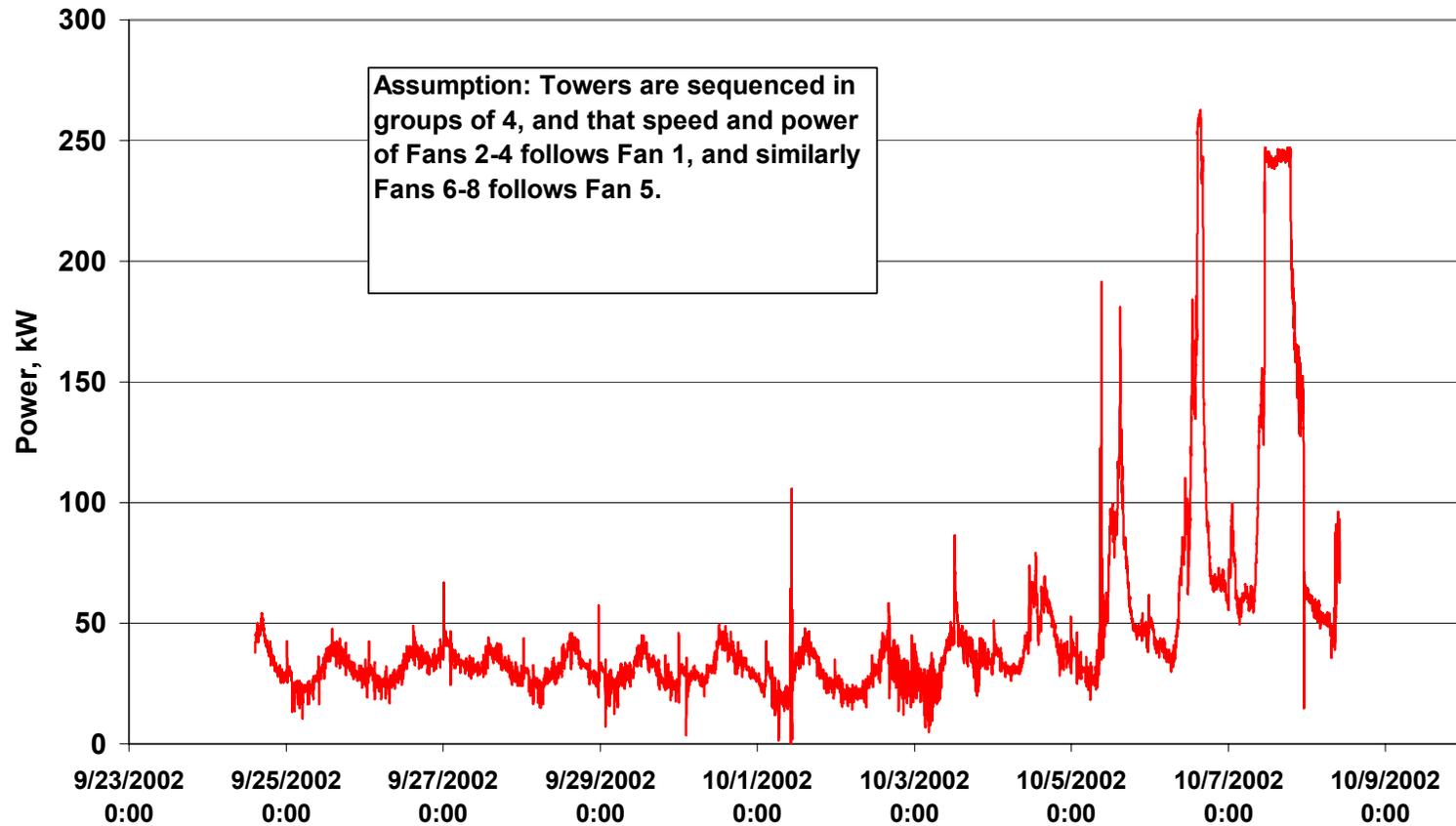
## Facility B Data Center Cooling Tower 1 Fan Power



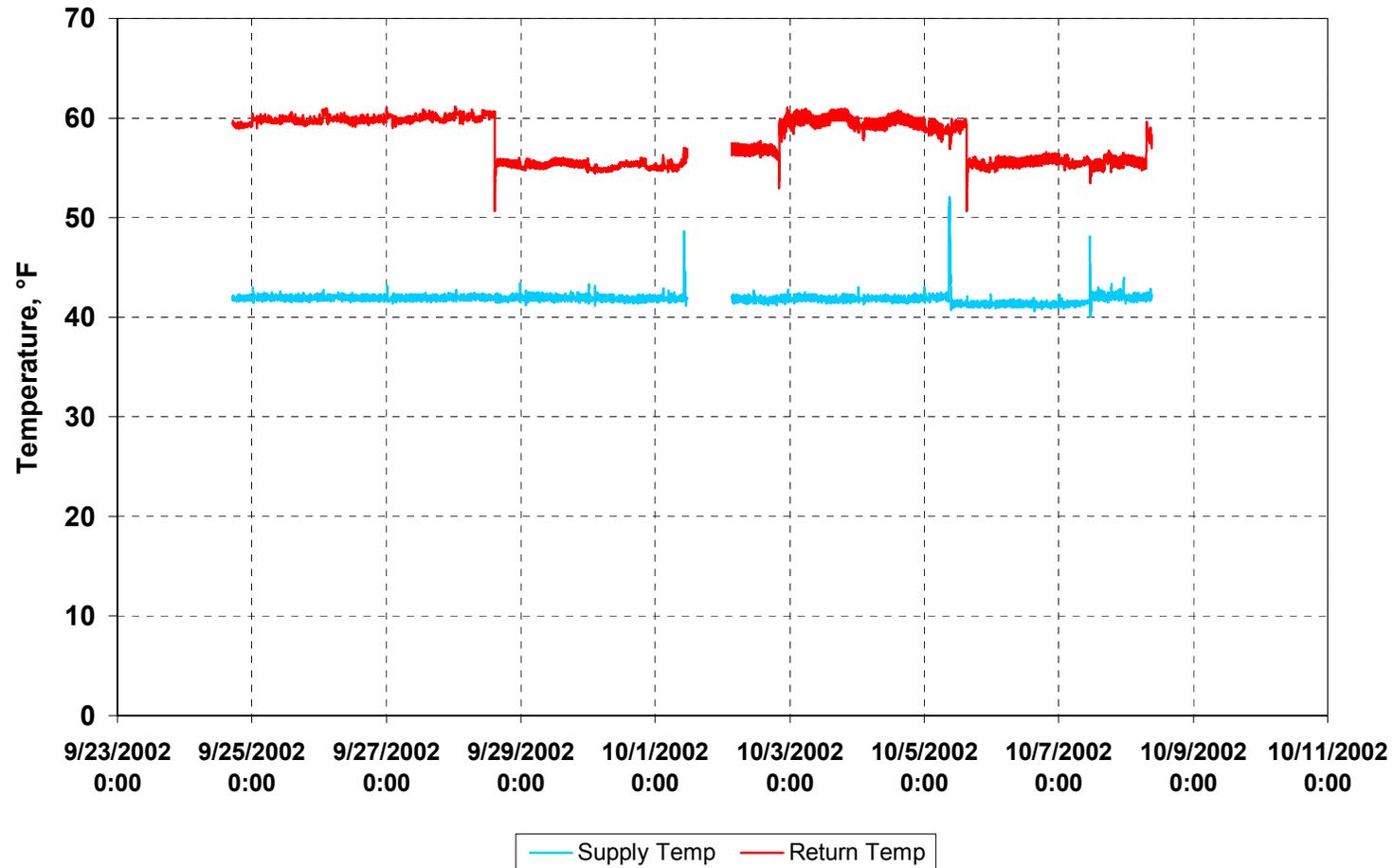
## Facility B Data Center Cooling Tower 5 Fan Power



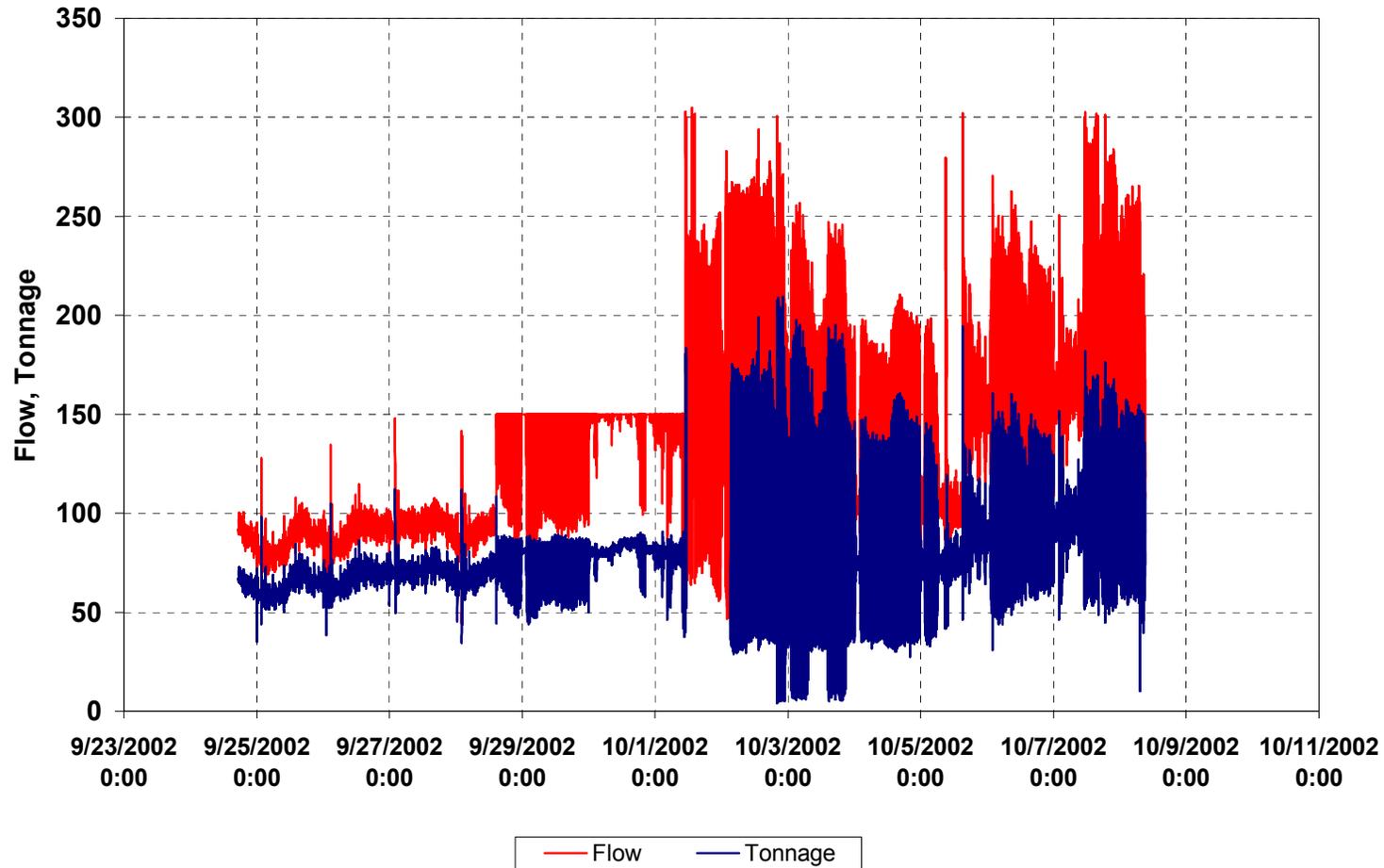
## Facility B Data Center Total Cooling Tower Fan Power



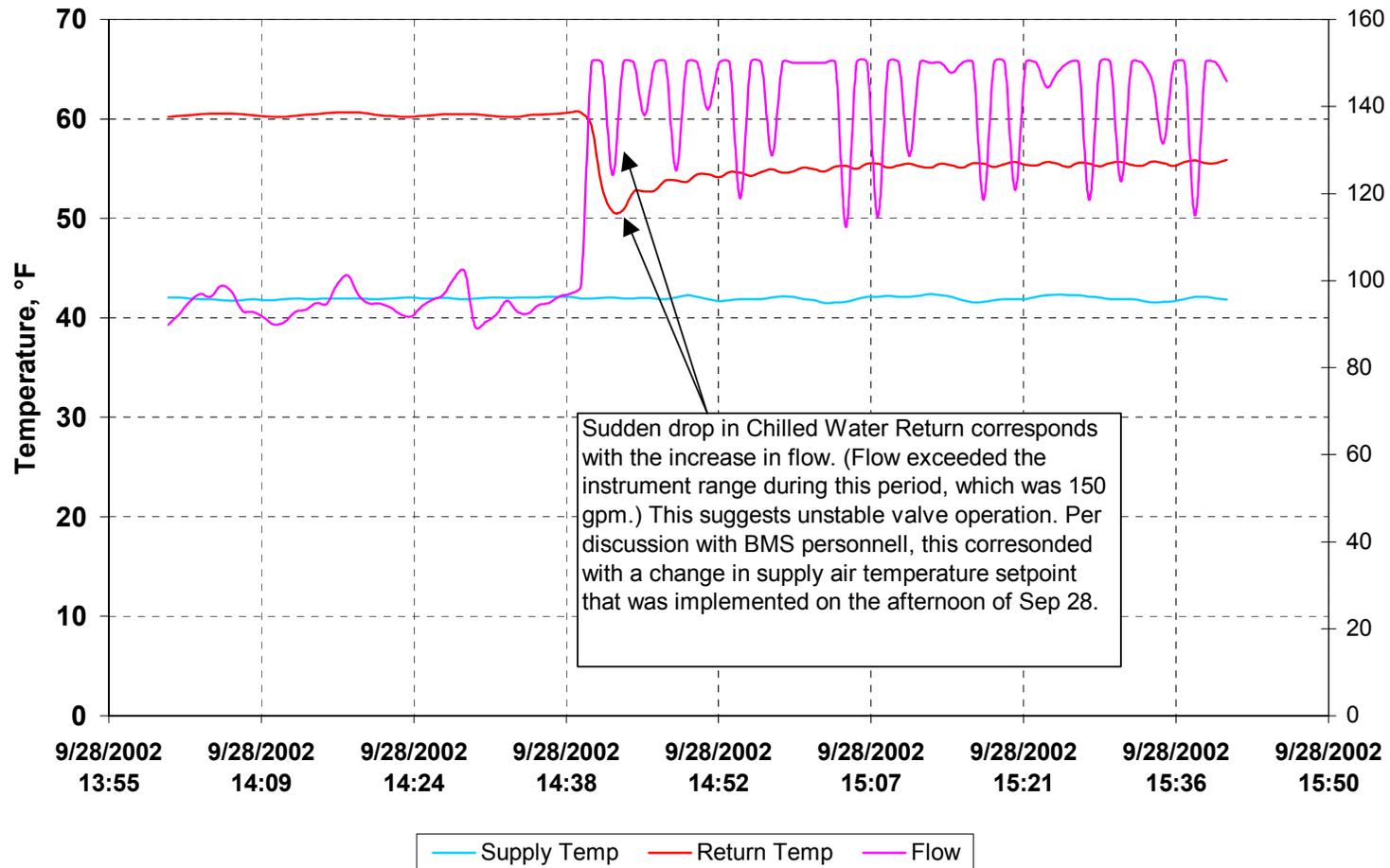
## Facility B Data Center AHU 4 CHW Supply & Return Temps



## Facility B Data Center AHU 4 Tonnage & CHW Flow

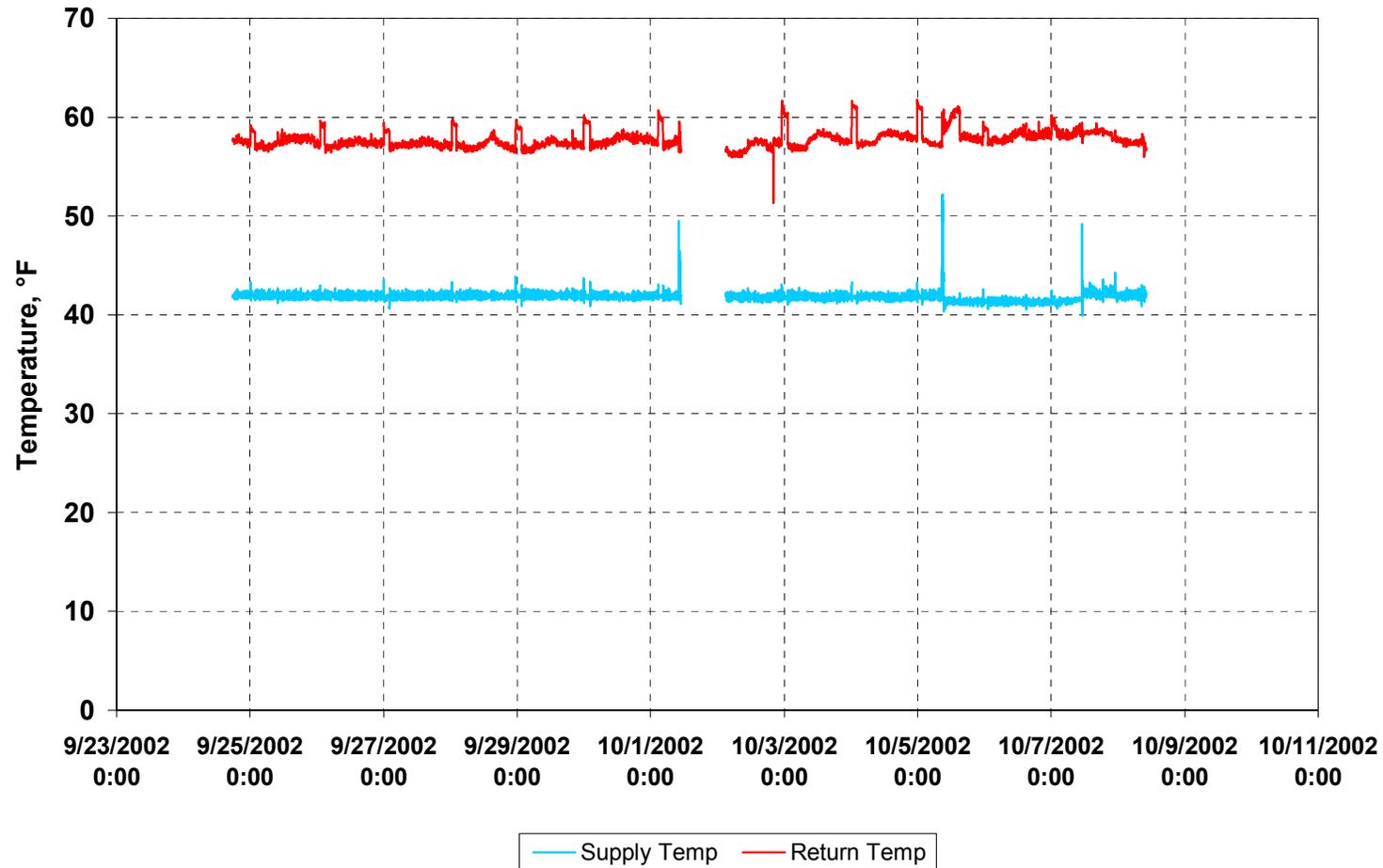


## Facility B Data Center AHU 4 CHW Temps and Flow - Sep 28 Afternoon

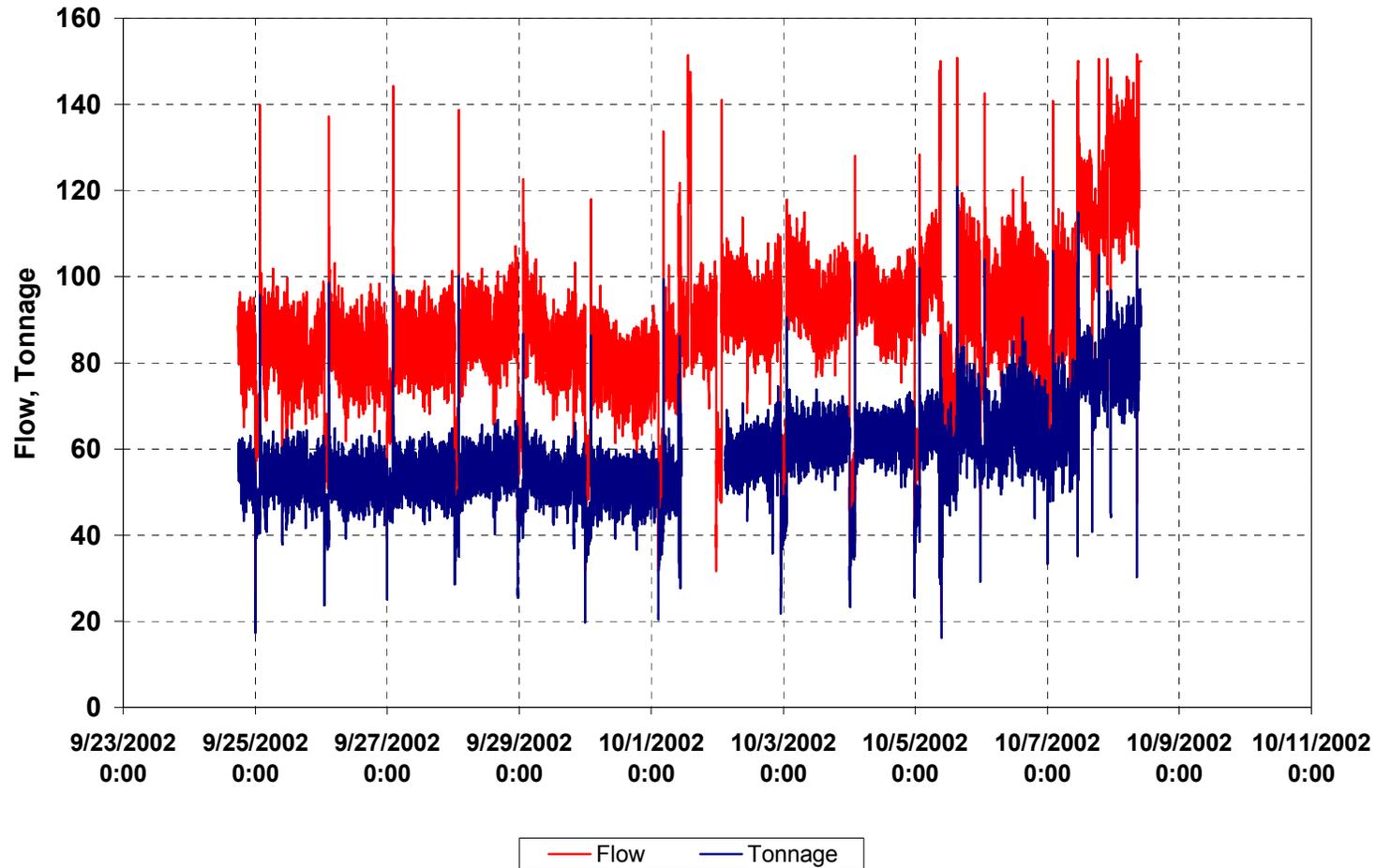


Sudden drop in Chilled Water Return corresponds with the increase in flow. (Flow exceeded the instrument range during this period, which was 150 gpm.) This suggests unstable valve operation. Per discussion with BMS personnell, this corresponded with a change in supply air temperature setpoint that was implemented on the afternoon of Sep 28.

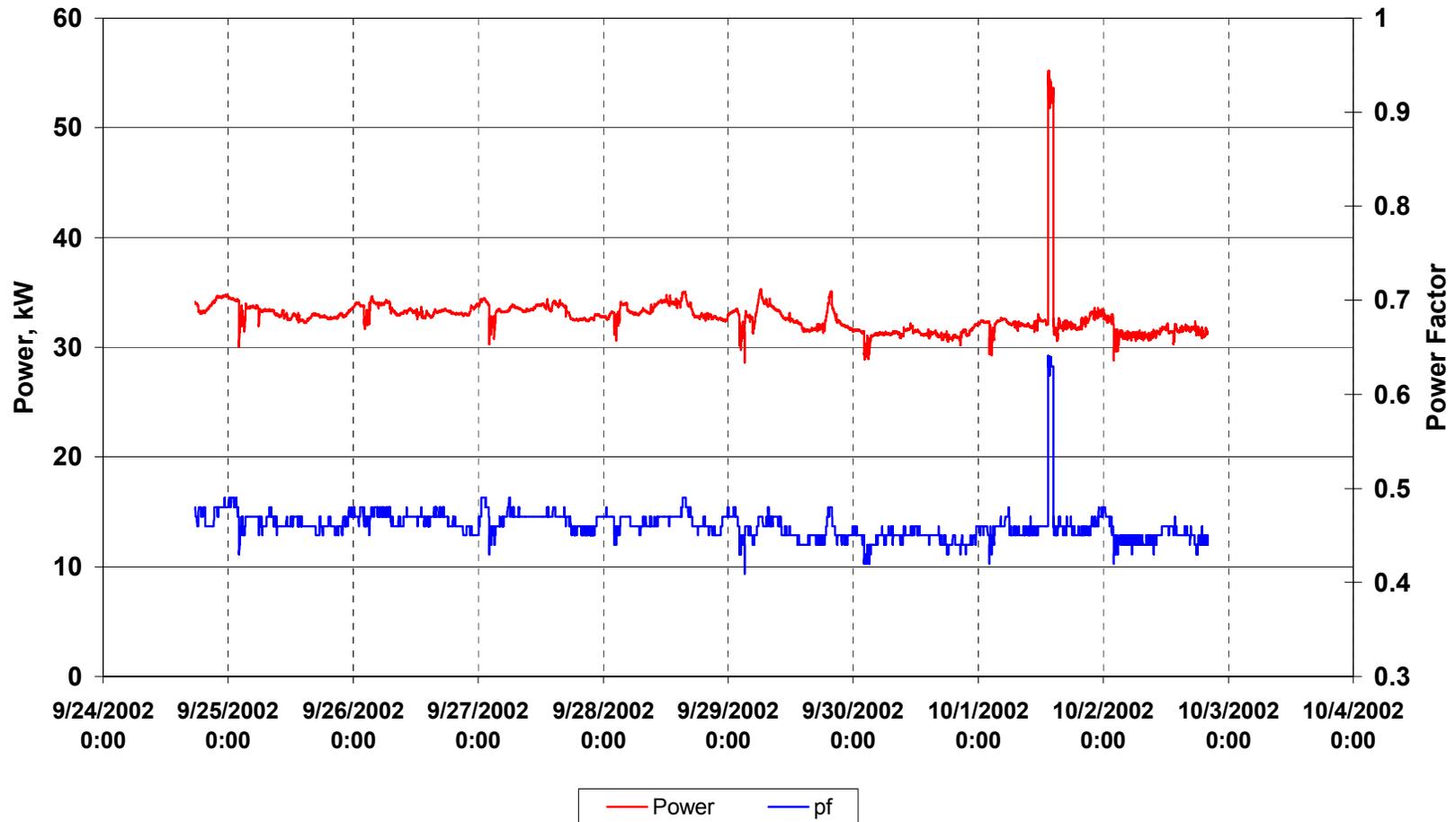
## Facility B Data Center AHU 5 CHW Supply & Return Temps



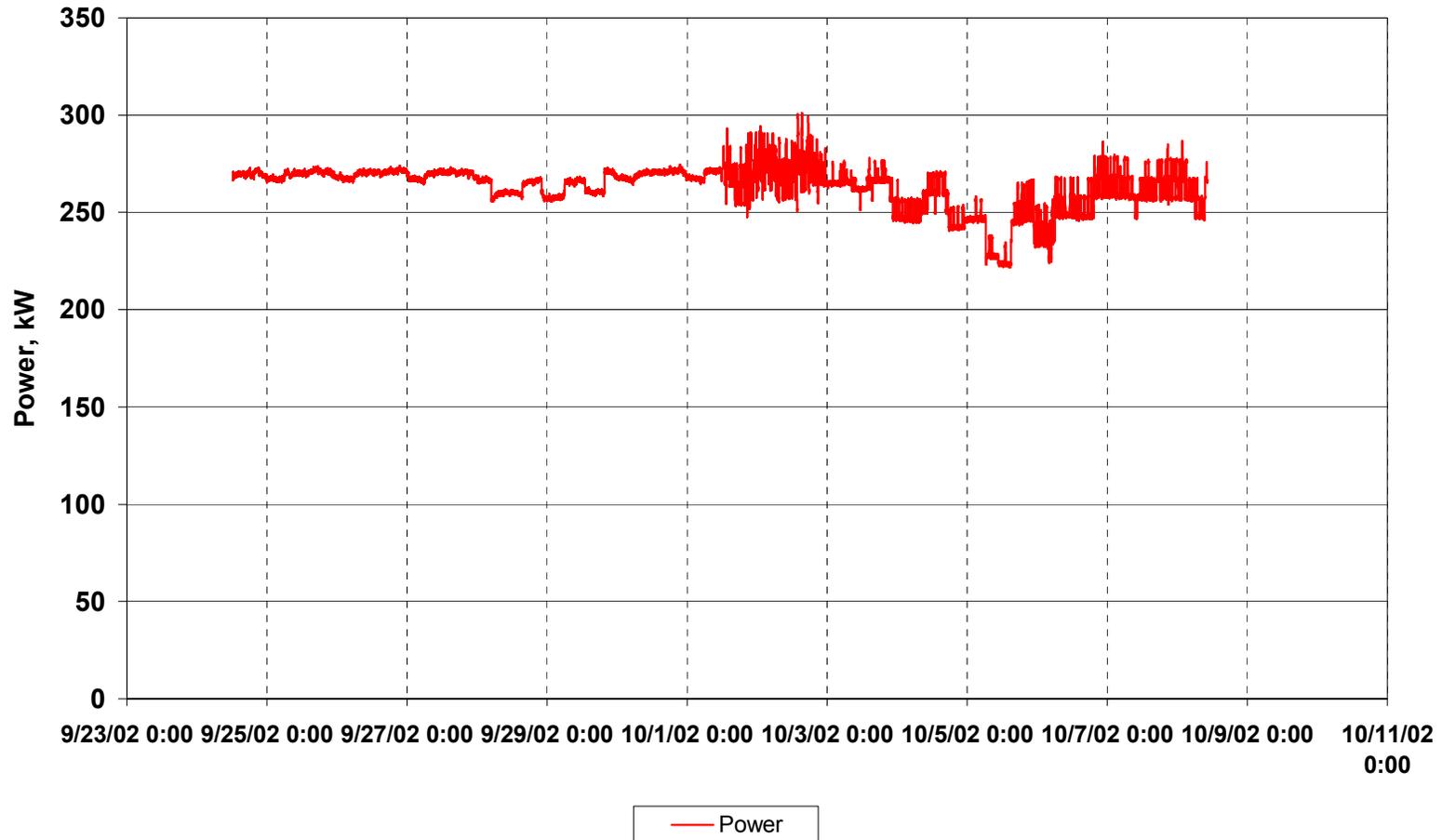
## Facility B Data Center AHU 5 Tonnage & CHW Flow



## Facility B Data Center AHU 5 Fan Power Consumption



## Facility B Data Center CRAC Power Consumption - Panel ATS 13



## Facility B Data Center CRAC Power Consumption - Panel ATS 13A

