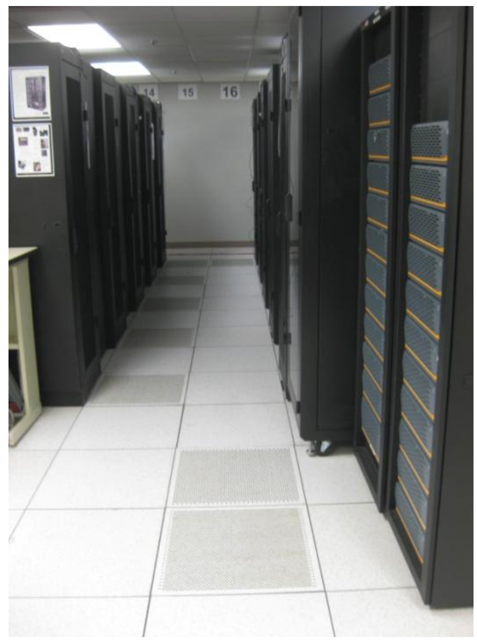
U.S. General Services Administration

Seventh Floor Data Centers
RAY Building, Saint Louis, Missouri



Energy Usage Efficiency Assessment Report

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BERKELEY LAB

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Disclaimer

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Executive Summary

This energy assessment, sponsored by the General Services Administration (GSA) and Federal Energy Management Program (FEMP), focuses on two data centers on the seventh floor of the Robert A. Young (RAY) Building. An important GSA tenant operates these data centers.

Lawrence Berkeley National Laboratory (LBNL) personnel performed the assessment. It establishes an estimate of baseline energy end use and identifies potential energy efficiency-measures (EEMs). Observation of the building physical conditions, environmental conditions, and energy use led to the operational and energy-efficiency improvement opportunities identified in this report.

It should be noted that this is not an investment-grade report. The precision of the EEM calculations is limited because:

- The total area of the data centers is about 10,500 square feet and is located on the seventh floor of an office building.
- The only power measurements available are at some of the automatic transfer switches (ATS).
- The same chilled water and glycol plants that serve data centers serve the entire building.

Despite these limitations, valuable observations and recommendations have been made. Assumptions and calculation methods are noted throughout the report.

Energy-Efficiency Measure Summary

Table 1 summarizes the EEMs and potential savings identified by the LBNL assessment. Further details for each EEM are contained in the report. The overall energy use savings is more than 23 percent of the total electricity used by the data centers. The estimated saving is about 930 megawatt-hours per year (MWh/yr). The cost to implement the EEMs is estimated at $77,500, with a $65,000 energy cost saving and a simple payback of 1.2 years.

Summary of Energy Savings Estimates	Savings			Cost	Payback
	kW	kWh/yr	$	$	years
Package 1	40.0	350,000	25,000	25,000	1.0
Package 2	14.2	125,000	8,700	10,000	1.1
Package 3	4.2	24,000	1,700	5,000	3.0
Package 4	5.0	44,000	3,100	2,500	0.8
Package 5	14.0	123,000	8,600	5,000	0.6
Package 6	15.0	263,000	18,400	30,000	1.6
Total Savings	**92**	**929,000**	**65,000**	**77,500**	**1.2**

Table 1: Saving and Payback Summary

Note: kW = kilowatt, and kWh/yr= kilowatt-hours per year.

1. SITE OVERVIEW

1.1 General

The Robert A. Young (RAY) building is located in Saint Louis, Missouri, and is an office building owned by the General Services Administration (GSA) with diverse tenants, one of which occupies data centers on the seventh floor.

1.2 Building Descriptions

The RAY building is an office building 1,130,000+ square feet. There are many different tenants occupy the building. The chiller room is in the lower level, and cooling towers are on the roof.

1.3 Seventh Floor Data Centers

The seventh floor data centers were built in 1990, but the IT equipment has been refreshed many times. The data centers had a 14" raised floor with 8 feet from the raised floor to the dropped ceiling. The height of the plenum above the dropped ceiling was 15". The IT equipment layout in the data center was configured in a hot aisle/cold aisle arrangement in some areas but not in all areas. Most of the cold aisles were approximately 4 feet wide.

Each of the two data centers is about 5,000 square feet. Data Center 1 is in a refresh phase, thus some of the racks hold old systems, some are empty, and some are being installed. The room also contains an uninterruptible power supply (UPS) and many power distribution units (PDUs). An office section is located on the east side of the room.

Figure 1 illustrates room 1 (called *Data Center 1* or *DC 1* throughout this report).

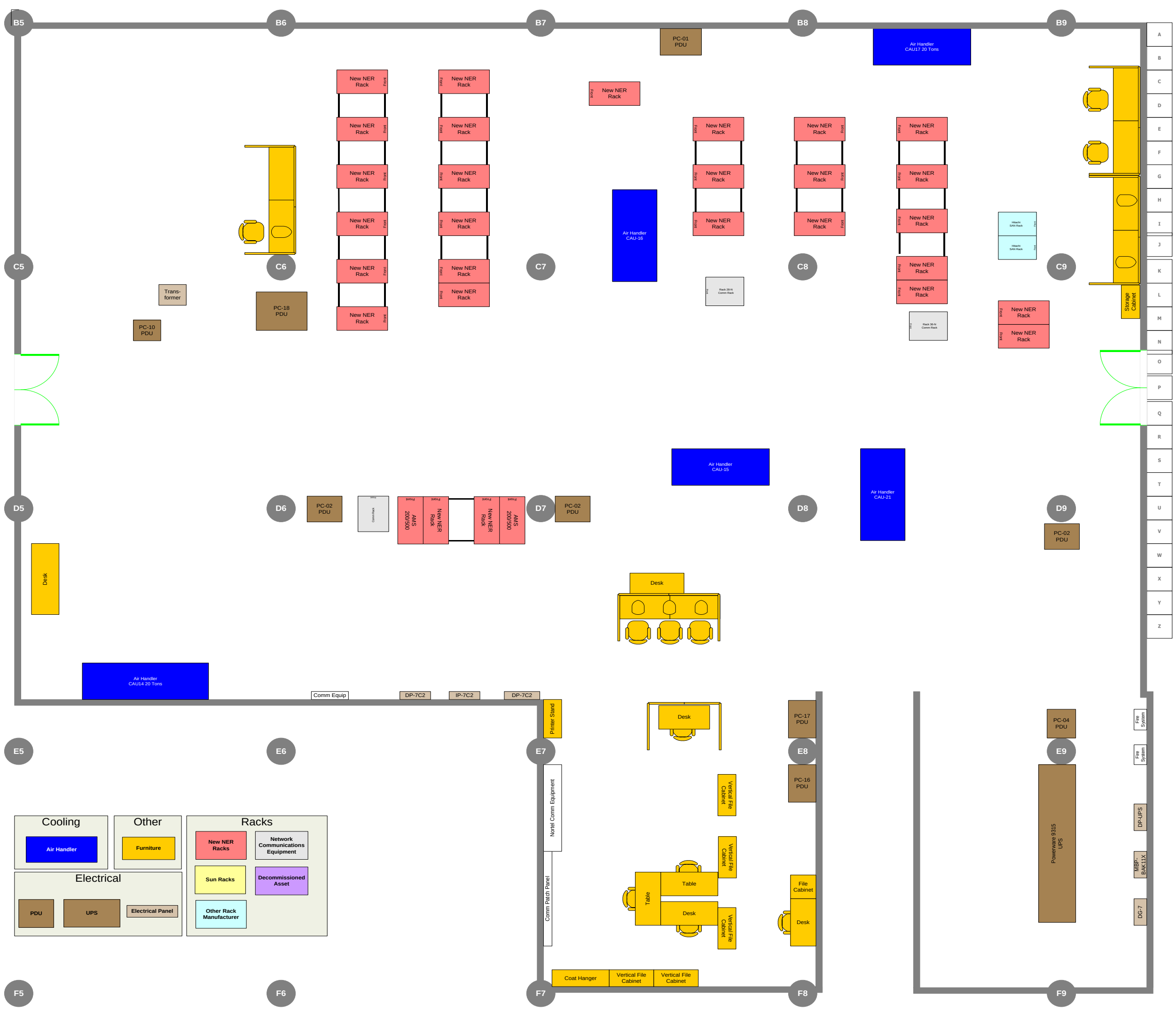

Figure 1: Data Center 1 Equipment Layout

Data Center 2 is in a refresh phase, thus some of the racks hold old systems, some are empty, and some are being installed. The room also contains a UPS and many PDUs. Figure 2 illustrates room 2 (called *Data Center 2* or *DC 2* throughout this report).

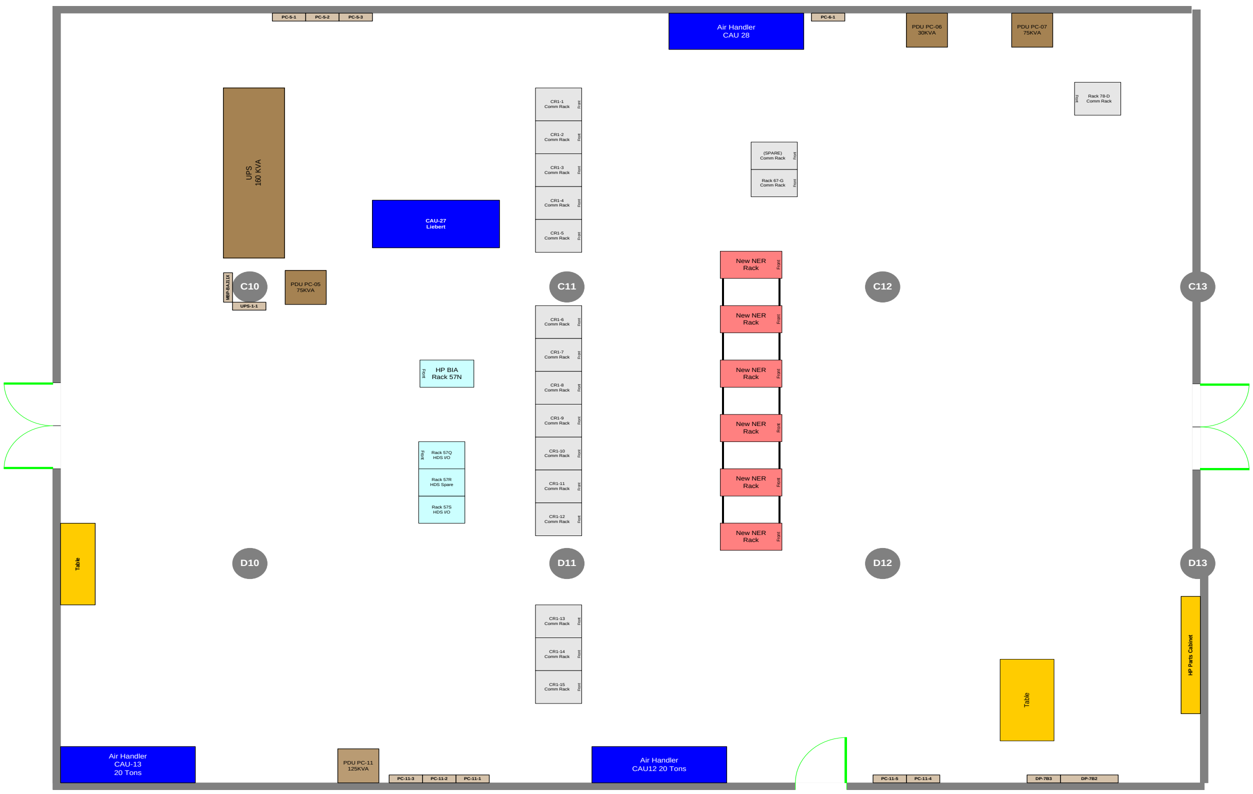

Figure 2: Data Center 2 Equipment Layout

2. FACILITY OVERVIEW

2.1 Data Center IT Equipment Loads

Based on output readings obtained from UPS units, the IT equipment power load was 118 kilowatts (kW) for DC 1 and 88 kW for DC 2. This equaled about 21 watts (W) per square foot for DC 1 and 17 W per square foot for DC 2, as summarized in Table 2 The infrastructure and data center floors are designed to accommodate data centers with an IT load as high as 180 kW for DC 1 and 103 kW for DC 2.

Data Center	DC Area (square feet, ft^2)	IT Load (kW)	Power Density (W/ft^2)
DC 1	5,500	102	19
DC 2	5,000	77	15

Table 2: IT Equipment Load Density

2.2 Cooling

The chilled water system serves the building heating, ventilating, and air conditioning (HVAC) system, including air handlers in the penthouse and on different floors. In addition, a glycol system serves local direct expansion (DX) units on different floors. Data centers on the seventh floor are supported by both systems. Cold air units (CAUs) provide cool air that is delivered through the raised floor plenum and through the perforated tiles to the racks.

3. FACILITY ENERGY USE

3.1 General

Most of the automatic transfer switches (ATS) are metered. ATS 5 supports the glycol system's dry coolers and primary pumps, as well as other non-data-center systems. ATS 7 supports the glycol system's secondary pumps and other non-data-center systems. Different automatic transfer switches support the chiller plant. ATS 10 serves Data Center 1 and ATS 11 serves Data Center 2. Readings of ATS 10 and ATS 11 power meters provided useful information, but most of the data were estimates based on motor nameplates, plus assumed efficiency of different systems. The UPS display reading was assumed to be actual IT power. By using the UPS efficiency curve, electrical power loss in the UPS was calculated. The PDU electrical power loss was estimated. Also, it was assumed that the generator block heater power used 10 kW, which is typical for many such generators. The fan and cooling load was estimated using the spreadsheet in Table 3 and 4. The numbers are result of one spot reading and not an average.

DC 1	Date	January 28		January 29		January 30		January 31	
CAU	Estimated Power use	General data	Power (kW)	General data	Power (kW)	General data	Power (kW)	General data	Power (kW)
CAU 7-1	Fan	ON	5	ON	5	ON	5	ON	5
	Dx %	0		0		0		0	
	Each DX		5		5		5		5
CAU 7-2	Fan	ON	5	ON	5	ON	5	ON	5
	Dx %	25	5	25	5	25	5	0	0
	Each DX		10		10		10		5
CAU 7-3	Fan	ON	5	ON	5	ON	5	ON	5
CAU 7-4	Fan	ON	5	ON	5	ON	5	ON	5
	Dx %	0		0		0		0	0
	Each DX		5		5		5		5
CAU 7-5	Fan	ON	5	ON	5	ON	5	ON	5
	Dx %	75	15	50	10	75	15	25	5
	Each DX		20		15		20		10
Total DX/Fan Power			45		40		45		30

Table 3: DC 1 Estimated Electrical Power Use by CAU (Dx and fans)

DC 2	Date	January 28		January 29		January 30		January 31	
CAU	Estimated Power use	General data	Power (kW)	General data	Power (kW)	General data	Power (kW)	General data	Power (kW)
CAU 7-6	Fan	OFF	0	OFF	0	OFF	0	OFF	0

	Dx %	**0**		**0**		**0**		**0**	
	Each DX		**0**		**0**		**0**		**0**
CAU 7-7	**Fan**	**ON**	**5**	**ON**	**5**	**ON**	**5**	**ON**	**5**
	Dx %	**25**	**5**	**25**	**5**	**25**	**5**	**25**	**5**
	Each DX		**10**		**10**		**10**		**10**
CAU 7-8	**Fan**	**ON**	**5**	**ON**	**5**	**ON**	**5**	**ON**	**5**
	Dx %	**75**	**15**	**75**	**15**	**100**	**20**	**50**	**10**
	Each DX		**20**		**20**		**25**		**15**
CAU 7-9	**Fan**	**ON**	**5**	**ON**	**5**	**ON**	**5**	**ON**	**5**
	Dx %	**50**	**10**	**50**	**10**	**25**	**5**	**50**	**10**
	Each DX		**15**		**15**		**10**		**15**
Total DX/Fan Power			**45**		**45**		**45**		**40**

Table 4: DC 2 Estimated Electrical Power Use by CAU (Dx and fans)

The estimated electrical end use breakdown associated with the data center space is summarized in Table 5.

Usage (kW)	**DC 1**	**DC 2**
IT load	102	77
UPS loss	12	8
PDU/transmission loss	4	3
Standby generator block heater	5	5
Lighting	4	3
Cooling DX compressors	25	30
Cooling, Chilled water	12	8
Cooling, Dry coolers/pumps	35	31
Fans	25	15
TOTAL	**224**	**280**
Current PUE	*2.2*	*2.34*

Table 5: Summary of Data Centers Electrical End Use

Figure 3 breaks out current DC 1 electrical power use by end use.

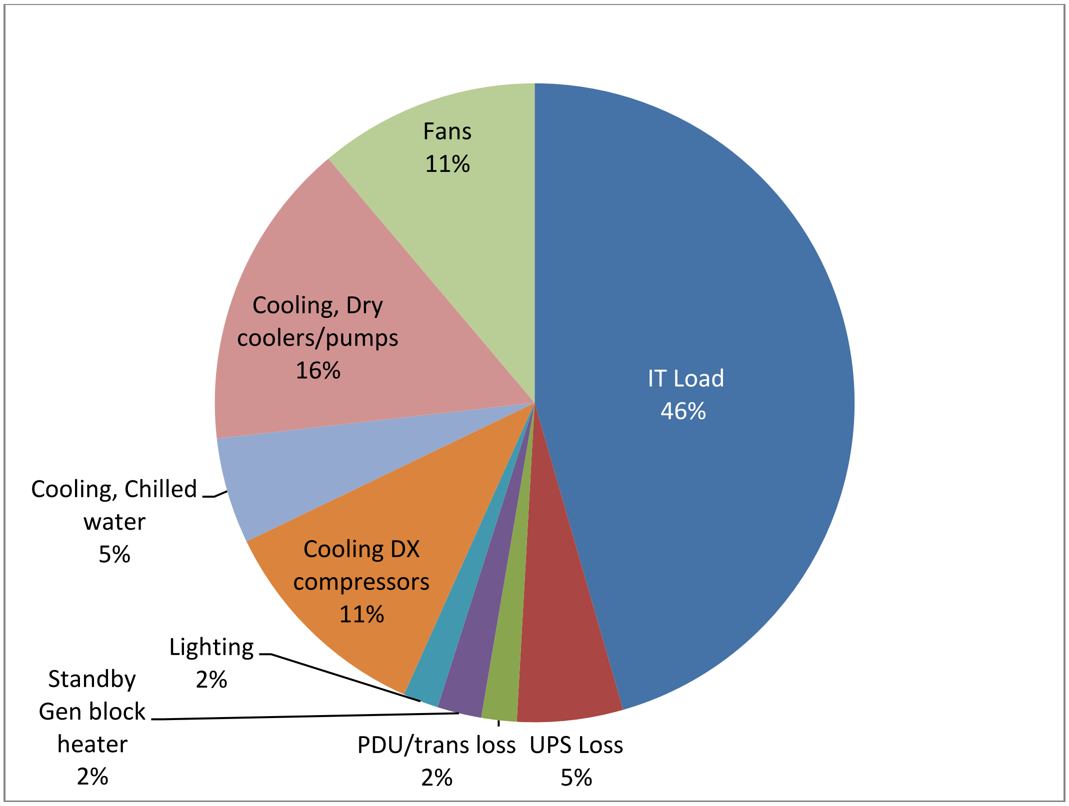

Figure 3: DC 1 Estimated Electrical Power Use Breakdown

Figure 4 breaks out current DC 2 electrical power use by end use.

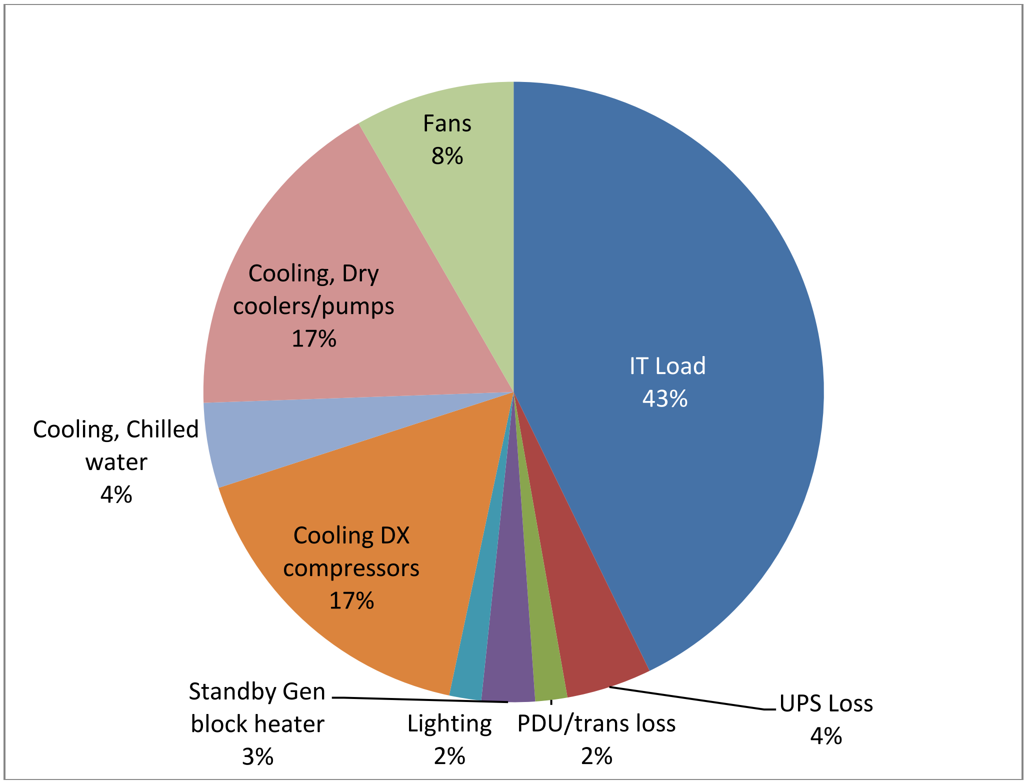

Figure 4: DC 2 Estimated Electrical Power Use Breakdown

4. MECHANICAL SYSTEMS

4.1 Chilled Water Plant

The chilled water system consists of four chillers, but during LBNL's visit, only a 400-ton stacked chiller was operational. The other three (one 1,000-ton chiller and 1,200-ton chillers) were off. Also at the time of the visit, one 400-ton cooling tower was operational, while two new 1,200-ton cooling towers were yet to be installed. Four primary chilled water pumps, three secondary chilled water pumps, three condenser water pumps, and one heat exchanger (economizer) pump serve the cooling system. The chillers reject heat to cooling towers on the building's roof. One 200-ton heat exchanger produces chilled water during cold seasons (ambient temperatures below 20°F), thus avoiding compressor cooling. There are fourteen 35-ton dry coolers on the roof. Five primary glycol water pumps serve the glycol water system (four were operating). Two secondary glycol water pumps on the seventh floor serve the data center CAU units (one was operating).

Figure 5 illustrates the RAY building's simplified chilled water system.

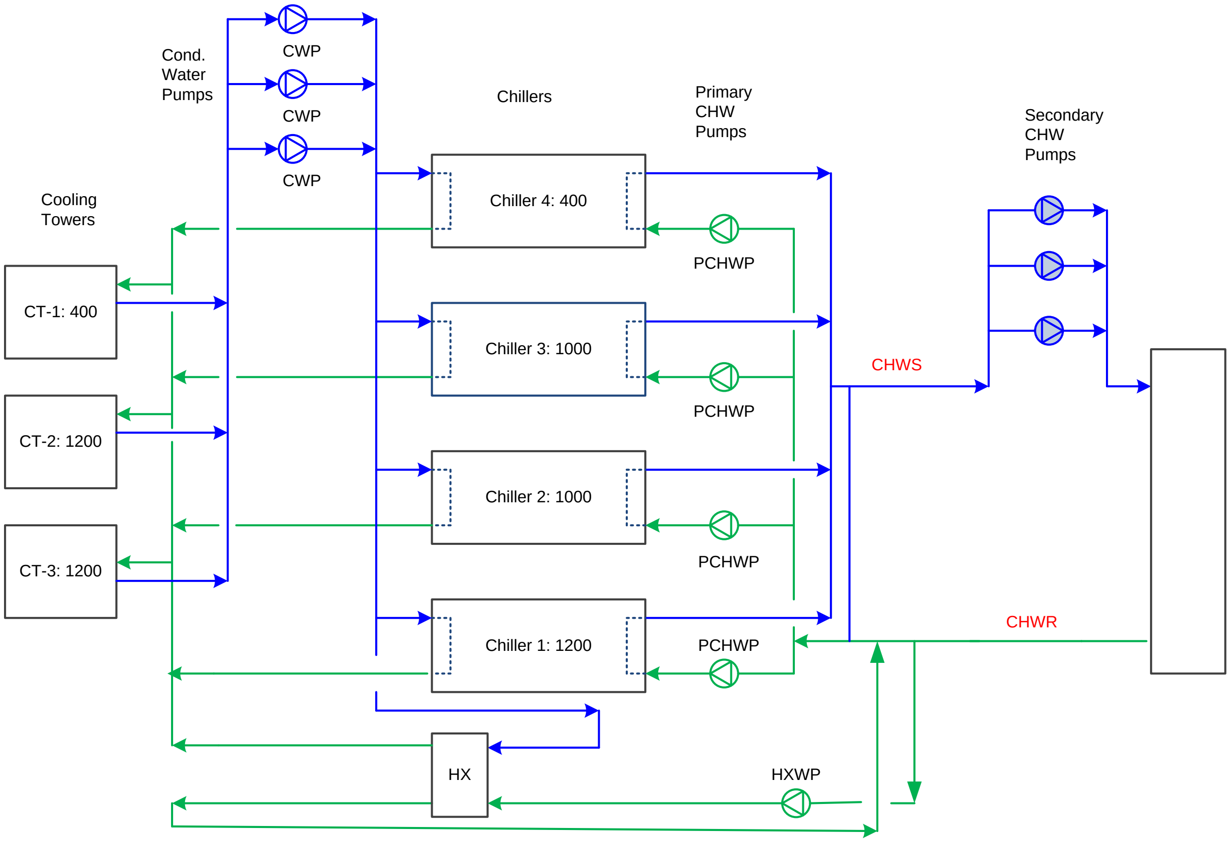

Figure 5: Simplified Chilled Water System Schematic

4.2 Data Center Mechanical Systems

The DC 1 and DC 2 equipment is air-cooled. Cool air is provided by five CAUs in DC 1 and 4 CAUs in DC 2. During the week of a January 27, 2014, visit we observed that 57°F chilled water was supplied to those CAUs through a chilled water coil to cool the air coming back from the room. The compressors for the glycol CAUs were running, and heat was rejected through the CAU condenser coil to the glycol-mixed water (40 percent glycol) provided by primary and secondary glycol pumps. Heat from glycol mix is rejected to the ambient by the dry coolers. Figure 6 illustrates the data center HVAC system (which is typical for both DC1 and DC2).

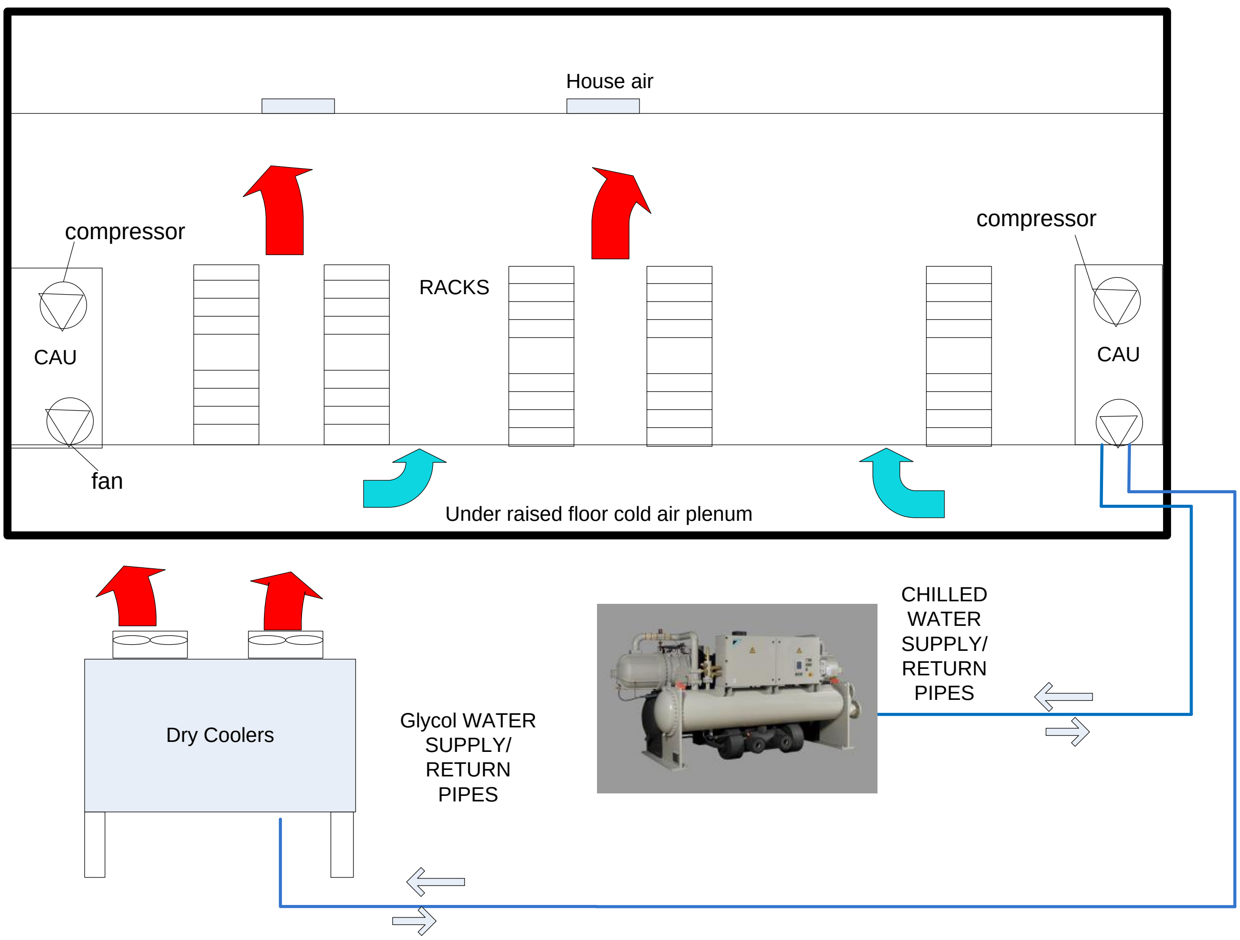

Figure 6: Data Center HVAC Schematic

For the two dual-coil CAU units, the chilled water coil is the primary cooling coil, and the DX coil is the secondary cooling coil. There was one chilled-water-only unit. Table 6 identifies the CAU types.

Unit Label	Type	Heat Rejection Primary
7-9	Glycol-only	Glycol-only
7-8	Glycol-only	Glycol-only
7-7	Glycol-only	Glycol-only
7-6	Glycol-only	Glycol-only
7-5	Dual Cool	CHW
7-4	Glycol-only	Glycol-only
7-3	CHW-only	CHW-only
7-2	DualCool	CHW
7-1	Glycol-only	Glycol-only

Table 6: CAU Types

5. ELECTRICAL SYSTEM DESCRIPTION

5.1 Electrical Distribution

Electricity from the site is provided by the utility, which steps the voltage down from 13.8 kilovolts (kV) to 480 kV. Power is delivered to the building at this voltage for motor loads, UPS, and other high-voltage users. Power is stepped down to 277 V for the lighting. For plug loads and other medium-voltage users, electricity is delivered at 120/208 volts. Figure 7 illustrates the electrical distribution related to DC 1 and DC 2 IT loads and supporting loads.

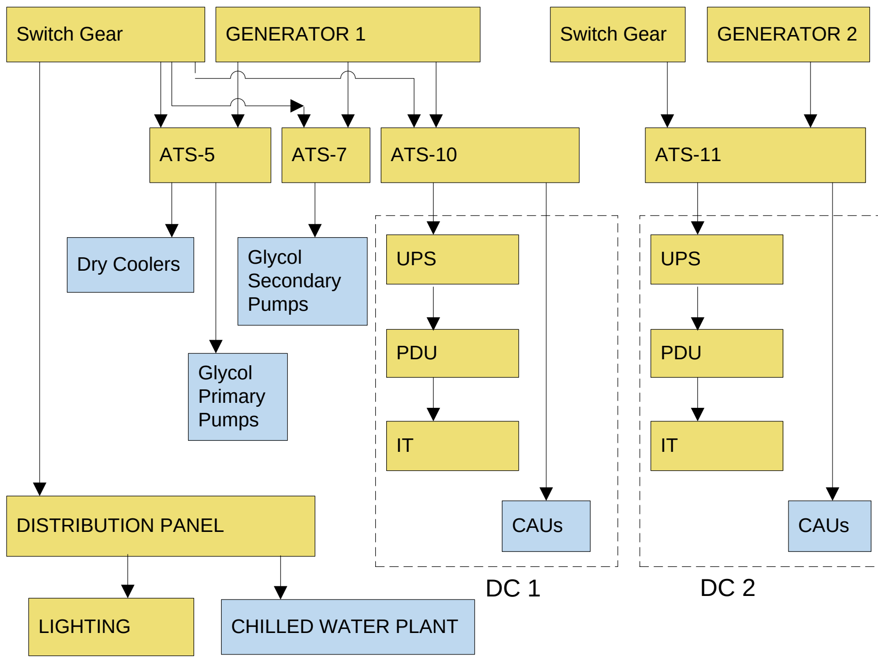

Figure 7: DC-related Electrical Distribution Schematic

5.1.1 Uninterruptible Power Supplies (UPS)

UPS 1 provides the power to the IT equipment in DC 1, and UPS 2 provides power to IT equipment in DC 2. Table 7 shows capacity, input and output power, losses, efficiency, and load factor for each of the UPS units. No redundancy is provided, which keeps the UPS load factor high; making the units more efficient, even though they are old and inherently inefficient.

UPS	UPS 1	UPS 2	Total
Capacity (kW)	180	128	308
INPUT (kW)	118	88	206
OUTPUT (kW)	106	80	186
Loss (kW)	12	7	19
% Efficiency	90	90	90
% Load Factor	65	69	67

Table 7: UPS Electrical Sample Measurements

5.1.2 Lighting

The total power used by the lighting in the data center and UPS rooms is estimated to be 4 kW for DC 1 and 3 kW for DC 2.

6. Benchmarking

6.1 Energy-Efficiency Metrics

Table 8 indicates the metrics and the interpretation of their values for DC 1. The DC 2 numbers are very close to those of DC 1.

Metric ID	***Metric Name***	***Value***	***Interpretation***
EM.M.1	PUE (Total Power/IT Power)	2.20	Poor
EM.M.2	HVAC Effectiveness (IT Power/HVAC Power)	1.8	Poor

Table 8: Data Center Energy Metrics

Figures 8 and 9 illustrate how DC 1 and DC 2 compare to other centers benchmarked by LBNL.

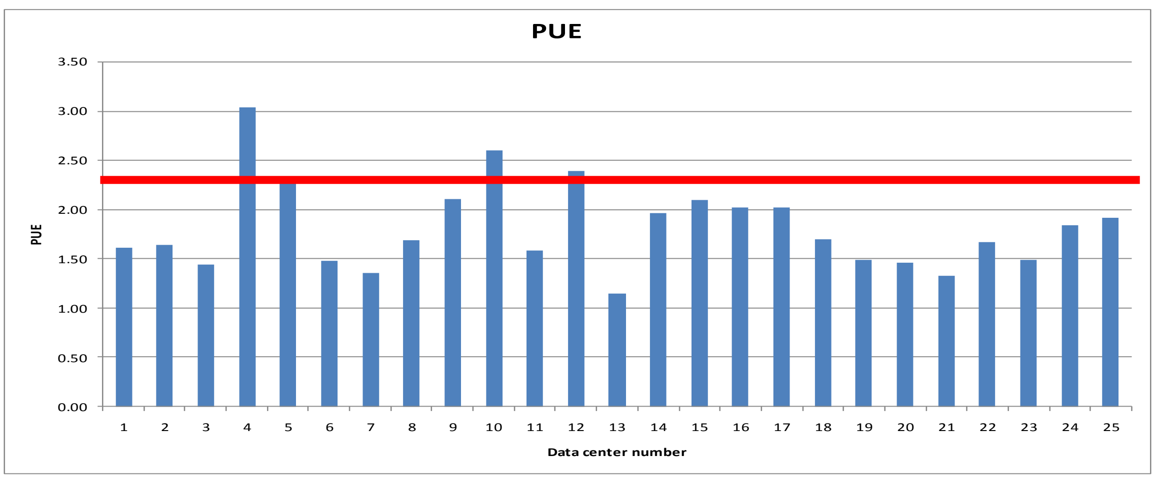

Figure 8: DC 1 Estimated Current Power Utilization Effectiveness (PUE) Compared to Peers

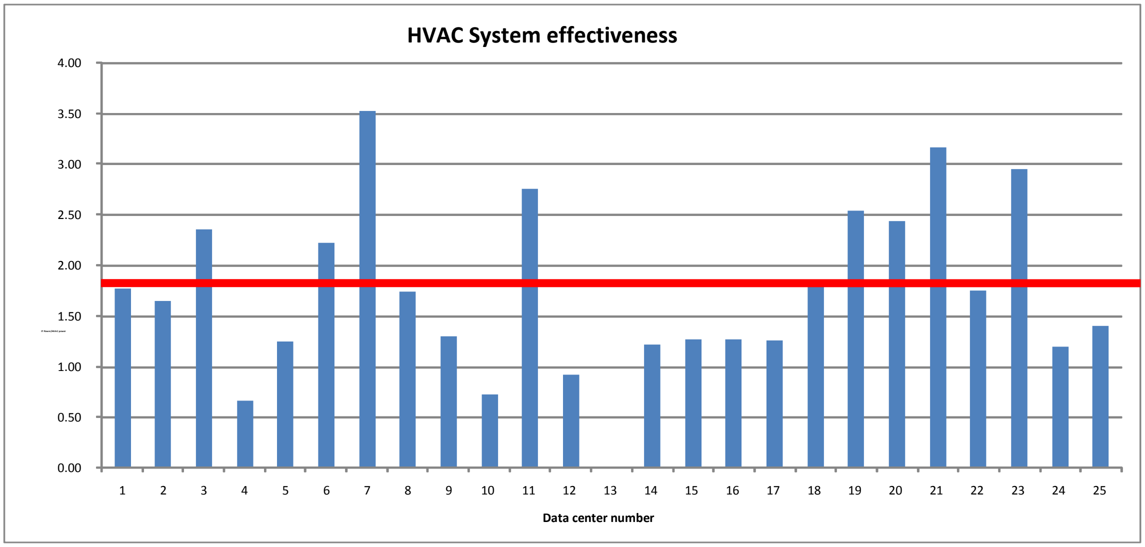

Figure 9: DC 2 Estimated Current HVAC Effectiveness Compared to Peers

6.2 Air Management and Air Distribution Metrics

Temperature data was obtained to establish an understanding of the environmental conditions in the data center and to identify any airflow distribution issues such as creation of hot spots. A number of server intake and exhaust temperatures were collected from a representative sample of servers in the data center. Several measurements of the supply temperature were taken at the discharge of the CRU units. This information helps to identify the health of the air distribution in the data center. From these temperature measurements, the following indices were calculated:

Rack Cooling Index (RCI)

Rack Cooling Index is a dimensionless measure of how effectively the equipment is cooled within a given intake temperature specification (e.g., the American Society of Heating and Air-Conditioning Engineers [ASHRAE] provides recommended values). The RCI provides a measure of the conditions at the high (HI) end and at the low (LO) end of the specified temperature range. The term $RCI_{HI} = 100\%$ means that no intake temperature is above the maximum recommended, and $RCI_{LO} = 100\%$ means that no intake temperature is below the minimum recommended. Using ASHRAE 2011 Class 1 temperature recommendations, "poor" conditions are ≤ 90 percent; whereas, "good" conditions are ≥ 96 percent.

Return Temperature Index (RTI)

The Return Temperature Index is a dimensionless measure of the actual utilization of the temperature differential in the equipment room, as well as a measure of the level of bypass air or recirculation air in the data center. The target is generally 100 percent; higher than 100 percent means recirculation air around racks; less than 100 percent means bypass air around the racks. The RTI is an average number across the data center, which means there are areas with air recirculation and areas with air bypass. Table 9 summarizes the actual values for the metrics.

Metric ID	*Metric Name*	*Unit*	*Value*	*Interpretation*
AM.M.1	CAU Temperature Differential	°F	10.5	Poor

AM.M.2	Average Rack Temperature Rise	°F	8	Poor
AM.M.3	Return Temperature Index	%	125	Fair amount of air is recirculating
AM.M.4	Rack Intake Temperatures	°F	70	Lower than ideal 80°F
AM.M.5	Rack Cooling Index	%	Lo 94 Hi 100	Some overcooled rack but not any overheated
AM.M.8	Airflow Efficiency	W/cfm	.52	Fair

Table 9: Air Management Metrics

W/cfm = Watt per cubic feet of air per minute

6.3 Data Center Electrical Power Chain Metrics

The UPS system typically represents an efficiency opportunity in most data centers. In this data center, the UPS was loaded to approximately 65 percent of its rated capacity on average. The efficiency at this load factor was estimated to be approximately 92 percent. This means that 8 percent of the power to the IT equipment is lost as heat within the UPS and that heat must be removed by the HVAC system, creating a further energy penalty. Table 10 summarizes the metrics that were collected for DC 1. The DC 2 numbers are not much different, so they are not listed.

Metric ID	***Metric Name***	***Unit***	***DC 1***	***DC 2***	***Interpretation***
ED.M.1	UPS Load Factor (average)	%	65	69	Low load factor
ED.M.2	UPS System Efficiency (average)	%	90	90	Higher efficiency at higher load factors
ED.M.3	Transformer Efficiency (upstream UPS system)	%	97	97	Assumed
ED.M.4	PDU (with built-in transformer) System Efficiency	%	97	97	Assumed
ED.M.5	IT Peak Power Density	W/ft^2	NA	NA	Average
ED.M.6	IT Ave Power Density	W/ft^2	19	15	Low
ED.M.7	IT Peak Power Density (design) based on UPS capacity	W/ft^2	32	21	High
ED.M.8	IT Rack Power Density	kW/rack	2.5	2.5	Average
ED.M.9	IT Rack Power Density (design)	kW/rack	3	3	Average
ED.M.10	UPS output voltage	V dc	480	480	More efficient than 120 V
ED.M.11	Standby Gen Block heater power	kW	5	5	Assumed

Table 10: DC 1 Power Distribution Metrics

W/ft^2 = watts per square foot; V dc = volts, direct current

Figure 10 illustrates the UPS load factor. There are no redundant UPS at the data center, so one UPS was supplying all the IT power. By increasing the load factor, the efficiency will improve, but a better option is to replace these units with more efficient ones, with units with offline options, or with smaller modules when the time comes to replace them.

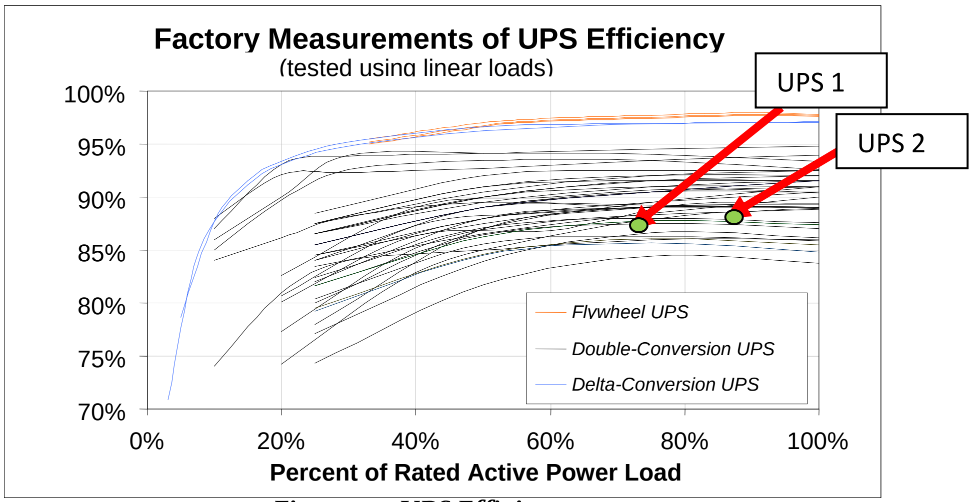

Figure 10: UPS Efficiency

Figure 11 below illustrates the UPS load factor of these data centers and how they are better loaded compared to other centers benchmarked by LBNL.

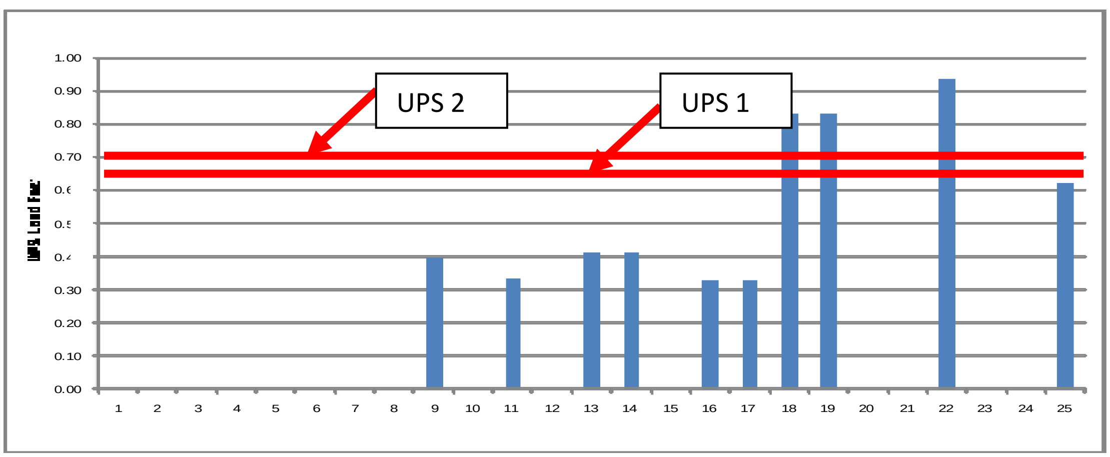

Figure 11: UPS Load Factor, Fraction of Capacity

7. Observations

7.1 Chilled Water Plant and Glycol Plant

For the period of observation, only a 400-ton chiller was operational. The estimate of the chilled water supply (CHWS) temperature was 43.6°F at the chiller, 56.3°F at the secondary pumps, and 60.6°F at the return. Recommissioning of the monitoring and control system seemed an urgent action, considering many obvious erroneous temperature readings. As shown in Figure 12, the heat was rejected to both sides of the heat exchanger! (The chilled water return [CHWR] is going from 60°F to 62°F, and the chilled water supply [CWS] is going from 52°F to 58.3°F). The variable-frequency drive (VFD) on the secondary pump is not getting the right signal. More than 60 percent of the secondary flow returns directly to the secondary pumps through the bypass. If the flow through the bypass is controlled to be very small, then the CHWS temperature setpoint can be increased, since no dilution of temperature is expected. The CHWS setpoint can be increased from 43.6°F to 55°F as a minimum. This is equal to a more than 15 percent improvement in chiller efficiency. With a higher temperature difference between the CHWS and the CHWR, the CHW flow can be reduced, thus saving pumping energy.

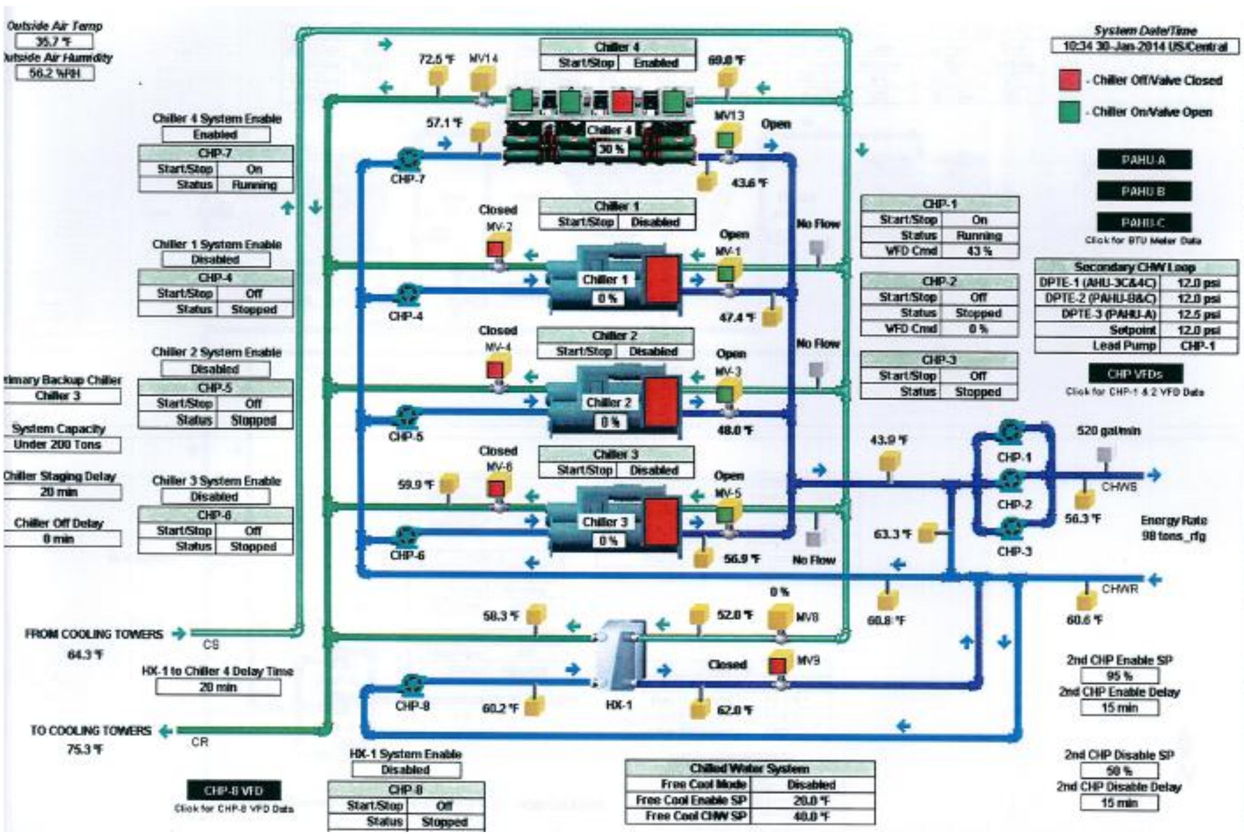

Figure 12: The Building Automation System (BAS) Chilled Water System Display

7.2 Data Center

7.2.1 General

During the baseline period, CAUs were being operated to control return air temperature to maintain rack inlet air temperature within the ASHRAE recommended guidelines. The ASHRAE 2011 ranges are shown in Table 11.

Class: Previous	Class: Current	Dry Bulb (°F)	Humidity Range	Max Dew Point (°F)	Max Elevation (ft)	Max Rate of Change (°F / hr)
Recommended						
1 & 2	**A1 to A4**	**64.4 to 80.6**	**41.9°F DP to 60% RH & 59°F DP**	N/A		
Allowable						
1	A1	59 to 89.6	20% to 80% RH	62.6	10,000	9* / 36
2	A2	50 to 95	20% to 80% RH	69.8	10,000	9* / 36
N/A	A3	41 to 104	10.4°F DP & 8% RH to 85% RH	75.2	10,000	9* / 36
N/A	A4	41 to 113	10.4°F DP & 8% RH to 90% RH	75.2	10,000	9* / 36

* More stringent rate of change for tape drives

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Table 11: 2011 ASHRAE Ranges (The GSA data center is considered class A1.)

Generally, the data center was over-cooled. The Average Supply Air Temperature (SAT) was low (approximately 62°F). As Table 11 above illustrates, the inlet air temperature could be set to 80°F, resulting in large energy savings with no impact on equipment reliability. This can be done only after air management issues are resolved. No major obstructions were observed under the raised floor except for few areas. Chilled water piping and cables were observed in some areas. Rack densities were low, and with both hot and cold air being mixed through these openings, the data center cooling efficiency was reduced. Figure 13 shows the empty racks, open spots, and tile openings that cause the hot and cold air to mix.

Figure 13: Empty Racks, Open Spots, and Tile Openings

The creation of hot and cold aisles should be complemented by closing the openings in the raised floor and between and within the racks. Many openings within the racks, which impaired the separation of cold and hot air, were observed. Another issue was related to the cooling of PDUs. Large openings were observed by and under PDUs. As a result, the cold air flows directly to the data center through the openings. Figure 14 illustrates pictures of perforated tiles out of place.

Figure 14: Examples of Misplaced Perforated Tiles

Figure 15 shows pictures of under the raised floor plenum and above the rack space. The top of the racks was open so air could exit from top as well as the back.

Figure 15: Under the Raised Floor Plenum and Above the Racks Space

Figure 16 shows perforated tiles in front of the cabinets and openings for cables.

Figure 16: Perforated Tiles in Front of Cabinets and Openings for Cables

7.2.3 Air Management

During baselining period (January 28-31, 2014), the server intake and exhaust temperatures were continuously monitored on many racks in the data center . In addition, during the same period, air temperatures were continuously monitored on the data center CAU supply and return, as well as in the sub-floor. This monitoring helped to establish an understanding of air management performance and identify any issues such as potential hot spots. The rack cooling and temperature indices were calculated from these temperature measurements, using an air management tool while baselining energy use at GSA.

For this assessment, the U.S. Department of Energy (DOE) DCPro air management assessment tool was used to calculate RTI for the data center. The RTI value of 90 percent is an average. It indicates some degree of bypassed air. The small temperature difference (10.5°F) between the CAU's return air temperature (RAT) and supply air temperature (SAT) and small temperature difference (8.4°F) between the rack's air intake and exhaust temperatures indicates the potential for major reduction in air the quantities exists. Table 13 illustrates baseline air management information for this data center based on wireless monitoring system readings. Table 12 is the output of the air management tool. As it can be observed there is little difference between the air management tool output and actual measurement.

Metric	Definition	Measured	Unit	Recommended
ΔT_{AHU}	Typical (airflow weighted) AHU temperature drop	10.8	^{0}F	20
ΔT_{Equip}	Typical (airflow weighted) equipment temperature rise	8.4	^{0}F	25
V_{AHU}	Total AHU airflow	42000	cfm	
V_{Equip}	Total equipment airflow	53000	cfm	
RTI	Return Temperature Index: $\Delta T_{AHU}/\Delta T_{Equip} = V_{Equip}/V_{AHU}$ (x100)	128	%	100
RCI_{HI}	Rack Cooling Index: Measure of absence of over-temperatures	100	%	100
RCI_{LO}	Rack Cooling Index: Measure of absence of under-temperatures	94.0	%	100

IAT max	Typical (not extreme) max IT equipment intake temperature	82	^{0}F	80.6
IAT min	Typical (not extreme) min IT equipment intake temperature	58	^{0}F	80.6
SAT	Typical (airflow weighted) AHU supply air temperature	60	^{0}F	78
∆SAT	Maximum difference between AHU supply air temperatures	11	^{0}F	0

Table 12: Air Management Metrics, DCPro Air Management Tool Report

7.2.4 Racks

Figure 17 shows the average rack intake air and exhaust temperatures for DC 1. The intake temperature is about 70°F, which identifies an opportunity for it to increase to 80°F. The temperature difference between the air intake and the exhaust is only about 7°F. Increasing this temperature difference to higher numbers like 20°F provides an opportunity to save energy by lowering CAU air flow and fan power.

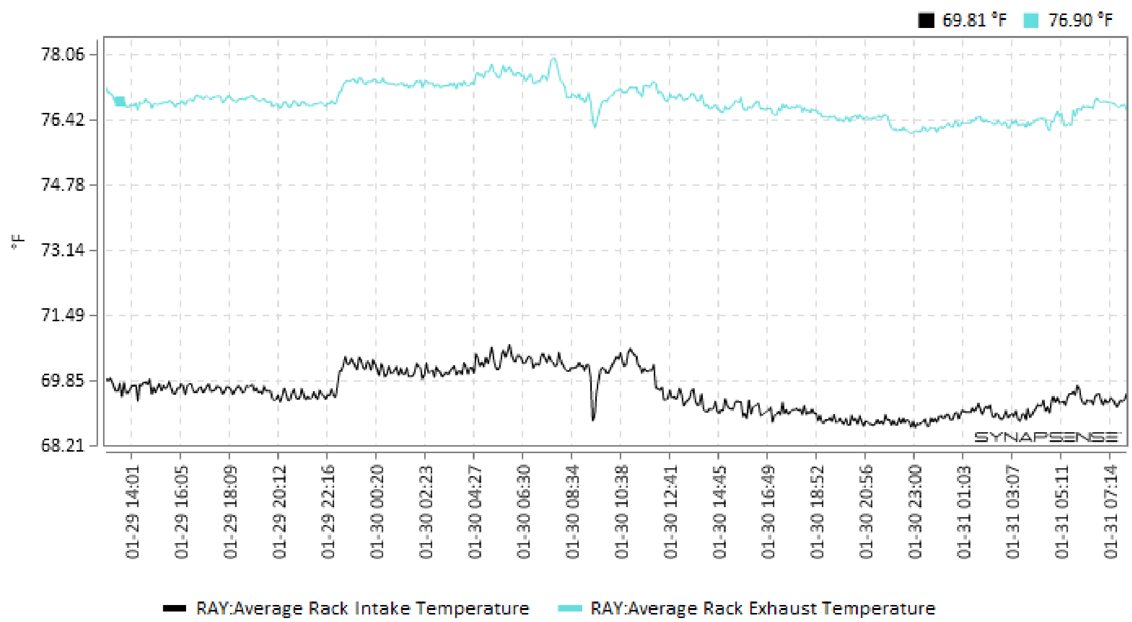

Figure 17: DC 1 Average Rack Intake and Exhaust Temperatures

Rack 2 is an example of good cooling airflow. As shown in Figure 18, the intake air temperatures at three levels (top, middle, and bottom) are close to one another. The same figure shows that the intake temperature at the top measured cooler than that at the bottom, meaning there is some recirculation through the rack at lower levels of the rack.

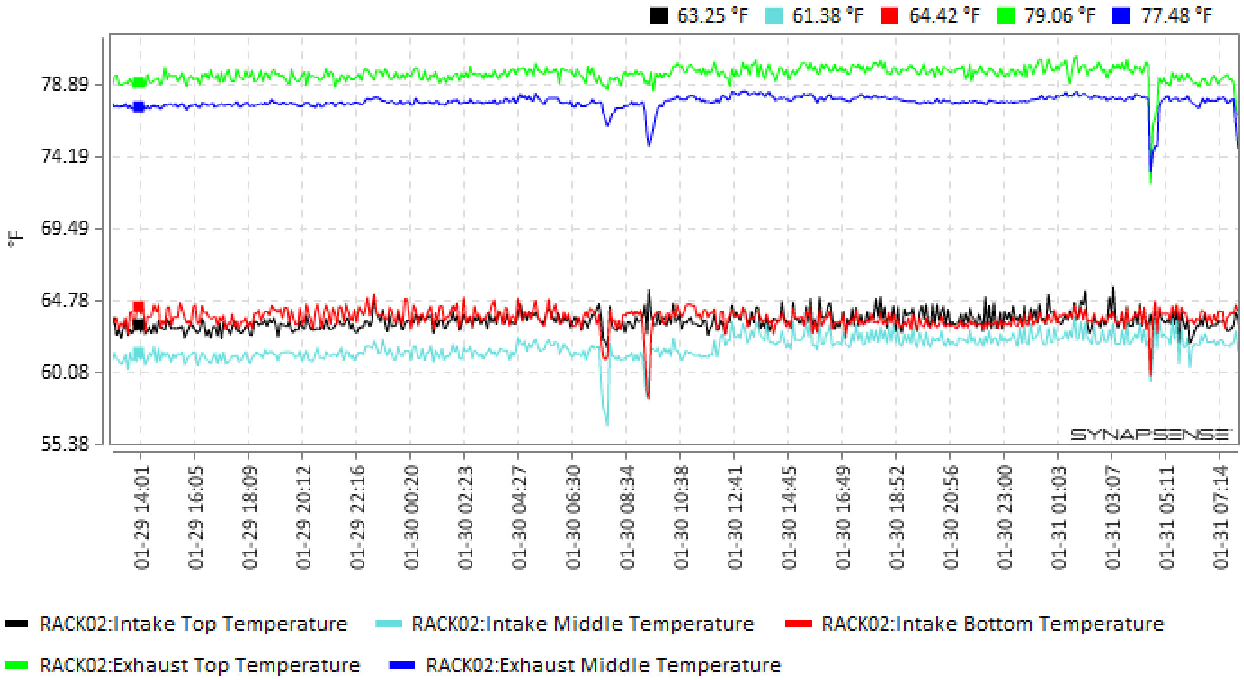

Figure 18: DC 1 Rack 2 Intake and Exhaust Temperatures

Rack 1 is an example of a typical cooling airflow in DC 1. As shown in Figure 19, intake air temperatures at three levels (top, middle, and bottom) are very different. The top and middle temperatures measured much warmer than the bottom, which illustrates major recirculation of hot air, through the rack, back to the front. Obviously when intake air at the top is at higher temperature, the exhaust will be at a higher temperature as well. Overall, this confirms a major recirculation of air through most of the racks.

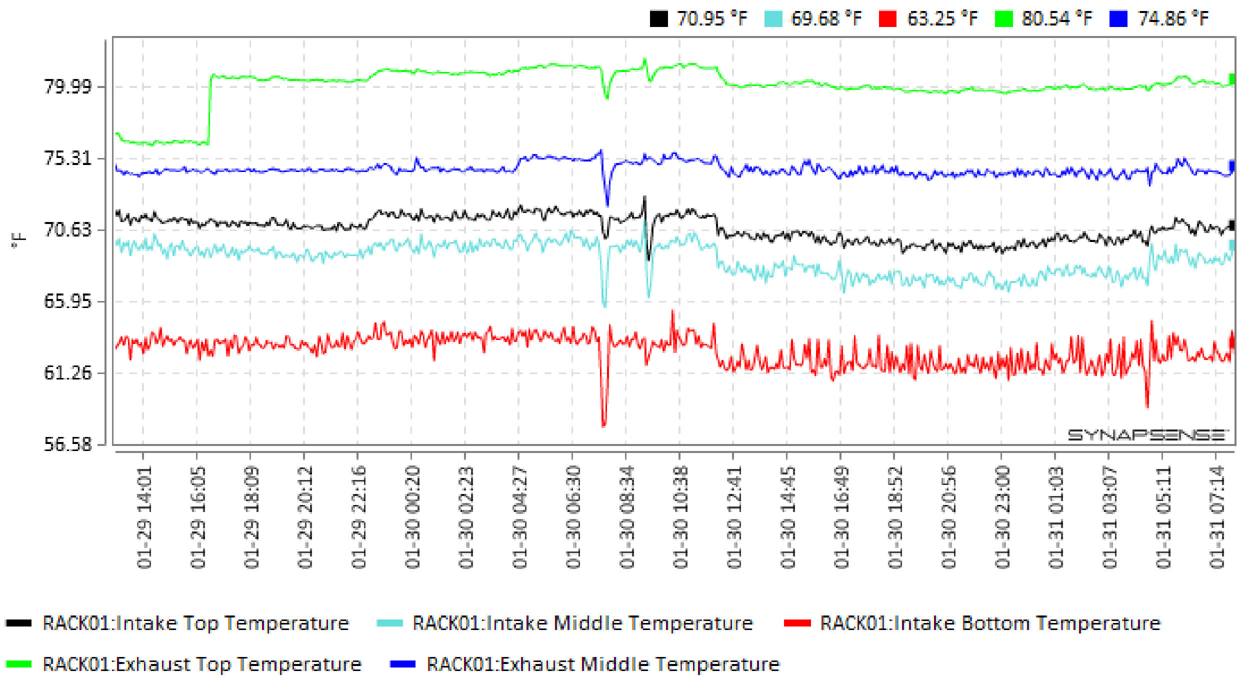

Figure 19: DC 1 Rack 1 Intake and Exhaust Temperatures

Rack 15 is another example of a typical cooling airflow in DC 1. As shown in Figure 20, intake air temperatures at three levels (top, middle, and bottom) are very different. The top and middle temperatures actually measured colder than the bottom, which indicates a recirculation of hot air at the very bottom; mainly from space underneath the rack, but also from the sides.

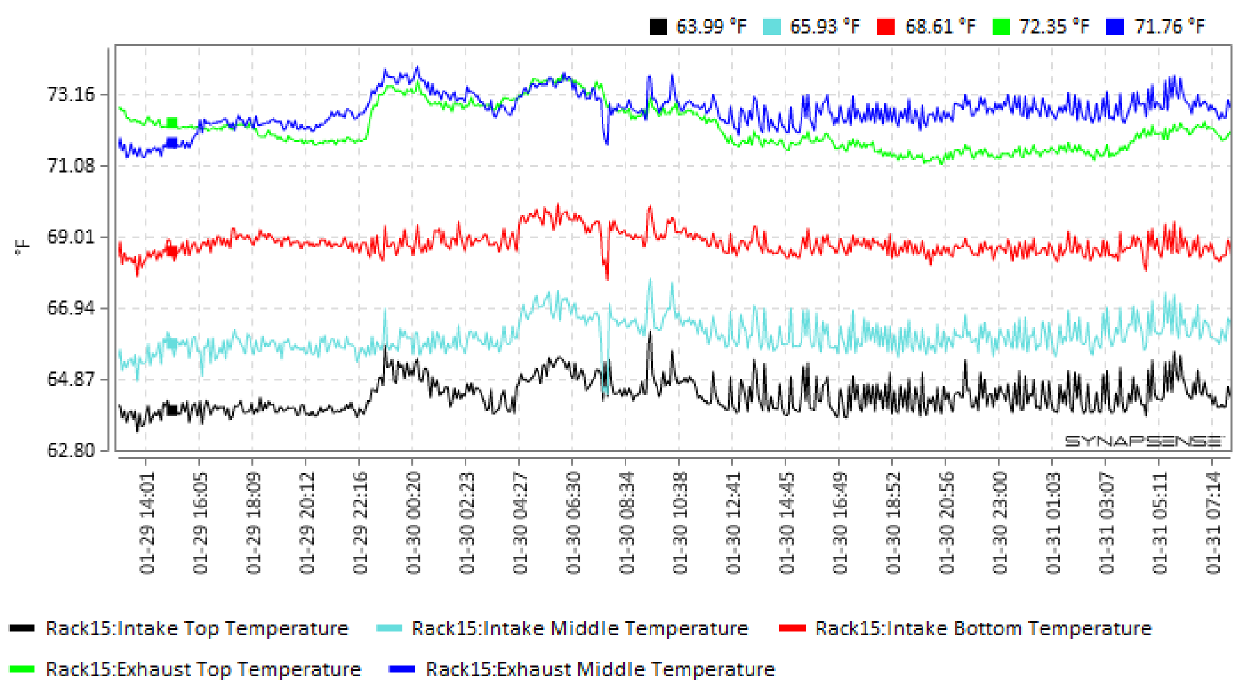

Figure 20: DC 1 Rack 15 Intake and Exhaust Temperatures

Note the wide variation between temperatures at the bottom of the rack and those at the top. This indicates that there is air recirculation from the back and top of the racks to the front of the racks. The mixing of hot and cold air is the main source of the problem.

7.2.5 Computer Air Units (CAUs)

Table 13 shows the average DC 1 CAU supply air temperature (SAT) and the temperature difference between the return air temperature (RAT) and SAT at each unit.

Unit Label	Type	Heat Rejection Primary	SAT (°F)	RAT,SAT difference (°F)
7-5	DualCool	CHW	65	7
7-4	Glycol-only	Glycol-only	54	14
7-3	CHW-only	CHW-only	62	10
7-2	Dual Cool	CHW	63	10
7-1	Glycol-only	Glycol-only	62	8

Table 13: DC 1 CAU's Average SAT and Temperature Difference

Figure 21 shows the DC 1 average CAU supply and return temperatures. The average supply temperature is less than 62°F. With improved air management, this temperature can be increased to 80°F, and with that action, the energy used by the cooling systems will be reduced.

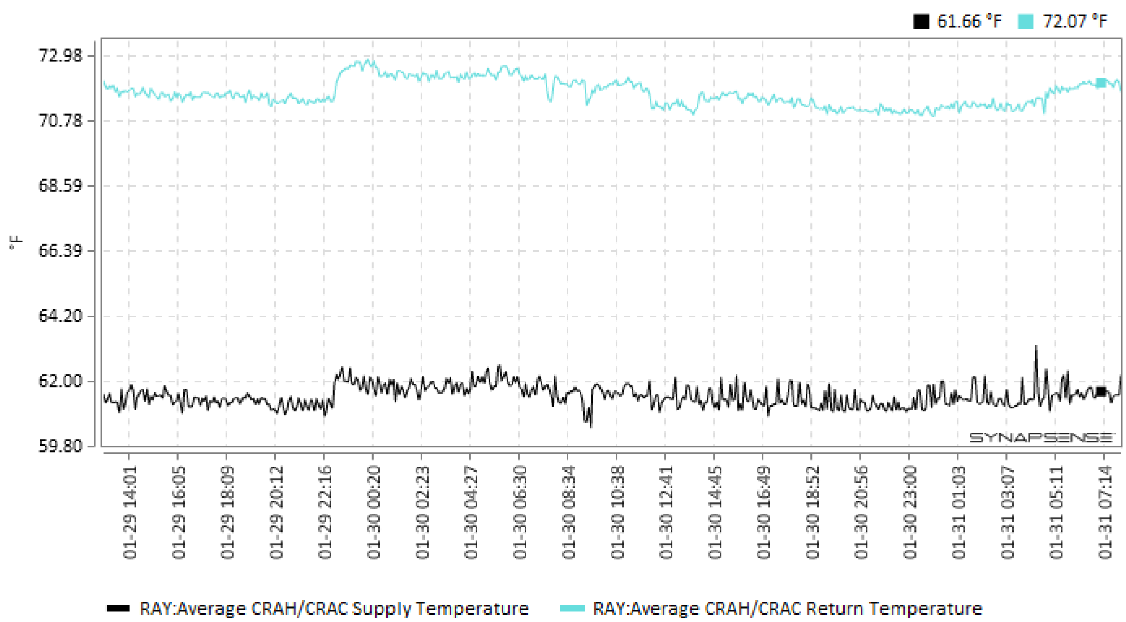

Figure 21: DC 1 Average CAU Supply and Return Temperatures

Figure 22 illustrates three important air management metrics: (1) average bypass air (BPA) percentage, (2) average rack recirculation air (RA) percentage, and (3) temperature rate of change. Both BPA and RA rated from 37 to 42 percent, as expected by observing temperatures in front of the racks.

The temperature rate of change was only about 1°F to 2°F, which is much lower than the ASHRAE limit of 9°F.

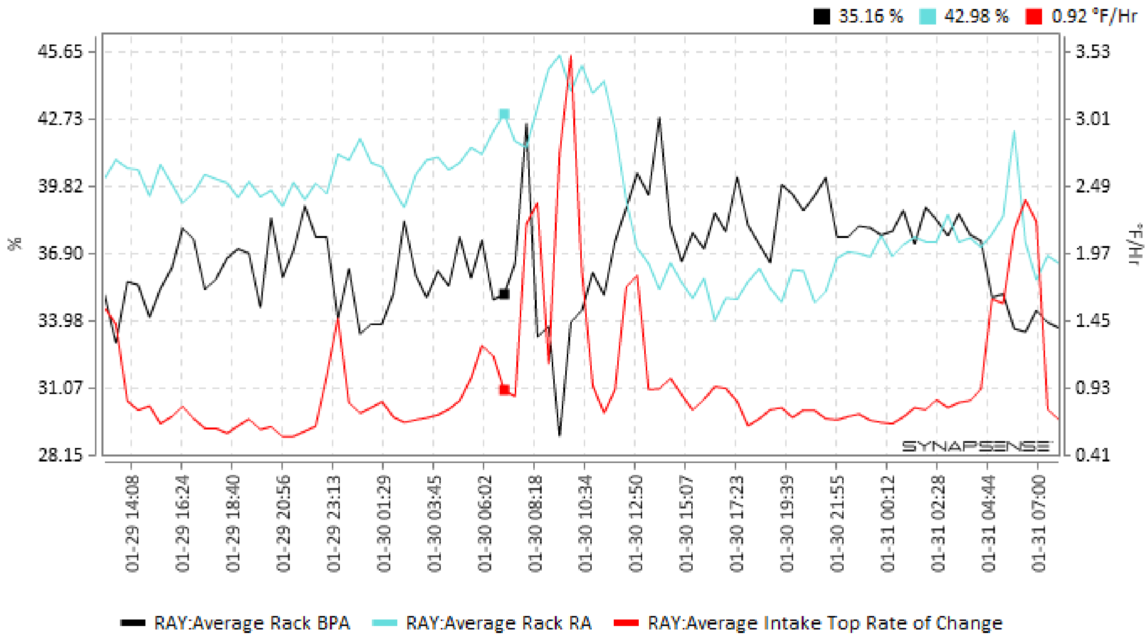

Figure 22: DC 1 Average BPA, RA, and Temperature Rate of Change

Figure 23 illustrates RCI_{Hi} and RCI_{Lo} for the data center. The graph is produced by monitoring system. These results are similar to those derived from execution of DCPro air-management and modeling tool. Based on an RCI_{Hi} of more than 98 percent, there were almost no racks with an air intake higher than 80.6°F (ASHRAE recommended). Based on an RCI_{Lo} of more than 94 percent, there were only few racks with air intake temperatures lower than 64°F (the ASHRAE-recommended lower limit).

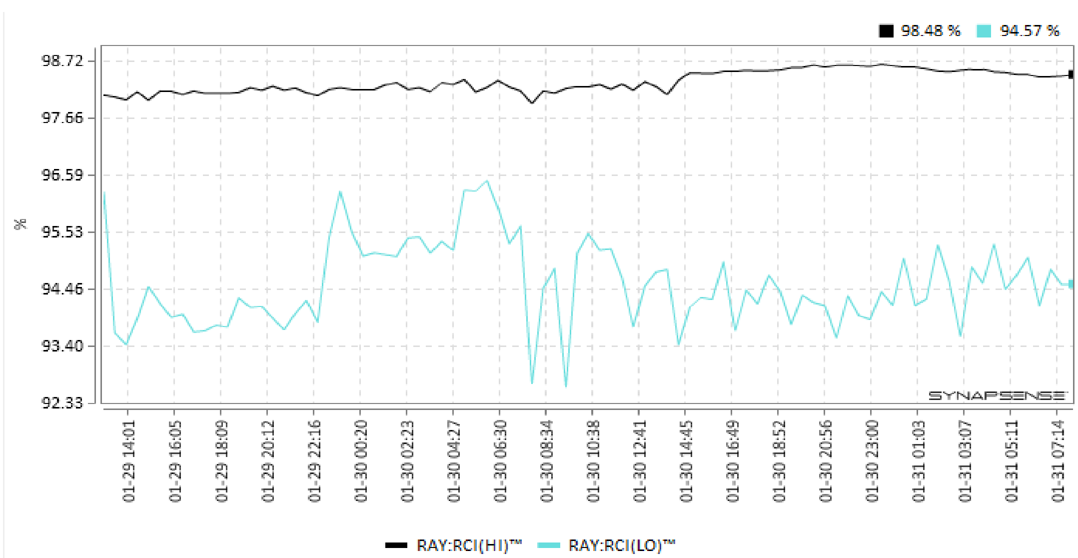

Figure 23: DC 1 RCIHi and RCILo

7.2.6 Cooling Load

The data center cooling system included a few chilled water CAU units, as well as CAUs with glycol-cooled compressors (DX systems). It was not possible to measure exactly how much cooling was provided by the chilled water system and the DX system. At the time of the assessment, approximately 500 tons of cooling were provided to the data center. The chilled water from the chiller plant was supplied at 56°F. The chilled water return temperature was 60.7°F (according to the BAS). This small temperature difference results in inefficient chiller operation. Table 14 breaks out the assumed cooling power use.

Cooling Energy Usage (kW)	DC 1	DC 2
Cooling DX compressors	25	30
Cooling, Chilled water	12	8
Cooling, Dry coolers/pumps	35	31
Fans	25	15
TOTAL	**97**	**84**

Table 14: Cooling Power Use Estimate

7.2.7 Lighting

The locations of some of the lighting fixtures were not optimal in that the lighting they produced , such as that over the corridors, was not needed. Lighting control was not employed, yet lighting could be turned off during many hours of operation. Locating the light fixtures in the aisles will help to reduce their number.

7.3 Environmental Analysis

7.3.1 Temperature Analysis

During the baseline period, the measurements identified temperatures mostly cooler than the ASHRAE 80.6°F upper limits. By improving the air management, raising the data center temperature is possible. It was determined that the root cause of the overcooling was the low supply air temperature being delivered to the racks by the CAUs. Similarly it was determined that hot discharge air from the IT equipment was recirculating back through and around the racks due to the absence of containment; thereby increasing server inlet air temperatures in some areas. In addition, a high level of stratification was occurring in front of some of the data center racks, with the bottom of the racks having the lowest temperatures, and in some cases, the highest temperatures. Removing the excess provisioned perforated tiles, blanking the openings within and between the racks and floors, and increasing supply air temperatures could reduce the over-cooling in the data center and raise the inlet air temperature to the IT equipment while remaining within the ASHRAE 2011 recommended range. Additional blanking is needed throughout the data center.

Figures 24 through 27 show thermal maps of the racks' air intake temperatures at the top, middle, and bottom, as well as under the raised floor. Warmer air was observed at the higher level. Very cold temperatures were observed under the raised floor and at the racks' bottom levels.

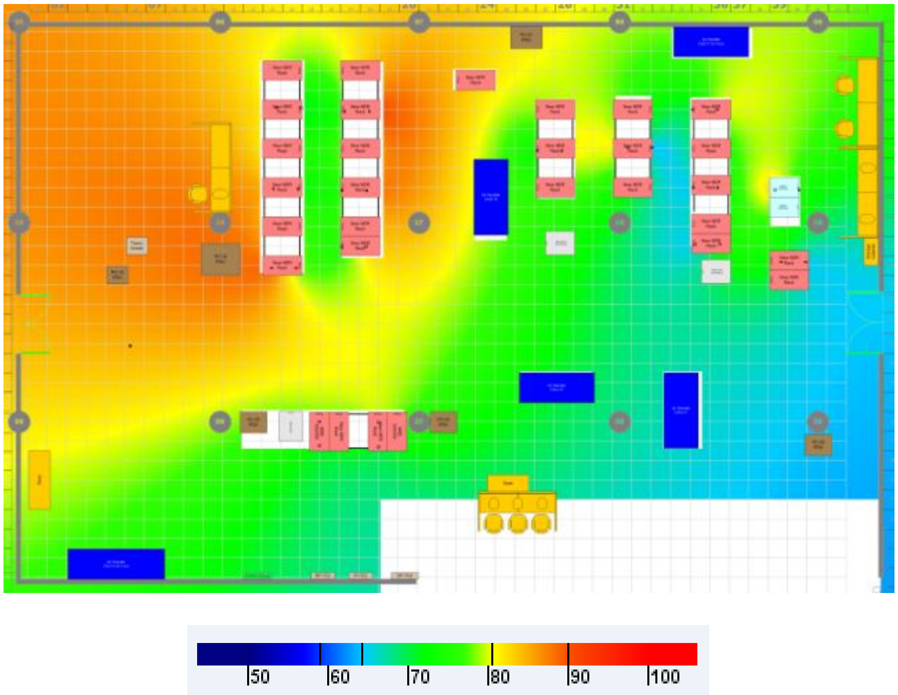

Figure 24: DC 1 Intake Air Temperature Map at the Top

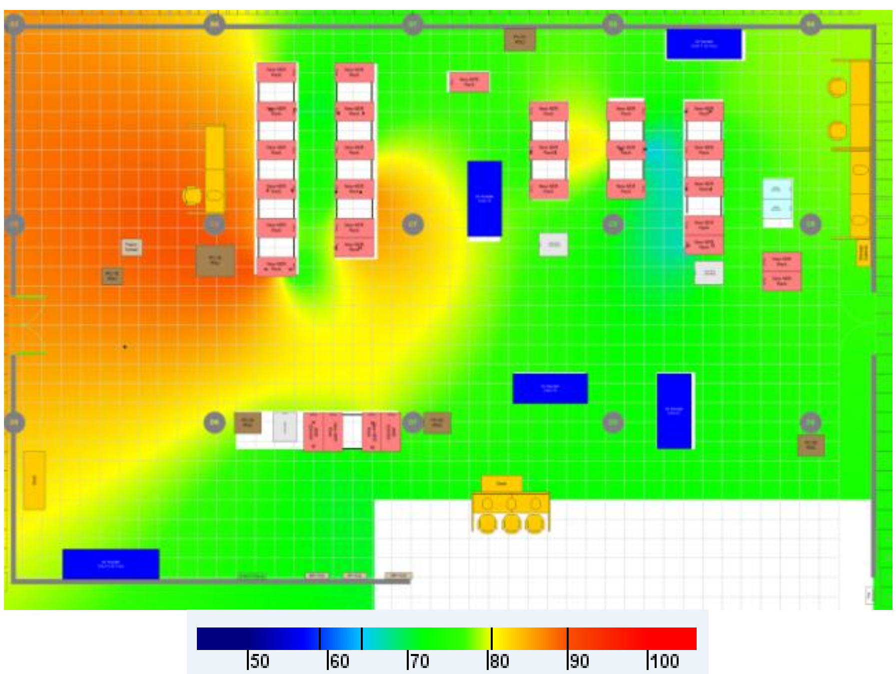

Figure 25: DC 1 Intake Air Temperature Map at the Middle

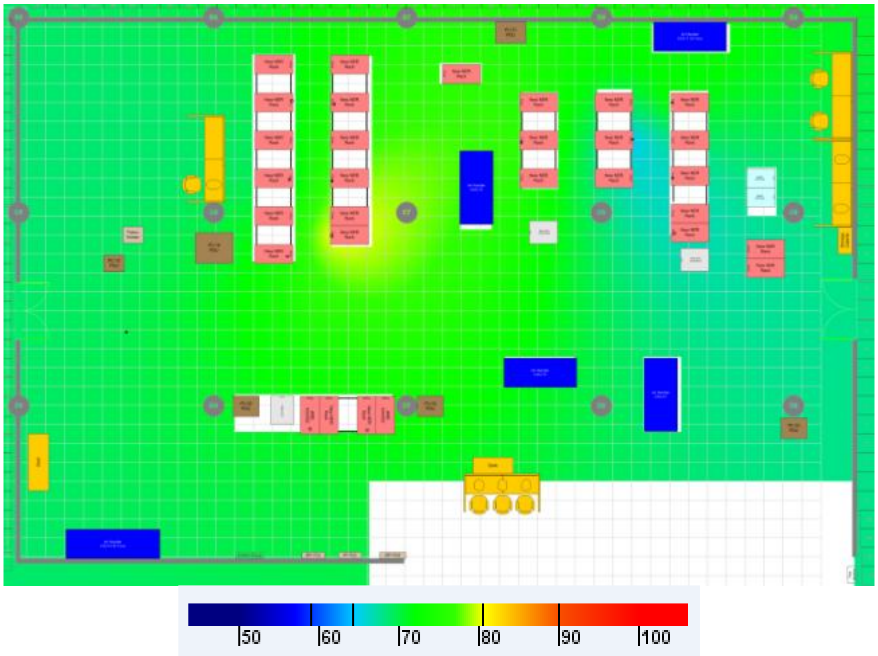

Figure 26: DC 1 Intake Air Temperature Map at the Bottom

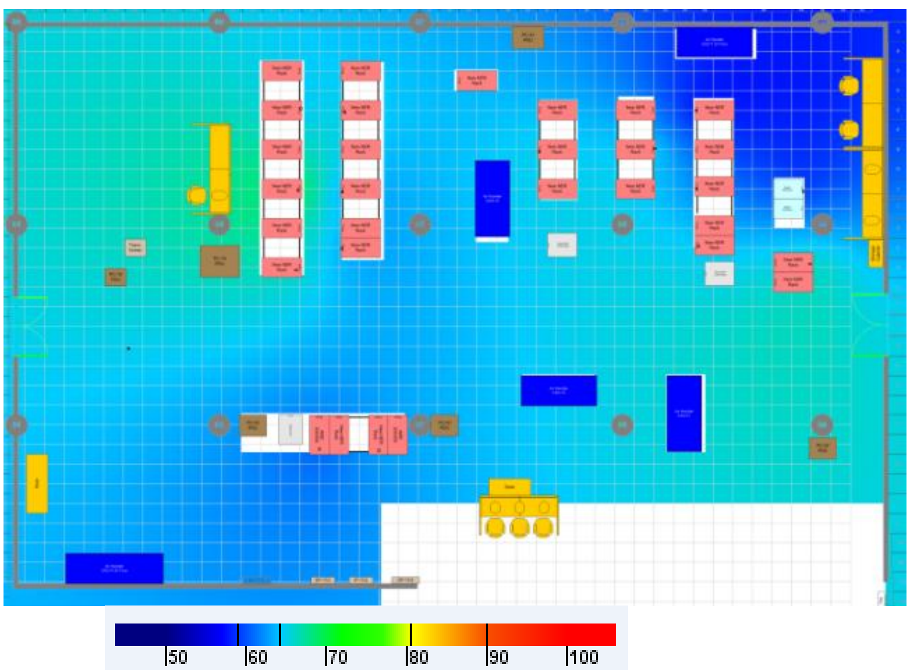

Figure 27: DC 1 Intake Air Temperature Map Under the Raised Floor

7.3.2 Relative Humidity Analysis

During the baseline period, the relative humidity measured at the top of racks was consistent across the data center. Figure 28 shows the humidity map in DC1. Humidity ranged between 20 and 30 percent. Make-up air entering the data centers was as dry as the data center environment.

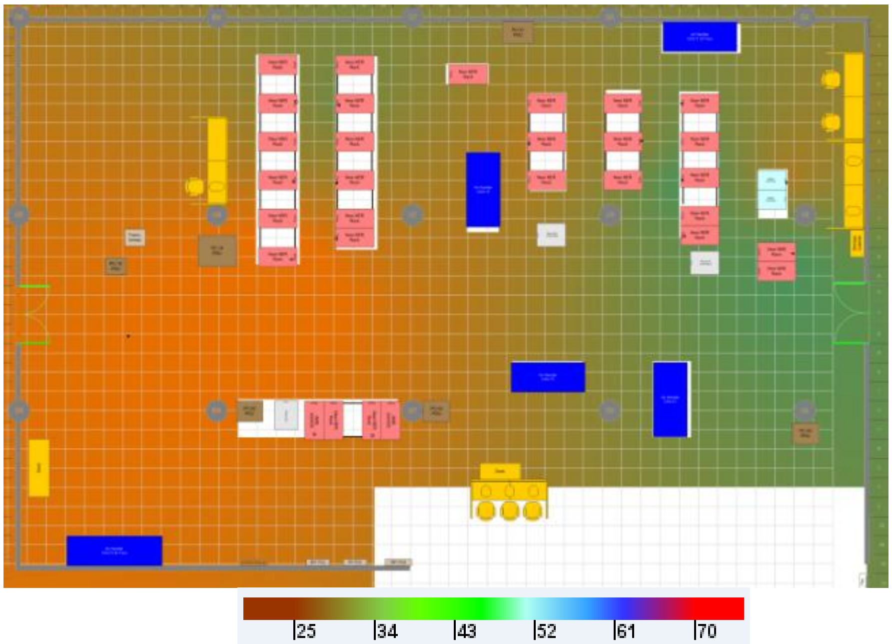

Figure 28: DC 1 Humidity Map

7.3.3 Sub-Floor Pressure Analysis

The pressure under the raised floor varied between 0.02 inches of water column (inwc) to 0.05 inwc. Figure 29 illustrates the pressure under the raised floor as measured by pressure sensors in different locations around the data center. Small variations in the raised floor pressure are due to a variation of airflow in the racks, as well as maintenance and operational work on the floor. The big increase in pressure on January 30 at 12:00 pm was the result of covering some of the misplaced perforated tiles. Once the recommended air management improvements are made, CAU units could be turned off, or they could be modified to operate based on pressure control. The recommended setpoint for pressure is 0.03 inwc.

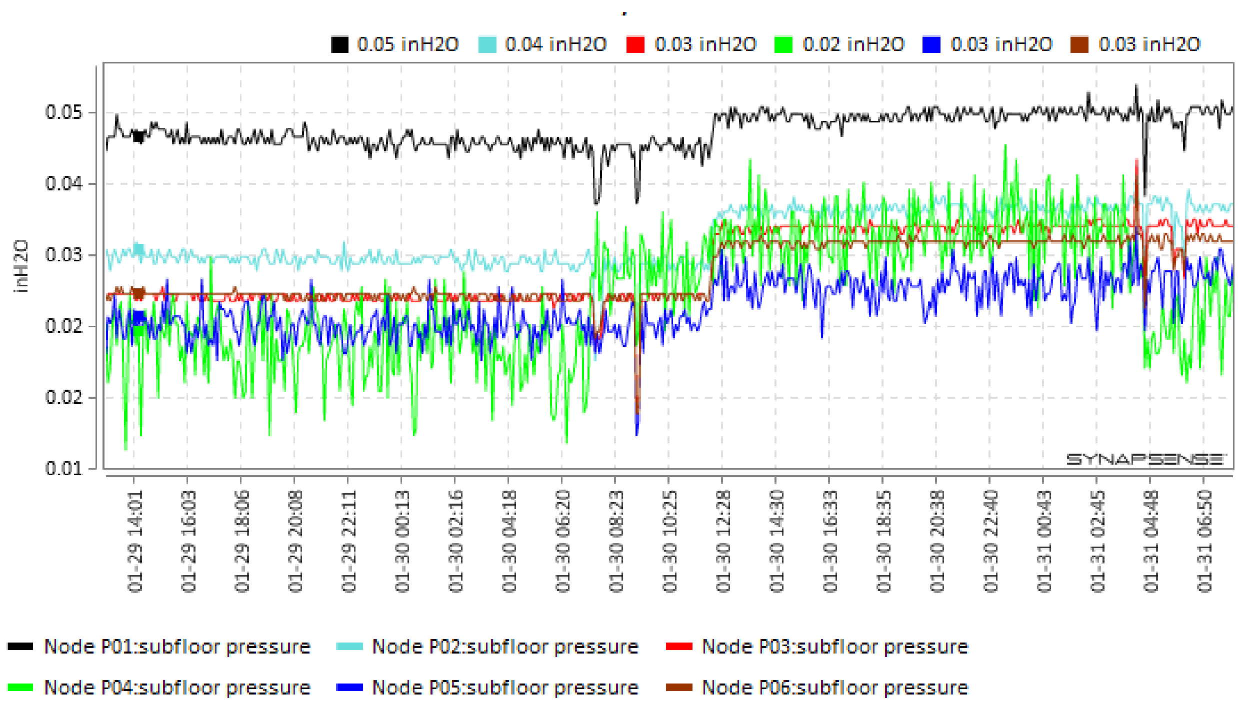

Figure 29: DC 1 Raised Floor Pressure Read-Outs

Figure 30 shows a pressure map that confirms the readings. Green area identifies area at higher pressure close to .05inwc. The red area illustrates the area with lower pressure close to .02inwc.

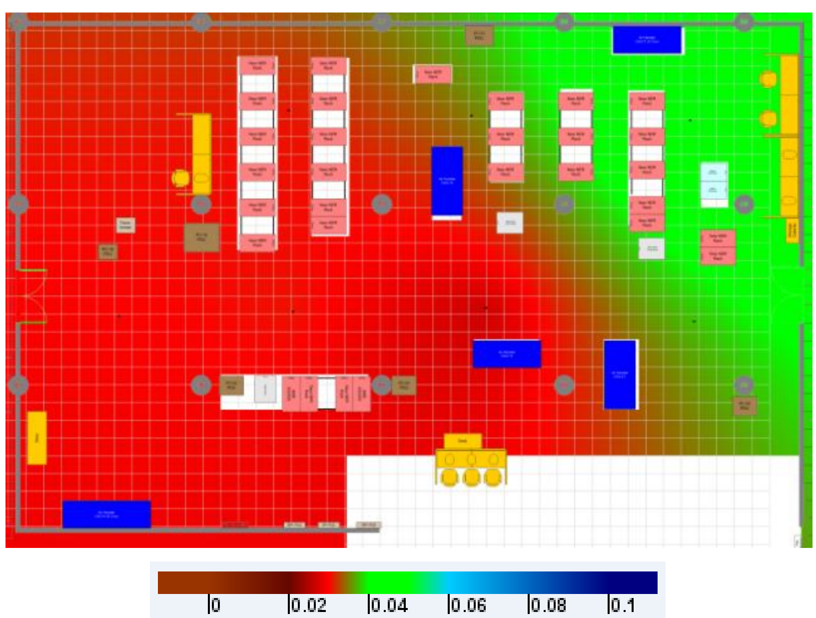

Figure 30: DC 1 Raised Floor Pressure Map

The second pressure map, illustrated in Figure 31, confirms the readings after some of the perforated tiles that were in open areas (no racks in vicinity) were covered. As it can be observed pressure in the area with covered perf tiles was increased substantially.

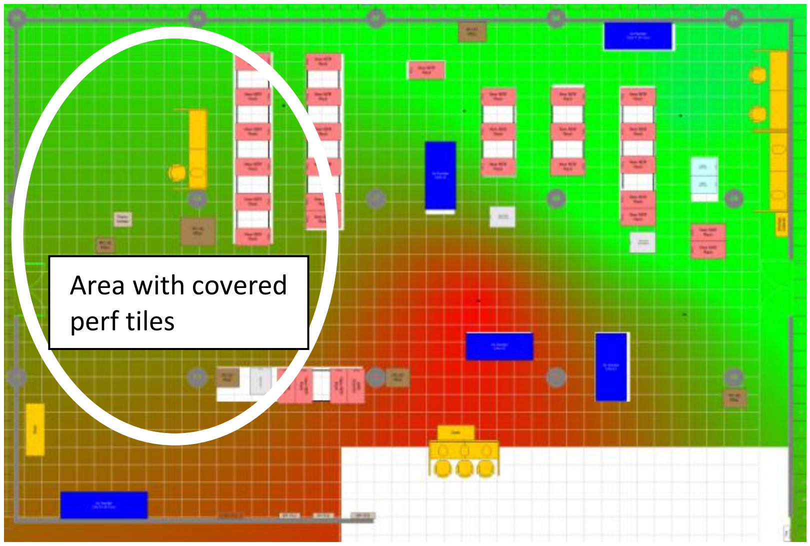

Figure 31: DC 1 Raised Floor Pressure Map After a Few Perforated Tiles Were Covered

8. Energy-Efficiency Packages for Evaluation (by System)

8.1 Electrical Distribution System

Load factor has an impact on the efficiency of most of the electrical distribution equipment, so any action to increase the load factor can improve efficiency and reduce power loss. Transformers, uninterruptible power supplies, and power distribution units are the most affected.

8.2 Recommended Energy-Efficiency Measures for the Data Center

The following measures are recommended for further evaluation. Some of them were more feasible, all things considered (especially considering the current state of the site), and were included in the EEM packages. Measures were also identified that could improve energy efficiency in the RAY building itself, beyond the data centers. Calculations showed that it would be possible to save $140,000 in annual energy costs by utilizing water-side economizers. Estimated payback was 1.7 years. See Appendix B for more detail.

The other issue that needs more research is planning to abandon the glycol system completely and utilize the house chilled water system. Major savings could result from the use of higher-temperature chilled water, since (1) high-temperature chilled water production is more efficient, and (2) economizer operation hours are increased, which means only partial compressor cooling would be needed.

Following are lists of energy-efficiency measures that could help to improve the RAY Building's data center energy performance:

General

To improve energy efficiency of the data center, make IT operations more efficient and improve power and data center monitoring and management through the following activities:

1. Virtualize the computer hardware platform, operating system (OS), storage device, or computer network resources.
2. During refresh, procure more efficient (e.g., ENERGY STAR) equipment.
3. Install IT management systems and applications.
4. Recommission the data center environmental and power monitoring systems.
5. Install an energy use monitoring and reporting system.

Air Management Measures

Certain measures that improve the airflow also can improve the air-cooled IT equipment (servers, storage, and network) operating conditions and the data center's energy efficiency.

1. Install missing blanking plates in the IT equipment racks to address the data center's hot spots.
2. Cover openings within and between racks. Investigate openings on top of the racks and ways to contain them. Hot aisle containment should address those openings.
3. Seal any remaining cable penetrations.
4. Rearrange the perforated floor tiles, locating perforated tiles only in cold aisles and matching tile flow rate with the IT equipment airflow rate.
5. Evaluate the air path (under the raised floor and in the ceiling space) and rearrange the cables, wires, and pipes to address possible congestion in the cooling air path.

6. Install racks in rows.
7. Maintain a hot-aisle/cold-aisle arrangement.
8. Change all remaining IT alignment to conform to a hot-aisle/cold-aisle configuration.
9. Plan to contain hot aisle or cold aisle. Evaluate the impact on the fire extinguishing system.
10. To separate cold and hot air, the most effective way is to contain the hot aisle and create a hot air return path (which can be ceiling space and chimney connecting the CRACs to the ceiling space).

Figure 32 shows (left) a temporary action of covering perforated tiles with boxes (we could not find solid tiles to replace the perforated ones), and (right) blanking the floor openings for conduits.

Figure 32: Covered Perforated Tiles and Conduit Penetration

HVAC and Cooling Measures

To improve the energy efficiency of the data center, the following HVAC and cooling system measures are recommended:

1. Convert data center CAU air temperature control to rack inlet air temperature control. Raise temperature setpoints to the upper end of the ASHRAE 2011 recommended range.
2. Turn off extra CAUs to reduce the cooling redundancy levels while reducing bypass air around racks that reduce the return air temperature on the CAUs.
3. Reset each CAU’s chilled water valve setpoint with the highest air intake temperature at the racks in the zone served by that CAU. For a dual-coil unit, use chilled water to remove as much as heat possible, then operate the DX compressors.
4. Generally, a central chilled water system that operates at a higher chilled water supply temperature (above 55°F) is more efficient than an individual DX system. Converting all of the cooling systems to just chilled water system will save energy.
5. Raise the chilled water temperature to increase chiller efficiency, thus reducing energy usage.
6. Addition of water-side economizer heat exchangers increases the capacity and hours of use of the economizer, thus reducing cooling annual energy use.
7. Integrate dry cooler controls with BAS.

8. Recommission all the monitoring and control systems (e.g., thermometers on chilled water systems to thermocouples on dry coolers and the glycol system, pressure differential on both chilled water and the glycol system). One example is to install thermowells in glycol headers to correctly run both dry cooler fans and system pumps.

Electrical System Measures

To improve the energy efficiency of the data center, the following electrical system measures are recommended:

1. If replacement or addition becomes necessary, acquire very efficient (> 96 percent) UPS systems.
2. Placement of light fixtures in the server rows should be evaluated based on its impact on efforts to seal hot or cold aisles. Regularly evaluate the amount of installed lighting in the data center and assess whether or not de-lamping could help to reduce light levels without adversely affecting operations or security. For the lighting that remains, consider the most efficient lamps and ballasts available, and implement some type of occupancy control to turn off lights automatically when nobody is in the data center**.** Occupancy sensors for lighting should have multiple circuits so that only the area occupied is lit.
3. Reset the standby generator’s block heater temperature setpoint.
4. Use premium-efficiency motors when replacing a failed or aging motor.
5. Addition of submeters to ATS 5 and ATS 7 can provide useful information on data center energy use.

Some of the more feasible energy-efficiency measures are integrated into the following “action packages.”

Action Package 1: Turn off CAUs

- Seal all floor leaks and those between and within the racks.
- Enclose all hot aisles.
- Rotate/replace server cabinets that are facing the wrong direction.
- Raise the supply air setpoint to 80^{0}F.
- Turn off some CAU units to achieve airflow reduction.
- Install chimneys on the CAU units to connect the return to the ceiling space.
- Remove tiles above the hot aisles to guide hot air to the ceiling space.

Action Package 2: Cooling System Retrofit/Adjustment Package

- Raise the chilled water supply temperature setpoint.
- Reduce CHW flow by increasing the temperature difference between the CHW supply and the return.

  Note 1: Saved energy was calculated only for the data center portion, but this action benefits the whole building. If applied to the whole building, overall savings would be much higher.
  Note 2: The savings related to the data center in its current state will not be significant. The saving becomes significant if the data center cooling is converted to chilled water only (i.e., the glycol system is removed).

Action Package 3: Lighting Retrofit/Adjustment Package

- Reposition light fixtures from above the racks to above the aisles.
- Reduce lighting.
- Install occupancy sensors to control selected fixtures. Retrofit the central monitoring and control system.

Action Package 4: Electrical System Retrofit/Adjustment Package

- Reset the generator block heater setpoint.

Action Package 5: HVAC System Retrofit/Adjustment Package

- Run both glycol secondary pumps, but at a lower speed.
- Control the flow with pressure differential (DP) across the supply and return.

Note: In another part of this report, removing of DX system is recommended. If DX system is removed, then Package 5 will be no longer relevant.

Action Package 6: HVAC System Retrofit/Adjustment Package

- Install VFDs on glycol primary pumps.
- Run all glycol primary pumps, but at a lower speed.
- Control the flow with DP across the supply and return.

Note 1: Saved energy is calculated only for data center portion, but this action benefits the whole building. If applied to the whole building, savings would be at least twice as much.
Note 2: In another part of this report, removing of DX system is recommended. If DX system is removed, then Package 6 will be no longer relevant.

8.4 Results

Preliminary energy savings calculations were carried out for action packages. Table 15 summarizes the energy savings. These actions packages are recommended for further evaluation, including investment-grade audits.

Summary of Energy Savings Estimates	Savings			Cost	Payback
	kW	kWh/yr	$	$	years
Package 1	40.0	350,000	25,000	25,000	1.0
Package 2	14.2	125,000	8,700	10,000	1.1
Package 3	4.2	24,000	1,700	5,000	3.0
Package 4	5.0	44,000	3,100	2,500	0.8
Package 5	14.0	123,000	8,600	5,000	0.6
Package 6	15.0	263,000	18,400	30,000	1.6
Total Savings	**92**	**929,000**	**65,500**	**77,500**	**1.2**

Table 15: Summary of Savings and Costs

Table 16 illustrates the current and potential power use by end use for data centers.

Usage (kW)	Current	Potential
IT Load	179	179
UPS Loss	20	20
PDU/trans loss	7	7
Standby Gen block heater	10	5
Lighting	7	3
Cooling DX compressors	55	35
Cooling, Chilled water	20	6
Cooling, Dry coolers/pumps	66	37
Fans	40	20
TOTAL	**404**	**312**
PUE	**2.26**	**1.74**

Table 16: Data Center Current and Potential Power Use After Packages Implementation

Figures 33 breaks out the current data center energy use, and Figure 34 shows the projected energy breakout after implementation of all of the recommended action packages.

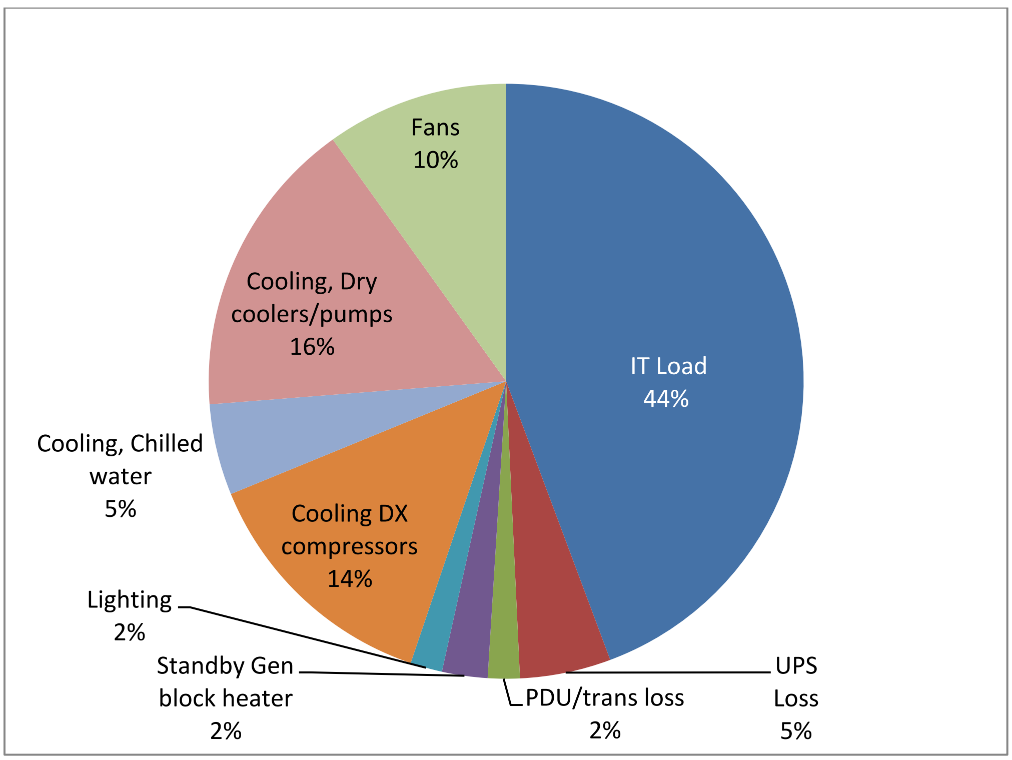

Figure 33: Current Facility Performance, PUE = 2.26

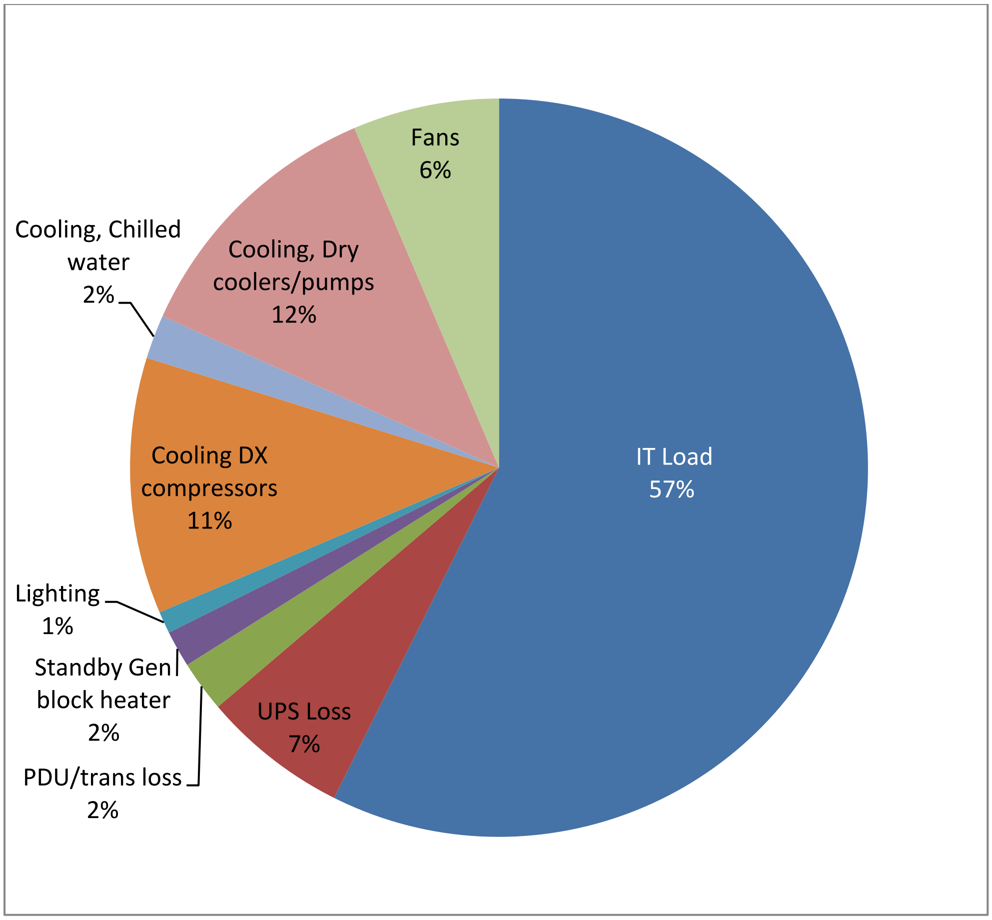

Figure 34: Potential Facility Performance, PUE = 1.74

Acronyms and Abbreviations

A	ampere
AHU	Air Handler Unit
ASHRAE	American Society of Heating, Refrigeration, Airconditioning Engineers
ATS	Automatic Transfer Switch
BAS	Building Automation System
BPA	Bypass Air
BTU	British Thermal Unit
CAU	Computer Air Unit
CHW	Chilled Water
CHWR	Chilled Water Return
CHWS	Chilled Water Supply
CRAH	Computer Room Air Handler
CRAC	Computer Room Air
CT	Cooling Tower
CWP	Cooling Water Pump
DC	Data Center
DOE	U.S. Department of Energy
DP	Dewpoint
DX	Direct Expansion
EEM	Energy-Efficiency Measures
GSA	General Services Administration
HVAC	Heating, Venilating, and Air Conditioning
HX	Heat Exchanger
HXWP	Heat Exchanger Water Pump
inwc	inches of water column
kV	kilovolt
kW	kilowatt
kWh/yr	kilowatt-hours per year
LBNL	Lawrence Berkeley National Laboratory
PCHWP	Primary Chilled Water Pump
PDU	Power Distribution Unit

PH	Phase
PUE	Power Usage Effectiveness
RA	Recirculating Air
RAT	Ram Air Temperature
RAY	Robert A. Young
RCI	Rack Cooling Index
RH	Relative Humidity
RTI	Return Temperature Index
SAT	Supply Air Temperature
UPS	Uninterruptable Power Supply
V	Volt
VFD	Variable Frequency Drive
W	Watt

APPENDICES

A. DATA CENTERS BEST PRACTICES

B. DATA CENTER EEMS CALCULATONS