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Demonstration of Intelligent Control and Fan Improvements in Computer Room Air Handlers

Henry Coles and Steve Greenberg, Lawrence Berkeley National Laboratory

Corinne Vita, Vigilent

Environmental Energy Technologies Division

November 2012
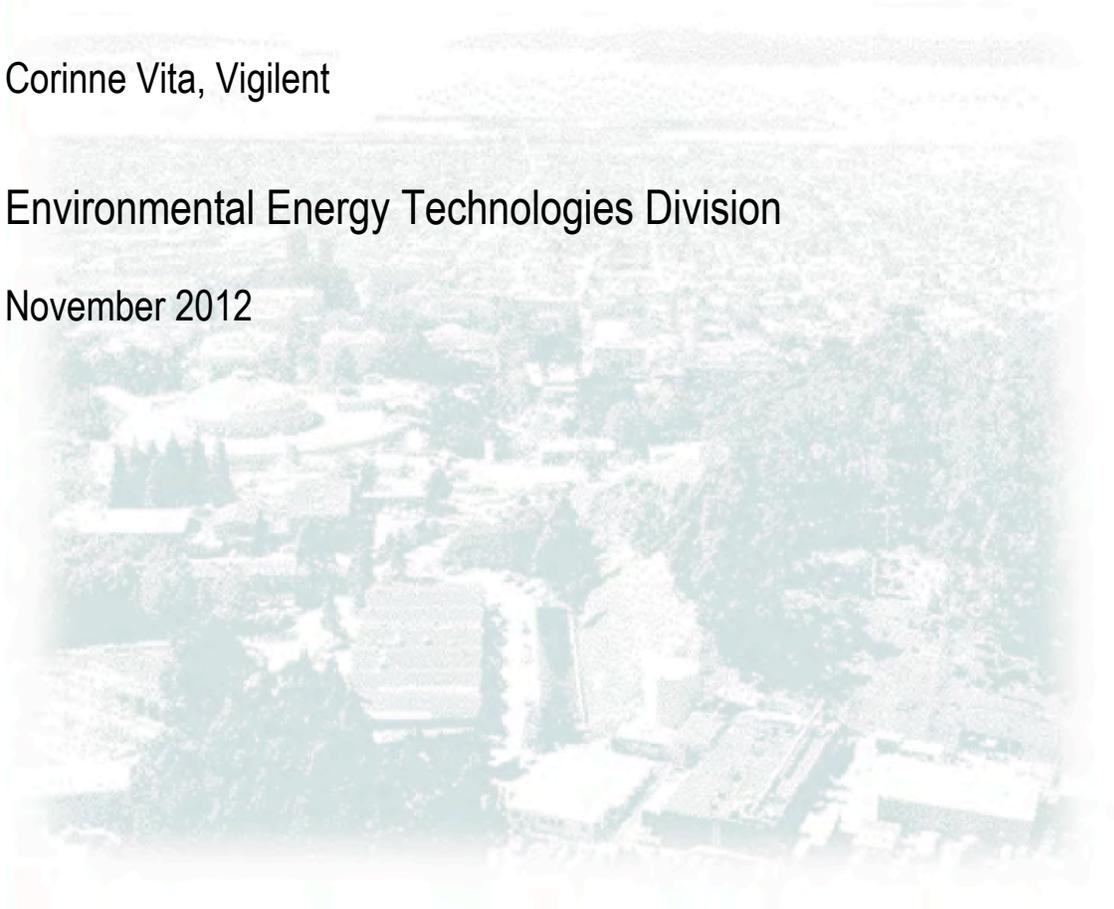
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ABSTRACT

This report documents a demonstration of the energy-efficiency improvement provided by a new control system for computer room air handling devices. It also analyzes measured and reported air handling device fan power associated with changing the fan type. A 135,000 square foot commercial data center was used for the demonstration. All air handling units were upgraded with improved efficiency fans, and a control system that automatically adjusts the fan speed for the air handling units was added. Power measurements were collected for a baseline and for a period with the fan speed control system active. Changing the fan type resulted in a savings of 47 percent of energy used by the air handling equipment and associated chiller plant energy needed to cool the air handlers themselves. The addition of the fan speed control resulted in an additional 37 percent savings in the same two categories. The combined savings for the two improvements for the same categories was 66 percent compared to the data center fitted with the original fans without a control system. The energy use reduction provided by the complete air handling device improvement program for the whole data center site is estimated to be 2.9 million kilowatt hours per year—an overall data center site savings of 8.0 percent. The reduced electrical energy use at the site provides a 1.9 million pound yearly reduction of carbon dioxide emissions. This demonstration showed that fan upgrades and a control system addition provide cost-effective improvements for data centers, with a payback reported to be under two years without utility incentives. In addition to the control system providing energy savings, the data collection and visual analysis capabilities provided immediate and long-term benefits. It is recommended that data center operators consider investing in fan upgrades and/or adding fan speed control for computer room air handlers.

Keywords: fan speed control, computer room air handler, data center CRAH, wireless control, CRAH, CRAH fan, VFD, ECM, EC Motor, ECM motor, plug fan, variable frequency drive

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EXECUTIVE SUMMARY

Introduction

This demonstration was part of a multi-step program that improved the energy efficiency in a commercial data center by upgrading the computer room air handler (CRAH) fan equipment. The improvements included upgrading the fan type and adding a closed-loop fan speed control system.

The demonstration was held in a 135,000 square foot data center located in El Segundo, California, owned by Digital Realty, headquartered in San Francisco, California. The computer room air handler fan speed control system demonstrated was provided by Vigilent.

Computer room air handling equipment consumes a considerable amount of energy in the form of electricity needed to operate the air circulation fans inside each air handler. A typical data center has computer room air handlers equipped with fixed speed fans configured to operate at a constant high speed thereby consuming the maximum amount of power. In many cases the required air circulation is less than that provided at full speed, and a lower air circulation rate can be provided at a much lower fan speed, thus a considerable amount of fan electrical energy can be conserved. The demonstrated control system reads air temperature sensors near the IT equipment air intake areas using a wireless network. The control system then analyzes the sensor data and adjusts the computer room air handler fan speed to the lowest power level that provides enough cooling to meet the desired IT equipment inlet air temperatures.

The goals of this project were to demonstrate that the computer room air handler fan speed control system is a viable solution for a commercial-sized data center and to evaluate the energy savings associated with adding the fan speed controls. An energy use evaluation comparing older scroll-type fans and upgraded plug-type fans also was completed.

Methods

The El Segundo data center is divided into ten colocation rooms, nine of which were occupied during the tests. Six CRAH speed control groups were divided among the nine rooms. Rooms with a common raised floor were controlled together. There were a total of 72 computer room air handler units in the nine active colocation rooms.

The power going to all computer room air handlers was recorded during a Baseline test (i.e., no fan speed controls were used). The fans all operated at full speed during the Baseline test. The power consumed during the Baseline test was compared to the power consumed with the fan speed control activated during an Auto mode test. The power difference was recorded for all computer room air handler units during both tests and analyzed as a site total and for each colocation room.

The evaluation also compared older style scroll-type fans to more efficient plug-type fans. This involved locating power measurement data from past incentive program activities and combining these with the demonstration measurements from the computer room air handlers equipped with upgraded plug-type fans.

Facility personnel were observed using real-time display functions provided with the control system to address areas with uneven server inlet temperatures by adjusting floor tile configurations.

Results

A computer room air handler fan speed control system was installed, put in operation, and used in a demonstration showing significant energy savings in a commercial-sized data center.

Upgrading the fans in all colocation (Colo) rooms from the older scroll-type to plug-type with more efficient motors lowered the power use by 47 percent. Implementing the computer room air handler fan speed control system, that controlled colocation rooms independently, lowered the required total computer room air handler fan electricity consumption by an additional 37 percent. The electricity consumption that was saved by the controls varied by colocation room, depending on the load versus cooling system capacity. The savings varied from 4 percent or less to 75 percent or more, depending on the Colo room. The overall average electricity consumption reduction for the fans and their cooling, including the fan type change and controls addition, was 66 percent.

During the demonstration, the site's electrical power demand was relatively constant, and close to 4 megawatts; overall site electrical energy savings provided by upgrading the fans and adding speed controls was estimated to be 8.0 percent. These savings should continue, assuming the IT equipment load and cooling system configuration remain relatively the same compared to the demonstration period.

Digital Realty is saving approximately 2.9 million kilowatt hours annually after implementing the computer room air handler fan type upgrade combined with the now-completed controls addition program, assuming that the IT equipment power and site infrastructure configuration stays constant. The electrical energy savings translates to a greenhouse gas emission reduction of 1.9 million pounds of carbon dioxide per year. Digital Realty reports that the investment for the combined fan type upgrade and computer room air handler fan speed control system addition has a simple payback period of less than two years.

In addition, the owner reports an improved ability to educate their customers on the merits of better rack management by the ability to display air flow distribution issues in graphical form.

Conclusions

Upgrading computer room air handler fans to a more efficient type and adding computer room air handler fan speed controls provides an excellent return on investment. In addition, greenhouse gas emissions associated with electrical energy use are substantially reduced, along with a reduction in average and peak electric power demand. Digital Realty is a partner with the Southern California Edison Company working closely to reduce average and peak summer load electrical power demand. The data center used in this demonstration consumed on average approximately 2.5 mega watts for the IT equipment. California has many such data centers cooled using air handlers. A large amount of energy would be saved by implementing the fan upgrades and/or fan speed control.

Recommendations

Computer room air handlers are commonly used in data centers to cool the air heated by the IT equipment. Many of these air handlers have been in service for a number of years and are equipped with older-type fans and lack a fan speed control system. This demonstration showed that a fan type upgrade and a fan speed control system should be strongly considered, due to the excellent payback period. It is not necessary to upgrade the fans to achieve significant energy savings; a fan speed control system and variable frequency drives can be added to existing computer room air handler fans. However, upgrading the fan type can significantly add to the savings.

CHAPTER 1:
Introduction

This demonstration was one part of a multi-part Digital Realty (DLR) program to increase energy efficiency. It built on the success of a previously completed Public Interest Energy Research (PIER)-sponsored pilot project at the California Franchise Tax Board data center in 2009. That project demonstrated efficiency gains using speed control on fans contained in computer room air handlers (CRAHs). Digital Realty is headquartered in San Francisco, California.

This project's goal was to show that the energy-efficiency success achieved with the same technology for CRAH fan speed control used in the 2009 pilot project (Bell 2009) could scale to large enterprise data centers. The 2009 project demonstrated a control system provided by Vigilent as part of the Emerging Technology Demonstration Grants Program (Tschudi 2009). This project demonstrates the same Vigilent system (control system) in a much larger facility. The data center selected for this demonstration is owned by DLR. The facility is 135,000 square feet (ft^2) divided into nine active colocation rooms (Colos) containing IT equipment operated and provided by multiple customers.

CRAH Basics

Computer room air handlers provide cooling to meet environmental requirements for IT equipment and are commonly placed on the periphery of the room or specifically located depending on the data center room shape. Data center operators should follow environmental guidelines published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ASHRAE recommends operating temperatures ranging from 18°C–27°C (64.4°F–80.6°F) and allows up to 90 percent relative humidity in some cases for IT equipment cooling air.

A CRAH consists of an air-to-water heat exchanger and one or more fans. In many data centers CRAHs use fans to pull warm air exhausted from IT equipment from the ceiling area, cool this air by pulling it through a heat exchanger that is cooled with chilled water, and push the cool air under the computer room raised floor, as shown in Figure 1-1. This cool air is released into the room through perforated floor tiles in select and configurable locations near the IT equipment air intake areas, completing a continuous loop.

Not considering humidity control, CRAHs can have two control points. For this demonstration, Control Point 1 (chilled water valve position) control method was not changed. Control Point 2 (fan speed control) was added to achieve the energy savings described in this report. These control points are decoupled and can be controlled independently.

- Control Point 1: A modulating water valve controls the chilled water flow as a function of set point for the warm server exhaust air temperature coming from the ceiling area or the supply air temperature entering the under-floor plenum.

- Control Point 2: Historically CRAHs have typically contained constant speed fans. This demonstration added variable speed capability by adding variable frequency drives (VFDs) to fans with alternating current (AC) motors or direct control of electronically commutated (EC) motors for fans with those type of motors. The EC motor fans have the speed control function and control signal connection point built in; therefore, VFDs are not required. This provided CRAH fan speed modulation (control) ability for the CRAHs in all Colos.
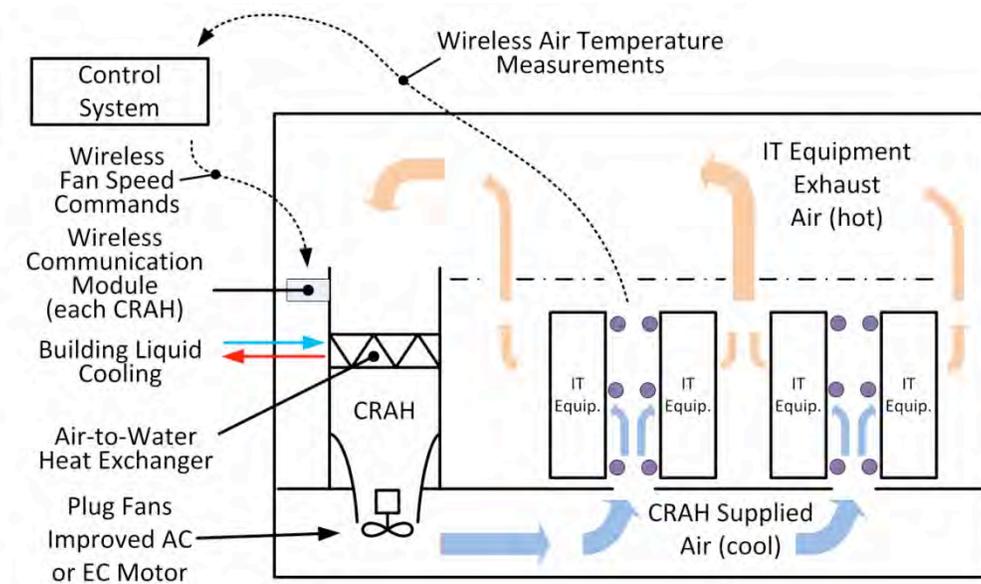
Figure 1-1: Closed Loop Wireless Air Temperature Control Diagram (Plug-Type Fan Pictured)

CRAH Fan Energy Consumption Improvement Program

This report describes two parts of the energy-saving program completed at the DLR facility located in El Segundo, California. The focus of this report is on demonstrating energy savings by adding automated CRAH fan speed control, but the complete program had two parts, both included in this report. In chronological order:

Part 1: Fan Upgrades

The original CRAHs were equipped with standard efficiency AC motors used to spin scroll-type fans using belt drive systems. These fan systems were upgraded for improved efficiency by changing the fans to a "plug"-type being directly driven by improved-efficiency AC motors or efficient EC motors. Figure 1-2 shows a plug-type fan installed in a CRAH. Electronically commutated motors are convenient for systems that need fan speed control, as the speed control feature is typically built in.

Plug-type fans used with CRAHs have improved efficiency, due in part to the impeller being located under the floor. This provides an airflow path with fewer turns, which reduces the fan energy required for the same airflow rate.

The following fan type changes were made:

Fan Upgrade 2008–2009: The CRAHs in Colos 1-6 were upgraded using a utility
    financial incentive.
    ○ AC scroll-type fans were replaced with AC direct-drive plug-type fans. (Fans in
      49 CRAHs were upgraded.)

Fan Upgrade 2011: The CRAHs in Colos 7, 9, and 10 were also upgraded as part of
    another more recent incentive program.
    ○ AC scroll-type fans were replaced with EC motor plug-type fans. (Fans in 23
      CRAHs were upgraded.)
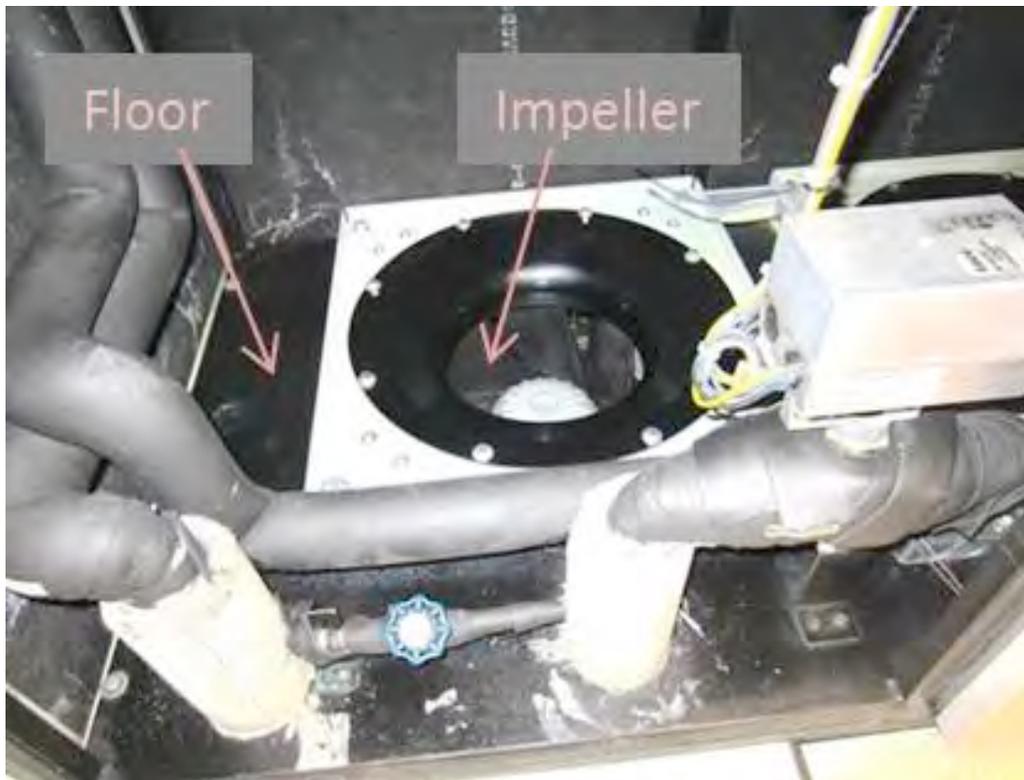
Figure 1-2: Plug Fan Installed. Note Impeller Located Below Floor Level

Part 2: Addition of Automated CRAH Fan Speed Control

An automated CRAH Fan Speed Control system, part of the most recent Southern California Edison SCE incentive program at the DLR center included:

- A wireless network for Colo room air temperature sensing and fan speed control for 49 CRAH VFDs (Colos 1–6) and 23 CRAHs (Colos 7, 9, and 10) equipped with EC motor fans
- A centralized computer control system.

How CRAH Fan Speed Control Works

Computer room air handler fan speed control is implemented by measuring the air temperatures near the IT equipment cooling air intake area at a selected number of IT equipment racks in each Colo and adjusting the fan speed to the minimum required for all CRAHs in the Colo, or as a group in multiple Colos (when sharing a common under-floor plenum), using closed loop control. The complete system used 580 sensor nodes, with 1,280 monitored points, and controlled 72 CRAHs. The temperature measurements and speed control commands were communicated to and from the control computer using a wireless network provided as part of the system. The fan speed was adjusted until the maximum measured server air intake temperature was at or just below the desired set point for the highest temperature measured in each Colo. For example, if an air temperature measurement point was above the desired set point, the fans in that Colo received a signal to increase speed. Higher fan speeds pushed more cool air from under the floor to the area near the IT equipment inlets, thereby lowering the measured air temperatures to satisfy the desired IT equipment air inlet temperature.

Demonstration Goals

Goals of this demonstration were to observe how well this technology performed in a typical commercial sized data center and to measure energy-efficiency differences associated with the CRAH fan system changes. The demonstration compared a baseline energy use scenario to an energy-efficient one that employed a system to control CRAH fan speed (Auto Mode). Energy savings from previous DLR CRAH fan upgrades are also reported, to provide context for the complete CRAH fan improvement program. In addition, a goal was to get input from facility operations personnel on additional benefits they see from their perspective. The data center owner provided commentary on the complete program financial benefits. An additional goal was to estimate greenhouse gas emission reductions.

Organizations Involved

A number of organizations were involved in this demonstration. Digital Realty (DLR) provided the facility and much of the capital investment. In addition, DLR provided a considerable amount of ongoing assistance with installation and data gathering during the project. Southern California Edison, the electric utility for the site, provided guidance, incentive plan coordination, and technical measurement and verification services. Vigilent provided the

complete control system that was demonstrated, along with a generous amount of technical and personnel support during the pre and post measurement and analysis parts of this demonstration. EMCOR Group Inc. provided measurement and verification for the El Segundo facility for Southern California Edison, and this information was provided to the demonstration team. Lawrence Berkeley National Laboratory (LBNL) provided project management, verification of the demonstration, technical guidance, data analysis, and reporting.

Chapter 2: Methods

Demonstration Layout

The data center facility that hosted this demonstration (Figure 2-1) is in El Segundo, California, and is owned and operated by Digital Realty, which owns and operates close to 20 million square feet of data center space distributed across more than 100 data centers worldwide. The El Segundo data center is a 135,000 ft^2 turnkey colocation facility. The facility contains nine active rooms that house IT equipment. The majority of the facility is colocation space allocated to IT equipment, but some office space is used for administration, meeting rooms, and security purposes.

Figure 2-1: Street View of the Digital Realty Data Center, Located in El Segundo, California

Figure 2-2 shows the Colo room layout, CRAH type, location, and identification, along with the upgraded fan type information. The fan speed control system was implemented in all active Colo rooms.
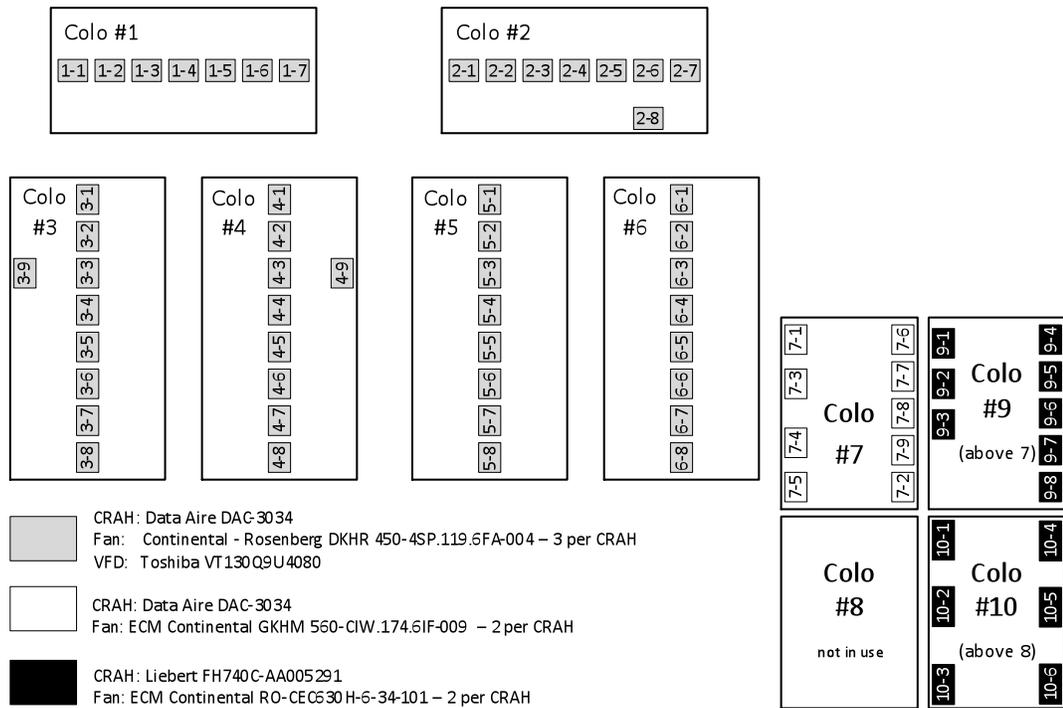
Figure 2-2: CRAH and Colo Locations, with CRAH Model and Upgraded Fan Information

The CRAH model and upgraded fan quantity and type are identified in Table 2-1. CRAH fan speeds were not individually controlled within a Colo room. Some Colo rooms shared a common under floor air plenum and were controlled as a group, as listed in Table 2-1.

Control Group	Colo Room	CRAH Model	CRAH Qty.	Fans/ CRAH	Total Fans	Upgraded Fan Model
A	1		7	3	21	
B	2		8	3	24	
C	3	Data Aire DACD-3034	9	3	27	AC 450mm with VFD
	4		9	3	27	
D	5		8	3	24	
	6		8	3	24	
E	7		9	2	18	ECM 560mm
F	9	Liebert FH740C AA005291	8	2	16	ECM 630mm
	10		6	2	12	
Totals			72		193	

Table 2-1: CRAH Control Group, CRAH Model, Quantities, and Updated CRAH Fan Details

Analysis Methods

A key goal of this demonstration was to quantify the energy savings resulting from the addition of the CRAH fan speed control system. Prior to adding the control system, fan upgrade projects were completed to change the fans from the older-style scroll-type with AC motors to improved efficiency plug-type fans that had higher-efficiency AC motors or EC-type motors. While this report is focused on the energy efficiency improvement related to the addition of the fan speed control system, the energy savings from upgrading the fans was significant, and those results are also included. The operations personnel at the site were observed using the system and were surveyed to determine if the system provided additional benefits. The data center owner Digital Realty was invited to comment on observed financial benefits or any other subjects they thought appropriate.

CRAH Power Data Collection

For CRAHs that had VFDs (Colos 1–6), the VFD was programmed to provide a DC signal level that related to the power consumed. This DC signal was available at an external connection point on the VFD. One VFD provided power and speed control to all fan motors in a given CRAH. This DC signal was recorded using the wireless network included as part of the control system, converted using Equation 2-1, and stored in the control system database.

> Estimated Real Power (kilowatts, kW) = measured DC signal at VFD x (a conversion factor)   (Equation 2-1)

For CRAHs that had EC motor fans (Colos 7, 9, and 10) there was a current sensing device connected to one of the three phases supplying power to all fans for a given CRAH. This device converted alternating current (AC) input to a direct current (DC) signal that was recorded by the Vigilent wireless network and stored in the database. Using an assumed supply phase to phase voltage and power factor the real power used was determined using Equation 2-2.

> Estimated Real Power (kW) = AC Current (calculated from recorded DC signal) x Assumed Phase to Phase Voltage x (square root of 3) x Assumed Power Factor   (Equation 2-2)

An initial analysis of the power data collected from the control system indicated that some assumptions made regarding power factor, supply voltage, or VFD programming may have been incorrect. On June 7, 2012, additional power readings were taken using portable instruments to investigate the magnitude of apparent data inaccuracies that existed as originally recorded in the control system database. The results showed that the power savings information provided by the control system was conservative compared to actual bench-type instrument measurements.

The data were collected by two systems:

- Digital Realty Building Management System (BMS) - recording frequency: 4 measurements per hour (IT equipment and total site utility power)
- CRAH fan speed control system - recording frequency: 60 measurements per hour (individual CRAH power)

Analyses

The collected data were analyzed to determine the following:

- Energy savings due to CRAH fan upgrades
- Energy savings due to the addition of CRAH fan speed controls
- Overall site energy savings combining fan upgrades and the speed control addition
- Other operational benefits provided by the control system
- Reported financial benefits and greenhouse gas emission reduction estimate

CRAH Fan Upgrade

Fans in CRAHs in Colos 1–6 were upgraded in the 2008–2009 timeframe. In 2011, DLR continued the CRAH fan upgrade program by replacing existing scroll-type fans with more-efficient EC motor backward inclined, open impeller plug-type fans in Colos 7, 9, and 10.

The following steps were used to analyze fan upgrade energy savings:
- Propose the hypothesis: Replacing existing scroll-type CRAH fans with plug-type fans equipped with energy-efficient AC- or EC-type motors saves energy
- Locate information related to previous fan type power measurements
- Calculate the power use difference for the Baseline period, comparing the previous original fan set to the current fan set. The overall electrical power saved because of CRAH fan power differences is included
- Analyze data addressing the hypotheses
- Test hypotheses and report the results and conclusions.

CRAH Fan Speed Control Addition

The following steps were used to analyze fan speed control energy savings:
- Propose hypotheses: (1) CRAH fan speed control works in an enterprise-sized data center, and (2) CRAH fan speed control saves energy
- Record CRAH fan and selected site power measurement points during a Baseline test
- Record CRAH fan and selected site power measurement points during an Auto mode test using CRAH fan speed control based on real-time air temperature measurements
- Analyze the data, and make additional measurements or corrections, if needed
- Calculate the efficiency metrics. Consider the power for cooling saved because of the lower CRAH fan power (Two methods are detailed below; one was used to obtain the final results)
- Test the hypotheses and report the results and conclusions.

The Colo facility is a dynamic environment. Customers frequently remove or upgrade existing IT equipment or install new equipment. It is not unusual that infrastructure components such as

power distribution devices or CRAH fans are taken out of service for maintenance activities or manually turned on and off in an attempt to better manage airflow. The IT equipment power consumed depends on the type of compute service provided. For example, some Colos may contain IT equipment that provides compute services that vary as a function of the time of day. Other Colo rooms may have a more constant computational load. The efficiency (and therefore electrical power demand) of supporting cooling infrastructure systems, such as cooling towers and chillers, vary with cooling load and outside environmental conditions. In an attempt to reduce analysis errors related to these variabilities, the test periods (Baseline and Auto) were taken adjacent to each other and were short duration—approximately two hours. The Baseline data recording period was April 18, 2012, from 9:48 a.m. to 11:48 a.m. The Auto data recording period was from 2:00 p.m. to 4:00 p.m. the same day. The period between 11:48 a.m. to 2:00 p.m. allowed time for CRAH fan power levels to stabilize including the control system response duration. The stabilization period can be seen in data graphed in Appendix A and shown in Figure 3-6.

Normalizing Energy Savings for Fan Upgrades and Speed Control

Three fan cases were normalized and compared:
- Case 1: Original Fans (all CRAHs equipped with the original, not upgraded, fans)
- Case 2: Upgraded Fans (all CRAHs equipped with improved efficiency AC or EC motor plug-type fans)
- Case 3: Speed Controlled (all CRAH fans were upgraded, and they were speed controlled using the control system).

The assumptions were as follows:
- IT power is constant.
- Infrastructure power has three components: CRAH power, Chilled water plant power needed to cool the IT and CRAH fan power, and Other infrastructure power.
- Other infrastructure power is constant.
- The increased chiller plant energy needed to cool the power going to the CRAH fans is calculated using a plant efficiency of 0.464 kW per ton of cooling (value provided by DLR facilities personnel). This chiller plant power change is included in the total infrastructure power change associated with the fan upgrades and fan speed control system addition.

The following method was used to combine and compare energy-efficiency improvements for both the fan upgrades and the controls addition. Note that this process can be followed with the actual values in Appendix B. Details of calculations for determining the change in infrastructure power associated with the change in CRAH fan power are shown in Appendix C.

> Step 1: Using BMS measurements obtained during a Long (24-hour) Baseline test, establish an average IT equipment and site power. Calculate the corresponding average infrastructure power.

Step 2: Using the high-frequency collected data, record the average CRAH power during both the Baseline (Case 2) and Auto Mode (Case 3) tests. Obtain fan power information from proprietary records to calculate the average CRAH power for Case 1.

Step 3: For all cases, calculate the chiller plant power necessary to provide cooling for the power values in Step 2 using a plant efficiency of 0.464 kW per ton of cooling.

Step 4: For Case 2, calculate Other infrastructure power, and assume that this value is the same for Case 1 and 3.

Step 5: For Cases 1 and 3, calculate the total infrastructure power by adding CRAH power, power needed to cool the CRAH power, and Other.

Step 6: For Cases 1 and 3, calculate the total site power.

At this point, all power values were determined and Power Usage Effectiveness™ (PUE) and reduction comparisons were made.

Other Benefits

The control system has other potentially very useful features, in addition to providing CRAH fan speed control. A number of visualization tools are included as part of the system. For example, there are several displays that show real-time conditions, such as the difference between the actual IT equipment inlet area air temperature and the set point, and the CRAH fan speed percentage of the available maximum speed. The facility operations personnel were observed using the system and interviewed to get a sense of how useful and easy to use these additional features were. Figure 2-3 shows examples of these features.
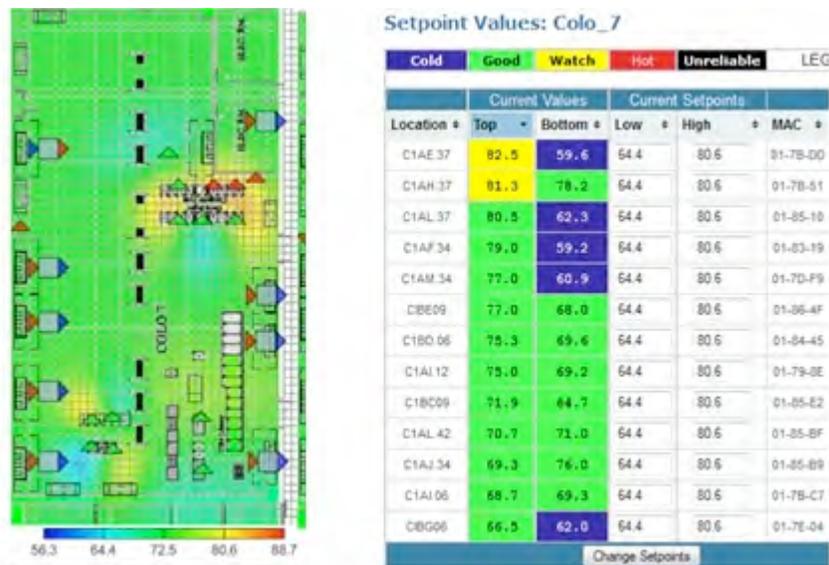
Figure 2-3: Example Data Center Floor Temperature Thermal Map and Set Point Status Screen

Financial Benefits and Environmental Conservation

Digital Realty, the data center owner, provided some comments on financial benefits and calculated an estimate of greenhouse gas reductions from the measures implemented. These are reported in Chapter 4.

Chapter 3: Results

The demonstration included collection and analysis of CRAH fan power data recorded by the control system. An investigation into the system data conversion accuracy revealed that the savings reported were conservative. Using additional measurements obtained on June 7, 2012, the data were corrected and used to calculate the results.

Fan Upgrade

The fan upgrade was completed in two parts. Part 1 replaced fans in 50 CRAHs in Colos 1–6 during the 2008–2009 timeframe. Part 2 was completed during 2011 and was also part of an incentive program with Southern California Edison.

The following paragraphs outline the fan upgrade details for this project:

Colo Rooms 1–6 (50 CRAHs)
Original CRAH/Fans: The CRAH model was a Data Aire DAC-3034. Each CRAH was originally equipped with three 5 hp Leeson motors consuming a total of 9.84 kW when operated at full speed. The original fans had no speed control, so all fans were operated at full speed at all times unless they were disconnected.

Upgraded Fans: Existing fans were replaced with three Rosenberg/Continental 450 millimeter (mm) impeller size AC plug-type fans using one VFD per CRAH to provide speed control. The power at full speed, measured as part of this demonstration, was 4.87 kW per CRAH.

Colo Room 7 (9 CRAHs)
Original CRAH/Fans: Same as Colo Rooms 1–6

Upgraded Fans: Existing fans were replaced with two Rosenberg/Continental 560 mm impeller size EC motor plug-type fans. Power at full speed, measured as part of this demonstration, was 6.28 kW per CRAH.

Colo Rooms 9 and 10 (14 CRAHs)
Original CRAH/Fans: Liebert FH740C-AA005291 CRAHs contained one ten horsepower motor with a belt and shaft system spinning three fans using a total of 6.57 kW at 100 percent speed per CRAH. Power data was obtained from DLR records.

Upgraded Fans: The existing one motor fan system was replaced with two Rosenberg/Continental 630 mm impeller size EC motor plug-type fans. Power at full speed, measured as part of this demonstration, was 4.72 kW per CRAH.

The power saving estimate due to the fan upgrades only (shown in Figure 3-1) does not assume that all the fans in all of the CRAHs were operating. Many CRAHs were found turned off or otherwise disabled on April 18, 2012, and therefore are not included in the calculation. Values in Figure 3-1 include associated additional infrastructure cooling power based upon 0.464 kW/ton needed to cool the heat generated by power supplied to the CRAHs. The reduction in CRAH

power alone (not including the power needed to cool the heat generated by the fan motors) went from 439 kW to 233 kW, a savings of 1,890,000 kilowatt-hours per year (kWh/year). The updated fans provided more air flow at full speed compared to the original type fans.

Therefore, the study confirmed the hypothesis that improved efficiency can be obtained by changing from older-type fans to updated, improved efficiency, plug-type fans, powered with AC motors with VFDs or EC motors.

Fan Type Change: CRAH Power Reduction
(includes associated infrastructure power)

Fan Type Change
CRAH Power Reduction 47%

497

264

Power (kW)

Original AC
Scroll Type
No Controls
(Estimated Baseline)

New ECM and AC
Plug Type
No Controls
(Baseline)
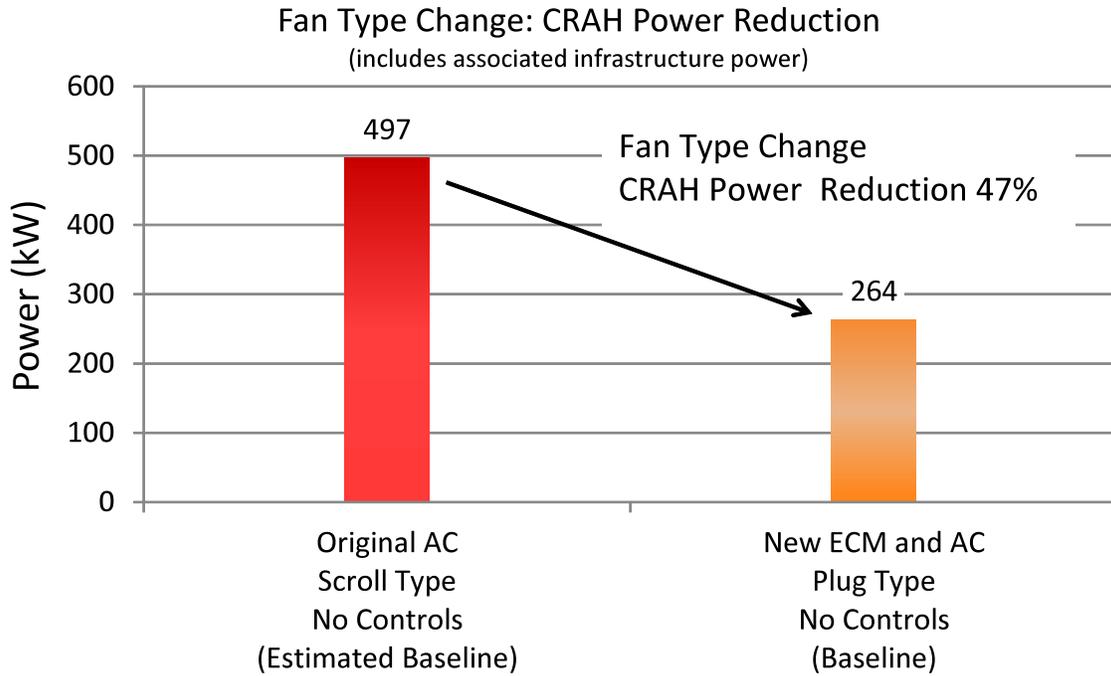
Figure 3-1: CRAH Power Reduction (Including Associated Infrastructure Cooling Power) Due to Fan Upgrade from AC Scroll-Type to an Improved Efficiency AC and EC Motor Plug-Type

Addition of CRAH Fan Speed Control

The total CRAH fan power level was 233 kW for the Baseline, reduced to 147 kW when the Vigilent controls were activated (Auto Mode)—a savings of 85.9 kW.

Results are discussed for each hypothesis.

The system works in an enterprise data center

A previous demonstration using a smaller installation successfully showed this technology was able to control CRAH fans, resulting in lower electrical power consumption. This demonstration successfully showed that CRAHs in a much larger (enterprise-sized) data center also can be controlled to reduce electrical power consumption significantly.

The fan type change saves energy

As shown in Figure 3-1, changing the fan type from the previous scroll type with lower-efficiency motors to plug-type fans being driven with improved-efficiency AC or EC motors provided the majority of the total energy savings.

CRAH fan speed control saves energy

Looking at the energy consumed by all CRAHs at the facility, the reduction in energy use when the Vigilent control system was activated was significant, as shown in Figure 3-2. CRAH power was lower by 85.9 kW (37 percent) when using the control system's Auto mode, compared to the Baseline.

There is an explanation for the reduction in CRAH energy consumption going from the Baseline test to the Auto test. The CRAH fans pressurized cool air under the data center raised floor. This air was released through perforated floor tiles with considerable velocity and reached the IT equipment intake areas. If enough cool air could be provided from under the floor at a lower pressure, the CRAH fans could be reduced in speed. In this demonstration, the Vigilent control system determined in many Colos that the pressure under the floor could be lowered, and it automatically reduced the fan speed. The fans operating at a slower rotational speed, providing less pressure and airflow rate, required less electrical energy. In the test going from the Baseline to Auto mode, the CRAH fan speed controls reduced the electrical energy required by the CRAH units by approximately 37 percent.

Speed Control Addition CRAH Power Reduction
(includes associated infrastructure power)
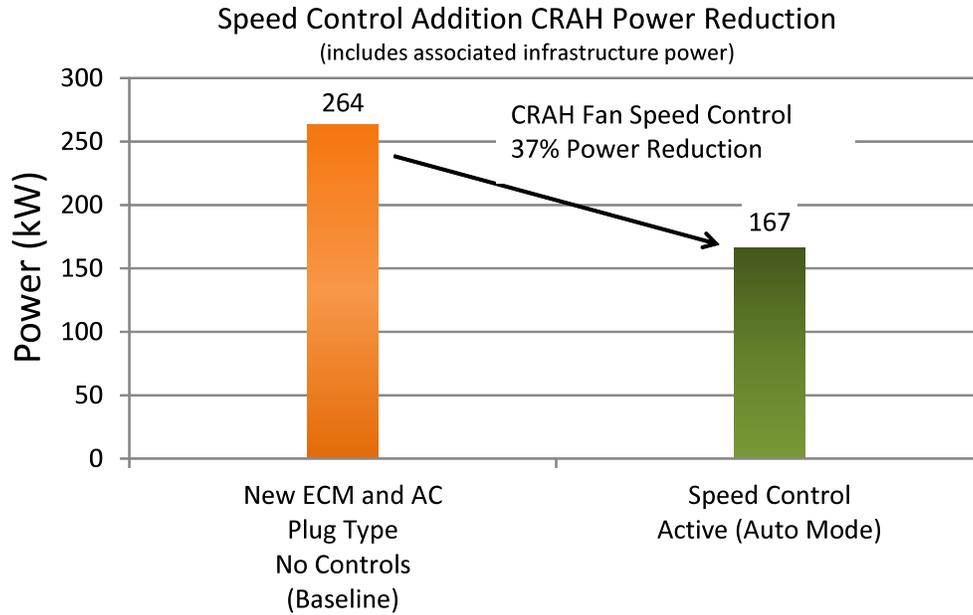
Figure 3-2: CRAH Power Reduction (Including Associated Infrastructure Cooling Power) Due to Wireless CRAH Fan Speed Control Addition

Figure 3-2 shows the combined savings from all of the Colo rooms, including infrastructure cooling. Figure 3-3 shows the power reduction for each Colo room, comparing the Baseline and Auto mode. The power reduction varies considerably across the Colo when the Vigilent controls are activated.

Total CRAH Power per Colo Room During Baseline and Auto Mode Test Periods

Baseline Total	233kW
Auto Mode Total	147kW
Reduction	37%

Baseline (No Control)

Auto Mode (Speed Controlled)

CRAH Power (kW)

Colo Room Number
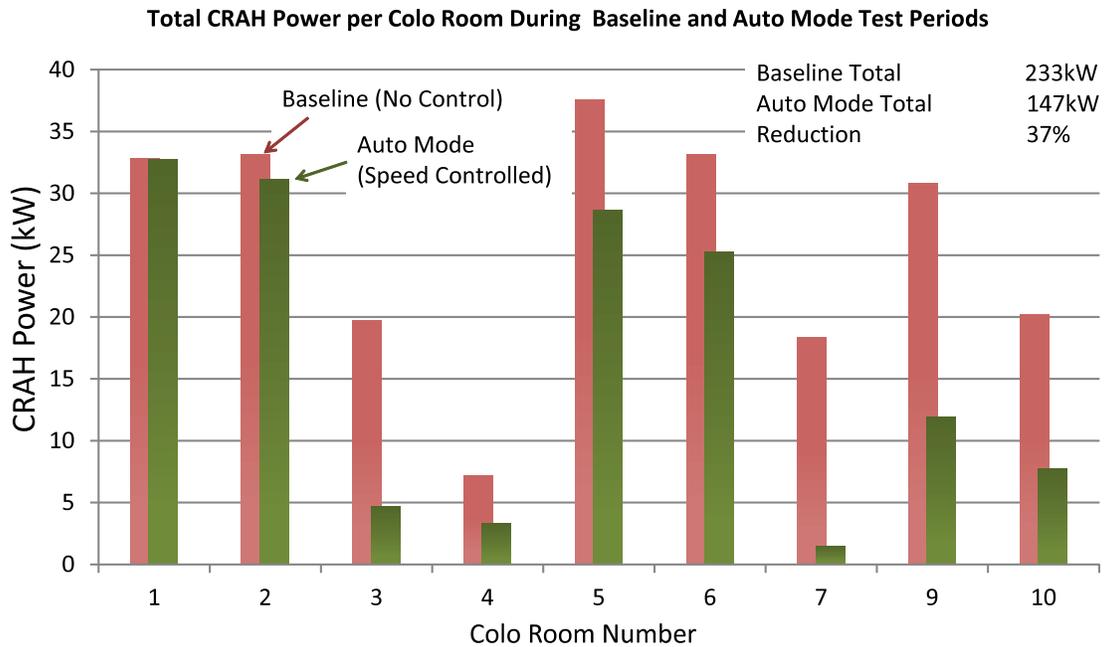
Figure 3-3: All Colos CRAH Fan Power Baseline (No CRAH Fan Speed Control) and Auto Mode (Using the Automatic Control System)

If we look at individual Colo rooms in Figure 3-3, we see some have minimal Auto mode CRAH power reduction. During the Baseline test, the facility technicians pointed out that all CRAH fans in Colo 1 and 2 were operating at or near 100 percent, and the actual critical air temperatures were near the air temperature set points. This indicated that if the CRAH fans were reduced significantly in speed, the air temperature set points were not likely to be met. When the Auto mode test was activated, the control system determined that the fan speeds could be reduced only slightly; therefore, the energy saved in Colos 1 and 2 was minimal. Figure 3-4 shows minimal power reduction in Colo 1 for each CRAH when the Auto mode was activated.
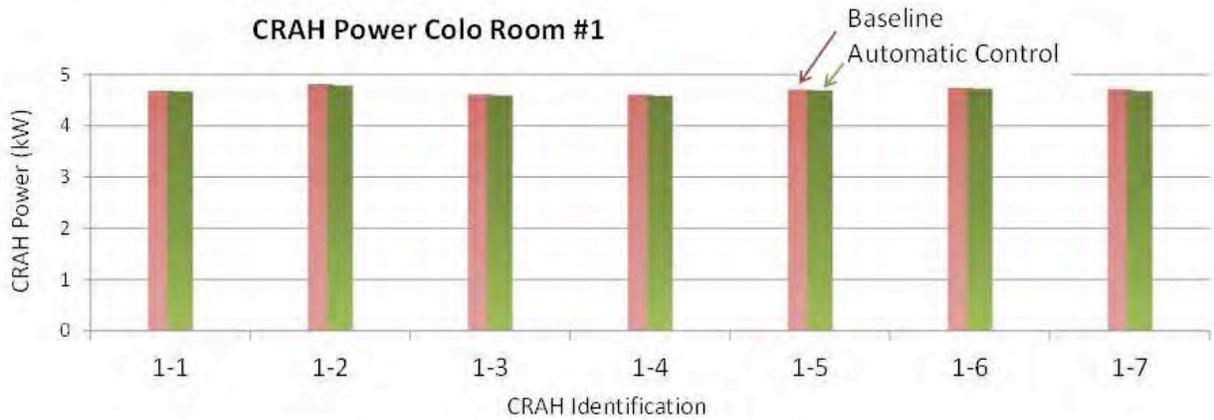
Figure 3-4: Base Case and Auto Mode CRAH Power Details for Colo Room 1

However there are Colos where automatic fan speed control is observed saving 75 percent or more compared to the baseline test. An example is Colo 3 (Figure 3-5 shows details for each CRAH). Colo 3 would have achieved considerably more savings, but some CRAHs had already been purposely turned off. Figure 3-6 shows high-frequency collection data for a few active CRAH units in Colo 3, for the Baseline and Auto Mode test periods. Appendix A shows the data collection for all CRAHs in Colo 3, including power measurements from CRAHs that were idle. Idle CRAHs consumed standby power, typically under 100 watts, for the variable frequency drives and internal CRAH controls.
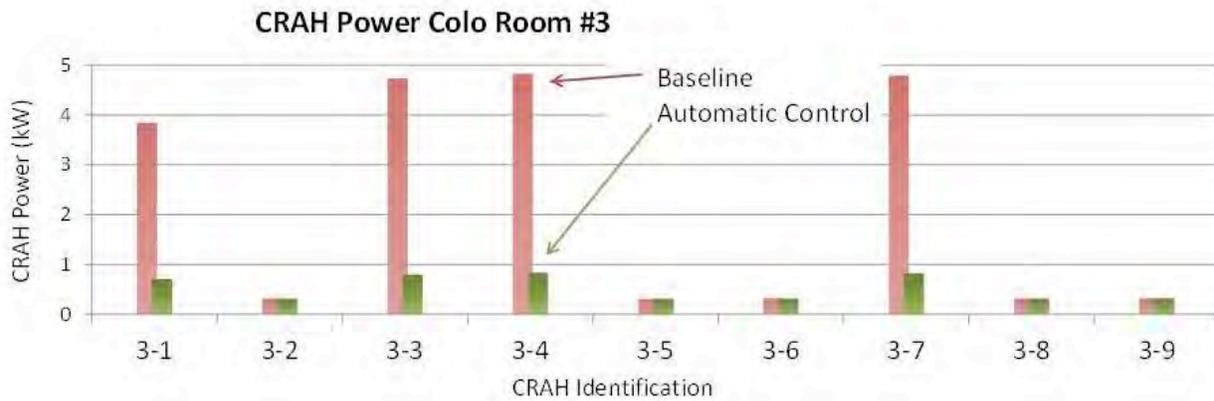
Figure 3-5: Base Case and Auto Mode CRAH Power Details for Colo Room 3
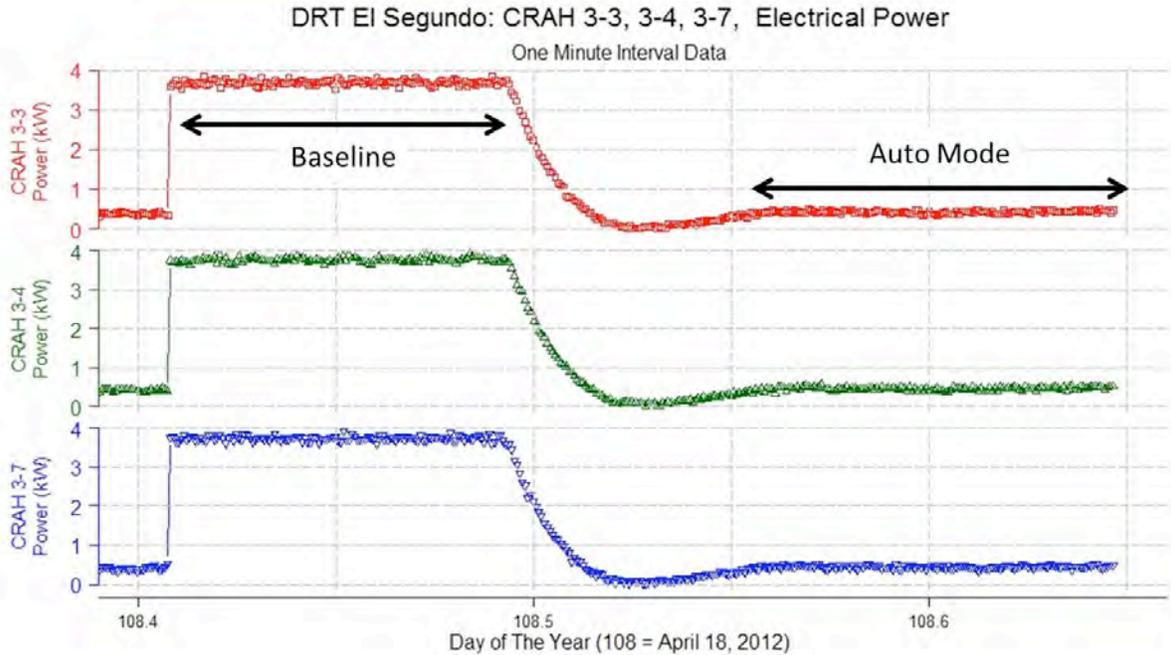
Figure 3-6: Select CRAH Power Data from Colo 3, with High-Frequency Collected Data Shown During Baseline and Auto Mode Test Periods

The hypothesis that CRAH fan speed control saves energy is correct for the data center with conditions observed during monitoring for this demonstration. However, the energy savings may be limited in some cases. For example the savings measured during the demonstration was limited for Colo room #1 as shown in Figure 3-4. In this case all the CRAH units were operating near their maximum performance before the control system was activated, therefore the savings available is small when the control system was used.

Estimating Overall Energy Savings Due to CRAH Fan Speed Control

Power Usage Effectiveness is a popular data center energy metric, and it can be used to assess overall infrastructure energy savings. This study estimated how PUE is affected by implementing CRAH fan speed control, using two methods. One was selected and used to obtain the results.

> **Method 1:** The building management system (BMS) meter data for power leaving the uninterruptible power supply (UPS) (assumed to be the total site IT power) and utility power were used to calculate the PUE and observe changes in PUE value comparing the Short (2-hour) Baseline and Auto mode periods. The available test period and number of data points was limited due to BMS data collection and storage system idiosyncrasies. This is shown in Figure 3-6.

> **Method 2:** Using a longer period (24 hours) of BMS meter data for UPS (IT equipment) power and total site power were collected to get a better idea of the average over time,

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including day versus night variation. Average infrastructure power and baseline PUE were calculated. The site average infrastructure power was adjusted using high-frequency data collected by the Vigilent system during the Baseline and Auto Mode test periods. This included an adjustment for chiller plant power reduction due to the change in CRAH fan power. The adjusted total infrastructure power was used to calculate an updated value for PUE since the IT equipment power was known (see Equations 3-1 and 3-2).

Method 1

The IT equipment power consumed was relatively constant—approximately 2.57 megawatts (MW) from at least two hours previous to the Baseline test period through the Auto mode data collection period. Using data gathered from the facility BMS system, PUE was calculated and plotted, as shown in Figure 3-6. The PUE changed from approximately 1.516 (average of BMS data) during the Baseline test period to approximately 1.491 (average of BMS data) for the Auto mode data collection period. This change equated to an overall site-estimated energy reduction of 1.6 percent. Due to the low number of data points, this method may have been subject to errors, but it had the advantage that all the data came from one source (the BMS system) and did not contain estimated adjustments.
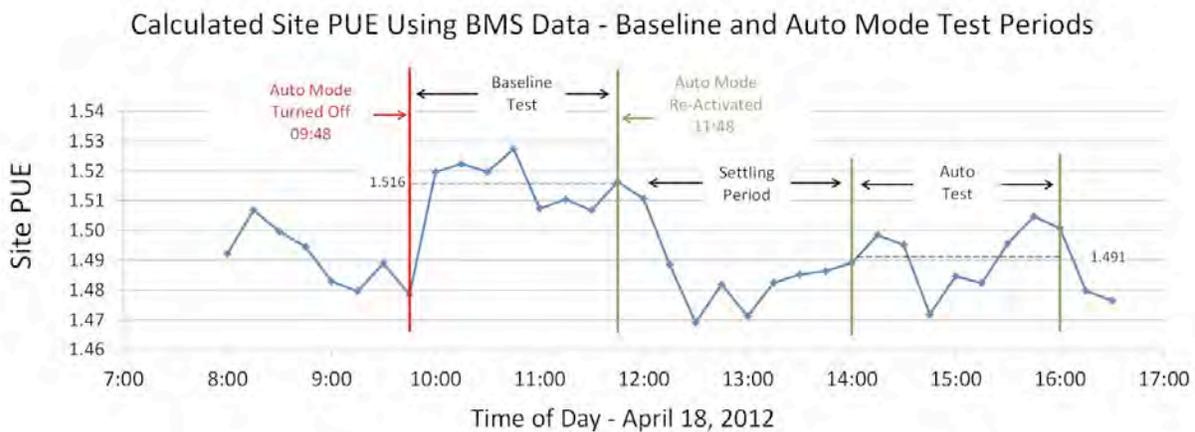
Figure 3-6: Calculated PUE from the Building Management System Data During 2-Hour Baseline and Auto Test Periods

Method 2

This method was more complicated, as it used data from the site BMS and data collected by the control system. The method used the following assumptions:

- The total infrastructure power has three components: CRAH power, chiller plant power needed to provide cooling to the CRAHs, and "other" power.

- The CRAH power was accurately determined using the data collected by the wireless system. The chiller plant power needed to provide cooling for the CRAH electrical

power was determined using the chiller plant efficiency of 0.464 kW/ton, provided by the site owner.

PUE = Total Site Power / IT Equipment Power

(Equation 3-1)

Total Site Power = IT Equipment Power + Total Infrastructure Power

(Equation 3-2)

- The change in CRAH fan power observed from the Baseline to the Auto test using the control system data (combined with calculated associated infrastructure power) was more accurate than the average total infrastructure power obtained using the BMS. See Appendix A for an example of high-collection-frequency CRAH power data obtained on April 18, 2012.

The total infrastructure power reduction due to lowering the CRAH power was conservative because other infrastructure power losses such as transformer and transmission could have been estimated and added to the CRAH and chiller plant power needed to cool the CRAH power.

A longer (24 hours versus 2 hours) baseline data gathering period compared to Method 1 was used to obtain a more characteristic Infrastructure and IT equipment power average, including day to night variation.

The longer baseline period of 24 hours (April 16, 2012 9:15 a.m. to April 17, 2012 9:15 a.m.) shown in Figure 3-7 where the infrastructure and IT power were assumed to be typical. The average IT equipment, total infrastructure power, and total site power were 2.593 MW, 1.298 MW, and 3.89 MW, respectively, during this Long Baseline test period.

The high-collection-frequency data indicated that the CRAH power dropped from 233 kW to 147 kW—a reduction of 85.9 kW.

To estimate the change in Total Infrastructure Power provided by the CRAH fan energy reduction the following information was used:

- Fan energy reduction corrected from measurements = 85.9 kW
  Using high-frequency data collection measurements from the Short (2-hour) Baseline test and Auto test; see Figure 3-6 above.

- Lower chiller plant energy due to reduced cooling required to cool lower electrical power consumed by the CRAHs is calculated as follows:

  Given: Chiller Plant Efficiency = 0.464 kW/ton (provided by Digital Realty) and direct thermal conversion constant of 3.516 kW per ton:
  85.9 kW / 3.516 kW per ton = 24.4 tons; at 0.464 kW/ton = 11.3 kW of infrastructure power reduction associated with a lower heat load because of the fan power reduction.

The total infrastructure reduction for Method 2 was calculated as 97.3 kW (85.9 kW + 11.3 kW).

The Long (24-hour) Baseline IT equipment power average was 2.593 MW, and the calculated average total Infrastructure power was 1.298 MW, as calculated from the data shown in Figure 3-6. The total infrastructure power was reduced by 97.3 kW corresponding to the power savings when the CRAH fan control system was active shown in Figure 3-7. The total site power reduction associated with the addition of the CRAH fan speed controls dropped from 3.89 to 3.79 MW (2.5 percent). Calculation details are shown in Appendix B.
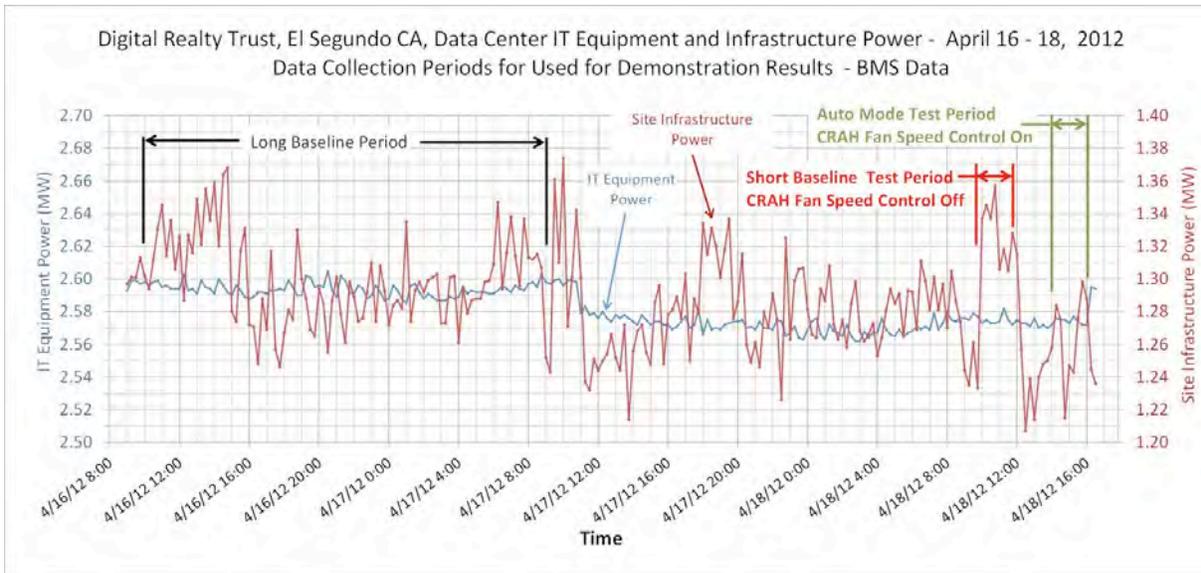
Figure 3-7: Total Infrastructure Power and IT Equipment Power for the Long (24-Hour) Baseline Test, Short (2-Hour) Baseline Test, and Auto Mode Test Periods

Final Site Level Energy-Use Savings

Method 1 and 2 measured overall site energy savings, but Method 2 resulted in a site energy savings of 8.0 percent and was assumed to be a better method for the following reasons:

- The Total Infrastructure Power savings was at least the difference in CRAH power value obtained using the high-frequency corrected data comparing the 2-hour Baseline and 2-hour Auto mode tests. This value by itself (not considering the chiller plant power needed to cool the heat released from the power supplied to the CRAH) was 76 kW and corresponded to an overall site energy savings of 2.0 percent. Method 1 indicated that the savings was only 1.6 percent. Therefore it was concluded that the low-frequency data used with Method 1 was not providing accurate results, as might be guessed when looking at Figure 3-6.

- Method 2 yielded a conservative overall site savings of 2.5 percent, assuming that the

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chiller plant efficiency was correct as provided; therefore, Method 2 was used for calculating the overall results.

Additional Benefits

The control system provided useful features other than CRAH speed control, and the facility's operations personnel were observed using these features. One feature was the ability to display colored temperature maps of the data center areas equipped with wireless temperature sensors. Figure 3-8 shows Colo 2; on the left with a restrictive floor tile arrangement and on the right after floor tiles were added to provide the desired temperatures with better distribution. The control system was an important tool used to justify the floor tile materials procurement.
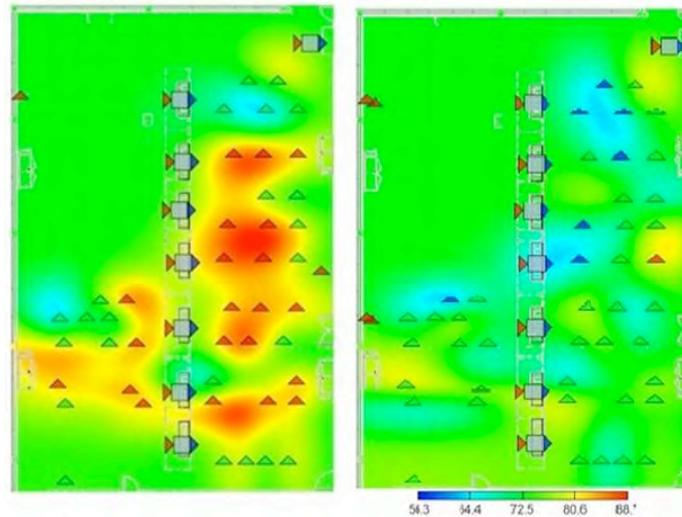
Figure 3-8: Colo 2. Left Screen: Some Temperatures Above Limit; Right Screen: All Temperatures at or Below Set Point After Floor Tile Adjustments

Results Summary

The study provided the following results, summarized as:
- Infrastructure power was reduced due to (1) the CRAH fan type change, and (2) the addition of the control system which lowered the fan energy use. These affected the total site power consumption, as shown in Figure 3-9.
- The PUE for the site as a whole (Figure 3-10) was affected because of the changes above.

- Additional features of the system assisted facilities personnel with IT equipment deployment, temperature monitoring, and room air flow configuration.

Digital Reality - El Segundo Site
CRAH Fan Improvement Program Total Site Savings Estimate
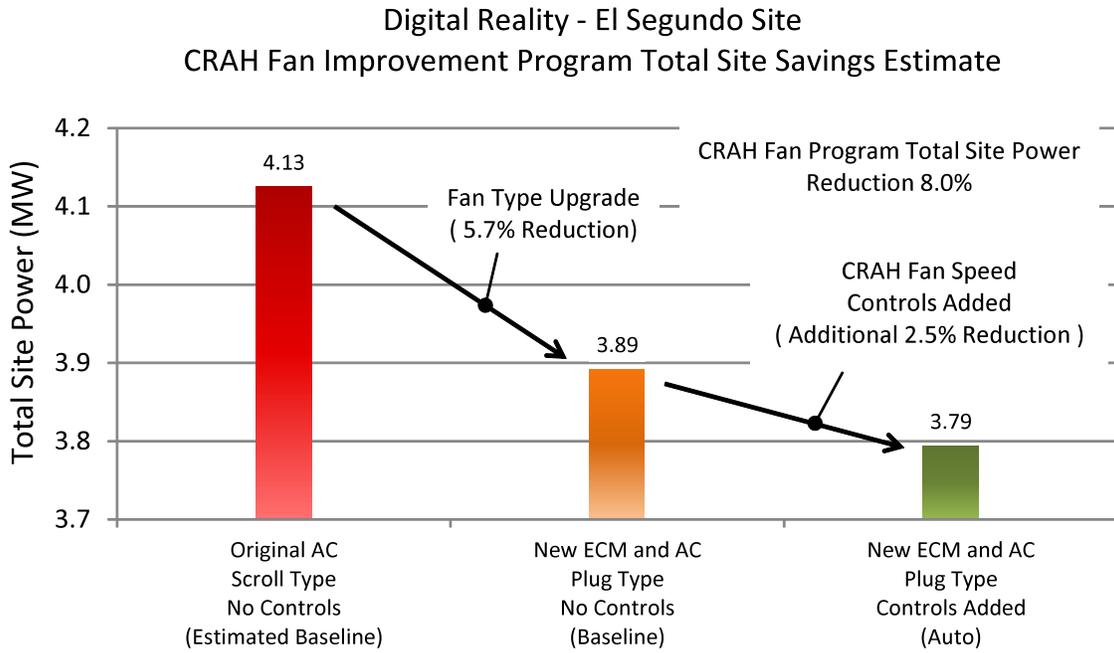
Figure 3-9: Total Site Power Affected by the CRAH Power and Infrastructure Associated Savings Due to the Fan Upgrades and Control System Addition
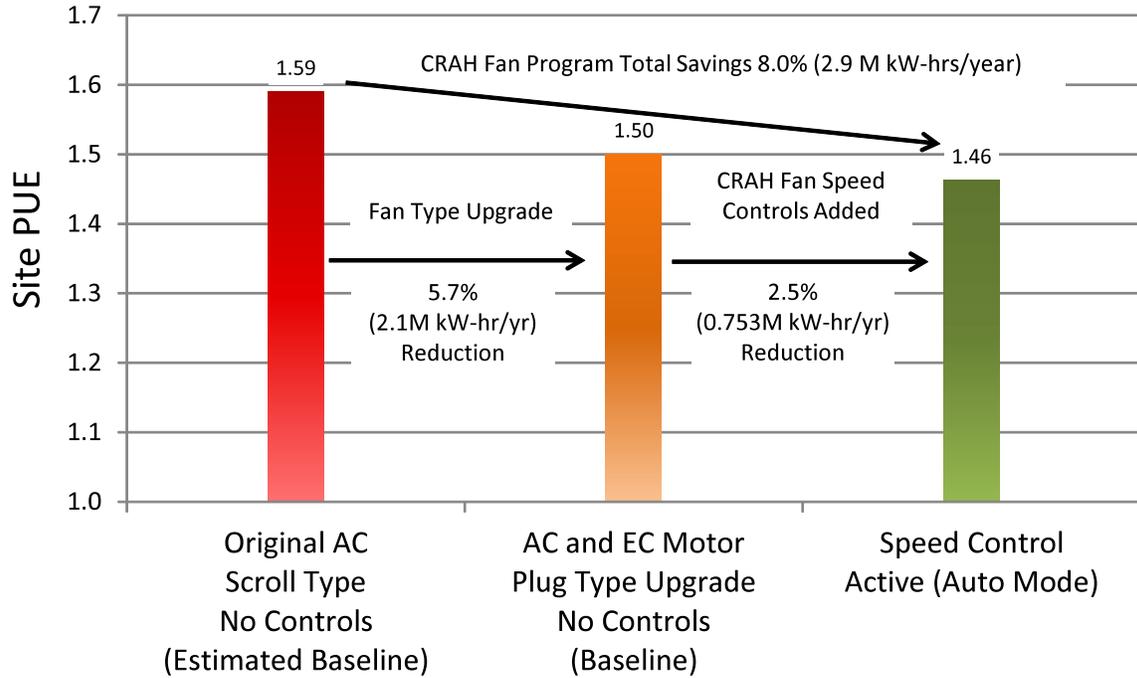
**Figure 3-10: Total Site Power Saving Due to Fan Upgrades
and Control System Addition PUE Estimate**

Site facilities personnel used the real-time temperature color maps to assist with spotting hot or cold areas and assessing the control system effectiveness. Figure 3-11 shows Colo Rooms 9 and 10 combined. On the left, the IT equipment was supplied with more cooling air than required. When the control system was activated, the needed air temperatures were achieved at a much reduced air flow rate, saving a significant amount of energy that had previously been going to the CRAH units' fans.
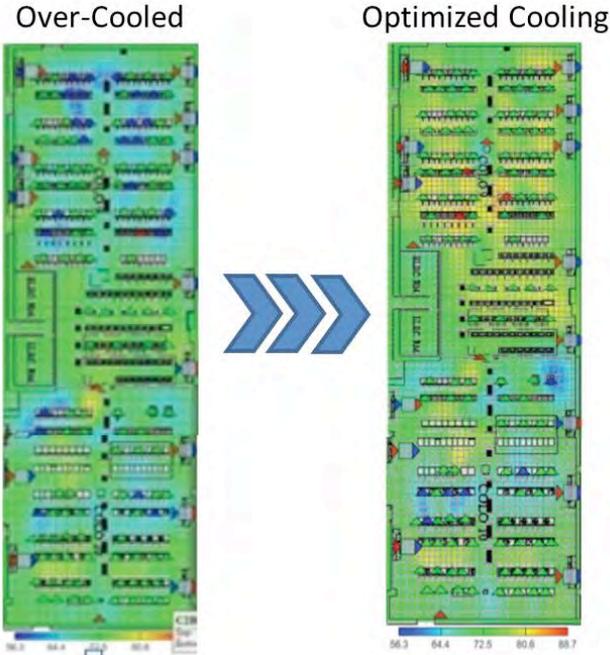
Figure 3-11: Two Colo Rooms (Colo 9/10) Combined. Left Image: Over-Cooled, without the CRAH Fan Speed Control; Right Image: Temperatures Rise to the Desired 80.6°F (27°C) Temperature with the Speed Control, which Reduces CRAH Power.

Chapter 4: Conclusions, Recommendations, and Financial and Environmental Benefits

The demonstration showed that this technology saved energy and aided facility technicians with ongoing energy efficiency efforts. The system was straightforward to install, and facility technicians found it easy to learn. The identification of cooling problems, possible adjustments, and justifying funds for additional improvements are straightforward using the visual display and reporting tools provided with the system. The data center used for this demonstration consumed approximately 2.5 MW for the IT equipment. The quantity of similar data centers in California is difficult to determine. It can be said many such data centers are cooled using air handlers. A large amount of energy would be saved by implementing the fan upgrades and/or fan speed control.

Conclusions

- The demonstration showed the system successfully controlled 9 Colo rooms, using 6 control zones in a commercial-sized data center (providing 2.6 MW of power to the IT equipment).

- The energy saving from using a CRAH fan speed control system may be substantial or minimal, depending on the maximum CRAH air flow capability, data center room design, and IT equipment deployment and utilization.

- The control system reduced the total site-associated CRAH power by 37 percent in this demonstration, however the energy saved varied by Colo room. The range was:
  > Colo 1 had a 4 percent CRAH power reduction.
  > Colo 3 had a ~75 percent CRAH power reduction.

- Users should consider upgrading the CRAH fans from the scroll-type to the plug-type with high-efficiency motors. In this demonstration the fan type change alone (with no speed control) accounted for a 47 percent CRAH power-associated savings.

- The total facility CRAH-associated power reduction provided by both projects (fan type changes and wireless controls addition) was 66 percent (497 kW to 167 kW).

- The ongoing overall site electrical utility energy savings estimate was 8.0 percent, including the CRAH fan type upgrade and controls addition.

Recommendations

Computer room air handlers (CRAHs) used in this demonstration are commonly installed in data centers. Many of these air handlers have been in service for a number of years and are

likely equipped with older-type fans and no fan speed control system. This demonstration showed that a fan type upgrade and the addition of CRAH fan speed control should be strongly considered, due to the excellent return on investment. In addition, implementing such changes in the data center will lower greenhouse gas emissions and lower average and peak period electrical power demand from the utility.

Financial and Environmental Benefits

Digital Realty is estimated to be saving approximately 2.9 million kilowatt hours annually after implementing the CRAH fan type upgrade and completed controls addition programs, assuming the IT equipment power and site infrastructure configuration remains similar to what it was during the demonstration. It reports that the investment for the combined fan type upgrade and CRAH fan speed control system addition will have a simple pay back period of less than two years, not including incentive plan contributions.

The carbon dioxide emissions rate using the U.S. Environmental Protection Agency (EPA) information[1] for the demonstration site location is 659 pounds per MWh. This translates to a reduction in greenhouse gas emission of 1.9 million pounds of carbon dioxide per year attributed to the Digital Realty data center in El Segundo California.

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[1] U.S. EPA. How clean is the electricity I use? – Power Profiler.
http://www.epa.gov/cleanenergy/energy-and-you/how-clean.html. (Accessed on 12/17/2012)

References

Bell, Geoffrey C. (Lawrence Berkeley National Laboratory). 2009. *Demonstration of Data Center Automation Software and Hardware (DASH) at the California Franchise Tax Board.* Publication number LBNL-3131E.

Tschudi, William (Lawrence Berkeley National Laboratory). 2009. *Demonstration of Intelligent Control for an Enterprise Data Center.* Grant submission. Emerging Technology Demonstration Grant Program. California Energy Commission. Publication number PON-08-006.

Glossary

AC	alternating current
BMS	building management system
Colo	room used by a customer in a leased space data center facility
CRAC	computer room air conditioner
CRAH	computer room air handler
DLR	common abbreviation for Digital Realty (NYSE: DLR)
EC	electronically commutated
ECM	electronically commutated motor
EPA	U. S. Environmental Protection Agency
kW	kilowatt = 1,000 watts
LBNL	Lawrence Berkeley National Laboratory
MW	Megawatt = 1,000,000 watts
NYSE	New York Stock Exchange
PUE	Power Usage Effectiveness™
SCE	Southern California Edison
VFD	variable frequency drive (used to control the speed of a fixed speed AC motor)

Appendix A: Example - Vigilent System Collected High-Frequency CRAH Power Data

Figure A-1 shows the power data recorded for all CRAHs in Colo 3 starting at midnight April 18 to near the end of the Auto mode test. Note that CRAHs supplied with an "off" command (CRAH 3-2, 3-8 and 3-9) appear to be consuming 30 to 50 watts, average.
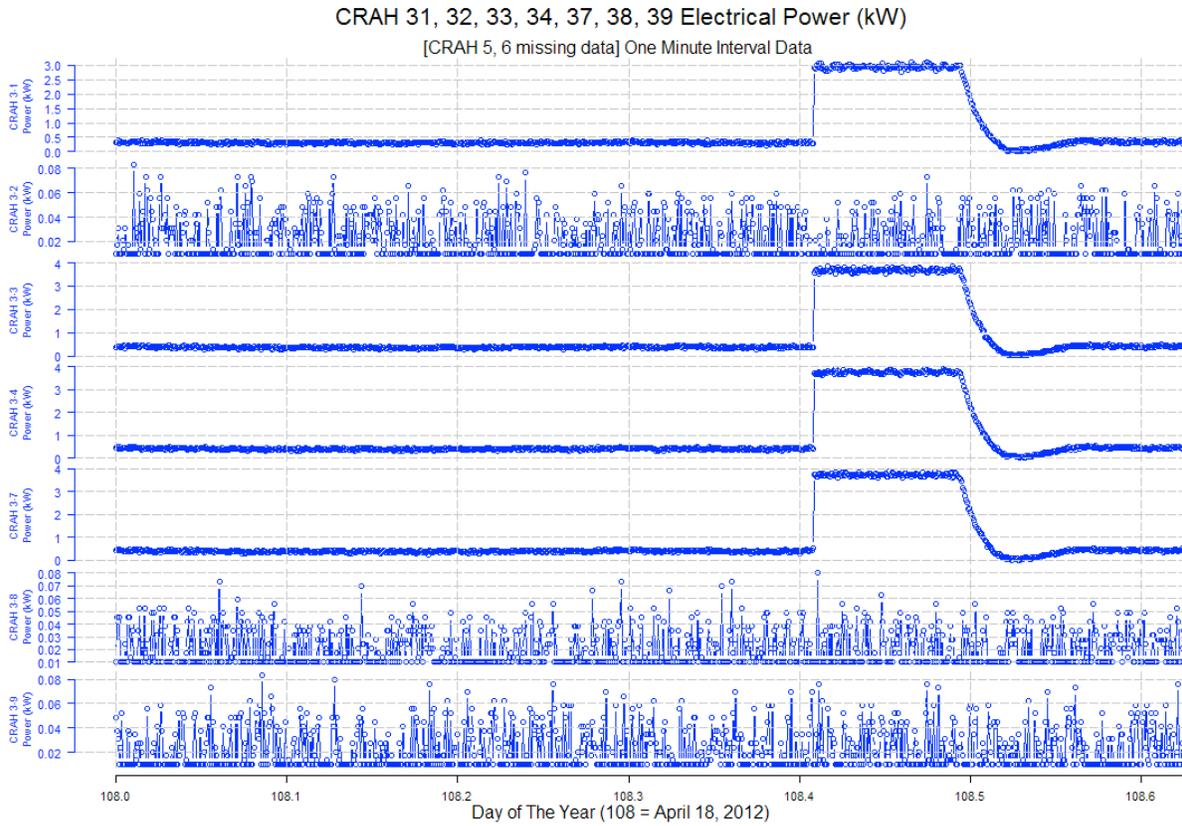
Figure A-1: CRAH Power From Colo 3 For April 18, 2012, Until Near the End of the Auto Mode Test Period

Appendix B: CRAH Power and Total Associated CRAH Power Reduction

	CRAH Power (kW)	Ref. CRAH Power Savings From Case 1	Ref. CRAH Power Savings From Case 2	Infrastructure Needed for CRAH Power Cooling (kW)	Total Infrastructure for CRAHs (kW)	Total Infra. Percent Saved Relative to Case 1	Total Infra. Percent Saved Relative to Case 2
(Case 1) Original Fans No Speed Control	439	NA	NA	57.93	497	NA	NA
(Case 2) Upgraded Fans No Speed Control	233	205.9	NA	30.76	264	46.9%	NA
(Case 3) Upgraded Fans Speed Controlled	147	291.9	85.98	19.41	167	66.5%	36.9%

Table B-1: Tabular Results of Power Changes Related to CRAH Fan Type Upgrades and Addition of Speed Controls

Appendix C: Input Data, Overall Energy Calculation Method and Results

Notes:	1 IT Equip. Power (MW)	2 Site Power (MW)	3 Total Infra. Power (MW)	4 CRAH Power (MW)	5 CRAH Cooling Power (MW)	6 Total CRAH Power (MW)	7 Other Infra. Power (MW)	8 PUE	9 Site Total MW-hours/ year	10 Site Total kW-hours/ year	11 Site kW hours Saved Rel. to Original (Case 1)	12 Site kW hours Saved Rel. to Baseline (Case 2)	13 Site Percent Saved Rel. to Original (Case 1)	14 Site Percent Saved Rel. to Baseline (Case 2)
(Case 1) Original Fans No Speed Control	2.59	4.125	1.53	0.439	0.058	0.497	1.035	1.59	36132	36,131,908	NA	NA	NA	NA
(Case 2) Upgraded Fans No Speed Control	2.59	3.892	1.30	0.233	0.031	0.264	1.035	1.50	34090	34,089,898	2,042,010	NA	5.7%	NA
(Case 3) Upgraded Fans w/Speed Control	2.59	3.794	1.20	0.147	0.019	0.167	1.035	1.46	33237	33,237,316	2,894,592	852,581	8.0%	2.5%

- measured
- assumed same
- calculated
- DLR records

Table C-1: Input Data and Overall Results Including Energy Savings Calculations

Calculation Notes: Reference notes #. In order of measurement or calculation:

1: [IT Equipment Power] Case 2 measured, assumed same for Case 1 and 3
3: [Total Infra. Power] for Case 2 only calculated : column 2 - column 1
4: [CRAH Power] Case 2 and 3 measured, Case 1 from previous measurements
5: [CRAH Cooling Power] calculate using 0.464 kW/ton of cooling and column 4
6: [Total CRAH Power] addition of columns 4 and 5
7: [Other Infra. Power] Case 2 only: subtract 6 from 3, assume Case 1 and 3 are the same as 2
3: [Total Infra. Power] Case 1 and 3 = addition of 7 and 6
2: [Site Power] Case 1 and 3 = addition of columns 1 and 3
8: [PUE] column 2 divided by column 1
9: Convert column 2 (1000 x 365 x 24)
10–14: Calculate savings and percent savings using other Cases. NA = not applicable.