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FINAL PROJECT REPORT

Bundle-Based Energy-Efficiency Technology Solutions for Commercial Buildings

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that benefit their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emissions in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility-scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Bundle-Based Energy Efficiency Technology Solutions for California is the final report for the EPIC Buildings Program (Grant Award #EPC-17-009) conducted by Willdan Energy Solutions. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) .

ABSTRACT

Energy managers, facility managers, and utility representatives for cities and buildings would all benefit from a deeper understanding of how complex energy-efficiency projects can improve the comfort of occupants within their facilities, reduce energy consumption, and lower maintenance costs. This project demonstrated the potential for energy-efficiency retrofits that provide at least 20 percent energy savings using a suite of emerging technologies.

South Coast Air Quality Management District (SCAQMD) headquarters near Diamond Bar, CA, was chosen as a demonstration site. This 30-year-old facility has laboratory space, office space, and meeting rooms across 350,000 square feet. SCAQMD is the public air pollution control agency for all or portions of Los Angeles, Orange, Riverside, and San Bernardino counties.

The project consisted of three technology "bundles," each demonstrating energy savings in some of the highest energy-consuming areas: chilled water plants, office and exterior spaces, and laboratory/critical environments. First, the team replaced the existing chilled water plant with high-efficiency chillers using low global warming potential refrigerant and an advanced automation system. Next, a combination lighting/HVAC retrofit was implemented in the office space, increasing zone control level by occupancy. Finally, the laboratory space ventilation system was converted from constant volume to variable volume, and the lighting system was converted to operate with DC power from an existing solar photovoltaic installation.

These three "bundles" of projects proved the viability and importance of pre-commercial energy-efficiency technologies and accelerated market adoption by identifying and addressing implementation barriers.

Keywords: bundle, chilled water plant, critical environment, energy efficiency, emerging technology, office, laboratory, refrigerant, new technology

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

EXECUTIVE SUMMARY

Introduction

The South Coast Air Quality Management District (SCAQMD) headquarters in Diamond Bar, CA, a 30-year-old 350,000-square foot campus of which 60,000 square feet is a critical lab environment, served as the demonstration site for this project. SCAQMD is the public air pollution control agency for all or portions of Los Angeles, Orange, Riverside, and San Bernardino counties. SCAQMD develops and adopts Air Quality Management Plans, blueprinting federal and state clean air standards and compliance. Annual energy consumption was reduced by 18.3 percent, or 1,463,380 kWh, by implementing the pre-commercial technology bundles.

There is a significant opportunity for using these technologies in commercial buildings within California and nationwide. For example, the California Energy Commission collects usage data by building type, showing that 97,000 GWh of electricity was consumed by commercial buildings statewide in 2020. In addition, the *2018 Commercial Building Energy Consumption Survey*, which contains the most currently available national data, shows continued growth in the commercial building sector; since 2012, the number of commercial buildings in the United States has grown by 6 percent and floor space increased by 11 percent.

As commercial building square footage increases, ensuring those buildings are as energy efficient as possible will be increasingly important. While California's Title 24 building code standard requires LED lighting and lighting controls for new buildings, older buildings built to previous standards typically consume more energy per square foot, as measured in kBTU per square foot. In California, Assembly Bill 802 mandates benchmarking commercial buildings greater than 50,000 square feet. Program data were only available for 2018, 2019, and 2020, and only 2,949 office buildings had been benchmarked as of 2020. Though this sample size is not representative, it provides insights into facilities' relative efficiencies over time. The median energy use for buildings built after 2010 was 40 kBTU/square foot; it was 47 kBTU/square foot for buildings constructed between 1940 and 1970. Laboratories consume far more energy per square foot. The median laboratory space energy consumption for buildings built after 2010 was 105 kBTU/square foot, while that consumption was 215 kBTU/square foot for buildings constructed between 1940 and 1970.

Project Purpose and Project Approach

This project aimed to showcase the significant potential of state-of-the-art, pre-commercial energy efficiency technologies in achieving substantial reductions in energy consumption within commercial buildings. Additionally, it seeks to emphasize the efficient utilization of advanced refrigerants and identify opportunities for energy efficiency enhancements in critical environments, including laboratories and hospitals.

The project team adopted a strategic approach focused on developing three distinct technology bundles to achieve these goals. These bundles targeted the most energy-intensive areas within commercial buildings, addressing specific challenges and maximizing energy savings. Through this approach, the project aimed to demonstrate the practicality and scalability of these innovative solutions in real-world commercial settings, paving the way for widespread adoption and significant energy efficiency improvements across various commercial end-uses.

The project team deployed efficiency bundles that include:

Chilled Water Plants: Optimized all-variable-speed chilled-water plants utilizing alternative refrigerant chillers. The existing chillers used R-123, which has a global warming potential of 93. This project replaced the two chillers at the test building with chillers that use R-1233zd(e), which has a global warming potential of 1.

Office and Exterior Space: LED fixtures with advanced controls and building management systems that optimize and integrate all HVAC zones and provide a comprehensive platform capable of demand response. The first floor of the open office area was converted to high-efficiency office space by upgrading existing pneumatic controls to direct digital control and replacing existing lighting fixtures with LED and advanced lighting controls.

Laboratory and Critical Environments: Advanced laboratory ventilation, fume hood exhaust controls, and direct current lighting systems. The ventilation system was replaced with variable control using occupancy sensors and pressure controls to dramatically reduce the energy consumed while maintaining a safe laboratory environment—solar power from an existing solar array powered lighting to illustrate the potential of a DC-powered lighting system.

Project Results

After installation, project results were measured and verified. Next, the team utilized those results to calibrate the building model, which determined the relative impact of each of the bundles. As a result, the whole-building energy model showed annual savings of 1,463,380 kWh, 91,055 therms of natural gas, and reduced peak electrical demand by 283 kW. Table ES-1 shows below displays simulation results for each bundle.

The results demonstrate that deep retrofits are possible in older buildings, showing a yearly reduction equivalent to 1,037 metric tons of carbon dioxide.

Table ES-1: Simulation Bundle Results

Energy Efficiency Measure	Electric Usage Reduction (kWh)	Electric Usage Reduction (%)	Electric Demand (kW)	Electric Demand Reduction (%)	Natural Gas Usage (therms)	Natural Gas Usage Reduction (%)
Bundle 1	819,522	10.27%	237	11.29%	0	0.00%
Bundle 2	53,412	0.67%	8	0.38%	45,109	16.44%
Bundle 3	590,446	7.40%	38	1.81%	45,946	16.75%
Total	**1,463,380**	**18%**	**283**	**13%**	**91,055**	**33%**

Source: Willdan Group eQuest model

Advancing the Research to Market

Knowledge sharing and transfer activities remain in progress with Willdan's substantial network of existing California contacts. This network includes state agencies, local government entities, utilities, schools, special districts, and commercial buildings by sharing and distributing case studies, web and social media, email, in-person meetings, public workshops, and events. Unfortunately, due to COVID-19, the project team has been unable to offer tours of the demonstration facility. The project team has also developed a public-facing roadmap to educate potential adopters about the technology benefits and lessons learned and to provide an implementation guide.

Benefits to California

Approximately half of existing buildings in California were built before the California Building Energy Efficiency Standards took effect in 1978. Commercial facilities consume 37 percent of the state's electricity. Therefore, older buildings have significant opportunities for improving lighting, shell, and mechanical system efficiencies[1]. However, these existing buildings face numerous challenges, including aging equipment and systems that require replacement, degradation of equipment calibration and performance, lack of monitoring and control capability, and rising energy cost. Overcoming these barriers will be critical for achieving California's ambitious mandated energy-efficiency goals.

The successful completion of this project demonstrates the twin viabilities of emerging technologies for reducing energy consumption and greenhouse-gas emissions while improving comfort in the built environment.

A significant reduction in energy and peak demand will have the important benefit of lowering overall demand on the electric grid and reducing the likelihood of summertime outages and constrained grid events. In addition, reducing energy consumption in commercial buildings will also reduce the greenhouse gas emissions largely responsible for climate change.

Significant retrofits such as those described in this project are more complex and, therefore, more expensive for many building owners and operators than they may have considered. A roadmap for these types of projects will help make these upgrades more accessible in the future.

CHAPTER 1: Introduction

Background

California policy makers have set aggressive energy efficiency and greenhouse gas emissions (GHG) goals through legislation including mandates in Senate Bill 350 (Author, Chapter, Statute) and the *California Energy Efficiency Strategic Plan*. Commercial facilities consume 37 percent of the state's electricity, making it the largest electricity-consuming sector and a logical target for energy-efficiency initiatives. An estimated 50 percent of existing buildings in California were built before the *California Building Energy Efficiency Standards* went into effect in 1978. Buildings of more recent vintages also have significant energy-efficient retrofit opportunities including improvements to lighting, building shell/envelope, and mechanical systems.

Energy managers, facility managers, and utility representatives for cities and buildings can all benefit from better understanding of how complex energy-efficiency projects can improve the comfort of occupants, reduce energy consumption and lower maintenance costs. This project demonstrated that energy-efficiency retrofits can provide at least 20 percent energy savings, using a suite of emerging technologies.

Project Goals and Objectives

The project's goals were to:

1. Prove the viability of three different bundles of pre-commercial energy efficiency technologies.
2. Accelerate market adoption of the technologies by identifying and addressing implementation barriers.
3. Reduce site energy consumption by at least 20 percent.

The project team started by prioritizing and selecting technologies for inclusion in the technology "bundles." Three bundles were chosen that provided savings in some of the highest energy-consuming areas in commercial buildings: chilled water plants, office and exterior spaces, and laboratory and other critical environments.

To achieve these goals the project team set two main objectives: to verify reduced energy consumption and reduced GHG emissions through a detailed task-level approach, and to accelerate market adoption through knowledge sharing and knowledge transfer activities.

Challenges

A common barrier in energy efficiency demonstration projects occurs when an approach focuses only on a single building function (for example, office space) or involves "cherry picking" high-volume market segments. Laboratories, while less common than general office spaces, use far more energy per square foot. Ventilation requirements, specialized research instruments, and more stringent health and safety requirements together result in higher energy use and therefore harder to implement projects in laboratories.

The project team overcame several other additional barriers during project implementation including:

- A lack of technological knowledge (familiarity with new technologies) among facility operators and industry stakeholders.
- A fear of "being first" (including, for example, concerns over the availability of post-implementation support services).
- A perceived high cost of early adoption.

The project team overcame many of these barriers through a strategic project design process; the end product provided a roadmap for custom combinations of pre-commercial technology bundles in almost any commercial building, including those with critical environments such as laboratories and hospitals.

Project Site

The project used the South Coast Air Quality Management District (SCAQMD) headquarters, located near Diamond Bar, CA as its demonstration site. This facility (Figure 1) is a 30-year-old, 350,000-square-foot campus with 60,000 square feet of critical lab environment. SCAQMD is the public air pollution control agency for all or portions of Los Angeles, Orange, Riverside, and San Bernardino counties. SCAQMD develops and adopts the district's air quality management plan, which also serves as the s the blueprint for federal and state clean air standards and compliance.

Figure 1: Satellite Image of SCAQMD Headquarters

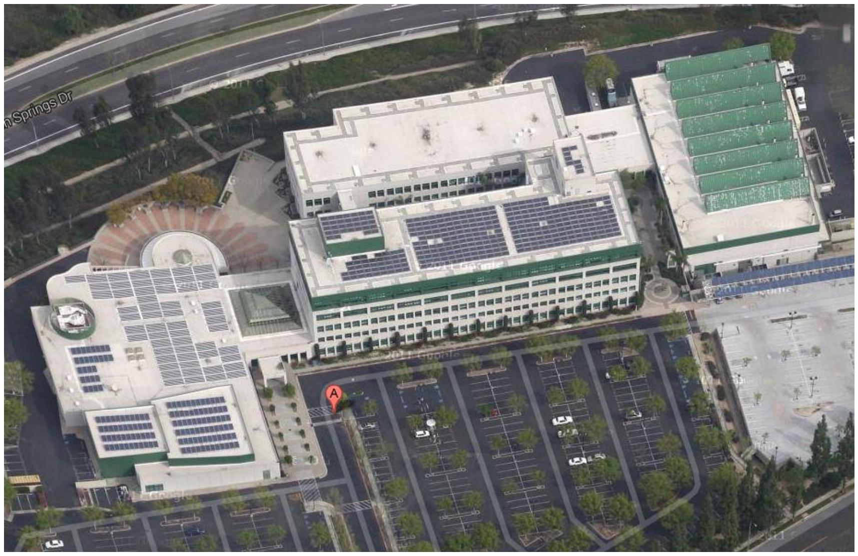


Photo of the overhead view of SCAQMD Headquarters.

Source: Google Earth, earth.google.com/web/

The facility consists of a five-story (plus basement) south office tower and a three-story (plus basement) north office tower, separated by a central open atrium. The lower level extends beneath the atrium. A laboratory wing is located at the east end of the facility, along with a basement that houses smaller equipment testing labs and storage. The west end of the facility has a large auditorium and conference center. The north and south towers have ample window area with lightly tinted, single-pane glass. Light shelves extend from the face of the building, above the windows. The light shelves block direct solar radiation and provide natural light by reflecting light upward, through the top portion of windows. Skylights provide lots of natural light to the laboratory.

The facility is open Tuesday through Friday from 7:00 a.m. to 7:00 p.m., with most staff working from 7:00 a.m. to 5:30 p.m., and closed Saturday through Monday. Facility staff estimate occupancy on closed days to be as high as 8 percent of normal facility levels during open days.

Bundle Development

This project demonstrates three bundles of pre-commercial technologies in commercial buildings, including solutions for buildings with critical environments such as laboratories and hospitals. The project team developed technology bundles that addressed the most energy-intensive areas in commercial buildings. The bundles included:

Bundle 1: Chilled Water Plant Retrofit

Central chilled water plants are rarely completely replaced. More commonly, the chillers or cooling towers are replaced independently and sized to match the previous design and existing components. By replacing all the components of the central plant at the same time, the project team was able to create a highly efficient design for the load and space constraints on the site.

The first bundle included optimized variable-speed chilled water systems with alternative refrigerant chillers. Several of the benefits from the retrofit included:

- Completely eliminating ozone-depleting potential.
- Reducing global-warming impacts by 300 times or greater.
- Reducing electricity and its associated costs by 15 percent.
- Increasing facility managers' ability to effectively control equipment.
- No longer reporting compound usage and refrigerant recovery since neither will be required by either the U.S. Environmental Protection Agency or by local air districts.

Bundle 2: Office and Exterior Space Retrofit

It is difficult to implement deep energy saving technologies in open office areas due to workspace layouts, occupancy changes, and client preferences. Office space retrofits are therefore typically made piecemeal with either lighting replacements or heating, ventilation, and air conditioning (HVAC) upgrades, which are rarely installed together. This is largely due to either a perceived complexity or failure to recognize that increased energy savings can result from combining projects. Schools and offices require innovative, energy-saving technologies that effectively address the specific needs of their spaces. This bundle uses a modular approach to integrate all major aspects of facility energy use, i.e., lighting and HVAC end-uses, while providing maximum occupant comfort and minimizing facility maintenance issues. The project team developed a project roadmap for this bundle for use by utilities, consultants, cities, and other large facilities with open office spaces. This roadmap includes step-by-step instructions for future adopters, with the objective l of reducing project time, costs, and risk.

The second bundle included LED fixtures with integrated advanced controls and an advanced building management system to optimize and integrate HVAC zones, integrate wirelessly with plug-load controls, and provide a comprehensive platform capable of demand response and off-grid exterior parking lot LED lighting. Several Bundle 2 of the benefits include:

- Improving occupant control and comfort.
- Enhancing safety from improved exterior lighting.
- Reducing electricity and its associated costs by 10 percent.

Bundle 3: Laboratory and Critical Environment Retrofit

Hospitals, universities, and research facilities often find it difficult to increase energy efficiency in critical spaces. These facilities have very little operational down time, and staff usually hesitate to make significant changes to these spaces for fear of disrupting experiments and lab occupants. Laboratories can be particularly difficult to retrofit due to their critical nature and the need to balance temperature with air pressurization. Laboratory spaces that dynamically respond to changes in occupancy require an extensive scope of work, a process for soliciting occupant input, feedback post-project, and a detailed commissioning plan to verify functionality.

Advanced laboratory ventilation and fume-hood exhaust and direct current (DC) lighting systems.

Benefits of Bundle 3 include:

- Improving resiliency and reliability while maintaining safety compliance.
- Reducing electricity and its associated costs by 6 percent

Potential for Scalability and Replicability

About half of existing buildings in California were built before 1978 when the California Building Energy Efficiency Standards went into effect. Because 37 percent of the state's electricity is consumed by commercial facilities, this is the largest energy sector in California. These older buildings have significant opportunities for lighting, shell, and mechanical-system efficiency improvements. These existing buildings face numerous challenges including aging equipment and systems, degradation of equipment calibration and performance, lack of monitoring and control capability, and the increasing cost of energy. Overcoming these barriers is critical to achieving the state's statutory energy goals.

Bundle 1: This project demonstrated that although the retrofit was complex, once completed there was no negative operational impact from using very low GWP refrigerants. Any building owner or facilities manager with an aging chiller should consider a replacement that uses the lowest GWP refrigerant available.

Bundle 2: While no data was collected to demonstrate market size, there are many commercial buildings that still have pneumatic controls. The implementation of this bundle demonstrated significant energy savings from direct digital control (DDC) retrofits, and the potential for simultaneous lighting upgrades to maximize savings. Commercial building owners and / or operators with pneumatic controls should consider this type of retrofit. Commercial building owners or operators interested in performing a lighting retrofit should also seize the opportunity to ensure that their HVAC system is operating as efficiently as possible.

Bundle 3: Laboratory environments tend to be retrofitted infrequently as operational disruptions can create significant production impacts. But given the existing technology on the market today, constant-volume laboratories are capable of retrofitting to variable controls.

There is little adoption of DC lighting in California despite the increasing prevalence of solar installations. This project was ostensibly about resilience in critical environments and the extent to which solar systems can be directly tied into building operations. Despite this advantage, project recommendations may be premature in today's market since development of available products is required to increase market adoption.

CHAPTER 2: Project Approach

Baseline Utility Use

Southern California Edison (SCE) supplies electricity to the facility under a single account; until approximately 2017 it was also supplied by a 400-kW fuel cell (decommissioned in 2019) owned and operated by a third party but located on site. The fuel cell was on a separate natural gas account, i.e., SoCalGas, which was paid by the fuel cell owner. A small percentage of electricity is also supplied by rooftop solar photovoltaic (PV) arrays, which experienced significant downtime over the course of this project due to failed equipment.

Electrical utility billing data were provided at 15-minute intervals, consisting of power purchased from SCE and the power generated by the fuel-cell. Historical electric energy consumption is shown in Table 2:

Table 2: SCAQMD Historical Electricity Usage

Month	Year	SCE-Provided Electricity (kWh)	Fuel-Cell-Generated Electricity (kWh)	Total Electricity Usage (kWh)	Peak Electric Demand (kW)	Cost of Utility-Supplied Electricity ($)
September	2015	806,020	35,690	841,710	2,208	$143,625
October	2015	566,332	289,954	856,286	2,079	$70,080
November	2015	393,444	291,791	685,235	1,724	$49,181
December	2015	378,892	300,116	679,008	1,637	$47,571
January	2016	377,212	295,991	673,203	1,562	$50,266
February	2016	416,584	262,155	678,739	1,695	$51,068
March	2016	442,260	278,725	720,985	1,772	$55,781
April	2016	434,080	278,674	712,754	1,713	$58,624
May	2016	435,460	303,631	739,091	1,699	$51,143
June	2016	616,712	184,344	801,056	2,119	$127,788
July	2016	607,316	226,032	833,348	2,034	$117,167
August	2016	750,956	61,034	811,990	2,009	$132,653
Total		**6,225,268**	**2,808,137**	**9,033,405**	**2,208**	**$954,947**

Source: SCE Utility Bill Data

From September 2015 through August 2016 about 30 percent of the project facility's electricity was supplied by the fuel cell. The Willdan Group, Inc. (Willdan Group), applied SCE's current time-of-use (TOU-8-Standby [Option B]) tariff to the SCE interval data to calculate the cost of electricity supplied by SCE. This resulted in an average cost of electricity of 15.3 cents per kWh. Note that this average cost of electricity does not include standby charges, which are added because of the fuel cell. To evaluate energy-use patterns, Willdan then combined the fuel cell and utility interval data and plotted average daily electrical demand profiles for each month for weekdays (Tuesday-Friday, Figure 2), and weekends (Saturday-Monday) in Figure 3. The plots demonstrate a significant difference in day and night use, as expected in an office building with a central chilled water plant that is disabled at night. The nighttime demand is still significant at 500-600 kW, much of which is attributed to continuous operation of laboratory air-handling units (AHUs) and the data center. Daytime peak demand is generally about 400 kW less on weekends than on weekdays.

Figure 2: Historical Electrical Usage Monthly Profiles (Weekdays)

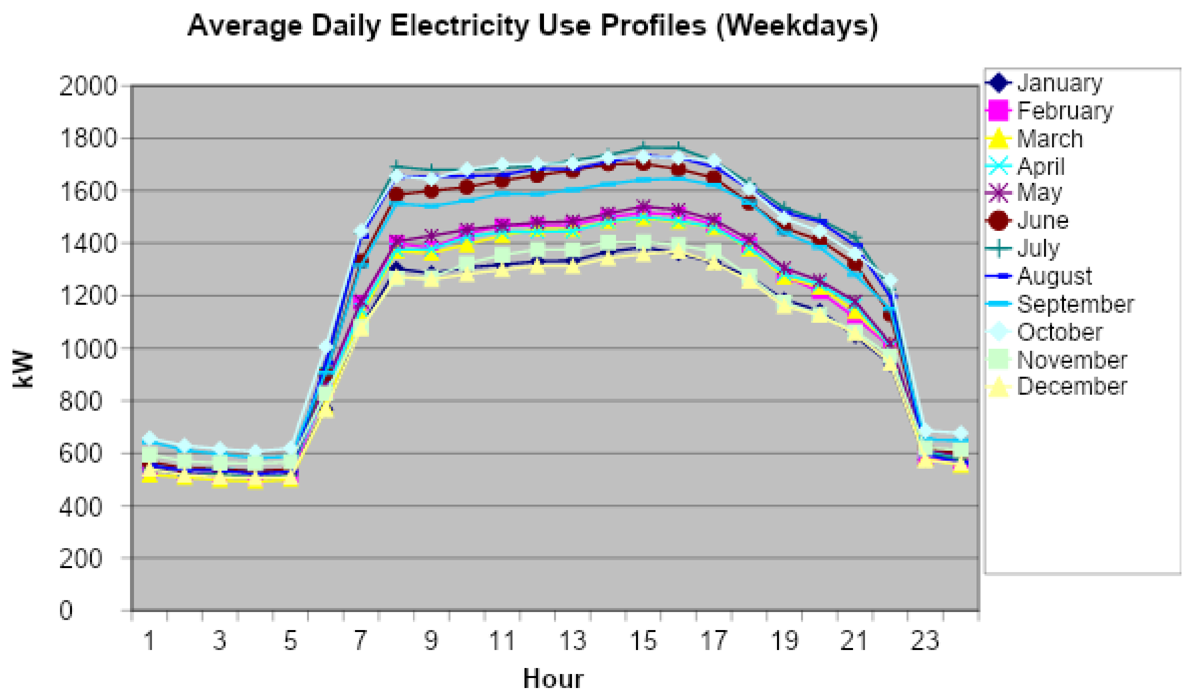


Image of weekday electrical demand plotted in a graph by hour.

Source: SCE Utility Bill Interval Data

Figure 3: Historical Electrical Usage Monthly Profiles (Weekends)

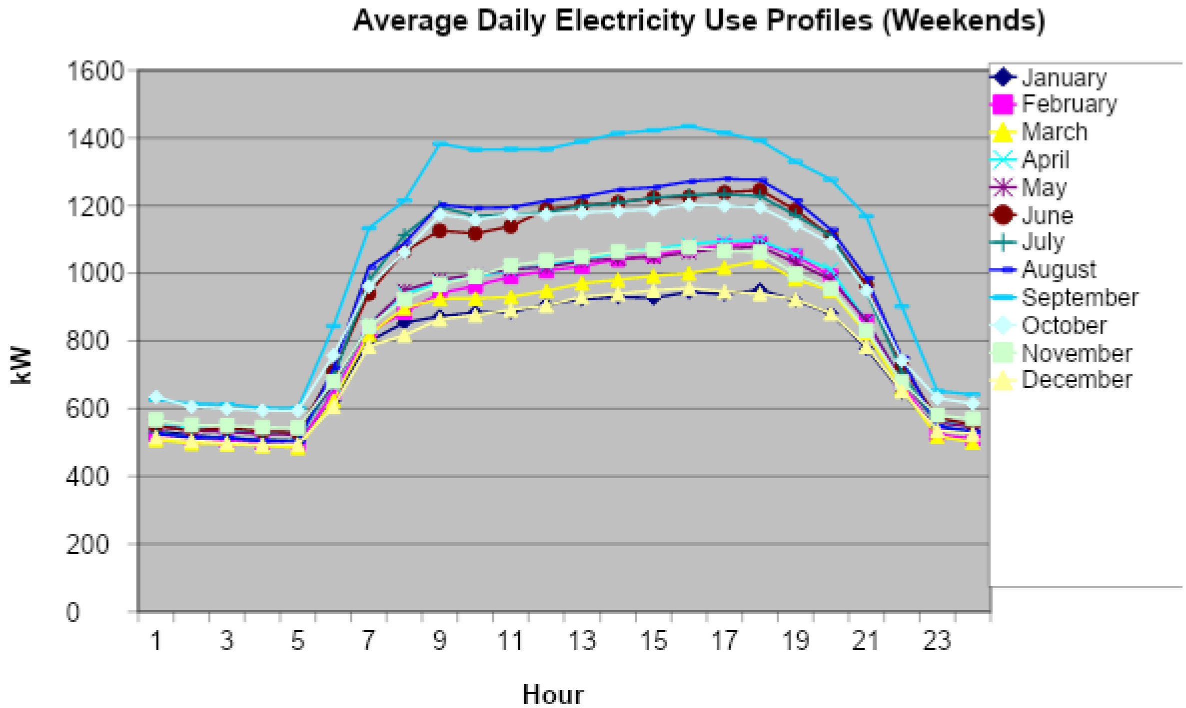


Image of weekend electrical demand plotted in a graph by hour.

Source: SCE Utility Bill Interval Data

Bundle 1: Advanced Chilled Water Plant

Bundle 1: Existing Conditions

The central chilled water plant located in the basement previously supplied heating and cooling to the entire facility. The chilled water plant had two water-cooled 770-ton centrifugal chillers. The original chillers were more than 20 years old but had been retrofitted with variable frequency drives.

These chillers used R-123 refrigerant which has a Global Warming Potential (GWP) of 93[2]. Typically, only one chiller was run at a time, and chiller use was alternated frequently to maintain even run time on each chiller. A second simultaneous chiller was manually enabled only occasionally on very hot days. Chilled water plant pumping was primary-secondary, with dedicated primary pumps that had fully open balancing valves. The secondary chilled water plant loop had two large, chilled water pumps with flow modulated by variable frequency drives that were controlled by secondary loop differential pressure. Chilled water plant supply return temperature readings were 46°F/54°F (7°C/12°C), a fair loop temperature differential, with both secondary loop pump variable frequency drives operating at approximately 50

[2] https://www.freon.com/en/-/media/files/freon/freon-123-push-bulletin.pdf?rev=b5fb1eba89d946d898997fea881b03b2

percent, indicating reasonably efficient chilled water pumping. Table 3 summarizes previous existing chiller profiles.

Table 3: Existing Chillers

Equip. ID	Manufacturer	Model	Description	Capacity (tons)	Voltage	Full Load Current (Amps)	Full Load Efficiency (kW/ton)
CH-1	York	YTL6M6F2-CAE	Water-cooled centrifugal R-123	770	460 V; 3-phase	778	0.70
CH-2	York	YTL6M6F2-CAE	Water-cooled centrifugal R-123	770	460 V; 3-phase	778	0.70

Source: SCAQMD Building Drawings

Heat from the condenser water loop was rejected by two original, forced-draft cooling towers, which were near the end of their service lives despite being equipped with variable frequency drives about five years ago. The cooling towers shared a common header with two 60-horsepower constant-speed condenser water pumps located outdoors with the original electric motors. During the original site audit, one condenser water pump and one cooling tower were running, with the tower fan variable frequency drive at 57 hertz (Hz) (near full speed), and condenser water supply/return temperatures at 73°F/80°F (23°C/27°C), according to the analog gauges. Automatic (electrically actuated) isolation valves were located at each cooling tower, with isolation valves between the towers that allowed either tower to operate with either chiller.

A smaller forced-draft fluid cooler is installed for the data center condenser water loop, which also has a variable frequency drive on the fluid-cooler fan motor. The data center condenser water loop rejects heat from the direct expansion data center computer room air-conditioning units and is circulated with two 7.5 horsepower pumps. During the day, the data center condenser water loop is connected to the main chiller condenser piping, and the fluid cooler is disabled. At night, one of the data center loop pumps and the fluid cooler are enabled, and the main chilled water plant is disabled.

According to operations staff, the chilled water plant and AHUs are enabled to the following schedule:

- Monday through Friday: 5:30 a.m. to 10:30 p.m.
- Saturday and Sunday: 6:30 a.m. to 10:30 p.m.

Tables 3, 4 and 5 show the equipment installed in the central plant prior to this project (including cooling towers and pumps), and Figure 4 provides a schematic of the existing chilled water plant from the building management system operator’s workstation.

Table 4: Existing Cooling Tower Equipment

Equip ID	Manufacturer	Model	Description	No. of Fans	Fan Motor (hp)	Variable Frequency Drive
CT-1	BAC	T1663-P	Forced-draft cooling tower	2	2 x 50	Yes
CT-2	BAC	T1663-P	Forced-draft cooling tower	2	2 x 50	Yes
CT-3	BAC	T1743-L	Forced-draft fluid cooler	1	1 x 20	Yes

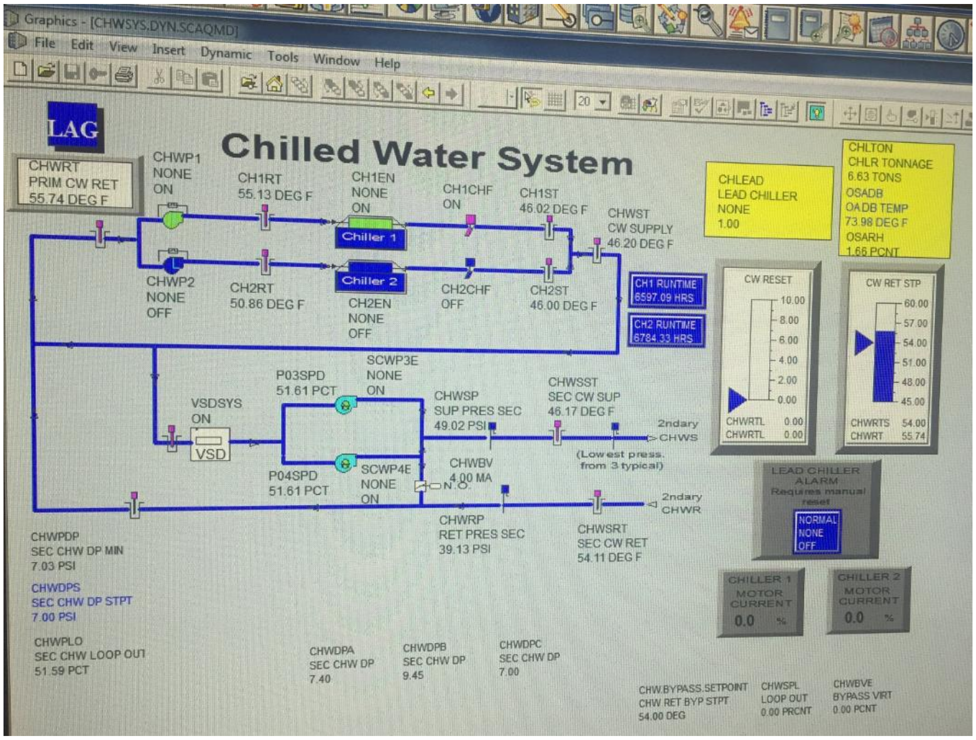
Source: SCAQMD Building Drawings

Table 5: Existing Pump Equipment

Equip ID	Description	Motor hp	Flow Rate (GPM)	Head (feet H_2O)	Variable frequency drive
P-1	Primary Chilled Water Pumps	20	1320	40	No
P-2	Primary Chilled Water Pumps	20	1320	40	No
P-3	Secondary Chilled Water Pumps	60	1540	100	Yes
P-4	Secondary Chilled Water Pumps	60	1540	100	Yes
P-5	Condenser Water Pumps	60	2400	70	No
P-6	Condenser Water Pumps	60	2400	70	No
P-13	Computer Room Air Conditioning Condenser Water Pumps	7.5	190	80	No
P-14	Computer Room Air Conditioning Condenser Water Pumps	7.5	190	80	No

Source: SCAQMD Building Drawings

Figure 4: Building Management System Screenshot of Chilled Water Plant



Screenshot of a schematic of the existing chilled water plant on the BMS computer.

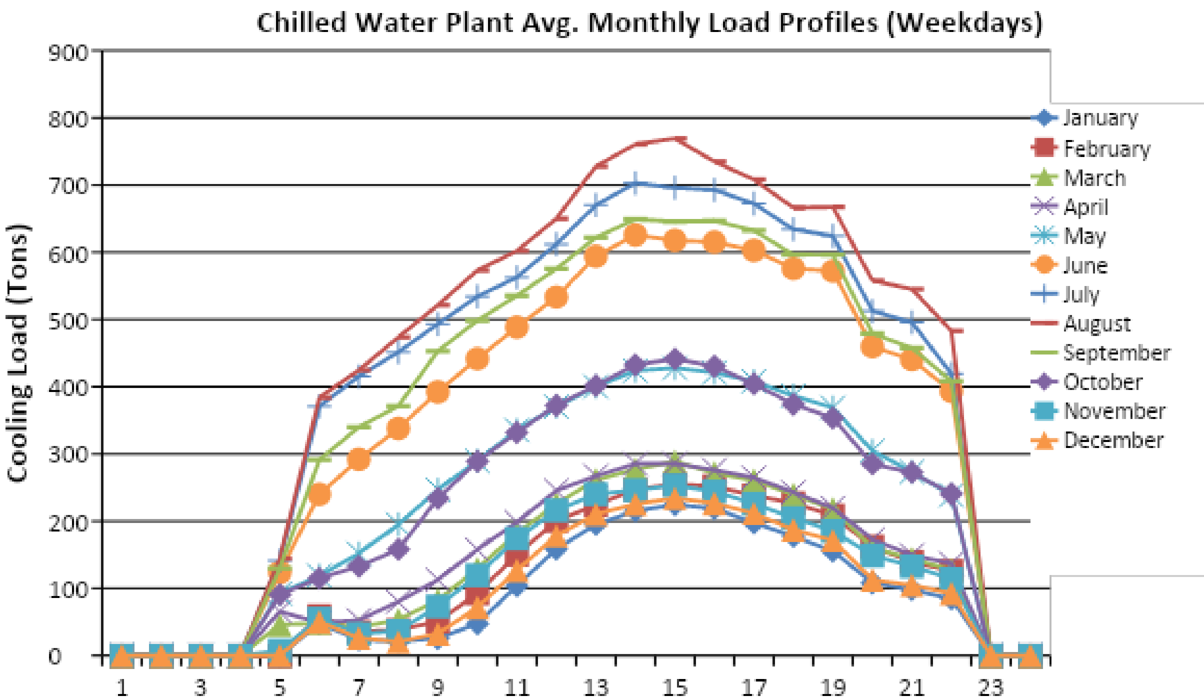
Source: Willdan Group

The chilled water plant supplies chilled water to the AHUs located throughout the building. The office towers are served by variable air volume (VAV) AHUs located on each floor. The VAV AHUs have chilled water coils and supply conditioned air to the zone VAV boxes with hot water reheat. The laboratory spaces are served by two AHUs that are 100-percent fresh-air, constant-volume dual-duct systems. There are also AHUs serving the west end of the building, where the kitchen, cafeteria, auditorium, and conference rooms are located. The kitchen AHU is also a 100-percent fresh-air unit. The rest of the systems are mixed-air with air-side economizers.

The existing control sequence includes a condenser water temperature reset sequence, a day-of-the-week schedule, lead/lag chiller control, and some local (workstation) alarms.

The average simulated cooling loads for both weekdays and weekends for each month are shown in Figure 5 and Figure 6, based on eQuest modeling intended to demonstrate pre-retrofit operating conditions. The modeled charts show significant variance in cooling loads from month to month, much of which can be attributed to large areas of window exposure and high ventilation rates, particularly in the laboratory. In the hottest summer month of August, cooling load approaches 800 tons on an average day. On the hottest days, simulated cooling loads on the chilled water plant peak at about 1,000 tons. Weekend cooling loads are still significant; this is attributed to the continuous operation of the laboratory. Chilled water plant loads were zero from about 11 p.m. to 5 a.m. due to scheduled shutdowns.

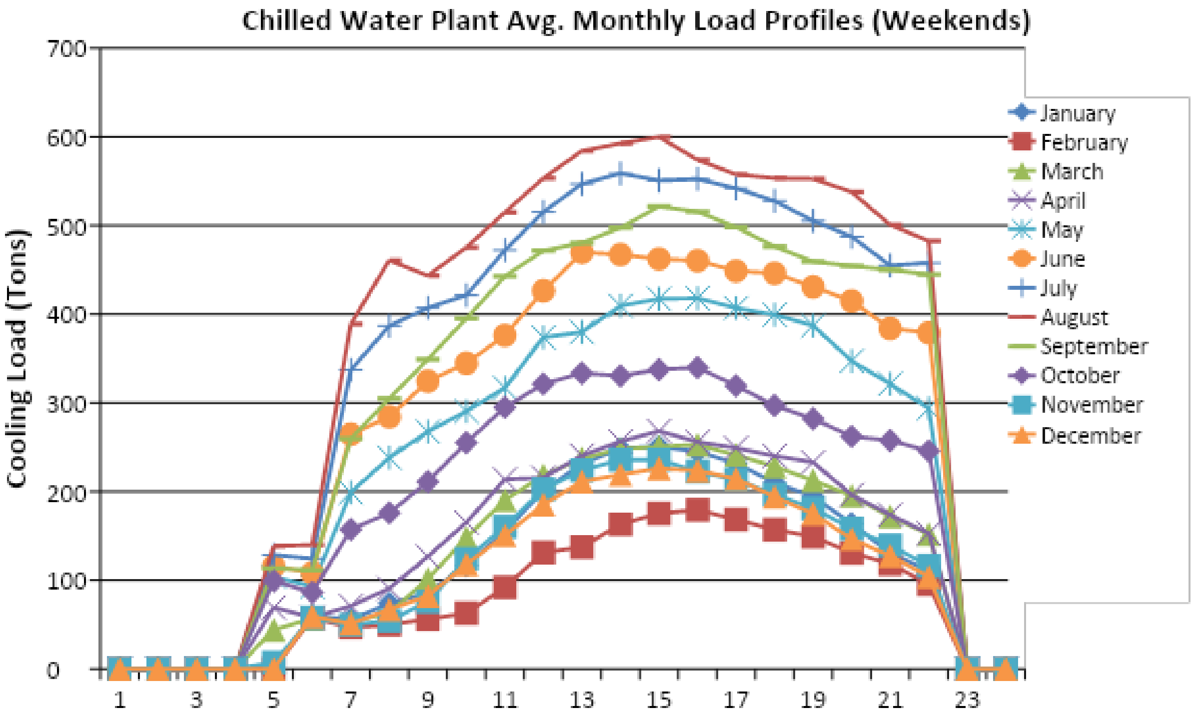
Figure 5: Simulated Average Monthly Weekday Cooling Load Profiles



This image is of a plot representing a data set of the chilled water plant cooling load average on monthly load profiles of weekdays.

Source: Willdan Group eQuest model

Figure 6: Simulated Average Monthly Weekend Cooling Load Profiles



This image is of a plot representing a data set of the chilled water plant cooling load average on monthly load profiles of weekends.

Source: Willdan Group eQuest model

Bundle 1: Project Approach

Two York YZ-MA095 chillers, operating with R-1233zd(e), were selected based on their ability to match the desired performance profile, cost, and the fact that R-1233zd(e) was already approved in the mechanical code. R-1233zd(e) has a GWP of 1[3] and is the recently developed single component, non-flammable A1, Hydrofluro Olefins (HO) FO refrigerant alternative to R123.

The project team evaluated which chillers were commercially or pre-commercially available by contacting representatives from Johnson Controls, Trane, and other major chiller manufacturers; two major brands met project requirements. Trane's chiller utilized R-514A, which was not included on the list of acceptable refrigerants in the 2016 California Mechanical Code (CMC) but was listed on the 2018 CMC. The City of Diamond Bar was the authority having jurisdiction (AHJ) for this project, yet in 2019 when the project was first submitted for plan check, Diamond Bar had not yet adopted the 2018 code. This is typical of many cities; code adoption is often delayed. The 2016 CMC states that "the refrigerant used shall be of a type listed in Table 1102.2 or in accordance with ASHRAE 34 where approved by the Authority Having Jurisdiction (AHJ)" and ASHRAE Standard 34-2016 considers R-514A to be an

[3] https://www.honeywell-refrigerants.com/europe/product/solstice-zd/

"approved refrigerant." In addition, the United States Environmental Protection Agency (US EPA) listed R-514A as an approved alternative in May 2016 through the Significant New Alternatives Program (SNAP), describing the refrigerant as an acceptable substitute, without restrictions.

R-514A has a GWP of 2. After further consideration of the relative performance of the two chillers, SCAQMD chose the York chiller using R-1233zd(e). The York chiller was first introduced by Johnson Controls in early 2018. At the time of chiller procurement, the chillers at SCAQMD were one of the first 10 YZ-MA095 chillers deployed in the United States. Figure 7 shows the new chillers fully installed inside SCAQMD's chilled water plant.

Figure 7: Installed Central Plant

Photograph of new chillers and piping.

Source: Willdan Group

The existing underground piping was excavated, removed, and replaced with Aquatherm piping. Figure 8 shows the excavation site for SCAQMD's underground condenser-water piping.

Figure 8: Underground Piping Trench

A picture containing a large excavation site where underground piping was replaced.

Source: Willdan Group

Final central plant design drawings illustrate the schedules of installed equipment, described in APPENDIX A.

The new chilled water plant is controlled by an upgraded building-management system that automatically optimizes the plant for the greatest efficiency. When building electric loads are low, only a single chiller operates. Should one operating chiller be unable to meet the chilled water-supply setpoint for 180 seconds, a second chiller is engaged. Each of the three variable primary chilled-water pumps serving the loop is sized to meet 66 percent of peak chilled-water loads. Only two of the three pumps typically operate to meet peak loads, and usually operate with two pumps, at the same speed. The pump speeds are modulated to maintain existing system differential-pressure setpoints. The three condenser water pumps are sized for 50 percent of the peak condenser water load and modulate the pump speed until both the lead and lag pumps can operate simultaneously at minimum speed to meet both the load and minimum flow requirements for the tower and condenser barrel.

The chiller evaporator control valves modulate to "full open" on chiller command and upon differential pressure readings across two operating chiller evaporators; the valves modulate “closed” to the minimum extent required to maintain the same pressures across both operating evaporators. The chiller bypass control valve only commands open and modulates to maintain chilled water plant system pressure when the pressure differential reaches the setpoint with a single chiller and the pump operates at minimum allowable pump speeds.

Each cooling tower is sized and operates for each chiller. The condenser water supply temperature setpoint is adjustable based on ambient wet-bulb temperature of 7°F (-14°C). Tower fans equipped with variable frequency drives modulate the fan speed to maintain the condenser water supply temperature setpoint, so it does not either go below 68°F (20°C) or above 85°F (29°C). Figure 9 shows the new cooling towers.

Figure 9: New Cooling Towers

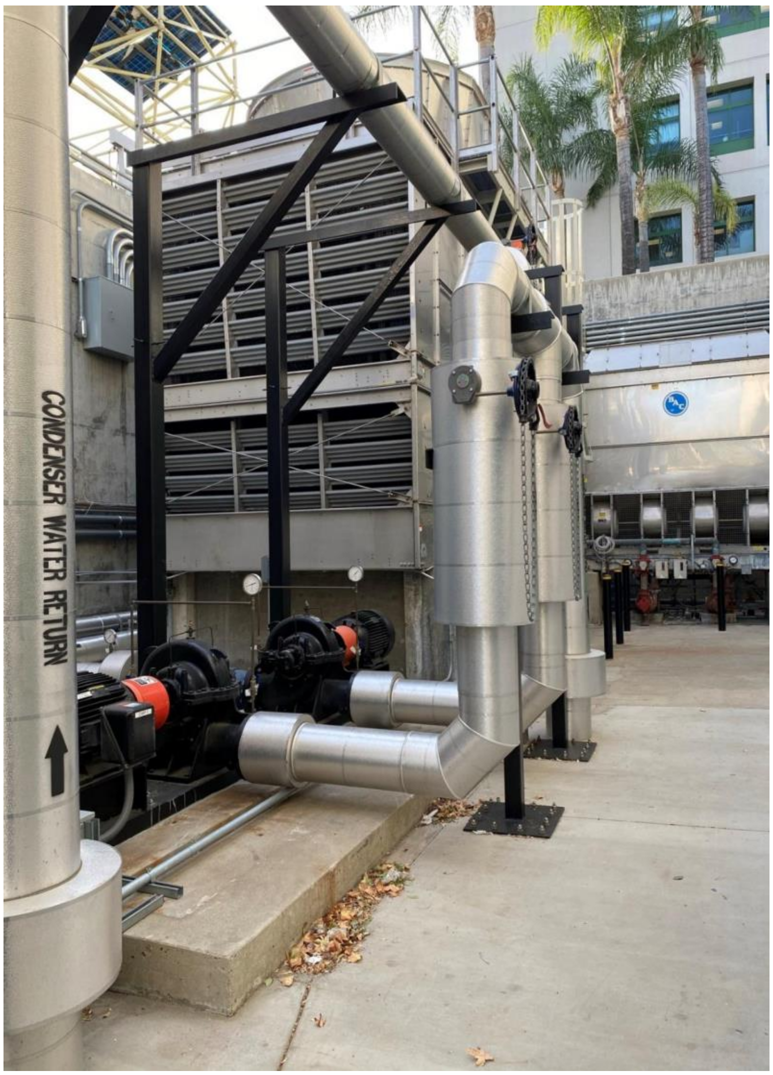


Image of a new cooling tower outdoors.

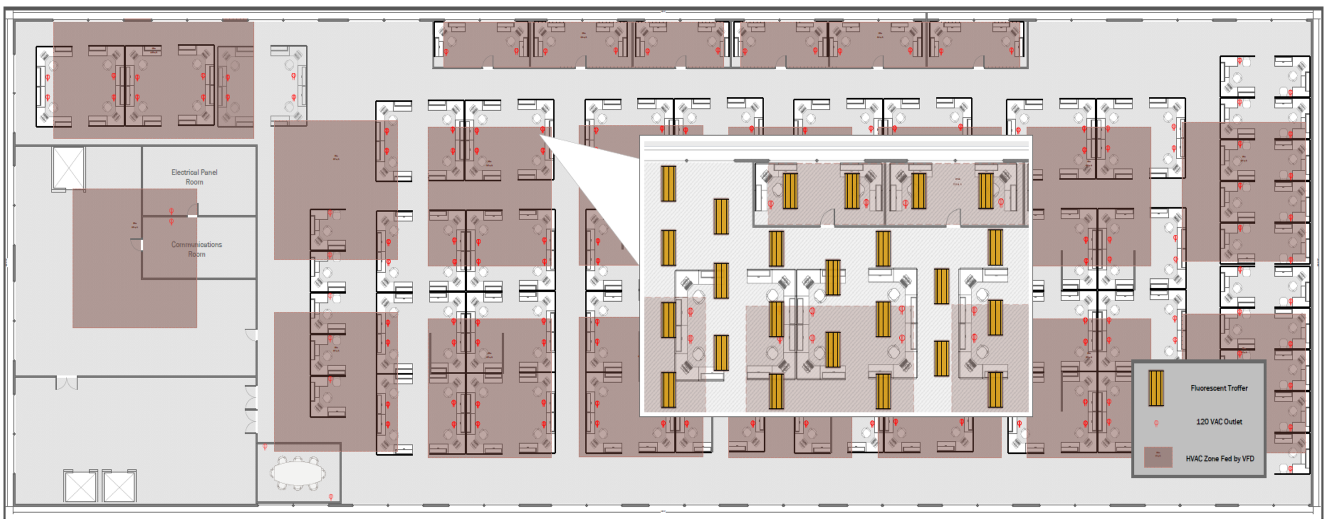
Source: Willdan Group

Bundle 2: Office and External Space

Bundle 2: Existing Conditions

The majority of the SCAQMD facility is office space. Seven floors of the facility have very similar layouts with open office cubicles surrounded by several private offices. Figure 10 shows a typical floor plan for a single floor of office space.

Figure 10: One Floor of Office Space With Lighting and HVAC Overlap



Overhead layout of the office space showing cubicles, overhead lighting, and areas of influence of HVAC.

Source: Willdan Group

The typical office space floor, seen in Figure 10 and in more detail in APPENDIX B, includes an elevator lobby that opens to the main open office space with conference rooms, cubicles, and offices along the walls.

Interior fluorescent lighting was retrofitted from T12- to T8-lamps over 10 years ago. Before this project's implementation, most fixtures were 2'x4', 2-lamp fixtures with normal output ballasts and reduced-wattage F32 28-watt T8 lamps. Inspection of a few fixtures revealed original old-generation electronic ballasts (Magnetek Triad; 277 V; instant start, high-power factor), although some were replaced with newer electronic ballasts when the older ones failed.

Lights were controlled with a General Electric central lighting controller, which disabled lighting circuits at 10 p.m. Occupants had switches to override occupancy schedules in the event of after-hours occupancy; this override lasted for one to two hours. While some rooms have legacy lighting occupancy sensors, most are no longer operational.

The office spaces at SCAQMD consist of large open spaces containing cubicles, a perimeter of enclosed offices, and some small conference rooms; some offices are split into multiple-person offices. Most electrical outlets are duplex 120 V outlets that are slightly modified to fit into the cubicle outlet boxes and do not use any form of plug-load control. These cubicle plugs are fed from the ceiling for each set of cubicles. The standard 120 V receptacles located around the outside walls are not generally used.

The office spaces are served by several AHUs with cooling coils as described and shown in more detail in Table 6.

Table 6: Existing AHUs Serving Offices

Equip. ID	Area Served	Type	Supply Air Flow Rate (CFM[4])	Supply Static Pressure (inches H_2O)	Supply Fan Motor (hp)	Return Fan Motor (hp)	Chilled Water Coil Capacity (MBH)	Flow Control Method
AH-3	Lower-Level Office	VAV Mixed Air	16,540	5.0	30	7.5	616	Variable Frequency Drive
AH-5	Lower-Level Office	VAV Mixed Air	20,000	5.0	30	7.5	732	Variable Frequency Drive
AH-6	First Floor S. Offices	VAV Mixed Air	24,000	5.0	40	10	820	Variable Frequency Drive
AH-7	First Floor N. Offices	VAV Mixed Air	25,000	5.0	40	10	854	Variable Frequency Drive
AH-13	Second Floor S. Offices	VAV Mixed Air	24,000	5.0	40	10	820	Inlet Cone
AH-14	Second Floor N. Offices	VAV Mixed Air	24,000	5.0	40	10	820	Variable Frequency Drive
AH-15	Third Floor S. Offices	VAV Mixed Air	24,000	5.0	40	10	820	Inlet Cone
AH-16	Fourth Floor Offices	VAV Mixed Air	24,000	5.0	40	10	820	Variable Frequency Drive
AH-17	Fifth Floor Offices	VAV Mixed Air	24,000	5.0	40	10	862	Variable Frequency Drive
AH-24	Third Floor N. Offices	VAV Mixed Air	23,790	4.5	40	10	744	Variable Frequency Drive

Source: SCAQMD As-Built Drawings

Most of these AHUs are VAV systems, although a few still have inlet cones with variable frequency drives on the supply and return fans. AHUs and the central plant are controlled by the existing building-management system, an older-generation Siemens Apogee system (but not the original system since the facility has an ongoing maintenance contract with Siemens). The building-management system provides the central plant and AHU scheduling, economizer, and warm-up cycle mixed air-damper control, as well as supply air-reset control strategies

[4] Cubic feet per minute

based on outdoor dry-bulb and wet-bulb temperatures. The building management system also provides a chilled water reset based on outdoor temperature.

While the AHUs have been upgraded to include direct digital controls that are visible from the front end, the individual VAV box and zone controls remain pneumatic. The facility has begun the process of upgrading zones to direct-digital controls, but that work is still in progress. The facility recently flushed the heating hot water system and received numerous occupant complaints regarding the temperature. These complaints were attributed to improperly functioning hot-water coil-control valves and a legacy of manually isolating or adjusting flow through coils. Without visibility of zone-level controls or thermostat setpoints, the facility relies on occupant complaints to address heating and cooling issues in the office spaces. There is additionally no feedback from the VAV box status to a central controller, which could alternatively be used to both optimize AHU static pressure and supply air-temperature setpoints.

Existing Exterior Lighting

The SCAQMD facility was built in 1991 and has original exterior metal halide parking lot lighting. There are limited dark areas in the parking lot during the evening hours, as well as only building lighting in the outdoor patio behind the building. Exterior parking lights are pole-mounted (one or two fixtures per pole), with 250-W metal halide lamps. The project team counted 89 pole-mounted fixtures, which were original from 1991. The project team also counted 13 flood landscaping up-lights with 150-W PAR30 incandescent screw-in flood lamps.

Bundle 2: Project Approach

The following measures were installed to advance project goals:

1. Advanced LED fixtures with integrated controls to enable dimming in accordance with occupant demands and daylight levels.
2. An optimized building management system to comprehensively integrate and wirelessly control all HVAC zones and lighting controls, and to provide a demand-response platform.

Although upgrading fluorescent lighting to LED is not an emerging technology, it was a requirement that allowed maximum lighting control and integration into the HVAC system. The project team initially created a scope of work and sequence of operation describing the system integration and prepared for the bidding cycle to begin. One of the three bidders bid on the HVAC work and the lighting controls but excluded installation of the luminaire replacements; A second company did not want to integrate into the existing Siemens building management system, and the third company after reviewing the scope requirements and project complexity, chose not to bid at the project due to its complexity. The final project design upgraded lighting and lighting controls using one vendor then relied on a second vendor (Siemens) to integrate the systems.

Lighting

Existing fluorescent fixtures were upgraded to high-efficiency LED fixtures that save 50 to 60 percent of energy (with the same lighting output) in addition to daylight sensors that dim or turn off lights near windows, and occupancy controls in offices, conference rooms and open cubicle spaces. While these upgrades were initially planned for more of the facility, budget limitations forced the retrofit demonstration to be limited to the first floor.

All fixtures in the north wing of the first floor were replaced with advanced nLight ECLYPSE™ enabled fixtures with automatic dimming control photocells. This system features an open automated demand-response interface, ceiling sensors, time-based schedule controller, battery fixtures for emergency-lighting strings, and some color-tunable fixtures.

The project team conducted an initial staff survey in this wing and received 25 responses. Of these, 8 respondents wanted brighter lights, 9 wanted the lights to be dimmer, and 8 thought the current lighting was adequate. The survey revealed that respondents had very divided feelings about whether the lighting was too warm (or "yellow") or too cool (or "blue"). On a scale of 1 (warm) to 100 (cool), the average was 48. While respondents had mixed results overall, it was clear that having this choice was important, so the project design was driven in part by the desire to give occupants more control over light levels and characteristics.

During the project design, the project team interviewed local lighting distributors and product representatives to fully understand industry designs and developments. In 2017, Acuity Brands launched its Tunable White product, which allows color-temperature changes to be programmed into the lamp control. This is also referred to as "circadian" lighting because it mimics changes in outdoor lighting as the sun either rises or sets. This was first studied in 2003 by the United States Department of Energy[5], but has not been widely implemented due primarily to the lack of technology and controls required for its successful execution. The lighting vendor only recently made this option commercially available, and SCAQMD was one of the first buildings in Southern California to implement it.

In consultation with SCAQMD, the following features were implemented.

Light Levels: Intensity is automatically maintained unless manually overridden by preset "scenes." These scenes are controlled locally at the switches and are pre-programmed.

1. HIGH = 100 percent output; 30fc at desk level
2. MEDIUM = 95 percent; 25fc at desk level
3. LOW = 85 percent; 15fc at desk level
4. TWILIGHT = 75 percent; 10fc at desk level

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[5] Boyce, P., Veitch, J. A., Newsham, G. R., Myer, M., Hunter, C., Heerwagen, J. H., & Jones, C. C. (2003). Lighting quality and office work: A field simulation study: *lighting research and technology*.

Color Temperature: Circadian (CCT) schedule (automatically maintained throughout the day by schedule and unaffected by manual preset scenes)

1. At sunrise, the color temperature is 3,200 K.
2. The color temperature gradually reaches 4,800 K by noon.
3. From noon to sunset, color temperature gradually shifts to 3,200 K.

The installed lighting system is shown in Figure 11. Figure 12 shows the preset scenes that can be controlled by occupants to dim lighting.

Figure 11: Open Office Space With Upgraded Lighting

A picture of the cubicles and overhead lighting on the first floor, north wing office space at SCAQMD.

Source: Willdan Group

Figure 12: Scene Controller

A picture of the scene controller for the office space area.

Source: Willdan Group

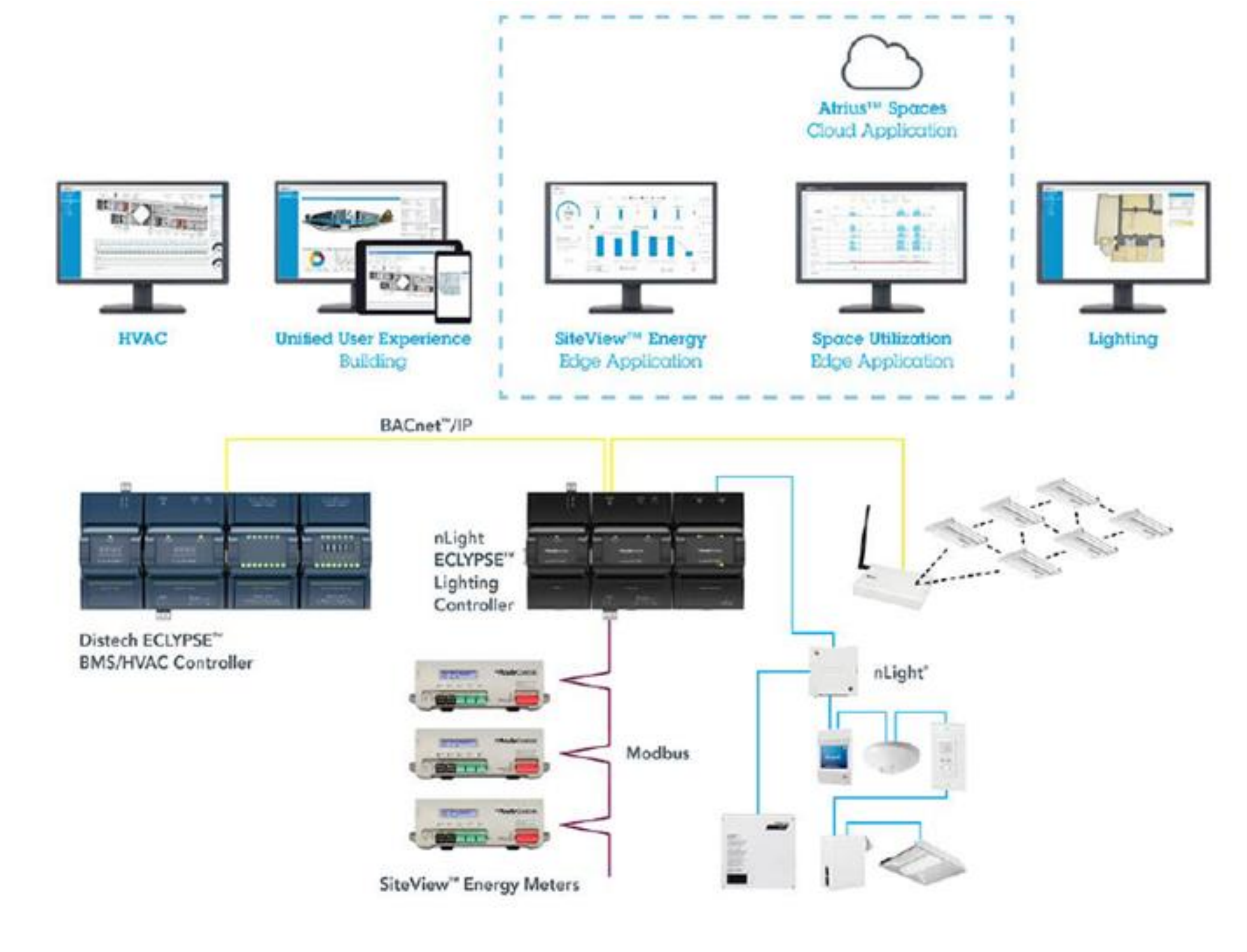
HVAC Integration

Required HVAC upgrades fell into two categories: zone-level upgrades and control-scheme changes.

1. **Zone-Level Upgrades:** All VAV boxes were converted from pneumatic to direct digital controls, including new electric damper actuators and hot-water valves. Existing air-flow sensors were also replaced to allow digital sensing of air flow. Thermostats were upgraded to direct-digital controls. This zone-level retrofit was tied into the existing Siemens building management system and allowed zone-level sensing, control, and visibility.
2. **Control Scheme Changes:** The sequence of operation for the AHU serving each space was modified to consider VAV box visibility and occupancy controls from the lighting-control system. Static pressure reset was implemented to allow the speed of the supply and return fans to be reduced based on the damper position of the VAV boxes and subsequent duct pressure. The static pressure reset takes precedence over the supply air-reset. Secondly, the project team implemented a supply-air temperature reset at the AHU for times when zones have low cooling requirements. Supply air temperature is raised only when the minimum static-pressure setpoint is reached. Each of the fixtures also has an integrated occupancy sensor. For every VAV box, the project team identified the light fixtures (and hence the occupancy sensors) in the same area of coverage. The occupancy-based lighting control signal feeds into the HVAC zone terminal box, which allows unoccupied airflow setbacks for spaces where the lighting has not been triggered by occupants.

The project team developed a sequence of operations, described in APPENDIX C. Given the existing Siemens building management system, SCAQMD’s strong preference to remain a Siemens-controlled facility, and the ability to tie other controls systems into a Siemens platform, the HVAC retrofit in the open cubicle office space was designed by Siemens. By integrating the nLight ECLYPSE™ and Siemens systems, further demand-response savings can be achieved in the future by raising temperature setpoints to predetermined values. However, given that the goal of this project was to demonstrate emerging technology and the forefront of integrated capability, the proposed design is a hybrid of Siemens technology and the Acuity nLight ECLYPSE™ platform. This is believed to be the first Design/nLight integration in California. Figure 13 shows how nLight controls interact with office equipment.

Figure 13: nLight Controls Architecture



A diagram showing the controls architecture of the nLight lighting system.

Source: Acuity Brands

Proposed Off-Grid Outdoor Lighting

Off-grid streetlights utilize a combination of solar, wind and storage to provide power to an LED fixture, with small solar and wind generators mounted on the same pole. This setup avoids the expensive trenching, conduit, and cable needed to add a small number of streetlights to an existing property, further made worse by paved parking lots and already complex siting on previously developed commercial properties (brownfields).

The project team initially considered off-grid solar and wind-powered pole-mounted LED lights. The red squares in Figure 14 show preferred locations: four in the outdoor patio behind the entrance, two in front of the main entrance, three in the middle of the parking lot, and one by the entrance road. Alternative locations are identified with blue stars.

Figure 14: Proposed Off-Grid Outdoor Lighting Locations

Image of an aerial view of a location that shows proposed Off-Grid Outdoor Lighting Locations.

Source: ARIS Wind and Google Earth

The project team worked with the Chicago-based company ARIS Wind. ARIS Wind designed the mockups in Figure 15 that show off-grid lights in the patio, as well as parking-lot lights with two LED fixtures. Four units in the patio include universal serial bus (USB) charging, where SCAQMD employees can charge small electronic devices like cell phones. The off-grid light poles have a 230 amp-hour battery in their bases, with 300-W wind turbines and 250-W solar panels. Each LED fixture is rated at 80 watts and must be turned on for 8 to 12 hours, depending on seasonal lighting.

With this configuration, a large portion of charging occurs during the sunny daytime, so intermittent wind throughout the day and night generally provides a larger portion of total energy to the unit. The battery is sized to provide power for 3 to 5 days with minimum generation, so a few days of inclement weather will not affect lighting output. The onboard controller charges and discharges the battery, connects to outside data collection, and has an onboard clock with sunrise and sunset schedules so that lighting levels can step up or down, further extending battery life.

Unfortunately, in February 2020, ARIS withdrew their planned expansion to offer their products in California (Figure 15). ARIS Wind is a relatively small startup and decided that the project was too small for them. The project team worked with ARIS for six months to find a solution but could not come to an agreement that was viable for ARIS, and the company ultimately decided against expanding its business into California.

Figure 15: ARIS Wind Mock-ups

Photo on the left: 3-D renderings of where ARIS Wind off grid lighting systems could be located.

Photo on the right: ARIS Wind Mock-Ups.

Source: ARIS Wind

Bundle 3: Advanced Lab/Critical Space

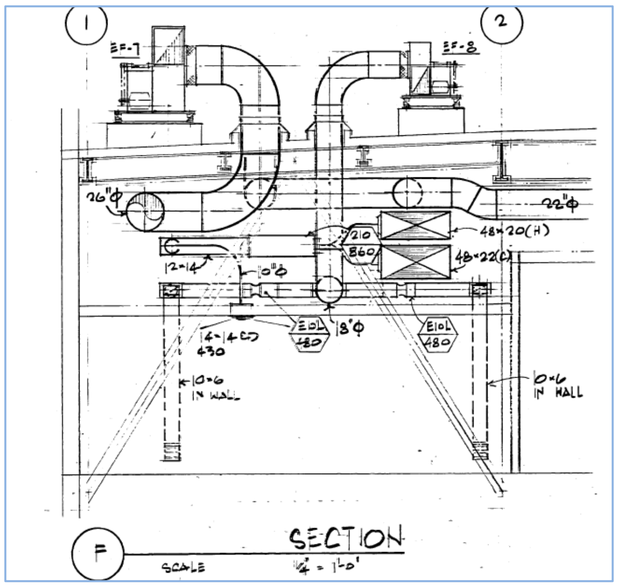
Bundle 3: Existing Fume Hoods and Lab Space

In most facilities, laboratory spaces operate in one of two ways: either positively or negatively pressurized. Traditional clean rooms, for example, are positively pressurized to ensure that outside contaminants are not able to enter the space. The laboratory facility at SCAQMD is negatively pressurized to ensure that chemicals are properly exhausted outside of the space. To achieve constant negative pressurization, exhaust fans run continuously, removing air through both fume hoods; the exhaust volume therefore exceeds the volume of supply air entering the space. The supply air is provided by AHU-1 and AHU-2, which operate continuously and exclusively serve the laboratory and laboratory basement areas. These AHUs provide 100-percent fresh air through dual-duct systems, have hot water preheat and hot-deck coils, and a chilled water cold-deck coil. The dual-duct system feeds constant-volume supply air boxes with 2-way pneumatic controls, allowing different ratios of hot or cold air, depending on the thermostat.

Constant volume exhaust fans are located on the roof and remove air from the space through a combination of fume hoods, exhaust air grilles built into the light fixtures, and other exhaust devices, including snorkels. The fume hoods have bypass air inlets, allowing the same volume of air to be removed from each fume hood, regardless of sash position. The laboratory therefore has continuous maximum ventilation regardless of either laboratory activities or fume hood sash positions. There is no unoccupied mode or setback. Exhaust fans have pneumatic actuators that close a damper on the roof if the fan is turned off; this precaution is to prevent unfiltered air from being pulled backwards through the non-operating exhaust fan by the negative pressure of the space.

Figure 16 shows the original laboratory fume hood exhaust configuration. Exhaust air from the fume hood entered the rectangular ductwork at the top of the fume hood. That ductwork passed above the ceiling, transitioned to round ductwork (including a Phoenix exhaust valve), then went through the roof to an exhaust fan. The Phoenix exhaust valves were all set to a specific flow rate and did not modulate. Each exhaust fan was served by several Phoenix exhaust valves, shown in Table 7.

Figure 16: Excerpt From Sheet M5.01



Drawing of a plant from an Excerpt from Sheet M5.01.

Source: SCAQMD As Built Drawings

Table 7: Exhaust Control Specifications and Configurations

Exhaust Control Valve Number	Exhaust Control Value Type	CFM	Drawing Number	Exhaust Fan Designation	Control Type
1	E10L	560	M4.05	EF-14	Other
2	E10L	500	M4.05	EF-14	Other
3	E10L	420	M4.05	EF-14	Other
4	E10L	360	M4.05	EF-14	Other
5	E10L	320	M4.05	EF-7	Other
6	E12L	760	M4.05	EF-4	Other
7	E12L	1130	M4.05	EF-4	Other
8	E12L	1250	M4.05	EF-4	Hood
9	E12L	920	M4.04	EF-4	Ceiling
10	E12L	1250	M4.04	EF-4	Hood

Exhaust Control Valve Number	Exhaust Control Value Type	CFM	Drawing Number	Exhaust Fan Designation	Control Type
11	E12L	1000	M4.04	EF-4	Other
12	E12L	920	M4.04	EF-4	Ceiling
13	E12L	1250	M4.04	EF-4	Hood
14	E12L	1200	M4.04	EF-4	Other
15	E12L	920	M4.04	EF-4	Ceiling
16	E12L	860	M4.04	EF-4	Other
17	E12L	960	M4.04	EF-8	Other
18	E10L	480	M4.04	EF-8	Other
19	E12L	1,250	M4.04	EF-8	Other
20	E12L	1,250	M4.04	EF-5	Hood
21	E210L	1,350	M4.04	EF-5	Ceiling
22	E212L	1,760	M4.04	EF-5	Ceiling
23	E212L	1,760	M4.04	EF-5	Ceiling
24	E12L	880	M4.04	EF-5	Ceiling
25	E10L	480	M4.04	EF-8	Other
26	E10L	480	M4.04	EF-8	Other
27	E12L	1,100	M4.04	EF-7	Other
28	E210L	1,380	M4.04	EF-7	Other
29	E210L	1,380	M4.04	EF-7	Ceiling
30	E210L	1,380	M4.04	EF-7	Ceiling
31	E210L	1,330	M4.03	EF-7	Hood
32	E12L	1,250	M4.03	EF-13	Hood
33	E12L	1,250	M4.03	EF-13	Hood
34	E6L	100	M4.03	EF-14	Ceiling
35	E210L	1,320	M4.03	EF-14	Ceiling
36	E212L	1,760	M4.03	EF-14	Ceiling
37	E210L	1,320	M4.03	EF-14	Ceiling
38	E10L	400	M4.03	EF-14	Other
39	E12L	1,250	M4.03	EF-15	Hood
40	E12L	1,250	M4.03	EF-17	Hood
41	E12L	1,250	M4.03	EF-17	Hood
42	E12L	920	M4.03	EF-14	Ceiling
43	E10L	150	M4.03	EF-14	Other
44	E12L	1,250	M4.03	EF-17	Hood
45	E12L	1,250	M4.03	EF-17	Hood
46	E12L	1,250	M4.03	EF-17	Hood
47	E12L	1,250	M4.03	EF-16	Hood
48	E12L	1,250	M4.03	EF-16	Hood
49	E12L	1,250	M4.03	EF-16	Hood
50	E12L	1,250	M4.03	EF-16	Hood
51	E10L	150	M4.03	EF-17	Other
52	E10L	150	M4.03	EF-17	Other
53	E12L	1,250	M4.03	EF-15	Hood

Source: SCAQMD As-Built Drawings

Each of the fume hoods has a Phoenix controller mounted to the outside face of the fume hood. Only some of these controllers had lit status lights, indicating that many of them were not functional. These controllers did not modulate flow with either sash position or occupancy. They did have an emergency indicator for low-flow and emergency exhaust but were not tested during site inspection given that they were going to be replaced as part of this project. Figure 17 shows a sample of a fume hood area in the laboratory and a close-up of its existing control panel.

Figure 17: Fume Hoods and Existing Fume Hood Phoenix Controls

Photo on the left: Fume Hoods and Existing Fume Hood Phoenix Controls.

Photo on the right: A photograph of a fume hood area in the laboratory and a close-up of its existing control panel.

Source: Willdan Group

Existing Lighting

Laboratory lighting is controlled by manual wall switches and scheduled by the lighting-control system, with limited access to changes by SCAQMD facility members. Some fixtures do not turn off as part of the building's emergency lighting circuits; these fixtures are served by a backup generator when required. There are 15 rows of 15 lighting fixtures for a total of 225 fixtures with two 4-foot T8 32-W fluorescent lamps. Peak demand for these fixtures is 14.4 kW when they are all illuminated, and they consume 44,928 kWh annually based on typical hours of operation. Natural lighting is provided by sawtooth skylights, which block direct solar radiation and reflect light through the north-facing window, and a row of windows on the north wall. Figure 18 shows the natural light from the saw tooth skylights side by side with the linear fluorescent lighting.

Figure 18: Existing Laboratory Lighting

Example image of a linear fluorescent lighting indoors.

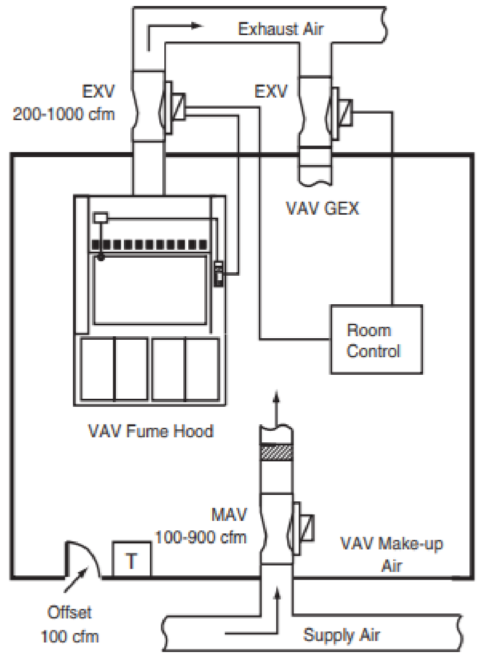
Source: Willdan Group

Bundle 3: Project Approach

There are two key features of a properly retrofitted advanced laboratory exhaust system: lower energy costs and adequate safety measures. The laboratory air-change rate dropped from 12 air changes per hour to as low as four air changes per hour because of this project, delivering significant fan energy savings from the supply fans.

The project team modified the laboratory ventilation system and fume-hood controls to reduce ventilation rates and fan motor energy use. As Figure 19 illustrates, a variable-volume lab requires control valves in the ducts of general exhaust, fume-hood exhaust, and the supply system. The three control valves work together to control space pressurization.

Figure 19: Variable Volume Laboratory Schematic



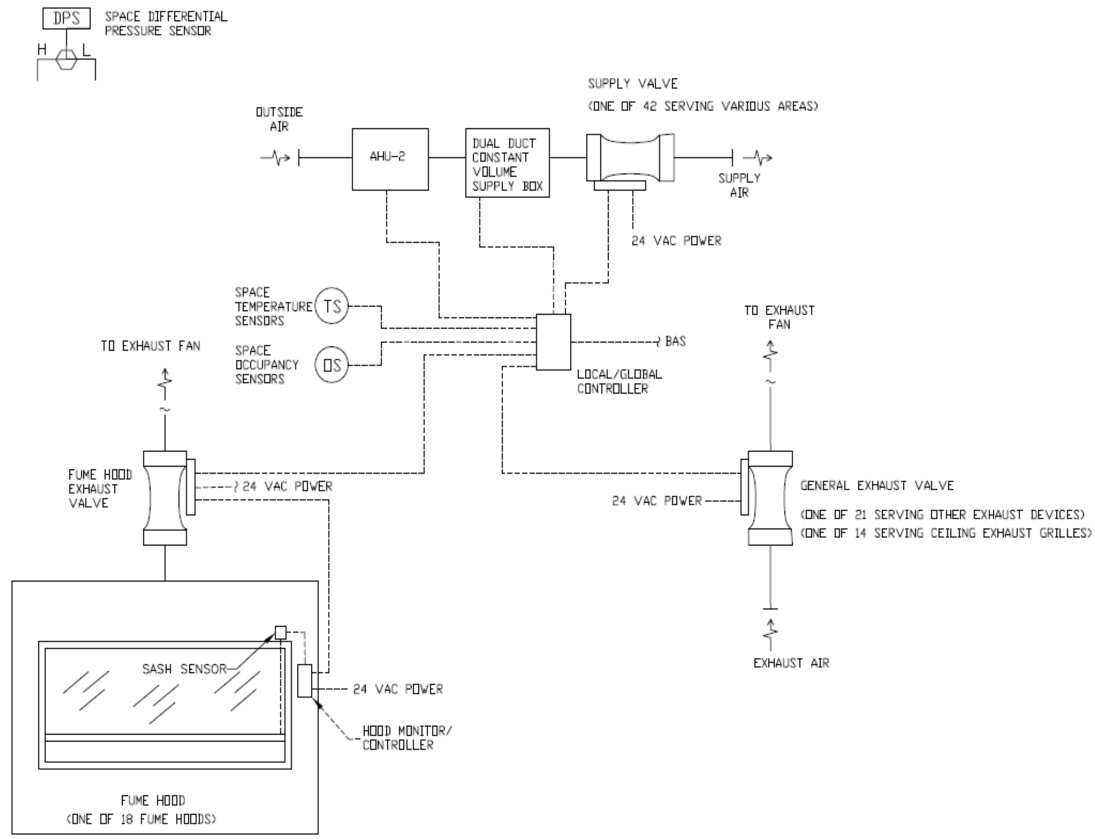
An image of a schematic drawing of Variable Volume Laboratory.

Source: Phoenix controls

A sequence of operations is included within the laboratory design drawings in APPENDIX A, as well as a list of each of the control valves and their minimum flow values. AccuValve (see cut sheet in APPENDIX D) was selected based on its low pressure-drop characteristics, quick response time, low noise profile, and ease in programming and calibration.

Further dynamic control of the laboratory environment was achieved using occupancy sensors at each fume hood. When not occupied, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) guidelines allow for a face velocity setback; instead of maintaining 100-feet per minute at the sash opening, the flow can be reduced to 60-feet per minute. This allows for further supply-air reductions.

Figure 20: Control Valve and Fume Hood Integration



Drawing of Control Valve and Fume Hood Integration.

Source: Willdan Group

The original proposed scope of work for the laboratory space included a full variable speed airflow retrofit including airflow valves in front of terminal mixing boxes on the existing dual-duct constant air-volume (CAV) system and variable frequency drives on the constant-speed exhaust fans. The primary change in the installed solution was the exhaust fans, which were not retrofitted with variable frequency drives but instead equipped with exhaust-air bypass dampers. This is because the overall anticipated change in exhaust was relatively negligible in comparison with the overall capacity of the exhaust fans. A change of less than 10 percent of the overall volume means that this would be an inappropriate use of a variable frequency drive. The system architecture allows for the operation of rooms with supply air and general exhaust air as well as rooms with supply, general exhaust, and fume-hood exhaust air requirements. AHU-2 had an existing fan wall system that only maintained the airflow necessary to maintain constant static pressure in both decks. For rooms with movable fume hood sashes, the position of the fume hood sash drives room airflow.

Table 8 provides a list of standards that dictate recommended air changes per hour.

Table 8: Air Change Rate Guidance

Standard/Guideline	Current Recommendation Info	Recommended Air-Change Rate
ANSI/AIHA Z9.5-2012	Standard for Laboratory Ventilation	The specific room ventilation rate shall be established or agreed-upon by the owner or his/her designee
NFPA-45-2019	Standard for Fires in Laboratories Handling Chemicals	Minimum 4 air changes per hour unoccupied, "typically greater than 8 air changes per hour" occupied
ACGIH Ind. Vent 30th Ed., 2019	Industrial Ventilation Manual	The required ventilation depends on the generation rate and toxicity of the contaminants – not on the size of the room in which it occurs
ASHRAE Laboratory Design Guide: Planning and Operation of Laboratory HVAC Systems, 2nd Ed., 2015	Planning and Operation of Laboratory HVAC Systems	4-12 air changes per hour
OSHA 29 CFR Part 1910-1450	Occupational exposure to hazardous chemicals in laboratories	4-12 air changes per hour

Source: Willdan Group

The implemented laboratory controls adjust airflow to as low as four air changes per hour in the open laboratory based on a determination by SCAQMD personnel that the laboratory chemicals were on the low end of all standards of concentration and volume referenced in Table 7.

To maintain safe fume-hood face velocities of between 80 feet and 100 feet per minute, the airflow volume increases when a fume hood sash is opened. This action then drives the modulation of the general exhaust airflow valve and the supply air valve. Further dynamic control of the laboratory environment was achieved using occupancy sensors at each fume hood. When not occupied, ASHRAE guidelines allow face velocity setbacks; instead of maintaining 100 feet per minute at the sash opening, the flow can be reduced to 60 feet per minute, allowing further supply-air reductions.

AccuValve airflow valves were installed in front of the CAV mixing boxes so that the mixing box controls supply the air temperature and the valves control air volume. Accutrol AccuValve valves were selected for their low-pressure drop characteristics, quick response times, low noise profiles, and ease of programming and calibration.

Figure 21 shows a close-up of the interior of an Accutrol AccuValve.

Figure 21: AccuValve

Image of an AccuValve with a hand of a person holding it.

Source: Willdan Group

The new laboratory airflow design schedule allows reduced airflows without negative impacts on either safety or comfort. The AccuValve lab controller totals required airflows and provides the lab AHU-2 supply fan wall to modulate both fan speeds and the hot and cold deck dampers to maintain static pressure setpoints in the ducts. The resulting control allows the AHU-2 fan wall to achieve much lower airflow while maintaining ventilation safety and compliance in the laboratory. Figure 22 shows a schematic drawing of the new laboratory exhaust and controls configuration.

While under construction, it was discovered that the existing CAV mixing box damper actuators and interior walls were damaged on many of the boxes. PRICE DDS mixing boxes were installed at all locations in the lab.

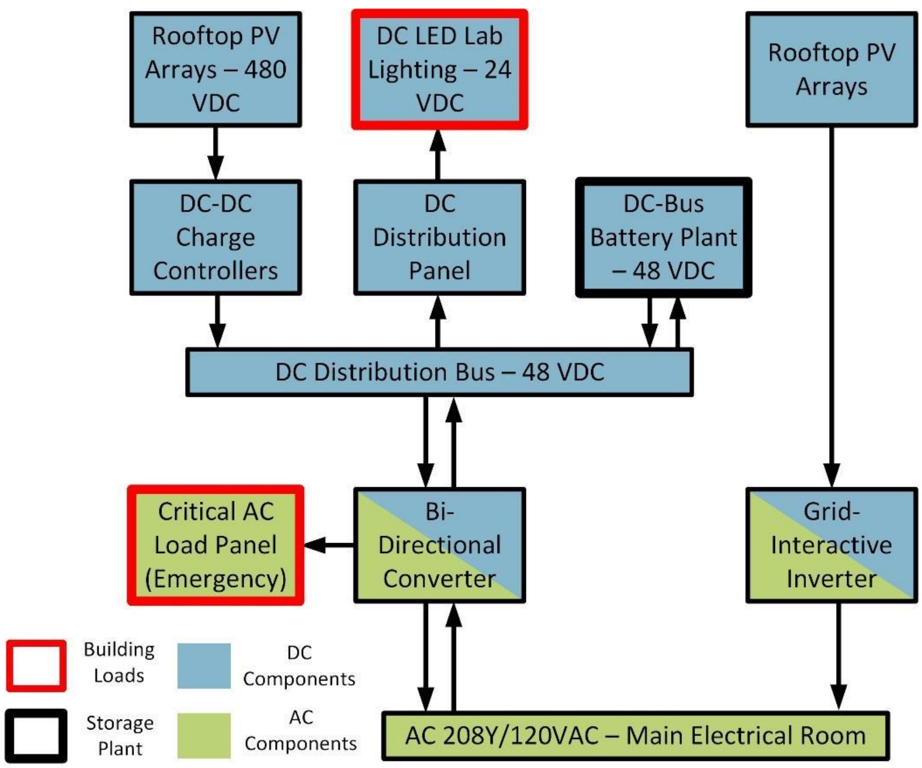
Each of the zones served by AHU-2 is controlled by a single controller, known as the laboratory controller. These controllers tie the individual fume-hood controllers together with the supply and exhaust control valves. The laboratory controller is Distech, an open-protocol platform that effectively integrates with AccuValve valves. The laboratory controller was integrated back into the Siemens building-management system to provide the SCAQMD facility's staff with full visibility of the laboratory. Upon loss of communication with the front end, the system continues to operate in stand-alone mode, a critical characteristic given the critical nature of the space.

DC Lighting

Existing fixtures along the perimeter of the laboratory space were replaced with advanced DC LED fixtures fed from an inverter, 18.5 kWh of batteries and the solar carport located on the top floor of the parking structure. With sufficient sunlight, the lights in the laboratory are powered directly from the PV-solar arrays. The benefits of this system include redundant power for the laboratory lighting and energy savings by avoiding significant losses during the DC-to-AC conversion. This PV integration is a primary and critical step toward zero-net-energy (ZNE) status for the building in support of California's ambitious ZNE goals.

Direct-current powered lighting relies on DC-driven LED fixtures, DC power generated by PV, a DC-to-DC converter that steps the voltage from the solar down from typical 480 V DC to 48 or 24 V DC, and a controller capable of regulating power flows to various DC circuits. The lighting can also rely on a battery to provide DC storage and power to the light fixtures when the sun is not shining. The system also contains a bidirectional AC-to-DC inverter to provide a path for excess DC power generated by PV, or to feed AC grid power back to charge the battery or operate the LED lights if DC power is unavailable. Figure 22 shows a schematic of the system.

Figure 22: DC Laboratory Lighting Block Diagram



Schematic diagram of the DC lighting system.

Source: Willdan Group

CHAPTER 3: Project Results

Project results were determined primarily by the measurement and verification (M&V) of energy savings. ASWB Engineering – an independent third-party M&V provider – created an energy savings M&V plan consistent with the most recent (2007) International Performance Measurement and Verification Protocol (IPMVP). The plan includes verification of energy savings and achieved benefits through a combination of methods:

- **Deemed:** Savings based on installed equipment specifications and values for operating hours, computed from utility data
- **IPMVP Option A:** Single-parameter measurements
- **IPMVP Option B:** System-level, short-term monitoring; proposed 3-months of trending, correlated with outdoor air temperature; or some other independent variable.
- **IPMVP Option C:** Utility bill comparison, used only for demand shave/response measures.
- **IPMVP Option D:** Whole-building energy simulation, calibrated with utility data, equipment specifications, spot- and short-term measurements, and normalized weather data.

The project team simulated the building baseline and post-implementation energy use with eQuest, a whole-building energy simulation model approved by the U.S. Department of Energy. Measurements and utility data calibrated the model to verify achieved energy savings. This method validated data and information that will be critical to projects at other commercial facilities. Table 9 displays the data collected and M&V method used to determine the baseline and post-implementation results for each technology bundle.

Table 9: Baseline and Post-Implementation M&V Overview

Bundle	Installed Measure	IPMVP Option	Data Collected / Methodology
Bundle 1: Advanced Chilled Water Plant	Chilled Water Plant Upgrade	Option B/D	Baseline: Used trend data from the existing building management system (controls and reports on cooling load, chiller sequencing, chilled- and condenser-water temperature, and so on) and existing nameplate data and specifications to calibrate the whole-building energy simulation model. Post: Updated the model with post-installation building management

Bundle	Installed Measure	IPMVP Option	Data Collected / Methodology
			system trend data and installed equipment specifications.
Bundle 2: Office and External Space	LED Lighting Retrofits and Controls	Option A	Baseline: Used lighting wattage from fixture count in electrical drawings and utility-accepted fixture wattage tables. Used operating profile and burn hours from sample logging of lighting panel amperage. Post: Based installed wattage on lighting contractor's as-built lighting audit and installed fixture specifications. Logging of lighting panel amperage verified the post condition.
Bundle 2: Office and External Space	HVAC Zone Building Management System Controls	Option B/D	Baseline: Calibrated the whole-building energy simulation model with trending data for air-side supply air temperatures and supply fan motor speed. Post: Performed the same trends.
Bundle 3: Advanced Laboratory/ Critical Space	Laboratory Exhaust Upgrades	Option B/D	Baseline: Used building management system trend data for laboratory supply fan supply air temperatures, variable frequency drive speeds, and cubic feet per minute (CFM). Post: Updated model with the same building management system trend data as above.
Bundle 3: Advanced Laboratory/ Critical Space	Laboratory LED DC Lighting Retrofits & Controls	Option A	Baseline: Used lighting wattage from fixture count in electrical drawings and utility-accepted fixture wattage tables. Used burn hours (profile) from logging of laboratory lighting panel amperage. Post: Based installed wattage on lighting contractor's as-built lighting audit and installed fixture specifications. Monitored the lighting Laboratory lighting panel and the DC circuit feed from the PV array to verify post-implementation, grid-connected power usage.

Source: Willdan Group

The project team independently verified and reported savings for each measure to provide more granular and specific results. A whole-building metering method would have only provided aggregated results for all measures combined. The project team added individual measures to the whole-building simulation to fully account for interactive impacts between the measures. Post-implementation results were reviewed in the whole-building simulation model (as either different scenarios or parametric runs), and inputs were updated based on verified, installed equipment specifications and measurements. The baseline and post-implementation data points acquired for this project are shown in Table 10.

Table 10: Data Points Collected in Measurement and Verification

Measure	Equipment / Location	Data Point	Logger Type	Unit	Duration; Interval
All	Outdoor Conditions	Outdoor Air Temperature	building management system	°F (dry bulb)	1 month; 15 minutes
Advanced Chilled Water Plant	Chiller-1, Chiller-2	% Full Load Amps	building management system	% Full Load Amps	1 month; 15 minutes
Advanced Chilled Water Plant	Chilled Water Loop	Supply and Return Chilled-Water Temperatures	building management system	°F	3-4 weeks; 15 minutes
Advanced Chilled Water Plant	Chilled Water Loop	Cooling Loop Flow	ultrasonic flow meter	GPM	3-4 weeks; 15 minutes
Advanced Chilled Water Plant	Primary Chilled Water Pumps (x2)	Spot kW Readings *(Baseline Only)*	3-phase power logger	kW	Spot Readings Only
Advanced Chilled Water Plant	Chilled Water Pumps (x2)	Pump Variable Frequency Drive Operating Speed	building management system	% Speed or Hz	1 month; 15 minutes
Advanced Chilled Water Plant	Cooling Towers (x4 Cells)	Tower Fan Variable Frequency Drive Operating Speed	building management system	% Speed or Hz	1 month; 15 minutes
Advanced Chilled Water Plant	Condenser Water Loop	Supply and Return Condenser Water Temperatures	building management system	°F	1 month; 15 minutes
Advanced Chilled Water Plant	Whole Plant	Net Plant Energy *(Post Only)*	Veris meter	kW	Permanent Meter
Laboratory Exhaust Upgrade	AHU-1 Supply Fan (Lower Level)	Supply Fan Variable Frequency Drive Operating Speed	building management system	Percent Speed or Hz	1 month; 15 minutes
Laboratory Exhaust Upgrade	AHU-1 Supply Fan (Lower Level)	Supply Air CFM	building management system	CFM	1 month; 15 minutes
Laboratory Exhaust Upgrade	AHU-2 Supply Fan (Main Laboratory)	Supply Fan Variable Frequency	building management system	Percent Speed or Hz	1 month; 15 minutes

Measure	Equipment / Location	Data Point	Logger Type	Unit	Duration; Interval
		Drive Operating speed			
Laboratory Exhaust Upgrade	AHU-2 Supply Fan (Main Laboratory)	Supply Air CFM	building management system	CFM	1 month; 15 minutes
Laboratory Exhaust Upgrade	Laboratory Exhaust Fans (x6)	Pre and Post Spot kW readings	3-phase power logger	kW	Spot Readings Only
Laboratory DC Lighting Upgrade	Laboratory Lighting Panel	Amperage *(Baseline Only)*	HOBO logger with current transformer	Amps	1 month; 15 minutes
Laboratory DC Lighting Upgrade	Laboratory Lighting Panel	Spot Power Reading	3-phase power logger	V, PF, Watts	Spot Readings Only
Laboratory DC Lighting Upgrade	Bi-Directional Inverter/Main Electrical	Power from Solar Array to LED Lighting DC Bus *(Post Only)*	HOBO logger with current transformer (DC)	kW	1 month; 15 minutes
Laboratory DC Lighting Upgrade	Bi-Directional Inverter/Main Electrical	AC Power from AC grid to Bi-Directional Inverter *(Post Only)*	bi-directional inverter	kW	1 month; 15 minutes
Office LED Lighting and Controls	Office Lighting Panels (3 of 8 floors)	Input Amperage	HOBO logger with current transformer	Amps	1 month; 15 minutes
Office LED Lighting and Controls	Office Lighting Panels (3 of 8 floors)	Spot kW Readings	3-phase power logger	V, PF, Watts	Pre- and Post-Install Spot Readings
Office HVAC Controls	Office AHUs (approximately 5 of 10)	Supply Air Temperature	building management system	°F	1 month; 15 minutes
Office HVAC Controls	Office AHUs (approximately 5 of 10)	Static Pressure	building management system	Inches of water column	1 month; 15 minutes
Office HVAC Controls	Office AHUs (approximately 5 of 10)	Fan Variable Frequency Drive Operating Speed	building management system	% Speed or Hz	1 month; 15 minutes

Source: Willdan Group

Bundle 1: Advanced Chilled Water Plant

The new central plant was commissioned several months in late 2020 and optimized for maximum efficiency. Figure 23 shows the average chiller operation profile in the new plant over a full week.

Figure 23: Operation Profile for Chiller-1 and Chiller-2, Combined by Day

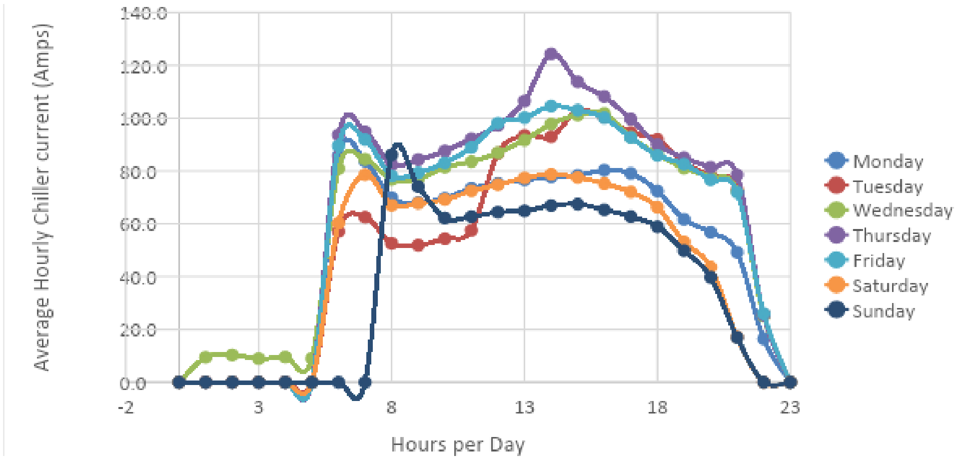


Image of a plot graph for the Operation Profile for Chiller 1 and Chiller 2, combined by Day.

Source: SCAQMD Siemens Desigo Data Collection

The chillers operated on a nighttime shutdown schedule when the building was unoccupied. The combined chiller current initially peaked in the morning when the central plant was started up, and again in the middle and warmest part of the day when the building was fully occupied. The cooling load dropped on unoccupied days (Saturday, Sunday, and Monday).

The chilled water supply temperature data collected during the trend period was averaged by day, as seen in Figure 24.

Figure 24: Chiller-1 Average Hourly Chilled-Water Supply Temperature, by Day

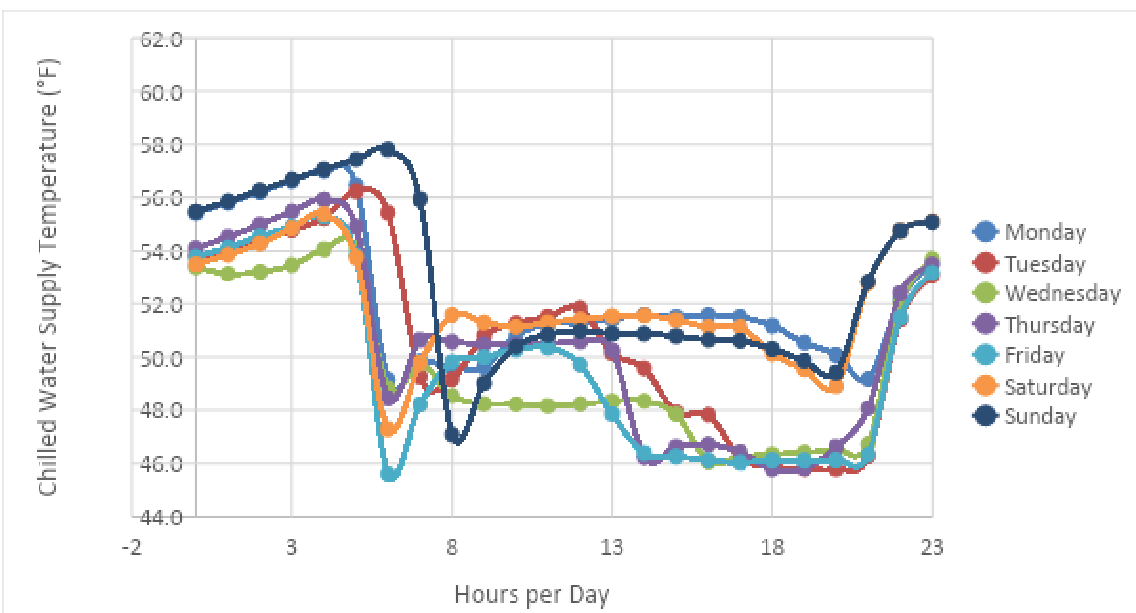


Image of a plot graph that shows the Chiller 1 average Hourly Chilled Water Supply Temperature by Day.

Source: SCAQMD Siemens Desigo Data Collection

When the central chilled water plant turned on early in the morning, the chilled water supply temperature for Chiller-1 dropped down to meet the 46°F (8°C) setpoint. As building occupation increased, the AHUs started up and the chilled water supply temperature increased. The chilled water supply temperature typically dropped back down to the setpoint in the afternoons, as cooling loads settled. The chilled water supply temperature was as high as 51°F (11°C) on weekends when there was very little load on the system. A similar curve appears in the data for Chiller-2.

The eQuest model was updated with a new chiller operating schedule and equipment control sequence, based on the M&V data shown in Figure 25 and Figure 26.

The cooling load was calculated based on the chilled water temperature differential and the secondary loop chilled water flow rate. The project team used the building cooling load from the M&V data to help calibrate the eQuest model. The calibrated model cooling load calculated from the M&V data is shown in Figure 26.

Figure 25: Central Plant Average Hourly Cooling Load, by Day

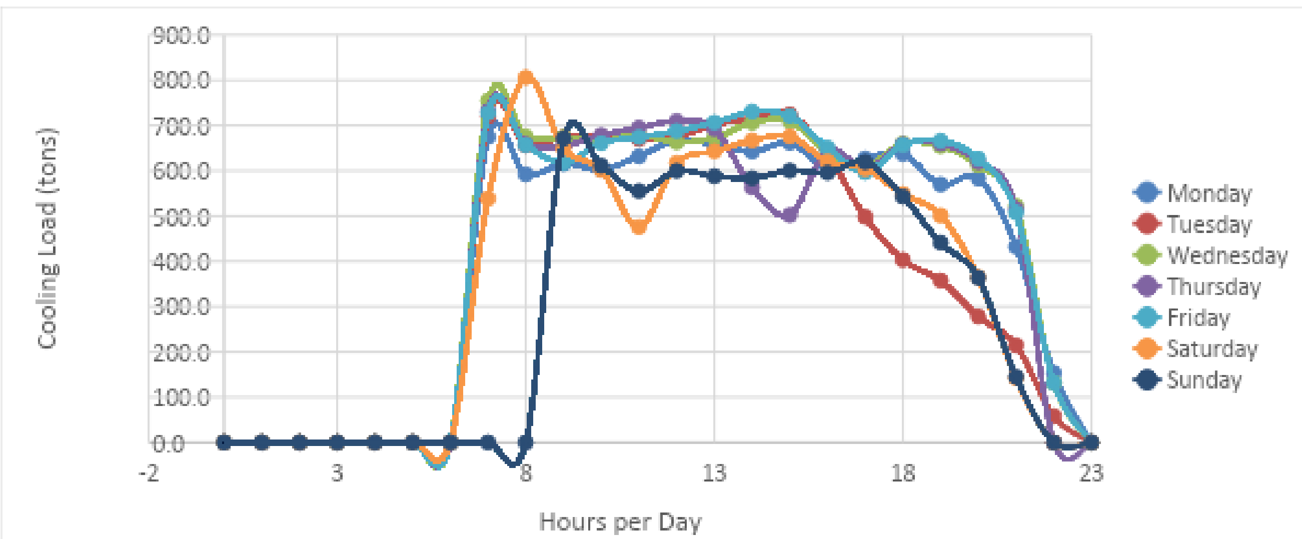


Image of a plot graph that depicts the central Plant Average Hourly Cooling Load by Day.

Source: Willdan Group eQuest model

Figure 25 shows that the central plant cooling load profile remained relatively constant for each day of the week. The load peaked when the plant started up in the morning to compensate for overnight temperature changes when the plant was shut down. The cooling load was used to update the central plant operating parameters in the eQuest model.

The cooling tower fan-speed data showed that cooling tower fans operated at full speed any time they were engaged. The data for Chiller-1's condenser water supply temperature is shown in Figure 26.

Figure 26: Chiller-1 Average Hourly Condenser Water Supply Temperature, by Day

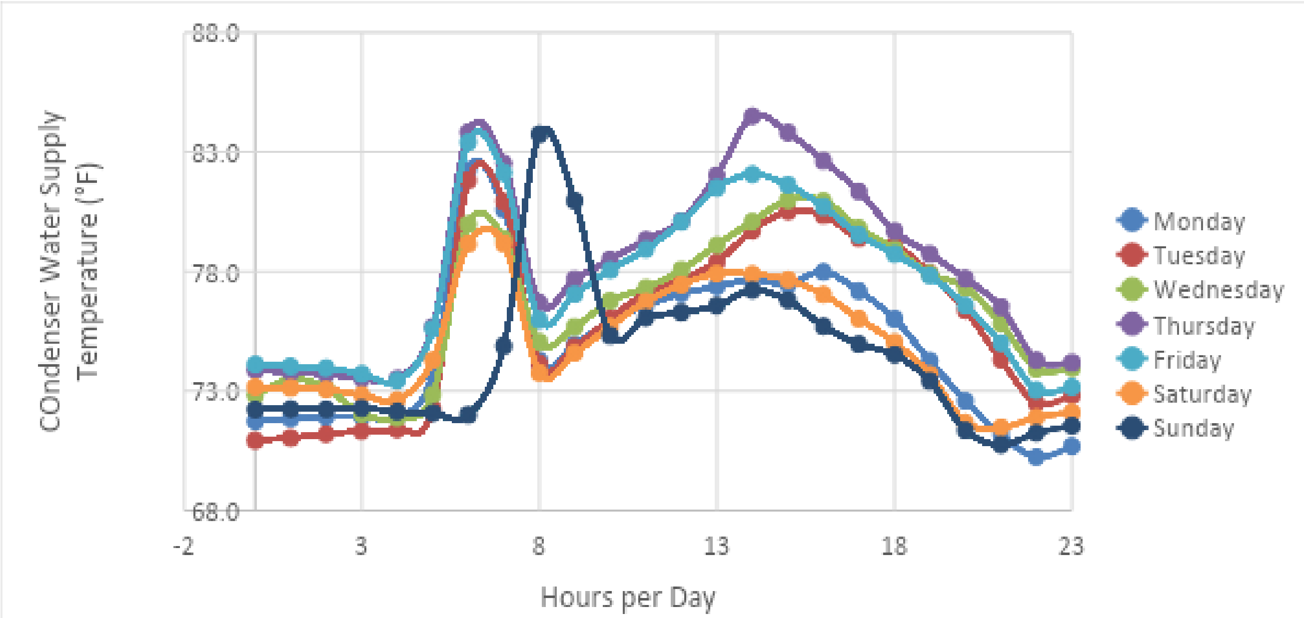


Image of a plot graph that shows the Chiller 1 Average Hourly Condenser Water Supply Temperature by Day.

Source: SCAQMD Siemens Design Data

The initial condenser water supply temperature peak occurred when the chillers turned on and the system came into thermal equilibrium. The condenser water-supply temperature dropped to about a 75°F (24°C) setpoint. As the building occupancy increased and the load on the chiller increased, so did the condenser water-supply temperature.

Overall, this bundle provided the following results:

- Total energy savings of 819,522 kWh and 237 kW
- Cost of $4.5 million (within budget)
- Simple payback of 34 years

Revisions for COVID-19 Low Occupancy Considerations

Reduced occupancy during COVID-19 reduced the total load on the chillers because spaces required conditioning less often. To fairly determine the energy savings of the new central plant, the project team modeled the system as though the normal baseline load had not changed. The eQuest model post-implementation parametric run for this measure was updated to only reflect the newly installed equipment specifications (such as the chillers, pumps, and cooling towers) and verified program control strategies. These strategies included:

- Chiller sequencing.
- Chilled water supply-temperature reset control.
- Condenser water-supply resets and tower fan control.
- Chilled water pumping programmed minimum operating setpoints, programmed differential pressure setpoints, and resets.

The verified specifications and strategies in the model simulated chilled water plant performance at full-occupancy cooling loads, even though full occupancy loads were not seen during the trending period.

Lessons Learned

1. **Less Reduction in Cooling Load than Anticipated:** Despite reduced facility occupancy during the COVID-19 pandemic, the cooling load did not decrease as much as expected because of the existing configuration of the pneumatic air handling systems on most of the office floors. These systems did not have occupancy sensors and, while staff implemented some manual temperature setbacks, these floors were operated as though normal occupancy conditions applied. Some staff were on site, and the office spaces were continuously conditioned and comfortable. This is an important reminder that what ultimately drives the electric load of a facility – in this case, air handling on each of the floors – is as important as the equipment consuming that electricity. No matter how efficiently a new central plant operates, it cannot overcome air conditioning system inefficiencies.
2. **Aquatherm Material Selection and Design:** Several design considerations were made throughout the project that may be helpful for developers of similar projects. The outdoor Aquatherm condenser water piping required sheathing with a metallic pipe covering for added UV protection, which was not originally in the project scope. However, during installation, the Aquatherm product vendor recommended that exterior installations with high ultraviolet radiation exposure be sheathed to avoid degradation of the piping material over time. Future Aquatherm projects with direct sun exposure should be aware of and accommodate this recommendation.
3. **Cost Control:** The project budget for the central plant was originally developed in 2016. Increases in steel and labor costs from 2016 to 2019 were significant, resulting in substantially higher costs overall for Bundle 1. This cost increase posed a challenge for project execution because several amendments had to be made to accommodate the cost increase and necessitated decreasing the scope of the lighting retrofit. The project team recommended further study of pricing variability and volatility related to the execution of large energy-efficient construction projects.
4. **Refrigeration Monitoring and Testing:** A new refrigerant monitoring system was installed that detected potential leaks of R-1233zd(e). There were many challenges with ordering, installing, and testing this system due to both the relatively new refrigerant type and current market scarcity. This will become less challenging over time as low-GWP refrigerants become increasingly available but remains an important part of project planning that should not be overlooked.
5. **No Operational Changes With New Refrigerant:** SCAQMD experienced no change in operations from adopting the new refrigerant. While much has been written about the requirement to phase-in new refrigerates over time, the challenges are manufacturing, procurement, and market adoption rather than operational changes. While R-1233zd(e) was used to charge a new chiller, it could potentially be used as a drop-in replacement for existing equipment. End users should expect no operational changes from replacing refrigerant.

6. **Commissioning Time:** The chilled water plant took almost six months to commission. This is an unusually long time and can be attributed to: high turnover of controls contractor personnel, both technicians and project managers; uncertainty of onsite visits during the pandemic; inclusion of a new controls platform; and lack of clarity in contractor scope. While some of these challenges may be unique to this project, commissioning (and, specifically, commissioning of controls) should be treated as part of a project's critical path because of its importance in ensuring that systems operate as designed.
7. **Communication:** As with all projects, clear communication between the project team, the contractors, and building operations staff was critical to successful project completion. Given emerging technology, this included receiving design input from vendors to ensure that all components of the final project were considered.
8. **Local Authority Having Jurisdiction Code Adoption:** California's building codes should consider all available low-GWP refrigerants. While this project did experience minor challenges with permitting, most AHJs do not have the capacity to become experts in new technologies. While CARB's 2020 HFC rules have been rolled out, now may be the appropriate time to ensure that local governments are aware of these new, energy-efficient refrigerants.

Bundle 2: Office and External Space

Lighting

The facility retrofitted interior fluorescent lighting from T12 to T8 lamps more than 10 years ago. Most fixtures prior to the retrofit were 2'x4' two-lamp fixtures with normal output ballasts and reduced-wattage F32 28-watt T8 lamps. This project upgraded lighting to LED, with advanced lighting controls.

Advanced lighting controls can harvest daylight, allow occupant control and dimming, and are auto-demand response (ADR) capable. Furthermore, Circadian CCT control was added to the system that changed color temperatures throughout the day. Circadian CCT is thought to improve the comfort of occupants and contribute to productivity by making it light bluer during midday and more yellow early in the morning and in the evenings.

The impact of this lighting upgrade was determined by modeling the lighting power density, which was based on lighting quantity and type within the space. The baseline was 1.1 watts/square foot, and the new lighting was modeled at 0.84 watts/square foot.

The overall impact of the lighting upgrade on total building consumption was relatively minor given that lighting accounted for about 19 percent of total energy consumption at this facility; the project impacted less than 10 percent, by square footage.

Revisions for COVID-19 Low-Occupancy Considerations

Consistent with the original design, lighting power density was calculated from verified, installed lighting fixture wattages and quantities, which were then used to update the eQuest parametric run. Direct measurement of lighting circuits showed disproportionate energy reduction because of the facility's low occupancy during COVID-19. Post-implementation lighting operating hours were reduced by a conservative value of 15 percent, based on the California Public Utilities Commission (CPUC) Database for Energy Efficiency Resources. If policies after COVID-19 reduce building occupancy rates and schedules, the baseline model will need to be updated to account for additional reductions to avoid over-counting energy savings from the project.

HVAC

VAV AHU systems served most of both office and external spaces. A few AHUs still had inlet cones instead of variable-frequency drives on supply and return fans. Some of these failed and were locked in a full, open position. A few AHUs had recently been retrofitted with fan walls containing variable-frequency drives, and there were plans to retrofit the remainder of the larger AHUs in a different initiative. The HVAC office retrofit impacted only the north wing of the first floor. This space was served by AHU-7, which had already been updated to direct digital controls. The original scope included:

- Retrofitting each of the VAV boxes with a motor to modulate the damper (as opposed to pneumatics).
- A new airflow sensor to measure VAV box airflow.
- A controls tie-in with the nLight ECLYPSE fixture occupancy sensor.

The project team executed this scope of work across the office space, but four VAV boxes had to be completely replaced due to leaking air seals around their dampers.

Each of the VAV zones was digitally tied to the occupancy sensors of the light fixtures in the same area. When zones were unoccupied for more than an hour, the temperature of the zone was permitted to float between 67°F (19°C) and 76°F (24°C). The VAV box also reduced airflow passing through it by slightly closing its damper. In turn, this indicated to the supply fan that less air was required in the space. When more than 5 of 20 zones were unoccupied, the temperature of the cold air leaving the AHU was permitted to increase because less cold air was required for air conditioning.

Figure 27 shows a typical day of AHU-7 operation post-retrofit as an example of how the retrofit affected AHU operation. This data is not weather normalized because the baseline data was measured in May 2018 and the new trends were taken in December 2021 so cannot be used directly for energy savings calculations. However, both sets of trend data were from a Monday when the site was closed. While differences in weather might have accounted for some of the differences in AHU-7 recorded trends, the weather could not account for all of the changes, which were significant. The baseline supply fan speed remained relatively constant throughout the day and appeared to run after hours. After the retrofit, the supply fan speed decreased to as low as 60 percent due to low occupancy. The supply air temperature also varied between the baseline, when it was maintained at 53°F (12°C) despite space occupancy, and post-retrofit, when the supply air temperature was allowed to rise above 60°F (16°C) when there were no calls to cool the space.

Figure 27: AHU-7 Operation Over 24 Hours

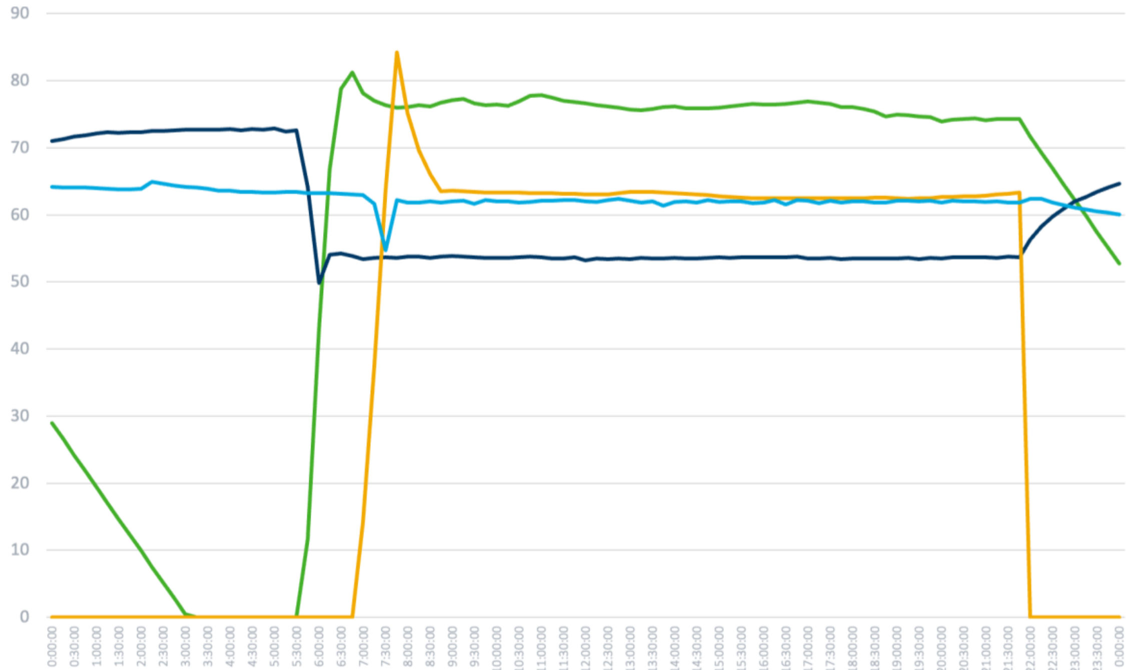


Image of a graph that has data on the AHU-7 Operation over 24 hours.

Source: SCAQMD Siemens n Data Collection

Overall, this bundle resulted in:

- Total energy savings of 53,412 kWh, 8 kW
- Cost of $947,868.
- Simple payback of 111 years.

Revisions for COVID-19 Low Occupancy Considerations

If these results were taken at face value during COVID-19, they would have overestimated energy savings for this project. The trends in Figure 27 are provided solely for demonstration purposes. HVAC energy savings were modeled assuming full occupancy. Database for Energy Efficiency Resources (DEER) lighting control savings assumed a factor of 15-percent reduction in unoccupied energy use for lighting occupancy controls. It was therefore assumed that 15 percent of the time during normal occupancy, HVAC-zone VAV boxes would be forced to the minimum position. This can apply to the model, using percentage airflow schedules for specific zones in eQuest.

Lessons Learned

1. **Integration:** As anticipated, the project team found it challenging to integrate the occupancy sensors integrated into the lighting system with the HVAC controls for AHU-

7. In the end, a manual process was required – a paper copy of the VAV box drawing was compared side by side with the lighting occupancy sensor drawing to identify which occupancy sensors were adequately proximate to the VAV box. The industry has not commonly accepted temperature setbacks conducted at a sub-AHU level, especially using a third-party vendor's occupancy sensors. This approach required significant explanation and discussion. Despite a sequence of operations that articulated the integration, the controls contractor was initially unconvinced that this integration could be successful. In the future, the project team recommends that a collaboration meeting take place between the lighting vendor and the controls contractor to ease some of these concerns and improve communications earlier in the project.

2. **Light Levels for Occupants:** We received many comments from occupants who work in the office space, mostly regarding light levels at their desks. The consensus was that dimmer was better – most preferred the 15fc "scene" given that they spent most of their time in front of illuminated computer screens. The 2021 International Energy Conservation Code is incorporated by reference into the California Mechanical Code and provides a range of 30-50fc for open office space, as does the Illumination Engineering Society of North America (IESNA). The scene control automatically defaults to the code-appropriate light levels, but during COVID there were many times when fewer than 5 staffers were working in the entire open office space; the team observed that they often overrode the scene control to the "low" (15fc) setting. There is clear conflict between the code requirement and occupant preference and comfort; this was resolved by providing occupants with a local, manual override.
3. **Circadian Controls:** The Circadian CCT was implemented successfully and demonstrated that very gradual lighting changes over time can be implemented without space occupants observing the change. This emerging technology has wide-ranging potential and requires further study regarding the efficacy of presumed behavioral comfort changes.
4. **Worthwhile Savings:** Based on the energy savings of occupancy sensor integration with VAV performance, we recommend the further dissemination and application of this control strategy at all office spaces, especially those that might already be scheduled for DDC upgrade.
5. **Implications for Pneumatic–to-DDC Conversions:** There are no available estimates of the number of buildings with pneumatic controls. In fact, pneumatic controls are still available for installation. While office spaces in California built to Title 24 standards can only meet code with digital controls, a significant building stock of older buildings with antiquated pneumatics provides significant opportunities for energy efficiency upgrades.

Bundle 3: Advanced Laboratory/Critical Space

This project required significant reduction of conditioned air volume flowing into the laboratory space from AHU-2. The project team accomplished this by reducing the amount of exhaust air rejected by the space and reducing supply air to match the exhaust air (with enough of an offset to maintain negative pressurization).

Figure 28 shows the total airflow volume in baseline M&V data from August 18, 2018, to October 2, 2018. Airflow from AHU-2 was generally greater than 46,500 cfm and peaked at 50,500 cfm.

Figure 28: Baseline AHU-2 Variable Frequency Drive, Total CFM

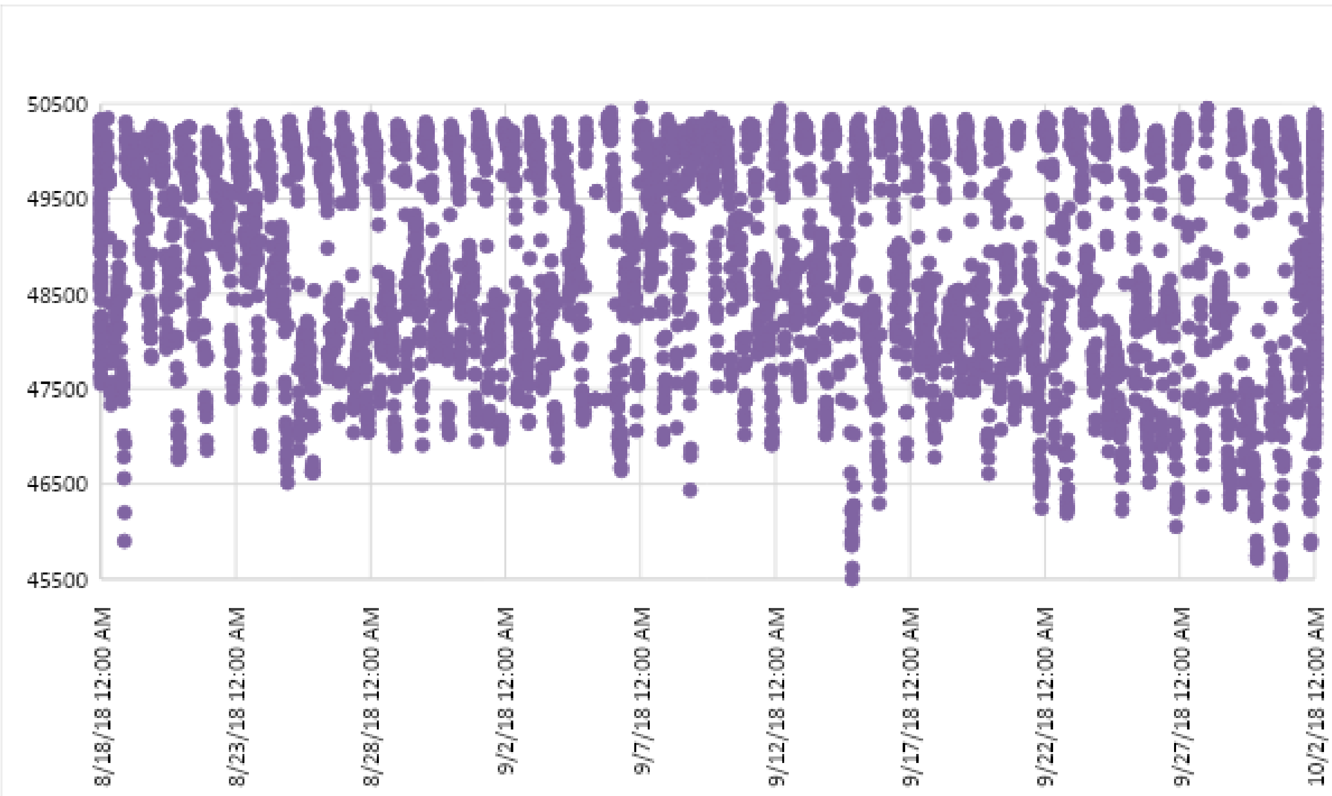


Image of a plot graph that shows the total airflow volume in baseline M&V data from August 18, 2018, to October 2, 2018, of AHU-2.

Source: SCAQMD AHU-2 Air Flow Monitoring Device

Figure 29 shows total airflow volume in post-implementation M&V data from October 31, 2020, to December 5, 2020. Most readings were below 25,500 CFM, almost 50-percent lower than the baseline.

Figure 29: Post-Implementation AHU-2 Variable Frequency Drive, Total CFM

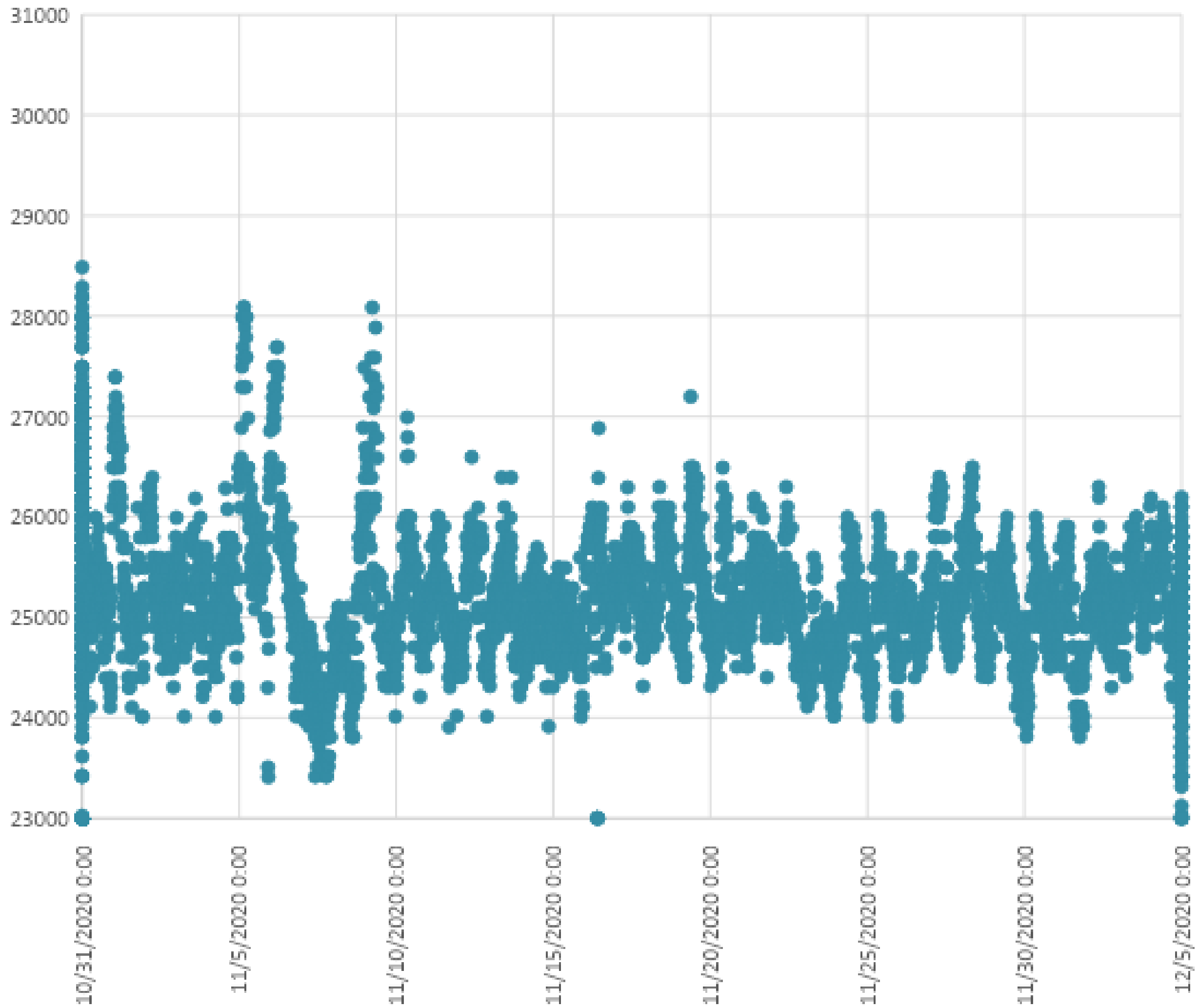


Image of a plot graph that shows the post implementation AHU-2 Variable Frequency Drive.

Source: SCAQMD AHU-2 Airflow Monitoring Device

Total air changes per hour were determined using the following equation:

Air Changes Per Hour = Volume of Supply Air (CFM) x 60 minutes/hour /Volume of Space

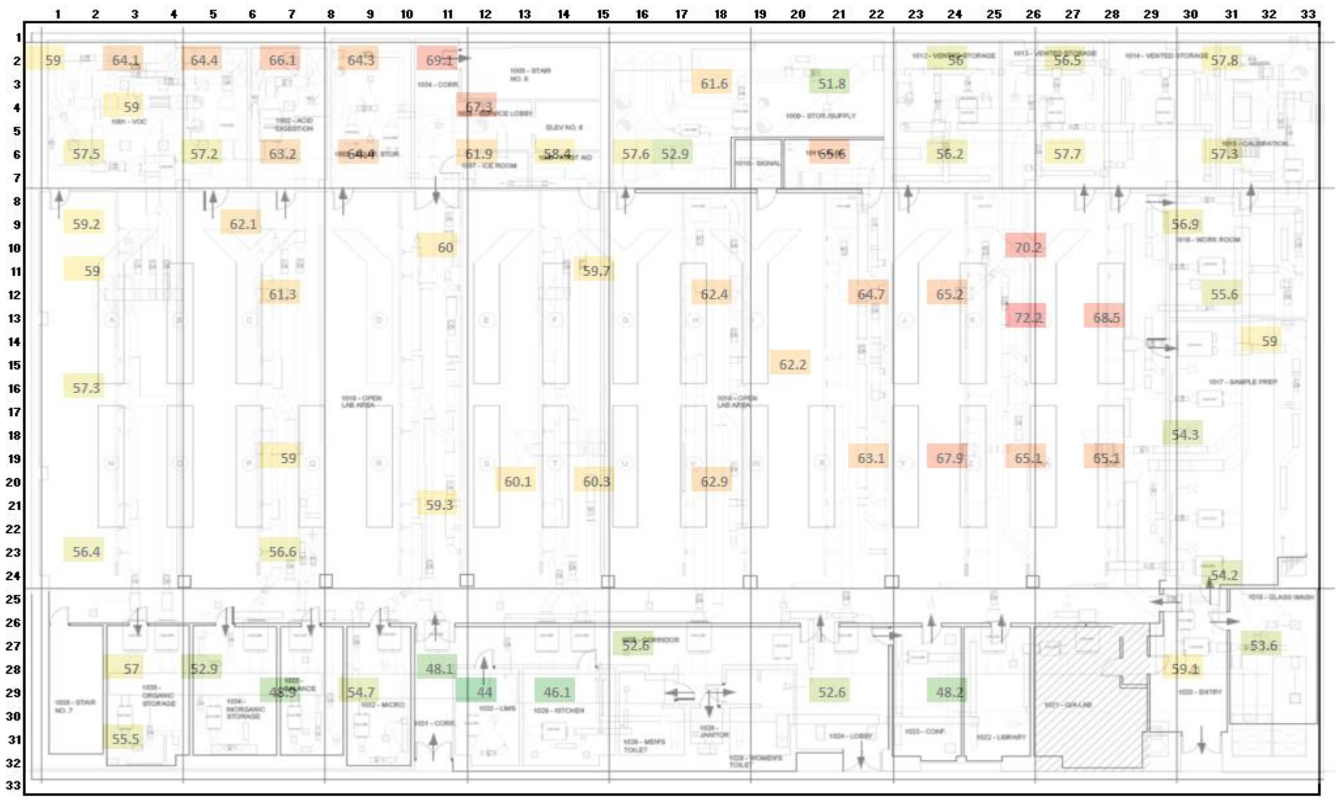
With 36 separate spaces in the laboratory, air changes per hour in each space were slightly different depending on the volume of supply air provided to that room and the volume of the space. Overall, the laboratory volume is 293,154 square feet. By reducing supply-fan volume by almost 50 percent, average air changes per hour decreased from 11 to just over 5. In the open lab space, the average air changes per hour fell as low as 4.2 during unoccupied hours.

Overall, this bundle resulted in:

- Total energy savings of 590,446 kWh, 38 kW
- Cost of $947,868.
- Simple payback of 10 years.

Less tangible benefits were also noted. Specifically, site staff noticed a dramatic reduction in ambient noise levels in the lab due to airflow reductions. The project team measured noise levels pre- and post-implementation and created heat maps for each. Figure 30 shows the baseline noise levels in decibels, measured across the laboratory. The median noise level for the space before project implementation was 59 decibels.

<u>Figure 30: Baseline Noise Levels</u>

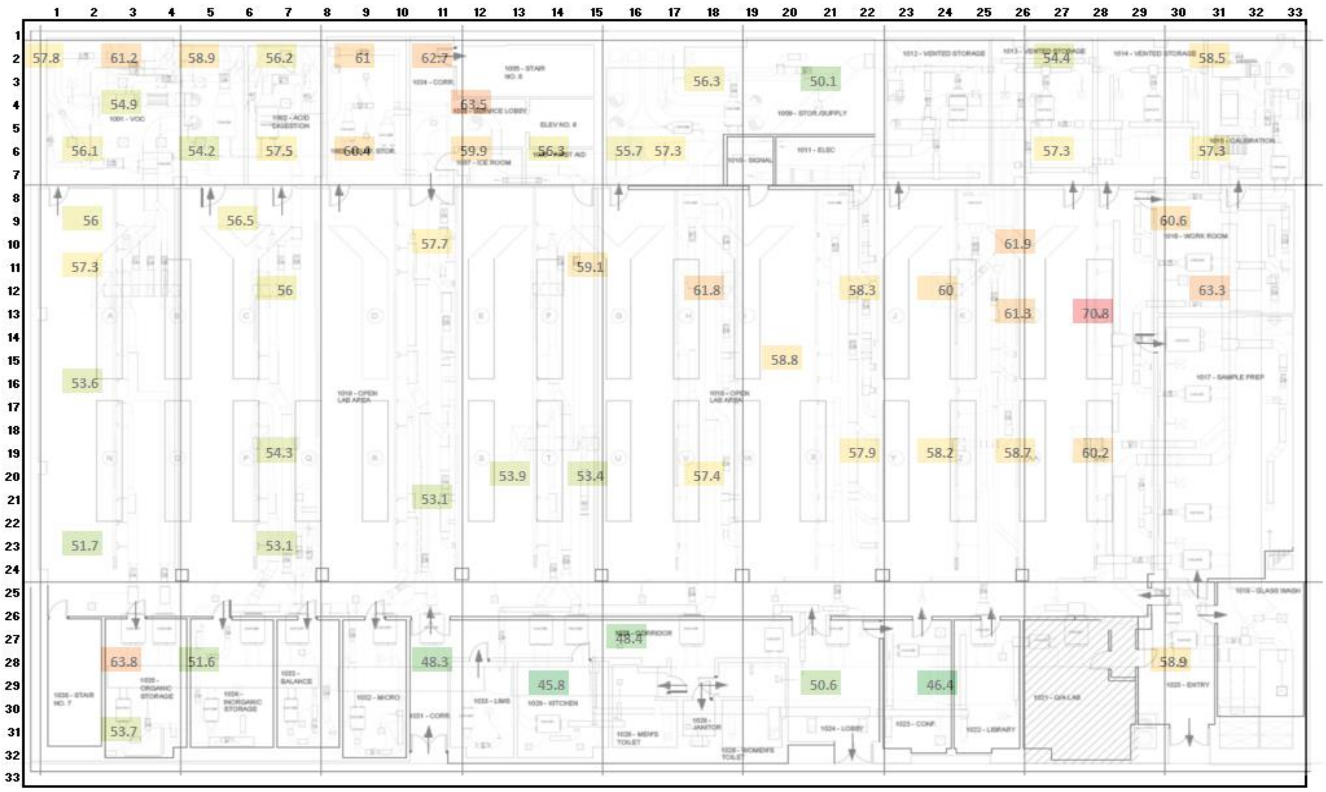


Heat map of the open laboratory environment with indications of decibel level ranging from 72.2 db to 44 db.

Source: Willdan Group

Figure 31 shows the noise levels after project implementation, measured across the laboratory. Some laboratories were inaccessible during the post-installation inspection.

Figure 31: Post-Installation Noise Levels



Heat map of the open laboratory environment with indications of decibel level ranging from 70.8 db to 45.8 db. Overall, fewer areas show high decibel levels.

Source: Willdan Group

The median noise level for the space after project implementation was 57 decibels (almost 3-percent lower than baseline).

DC Lighting

Direct current lighting replaced 31 existing figures in the lab's lobby, as well as in the adjacent corridor and an additional corridor in the space's interior. The new fixtures are 24 V DC and fed by a DC/DC LED driver from the carport's PV system via an 18.5 kWh battery located in the laboratory.

The system was deployed after nearly two years of attempting to enroll a qualified contractor, followed by additional significant delays due to equipment availability during the pandemic. This was compounded by a lack of available DC equipment; the lighting vendor assumed that its own fixtures would be customized, which further increased delays.

Additionally, DC lighting controls were not available for this project. While the size of this project prevented a Title 24 application, the original design drawings called for occupancy sensors and daylighting that allowed light levels to be adjusted throughout the day. Instead, the system was configured with standard on/off switching because lighting controls for DC fixtures were not available on the market.

This project also resulted in no true energy efficiency savings except for those savings realized from converting linear fluorescent lamps to LED. Initially, Willdan Group had hoped to realize savings from lighting controls and some amount of DC to AC inverter losses that could be eliminated by not converting DC solar power to AC lighting. But the DC lighting project replaced the existing lighting panel, making it impossible to take accurate before-and-after measurements. Moreover, the DC system required a transformer to be located in the facility's basement, which created additional line losses. Lastly, because the project could not be installed with lighting controls, no savings were realized from that upgrade. Instead, savings were estimated at approximately 10,000 kWh solely from the fluorescent-to-LED conversion.

Revisions for COVID-19 Low-Occupancy Considerations

Because the labs were still operational and the systems operated 24 hours a day, 7 days a week, the M&V plan for this measure did not change due to COVID-19. Ventilation in the laboratory is driven by ventilation rate requirements instead of occupancy.

Lessons Learned

1. **Communication:** Early and frequent coordination with laboratory staff was critical to this bundle's success. The project team displayed the project schedule on a wall in the laboratory so that staff could plan around expected construction times. This was moderately successful but failed to anticipate changes when the construction crew was either ahead of or behind schedule. Weekly meetings were critical for reconciling staff expectations and the construction schedule.
2. **Laboratory Cleanliness:** Laboratory cleanliness was critically important to avoid contamination of experiments and damaging delicate laboratory equipment. Construction crews minimized the creation of dust and debris whenever possible. However, since dust was inevitable, the contractor purchased an enclosed dust barrier system. This system fully enclosed each work area in plastic so that laboratory work could continue adjacent to construction.
3. **Exhaust Bypass or VFD:** The original proposed scope of work for the laboratory space included a full variable speed airflow retrofit including airflow valves in front of terminal mixing boxes on the existing dual-duct constant air volume (CAV) system, and variable frequency drives on the constant-speed exhaust fans. The primary change in the installed solution was that exhaust fans were not retrofitted with variable frequency drives but instead equipped with exhaust air-bypass dampers. This is because the overall anticipated change in exhaust was relatively negligible in comparison with the overall capacity of the exhaust fans. A change of less than 10 percent of the overall volume means that this would be an inappropriate use of a variable frequency drive.
4. **Existing Conditions to Consider:** The existing CAV boxes were in poorer condition than anticipated, and all 42 boxes had to be replaced. While the project team had conducted some preliminary investigation into existing conditions, the CAV box interiors and the extent of their degradation were not observed. Had the project team been

aware of any indication of these conditions earlier, each of the boxes would have been inspected much sooner, allowing for more coordinated and timely replacement.

5. **Significantly Reduced Airflow:** By operating the laboratory at 4-6 ACH, the laboratory significantly reduced required airflows (a 50-percent reduction in supply fan speed) while still complying with all required safety guidelines and ASHRAE standards. This demonstrates the savings potential across laboratories with constant-volume ventilation.
6. **Effectiveness of Local Occupancy Control:** One control strategy not commonly employed is the use of fume hood occupancy to drive local face velocity at specific fume hoods. While this has only negligible energy savings at individual fume hoods, the cumulative impact over dozens of fume hoods was significant. Moreover, the occupancy control was entirely seamless for laboratory staff, who noticed no change in operations.
7. The project team struggled to identify a contractor who could install the DC lighting as designed. This remains an area of market potential and further work is required to train and identify contractors for this work. Lighting installers, solar installers, and electrical contractors were all asked to submit bids, but none expressed interest due to its complexity. In the end, the team selected a contractor with deep experience installing onsite generation (including cogeneration) since this contractor was familiar with battery and inverter technologies. It was also challenging to obtain equipment for this project as there is an overall lack of availability of DC-specific lighting and lighting controls. This was compounded by overall supply chain delays during the pandemic.

Summary of Results

After eQuest was updated with the newly installed equipment parameters and operating strategies, the whole-building energy model showed annual savings of 1,463,380 kWh and 91,055 therms of natural gas, as well as a reduced peak electrical demand of 283 kW. Table 11 displays the simulation results for each bundle.

Table 11: eQuest Model Simulation Results

Energy Efficiency Measure	Electric Usage Reduction (kWh)	Electric Usage Reduction (%)	Electric Demand (kW)	Electric Demand Reduction (%)	Natural Gas Usage (therms)	Natural Gas Usage Reduction (%)
Bundle 1	819,522	10.27%	237	11.29%	0	0.00%
Bundle 2	53,412	0.67%	8	0.38%	45,109	16.44%
Bundle 3	590,446	7.40%	38	1.81%	45,946	16.75%
Total	**1,463,380**	**18%**	**283**	**13%**	**91,055**	**33%**

Source: Willdan Group eQuest model

CHAPTER 4: Technology/Knowledge/Market Transfer Activities

Documents

The following documents in Table 12 were generated in connection with this project.

Table 12: Documents

Documents	Content	Audience
Case Studies For each Bundle (2 Pages)	▪ Site information and context of SCAQMD vs. California market ▪ Method and problems being addressed. ▪ Summary of findings ▪ Action plan and recommendations	▪ Energy managers ▪ Facility managers ▪ Utility representatives
Roadmap for emerging technology implementation	▪ Intro to solutions, current market status, summary of benefits ▪ Detailed technology information, applications, fuel types, simple diagrams ▪ Case studies of SCAQMD and any other current installations in California ▪ Permitting and regulatory lessons learned and process summary. ▪ Potential incentives available at both state and federal levels ▪ Installation guide including assessment, economic feasibility, technology and contractor selection, permitting, installation, operations, and maintenance. ▪ Summary of barriers and challenges encountered during the demonstration project	▪ Utilities ▪ Consultants ▪ Cities ▪ Large facilities
Fact sheet	▪ CEC format with issue, solution, and results summary	▪ General public
Press release	▪ High-level project overview, funding, goals, Willdan company info	▪ Industry members

Source: Willdan

Transfer Plan

Knowledge sharing and transfer activities remain ongoing with Willdan Group's substantial network of existing California contacts. This network includes state agencies, local government entities, utilities, schools, special districts, and commercial buildings via the sharing and distribution of case studies, web and social media, email, in-person meetings, public workshops, and events. Unfortunately, due to COVID-19 the project team has been unable to offer tours of the demonstration facility. The project team has also developed a public-facing roadmap to both educate potential adopters about the technology benefits and lessons learned and provide implementation guidelines.

Conferences

The project team both presented at and attended the following conferences.

Table 13: Planned Conferences

Name	Location	Date
Emerging Technologies Coordinating Council	Webinar	February, 2021
Virtual Energy Innovation Tour	Virtual	November, 2020

Source: Willdan

Other Dissemination

The project team has submitted the project for three additional conferences and will be submitting the white paper for consideration by IEEE and ASHRAE publications. Case studies are in the process of being posted to the Willdan Group's website, which serves thousands of both public and private companies across the country. All press releases, white papers, and the SCAQMD project roadmap will be highlighted for our range of customers and anyone else who searches for them.

Policy Development

The project team continues to work with our contacts from California investor-owned utilities Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas & Electric to develop incentive applications for emerging technologies. This project roadmap helps utilities propel the energy efficiency market forward and promote adoption of cost-effective emerging technologies.

CHAPTER 5: Conclusions/Recommendations

An estimated 50 percent of existing buildings in California were built before California's Building Energy Efficiency Standards went into effect in 1978[6]; 37 percent of the state's electricity is consumed by commercial facilities, making it the largest sector in California[7]. Buildings of later vintages have significant opportunities for lighting, shell, and mechanical system efficiency improvements[8]. These existing buildings face numerous challenges, such as aging equipment and systems that require replacement, degradation of equipment calibration and performance, lack of monitoring and control capability, and the rising cost of energy. Overcoming these barriers is critical to achieving the state's statutory energy goals.

The successful completion of this project demonstrates the viability of emerging technologies for reducing energy consumption and GHG emissions while improving the comfort of the built environment.

Bundle 1 (Advanced Chilled Water Plants) deployed a chiller with a very low global warming potential refrigerant. As with most technical projects, the major challenges related to budgets and schedules rather than with the technology itself. Despite being some of the first of their kind installed in California, the chillers themselves had very few issues except for an electronics failure that required replacement of a part. The all-variable speed chilled water plant bundle also includes an "above code" building management system controls overlay. The overlay integrates the chilled water plant operating parameters to automatically optimize operation of chillers, pumps, and cooling towers, which together produce cooling at the lowest possible kW/ton. This generates substantial energy savings when compared to typical chilled water plants, which are often constant speed and flow and are manually controlled. Demonstration of these emerging environmentally friendly chillers will increase awareness of their benefits and encourage other facilities in need of upgrade or replacement to consider implementing them, which would in turn accelerate market adoption.

Policy makers should actively consider ensuring that cities adopt the most recent CMC in a timely manner, and that California building codes consider all available low-GWP refrigerants. While this project did experience minor challenges with permitting, most AHJs do not have the capacity or resources to become experts in new technologies. While the California Air Resources Board's (CARB) 2020 Hydrofluorocarbon, i.e., Hydrogen, Fluorene, Carbon (HFC)rules are rolled out, it is now the appropriate time to ensure that local governments are aware of new types of refrigerants.

[6] California Energy Commission, 2011 IEPR, document CEC-100-2011-001-CMF, page 63.

[7] California Energy Commission, Integrated Energy Policy Report, 2008.

[8] California Energy Commission, 2015 Existing Buildings Energy Efficiency Action Plan, page 8.

Bundle 2 (Advanced Office and Exterior Spaces) upgraded the HVAC and lighting systems in office space typical of millions of square feet of commercial office space in California. Most significantly, this project tied the two systems together for maximum benefit, a highly uncommon practice in office spaces today. Unfortunately, low occupancy levels during the pandemic made it challenging to determine accurate post-installation measurements of energy savings; to avoid overestimating savings, the project team assumed that the addition of occupancy sensor-based controls only modified how the space would respond 15 percent of the time, based on current industry standards. However, based on the AHU-7 data, fan speeds were reduced by 10 percent throughout the day, and supply air temperatures were up to 10 degrees higher during periods of low occupancy (like Mondays). These results were like results for the same periods prior to the pandemic. This dynamic suggests that savings might be undercounted during periods of low occupancy.

The project team recommends that SCAQMD upgrade the remainder of its office space in this manner, by combining lighting and HVAC retrofits and using common occupancy sensors to control both. Almost 90 percent of existing floor space in the facility remains to be retrofitted.

The failure of the ARIS wind project installation provides valuable lessons learned. The product was sound; existing installations in the Midwest showed that the company was capable of building, delivering, and servicing its products. However, the project team identified numerous design challenges while researching installation locations and requirements. California's seismic requirements meant that an unexpected level of structural engineering was required for the system's foundation. The project budget did not anticipate asphalt repair or fully recognize the complexity of the foundation requirements. The entire project site is located on a bluff, and exterior areas with the lowest light levels were adjacent to the bluff. Existing utility drawings were inadequate and did not identify all underground utilities. The project team conducted an extensive ultrasonic survey to identify areas where underground utilities could prevent construction of a foundation for one of the ARIS turbines. These are important details that are often overlooked; the cost implications of the required installation must be carefully considered and included in a project's budget when deploying a system like this, even when the promise of off-grid lighting ultimately reduces the cost of utility connections.

Bundle 3 (Advanced Laboratory/Critical Environment Systems) modified the laboratory ventilation system and fume hood controls to reduce ventilation rates and fan-motor energy consumption. While laboratories have slowly upgraded to variable ventilation systems over the past 10 years, these projects typically have a poor return on investment, create a significant disruption to the site, and pose challenges for building owners unfamiliar with the latest technology. A key element of Bundle 3 was education and engagement with the onsite laboratory staff. Weekly meetings were held over the course of the project to provide staff with schedule updates, receive feedback on construction impacts and, generally, describe how the project will affect them. When describing the barriers currently preventing California from implementing more energy-efficiency projects, the California Energy Commission's *2018 Integrated Energy Policy Report* specifically identified a lack of customer and contractor education about a project's high payback as a primary reason that more deep energy retrofits are not more frequently considered and implemented in the state.

Recommendations for Further Research

The project team identified three areas for future research based on findings from this project.

1. **Circadian Control:** The Circadian correlated color temperature (CCT) system was successfully implemented in this project and demonstrated that building occupants rarely notice gradual lighting changes over time. This emerging technology has wide-ranging potential to improve occupant comfort and productivity and reduce eye strain; it is therefore deserving of further study to quantity the efficacy of claimed behavioral comfort improvements.
2. **Pneumatic-to-DDC Conversions:** Surprisingly, there is very little available research on the number of buildings with pneumatic controls. Although DDC technology has been available for more than 15 years, some commercial buildings still operate with limited control, which creates greater opportunities for energy-efficiency upgrades. Additional effort is important to quantify this opportunity and direct available statewide resources to improving this subset of existing buildings.
3. **DC Lighting Contractors:** The project team struggled to identify a contractor qualified to install the DC lighting as originally designed. This remains an area of significant market potential as more solar and battery systems and resilient microgrids are increasingly deployed. To power these systems (beyond lighting) from a single solar or battery source requires that contractors have the knowledge, experience, and skills required to work with DC power and install systems customized to existing facilities. The Willdan Group recommends a market assessment and possibly a training facility and training materials to increase capacity within the existing market.

CHAPTER 6: Benefits to Ratepayers

The successful completion of this project demonstrates the viability of emerging technologies for reducing energy consumption and GHG emissions at a large commercial facility while improving the comfort of the built environment.

A significant reduction in both energy consumption and peak demand has the important benefit of lowering demand on the electric grid overall, reducing the likelihood of summertime outages and constrained grid events. Reducing energy use in commercial buildings also reduces the GHG largely responsible for climate change.

For many building owners and operators, significant retrofits such as those explored in this project are more complex and cost more than they might consider. Providing step-by-step road maps and thinking differently about operations would go a long way toward making projects like this one more accessible.

LIST OF ACRONYMS

Term	Definition
AC	Alternating current
AHU	Air-handling unit
CAV	Constant air volume
CFM	Cubic feet per minute
DC	Direct current
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
PV	Photovoltaic
M&V	Measurement and Verification
MAV	Make-up air valves
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
VAV	Variable air volume

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