Title
Zone Level Occupant-Responsive Building Energy Systems at the GSA

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Environmental Energy Technologies Division

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Disclaimer

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

Zone Level Occupant-Responsive Building Energy Systems at the GSA

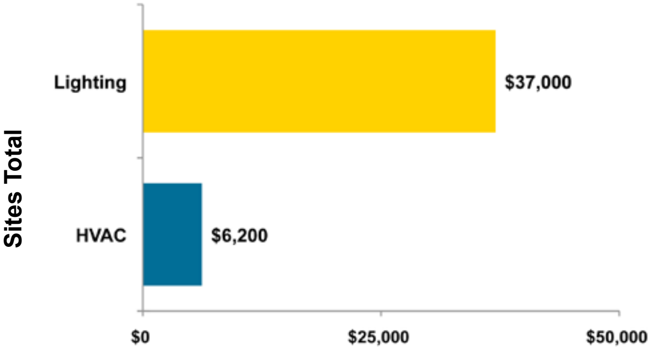
Overview

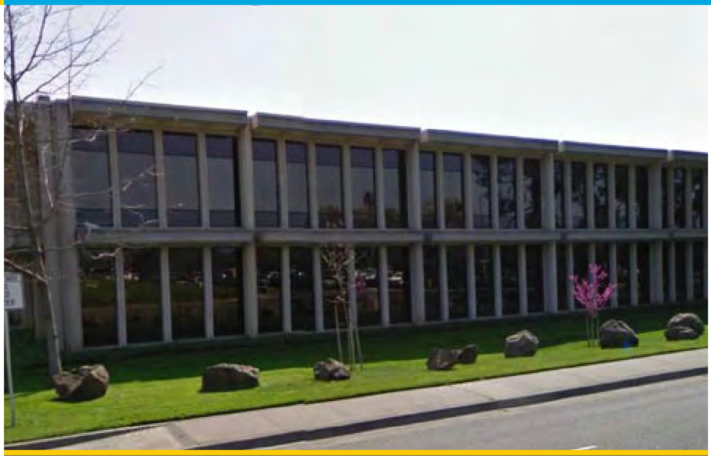
The General Services Administration (GSA) partnered with the U.S. Department of Energy (DOE) to develop and implement building energy system retrofits, aiming to reduce energy consumption of at least two building systems by a total of 30 percent or more, as part of DOE's Commercial Building Partnership (CBP) Program.[1] Lawrence Berkeley National Laboratory (LBNL) provided technical expertise in support of this DOE program, working with the GSA and a team of consultants.

The GSA is the biggest property owner and lessee in the United States and has a building portfolio consisting of over 9,600 facilities, with a total combined floor area of approximately 370 million square feet, and over one million employees. The GSA environmental mandate includes making significant efforts, including the use of innovative technologies and control strategies, to reduce energy use across its portfolio. A key goal was to identify energy-saving measures that could be applied more broadly to GSA buildings elsewhere in the United States.

This case study reports expected energy savings from appropriate energy efficient design and operations modifications to lighting and heating, ventilating and air conditioning (HVAC) systems at the selected study sites. These retrofits comprised installation of new lighting systems with dimming capability and occupancy-sensor control at the individual light fixture level, and utilized lighting system occupancy sensor signals to continually readjust zone-level ventilation airflow according to the number of people present, down to minimum rates when vacant.

Expected Energy Cost Reductions





Cottage Way Federal Building.

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Project Type	Office, Retrofit
Climate Zone	ASHRAE Climate Zones 3B and 3C, Warm and Dry, Warm Marine
Ownership	Public
Barriers Addressed	• Existing energy management practices • Lack of measured energy data • Lack of attention paid to lighting quality
Square Footage of Project	200,000 (Lighting), 75,000 (HVAC) — sites total
Expected Energy Savings (vs. existing energy use)	~47% (Lighting), ~14% (HVAC), ~37% (Combined) — site average
Expected Energy Savings (vs. ASHRAE 90.1-2007)	~37% (Lighting) — sites average
Actual Energy Savings (to be verified)	370,000 kWh / yr electricity — sites total
Expected Cost Savings[2]	~$43,000 (Combined), ~$37,000 (Lighting), ~$6,200 (HVAC) — sites total
Project Simple Payback	~11 years (Lighting), ~ 5 years (HVAC) — site average
Actual Cost Reductions	To be verified
Expected Carbon Dioxide Emissions Avoided	~102 metric tons per year — sites total[3]
Construction Completion Date	2014 (expected)

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1. The Commercial Building Partnership (CBP) program is a public/private, cost-shared initiative that demonstrates cost-effective, replicable ways to achieve dramatic energy savings in commercial buildings. Through the program, companies and organizations, selected through a competitive process, team with U.S. Department of Energy (DOE) and national laboratory staff who provide technical expertise to explore energy-saving ideas and strategies that are applied to specific building project(s) and can be replicated across the market.
2. Energy prices reflect local rates at the study site. For sites in California, rates ranged from $0.11–$0.13 /kilowatt-hour; for sites in Nevada, the rate was $0.09/kilowatt-hour.
3. Calculated using EPA's Greenhouse Gas Equivalencies Calculator.

The lighting retrofits are projected to reduce lighting energy consumption by approximately 47% averaged across sites, with average energy reductions from the HVAC retrofits estimated at 14%. Combined average energy savings from the two systems across study sites normalized by unit floor area are projected to be approximately 37%.

The CBP project focused on improving the energy performance of selected buildings in the Region 9 (Arizona, California, Nevada, and Hawaii) building portfolio. Seven buildings, six located in California and one in Nevada, were the focus of a CBP lighting and HVAC controls retrofit collaboration. Within the seven buildings, a total of 10 study locations were selected for assessment of the lighting retrofits, each consisting of several occupied zones. For assessment of the HVAC retrofits, the study team selected four study locations, each consisting of several HVAC zones, from two of the seven buildings. Both lighting and HVAC zones typically consisted of multiple-occupant open office space and private offices, and included transitional areas such as corridors and non-occupied spaces such as conference rooms and break areas. Zones were located in building perimeter and core areas

The seven buildings selected ranged in age and characteristics from heavy concrete edifices from the 1960s to lighter mass concrete, steel, and glass structures built in the early 2000s. The range of agencies and space types resulted in a range of interior designs and workspace layouts, influencing the retrofit designs, particularly for lighting. Prior to the retrofits, lighting typically consisted of recessed fixtures. Some buildings also utilized schedule-based lighting controls and wall switches to activate lights outside of those times, while other buildings had no coordinated site-wide approach; some wall switches, some occupancy-based control, some with 24-hour operation. Open office cubicles at many sites had under-cabinet task lighting to supplement overhead lighting. The existing HVAC systems typically operated on a schedule basis, and during designated occupied hours, to meet interior setpoints and ventilation requirements with supply temperatures reset based on outside air temperatures.

The lighting project arose from GSA's interest in examining the technical performance and cost-effectiveness of various energy-efficient lighting technologies in its existing building portfolio. The lighting energy-efficiency measures (EEMs) proposed for each site comprised a combination of new equipment and controls. This included replacement of existing lighting fixtures and installation of new digital, addressable electronic dimming ballasts, as well as implementation of various advanced control strategies that effectively utilized the new equipment. Lighting designs were chosen based on the type of building space. For open office areas, three-lamp “workstation-specific” pendants—where a single lamp provides an uplight, ambient component, and two downlight lamps provide task oriented light—were installed, with one light fixture centered above each work cubicle, and with each fixture having dimming capability and a dedicated occupancy-sensor. For private offices, conference and training rooms, and transition spaces, the new light fixtures installed largely consisted of a like-for-like replacement of ceiling troffer fixtures. Because of the range of space use types studied, a range of lighting control strategies were implemented; this was essential in order to realize the full energy saving potential at each site. For open office areas and for temporarily occupied spaces, the team focused on implementing occupancy sensing (which relies on the presence of occupants to activate lighting) and setpoint tuning control strategies (which dim lighting output from the installed maximum to a level according to an institutional standard—in the case of GSA, the P100 facilities standard—or according to occupant preferences). For private offices, daylight harvesting (the dimming of electric lighting according to availability of natural light in building perimeter areas), occupancy sensing, and set-point tuning were utilized, and the manually operable light switches remained.

The study locations comprise a combined floor area of approximately 200,000 square feet—most of which was office space—and include installation of new lighting fixtures and the implementation of a range of lighting control strategies. Study areas were a fraction of the total area proposed for the retrofits—which ranged from 50% of the building floor area to it's entirety—but were selected to be broadly representative of the building use types as a whole. Lighting power density was anticipated to increase at 6 of the 10 sites as a result of the new lighting. Despite this increase, a combination of dimming capability to a preset level significantly below 100% output for the new lights and occupancy-based control is expected to result in significant energy savings. Predicted energy savings for the new designs ranged from 24%—70% across study sites. The goal was for new designs to not only significantly reduce energy use at the selected locations, but also that their performance provide insight into where else in the GSA building portfolio similar designs and control strategies should be implemented. The overall success of each installation will depend on occupant satisfaction, based on the principle that only technologies and strategies acceptable to occupants have appropriate value to justify replication in other GSA buildings. An assessment of occupant perceptions of technology performance will be carried out for each study site, focusing on visual comfort satisfaction and satisfaction with control settings and protocols. This analysis will be undertaken

Workstation-specific pendant fixtures installed in GSA offices.

Source: LBNL

by distributing surveys the occupants, both before and after the retrofits, to determine their perceptions of their working environment with regards to lighting quality. The responses will be correlated with light level measurements recorded before and after the retrofit, and with the technical performance of the new fixture and controls.

For the HVAC retrofits, the study areas selected had to have undergone the lighting controls retrofit, so that they had the infrastructure necessary to enable the occupancy-sensor signal based HVAC controls. The new design was being tested to evaluate its effectiveness and possible wider deployment within GSA buildings. The project team implemented occupancy-based control of the air supply terminal units, called variable air volume (VAV) boxes, and reduction of minimum airflow rates in approximately 75,000 square feet of office floor space, resulting in modeled energy savings of between 2% (although this low figure is for service spaces seldom occupied prior to the retrofit) and 18% across the four sites, with an average saving of 12% per site. By taking advantage of occupancy sensors already present for operation of the lighting systems, the installation costs for occupancy-based HVAC controls can be significantly reduced and the payback period shortened.

Two different air-side system types were present in the study buildings: the Philip Burton Federal Building in San Francisco had a dual-duct system that utilized separate ducts for supply of hot and cold air, and the Cottage Way Building in Sacramento had a more modern single-duct system, where heating and cooling was supplied through a common duct, with reheat coils located at zone terminal VAV boxes to tune supply air temperatures as needed. In both buildings, the outside air ratio for the air-handling units was set at 20%. The Philip Burton building utilized an economizer cycle using enthalpy-based control; Cottage Way operated a dry-bulb-based control protocol. Typically, supply air temperature was reset 10 degrees Fahrenheit, based on the warmest or coldest zone, depending on whether the system was in heating or cooling mode. These operating characteristics will not affect implementation of the control strategy but will impact the energy savings resulting from implementation across the various sites.

The HVAC modifications consisted of reprogramming existing VAV boxes to control occupancy signals from existing lighting occupancy sensors in open office areas, where occupancy varies incrementally—this strategy is also applicable to private offices and temporarily occupied rooms when they are supplied by dedicated VAV boxes. The principle is to control airflow according to need; primary control of the VAV boxes during occupied hours would be to a temperature setpoint, secondary to occupancy-sensors, with minimum airflow rates adjusted according to the control protocol, so zone temperature must be maintained at or near the setpoint, and as occupancy increases and decreases, correspondingly so does supply air volume according to an air supply per person requirement. For unoccupied periods, the temperature control setpoint would be set back, with the temperature setpoint depending on whether it was heating or cooling season. Energy savings will come primarily from reduced air-handling unit (AHU) fan operation, with reduced operation of heating and cooling plant and supply pumping contributing further reductions. With the AHU fan speed reduction comes a reduction in outside air delivery to spaces, so carbon dioxide (CO_2) levels were consequently monitored to ensure that they met ASHRAE standard guidelines.

The retrofits are expected to significantly reduce lighting and HVAC energy use. Predicted energy reduction for VAV boxes per unit floor area is lower than that for lighting, and is effective mainly for open office areas due to the granularity of control available at various levels of occupancy. However, implementation costs per unit floor area are correspondingly low, which incentivizes implementation across similar spaces in GSA buildings.

The combination of lighting and HVAC energy-efficiency measures would assist GSA in achieving its strategic planning goals, which aim to reduce the organization's environmental impact and to leverage benefits such as utility incentives and rebates that further improve the business case for energy efficiency technologies.

Decision Criteria

The proposed lighting EEMs are to be tested in a variety of GSA buildings to verify their overall cost-effectiveness and their potential to save energy in different settings, and to determine occupant perspectives on the conditions created by the new lighting systems. The lighting systems selected had been piloted previously at another GSA facility, and that pilot resulted in a proposed larger-scale rollout for this CBP project. Implementation of the HVAC retrofit element will follow the lighting retrofits, as the infrastructure necessary for demand-based lighting control is a prerequisite for implementing the equivalent protocol to supply heating, cooling and ventilation air.

Economic

The GSA's investments are measured using three investment metrics: simple payback, life-cycle cost (LCC), and savings investment ratio (SIR).[4] The target payback for EEMs is typically less than 10 years to justify investment, however, projects with expected paybacks longer that the investment threshold are implemented as a result of GSA's commitment to field testing of emerging and under-utilized building energy technologies. It is from these field tests that decisions on wider deployment are based—whether a technology is approved for scale roll-out, targeted deployment or rejected as an option.

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[4] Calculated as being (Annual Energy Delivered * Cost of Electricity * Present Worth Factor) / System Cost

- For LCC and SIR calculations, GSA uses a discount rate of 3.9% to calculate present value and the ratio, respectively. Therefore, the key economic criteria for EEMs included the following:
- Target simple payback period to justify rollout across the portfolio: 10 years as an initial filter.
- A SIR rating of greater than one, assuming an appropriate technology lifetime, which in the case of lighting and HVAC systems, was assumed at 15 years.

Policy and Operations

As owner of the largest commercial buildings portfolio in the United States, GSA has the opportunity to realize significant energy cost reductions from new technologies. Furthermore, as the effective landlord for the federal government, it is important that GSA be at the vanguard of energy reduction initiatives. General Service Administration sustainability policy goals strongly influence its approach to energy efficiency; it has committed to a reduction in energy use intensity of 30% by 2015 and a reduction in greenhouse gas emissions of 28% by 2020.[5] These goals drive decision making at the individual building, region, and federal level.

Occupant Acceptance

This project was about more than just assessing financial value: another goal was understand the lighting quality implications of the new fixtures and whether occupants were satisfied with the environment created by the new lighting and controls. Evaluating occupant perceptions of lighting quality provided by the new system was accomplished through distribution of online surveys to occupants before and after the retrofit. Such evaluations are important, given the role of lighting in creating a comfortable, safe working environment.

Energy Efficiency Measures Snapshot

The analysis for this project focused on assessing EEMs at a range of locations, as shown in the table below. The range of results reflects the variation in site characteristics and floor area.

- Expected energy savings are shown for multiple lighting controls strategies implemented together, for each site. For the HVAC projects, a single energy-efficiency measure was implemented at all study sites.
- Electricity rates varied across sites, from $0.09/kWh to $0.13/kWh, depending on the utility service territory and reflecting the prices currently paid at each building.
- Lighting EEMs were selected from a range of available control strategies: rescheduling, setpoint tuning, occupancy-based control, daylight harvesting, and personal control. The EEMs implemented depended on the space type.
- The HVAC energy-efficiency measure will be implemented to meet minimum airflow recommendations from ASHRAE Standard 62 for Acceptable Indoor Air Quality. Reducing AHU fan speed below the manufacturer's recommendations is an option, but it requires assessment, as equipment maintenance issues are associated with this activity. The minimum airflow requirements according to occupant numbers, as set out in ASHRAE Standard 62.1, will ultimately determine the VAV box settings and minimum fan speed at the AHU. As a check on the interior air quality as part of this project, CO_2 sensors were installed to ensure that industry-acceptable CO_2 levels were maintained.
- The EEMs are presented by system type and by site.

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[5] http://www.gsa.gov/portal/mediaId/162943/fileName/GSA_FY2012_Sustainability_Plan

Energy Efficiency Measures for Selected GSA Sites

	Implement at GSA	Consider for Future	Expected Savings		Expected Improvement Cost	Simple Payback	Cost of Conserved Energy (CCE)[6]
	Yes/No	Yes/No	kWh/yr	$/yr	$	yrs	$
GSA Offices — Lighting Energy Savings ~47% (Sites Average)							
Project Scope: Sites underwent lighting system retrofit with high granularity control in terms of institutional tuning setpoints, occupancy, daylight dimming, and personal control. The retrofit included installation of efficient fixtures with dimmable addressable ballasts and occupancy sensors (plus photosensors where applicable). For open office areas; lighting fixture layout was typically modified to correspond to workstation layout in open office areas, for private offices; the existing fixture layout was maintained. Sensors controlled the lights for individual work spaces, private offices or individual cubicles. Details of the control strategies implemented for each site are outlined below.							
Chet Holifield Federal Building, Laguna Niguel, CA (27% Energy Savings)							
Open office cubicles and transition areas — downlights tuned to 50% input power, uplights tuned to 20% input power, overhead lights tuned to 50% input power, 30-minute timeouts. Occupancy-based control throughout.	No	Yes	36,936	$4,802	$75,795	12.9	0.14
Cottage Way Federal Building, Sacramento, CA (40% Energy Savings)							
Daylit areas (open office cubicles, private office, and transition areas) — light levels maintained at 50 footcandles (fc) within a range of 20%-80% input power. **Non-daylit areas (open office cubicles, private offices, and transition areas)** — downlights tuned to 50% input power, uplights tuned to 20% input power, overhead lights tuned to 50% input power. In areas with occupancy-based control, 30-minute timeouts, 10% input power for final 10 minutes of timeout. Operable switching in some private offices.	No	Yes	21,299	$2,705	$49,526	14.3	0.15
Lloyd George Federal Building Site 1, Las Vegas, NV (37% Energy Savings)							
Daylit areas (private offices and transition areas) — light levels maintained at 50 fc within a tuned range of 20%-80% input power. **Non-daylit areas (private offices, conference and break rooms, and transition areas)** — overhead lights tuned to 50% input power. In areas with occupancy-based control, 30-minute timeouts, 10% input power for final 10 minutes of timeout. Operable switching in some conference and break areas.	No	Yes	11,623	$1,046	$44,143	30.9	0.23
Lloyd George Federal Building Site 2, Las Vegas, NV (56% Energy Savings)							
See Lloyd George Site 1 description	No	Yes	25,458	$2,291	$39,770	12.7	0.10

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[6] The CCE was calculated using a 3.9% discount rate for 15 years (Meier, 1984).

Energy Efficiency Measures for Selected GSA Sites

	Implement at GSA	Consider for Future	Expected Savings		Expected Improvement Cost	Simple Payback	Cost of Conserved Energy (CCE)[6]
	Yes/No	Yes/No	kWh/yr	$/yr	$	yrs	$
Robert Matsui Courthouse, Sacramento, CA (70% Energy Savings)							
Daylit areas (open office cubicles, private office, and transition areas) — light levels maintained at 50 fc within a tuned range of 20%-80% input power. **Non-daylit areas (open office cubicles, private office, and transition areas)** — downlights tuned to 50% input power, uplights tuned to 20% input power, overhead lights tuned to 50% input power. In areas with occupancy-based control, 30 minute timeouts, 10% input power for final 10 minutes of timeout. Operable switching in some private offices.	Yes	Yes	47,613	$5,237	$23,251	3.4	0.03
Philip Burton Federal Building, San Francisco, CA (46% Energy Savings)							
Daylit spaces (private offices and transition areas) — light levels maintained at 50 fc within an input power range of 20%-65%. **Non-daylit spaces (private offices and transition areas)** — light levels tuned to 50% input power. Occupancy-based control (with manual override in private offices).	No	Yes	27,235	$3,241	$37,190	9.7	0.10
Ron Dellums Federal Building Site 1, Oakland, CA (26% Energy Savings)							
Open office cubicles — downlights tuned to 40% input power, uplights tuned to 20% input power, occupancy-based control throughout. **Daylit private offices** — light levels maintained at 50 fc within a range of 20%-30% input power. **Non-daylit spaces (private offices and transition areas)** — light levels tuned to 30%-35% input power.	No	Yes	13,578	$1,788	$48,117	16.5	0.18
Ron Dellums Federal Building Site 2, Oakland, CA (24% Energy Savings)							
See Ron Dellums Site 1 Description	No	Yes	8,363	$1,101	$38,703	21.5	0.24
Ron Dellums Federal Building Site 3, Oakland, CA (30% Energy Savings)							
See Ron Dellums Site 1 Description	No	Yes	6,428	$847	$20,343	14.7	0.16

Energy Efficiency Measures for Selected GSA Sites

	Implement at GSA	Consider for Future	Expected Savings		Expected Improvement Cost	Simple Payback	Cost of Conserved Energy (CCE)[6]
	Yes/No	Yes/No	kWh/yr	$/yr	$	yrs	$
Roybal Federal Building, Los Angeles, CA (67% Energy Savings)							
Open office cubicles — downlights tuned to 50% input power, uplights tuned to 20% input power, occupancy-based control throughout. **Daylit spaces (private offices and transition areas)** — light levels maintained at 50 fc within a range of 20%-80% input power. **Non-daylit areas (private offices and transition areas)** — downlights tuned to 50% input power, uplights tuned to 20% input power. In areas with occupancy-based control, 30-minute timeouts, 10% input power for final 10 minutes of timeout. Operable switching in some private offices.	Yes	Yes	112,668	$13,520	$47,817	3.3	0.03
GSA Offices — HVAC Energy Savings ~14% (Sites Average)							
Project Scope: Sites underwent reprogramming of the zone level HVAC controls, applying an occupancy-based control strategy to the supply of ventilation air, heating, and cooling. This capitalized on existing occupancy sensors in open office cubicles, private offices, and conference and break room areas.							
Cottage Way Federal Building Site 1, Sacramento, CA (18% Energy Savings)							
Private offices and smaller rooms — occupancy-sensor controlled, demand-based VAV operation to minimize airflow and reduce heating and cooling. Manual switch override for occupancy sensors in private offices.	Yes	Yes	11,882	$1,509	$4,559	3.0	0.03
Cottage Way Federal Building Site 2, Sacramento, CA (18% Energy Savings)							
Open office cubicles and private offices — occupancy-sensor controlled, demand-based VAV operation to minimize airflow and reduce heating and cooling.	Yes	Yes	36,489	$4,634	$16,309	3.5	0.04
Cottage Way Federal Building Site 3, Sacramento, CA (2% Energy Savings)							
Mixed spaces types in building core — occupancy-sensor controlled, demand-based VAV operation to minimize airflow and reduce heating and cooling. Manual switches override occupancy sensors in private offices.	Yes	Yes	361	$46	$4,055	88.5	1.00
Philip Burton Federal Building, San Francisco, CA (9% Energy Savings)							
Open office cubicles and private offices — occupancy-sensor controlled, demand-based VAV operation to ventilation airflow and reduce heating and cooling.	Yes	Yes	14,053	$1,672	$16,914	10.1	0.11

Energy Use Intensities By End Use

The project team identified and analyzed EEMs for all sites and created lighting energy models to estimate energy savings relative to the existing systems and to ASHRAE 90.1-2007, and to simulate the impact of occupancy on lighting operation. The team developed an occupancy profile by monitoring occupancy events from installed occupancy sensors, filtering out false readings of occupancy and vacancy, and creating an hourly profile using average data collected over several months. This profile was utilized in estimating the impacts of lighting-based occupancy controls.

The workstation-specific pendant lighting fixtures were originally piloted at a single site and found to contribute significant energy savings (40% over an area comprising 80 open office cubicles) compared to the original ceiling troffer lighting. The pilot study also concluded that occupancy patterns, standby power, and shorter timeout periods further significantly reduced energy use. An inventory of the lighting fixtures, lamp types, and existing control functionality, which informed the energy modeling, was also taken at each site, following recommendations from the pilot. Lighting system design focused on providing comfortable lighting quality for occupants and incorporating advanced lighting controls that were not part of the original design. For open office areas, design modifications included decommissioning the overhead fixtures and installing new pendant fixtures: their layout would correspond with the cubicle layout so that each cubicle would be served by a dedicated three-lamp fixture. Although lighting power density would be increased as a result, implementation of the various control strategies would result in significant lighting savings. A consequence of the open office redesign was that transition spaces between the cubicles would no longer be electrically lit from overhead ceiling lights, but from ambient lighting from the local cubicles.

Energy models for the HVAC sites were based on occupancy data from the lighting control systems, existing equipment schedules, information from building plan drawings, and other data collected during site visits. Metered energy and weather data collected from the sites over the course of several months were used to calibrate the existing building energy model. Occupancy-based control of supply of ventilation air, heating, and cooling to ASHRAE minimum airflow recommendations was the EEM considered as an alternative to conventional demand-controlled ventilation, which is based on measured CO_2 levels. To test whether this strategy would comply with the ASHRAE interior air quality standards, sensors measuring carbon dioxide concentrations were placed around the study sites.

The HVAC projects were selected at locations where the majority of floor area is occupied by open office space. The double-duty operation of occupancy sensors, where they were controlling both lighting and HVAC systems provides the opportunity for higher granularity of control of the existing HVAC systems at a relatively low cost. The GSA's mechanical systems subcontractor programmed individual VAV boxes according to the operating protocol. For one study site that was initially considered but eventually rejected, multiple private offices were supplied by a single air-handling unit. If an individual private office becomes vacant, adopting the proposed controls protocol could reduce air flow to all private offices supplied, not only the one vacated. The reduction in outside air delivery to the occupied private offices represents a situation that is not acceptable per industry standards. Consequently, the proposed design has limited potential for private offices and was not implemented in this condition.

The energy impacts of the installation of new light fixtures and operation in concert with advanced control strategies became readily apparent in the pilot study conducted. The GSA was supportive of pairing the occupancy-based HVAC retrofits with the lighting occupancy sensors, as this presented an opportunity to extract greater energy cost savings for little investment. Because the schedule of the HVAC projects was offset from the lighting project schedule, study sites were selected somewhat independently, according to consent of the facilities manager and building occupants. Consequently, one of the HVAC study sites was not part of a lighting controls upgrade project.

Lighting savings were estimated compared to pre-retrofit energy consumption and also to the Energy Standard 90.1.2007 of the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute (ANSI), and the Illuminating Engineering Society of North America (IESNA) for maximum energy intensity for commercial office buildings. Energy savings for the HVAC systems were estimated compared only to pre-retrofit energy consumption.

Energy Model Results

Graphic results from several models show the impact to date of both projects. Models 1 to 3 were created to evaluate the performance of the lighting retrofits at each of the 10 study sites. Model 3 (Proposed Design) was then compared to the two baselines—Model 1: Pre-retrofit Design and Model 2: Code Baseline (ASHRAE 90.1-2007)—to estimate energy savings.

Model 1: Pre-retrofit Design

Model 1 represents the pre-retrofit lighting operation in the study area of each building targeted for retrofit. This model has an annual energy use intensity (EUI) range of 6.1 thousand Btu per square foot (kBtu/ft^2) to 22.2 kBtu/ft^2 across the 10 sites.

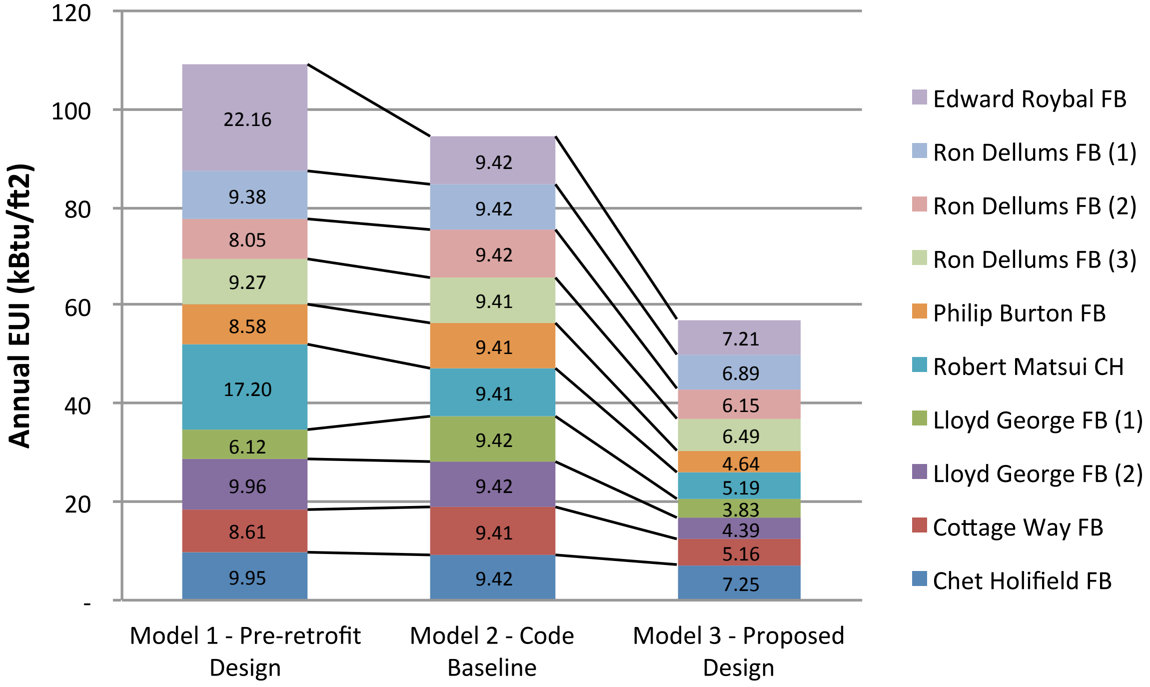
Model 2: Code Baseline

Model 2 represents the ASHRAE 90.1-2007 standard baseline for the study area of each building targeted for the lighting retrofit. This model has an annual EUI of 9.4 kBtu/ft^2 at each of the 10 sites.

Model 3: Proposed Design

Model 3 represents the proposed design for the study area of each building and includes new lighting fixtures and an overall lighting redesign, including a new control system with occupancy and daylight harvesting sensors. It also incorporates time-scheduling and institutional setpoint tuning to meet workplane illuminance requirements. This model has an annual EUI range of 3.8 kBtu/ft^2 to 7.3 kBtu/ft^2 across the 10 sites.

Comparing EUI of the Pre-retrofit Design, Code Baseline, and Porposed Design for GSA Buildings



Expected Annual Energy Use and Percentage Savings by End Use

	Model 1 – Pre-retrofit Design	Model 2 – Code Design	Model 3 – Proposed Design	Model 3 – Proposed Design
End Use Category	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Percent Savings Over 90.1-2007
Chet Holifield FB	9.95	9.42	7.25	27%
Cottage Way FB	8.61	9.41	5.16	40%
Lloyd George FB (1)	6.12	9.42	3.83	37%
Lloyd George FB (2)	9.96	9.42	4.39	56%
Robert Matsui CH	17.20	9.41	5.19	70%
Philip Burton FB	8.58	9.41	4.64	46%
Ron Dellums FB (1)	9.38	9.42	6.89	26%
Ron Dellums FB (2)	8.05	9.42	6.15	24%
Ron Dellums FB (3)	9.27	9.41	6.49	30%
Edward Roybal FB	22.16	9.42	7.21	67%

Models 4 and 5 focus on the HVAC systems. Model 4 represents the Pre-retrofit Design HVAC energy use against which Model 5 (the Proposed Design) is compared in order to estimate energy savings.

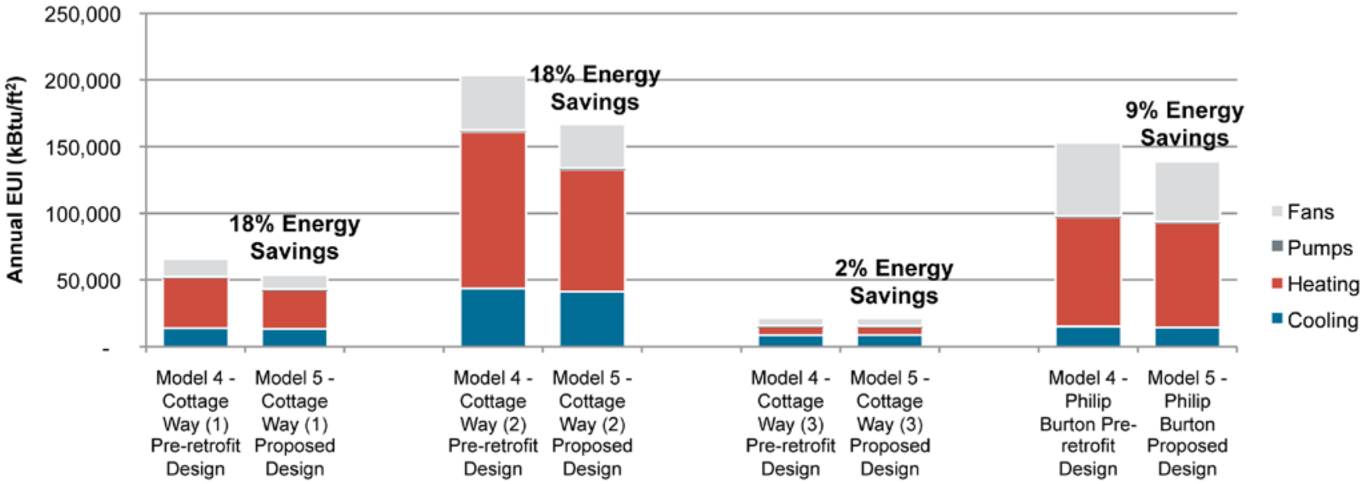
Model 4: Pre-retrofit Design

Model 4 represents the pre-retrofit HVAC operation within the area of each building targeted for the retrofit, and includes heating, cooling fan energy, and pumping associated with the VAV airflows. This model has a range in annual EUI of 2.5 kBtu/ft^2 to 6.8 kBtu/ft^2 across the four sites.

Model 5: Proposed Design

Model 5 represents the proposed design for the study area of each building and includes new occupancy-based airflow control below the VAV box manufacturer's recommended minimum values, controlling to maximum carbon dioxide concentrations. This is accomplished by tying the control of VAV boxes to the lighting system occupancy sensors. When occupancy in a VAV zone decreases, the minimum supply airflow will also decrease, an energy savings approach outlined in the California Energy Commission's Advanced Variable Air Volume Systems Design Guide. Since many of the zones were observed to operate at minimum airflow (with reheat in some cases), a lower minimum damper position will save fan energy and heating/cooling energy, depending on the zone conditioning requirements. This model has an annual EUI range of 2.5 kBtu/ft^2 to 5.5 kBtu/ft^2 across the four sites.

Expected Building Energy Savings from Implemented EEMs by End Use



Expected Annual Energy Use and Percentage Savings by End Use

End Use Category	Cottage Way Site 1 - East Block, 2nd Floor, West Façade			Cottage Way Site 2 - East Block, 2nd Floor, South, East and North Facades			Cottage Way Site 3 - East Block, 2nd Floor, Core Zone			Philip Burton - 4th Floor, East Façade		
	Model 4 - Pre-retrofit Design	Model 5 - Proposed Design		Model 4 - Pre-retrofit Design	Model 5 - Proposed Design		Model 4 - Pre-retrofit Design	Model 5 - Proposed Design		Model 4 - Pre-retrofit Design	Model 5 - Proposed Design	
	Annual EUI (kBtu/ft^2)	Annual EUI (kBtu/ft^2)	Percent Savings over existing	Annual EUI (kBtu/ft^2)	Annual EUI (kBtu/ft^2)	Percent Savings over existing	Annual EUI (kBtu/ft^2)	Annual EUI (kBtu/ft^2)	Percent Savings over existing	Annual EUI (kBtu/ft^2)	Annual EUI (kBtu/ft^2)	Percent Savings over existing
Fans	1.36	1.08	20%	1.18	0.94	20%	0.67	0.65	3%	1.93	1.59	18%
Pumps	0.04	0.04	0%	0.04	0.04	0%	0.03	0.03	1%	0.04	0.04	0%
Heating	3.92	3.04	22%	3.38	2.63	22%	0.81	0.78	4%	2.89	2.77	4%
Cooling	1.44	1.36	5%	1.25	1.19	5%	0.98	0.99	-1%	0.53	0.51	5%
Total	**6.76**	**5.54**	**18%**	**5.85**	**4.80**	**18%**	**2.50**	**2.45**	**2%**	**5.40**	**4.90**	**9%**

Expected Building Energy Savings from Implemented EEMs by End Use (Sites Total)

	Electricity End Use Category	Energy Savings
🟨	Interior Lighting	310,000 kWh
⬛	Fans/Pumps	21,000 kWh
🟥	Heating	130 kWh
🟦	Cooling	3,600 kWh
	Electricity Total	**~336,000 kWh**

Lessons Learned

Continued Reduction in Materials and Labor Costs

At present, advanced lighting controls in the U.S. market have relatively high implementation costs and vary significantly due to many diverse factors, from the type and age of the building proposed for installation to local labor rates. As the market grows, both material and labor costs are anticipated to decrease significantly, with the target cost of implementing advanced lighting controls solutions estimated at an incremental cost of approximately one dollar per square foot, which is a reasonable target cost. At this market price point, 70% of the GSA sites studied would be cost-effective if assessed against a simple payback period threshold of 10 years.

Value of Combined Lighting and HVAC Measures

Using a single-sensor output as an input to control two building systems provides value beyond current conventional control systems, which are typically design-integrated for their specific system type, such as lighting. Additionally, as lighting output has a direct influence on the cooling load, controlling operation of the two systems together should provide a level of system integration to significantly increase overall energy savings; this requires coordination on operation of the two systems and verification that operation is according to design intent. It is worth noting that if the lighting and HVAC control systems were installed simultaneously, the cost of implementation would be shared—the economic results presented here reflect a situation whereby the HVAC controls leverage the benefits of the lighting controls infrastructure, while avoiding the costs. Consequently, the lighting element receives less credit than it would do otherwise.

The benefits of tying multiple systems into the occupancy-based control strategy can be seen at the Cottage Way site. The study areas for occupancy-based control were common to lighting and HVAC systems (one lighting study site and three HVAC study sites); therefore, it was possible to assess both as part of a single installation. Results of energy modeling suggest that lighting energy savings will be approximately 40 percent, and zone-level HVAC savings will be approximately 17 percent, with a combined savings of 20 percent of lighting and HVAC energy overall for the study area. The simple payback for occupancy-based control of both lighting and HVAC was 13.5 years. In situations where the incremental cost of lighting controls was reduced to around one dollar per square foot, payback would be reduced to an average of 6.5 years.

The Value of Pre-installation Assembly

Pilot installations were implemented prior to the full-scale lighting retrofits, and it was discovered that the installation needed to be as streamlined and efficient as possible to minimize cost disruption to the occupants. This involved integrating the lamp controller (electronic ballast) in the pendant fixtures to avoid having to install a separate enclosure for it within the ceiling plenum—an activity that would have incurred additional materials and labor costs and required significant work in and around office cubicles. Consequently, the product vendor pre-assembled luminaires prior to installation at all 10 sites. Aside from the benefits of reducing occupant disruption and modifications to the work space, this also reduced installation errors and streamlined the installation process, thereby further reducing costs.

Leveraging the Full Benefits of Commissioning

To realize the full benefits of commissioning, the processes and methods should be transparent and effective. Some GSA project managers reported that they were not sufficiently apprised of systems operation, and that better training and documentation would be required to repeat these activities in future to ensure persistence of lighting system performance, as well as to achieve significant energy and cost savings. This particularly related to clarity over commissioned control settings, equipment performance, and operational sequences. Ideally, a commissioning agent would be provided with a protocol for commissioning that is reflected in contractual language, emphasizing the importance of a clear, well-documented commissioning process, a set of milestones that would be completed, and a set of documents that would be produced and signed off prior to the agreed project completion and handover.

Usability of Systems User Interface

Building energy systems controls software should be intuitive to operate for the target user groups; useful data should be accessible for viewing and analysis by the same. A searchable record of setting changes and a trail of their energy impacts would provide additional support for operators. Built-in diagnostics should identify and pinpoint system errors or malfunctions to 1) ensure persistent system operation and maintenance of energy savings, and 2) reduce resources that need to be allocated to system maintenance.

Be Prepared to Adapt to Project Constraints

If the resources are available to build an accurate whole-building model, it is recommended to do so; however, for smaller, less well-resourced projects this is frequently not done. Initially, analysis of the HVAC system was anticipated to be at the zone level. However, the nature of existing building monitoring systems and the available building data points did not provide sufficient detail at that level. The complex systems design, in contrast to the simple and tight project scope, led to analysis at the system (air-handling unit) level. At that level, calibration of the energy model to the trend data was simpler, by virtue of removing many unknowns from the realm of study, and therefore increasing confidence in the modeling results.

Bigger May Be Better

Implementing protocols to operate plant higher up the building energy systems chain may be less complex and time intensive. The scope of the HVAC project led to a focus on controlling the VAV boxes—at zone level. Where controls and building systems communications allow, the option of controlling at the system level, in this case, the operation of the air handling units, should also be assessed. A direct comparison of zone and system level control in terms of implementation costs and savings will determine which is best in each specific case.

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