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Zone Level Occupant-Responsive Building Energy Systems at the GSA

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DISCLAIMER

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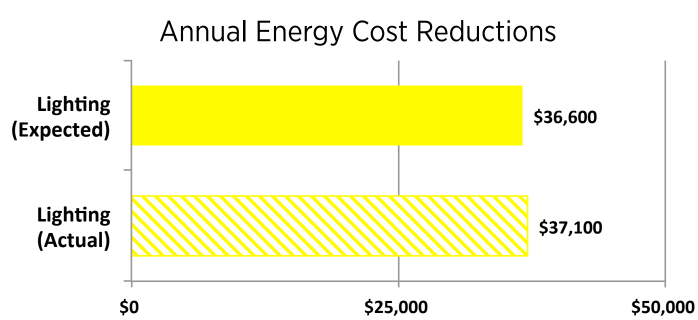
Overview

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 at least 30 percent, 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. The CBP project focused on improving the energy performance of selected buildings in the GSA's Region 9 building portfolio (Arizona, California, Nevada, and Hawaii). Seven buildings, six located in California and one in Nevada, were the focus of a CBP lighting retrofit collaboration. A key goal for the CBP project was to identify energy-saving measures that could be applied more broadly to GSA buildings elsewhere in the United States.

This case study reports measured energy savings from appropriate energy efficient design and operations modifications to lighting systems at the selected study sites. These retrofits comprise installation of new lighting systems with dimming capability and occupancy-sensor control at the individual light fixture level.



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 energy consumption and lighting quality
Square Footage of Project	200,000 — sites total
Expected Energy Savings (vs. existing energy use)	~47% — site average
Expected Energy Savings (vs. ASHRAE 90.1-2007)	~37% — sites total
Actual Energy Savings	320,000 kWh / yr electricity — sites total
Expected Cost Savings	~$37,000 — sites average
Project Simple Payback	~11 years — site average, project paybacks ranged from 3 – 30 years
Actual Cost Reductions	~$37,000 — sites total
Expected Carbon Dioxide Emissions Avoided	~88 metric tons per year — sites total
Construction Completion Date	2014 for all sites

NOTES:
1. 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.
2. Carbon emissions calculated using EPA's Greenhouse Gas Equivalencies Calculator.

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 repli¬cated across the market.

The lighting retrofits reduce lighting energy consumption by approximately 47% averaged across the seven buildings.

This project originally also comprised implementation of retrofit modifications to zone-level HVAC controls programming. These retrofits were implemented as a subset of the selected lighting sites, utilizing the same occupancy sensors that operate the new lighting. However, there were numerous challenges with the HVAC analysis arising from complexities and interdependencies of factors that influence thermal conditions within the buildings — the HVAC equipment, the numerous interacting HVAC controls protocols, the operational priorities of the system (i.e. maintaining stable temperature and meeting occupant comfort requirements) and the variable, unpredictable energy loads associated with equipment and people that work within the building itself. Statistical analysis of the HVAC data and its comparison with modeled energy use showed that it was not possible to assert with confidence that measured energy savings were a direct result of the implementation of the selected energy measure. This uncertainty means that the results of the HVAC analysis are not presented below.

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. A total of 10 study locations were selected for assessment of the lighting retrofits, which included a number of agencies and space types that resulted in a range of interior designs and workspace layouts, influencing the retrofit designs. The lighting zones typically consisted of multiple-occupant open office space and private offices, transitional areas such as corridors, and conference rooms and break areas. Zones were located in both the building perimeter and core areas. Prior to the retrofits, lighting typically consisted of recessed ceiling fixtures. Some buildings 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 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 were comprised of a combination of 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, occupancy and operation characteristics. 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 with added controls. Because of the range of space use types studied, a range of lighting control strategies were implemented 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. Study areas were a fraction of the total area proposed for the retrofits – which ranged from 50% of the building floor area to its entirety – but were selected to be broadly representative of the building use types as a whole. Lighting power density increased at 6 of the 10 sites as a result of the new lighting — this largely reflected an increase in the average number of lamps per fixture in open office areas. Despite this increase, a combination of tuning capability to a preset level significantly below 100% output for the new lights and occupancy-based control, plus dimming for daylight in perimeter areas resulted in significant energy savings. Measured energy savings for the new designs ranged from 26% - 66% across study sites.

The goal was for new designs to not only significantly reduce energy use at the selected locations, but to also provide insight into where else in the GSA building portfolio similar designs and control strategies should be implemented. The overall success of each installation depends 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 was carried out for each study site, focusing on visual comfort satisfaction and satisfaction with control settings and protocols. Surveys were distributed to the occupants, both before and after the retrofits, to determine their perceptions of their working environment with regards to lighting quality. The responses were correlated with light level measurements recorded before and after the retrofit, and with the technical performance of the new fixture and controls.

Workstation-specific pendant fixtures installed in GSA offices.

Source: LBNL

Decision Criteria

The proposed lighting EEMs were 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 installed had been piloted previously at another GSA facility, and that pilot resulted in a proposed larger-scale rollout for this CBP project.

Economic

The GSA's investments are measured using three metrics: simple payback, life-cycle cost (LCC), and savings investment ratio (SIR).[2] The target payback for EEMs is typically less than 10 years to justify investment, however, projects with expected paybacks longer that the investment threshold were 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.

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

GSA 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.[3] These goals drive decision making at the individual building, region, and federal level.

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.

The implementation of lighting energy-efficiency measures is assisting 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.

Occupant Acceptance

This CBP 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.

2. Calculated as being (Annual Energy Delivered * Cost of Electricity * Present Worth Factor) / System Cost
3. http://www.gsa.gov/portal/mediaId/162943/fileName/GSA_FY2012_Sustainability_Plan

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.
- 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 EEMs are presented by system type and by site.

Energy Efficiency Measures for Selected GSA Sites

	Implement at GSA site	Consider for Future	Annual Savings (kWh / yr)		Annual Savings ($ / yr)		Actual Cost	Simple Payback	Cost of Conserved Energy (CCE)[4]
	Yes/No	Yes/No	Expected	Actual	Expected	Actual	$	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, and installation of efficient fixtures with dimmable addressable ballasts. Lighting fixture layout was typically modified to correspond to workstation layout in open office areas, for private offices; the existing ficture layout was maintained. Details of the control strategies implemented for each site are outlined below.								Economic performance of the installed systems reflects relatively high implementation costs, with payback range reflecting site specifics such as building type and local labor rate.	
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	16,536	1,046	1,488	44,143	21.8	0.16
Ron Dellums Federal Building Site 2, Oakland, CA (24% 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	8,363	15,724	1,101	2,071	38,703	11.4	0.13
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	24,879	2,705	3,160	49,526	12.2	0.13
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	20,189	3,241	2,402	37,190	13.0	0.13

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

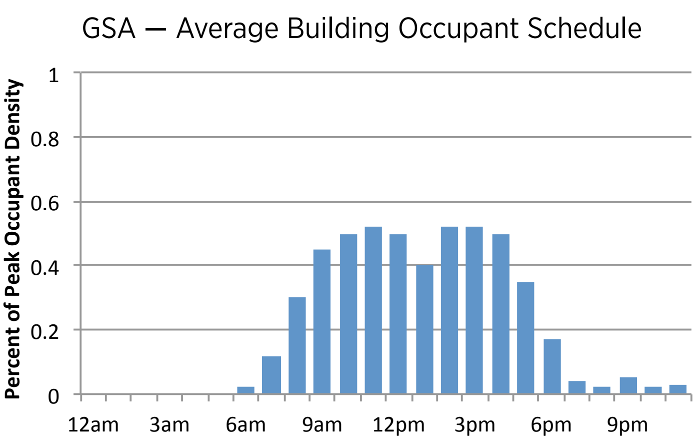
Energy Efficiency Measures for Selected GSA Sites

	Implement at GSA site	Consider for Future	Annual Savings (kWh / yr)		Annual Savings ($ / yr)		Actual Cost	Simple Payback	Cost of Conserved Energy (CCE)[4]
	Yes/No	Yes/No	Expected	Actual	Expected	Actual	$	yrs	$
Ron Dellums Federal Building Site 3, Oakland, CA (30% Energy Savings)									
See Ron Dellums Site 2 Description	No	Yes	6,428	9,828	847	1,294	20,343	9.6	0.11
Ron Dellums Federal Building Site 1, Oakland, CA (26% Energy Savings)									
See Ron Dellums Site 2 Description	No	Yes	13,578	17,888	1,788	2,356	48,117	12.5	0.14
Lloyd George Federal Building Site 2, Las Vegas, NV (56% Energy Savings)									
See Lloyd George Site 1 description	No	Yes	25,458	28,540	2,291	2,569	39,770	11.4	0.09
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	34,805	4,802	4,525	75,795	13.7	0.15
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	36,590	5,237	4,025	23,251	4.4	0.04
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	110,219	13,520	13,226	47,817	3.4	0.03

Energy Use Intensities by End Use

For the modeling phase, the project team identified and analyzed the 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 at a pilot demonstration site, filtering out false readings of occupancy and vacancy, and creating an hourly profile using average data collected over several months. This profile, shown below, was utilized in estimating the impacts of lighting-based occupancy controls at all demonstration sites.

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 system's 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.

The energy impacts of the installation of new light fixtures and operation in concert with advanced control strategies became readily apparent in the pilot conducted. The measurement and verification phase of the project confirmed what had been learned in the pilot — that well designed lighting retrofits can have a significant energy savings impact.

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 Model Results

Graphic results from several models show the measured energy savings impacts. Models 1 to 4 were created to evaluate the performance of the lighting retrofits at each of the 10 study sites. Model 3 (Proposed Design) and Model 4 (Actual Design) are compared to the two baselines - Model 1: Pre-retrofit Design and Model 2: Code Baseline (ASHRAE 90.1-2007).

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

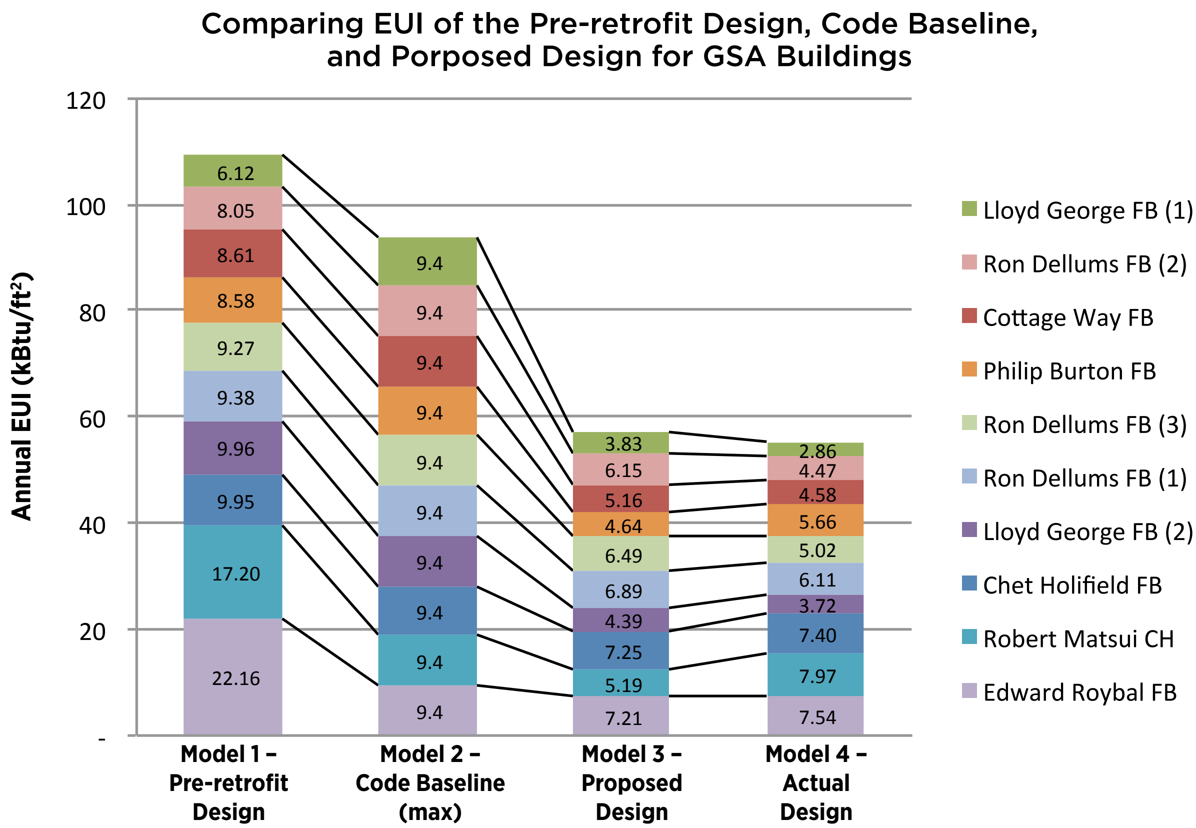
Model 2 represents the ASHRAE 90.1-2007 standard baseline for the study area of each building targeted for the lighting retrofit. This model has an annual EUI of 9.4 kBtu/ft^2 at each of the 10 sites.

Model 3: Proposed Design

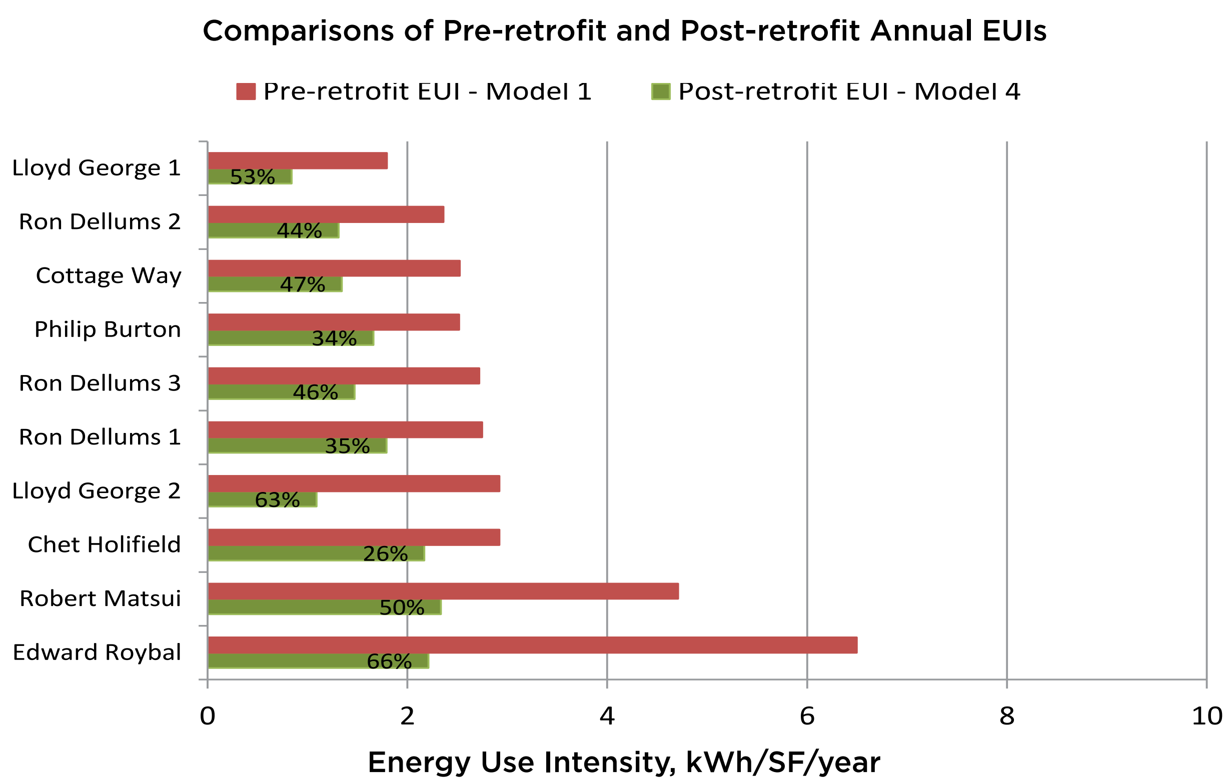
Model 3 represents the proposed design for the study area of each building and includes new lighting fixtures and an overall lighting redesign, including a new control system with occupancy and daylight harvesting sensors. It also incorporates time-scheduling and institutional setpoint tuning to meet 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.

Model 4: Actual Design

Model 4 represents the measured results for the study area of each building, including new lighting fixtures and the range of advanced lighting control measures described for Option 3. This model has an annual EUI range of 2.9 kBtu/ft^2 to 8 kBtu/ft^2 across the 10 sites.



Expected Annual Lighting Energy Use and Percentage Savings by Site



Expected Annual Energy Use and Percentage Savings by End Use

End Use Category	Model 1 – Pre-retrofit Design Annual EUI (kBtu/ft²)	Model 2 – Code Baseline (max) Annual EUI (kBtu/ft²)	Model 3 – Proposed Design Annual EUI (kBtu/ft²)	Model 4 – Actual Design Annual EUI (kBtu/ft²)	Model 4 – Actual Design Percent Savings over Original Design
Lloyd George FB (1)	6.12	9.4	3.83	2.86	53%
Ron Dellums FB (2)	8.05	9.4	6.15	4.47	44%
Cottage Way FB	8.61	9.4	5.16	4.58	47%
Philip Burton FB	8.58	9.4	4.64	5.66	34%
Ron Dellums FB (3)	9.27	9.4	6.49	5.02	46%
Ron Dellums FB (1)	9.38	9.4	6.89	6.11	35%
Lloyd George FB (2)	9.96	9.4	4.39	3.72	63%
Chet Holifield FB	9.95	9.4	7.25	7.40	26%
Robert Matsui CH	17.20	9.4	5.19	7.97	54%
Edward Roybal FB	22.16	9.4	7.21	7.54	66%

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

Electricity End Use Category	Energy Savings (across all study sites)
Interior Lighting	320,000 kWh

Lessons Learned

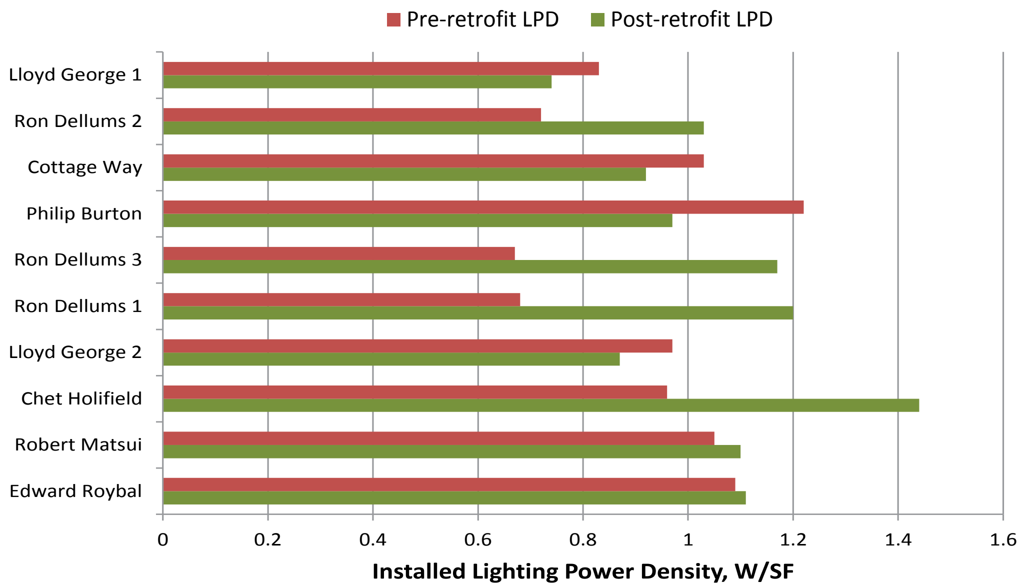
Lighting Efficacy and Performance

Lighting power density was increased at 6 of the 10 sites as a result of the installation of the new lighting and controls (see chart below), but this did not translate to higher energy use. Careful placement of fixtures in relation to work locations and implementation of tuning control, where the maximum output of lighting is adjusted to the required level, led to a higher performance lighting solution at all 10 sites.

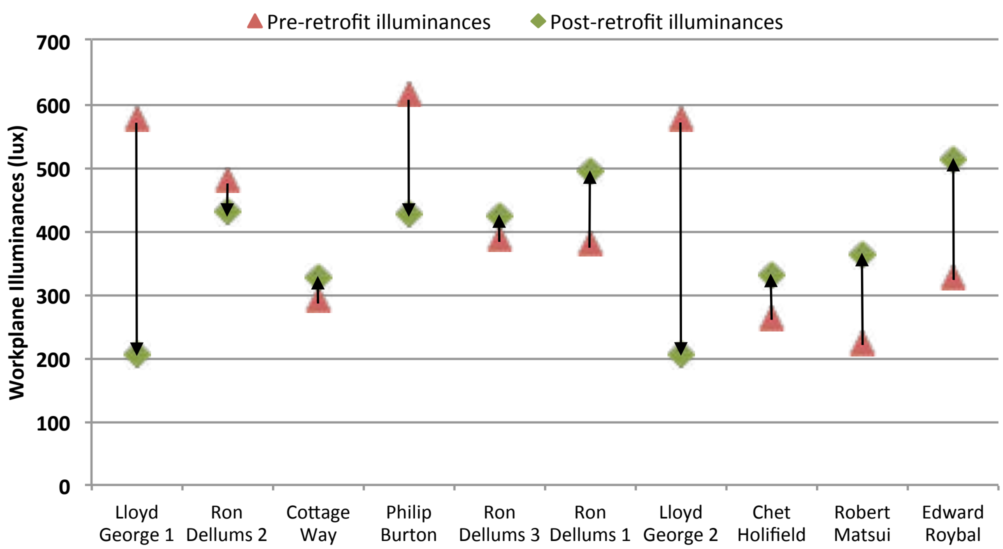
Applying the guidelines on workplane lighting levels contained in the GSA Facilities Standards for the Public Buildings Service document, also known as the P100, has led to a more uniform lighting environment at all locations (see bottom chart). The P100 refers directly to guidance in the IESNA Handbook (10th ed.), stating that workplane illuminance should be approximately 30 footcandles (or 323 lux). Light levels were increased at locations where they were not previously achieving P100.

We discovered that at the majority of sites, post-retrofit workplane illuminances were higher than under the original lighting system, with increased efficacy due to placement of fixtures over work locations and use of higher efficiency lamps. Light levels below 30 footcandles are thought to induce premature eye fatigue, and therefore impact worker productivity and comfort. Conditions brighter than the P100 guidance are acceptable, although care is needed in order to minimize glare.

Comparisons of Pre-retrofit and Post-retrofitInstalled LPDs



Comparisons of Pre-retrofit and Post-retrofit Workplane Illuminances



Occupant Satisfaction

The lighting retrofit resulted in increased occupant satisfaction — at 9 out of 10 sites, the new lighting was as good as, or preferred to, the original lighting. Overall, levels of satisfaction across sites were higher with the new lighting, with at least 8 out of 10 people happy with the lighting environment created, compared to less than 7 out of 10 for the pre-retrofit case. This is a key positive outcome as occupant perceptions are at least as important as any energy cost savings — in the absence of creating a comfortable working environment, there is little value in implementing these systems.

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. Both of these have a significant influence on the relatively high paybacks seen at the demonstration sites. 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.

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.

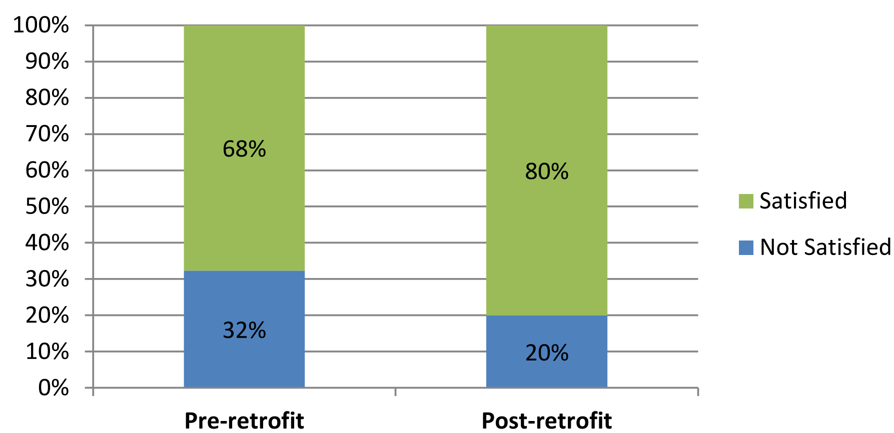
Leveraging the Full Benefits of Commissioning

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 the 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.

Comparisons of Pre-retrofit and Post-retrofit Occupant Satisfaction



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