Daylight in Existing Office Buildings: An Untapped Retrofit Resource

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ABSTRACT

Daylight in existing buildings represents a vast untapped resource for energy and demand savings, however estimating these savings is not a trivial task. Daylighting savings are influenced by multiple aspects of building design, window properties, climate, orientation, electric lighting and operation. Savings are also importantly a function of operation of window blinds or shades for glare control.

This paper describes the results from the recently completed California Energy Commission, Public Interest Energy Research (CEC PIER) project on Office Daylighting Potential (Saxena 2011), that estimated the demand and energy savings potential from adding photocontrols to existing office spaces in California, and quantified how much further those savings could be improved with additional daylighting enhancements. The California Commercial End-Use Survey (CEUS) dataset of 536 existing office premises provided the basis for the analysis. A Radiance-based annual daylighting simulation and a new façade-templates methodology were used to improve previous estimates.

The statewide results show a technical potential of 458.5 GWh of energy saving per year and 184.2 MW of peak demand reduction from the simple addition of photocontrols to existing conditions in four utility districts. The project also identified improvements from various daylighting enhancements, such as increased interior reflectances, reduced furniture partition heights, and addition of light shelves, each of which can increase savings by another 10-20%. Building types and physical characteristics of office spaces were identified that hold the greatest potential for savings, and thus could be used to target audits or utility retrofit programs for greatest impact.

Introduction

The primary goal of the research was to develop an estimate of potential energy and demand savings from daylighting in existing office buildings in California. This is the energy savings that could be realized by simply adding photocontrols to existing spaces, without changing any other physical attribute of the space. Another project goal was to estimate additional energy and demand savings from improvements made to spaces to enhance daylighting. The improvements that the project team investigated were purposely limited to those that could be easily made to existing buildings such as, reducing furniture partition heights, increasing interior reflectances and adding light shelves.

To achieve the goals of the project, a research plan was developed to collect detailed data about the physical geometries of existing offices spaces in California from CEUS (Itron 2006). Daylight availability in each office space in the CEUS dataset was then calculated using Radiance-based annual daylighting simulation. The results from these annual simulations were then used to modify existing electric lighting usage schedules of each office space from the

CEUS dataset, to represent lighting schedules of the spaces with photocontrols. Energy and demand savings were then calculated and extrapolated to a statewide savings estimate, by each utility territory and climate zone.

Existing Office Buildings Data

CEUS and its dataset of existing buildings provided the basis for the detailed data about physical geometries of existing offices buildings in California. The CEUS data (Itron 2006) used in this study included information about existing commercial facilities, called 'premises', in four major California utilities; namely Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), and Sacramento Municipal Utility District (SMUD). The data characterized building populations through the year 2002, representing about 77% of the total state electricity load for that sector. Other municipal utilities represent the remaining 23% of the state electric load, and were not included in this analysis. Thus, this is considered a 'limited statewide estimate'.

CEUS consists of eQuest (DOE2.2) simulation models developed from on-site survey data for each premise. For this study, the authors obtained special permission from the CEC to access the raw data for the 'Office' building type, representing a total of 536 eQuest models representing different types of office facilities across the state. The on-site survey data and corresponding eQuest models for the office facilities are hereafter referred to as the 'CEUS dataset'.

Limitations of CEUS Dataset

The CEUS dataset provided extremely valuable information for analysis of energy use in existing buildings through a representative sample of buildings in the state; however, it also presented some key limitations for a daylighting analysis. Simulation models have been historically created and used to estimate HVAC energy use, and the level of detail employed in these models has been sufficient to estimate HVAC loads. As discovered in this study using the CEUS dataset of eQuest (DOE2) models, details that have a significant impact on the daylighting of a space were either greatly simplified, poorly incorporated, or missed all together. For example, window size and placement was reduced to one centralized area per wall. Data on exterior obstructions due to trees and other buildings, interior partitions and walls within thermal zones, interior finishes and reflectances, and type of window blinds/shades are further examples of inputs that were not captured at all in the CEUS database. Beyond these serious limitations, we also discovered inaccuracies in the models, especially in glazing properties, such as there was little or no information about the variation of window tints and glazing type. The team worked to collect additional information about window tint as well as exterior obstructions from the raw site data to improve the daylighting analysis.

CEUS eQuest models divide buildings into 'spaces' which represent aggregate HVAC thermal zones, but not 'rooms' in the sense of lighting analysis. For example, 10 private offices along a façade, plus interior open office work area could likely all be categorized as one CEUS thermal zone or 'space.' For our analysis, we had to add assumptions about typical office layouts for both partitions and furniture.

Existing Office Characteristics

Analysis of the CEUS dataset revealed important characteristics of existing office buildings in California, which the team used to refine the methodology for the study.

Building Characteristics

Analysis showed that 75% of office square footage in California was low rise, i.e. under four stories. Given the largely suburban nature of California this result is not surprising, but stands in contradiction to many people's image of offices as existing primarily in high rise downtown buildings. The average site 'footprint' of office buildings in California was 6,491 sf, but three-quarters of offices had a footprint under 3,600 sf. The ceiling height (excluding plenum) was an average of 9.4 ft, with a median of 9 ft. On average, the lighting power density was found to be 1.28 W/sf, with half the office spaces having a lighting power density between 0.81 W/sf and 1.59 W/sf.

Window to Wall Ratio (WWR)

The average building Gross-WWR[1] was 17%, and Net-WWR[2] was 25%. However, there were a large number of spaces in the sample that had at least one exterior wall but no windows. When excluding these non-windowed spaces, the average Gross-WWR was 24%, and Net-WWR was 38%, with about half the spaces having a Net-WWR above 39%. Most exterior walls had a Net-WWR between 21% and 52%. Window sill height measured 2.1 ft on average, while head height was 7.3 ft on average. In the case of WWR, we did not observe a smooth distribution of data but rather discontinuity related to design and construction type.

Skylights: Skylights could be found in 5.6% of office spaces in California, and these spaces had an average skylight to roof ratio (SRR) of 1.1%. One possible reason that this average SRR was so low is that is applied to the HVAC 'space' per discussion above, rather than an illuminated 'room'.

Photocontrols

The percent of daylit areas identified with existing photocontrols was less than 1%. This finding is supported by earlier findings such as from HMG field study of sidelighting and photocontrols (HMG 2005) that estimated that as of 2004, there were only about 200 sidelit buildings that the research team could find with installed photocontrols on the west coast. This result shows that there is great potential for retrofitting photocontrols in existing office buildings for energy savings in the state.

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[1] Gross-WWR is defined as the ratio of total widow area to total exterior wall area in the building including the plenum walls.

[2] Net-WWR is defined as the ratio of total widow area to total interior wall area in a space, excluding the plenum walls.

Window Characteristics

A vast majority of existing office buildings in California had either clear or medium tint windows, representing 42% and 50% of the total state's office floor area respectively. Dark tint windows were uncommon, found in only 8% of office floor area. For this study, window layouts on facades were categorized as: punched, grouped, strip, and curtain wall. The four types of window layouts were found to be more or less evenly distributed across the dataset. The high proportion of clear and medium tint windows bodes well for a daylighting retrofit program, implying that the 1980s fashion for very dark tinted windows has not impacted too large a proportion of the state's building stock.

Exterior Obstruction Characteristics

Exterior shading information was collected for trees, adjacent buildings, and exterior attachments. The results show that 60% of all total office floor area had some shading from trees. This was a key finding as it showed that a majority of office buildings in California have at least some type of obstruction provided by trees. The 2-4 story office buildings were most likely to have trees obstructions. A large majority of office buildings (83%) "saw" little to no obstructions from adjacent structures or urban shading. However, 41% of total floor area of high rise buildings, which were mostly located in dense urban downtowns, were impacted by heavy urban shading to some degree. An overwhelming majority of office buildings (95%) had no exterior window attachments like screens, awnings or advertisements. The remaining 5% had either screens or awnings. Overall, this information suggests that cooling load impacts of window solar gains tend to be overestimated in energy analysis dependent upon the CEUS database, since all those models assume no exterior obstruction of solar gains except form self-shading. This overestimation is also likely compounded by the glazing modeling errors in CEUS mentioned earlier.

Analysis Approach

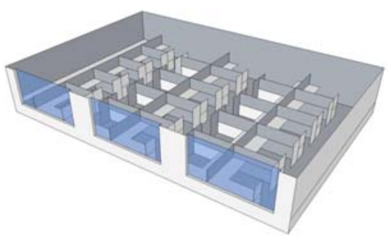
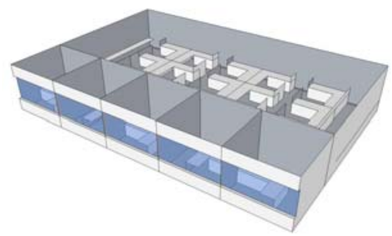
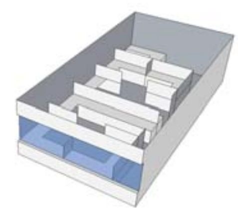
The project team considered multiple approaches of using the CEUS dataset as input for annual simulations in either eQuest (DOE2) or Radiance. Each approach varied in complexity of pre- and post- processing of simulation data, simulation run times issues, as well as in addressing CEUS dataset limitations. Working within the constraints of the project, the project team developed an innovative approach of using 'façade templates' to tackle the challenge of running a large number of annual daylighting simulations with Radiance based on the CEUS dataset while maintaining a representative sample.

Façade Templates

Façade templates are generic representations of various façade types, attached to one of three generic office layouts (Figure 1), which were then modeled in Radiance. Annual illuminance results from these templates were then mapped back to all the façade variations found in the 536 CEUS office models. The mapping process involved modifying the electric lighting schedule for a space based on daylight illuminance patterns for each façade template, thus enabling calculation of electric lighting energy savings. The variations in façade design incorporated different window layouts, glazing characteristics, and other building characteristics such as overhangs, ceiling heights, etc.

Each facade template represented one wall orientation of a floor of a building. Thus a simple rectangular building, for example, might be composed of 4 ‘facades’ per floor. This approach of using façade templates allowed the team to minimize run times in Radiance compared to a direct simulation of each space in the CEUS dataset. A total of 5,184 façade templates were developed and run for this study, and mapped to 7,979 individual façades representing the 536 building models in the CEUS dataset.

Figure 1. Façade Templates for Office Spaces

		
Large open office layout	Large private office layout	Small office layout

A great advantage of this approach was that the limitations inherent in the CEUS eQuest models could be addressed in the design of the façade templates. For example window layouts could be designed in each façade template, instead of modifying each CEUS eQuest model. Similarly, ambiguity of space versus HVAC thermal zone definition could be addressed using an open, private or small office template, which represented spaces as defined by floor to ceiling partitions, and not thermal zones, as shown in Figure 1. Variations in furniture, interior partition heights, surface reflectances, and exterior obstructions could be added as layers to the template spaces and modified in parametric runs.

Radiance Simulations

Radiance is a reverse ray-tracing simulation program (Ward 1994), known to provide a higher level of accuracy in predicting daylight levels, especially compared to the default daylighting algorithms in eQuest (DOE2) and EnergyPlus (Reinhart & Jones 2004; Koti & Addison 2007). Radiance files were developed for each façade template space, and annual daylighting simulations were run to predict hourly daylighting illuminance levels. To allow Radiance to capture the effect of blinds or shades and their operation, the project team employed the recently developed method of running matrix based daylighting simulations with Radiance called the ‘Dynamic Radiance approach’ (Saxena 2010; Heschong et al. 2010). This approach, also known as the ‘Three-phase daylight coefficient method’ (Ward et al. 2010) can predict interior daylight distribution with varying sun positions and/or operating schedule of a blinds or shades layer with significantly reduced run-times.

The layer representing blinds or shades (hereafter, referred to as ‘blinds’ for brevity) in Dynamic Radiance approach is defined in the form of bidirectional scattering distribution function (BSDF), a data description format, describing resulting hemispherical daylight distribution in the space, which can be varied hourly. This allows modeling of blinds operation at an hourly time-step in the annual simulation.

Illuminance sensors were located at task level (30" AFF) on a 1' square grid throughout each space.

Climate zones. In order to keep the run times and data processing manageable, four out of sixteen California climate zones were chosen to represent four basic climate categories in California: North coastal - Heating dominated (CZ2), Central valley - Intermediate (CZ12), Sunny inland - Cooling dominated (CZ13) and South coastal - Mild (CZ6). A total of 20,736 simulations results for the 5,184 template spaces were generated.

Blinds definition and operation. The Daylight Metrics project (Heschong 2011) showed that windows blinds, and their operation play a critical role in determining the quantity of daylight in a space. To model typical mini-blinds or venetian blinds, a BSDF file was generated using WINDOW 6 software from Lawrence Berkeley National Laboratory (LBNL).

The Daylight Metrics study also found from both site interviews and survey data that the occupants were actively using the blinds to modulate daylight and sun penetration in their spaces. Thus, it was determined that modeling blinds operation, hourly by orientation, was necessary to generate more realistic annual daylight conditions in the study spaces.

This study used a standardized blinds operation trigger developed for the Daylight Metrics study, and subsequently adopted into a new Illuminating Engineering Society (IES) calculation protocol, based on the risk of sunlight penetrating into a space. Blinds for any window group, grouped by orientation and shading characteristics, were closed for each hour when 2% or more of the sensors in the space were found to be in direct sunlight. While this is an aggressive operation schedule, it was judged to be the minimum condition likely to be employed by space occupants.

Lighting and HVAC Energy Savings

To model electric lighting savings, the 1' grid illuminance data from the Radiance runs was compiled into 'lighting zones' for each space, in 8' depth increments from a window. A single photocontrol was assumed for each 8' deep zone, responding to the lowest 10^{th} percentile illuminance sensor reporting for that zone. Two lighting control strategies were modeled, one a two-level-plus-off switching system; the other a continuous dimming system, with a minimum of 20% output, and slightly decreasing efficiencies at low output. Lighting operation schedules were as reported for each CEUS space. Target illumination was set at 300 lux.

When electric lights are turned off or dimmed, the associated heat from those lights is also reduced. This is seen as a reduced cooling load in the summer time and an increased heating load in the winter. To estimate the effect of turning off electric lights using photocontrols on HVAC energy use in the CEUS space, the project team utilized the Database for Energy Efficient Resources (DEER) interactive HVAC factors (DEER 2008).

Findings: Energy Savings Potential

The results for technical potential of energy savings from daylighting in existing office buildings in California are provided at 'limited' statewide level. In this paper we have provided results mostly with a two-level-plus-off switching photocontrol system. Additional results and analysis, by the four major utility areas, climate zones, and for dimming systems can be found in the Appendix to the PIER Office Daylighting Potential report (Saxena 2011).

Statewide Energy and Demand Savings

Table 1 provides lighting and HVAC savings for the 'limited' statewide estimate. Savings are given for All Office Buildings, Small Offices (SOFF <30,000 sf) and Large offices (LOFF >30,000 sf). Negative values are in parentheses.

Table 1. Statewide Energy and Demand Savings from Daylighting

LIGHTING AND HVAC SAVINGS

Results for >> **CA Statewide**

	Energy Savings (GWh)	Demand Savings (MW)	Gas Savings (Mtherms)
All Office Bldgs	458.53	184.24	(1.56)
SOFF (<30,000 sf)	207.00	86.32	(0.37)
LOFF (>30,000 sf)	251.53	97.92	(1.19)

The results show that the total annual statewide energy and demand savings[3] from 'All Office Buildings', from adding a two-level-plus-off switching system was 458.53 GWh and 184.24 MW, when lighting and associated HVAC impacts are considered together. The tables also show that the energy and demand savings were fairly evenly split between small and large offices at the statewide level. The tables also show that the increase in heating energy was very small in magnitude compared to the electric energy and demand savings.

Results by Building Area

Table 2 provides statewide energy and demand savings estimates per square foot of office building floor area (Building level analysis). In the building level analysis, building area consists of all spaces in the building, i.e. the daylit perimeter as well as the non-daylit core. The table reports energy and demand savings for a 2-level switching photocontrol system.

Average lighting and HVAC energy savings calculated per square foot of building area for all office buildings in California was 0.70 kWh/sf-yr. Compared to baseline average interior lighting energy use of 4.24 kWh/sf-yr and total energy use of 16.08 kWh/sf-yr, the daylighting savings amount to a 16.5% reduction of a building's interior lighting energy use, or a 4.4% reduction in total energy use.

With all office buildings considered, an average of 23% of building area falls in primary daylight zones and 31% in all daylit zones, which includes secondary and tertiary. As can be expected, on average, about three quarters of the total energy savings (76%) were found in the primary daylit zones.

The results broken down by small and large office show that annual energy savings per building square foot in small office buildings was consistently higher than that of large offices. This is an expected result as daylighting savings are mainly found in the perimeter of a floor plan

[3] Technical potential for limited statewide population

(for sidelit office spaces), and large offices have larger floor plans with more central core area. Small offices with larger window areas had the highest average savings per square foot of building, at 0.95 kWh/sf. The average savings were 44% to 67% higher for buildings with larger window areas, compared to those with smaller window areas.

Table 2. Energy & Demand Savings Per sf - At Bldg. Level

LIGHTING AND HVAC SAVINGS - BUILDING LEVEL ANALYSIS

Results for >> **CA Statewide**

		Energy Savings per Bldg sf kWh/sf-yr	Peak Demand Reduction per Bldg sf W/sf	Total Building Area Msf	Average Building area sf	% Bldg area in primary daylit zone %	% Bldg area in all daylit zones %	% Energy savings - primary daylit zones %
All Office Bldgs		0.70	0.29	1002.75	7,088	23%	31%	76%
SOFF (<30,000sf)	Gross WWR < .20	0.66	0.27	237.51	2,204	23%	30%	77%
	Gross WWR > .20	0.95	0.39	76.95	4,915	22%	37%	67%
	Skylight	0.86	0.41	37.03	4,352	35%	40%	93%
LOFF (>30,000sf)	Gross WWR < .20	0.28	0.11	180.05	60,674	8%	10%	72%
	Gross WWR > .20	0.47	0.19	407.71	75,081	12%	16%	73%
	Skylight	0.45	0.18	63.50	55,592	14%	17%	93%

Gross WWR: Ratio of total window area to total exterior wall area in the building including plenum walls
SOFF: Small Office, LOFF: Large Office

The tables also provide the total building area under each category in million sf (Msf). In general it was found that while small offices buildings tend to have higher energy and peak demand savings potential, there is almost two times as much large office building area as there is a small office building area in California, resulting in greater overall savings potential for large offices taken in aggregate. Notably, the average large office size is about 10 to 14 times the average small office.

Results by Space Area, and Daylight Improvements

In the space level analysis, the space area consists of all HVAC zones (hereafter referred to as spaces), in a building that have at least one daylit zone, i.e. spaces with at least one window or a skylight. Theses spaces represent areas that have "daylighting potential", and thus exclude spaces such as core elevator lobbies, basements, or interior corridors with no window or skylights. These spaces are referred to in this section as "daylit spaces". Table 3 provides statewide energy and demand savings estimates for photocontrols only (PC's only) per square foot of these daylit space areas, and for four categories of daylight improvements.

The results for each category of improvement are separated into three groups, smaller and larger WWR.

- PC's Only: Savings from adding photocontrols only, baseline comparison.
- FF01: Reduce furniture partition height from 60" to 45"
- FF02: Reduce furniture partition height from 60" to 30"

- IS01: Increase interior surface reflectance from 20/50/70 to 30/60/85 ,where the values are for floor/wall/ceiling
- LS01: Change from no light shelves on any windows to adding 3’ deep light shelves located 8’ above the floor. Light shelves were added to only South, South-East or South-West facing windows, in spaces with where the ceiling height was 10’ or more, and the windows extended up to the ceiling.

Table 3. Energy & Demand Savings - From Daylighting Improvements

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

			Energy Savings per Space sf kWh/sf-yr	Percent Savings Increase %	Peak Demand Reduction per Space sf W/sf	Percent Demand Reduction Increase %	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf
2-level Switching	**All Daylit Spaces**	PC's Only	0.91	-	0.38	-	2.26	0.85
		FF01	0.97	7%	0.40	6%	2.47	0.99
		FF02	0.95	4%	0.39	3%	2.42	0.98
		IS01	1.04	15%	0.44	17%	2.61	1.07
		LS01	0.91	0%	0.38	0%	2.49	1.00
	Net WWR < .40	PC's Only	0.79	-	0.34	-	2.14	0.83
		FF01	0.79	0%	0.33	-1%	2.27	0.93
		FF02	0.75	-5%	0.31	-8%	2.22	0.92
		IS01	0.89	13%	0.39	16%	2.44	1.02
		LS01	0.76	-4%	0.32	-5%	2.29	0.94
	Net WWR > .40	PC's Only	1.24	-	0.48	-	2.57	0.89
		FF01	1.36	10%	0.52	10%	2.71	0.98
		FF02	1.41	14%	0.54	14%	2.67	0.98
		IS01	1.32	6%	0.50	6%	2.78	1.00
		LS01	1.19	-4%	0.46	-4%	2.73	0.99

Net WWR: Ratio of total window area to total interior wall area in the building excluding plenum walls

Of the four improvements reported, increasing interior surface reflectances (IS01) was found to be the most consistent at providing energy and demand savings across all three space categories. It also had the highest average energy savings improvement at 15%.

Reducing furniture partition heights from 60” to 45” (FF01) and 60” to 30” (FF02) also showed significant energy savings improvements, but only in those spaces with larger window areas, i.e. Net-WWR > 0.40. For those spaces with larger window areas, the savings increase was 10% for FF01 and 14% for FF02. This result also showed that greatest boost in energy savings is achieved in reducing partition heights from 60” to 45”; reducing partition heights further by another 15” to 30” has significant, but much smaller improvement. In spaces with smaller window areas, there was little or even slightly negative savings with lower furniture heights. The negative savings were due to reduced daylight levels caused by the absence of a bounce of daylight from the higher furniture into the primary daylit zone.

The results show that an average for all office spaces in the state, there was minimal or no improvement from light shelves, largely due to the limited area that qualified: light shelves were only included if the space was South, South-East or South-West facing, had a ceiling height of

10' or more and windows extends to the top of the ceiling. This condition was only met in 11.2% of all statewide office area (15.4% of daylit spaces). The remaining 88.8% of office area did not qualify for light shelves. The value of 11.2% represents the statewide market potential for light shelves in California. The savings in only those spaces that received light shelves in our analysis is provided in Table 4 below.

Table 4: Energy & Demand Savings for Only Spaces with Light Shelves

LIGHTING AND HVAC SAVINGS - SPACE LEVEL ANALYSIS

Results for >> **CA Statewide**

		Energy Savings per Space sf kWh/sf-yr	Percent Savings Increase %	Peak Demand Reduction per Space sf W/sf	Percent Demand Reduction Increase %	Energy Savings per Primary Daylit Zone sf kWh/sf-yr	Peak Demand Reduction per Pri. Daylit Zone sf W/sf
2-level Switching	PC's Only	1.06	-	0.41	-	3.29	1.19
	LS01 (Spaces with LS)	1.08	3%	0.41	1%	3.30	1.20

These results show when only those spaces are considered that are suitable for light shelves, the measure has a small bump in energy savings of 3%. Peak demand reduction also has a slight improvement, by 1%.

Implications for Daylighting Retrofit Programs

Existing office buildings offer an important opportunity for new energy savings through the addition of photocontrols. Existing office buildings were typically designed with ample windows to admit daylight and provide occupants with view to the outdoors. With the addition of photocontrols, significant energy and demand savings from lighting and HVAC energy reductions can be obtained with little imposition, and fairly low cost.

The results from this study provide estimates for average annual energy savings from photocontrols in office spaces in California, as well as information about which building types have the greatest potential for daylighting savings, and how much those savings can be enhanced with practical improvements.

With these results, energy efficiency programs run by utilities or other entities can tailor a targeted approach for a daylighting retrofit program that could incentivize the cost and installation of photocontrols and dimming ballasts in office buildings. A recent survey of photocontrols cost conducted for the California Title 24 Codes and Standards Enhancements (CASE) work (California Utilities Statewide Codes and Standards Team 2011) found that the cost to purchase and install a switching photocontrol system for a room with one façade with windows, was between $350 to $560, and that for a dimming photocontrol system was between $470 to $890[4]. These costs reflect new construction for daylit areas[5] ranging from 250sf to 900sf. Costs for retrofits are likely to be higher, due to additional installation costs. The CASE report also found that the cost of photocontrols has dropped significantly in the last few years.

[4] Costs do not include cost of dimming ballasts

[5] Daylit areas as defined as in Title 24 - is the area on a plan directly adjacent to each vertical glazing, one window head height deep into the area, and window width plus 2' wide on each side of the rough opening of the window.

A daylighting retrofit incentive program should logically target buildings with the greatest opportunity first. The results show that small office buildings generally have a building-wide per square foot energy savings potential that is two or more times that of large office buildings, primarily because small offices have a higher percentage of daylit area per building. However, at a statewide level, there is about twice as much large office area as there is small office area, thus a greater overall opportunity for larger buildings. It is also important to note that buildings with larger window areas have greater saving potential.

Based on results from daylighting improvements, it is recommended that a retrofit program that incentivizes photocontrols should also include mandates or higher incentives for simple improvements to the spaces to enhance energy savings from daylighting, such as replacing ceiling acoustic tiles and painting walls to achieve higher visible light reflectance, and replacing existing office furniture with reduced partition heights and/or transparent panels.

The Next Frontier: Window Attachments

An important finding of the Daylight Metrics project (Heschong 2011), echoed in this study, is the opportunity to use improved window blinds and shades to greatly increase daylight availability. Blinds, shades, louvers, awnings etc. collectively called window attachments, are common retrofit options at tenant turnover that can impact daylighting savings in a big way, either positive or negative. Simple improvements in the design and operation of blinds, such as lighter colors, split operation for upper and lower panels, and default operational settings, can have a sizable impact on the annual daylight availability and finally the building's energy use.

Nuances in the optics of blind designs, and assumptions about their hourly operation, can now be modeled more accurately in annual simulation because of the recent improvements in tools like Window 6 (LBNL 2006), development of product optical performance reporting formats like BSDFs, and annual simulation daylighting tools like the Dynamic Radiance approach/Three-phase daylight coefficient method. With these new tools, we now have the means to evaluate the energy savings impacts of retrofit products for window attachments already in the market today.

Window attachments that redirect sunlight from the upper window to the ceiling, either through micro optics on window films, or with more traditional reflective louvers or blinds, effectively extend the daylit area even further into the space from the window. The 'lightshelf' option from this project provides a minimum expected impact of such products, but generally optics of light redirecting attachments are significantly improved over simple lightshelves. Thus, the next frontier for daylighting retrofits is to take a step beyond the most obvious retrofit options considered in this paper, and look to improve window attachment optics and operation.

References

California Utilities Statewide Codes and Standards Team. 2011. *California Utilities Statewide Codes and Standards Team Draft Measure Information Templates*. 2013 California Building Energy Efficiency Standards. California Energy Commission, Calif.

Database for Energy Efficient Resources (DEER). 2008. *Summary of Measure Energy Analysis Revisions*. Version 2008.2.05 for 2009-2011 Planning/Reporting.

Heschong Mahone Group (HMG). 2005. *Sidelighting Photocontrols Field Study*. Southern California Edison Co., Pacific Gas and Electric Co., Northwest Energy Efficiency Alliance.

Heschong, L. 2011. *Daylight Metrics*. Publication number: CEC-500-2012-053. California Energy Commission, Calif.

Heschong, L., M. Saxena, R. Higa. 2010. Improving Prediction of Daylighting Performance. In *Proceeding of ACEEE 2010 Summer Study on Energy Efficiency in Buildings, Pacific Grove, Calif.*

Itron. 2006. California Commercial End-Use Survey. Publication number: CEC-400-2006-005. California Energy Commission, Calif.

Koti, R., M. Addison. 2007. “An Assessment of Aiding DOE-2’s Simplified Daylighting Method with DAYSIM’s”. In *Proceeding of Solar 2007 Conference, Cleveland, Ohio*.

Reinhart, C., C. Jones. 2004. “Electric lighting energy savings for an on/off photocell control – a comparative simulation study using DOE2.1 and DAYSIM”. In *Proceeding of eSim 2004, Vancouver, B.C.*

Saxena, M. 2011. *Office Daylighting Potential.* Public Interest Energy Research, California Energy Commission, Calif.

Saxena, M., G. Ward, T. Perry, L. Heschong, R. Higa. 2010. “Dynamic Radiance – Predicting Annual Daylighting with Variable Fenestration Optics Using BSDFs”. In *Proceeding of the SimBuild 2010.* New York, N.Y.: International Building Performance Simulation Association.

Ward, G. 1994. “The RADIANCE Lighting Simulation and Rendering System”. In *Proceeding of SIGGRAPH 1994*.

Ward, G., R. Mistrick, , E. S. Lee, , A. McNeil, J. Jonsson. 2010. “Simulating the Daylight Performance of Complex Fenestration Systems using Bidirectional Scattering Distribution Functions within Radiance”. In *Proceeding of the Annual Conference of the Illuminating Engineering Society, Toronto, Canada.*

Windows & Daylighting Group. 2006. *WINDOW 6.1 / THERM 6.1 Research Version User Manual*. Lawrence Berkeley National Lab, Berkeley, Calif.