Advanced lighting upgrades in daylit offices improve comfort and lighting quality

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

High-resolution lighting and shading controls enable comfortable, energy efficient, daylit work office environments

Four types of LED lighting with high-resolution, luminaire-level controls and automated roller shades were evaluated in a 3700 m² Living Laboratory in New York City. The innovative systems delivered significant lighting energy savings with enhanced indoor environmental quality and comfort.

The project

A Living Laboratory was constructed on an upper floor of a high-rise office building in Manhattan (Fig. 1) to evaluate advanced lighting and daylighting retrofit options under normal occupied conditions. The owner intended to apply lessons learned across their global real estate portfolio. The Laboratory enabled the owner and employees to experience and compare the new visual environment to prior conditions, understand the unique features of the various solutions, obtain user feedback, and compare replacement options and costs associated with the upgrade. Monitored results, design guidelines, and procurement specifications were shared publicly to support a new New York City local law mandating energy efficient lighting upgrades and to reduce peak electric demand to improve grid resiliency. An educational series for design professionals, owners,

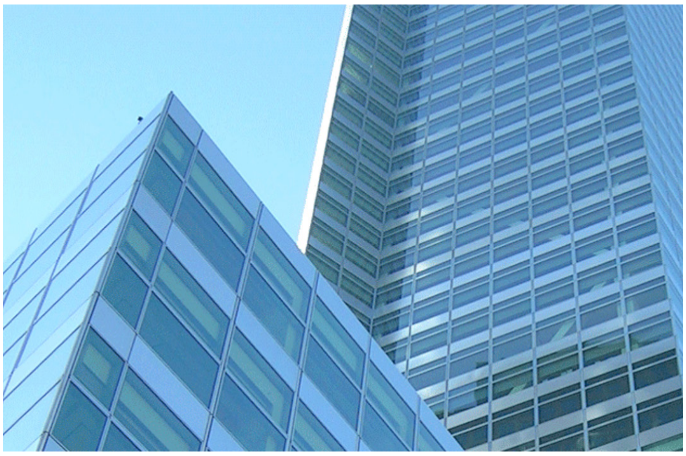
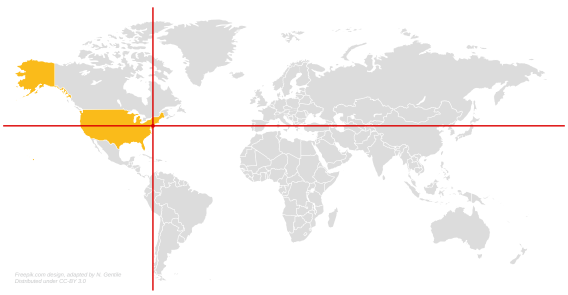


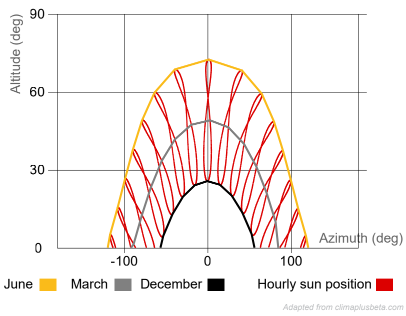
Figure 1. Exterior facade of the monitored commercial office building.

installers, and facility managers was developed and delivered in over 100 interactive sessions. A second hands-on tech series trained over a thousand electricians on installation and commissioning best practices.

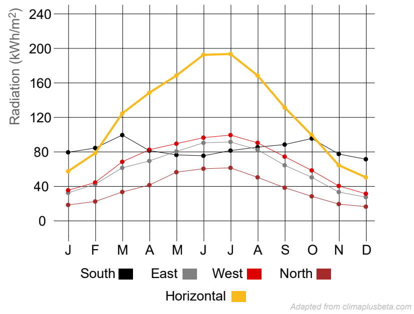
Retrofit options included high-resolution lighting systems with individually-addressable, direct-indirect LED luminaires, separate dimming control of up- versus down-light output, and setpoint tuning, occupancy, scheduling, and daylighting control. This network of luminaires enabled fine spatial, spectral (i.e., daylight + electric light mix), and temporal control across the open plan floor plate. A



Location: New York City, New York, USA
40.71° N, 74.0° W



Sun path for
New York City, New York, USA



Global horizontal and vertical radiation for
New York City, New York, USA

IEA SHC Task 61 Subtask D

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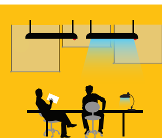

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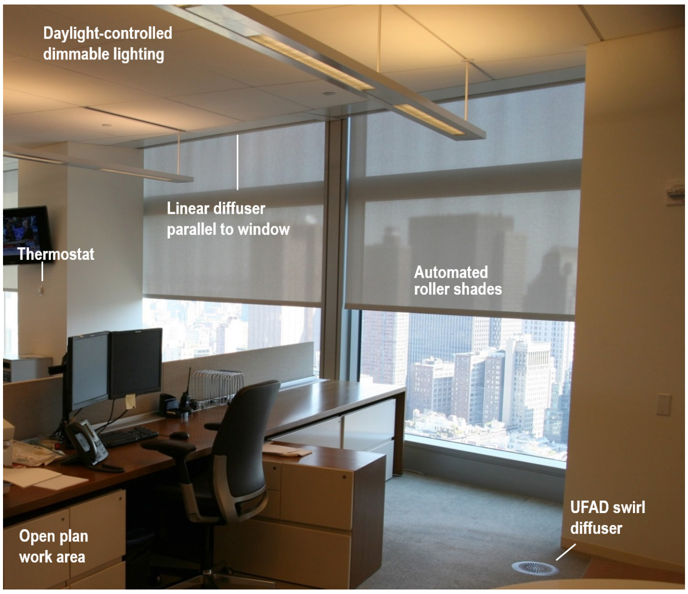

Figure 2. View of the open plan office with automated shades.

mesh network of sensors throughout the open plan space detected local light levels and occupancy. A new shading system automated to control visual and thermal comfort, view, solar heat gains, and daylight was also evaluated (Fig. 2). The building's existing system consisted of direct-indirect T5 fluorescent luminaires with scheduled, area-wide controls, daylighting controls for the row of luminaires closest to the windows, and an alternate automated roller shade system.

Monitoring

The Living Lab floor was divided into four 12.2 m deep quadrants. Four lighting and two shading systems were installed. Monitored data were compared to data collected simultaneously on a reference floor with the existing conditions. Continuous monitoring of lighting energy use, illuminance, temperatures, humidity, air velocity, and control status of luminaires and shades was performed for a year leading up to the retrofit (March 2014 to June 2015) then for a six-month, solstice-to-solstice period following the retrofit (December to June 2016). Time lapsed, high dynamic range (HDR) and infrared thermal images were obtained on select days during solstice and equinox periods. A survey was issued to occupants on both reference and Living Lab floors at the conclusion of the monitored period to assess comfort and satisfaction with the installations.

Energy

Compared to the reference floor, annual lighting energy use was reduced by 36 kWh/m^{2}yr (79%) while peak electric demand was reduced by 6.78 W/m^2 (74%). Of the total savings during weekdays, 41-59% was due to the change from T5 to LED luminaires, 27-51% was due to setpoint tuning, and 8-14% was due to occupancy and daylighting (range in savings reflects the four zone orientations). On average, LED source savings made up 51% of the total savings while advanced controls made up 49% of the savings. Example quadrant-level savings are represented in the waterfall graph shown in Figure 3. Savings were due to dimming of all networked addressable luminaires across the entire perimeter zone, not just the luminaires nearest the window. Occupancy controls were implemented at a 40-60 m^2 resolution. The photosensor-to-luminaire ratio ranged from 1:1 to 1:6, where readings from one or more photosensors could be used to control a single luminaire.

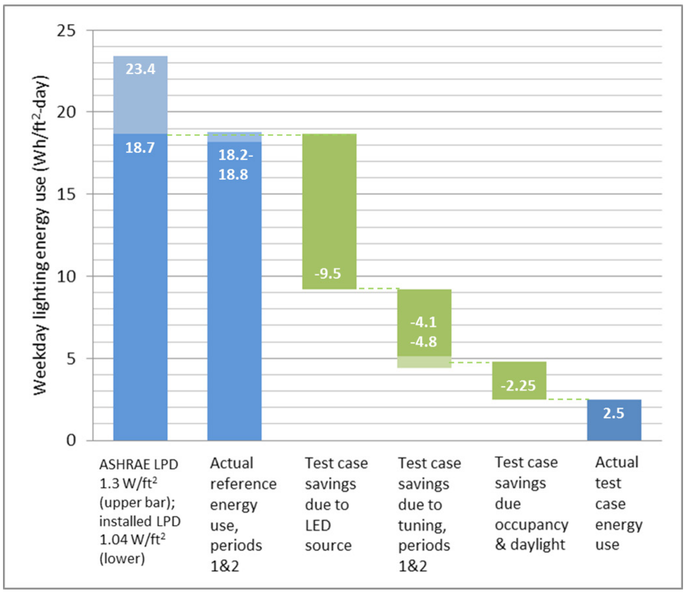

Figure 3. Annual lighting energy savings in southwest quadrant G1 (weekdays only).

Additional energy savings from daylighting could have been obtained but in some quadrants, the lighting dimming response was set more conservatively. In one quadrant, for example, daylight illuminance levels exceeded the 200-300 lx setpoint for 47%, 38%, and 25% of the monitored period at the three sensor depths of 0.76, 3.02, and 5.24 m from the window whereas dimming in the deeper zones was minimal to none (Fig. 4).

Photometry

Work close to the windows involved intense use of multiple, large-area computer displays so control of excessive daylight, direct sunlight, and glare was essential. At the same time, a spacious, well lit work environment with views to the outdoors is highly desirable. The combined lighting and automated shades helped to balance these two competing goals.

Total workplane illuminance levels at a depth of 0.76 m from the window were maintained within an acceptable

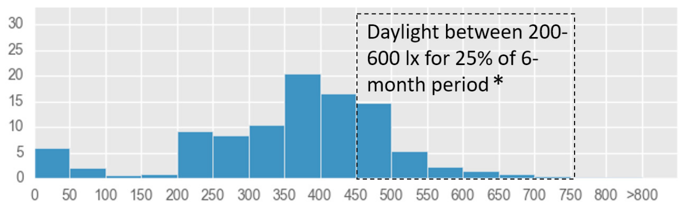

Figure 4. Percentage of time (y-axis) that total workplane illuminance at 5.24 m from the window was within the binned range. Daylight levels estimated assuming that 250 lx was provided by electric lighting at all times. Northwest quadrant G2.

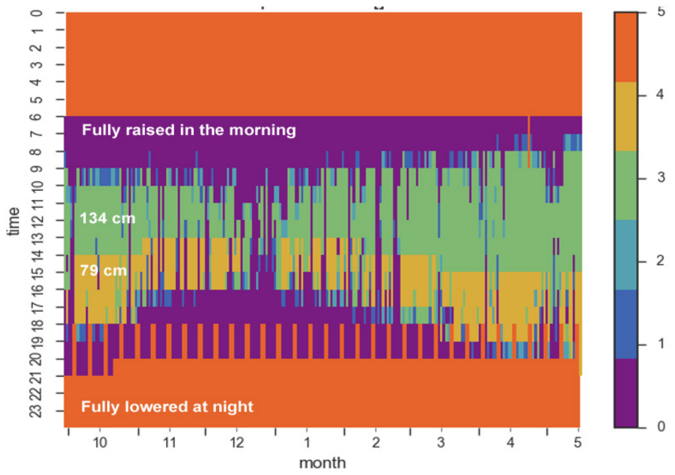

Figure 5. Height of automated shade per hour of day and day of year (including weekends) in the G1 southwest quadrant. Height of lower edge of shade above floor level (cm).

range due to the automated shades (light grey fabric with a 1% openness factor). For 81% of the monitored period, illuminance levels were within the range of 250-2000 lx and exceeded 2000 lx for no more than 1% or 21 hours of the monitored period in each of the four perimeter quadrants.

When possible, the shades were raised to a height that enabled views out, reduced glare from the bright sky, and provided diffuse daylight further from the window (Fig. 5 & 6). To counteract the brightness contrast between areas nearest and furthest from the window, all up-lights remained ON (at no lower than 70% output) irrespective of occupancy during core working hours so as to maintain a bright ceiling plane across the open plan work areas.

Measured data indicated minimal visual discomfort. HDR measurements were conducted with views parallel to the window at the first workstation closest to the window (Fig. 7) – the automated shading was programmed to control discomfort glare for this angle of view. During all periods, visual comfort was maintained within acceptable limits (Daylight Glare Probability (DGP) Class A) in all perimeter zones over the course of the day. The closely-woven fabric reduced discomfort glare for views facing the window.

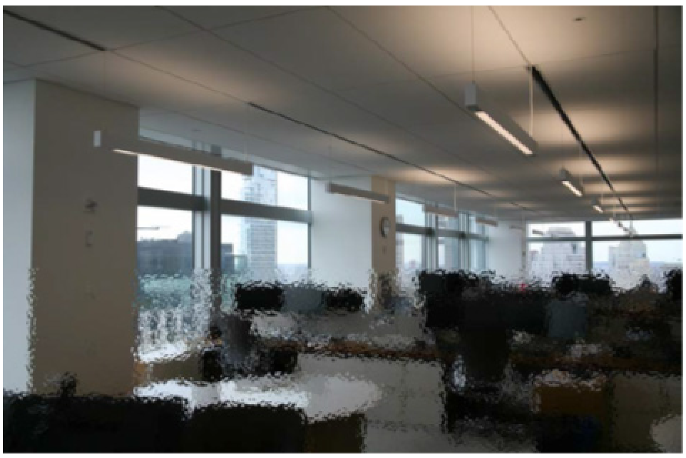

Figure 6. Northeast quadrant G4, full occupancy with daylight dimming of downlights and partial dimming of uplights.

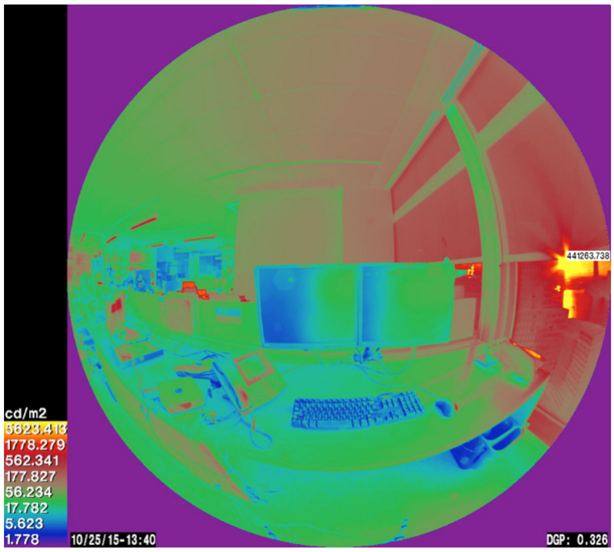

Figure 7. Falsecolor luminance map (cd/m^2) for a view parallel to the window with partial direct sun transmission through the fabric shade. DGP was 0.326 (“imperceptible” glare), October 25, 4:40 pm, southwest quadrant G1.

For the 1%-open fabric, Class A (best) was achieved for four out of the five (80%) monitored days, while with the existing 3%-open fabric, Class A was achieved for only two out of the six days (33%).

Thermal discomfort was also found to be minimal. Assuming business attire (clo=1.0), the amount of time that thermal discomfort levels were not acceptable (i.e., predicted percentage dissatisfied (PPD) greater than 20%) was less than 0.5-1.8% of the monitored period. The space was designed with an underfloor air distribution (UFAD) system with supplementary heating and cooling at the window wall. The automated shades controlled direct sunlight and reduced radiant asymmetry between the indoors and outdoors. The mean radiant temperature, for example, was maintained to within 6°C of the dry-bulb temperature when warm discomfort occurred while the predicted mean vote (PMV) was greater than 0.5 for no more than 7-16 hours over the six-month period, indicating that temperature asymmetry due to direct solar transmission through the shade fabric was not a significant factor in thermal discomfort.

Circadian potential

Deliberate, controlled use of daylight and electric light to stimulate circadian response was not implemented. However, this case study illustrates the potential of well-managed daylight to entrain Circadian rhythm without introducing additional discomfort glare.

User perspective

A total of 58 responses on the test floor and 20 responses on the reference floor were received from the survey. Survey responses indicated that the overall level of satisfaction with the lighting systems was neutral (neither agreed nor disagreed that occupants were satisfied with the lighting; Fig. 8). Occupants disagreed or were slightly below

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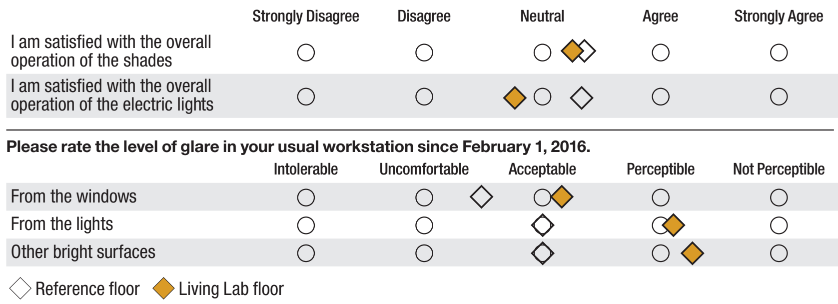

> ***"Automated shades allowed me to better focus on work"***

> ***"I prefer natural light and outside views over artificial lighting"***

Figure 8. Occupant response on the reference floor (white) versus Living Lab floor (orange). Average response of the four quadrants.

neutral (toward "disagree") regarding whether the electric lighting was too dark in the test and reference areas. Overall light levels from both electric light and daylight were slightly above "just right".

High-resolution control based on occupancy sensing at the luminaire level resulted in a few comments of dissatisfaction, particularly during periods of low occupancy at night or on weekends. Erroneous control was likely a result of occupied areas that fell outside of the detectable area of the sensors (e.g., small table areas between the primary desks (Fig. 9)). Inadvertent shut offs during the day were not commented on, perhaps because they were less noticeable with the available daylight. Poor lighting quality resulted from contrasts in lighting level between occupied and unoccupied areas at night; dimming was graduated to lessen the contrasts.

With the automated shading, occupants were also generally neutral about whether they were satisfied with the reference (operated for the prior seven years) and test case automated shades. To override the position of the automated shades, occupants telephoned or submitted an electronic request to have the shades adjusted. Sixteen requests were made over the year to override the test shades and none were made to override the reference shades.

Glare from the windows was perceived as lower in the west test area with the more densely woven fabric compared to the west reference area, however there were far more comments about glare in the test areas with more densely woven fabric than the same reference areas. There were also comments about illogical shade movement. Both control systems provided options for the facility management team to finetune the controls to better suit occupant preferences.

Based on limited data for the test area shade and site observations by occupants and staff, the reference shading system tended to raise the shade more frequently to permit view. There were comments from the occupant surveys that indicated a desire to raise the shades more frequently

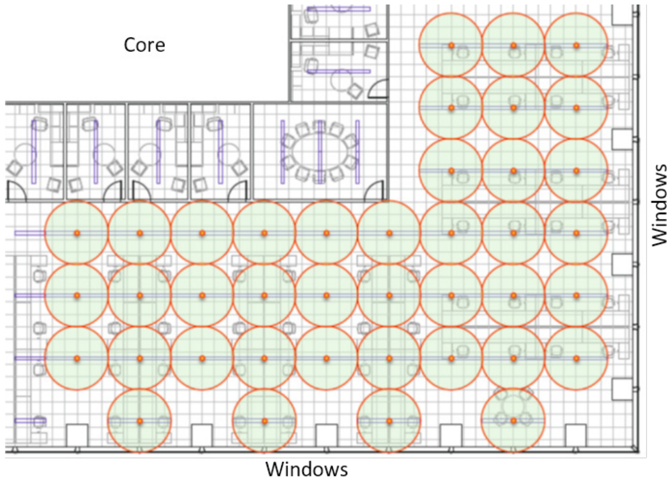

Figure 9. Floor plan showing detection range of occupancy sensors installed in each luminaire.

in the test area for unobstructed access to outdoor views.

Lessons learned

The project sought to balance the benefits of natural light with visual and thermal comfort and provide workers with views when possible. Because this was an installation in a high-end office building, there were many discussions amongst the design team and with the owner on how to deliver an aesthetically acceptable, high quality indoor environment. Use of dimmable direct/indirect lighting systems with high resolution controls and automated shading provided a multitude of options to fine tune the visual environment both spatially and temporally.

Further information

Lee, E.S., et al. Demonstration of Energy Efficient Retrofits for Lighting and Daylighting in New York City Office Buildings. Lawrence Berkeley National Laboratory: April 2017. https://facades.lbl.gov/sites/all/files/Downloads/NYC-Living-Lab-Final-Report.pdf

Annotated specifications for advanced lighting controls: https://facades.lbl.gov/sites/all/files/Downloads/NYC-Lighting-Controls-Spec-Final.pdf

Specifications for shade controls: https://facades.lbl.gov/newyorktimes/nyt_shades-controls.html

Acknowledgements

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