Test and verify to take the guesswork out of achieving high performance goals

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Following through on design intent across construction and commissioning phases helped owners achieve high performance goals

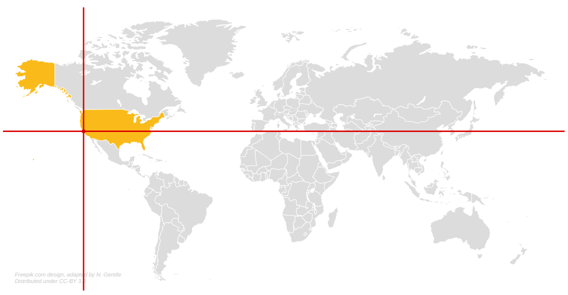
Monitored, full-scale, outdoor mockups were used to finetune design and control system details then, in the final building, performance was verified with monitored data prior to occupancy.

The project

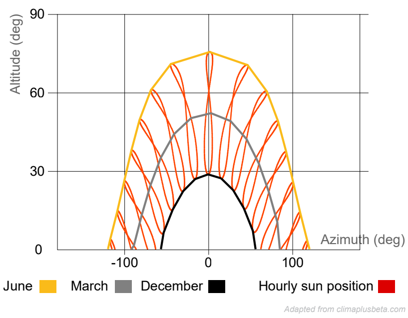
Many new projects start with aspirational performance goals for energy efficiency, comfort, indoor environmental quality, health and wellness, and operational efficiency. Following through on design intent over the design and construction phases of the project and then ultimately over the life cycle of the building, however, remains a key challenge for the buildings industry. In this project, the owner had institutional performance requirements that were verified and signed off at each phase of the design process. Prior to construction, the design and construction team transitioned from engineering calculations to monitored verification in full-scale outdoor mockups under real world conditions, enabling details, specifications, and control sequences of operation to be evaluated prior to procurement. A "burn-in" phase in the newly constructed building was used to commission and verify control system performance prior to occupancy, resulting in a workplace that met defined goals.

Figure 1. Rendering of the new commercial office building.

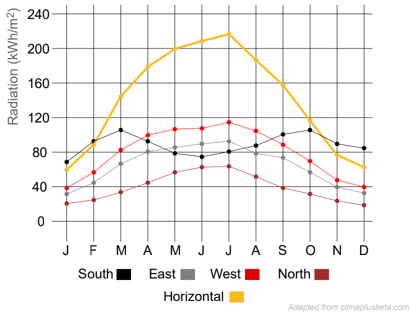
The design intent for the new building, a seven-story, 24,000 m^2 office building (Fig. 1) situated on the company's campus in South San Francisco, was to create a real estate asset with long term value based on rigorous energy efficiency requirements, functional flexibility, and an environment that enhanced employee well being. Daylighting and views to the Bay and surrounding hills were regarded as critical but the design team was also cognizant that solar control and minimizing discomfort ran counter to these goals. A myriad of details needed to be resolved to achieve a satisfactory balance between competing performance objectives. The design team relied on a rich, diverse set of sources to inform final decisions: empirical data from full-scale mockups, hands-on experiential



Location: South San Francisco, CA, USA
37.6547° N, 122.4077° W



Sun path for
San Francisco, CA, USA



Global horizontal and vertical radiation for
San Francisco, CA, USA

IEA SHC Task 61 Subtask D

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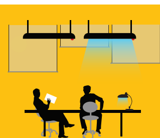

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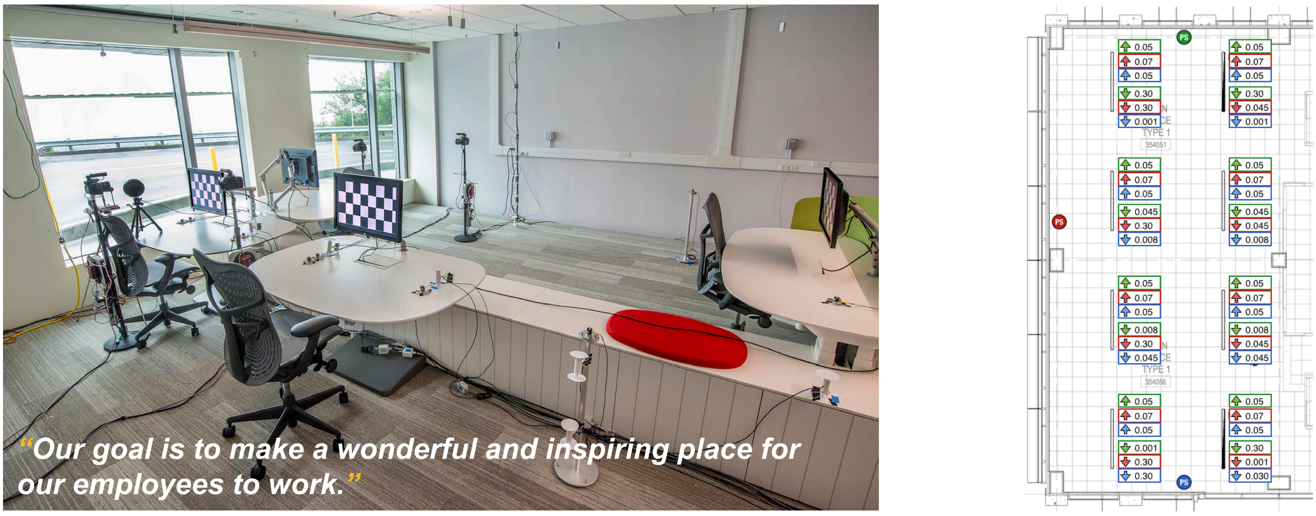

Figure 2. Left: FLEXLAB mockup. Right: Gain settings for the up- and downward dimming output for each of the eight fixtures in the north zone. The red, blue, and green values correspond to the photosensors at the window wall.

observations, and weekly collaborative team discussions between the owner, employee representatives, architects and engineers, interior designers, domain experts, and general contractor.

Monitoring

A monitored field test in the Lawrence Berkeley National Laboratory’s rotating FLEXLAB testbed (Fig. 2) was commissioned prior to construction. At this stage of the project, details regarding siting, massing, and facade design had been finalized. The monitored evaluation was expected to resolve outstanding questions related to visual and thermal comfort and indoor environmental quality prior to specifying final interior finishes and procurement of dimmable LED lighting, automated shading, and open plan furniture systems. Mockups of the east, south, and west perimeter zones were evaluated for one week each three times over the summer season (July to October). Modifications were made prior to the next test to address flagged issues and improve performance.

Prior to occupancy, monitoring was conducted on site over a 30-day “burn-in” period in representative perimeter zones of the final building to commission the systems, verify performance, and train the building operations team on use of the shading, lighting, and HVAC control systems.

Energy

Daylight control to reduce lighting energy use has been characterized historically as unreliable: providing too little or too much light, causing occupant complaints, and failing to reduce energy use. Fortunately, digitalization has vastly improved performance despite the increased complexity of high-resolution lighting controls. FLEXLAB tests were conducted to evaluate the daylight dimming performance of the pendant LED lighting system with an open- versus closed-loop control system. The open-loop control system had unique self-commissioning features that enabled

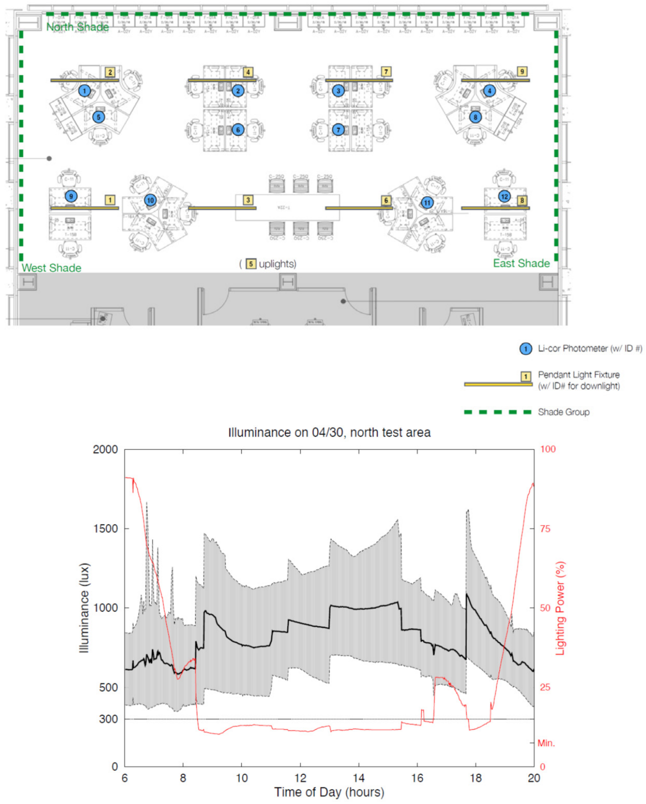

Figure 3. Top: Floor plan layout of furniture, work plane sensors, shades, and light fixtures in the north zone. Bottom: Minimum, average, and maximum work plane illuminance (lx) and average dimming level (%) in the north zone of the new building on a sunny day.

determination of source contributions to each photosensor: i.e., 1) contribution of up- and downward output per fixture to the photosensor signal, 2) photosensor signal versus source power level over the full dimming range, and 3) daylight work plane illuminance versus photosensor signal (Fig. 2). Monitored data were used to evaluate control performance, followed by adjustments to default settings for minimum dimming and light levels to improve energy efficiency, changes to grouping of sources to improve luminance uniformity, and then re-evaluations of dimming performance. Adjustments were made on a trial-and-error basis with observations of lighting quality playing a role in the final design. Based on monitored data, the open-loop system was selected for use in the final building: it dimmed lighting appropriately in response to available daylight for 70% of the monitored period, while the closed-loop system dimmed lighting appropriately 56% of the time. Peak hourly lighting energy savings due to daylighting in the 9.14 m deep open plan workspace with a 300 lx setpoint, 6.17 W/m² lighting power density (LPD), and relay shutoff to minimize standby power was: 71% (east at 12-1 pm), 59% (south at 11-12 am), and 58% (west at 1-2 pm) of nighttime power use (at 300 lx). These summer savings reflected daylight control with automated shades.

In the new building, FLEXLAB conditions were representative of most areas of the floor plan so lessons learned were transferrable, but for the end office areas, which had three facades that contributed daylight to the space, the controls had to be re-evaluated (Fig. 3). Here, daylight illuminance per work area needed to be correlated to the open-loop, ceiling-mounted photosensors at each facade with their respective automated shade controls (Fig. 2). Recommendations for sensor settings were made, then after commissioning, lighting was determined to dim appropriately with a resultant reduction in daytime LPD from 5.52 W/m² to as low as 1.4 W/m² (74%) for the 6.1 m to 9.1 m deep zones when LBNL-recommended settings were used. During afternoon peak periods, lighting demand was reduced to 0.005 W/m² with daylight controls.

Photometry

The critical task of balancing daylight and view objectives against opposing goals of minimizing glare and thermal loads is typically left to manual adjustments of indoor shades. This can lead to a poorly daylit building and defeats the good intentions of the design team. For this project, the team designed a facade with moderate-sized windows (window-to-exterior-wall area ratio of 0.31, solar heat gain coefficient of 0.23, visible transmittance of 0.42) and punched metal overhangs and/or fins, lessening dependence on indoor shades. To further improve performance, automated, motorized, roller shades were considered for purchase (Fig. 4) and so were evaluated in FLEXLAB. For fabric selection, improvements to simulation tools are underway to improve prediction of discomfort glare for light-scattering shades such as fabric roller shades. In the meantime, field assessments can be a good substitute for deciding which fabric to use for protection against discomfort glare.

Two fabrics were evaluated in FLEXLAB: a medium grey and a dark grey fabric, both with a 3% openness factor that provided views to the outdoors. High dynamic range (HDR) imaging was used to measure daylight discomfort glare. The medium grey fabric was found to be slightly less effective in controlling glare, particularly for east-facing windows. Two of six team members working in FLEXLAB observed that the 3% fabric would need to be denser for protection against glare from direct sunlight.

FLEXLAB tests also helped the team understand details

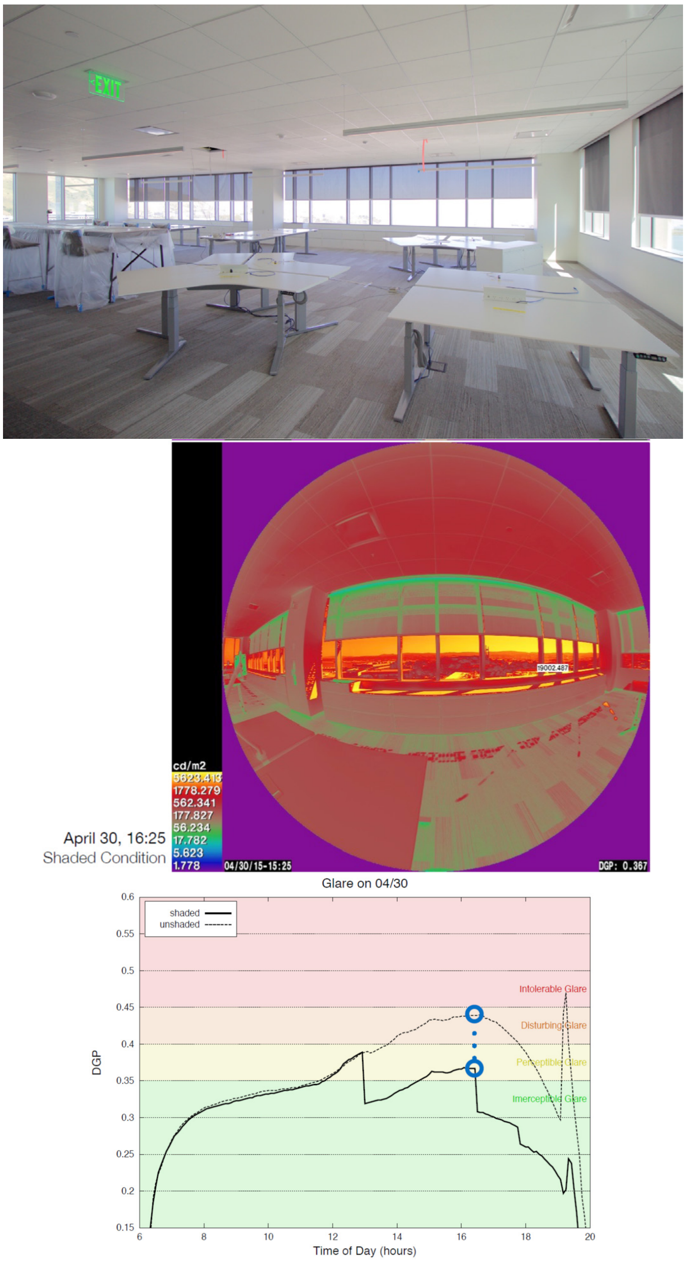

Figure 4. Upper: View of north area in the new building; Middle: HDR image with automated shades; Bottom: Daylight glare probability (DGP) in north area.

of the underlying shade control algorithm and identify options to finetune performance. Adjustments were made to the control system to increase daylighting: the lower stop limit was raised above sill height to admit more daylight and thresholds for determining sunshine were adjusted to be less conservative. Control of overcast sky glare was found to be inadequate, so thresholds were tightened in locations where occupants were seated close to and facing the window.

In the final building, glare and daylight levels were evaluated at key workstation locations across a typical floor. The automated shades kept glare below “imperceptible” levels for most desk locations in the north, east, south, and west areas. For atypical views looking toward the window, glare was maintained below “noticeable” levels (Fig. 4). Daylight

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Figure 5. Exterior vertical fins on east and west facades.

Figure 6. Left: Monitoring set up in the new building during the burn-in phase. Right: Recommended furniture placement if visual comfort is achieved at 5.5 ft (1.68 m) from the window.

levels were bright but constrained within an acceptable range by the automated shades. For the north or south areas daylit by three facades, average desk illuminance varied from 600 lx to 1200 lx (Fig. 3), while for the east and west areas daylit by a single facade, average illuminance varied from 300 lx to 1200 lx over a clear sunny day (April 30). For the north and south areas, the automated shades raised the shades for unobstructed views throughout the day for at minimum one of the three orientations. For the east and west areas, the exterior fins provided partial glare protection from low direct sun (Fig. 5), enabling the shade to be raised more often.

Circadian potential

Controls for tunable white lighting were evaluated in FLEXLAB. Dynamic white lighting is thought to reinforce Circadian rhythms through shifts from warm to cool white throughout the day. Based on observations, the team opted for a static 4000K white light in part because 93% of regularly occupied spaces had access to daylight and by design there was a higher than average amount of daylight available in the building overall. Equivalent melanopic lux (EML) levels were not evaluated in this study.

User perspective

FLEXLAB tests were conducted to support space planning decisions related to occupant density and allocation of space. Locating desks close to windows allows increased occupant density but close proximity can reduce daylight and views for all others further from the window. A sensitivity analysis was conducted by measuring discomfort glare as a function of distance from the window, leading to recommendations for minimum seated distance from the window for views parallel and perpendicular to the window (Fig. 6). With exterior and automated interior shades, monitored data indicated that desks could be placed within 0.76 m from the south window for views parallel to the window while for views facing the window on the east, desks needed to be located greater than 1.8 m from the window.

The work place was designed with an open plan concept with unassigned seating so occupants could decide where to work based on personal preferences and tolerances for glare, daylight, and views. Switches to manually override the automated shade controls were not provided. The facility management team was open to feedback from occupants and made adjustments to thresholds to satisfy general requests such as "we'd like the shades raised more often" or "we'd like more daylight in our space". Surveys concerning satisfaction with the workplace were issued by the company but details were not shared publicly. Generally, the facility management team reported that occupants were satisfied with the daylighting and views and in the case of north-facing perimeter zones, occupants desired even more daylight.

Lessons learned

Achieving high-performance goals requires follow through during the later stages of procurement, construction, and commissioning in the final building. Monitored verification under real-world conditions can help identify critical issues well before procurement and occupancy. This is particularly relevant for integrated, innovative shading and lighting systems where balancing tradeoffs between competing performance criteria is required. This project was able to provide daylight and views throughout the workplace, reduce energy use significantly through daylighting and solar control, and meet comfort requirements. The facilities team was trained and occupants were educated on the advanced features of the building, enabling performance to be maintained over the long term.

Further information

McNeil, A., Lee, E.S. April Burn-in Testing Report for Genentech B35, South San Francisco Campus, LBNL-2001116, 2015. https://eta-publications.lbl.gov/sites/default/files/genentech_burn-in.pdf

McNeil, A., Kohler, C., Lee, E.S., Selkowitz, S.E. High Performance Building Mockup in FLEXLAB, LBNL-1005151, 2014. https://eta-publications.lbl.gov/sites/default/files/lbnl-1005151.pdf

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