Energy Use Intensity and its Influence on the Integrated Daylighting Design of a Large Net Zero Energy Building

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Energy Use Intensity and Its Influence on the Integrated Daylighting Design of a Large Net Zero Energy Office Building

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ABSTRACT

Low energy or high-performance buildings form a vital component in the sustainable future of building design and construction. Rigorous integrated daylighting design and simulation will be critical to their success as energy efficiency becomes a requirement, because electric lighting usually represents a large fraction of the energy consumed. We present the process and tools used to design the lighting systems in the newest building at the National Renewable Energy Laboratory (NREL), the Research Support Facility (RSF). This 220,000-ft2 [20,439-m^2*] office building was turned over in June 2010. Employees began to move in almost immediately; their number will soon reach 820. The RSF will house a large data center, and is projected to eventually produce as much energy annually as it consumes. Its rapid construction schedule meant that the entire process had to be tightly integrated. Daylighting had to be integrated with the electric lighting, as low energy use (50% below ASHRAE 90.1-2004) and the LEED daylight credit were contractually required, with a reach goal of being a net-zero energy building (NZEB). The oft-ignored disconnect between lighting simulation and whole-building energy use simulation had to be addressed, as ultimately all simulation efforts had to translate to energy use intensity predictions, design responses, and preconstruction substantiation of the design. We discuss how the lighting and building energy use simulation endeavors were married to inform the RSF design. During the coming year, the RSF will be thoroughly evaluated for its performance; we present preliminary data from the postoccupancy monitoring efforts with an eye toward the current efficacy of energy and lighting simulation methodologies.*

INTRODUCTION

In 2007, the National Renewable Energy Laboratory (NREL) began the procurement process for a new office building. NREL early on decided to create a building that would use one-half the energy of a typical large-scale office building. Building researchers used results from Griffith et al. (2006) to establish the 50% savings level as achievable with no additional capital cost. This target is expressed as *energy use intensity* (EUI).

In June 2010, NREL employees began to occupy the Research Support Facility (RSF). This 220,000-ft^2 [20,439-m^2] office building in Golden, CO, USA, is projected to use 33.3 kBtu/ft^2/yr [0.38 GJ/m$^{2/}$yr] – less than half the typical energy use for office buildings in the Denver Metro area. This was achieved by using a tightly integrated design-build construction process, and by keeping a sharp focus on the aggressive EUI – distilling the building's energy performance down to a single number – that was part of the original Request for Proposals (RFP). We focus on how daylighting and thoughtful electric

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lighting systems and controls design and simulation can significantly reduce energy consumption, and on how approaching the design from the standpoint of EUI gives designers and engineers more freedom to design an efficient building by rewarding integrated design, daylighting, and lighting controls.

Daylighting – the thoughtful introduction of natural light into a building – is compelling not only for its many aesthetic and health benefits, but also for its energy savings opportunity. If a building admits sufficient daylight to the interior spaces, the electric lights can be dimmed or switched in response – saving energy that otherwise would have been used to energize the light fixtures, and potentially addressing the added heat from the lamps. Daylighting means much more than letting light in, however. Windows and skylights allow natural light into a space, but can also hasten heat loss in winter and increase solar heat gain in summer; occupants can experience disabling glare from poorly shielded fenestration. In essence, if one merely adds daylighting *features* – such as windows and skylights – without considering daylighting *functionality* – such as lighting controls that respond to available daylight – daylighting is likely to fail. But with lighting typically representing 30-40% of a commercial building's total energy use, an integrated daylighting design strategy that reduces the duration and intensity of electric lighting use should be considered a keystone strategy in any high performance/low energy building.

To that end, Torcellini et al. (2006) classify daylighting as a best practice in high-performance building designs, and list six keys to its successful implementation. These key aspects were integrated into the RFP for the RSF:

- Design daylighting into all occupied zones adjacent to an exterior wall or ceiling
- Provide for integral glare mitigation techniques in the initial design
- Provide automatic, continuously dimming, daylighting controls for all daylit zones
- Design interiors to maximize daylighting distribution
- Integrate the electric lights with the daylighting system
- Commission and verify postoccupancy energy savings

The RSF was procured as a high-performance building, and the lighting design (which includes the daylighting) was critical for its success as a low energy building; still, *all* buildings can benefit from this lighting design concept.

ENERGY USE INTENSITY AS A DAYLIGHTING DRIVER

A primary goal of the RSF project was to create a low energy building; this was expressed in the EUI goal that was central to the procurement process, and to the selection of a capable design-build contractor (the RFP and amendments are available at http://www.nrel.gov/sustainable_nrel/rsf.html). The RFP mandated an EUI of no more than 25 kBtu/ft^2/yr [0.28 GJ/m^2], assuming a standard government building occupant density of 650 employees, 220,000-ft^2 [20,439-m^2] building area, and a data center large enough to serve the RSF occupants. As part of the RFP, a method to normalize for additional space efficiency and external data center use was established. As a result, the final as-built EUI was normalized to 35 kBtu/ft^2/yr [0.40 GJ/m^2] for a building that accommodates 820 people, and includes a data center that can serve the entire NREL campus (at the time of project completion, this was approximately 1200 users). This ambitious energy target refocused the design team on total energy consumption by the lighting systems in a way that current codes and building rating systems do not capture.

Building codes generally approach lighting energy efficiency via ever-tighter lighting power densities (LPDs), but as these allowances continue to be revised downward, this approach has begun to infringe on the lighting designer's ability to meet other critical criteria such as minimum illumination levels and uniformity ratios, not to mention aesthetic creativity. Reliance on the connected load as the sole standard for lighting energy efficiency also prevents the design from taking credit for daylighting controls; daylighting a building will not save energy unless the electric lighting is used less often. By moving toward an energy use-based metric such as EUI to define building performance, the lighting designer is empowered to take advantage of daylight-responsive electric lighting controls, and in turn is incentivized to consider daylight as a core component of the lighting system. The entire team becomes motivated to work together toward an optimized, integrated lighting solution that saves energy. We believe this optimization is most efficiently discovered through simulation.

DAYLIGHTING

A LEED Platinum rating was sought for the RSF; as such, every point that could reasonably be achieved was considered. The LEED iEQ8.1 "daylight credit," which dictates that a large percentage of the occupied space receive illumination from daylight, was also mandated. As a result of this target and the aggressive EUI goal, the design-build team looked at daylighting as an energy efficiency strategy from a very early stage. Work to integrate and best take advantage of daylighting took place during the design competition phase. Daylighting simulation with Radiance (Ward 1994) was already being used during this phase. Based on Torcellini at al. (2006), the team sought to extend the daylight-illuminated zone as far north as possible, and optimized the fenestration by creating two discrete panes of glass with specific functions. The lower glazing was intended to provide shielded, glare-free views to the exterior; we call this the *view glazing*. The upper glazing was designed to provide maximum daylight penetration. This has a high visible light transmittance and is located high on the wall section to maximize the potential for daylight flux delivery to the interior; we call this the *daylight glazing*. The team selected an optical louver system to occupy the daylight glazing to provide glare control and to redirect the incoming solar radiation onto the ceiling and deeper into the space. To explore the system's ability to optimize the floor depth, a 3D building model of a typical office wing was created in AutoCAD and simulated in Radiance. With an eye toward the LEED iEQ8.1 goal, point-in-time simulations were conducted to determine how broadly an illuminance level of 25 footcandles [269 lux] could be achieved at 30" [0.76 m] above the finished floor under clear skies, at noon, on the equinox – one compliance demonstration method available under LEED iEQ 8.1[1].

The building model was modified to study different fenestration options such as window head heights, window-to-wall area ratios (WWRs), and glazing visible light transmittances. This iterative modeling process revealed 60'-0" [18.3 m] to be the maximum floor plan depth (north-south) that could be illuminated to the criteria set forth by the LEED compliance standards, given other optimization constraints such as floor to ceiling height and WWRs.

Through the normal course of design development, Radiance was used to evaluate various changes to the design to determine their impact on the daylighting. A variety of interior finishes were studied, furniture options such as plan location, partition heights, and interior wall and ceiling configurations were investigated, and a series of changes were recommended. Changes included increasing the size and lowering the mounting height of the optical louver units, and revised room surface finish reflectances.

ELECTRIC LIGHTING

The electric lighting design was influenced by best practices and lessons learned from other NREL campus buildings – again, informed through simulation.

Design Process and Criteria

The EUI is useful for a broad view of the design's progress toward the unifying team goal, but every energy-efficient building design must include smaller task, load, and aesthetic-specific subgoals. For quantity, the team first decided on space-by-space design illuminance criteria, which were based on recommendations from IESNA (2000) (see Table 1). For the open offices, 25 footcandles (fc) [269 lux] and a 4:1 maximum-to-minimum illuminance ratio were selected as the ambient workplane illuminance and uniformity criteria. The task lighting contribution was set to 20-30 fc [215-323 lux] additional, to meet the IESNA office recommendation of 30-50 fc [323-538 lux] for general office task lighting overall. Additional lighting design expectations were also defined: accent lighting for architectural features, displays, and artwork; ease-of-service; emergency and security requirements; and system durability.

Energy subgoals were defined as well. EUI information about high-performance buildings is not prevalent enough to warrant system-specific design criteria, so the RSF started with a more pragmatic design approach. The ASHRAE/IESNA

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[1] The RSF project was certified under LEED v2.2; the new LEED 3.0 simulation-based compliance path for the daylight credit is slightly different.

90.1-2004 LPD limit for typical office space (per the building area method) was reduced by 30%, from 1.0 to 0.7 Watts/ft^2 [10.7 to 7.5 Watts/m^2]. Additional energy-related subgoals included reasonable feature proportions and zoning consistent with annual daylight saturation.

After lighting subgoals were defined, an iterative process of selecting and laying out electric lighting fixtures, estimating illuminance and uniformity, and performing simulations – in this case, using AGi32 (Lighting Analysts, Inc. 2010) – for design validation ensued. The final primary light fixture selection for the open offices was a 92.8% efficient, direct/indirect pendant-mounted luminaire utilizing four-foot, 25-Watt T8 fluorescent lamps, which provide 25 fc [269 lux] maintained illuminance at the workplane. Because these lamps are sometimes incompatible with dimming ballasts, the team required letters from all proposed lamp manufacturers that ensure extended dimming operation to 10% would not diminish lamp life. (Lamp striation at discrete dimming levels and temperature conditions is still a possibility, but has not been observed in the RSF.) Task lights (6-Watt LED arrays on adjustable heads) were included as part of the procurement package and provided at all workstations. Compact fluorescent downlights, metal halide accent lights, and LED interior and exterior pathway lighting were also included. The final building LPD is 0.62 Watts/ft^2 [6.7 Watts/m^2]; a sampling of space-by-space LPDs is given in Table 1.

Controls Philosophy

The lighting controls were developed in tandem with the electric lighting design. Much like the electric lighting quantity was "layered" with ambient and task contributions, layering of control types was also implemented. This approach was an attempt to balance energy (using electric lighting only where and when needed), cost, usability, and ease of commissioning. The latter two drivers came from previous experiences where an entirely automated lighting control system was confusing for occupants and frustrating for commissioning agents. This ultimately causes the system to never be implemented as planned, and results in higher-than-expected energy use.

The first control layer in the RSF is vacancy sensing. The occupants must turn on the lights manually; they may also turn the lights off manually, but motion sensors and timeclock-based lighting sweep by the building automation system turn lights off when occupants forget. The sublayers of vacancy sensing include:

- "Dark building" during unoccupied nighttime hours. For this, the team selected UL924-rated control devices to allow emergency egress lamps to be switched ON and OFF under normal power and forced ON under emergency power. In addition to the design driver of EUI, usability is addressed by allowing the emergency egress lamps to be switched or dimmed by all layers of the control system.
- Pathway lighting for nighttime building security walkthroughs. By mapping security walkthrough switch locations to the pathways walked by security personnel and turning ON emergency egress fixtures for 10 minutes, lights are used only when and where needed. These switches are disabled during the day through the networked lighting controller (see fourth bullet).
- Local manual ON, automatic OFF switching (vacancy switching) for walled spaces that are intermittently occupied. This addressed the drivers of cost (by not using a completely networked system) and usability (occupants have simple switch control of these spaces). A vacancy control system contrasts with an automatic ON, automatic OFF system in that no lighting energy is used when occupants do not need it. Tzempelikos (2010) and Hunt (1979) discussed potential energy savings from this general concept.
- Networked solution, allowing communication between lighting devices, for typical spaces such as open offices and corridors. A networked system can minimize energy use and expedite commissioning. Energy use is reduced by allowing timed lights-OFF sweeps to occur (with a blink-warn function allowing occupants to override to ON) for spaces where a local occupancy sensor would be difficult to implement. With manual switching, lights can be left ON accidentally if nighttime security takes an unexpected path and misses a switch or an occupant leaves the space with the manual switch ON because the lights were overridden to OFF because the lights were dimmed. Sweeps scheduled every two hours starting at 6:00 p.m. address this oversight. Ease of commissioning is an additional benefit: a single commissioning motion can apply settings to all similar spaces. Enclosed, private (but ceilingless)

offices use network relays because they are easier to locate and maintain than locally installed switch packs, but the network relay system does not control the occupancy time settings. Lights in private offices are controlled by local vacancy sensors.

To account for these control measures in the energy model as a cross-check with the EUI goal, the ASHRAE 90.1-2004 Table G3.2 recommendation of 10% occupancy sensor reduction was used in the energy model for all spaces with local vacancy sensors. Open area scheduled BAS sweeps were included in the model schedules as well, and a 90% diversity factor in the hourly lighting schedule accounted for unoccupied spaces during the day and for occupants choosing not to manually switch ON lighting loads. Nighttime workers were not accounted for, but security walkthroughs every two hours were included in the energy model lighting schedule. These broad assumptions were made about the occupancy layer; this will be a point for scrutiny in future comparisons of the modeled and metered energy results. Annual energy use as modeled is presented in Table 1.

The second layer of control – assuming occupants are present and choose to turn ON the lights – is daylight response. The sublayers of daylighting control include:

- Local, closed loop daylight sensors in all spaces with a local occupancy sensor and some daylight contribution, and for office zones using dimming versus switching. Local, closed loop systems were viewed as beneficial to balancing capital cost and energy savings.
- Global, open loop daylight sensors for override of local dimming systems and for large switching zones. Taking dimming zones to OFF versus the minimum local dim level of 10% adds to energy savings and the global OFF override adds to ease of commissioning since any networked set of lamps in daylit areas can be controlled by the global sensors such as downlight and accent fixtures.

Controls Simulation and Analysis

Similar to the daylight modeling effort, a controls modeling approach used rigorous simulation to determine how fixtures in open offices should be zoned, where dimming or switching should be used, and to derive expected energy savings for comparison to the EUI goal. The following sections describe this process.

For the large open office areas, the electric lighting control zones were optimized such that they are best able to respond to available daylight while not being overly subdivided, which would have added cost and complexity to the design. A parallel plan projection view of each floor was rendered with a radmap-generated (Anselmo 2003) “cumulative sky” in Radiance. The cumulative sky is simply an amalgam of all the daytime skies[2] for a given climate, defined by the direct normal and diffuse horizontal irradiance in a TMY file, translated to CIE standard sky definitions. When visualized in falsecolor (see Figure 1), the renderings afforded a clear view of the resulting daylight distribution in the space and allowed the design team to logically circuit the electric light fixtures so that they could best respond to the daylight while not adding too many zones. The distribution across the core of the open office space was fairly uniform, leading to the decision to zone the two core rows (rows two and three) of light fixtures together, rather than separately. The remaining rows (1 and 4) were circuited into their own zones – a north perimeter zone and a south perimeter zone. The north perimeter zone, containing private offices, has an additional layer of control in that individual offices have independent local vacancy control. It was also determined that the daylight saturation at the south perimeter was so high that the added resolution of continuous dimming ballasts was not needed, and lower cost dual-level switching ballasts were used for this zone instead.

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[2] The main goal of this part of the analysis was to optimally zone lighting that would be controlled during normal business hours, so the TMY weather file was modified to include only the hours between 7:00 a.m. and 6:00 p.m.

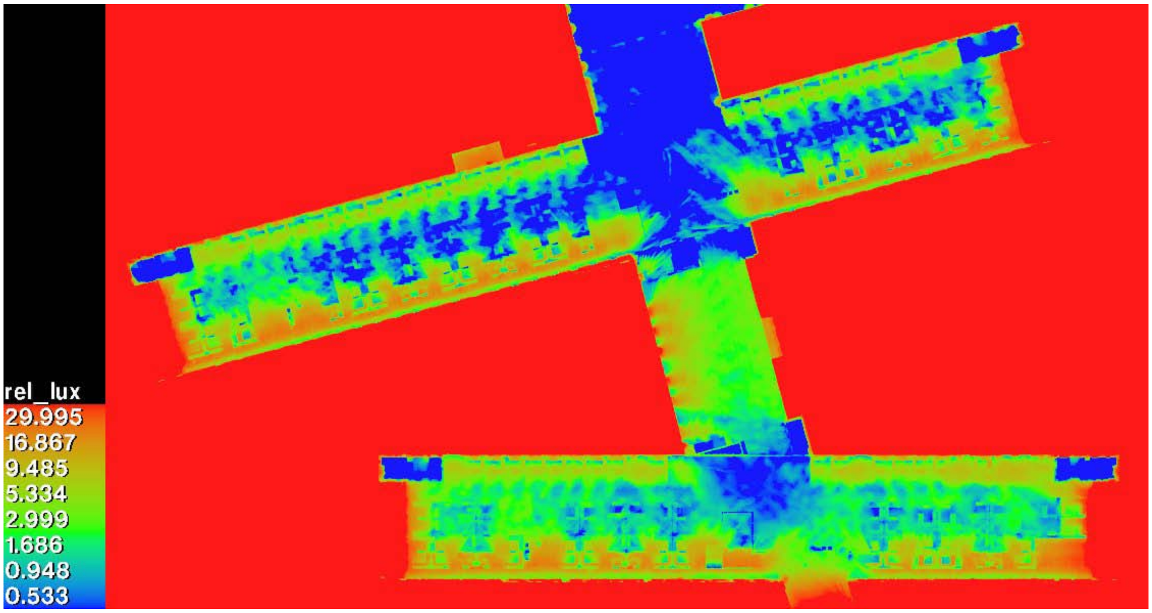

Figure 1: *Cumulative annual sky falsecolor rendering (Image Credit: R. Guglielmetti/NREL)*

Radiance was then used to provide a crucial link to the energy model so the engineers doing the energy modeling (and ultimately responsible for determining the building's final EUI) had an estimate of the hourly lighting system response to the available daylight – in other words, a quantification of the *daylighting functionality*.

For this phase, the Sensor Placement and Optimization Tool, or SPOT (Architectural Energy Corporation 2005) was used. SPOT can generate a lighting schedule that can be merged with an energy simulation via an "include file." Radiance can thus be used to rigorously evaluate the direct and global illumination, and then a given photosensor's spatial response to the available daylight and resultant dimming or switching response over a number of control algorithms. This produces an 8,760-hour schedule of the lighting power fraction for a given design. It is still divorced from the building energy use simulation, but represents a significant improvement in the depth and rigor of the lighting and controls portion of an annual energy simulation, and the ability to communicate the results to energy simulation tools poses a significant improvement in the estimation of building energy savings through daylighting measures. SPOT simulations were carried out for representative spaces and the include files were then passed to the mechanical engineers and used in the building energy simulations in lieu of the internal split flux daylighting calculation those programs typically use. Several coordination exercises were undertaken between the primary authors and the mechanical engineers to ensure the building envelope, lighting layouts, LPDs, control zones, and occupancy schedules were in alignment between the two models.

Additional detail on the daylighting and controls simulation methodologies – and the challenge of coordination with the building energy model – can be found in Guglielmetti et al. (2010).

Final Design Results

Table 1 gives the final design LPD and EUI quantities by space type. The total predicted lighting EUI is 7% of the final as-built energy model total EUI of 33.3 kBtu/ft^2/yr [0.38 GJ/m$^{2/}$yr]. As discussed in the preceding section on design process, EUI is not a commonly used metric. It will take time for designers to digest how these values relate to the building design before it becomes a rule of thumb for initial design iterations.

Table 1. Final Lighting Design LPD and EUI

Space Type	Maintained Illuminance, fc [lux]	Average LPD, W/ft^2 [W/m^2]	EUI, No Controls, kBtu/ft^2/yr [GJ/m^2/yr]	EUI, Controls, kBtu/ft^2/yr (GJ/m^2/yr)[a]
Open Office (ambient)	25 [269]	0.54 [5.8]	7.5 [0.09]	3.6 [0.04] - 4.6 [0.05]
Private Office (ambient)	30 [232]	0.83 [8.9]	7.5 [0.09]	2.6 [0.03] - 3.7 [0.04]
Huddle Rooms	30 [232]	0.70 [7.5]	5.2 [0.06]	5.2 [0.06]
Conference Rooms	30 [232]	0.75 [8.1]	7.0 [0.08]	1.5 [0.02] - 2.8 [0.03]
Lobby	10 [108]	0.66 [7.1]	8.7 [0.10]	4.0 [0.05] - 5.2 [0.06]
Lunchroom	20 [215]	0.39 [4.2]	2.8 [0.03]	0.8 [.009] - 1.3 [.014]
Stairway - Egress	10 [108]	0.65 [7.0]	7.8 [0.09]	7.8 [0.09]
Total[b]	-	0.62 [6.7]	-	-

[a] Approximation based on installed LPD, occupancy assumptions, and measured sunny and cloudy daylight response, overlaid. These should be taken as general, achievable ranges.

[b] Includes ancillary space types not listed in table.

In addition to energy performance, the visual performance of a design can be evaluated through simulation. Visual reality and prediction are presented as a photograph and a computer-generated rendering of a typical wing of the RSF in Figure 2 (left) and Figure 2 (right) respectively, illustrating the predictive power of design analysis tools. The primary visual difference between the two images is that the insulating panels in the central piece of glazing are not yet installed in the construction photo, but are represented in the simulation rendering. Beyond that difference, we believe the rendering accurately captures the distribution of the illumination and that the simulation renderings provided a valuable visual/aesthetic diagnostic tool to the design team and to the owner throughout the design and substantiation efforts.

Figure 2 *Construction photo of RSF Interior (left) and Radiance rendering of same space (right) (NREL PIX Image #17986)*

COMMISSIONING AND MONITORING

Lighting control commissioning involved verifying appropriate sensitivity and manual ON settings of vacancy sensors, checking that local photocells view a constant surface with appropriate daylight contribution (e.g., no glare from the LightLouver units at ceiling level), and verifying switch groups and time-sweep settings. Aside from some glitches – discussed in the Lessons Learned section – the final implementation matched design intent and energy model inputs well, with a minimum of 25 fc [269 lux] at the workplane for all open offices, local systems operating on a use basis, and global photocell and time sweeps functioning properly for public spaces. The energy-use impact of controls is shown in Figure 3.

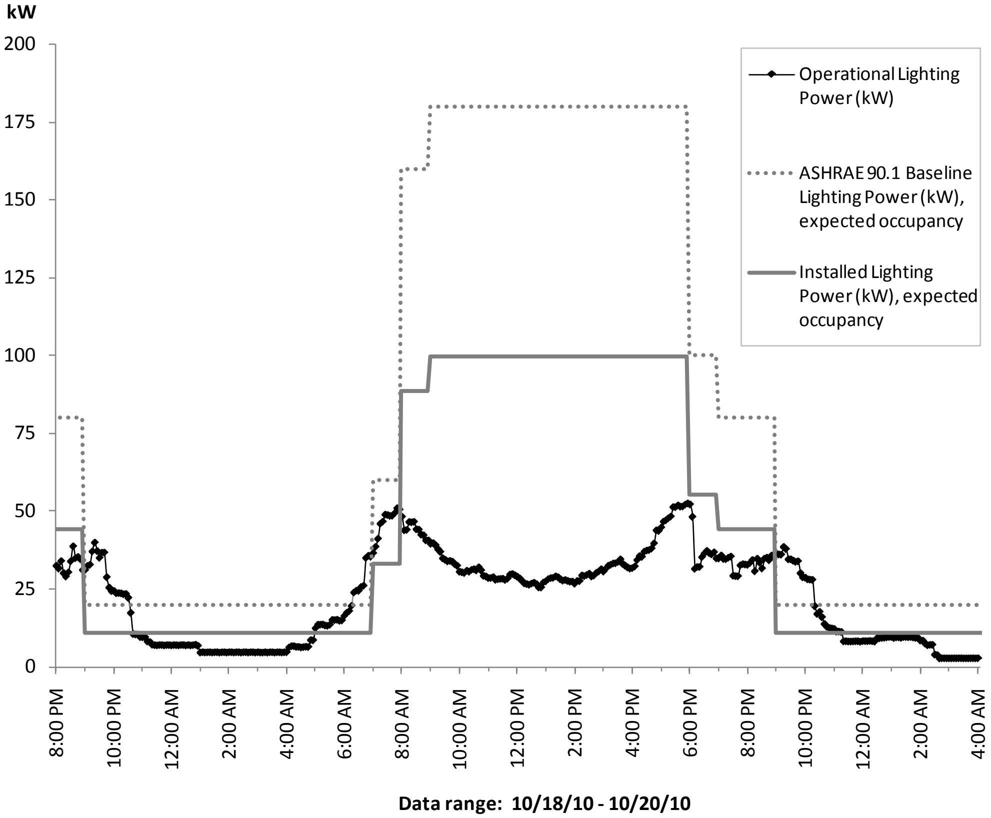

Figure 3 *RSF lighting power profile comparison (operational load, installed load, and code baseline)*

Figure 4 clearly illustrates the energy savings potential inherent to daylighting, when paired with daylight-responsive lighting controls. This plot of a single clear day quantifies what is possible when daylight-responsive controls (*daylighting functionality*) are paired with generous daylight availability (a result of the *daylighting features* in the design). The electric lighting load decreases proportionally as daylight increases midday, when direct solar radiation impacts the south façade of the building. (We also assume that all the architectural design responses to that are operating efficiently.) This relationship proceeded in lockstep throughout most of the workday, with daytime electric lighting power use bottoming out at the same time that daylight availability was peaking. Upon viewing the nighttime lighting energy use, it was easy to make a case for daytime cleaning, a strategy that has worked in other government buildings (Smith 2008) and is currently being scoped for the RSF.

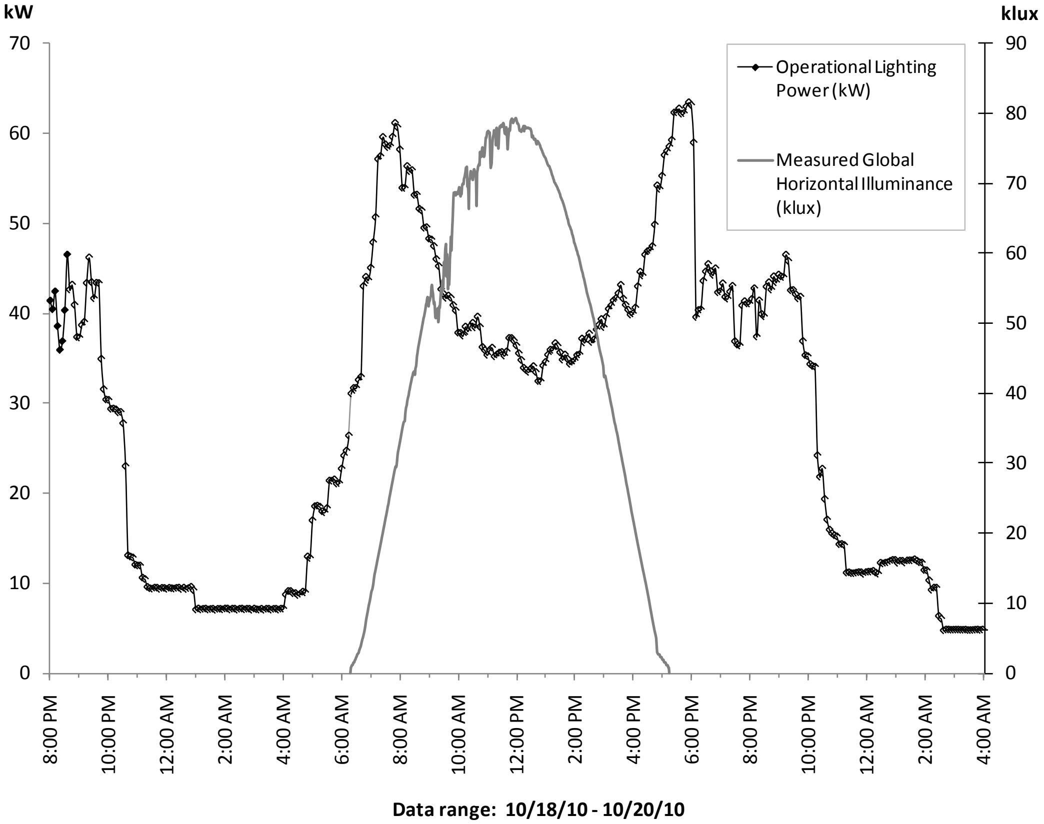

Figure 4 *RSF lighting power profile, correlated with global exterior horizontal illuminance*

LESSONS LEARNED

The process for creating an effective low-energy solution was successful. Several lessons were learned:

- A final construction details review could have prevented some locations from having less daylight than the modeled open office bay. The transpired solar collectors were placed too close to the window openings and shade the optical louvers during the summer. Some unique enclosed office spaces were placed such that they have less daylight saturation than expected. In the instances where an entire workgroup bay was affected, photosensor set points were increased. In locations where only one or two workstations were affected, staff were relocated, the positions of desks and monitors were adjusted based on lighting preferences, and more task lighting was added.
- Some redundancy was present with both local and global sensors controlling the open office perimeter switching zones. The commissioning team originally used settings at the local sensors to control the lamps but switched to the global sensors since set point could easily programmed using the network system interface. Cost and time could have been saved by using global sensors for all network-switched daylighting zones.
- Although vacancy sensors were touted in this paper as an obvious best solution to occupancy control, the spaces that use line voltage switches with in-line occupancy sensors find themselves in a state of automatic ON if someone leaves the switch on. Ensuring that all occupancy switches can only be operated in manual ON (vacancy) mode will prevent lights from turning on when a person does not need them, such as in a daylit kitchen.
- While color temperature matching is more of an aesthetic issue than an energy, cost, or maintenance concern, the difference in color temperature between the cooler daylight and the fluorescent lamp is somewhat distracting, and

potentially disorienting, even though cooler fluorescents were specified on this project (4100 Kelvin, vs. more commonly specified 3500 Kelvin). As these spaces still have a nighttime operational function (particularly in winter), we do not believe still cooler fluorescents would resolve the issue. The aesthetics of cool fluorescents at nighttime are suboptimal, and while the energy savings potential of so-called scotopic lighting is demonstrable, lighting designers must currently still design to IESNA-established lighting criteria and recommendations, which are all based on the photopic luminous efficiency function V(λ) (IESNA 2010, U.S. Department of Energy 2010).

- The original switching scheme included relays in multiple groups. The final, and recommended, solution is to match relay groups and switches as cleanly as possible (one-to-one mapping) so a user can press a switch and have a clear expectation of which relays will turn ON.

On the success side, themes the owner will encourage again are:

- Simulation to inform basic building geometry through to selection of control technologies and strategies. Use of occupancy pattern algorithms (Reinhart 2004) in lighting simulation tools will be helpful in future design to cost justify the variety of control layering options.
- Where applicable, an optimized floor footprint with the long axis aligned east-west for daylight saturation; in the RSF this includes a 60'-0" [18.3 m] floor depth (nominal 13'-6" [4.1 m] ceiling height, optimized WWR, and daylight redirection devices).
- Modularity of spaces to ensure simplicity of controls, ease of commissioning, and ability to analyze the details of the design through a reasonable modeling effort.
- Manual ON for all electric lighting with OFF sweeping as appropriate to the space (vacancy based control).
- Balance simplicity of lamps/fixtures and controls with enough layering to create an environment where occupants can use exactly the electric lighting they need.
- Metered data in the commissioning and occupancy phases to mine for additional savings. In the RSF, this happened with regard to the cleaning staff schedule. The 9:00 p.m. jump in lighting load (Figure 4) will not occur in future measurements because the cleaning schedule is being shifted to early afternoon.
- A familiar lighting control interface with intelligent switches that look and behave like traditional ON/OFF switches.
- Education through user manuals, posters, and outreach help occupants feel comfortable in the new space.

Active monitoring of energy and comfort, along with the LEED post occupancy survey, will allow the lessons learned section to become exhaustive over the next year, providing a framework of design and modeling recommendations from which to work for future EUI-driven office buildings.

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14. ABSTRACT *(Maximum 200 Words)*

Net-zero energy buildings generate as much energy as they consume and are significant in the sustainable future of building design and construction. The role of daylighting (and its simulation) in the design process becomes critical. In this paper we present the process the National Renewable Energy Laboratory embarked on in the procurement, design, and construction of its newest building, the Research Support Facility (RSF) – particularly the roles of daylighting, electric lighting, and simulation. With a rapid construction schedule, the procurement, design, and construction had to be tightly integrated; with low energy use. We outline the process and measures required to manage a building design that could expect to operate at an efficiency previously unheard of for a building of this type, size, and density. Rigorous simulation of the daylighting and the electric lighting control response was a given, but the oft-ignored disconnect between lighting simulation and whole-building energy use simulation had to be addressed. The RSF project will be thoroughly evaluated for its performance for one year; preliminary data from the postoccupancy monitoring efforts will also be presented with an eye toward the current efficacy of building energy and lighting simulation.

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