Natural light is a blessing. The human eye seeks it, and there are well-documented health benefits to humans from its presence. Yet while natural light is highly desirable and an essential part of any sustainable design program, it must be supplemented by supplied electrical lighting. Thus, an effectively integrated balance of electrical lighting and daylighting is an important goal—and a significant technical challenge—for today’s Building Teams, especially those seeking certification for their projects under LEED, Green Globes, or other green building rating programs.

Consequently, leading design and construction professionals are working with building owners to leverage new technologies and integrated project approaches while tapping into the latest industry expertise and available design guidelines.

Successful integration of light sources starts with a holistic sensibility about project design, tapping into the specialties of all team members at once, say experts like Tom McDougall, PE, a vice president with The Weidt Group,
Minnetonka, Minn., which specializes in building energy, daylighting, and sustainability. “Identifying goals early on in the design process is part of an integrated design approach that involves architectural, lighting, and interior design right from the conceptual stage,” he says. “Daylighting is a complex design strategy that requires contribution from all these players in order to make it successful.”

One reason close coordination is critical is that it is easy for design teams to fall into traps that result in poor or insufficient daylighting, with severe negative consequences for their projects. “One of the primary reasons for daylighting buildings is to enhance occupant comfort and productivity, but bad daylighting creates glare and uncomfortable lighting conditions, which has a detrimental effect, so it is counterproductive,” says McDougall.

Poor daylighting design can lead to excess energy usage and substandard visual and thermal conditions, “and [occupants] just don’t feel good in such environments,” says Matthew Tantieri, IES, an educator with the International Association of Lighting Designers and principal of the daylighting design consultancy Tantieri + Associates, Irvington-on-Hudson, N.Y.

In situations where the building is designed with daylight sensing controls as an integral part of the design, improper installation, calibration, and maintenance may be doing more damage than good, says Kevin Van Den Wymelenberg, an assistant professor at the University of Idaho’s College of Art & Architecture and director of the school’s Integrated Design Lab, in Boise. “It is probable that spaces like that will actually use more energy than spaces with no daylight,” he cautions.

**CONSIDER THE DESIGN VARIABLES**

When embarking upon a daylighting design project, it’s important for the full Building Team to carefully consider the variables associated with the local daylight conditions and electric light sources as well as building materials and systems. These include surface color, color temperature, color rendering, and, where applicable, the types of blinds and controls under consideration. All of these factors must be examined against the backdrop of occupant needs. Designers must ask, Who will occupy the facility and what are their expected tasks and activities? says Wymelenberg, who draws on his experience as a consultant for more than 400 projects since 2000. “Building inhabitants have a wide range of lighting preferences and designers should conceive solutions that accommodate these preferences.” he adds, citing studies conducted by the National Research Council of Canada.

Environmental factors should be the first to be studied, says Tantieri: “Daylighting is very specific to site, climate,
and program. There is no one-size-fits-all," he explains.

Daylighting apertures and integrated electrical illumination systems are deeply influenced by building location and predominant sky conditions—sunny, cloudy, or a mix. Then the building’s component uses are analyzed in this context, with attention to how uses are arranged and oriented, he adds.

“One tip is to optimize for the predominant sky condition, yet still work to some degree during all possible sky conditions,” says McDougall, who has contributed to a number of energy guidelines, in addition to developing building analysis software tools and authoring books and articles on environmental building design. “Another is to make the daylighting systems as fail-safe and foolproof as possible—for example, utilizing passive over active systems, and not leaving critical operations up to occupants.”

**To get building orientation right**, the Los Alamos National Laboratory Sustainable Guide offers this rule of thumb: Optimal positioning is to orient the building with the long side on the east-west axis, up to 15 degrees off true south, to enable the greatest winter solar gains and least summer solar gains. In addition, Aaron Smith, a senior research specialist at Rensselaer Polytechnic Institute’s Lighting Research Center (LRC) in Troy, N.Y., and a member of LRC’s DesignWorks consulting team, says, “In general, lower-story buildings elongated east to west, with shallow floor plates and a smaller size, are desirable for reducing energy consumption and maximizing the benefits of daylighting.”

As for obstructions such as landscaping and surrounding buildings, the New Mexico Solar Energy Association’s Passive Solar Design Guidelines instruct that on the south side, such obstructions should ideally be absent from within 60 degrees horizontally, as measured from the building’s southern corners, and minimally from within 45 degrees. While the same applies to deciduous trees, the guide points out that they can be very advantageous to the east and west as the trees will still let in the solar gain in the late spring, prior to blossoming, while providing additional shading into the fall season, which is ideal for warm climates.

**Regarding the building form**, LRC’s Smith recommends designing daylight into the majority of building spaces at levels sufficient to obviate the need for electrical lighting during peak sun hours, but not so high as to exceed lighting needs for that space. “A balance must be made between daylight autonomy—the amount of time the daylight harvesting system is able to turn off the electric lights—at the designed light level, and glazing size in order to maximize savings,” says Smith, whose specialties include daylighting strategies for retail stores and corporate office facilities, conducting software-based lighting analyses, and creating 3-D visualizations of daylighting and electric lighting designs.

One useful technique for this purpose is to calculate sun angles, which help determine the effects of direct sunlight at specific times of day and year based upon geographic location. Moreover, knowing the profile angle, as applied to a building section, will reveal sunlight penetration into the interiors and the effectiveness of exterior shading devices in different seasons. (To assist with this, some glazing manufacturers offer sun angle calculator manuals.)

**Two other general principles** to keep in mind are: 1) daylight penetrates twice the window head height, and 2) the amount of admitted light is a product of window area and the glazing’s visible light transmittance (VLT), says Tanteti, an adjunct professor at Parsons The New School for Design. Once these criteria have been accounted for, factors like glazing, window treatments, exterior shading devices, finishes, and interior light shelves can then be evaluated.

Smith and other lighting experts also recommend sizing windows to provide shading throughout the entire cooling season, which can be accomplished using sun angle data. When glazing the fenestration, it’s important not to overdo it as this can increase the building’s heating and cooling loads; a rule of thumb here is that, in temperate climates, a maximum 40% of the enclosure area should be glazed. As for finishes, a highly reflective matte white finish for the ceiling is a good choice, as are light colors for interior surfaces.

Design guidelines won’t work for every situation, of course, and many project teams employ sophisticated visualization, calculation, and physical modeling programs as a central part of the design process.

“Effective daylighting is as much an art as a science, with many complex and nuanced design issues,” says Erik Ring,
director of MEP engineering with LPA Inc., Irvine, Calif. “Consequently, there is no single definitive technical standard for daylighting.” There are, however, a wide variety of daylighting standards, tools, and references from such sources as the Illuminating Engineering Society of North America, Lawrence Berkeley National Laboratory, the Energy Center of Wisconsin, and the RPI’s Lighting Research Center.

Other key standards for harvesting daylighting and for integrated lighting controls include California’s Title 24, Standard 90.1 from the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), and the International Code Council (ICC) International Energy Conservation Code (IECC).

While Title 24 has set the bar the highest, Craig DiLouie, education director with the Lighting Controls Association, Rosslyn, Va., points out that ASHRAE and ICC are beginning to follow suit. These organizations now see controls as “the new low-hanging fruit for generating high energy savings,” says DiLouie. “IECC 2009 establishes daylight control zones that must be controlled separately from the general lighting—without specifying control method—and ASHRAE 90.1-2010 will likely include some type of daylight-harvesting control requirement.”

DIMMING AND CONTROLS SYSTEMS

Beyond codes and standards, any successful building incorporating daylighting and electrical lighting systems must include a carefully designed, integrated, and calibrated control system. According to Tanteri, the best way to approach this is to first design the building for daylight,

Dynamic Daylighting: A Brief Glossary

Some key daylighting terms on the cutting edge of the practice, as explained by Kevin Van Den Wymelenberg, assistant professor at the University of Idaho’s College of Art & Architecture and director of the school’s Integrated Design Lab in Boise, Idaho:

Daylight factor (DF), a standard and relatively common daylight metric, measures daylight in a space on a scale of 0.1 to 10 DF. Daylight factor can be measured point-by-point or as an average value over an interior space. DF tends to be consistent over time, even as illumination levels outdoors vary. For that reason, the measure is especially useful in regions with overcast sky conditions, rather than those locations with very sunny climates.

• Daylight autonomy, as defined by the Illuminating Engineering Society, is the percentage of annual daytime hours during which various locations in a space are illuminated above a specified threshold value. What's unique about this metric is that it considers weather information on an annual basis for the locations of the buildings under consideration.

• Useful daylight illuminance, or UDI, is a version of daylight autonomy that categorizes hourly time values based on three illumination ranges: 0–100 lux, 100–2000 lux, and more than 2000 lux.

• Daylight saturation percentage, created by the Collaborative for High Performance Schools in 2006, modifies useful daylight illuminance by quantifying the percentage of floor space receiving more than 60% daylighting—defined as illuminance between 40 footcandles and 400 footcandles, or 150 – 1500 lux—during business hours. The metric incorporates a penalty for illuminance levels of more than 400 footcandles when there is too much daylight in the floor area.

Additional daylight metrics to describe performance over time and under changing conditions are currently being developed by the IES’s Daylight Metrics subcommittee, with the goal of publishing standard definitions by 2010. This new category of “dynamic daylighting metrics” essentially uses local weather data to calculate daylight performance on that specific site and over a full space grid. Because the metrics are so complex, digital simulation tools are often used to make the calculations and interpret the results.

Still, in spite of their complexity, these dynamic daylighting concepts can bring the Building Team new insights into their projects – and new ways to use more daylight and reduce energy use.
then for electric light. “The first step is to maximize the daylighted floor area with the goal of eliminating electric light when daylight is available,” he says. “Space programming, zoning, control intelligence, and interoperability all come into play in this endeavor, but the message is, Daylight first.”

In general, there are two types of systems for daylighting controls, which refer to the methods for measuring daylight contribution: closed-loop and open-loop. Closed-loop photosensors measure combined illuminance from all lighting sources, and those readings adjust the electrical lighting levels. In contrast, open-loop sensors have photocells that measure only incoming daylight. With open-loop sensors, the system controllers dim the electrical lights based on an estimate of daylight contribution.

Then, when sitting down to put together those control specs, Building Teams should consider the following punch list from RPI’s Smith offers:

- Select the appropriate type of control for space—for example, switching vs. dimming.
- Determine the type and location of fenestration, and occupant interaction with blinds or shades, such as open-loop vs. closed-loop system.
- Calculate the number of control zones as dictated by fenestration size, space size, and required light levels.
- Establish the range of response, spectral response, spatial response, speed response, and time-delay adjustment.
- Determine the number of ballasts each photosensor can control.
- Make sure that the photosensors and ballasts are compatible.

Keep in mind, too, that readings of daylight and electric light are not consistently proportional for most, if not all, daylight-sensing lighting controls. In other words, the lighting criteria will rarely be delivered precisely, making a greater case for user control of lighting and shading systems, says Wymelenberg.

Advances in lighting controls are coming quickly, however, say engineers and lighting designers. “The digital lighting-control revolution has arrived and has redefined the state of the art,” says DiLouie. “In these systems, intelligent control devices are tied together using digital communication architecture in a network that easily integrates control functions such as daylight harvesting, load shedding, load scheduling, and occupancy sensing.”

Among the main benefits of such digital systems, he lists:

- Real-time energy reporting
- The ability to create zones using software instead of wiring
- In some cases, remote configuration and commissioning using software
- Potentially setting up zones as small as individual fixtures

Whether or not the controls are digital, the proof comes over the life of the installation, says Smith. To effectively deliver a lighting control system, he stresses the importance of calibration, maintenance, analysis, and education. “Plan on the time and cost of having the system calibrated, and make sure that building engineers receive training in order to make adjustments to the daylight harvesting system,” he says. Similarly, system instructions and calibration procedures need to be accessible to facilities managers and maintenance personnel who perform routine maintenance.

For design analysis, Smith suggests using lighting and energy software to optimally size daylighting elements and verify that the systems meets all user requirements. “It is through analysis that better design decisions can be made, and through analysis, those decisions can be made efficiently and effectively,” he says.

Wymelenberg also stresses the importance of system testing. “There are so many tools available. Universities across the country have solar simulators and overcast sky simulators, and there are several digital tools that are increasingly user-friendly,” he says. “If these options are either not available or out of a designer’s price range or skill set, then a physical model can be built and taken outdoors. There is really no excuse for not testing daylighting design ideas.”

**LIGHTING CONTROLS COMPONENTS**

Getting into the nitty-gritty of how lighting-control technologies actually work, it’s important to emphasize the distinction between open-loop and closed-loop photosensors and their resulting performance benefits.

**Open-loop sensors** measure only daylight and adjust the electrical lighting accordingly. While these systems work well during the middle of the day when outdoor lighting is a more accurate reflection of indoor lighting levels, they don’t perform as well with partly cloudy skies and during the early morning and afternoon hours when the sun is at a low angle. Because open-loop systems only sense daylight from the exterior, they cannot account for diminished indoor lighting levels at these times and under these conditions. Therefore, they may tend to over-dim.

**Closed-loop systems** are more in tune to the interior lighting levels as they are calibrated to maintain a specific set point and will adjust the dimming accordingly. However, closed-loop systems cannot distinguish between daylighting changes and occupant interference. Furthermore, when renovations to a space—such as repainting or new carpeting—change the
lighting dynamics, the set point and dimming steps need to be recommissioned, which can be costly.

The California Lighting Technology Center, in Davis, is combining both types of systems into one, a self-commissioning dual-loop sensor dimming system. In addition to distinguishing between daylight and interference, the system constantly updates itself by using daily measurements of electric light levels and establishing a set point and dimming curve accordingly. CLTC is currently working with a manufacturing partner to commercialize the technology, and a big-box retail store is demonstrating the commercial prototypes.

Another recent development is LRC’s self-commissioning photosensor. Utilizing digital controls, the wireless photocell is entirely contained within a control box that fits inside a standard light-switch mounting box. The Lighting Research Center says the system can help reduce installation costs and performs self-commissioning in just two minutes’ time.

Once the decision has been made as to the type of photosensor to be used, the next technology decision is the choice of ballast type. There are two main types: voltage-reducing ballasts and dimmable ballasts. Each can be used to dim a group of fixtures. Voltage-reducing ballasts utilize either a transformer to curtail the voltage traveling to the ballasts, or electronic controls to alter the electricity’s waveform. (In some cases, the use of electronic controls may adversely affect building power quality.) New technologies are better enabling ballast dimming, according to experts from Washington State University’s energy program. Dimmable ballasts typically operate via control wiring, which is separate from the power wiring. While they usually use low-voltage wiring, dimmable ballasts can operate on line voltage as well. In either case, dimmable ballasts can be very energy efficient.

**DAYLIGHT HARVESTING AND ADVANCED CONTROLS**

Yet another related development is the rise of systems for daylight harvesting. This technology capitalizes on peak-demand reduction in a more cost-effective manner than traditional dimming systems, which have additional equipment and commissioning expenses.

An example is the Simplified Daylight Harvesting system, developed by CLTC and now commercially available, which consists of a photosensor to measure light levels, relays to switch the electric lights, a controller that determines when to change the lighting, and an optional occupancy sensor. According to a technical brief from the California Energy Commission’s Public Interest Energy Research Program, the system enables users to set their own on and off set points, and the technology accounts for interior changes—furniture layouts, interior surface reflectance, and the like as well as adapting to decreasing electric light levels as lamps age.

More sophisticated systems for lighting controls offer high levels of intelligence and interoperability with other buildings systems. Because the lighting controls market largely consists of individual components such as ballasts, switches, and controls, these products often don’t function optimally as a system, especially when supplied by different manufacturers. To address this problem, LBNL is now developing an Integrated Building Environmental Communications System, or IBECS. By utilizing embedded device networks, IBECS essentially...
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optimizes lighting control system interoperability and enables the system to communicate with and control individual light fixtures.

OPTIMIZING ELECTRICAL LIGHTING

Regardless of controls approach, anytime the Building Team is integrating daylighting with electric lighting, it is important to follow established best practices for maintaining an effective system.

One vital area is balancing ambient lighting with task lighting. “Daylight that consistently enters the space generally provides ambient lighting,” explains LCA’s DiLouie. Consequently, the task lighting (and accent lighting, if called for) is then accounted for by the electric lighting design.

McDougall offers a few key design pointers: “For an effective ambient/task lighting design, vertical and ceiling illumination is critical along with horizontal illumination. Brighter ceilings and walls enhance the perception of brightness even at lower light levels on the horizontal work plane.”

Selecting the proper lamp color temperature is another crucial choice. Essentially, when fluorescent sources with warm color temperature are used with very cool daylight, the lamps may appear yellow, notes DiLouie. According to McDougall, “If the space is typically occupied during daylight hours, a high color temperature of more than 4100K is recommended. If the space is occupied often during daylight hours and at night, a compromise in a lower color temperature should be considered.” DiLouie adds that diffuse sources such as fluorescents can be helpful to match the diffuse nature of daylight.

Overall, says McDougall, the electric lighting design should take into such factors as:

• lamp efficacy (lumens/watt)
• light output
• color rendering index
• lamp life
• lumen depreciation
• mercury content
• fixture efficiency
• luminaire photometry
• glare prevention

When it comes to controls specifications, McDougall says he often sees daylighting controls as leaving much to be desired. “We see many examples where lamps, ballasts, and fixtures are specified clearly, but the specification for the daylighting control is too general to know it will be compatible,” he explains. “This is a huge issue, as the general nature of the daylight control specification also leads to problems on what system should be approved during construction submittals and how it should be wired and
SUSTAINABLE DESIGN

Passive Solar—High Sustainability

To accompany technological advancements in lighting controls and more sophisticated daylighting designs, passive solar strategies for illuminating and heating a building can go far in achieving energy savings. “Passive solar lighting strategies are very important,” confirms Richard King, AIA, a senior associate with RMJM, Philadelphia. “Designs can often feature spaces that work for a better part of the day with the lights turned off. What could be more sustainable?”

Care should be taken to consider thermal and illuminance effects, says Wymelenberg: “The most important first step is to ensure there is enough mass to make use of solar gain. The second step is to be careful to introduce solar gain in a manner that does not cause glare.”

In addition to tying passive strategies to the local climate and building design, Building Teams must consider such feasibility factors as the number of heating degree days, sunlight availability, and surrounding window obstructions. “From the onset, passive solar heating needs to be an integral part of the building’s thermal equilibrium and direct the design of the fenestration and mechanical systems,” says lighting consultant Tantari. “Following this are superior envelope design, building components, and a high standard of construction.”

According to McDougall, passive strategies that can be employed to help control direct sun and convert it into useful daylight include tubular skylights, light louvers, glazing with integrated louvers, fiber-optic systems, and simple devices like interior baffles. RMJM’s King particularly likes tubular lighting devices. “Some of the more interesting work being done in daylighting right now involves pushing light into spaces which otherwise could not receive it,” he says. “For example, light tube systems are like supersized fiber optics and are bringing life to spaces which would otherwise only be lit artificially.”

Other lighting technologies such as light-emitting diodes (LEDs), dynamic lighting, and high-dynamic-range imaging promise to raise standards for lighting and daylighting designs. “All of these technologies are in various stages of development and will no doubt improve the suite of tools designers have to incorporate comfortable daylighting that saves energy,” says Wymelenberg.

For example, dynamic lighting technology—introduced by Netherlands-based lamp manufacturer Philips Lighting—tackles the problem caused by dimming and shutting off electrical lights, which causes a perceptible shift in color temperature that can disturb building occupants. By putting differentially dimmable cool lamps and warm lamps within the same fixture housings, the resulting tandem allows for flexibility in combined color temperature and intensity, according to Wymelenberg.

Seeking to complement the natural cycles of the human body, the dynamic lighting approach consists of four states: 1) In the morning, a cool light helps raise the energy level of people coming into the office, 2) at midday, the light level decreases and a warm light encourages relaxation; 3) to counter the “post-lunch dip,” the light level rises to a cool white; and 4) at the workday’s end, an even cooler white light helps provide an energy boost for the journey home.

High-dynamic-range (HDR) imaging, a technology developed by Lawrence Berkeley National Laboratory, was first introduced on a large commercial scale in the New York Times Building in midtown Manhattan. Illumination sensors were installed on the building perimeter facing the glass to the exterior. Spatial luminance data from pixels captured by a digital camera was then calibrated with data collected by the sensors in order to develop a blind control system to optimally minimize glare, according to Wymelenberg.

LEDs are also being used more commonly in general illumination applications. Though the results tend to be good, a new U.S. Department of Energy initiative is addressing persistent issues of confusing or false information from lamp and fixture manufacturers. The Solid-State Lighting Quality Advocates program is creating a verifiable product performance data label to list lumens, efficacy, watts, correlated color temperature, and color rendering index. This information will be posted on a label similar to the Nutrition Facts label printed on food product packaging.

Shuffling Away

Because lighting, daylighting, and controls require a complex integration of expertise from many disciplines, there is still quite a learning curve ahead. And while there are a number of promising technology developments in the works, when it comes to integrating daylight with electrical systems, “Unfortunately, there are no silver bullets yet,” says McDougall. “Better education and experience within the design, construction, and facility management realm will be needed to keep pace with the improvements in daylight technology and to relearn the daylight expertise within the architectural community before Thomas Edison made his invention.”

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