Net Zero Requires Daylighting and Super Efficient Lighting Design[1]

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Abstract

Lighting consumes about 10-12% of the total energy use in industrial nations. Most of it is generated by burning coal or gas. With an immediate and permanent crisis of global climate facing us, lighting improvements can contribute significantly to reducing the CO_2 load on the environment and help attenuate ecosystem damage.

Daylighting is by far the best contribution we can make. It is available at the right time of day and in more than needed amounts. The problems with daylighting today, however, are substanial as the architectural and engineeering communities have little training and experience in using it. Low cost electricity from fossil fuels has encouraged four generations of energy-wasteful design, and those lessons remain ingrained in our current workforce and academics.

We can also reduce our use of electric lighting energy through energy conscious design. But to be effective it must be an honest and thorough effort and must begin with less-is-more philosophy.

Background

Lighting designers can respond and make a significant positive impact. Major skills that will be needed include:

- Our ability to design daylighting. While architects claim daylighting as part of their domain, they generally lack the education and tend to overglaze buildings. With our assistance, they will design more efficient buildings that are well daylighted.
- Our ability to use state of the art lighting technology. Without the silly killing of the incandescent lamp, we must master the efficient technologies of today to produce excellent design without sacrificing any lighting quality,
- Our ability to show restraint and to avoid excessive, flamboyant and gratuitous lighting. (Yes it wins awards. No, it is generally not good for the planet.)

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- Our ability to make use of lighting controls to provide further savings and to integrate lighting and daylighting better into whole building energy efficiency,
- Our ability to reverse the damaging trends in exterior lighting and to return the night sky to as many parts of the world as possible, freeing up the wasted energy of street lighting for other uses like electric cars that reduce carbon footprint.

After many years of complacency and debate, we now acknowledge the environmental damage of energy use and waste by humans as a serious and imminent threat to the planet and the future of life on it. Avoiding the politics of the problem, the challenge facing us is to curtail the growth of consumption and to seriously pursue measures to mitigate and where possible, reverse the damage. Every use of energy should be part of the solution as waste is no longer an option.

Unfortunately, it is the nature of 21st century communications to manipulate issues into marketing programs, slogans, and styles. The phrase ***sustainability***, once revered as the goal of worldwide change that sustains life on the planet, has now become abused to the point of becoming fashionable. It seems like everyone and everything is referring to themselves as green, from oil companies to rock bands. This makes it hard to distinguish meaningful efforts to mitigate and reverse the environmental damage from superficial gimmicks designed to sell products and services.

A case in point is the current generation of LED lighting. Made throughout the world in factories using coal-derived energy, harsh chemicals and often without environmental regulation, soldered onto circuits using heavy metals with other components made of petroleum-derived plastics, abutted to extruded aluminum heat sinks, and driven by complex electronic circuits of questionable efficiency (and also built in unregulated manufacturing environments), the average LED makes the equivalent of a trip around the world before being installed. Its efficacy is at best about ½ of that available from conventional fluorescent lighting, and lacking serious industry standards and protections, the consumer will be lucky to get anywhere near its rated lifetime before being forced to throw it (and the luminaire to which it is attached) away. In other words, LED's aren't nearly as green as they are new, interesting and cool. Yet, way too many people and companies are unabashedly promoting LED lighting as better, more environmental and the most efficient lighting we've ever seen. With the exception of a small number of products, it is just not yet true.

Obviously, lighting is a measurable and significant part of the problem. With somewhere between 22 to 25% of all electricity used by lighting, the opportunity is unmistakable. Worse, most of that energy use is during the day, at the peak of human activity, concurrent with the demand for energy for commerce and air conditioning. This points the finger of opportunity straight at daylighting, an aspect of architecture and engineering lost 70 years ago to the convenience of electric lighting and air conditioning. Daylighting today is mostly fashion and style; architectural awards are still given to over glazed, badly sited and massed buildings, and architectural textbooks celebrate more-is-better design and illustrate building after building with too much daylight and every interior electric light on.

The USGBC LEED system is supposed to provide a fair, objective and juried system of assessing sustainable design. Indeed, LEED is far better than the lighting design award programs because it requires the submission of energy calculations and actually checks them. Yet, far too many projects that just meet basic federal energy codes and neglect daylighting can achieve LEED Silver and Gold certification anyway. Other systems for measuring "sustainability" may do a better job, but since they failed to achieve LEED's popularity, it's a moot point.

If we plan to save the planet from exponential warming and the corresponding catastrophic changes, our current band aid and bubble gum efforts need to give way to seriously sustainable design. Buildings and the activities in them still use about 39% of all energy use in the US, and we need to stop designing the same old buildings and start designing new structures a whole lot differently. By the necessary future standards, even most LEED Platinum buildings fail. It is because we've developed bad habits over 120 years of electric lighting that we need to change more completely than we've ever thought. It won't be easy, but compared to the alternatives, it is one of the key ways that the devastating effects of global warming can be addressed.

Because of its huge role, lighting is the low-hanging fruit of opportunity. The following are suggestions for sustainable lighting basics, a foundation for new projects and practices that must be considered by those wanting to design seriously sustainable projects.

What is Net Zero?

Net zero is the concept that buildings can be equipped with renewable energy systems such as PV or wind power generators that are grid connected. When the building has excess energy, it dumps power into the grid, and when the building has greater need, it draws the energy back from the grid. The grid is a bank for energy, and if the systems are designed right, the building will have a net "zero" use of grid power when examined over any period of time.

Net zero is not universally defined or understood. For example, in California the grid capacity can be exceeded in the afternoon of hot, sunny days statewide. Power emergencies are declared and rolling blackouts affect customers throughout the state. It would be preferred that buildings capable of net zero would make a significant contribution TO the grid at this time, and only draw FROM the grid at night when the emergency is over. This is time-of-use (TOU) net zero, the best kind.

Throughout the latter half of the 20^{th} Century, turning on lights regardless of daylight was standard practice in businesses of all types. Skylights were dismissed as leaky dirt collectors. But the fact is that 50% of all buildings could be daylighted with minimal cost and effort. Turning off electric lights by day for all such spaces could reduce the TOTAL electric grid load by 5% or more, enough to not only avert a power emergency but to allow economic growth without the need for more generating plants.

Net zero is not an esoteric concept. Originally presented in the US by Ed Mazaria (Architecture 2030) the concept has caught on among regulators of all kinds. California passed laws in 2008 requiring all new residential buildings to be Net Zero by 2020 and all new buildings to be Net Zero by 2030. Lighting designers are integral members of architectrural and engineering teams than must rise to meet this challenge.

Design Daylighted Buildings

The most sustainable lighting is daylight. It is widely available during most of the hours of normal business and work, and done correctly, it provides free light, less cooling load than a similar amount of electric light, and more desirable heat gain in the winter. Moreover, daylight provides a number of physical and mental health benefits not available from electric light.

But daylighting is not easy. To begin with, it must be rescued from the world of architectural fashion. This is going to take several important steps beginning with architects and architectural schools. Passive solar design must again be the basis of architectural education. Conversely, harsh criticism must be heaped onto irresponsible design, especially buildings with glass curtain walls with broad east and west exposures. Just because a building has windows or contrived expressions like heliostats does not mean it is daylighted. We need to design and engineer the daylighting and avoid unvetted concepts and flights of technical fantasy.

Daylighting Basics

Natural daylight includes visible light, infrared light (radiant heat), and ultraviolet light. All contain energy that can heat a building. Infrared light is essentially all heat; visible light produces heat as a byproduct; and ultraviolet light, although it can produce heat, is mostly unwanted anyway. Glass and plastic ("glazing") generally absorb ultraviolet energy, but transmit both infrared and visible light. A great invention of the late 20th century was a special coating that can be applied to glazing called "low emissivity" or "low-e" that allows visible light to pass through the material, but reflects infrared energy. This ability to transmit light energy with reduced heat energy is a critical technology in designing high efficiency daylighted buildings.

Daylight is provided directly from the sun whose direct rays contain significant amounts of visible and infrared energy. But daylight is also provided by the sky itself; both the clear sky and the glow of clouds are light sources, too. The sky and clouds produce light that is "cooler" in both coloration and reduced infrared content. Outdoor light levels of sky and direct sun can achieve up to 100,000 lux (10,000 footcandles) while cloudy skies alone typically produce about 5000-20,000 lux (500 to 2,000 footcandles). This is an important point: while direct sunlight produces a lot of useable light, clear and cloudy skies *without direct sunlight can also* produce useable amounts of daylight for interior lighting if the building is properly designed.

There are two principal types of daylighting; ***sidelighting***, through windows and other vertical glazing, and ***toplighting***, through horizontal glazing ("skylights"). The basic concept of sidelighting is that the specific window allows energy to enter the building from a specific portion of the sky and, depending on shading, the sun. The basic concept of toplighting is that the skylight allows energy to enter to the building from the entire ***skydome***, which includes both sun and sky.

Daylighting design is the process by which an optimum combination of sidelighting and toplighting is selected in consideration of the climate, latitude, building mass and orientation, site and adjacent structures, and ground plane reflectance. Design choices include fenestration, shading, and other elements whose importance depends on the design itself.

Fenestration

Solar energy enters a building through fenestration. Excluding shading, several key factors apply:

- Visible light transmission (VLT or T_{vis}), the percentage of available light transmitted to the interior of the building which both lights and heats the building. Glazing with high transmission (>50%) is generally considered clear; lower percentages indicate dark-appearing windows. Below 35% VLT glass becomes surreal and visually isolating.
- Solar heat gain coefficient (SHGC), the percentage of available heat energy from daylight transmitted to the interior of the building. When using simple glazing, the SHGC and the VLT are the same, with equal amounts of available visible and infrared light passing to the interior of the space. With low-e glazing, the SHGC is lower than the VLT, indicating that more visible light than infrared is passing to the interior. Glazing with a high ratio of VLT to SHGC (>1.5) is considered high performance glass; those above 2.0 are by today's standards super high performance.
- Reflected light, the amount of daylight energy reflected by the glazing and having no interior impact. Glazing with a high reflectance value (>25%) indicates a mirrored effect of the glazing. Reflected light affects VLT directly.
- Absorbed light, the amount of daylight energy absorbed by the glazing and potentially affecting the buildings' energy use. Glazing absorbs light with pigment in the material, which also directly affects VLT.

Glazing can also alter the color of transmitted light. Most low-e glazings alter visible light to a certain extent, and in general the higher the ratio of VLT to SHGC, the bluer the transmitted light will appear. However, there are many choices of tinted glazings, most of which use a combination of low-e and absorbing tint to reduce the SHGC.

Passive Solar Theory

Passive solar design is based on the concept that solar energy can be regulated to reject unwanted heat and to harvest wanted heat. During the summer, solar gain is generally unwanted, and every effort should be made to keep direct sunlight from entering the interior of the building. During the winter, in most climates direct sunlight creates glare but its heat is welcome.

For sidelighting, well designed buildings use a combination of building mass, orientation and shading angles to regulate light. Daylight studies are used to determine interior light levels and to illustrate direct light penetration. As a general rule, a transition date is set at which direct solar penetration is allowed to begin. This date generally corresponds with the start of the shoulder season; a time when neither heating nor cooling is desired. In the fall, as winter approaches, the amount of direct penetration increases, the opposite occurs in the spring. The easiest solutions occur when the fenestration faces north or south; east and west facing designs are the most challenging. Horizontal building elements such as overhangs provide useful, low cost shading.

For toplighting, there are two major options. Vertical glazing used as a clerestory can, like sidelighting, be aimed and shaded to regulate direct lighting. In desert climates, clerestory daylighting with appropriate roof overhangs has the profound benefit of almost totally rejecting any direct light as well as minimizing ground plane reflectance, thereby allowing the coolest incoming light. For most climates, however, toplighting using horizontal glazing ("skylights") can deliver more useful daylight over a wide range of daylight conditions with the caveat that the peak solar condition is carefully evaluated. A good design generally occurs when the peak solar gain does not produce cooling load exceeding a well designed electric lighting system. The advent of modular, high efficiency low-e skylights makes this possible.

Deep daylighting is a method by which forms of top and/or sidelighting are combined with major architectural expressions that permit daylight to penetrate deeply into the building. One of the most popular methods is the use of external light shelves that shade the lower view glass while bouncing light onto the ceiling through the clerestory glass. Other methods include sloped ceilings permitting higher windows that in turn introduce daylight further into the building.

The mission of passive solar is to combine these methods in an architecturally appropriate and appealing way. What we are just learning is how to use computer energy and lighting analyses to optimize the effect by hitting the "sweet spot" where the design produces substantial useful daylight with cooling and heating systems of the same or less capacity than an electrically-lighted, unfenestrated box. Passive solar is the starting point for better daylighting in the future.

21st Century Daylighting

If we are to successfully advance the state of daylighting, we will have to improve upon our current philosophy and tools. First, we must begin to look upon daylighting not as purely architecture, but rather, the most integrated form of lighting design.

In lighting design, balance is usually achieved by a combination of different light sources, with uplighting, downlighting, and diffuse lighting combining in a composition called layered lighting design. The same principles should apply to daylighting. Rather than getting all of the daylight from a single element, consider several layers. In classrooms for example, use windows and skylights to ensure comfortable, even light with a view that neither alone could provide. These layers effectively permit, rather than limit, architectural design and interest.

Next, we must develop tools and concepts to permit daylighting design without whole building energy analysis. Presently, architects deliberate over combinations of siting, rotation, massing and fenestration, and then use small-scale foam core models to study their ideas. Without elaborate large scale models and labs with artificial skies and heliodons, models provide almost no useful information about the performance of the daylighting. Well equipped labs and expert technicians are expensive and rare, with fewer than 10 in North America. In addition to more labs, computer tools need to improve as well, as daylighting lab analysis is expensive, time consuming, and often a long distance from the architect's office.

In order to properly analyze the daylighting concept, we need to be able to answer several key questions with relatively tight tolerance (10%) during early schematic design:

- How many hours of useful daylight per year will the proposed design provide in each building room or area? (Do not include spaces that are not used much, like janitor closets)?
- How does the indoor daylight quantity and quality vary due to time of day, weather, and season?
- What is the impact of the daylighting design on the building's heating and cooling energy use?
- How do these compare to useful design criteria so that the performance of the building might be more optimized?

The tools to enable answering these questions cost-effectively do not exist yet. The next great breakthrough for daylighting will occur when they do.

Finally, we need to learn more about shading systems and perhaps design and use new products. As a rule, the first and most desirable line of defense against solar gain is exterior shading, in which the building is protected from unwanted direct solar exposure. While this can include site topography and other buildings, most of the time the best results are through the use of south and north facing glass protected in the cooling season by overhangs, awnings, light shelves, or similarly simple means. The second line of defense is the glass itself, using SHGC and VLT to achieve the right amount of available light. The third line of defense is using interior roller shades, louvers, blinds or curtains.

The best of the methods is exterior shading, allowing permits the largest windows, as these are often seen as desirable for view and aesthetics. The second line, characteristics of the glass itself, are almost as good, but problems can arise if the glass absorbs too much light, for it can become warm and radiate, conduct and convect the heat energy to the interior.   Interior shading is weakest because the thermodynamic principle that reduces radiant heat transfer (low-e) from entering the building also tends to keep it inside.

Day lighting Controls

Every energy code contains mandatory measures which include lighting controls that must be provided. In current codes in the US, these include requirements to provide readily accessible switches for every space and, in most buildings, automatic lighting shut off controls such as occupancy sensors, time switches, or photoelectric switches. Also, when lighting systems exceed a threshold power level, the ability to reduce lighting levels manually is also required. Some codes, notably California, Oregon and Washington, further require the automatic reduction of interior electric lighting in some buildings or spaces when adequate daylighting is present.   But for the most part, energy codes fail to require important components and systems that can make a profound difference.

Strategies for Lighting Energy Management

There are seven major ways lighting energy use can be reduced through the use of controls:

1. ***Predictable scheduling***, when lights are switched on only for predictable periods of need. This can be done using time of day, solar time (“astronomic”), timer, or photoelectric switching.
2. ***Unpredictable scheduling***, when lights are switched on only when use is demanded. The most common control of this type is motion sensing, but switches in doors and process equipment are also good examples.
3. ***Daylighting,*** when lights are reduced or extinguished automatically when adequate natural light is present.
4. ***Tuning,*** when maximum allowable light levels are adjusted downward during commissioning to harvest the overdesign of electric lighting normally caused by limitations in available standard equipment sizes
5. ***Manual dimming,*** where occupants are provided with the ability to reduce light levels as desired.
6. ***Adaptation Compensation,*** where lights are dimmed on the interior of spaces at night so that people entering the space can more readily adapt (*aka* tunnel effect)
7. ***Demand response,*** where lights are dimmed or extinguished to reduce building power demand to save peak energy costs and aid in regional energy demand schemes.

Each of these strategies relies upon a combination of lighting and control elements, properly applied to the application. Some are presently required by code; future codes must improve these capabilities with the following required technologies.

Dimming Ballasts

Aside from California Title 24, which has controls credits for the use of dimming ballasts, there are no incentives to encourage dimming at all. The comparatively high incremental cost of ballasts has been held out as the reason for not making them mandatory.

However, without dimming ballasts, strategies other than scheduling are difficult to implement. Stepped dimming is a poor approach, often annoying unless the increments are small and a fade rate is employed. Moreover, even with stepped systems, daylighting and adaptation compensation are marginal and other strategies still not possible. In other words, to fully realize all possible lighting strategies, dimming ballasts make it possible.

The cost barrier may be about to fall. Where once the cost difference between a dimming ballast and non-dimming was $40 per lamp, current cost differences have dropped to about $25 per lamp, while electric rates have increased. With each lamp using an average of 35 watts, a payback period of 7 years[3] is reached with only 30-40% average dimmed level in a typical office building; in retail stores with long hours of operation, the 7 year payback can be achieved with only 16% average dimming. There are additional cost benefits associated with "smart" dimming ballasts.

It has been said many times that if dimming ballasts were required by code, the cost would fall. Now is the time, because whether costs drop or not, cost effectiveness is at hand.

Digital Lighting Controls

When DALI (digital addressable lighting interface) was first introduced, it floundered. A brilliant idea, it lacked design and application instructions, accessories and peripheral components, software, and worst of all, it was a commissioning nightmare. The Tridonic engineer responsible for commissioning the first 200,000 sf system for Capital One in Virginia spent 6 months getting the system right[4]. At $100 per hour, the commissioning costs were probably in excess of $100,000, or at least 50¢ per sf. Costs like this are not budgeted; who pays is a sticky question, and wise specifiers saved DALI for small projects in which a days' worth of commissioning was fun whether paid or not.

The problem is simple. DALI is an infrastructure, not a system. With modern electronics it is no problem to send signals all directions through a pair of twisted wires. The basic specifications are contained in IEEE RS-485 and have been used by several controls system manufacturers for a number of years. The technology is as close to an open source wiring method as you can get – and it supports DALI, Ecosystem, IGEN, and even DMX-512, all complete systems including peripherals and software.

The promise of digital lighting controls is to dramatically improve performance and reduce installation costs. Digital eliminates line voltage controls completely. No more line voltage switches, motion sensors, relays, or dimmers. One designer[5] estimated that a digital system reduced the amount of copper and steel in wiring systems by almost 50% compared to a comparable analog system. With the costs of steel and copper rising at 2-10 times inflation, not to mention $75/hour electrician's time, the savings dramatically improve the amortization rate of digital ballasts, which now cost $50 more than generic electronic ballasts. In fact, recent studies on current projects by my office demonstrate that an analog system[6] with dimming and daylight sensors actually costs more installed because of copper, steel and labor.

This is a very simple and inexpensive opportunity. Codes should require all branch circuits to carry a pair of RS-485 data wires with the power wires to every junction box. This will enable powerful controls whenever the building is ready. The cost will be trivial; the capability will be significant. Not installing this low cost method of control

[3] This is the approximate cost effectiveness test required for California Title 24 and ASHRAE-IESNA 90.1 standards.

[4] Personal communication with John S., the engineer who did the work.

[5] Personal communication, Clanton and Associates

[6] Using 0-10 volt technology

will force future projects in the building to use wireless technologies which, in addition to their cost and complexity, remain unproven (see below).

The benefits are profound. In a project in Washington DC[7], a digital lighting control system with digital dimming ballasts in a school achieves 92% energy savings compared to a minimally code-compliant design. While the low lighting power density and other factors contribute, the designers estimate that more than half of the savings are due to the digital controls.

Is Net Zero Possible?

There are now a number of "net zero" buildings worldwide. They are early examples of the design philosophy and processes described in this paper. However, there are few (if any) net zero buildings that have significant worker population density or energy intensive work activities. Designers should be advised that computer energy use now exceeds lighting energy use in offices and schools. Controlling "other" loads will be an issue as daylighting designs extinguish electric lights all day long. Needless to say, if as lighting designers we are successful at developing more "sustainable" skills and methods, the emphasis will shift towards controlling the energy use in other aspects of our daily lives.

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[7] Sidwell Friends School, see http://www.lutron.com/cms400/assets/0/609/2617/2625/3DAF397F-5A81-4E5E-9F82-DE429B8B5AE7.pdf