Zero Energy Commercial Buildings Consortium (ZECBC)

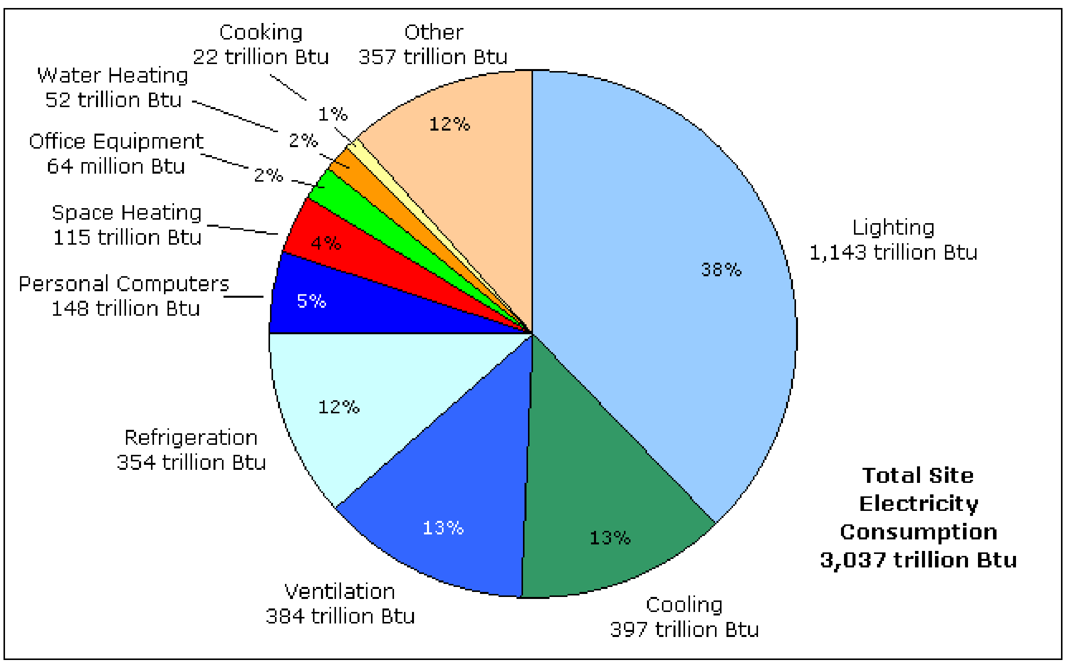
Lighting / Daylighting / Controls Working Group

September 9, 2010

Introduction

Lighting accounts for 38 percent of the electrical energy used in commercial buildings or 1,143 trillion Btu's. It is by far the largest single user of electrical energy consumed in these buildings. More than half of this energy is wasted because energy efficient lighting has not been installed, lights are left on in vacant rooms and the availability of daylight is not exploited. Since savings of 50 percent or more of lighting energy are easily achievable with the technology available today, we can save 571 trillion Btu's or 19 percent of total building electrical energy each year by installing energy efficient lighting and lighting controls now. The savings would be enough to provide the electrical energy needed for all the households in the entire metropolitan areas of Atlanta, Boston, Chicago, Dallas and Los Angeles. Much of the dollar savings could be considered picking low hanging fruit or even gathering fruit off the ground.

More site electricity is consumed for lighting than for any other end use.



Note: Data are for non-mall buildings. Site electricity excludes energy used to generate and transmit electricity.
Source: Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Table E3.

In addition to the proven financial benefits already available by using energy efficient lighting products, the Commercial Buildings Tax Deduction enacted in the Energy Policy Act of 2005 and extended through 2013 by the Emergency Economic Stabilization Act of 2008 offers an added incentive to make buildings more energy efficient now. These tax deductions provide financial incentives up to $0.60 per square foot for reducing new and existing building lighting energy use by 25 to 50 percent. Additional deductions up to $1.20 are available for achieving energy savings due to improvements in heating, air conditioning, hot water and building envelope systems. Also, many electrical utility companies and some states have incentive programs of their own. .

As of the writing of this document, over $350 million in tax deductions have been claimed with more coming in daily. The technology, the solutions, and the incentives are in place to move forward rapidly with policy centered on energy efficiency and cost effectiveness.

These points are clear:

1. Efficiencies to be gained by individual electrical components are limited
2. For Zero Energy Buildings to become a reality, building owners must be convinced to invest in new technologies. Tax incentives and credits have value but often offer limited life in the marketplace.
3. The proper use and proliferation of existing technologies offer tremendous opportunity today. For example, the implementation of lighting control technologies that exist today can reduce lighting electrical energy by 40% or more.
4. Gains in energy efficiency can be achieved today through proper training and operational procedures by building personnel in commercial buildings. This point becomes even more significant as building become more sophisticated.
5. New standards and associated integration of systems within a building offer promise for overall building management. For example, communications between lighting control systems and the systems that manage HVAC and the motors that run the escalators/elevators.
6. Integration between the building and the smart grid will create a new future in energy efficiency. For example the SPC 201 standard co-sponsored by ASHRAE and NEMA and being developed in coordination with NIST for interoperability between commercial, residential, and industrial buildings and the smart grid will create tremendous opportunities for demand-response and synergistic opportunities for energy savings by utilities and building owners/managers.
7. The use of "smart systems" that do not require human intervention will ensure maximum benefit is realized at all times.
8. Coordination between electric lighting and daylighting is necessary, but inter-system coordination between lighting controls and the overall building automation system is also imperative. Standardized protocols need to be adopted.
9. DOE might consider providing a "test bed" for new technologies – a building or site where new products and systems can be tested under conditions similar to actual buildings. State of the art sensors and data collection equipment would be integrated into the building to expedite test and measurement procedures. This site could also be used to

train building operation personnel in the installation, use, and maintenance of new advanced systems.

Details of this Working Group report on lighting (more appropriately *electric lighting*), daylighting, and lighting controls will be found in the corresponding papers that follow. Our goal is to present a relevant future in these areas of lighting technology so that we can all benefit as the trend toward substantial improvement in energy efficiency becomes a reality.

Electric Lighting

This section presents the analysis of electric lighting and its potential contribution to Net Zero Energy Buildings. In this case, electric lighting refers to lamps, ballasts, and luminaires. Daylighting and Controls are addressed in other sections.

The ability to achieve a zero energy building based on improvements in lighting will, to a large extent, be determined by the configuration of the building itself. Merely changing out inefficient lighting for more efficient lighting can achieve tremendous gains in reducing the energy requirements of a building, however, the most energy efficient lighting is that which can be turned off or reduced when not needed. Furthermore, commercial buildings are functional, living entities. Merely lighting a building is not enough; the lighting must not detract from the function of the building and the support of the occupants' tasks. Thus, any technological solutions that move toward a zero energy commercial building must provide **both** the quantity of light required by the tasks and the quality of light that allows for the comfort, productivity, and safety of the occupants. It is short sighted to consider the energy that could be saved by using low quality lighting, such as high CCT LED lighting, but no one wants to work under bluish lighting with poor color rendering. Savings provided by poor quality light are also illusory since the higher quality the light, the less light that is needed and the more productive people are under the light.

A little history

There have been significant advances in electric lighting over the last 20 – 30 years:

- The T8 fluorescent lamp was introduced into the U.S. market in 1981
- Electronic ballasts became more reliable and popular in the early 1990's
- Compact fluorescent lamps were introduced in the U.S. in 1985
- PAR halogen lamps using Infra-Red (IR) technology were introduced in the mid-1990's
- Low wattage, improved color Metal Halide lamps were introduced in 1991
- Ceramic Metal Halide lamps introduced in the mid-1990's
- The T5 fluorescent lamp was introduced in 1997
- Improved performance T8 lamps were introduced in 1998
- Luminaire designs have evolved to take advantage of the new lamp types
- Highly efficient luminaires using premium reflector systems have provided a means of reducing energy consumption while maintaining proper light levels.
- High output blue LEDs introduced in the mid-1990's allowed development of "white LEDs"
- The development and adoption of energy codes and standards have helped push higher efficiency lighting systems into the commercial and residential lighting market

- Lighting designs have become more sophisticated and have integrated the areas of new product technology, new codes and standards, and human factors

This is by no means a complete list, but shows that the lighting industry has been quite active in introducing and applying energy efficient products, systems, and techniques for many years.

Technology Assessment

Incandescent/Halogen Lamps

The highest efficiency exists in IR Halogen. Current state of the art in IR technology provides an efficacy of approximately 21 lumens per watt (lpw) for the PAR lamp, which is the most common type of halogen lamp for commercial applications. Further improvements are possible, but only on an incremental basis. Higher temperature sources and selective radiators are possible improvements[1], but it is difficult to justify major expenditures of resources in this traditional technology. Legislation and ever more stringent energy codes will force lighting designs to be biased toward the more energy efficient sources and away from filament-based sources. The exception may be retail stores and restaurants, where limited amounts of low voltage halogen accent lighting may be advantageous or for specialty applications in office buildings. In general, however, it is not felt that this family of sources will contribute in any significant manner to Net Zero Energy Buildings.

Fluorescent Lamps and Systems

As noted in the bulleted list above, there has been much progress made in improving fluorescent lamp and system efficacy. The best fluorescent systems (lamp and ballast) today have efficacies approaching 105 lumens per watt (lpw). These systems are capable of providing significant savings now; increased adoption of these systems in both new and existing buildings is needed. Fluorescent lamp development, however, appears to be reaching the limits of efficacy. The one potentially significant technological improvement is through the use of multi-photon phosphors, however, the maximum foreseeable improvement in lamp efficacy is only about 15%. This effort is currently in the basic research phase; due to the small increase in efficacy, the potential return is not enough to justify major R&D efforts. It should be noted, however, that current fluorescent lamps have useful lives of 20,000 – 30,000 hours, the same that is claimed for some white LED systems. Fluorescent systems may still be the most cost effective option for general lighting. However, while fluorescent may still be an option for Zero Energy buildings, it should probably not be the area in which to invest significant research efforts.

The same applies to Compact Fluorescent (CF) lamps. In the commercial arena, pin-based CF lamps (lamps requiring a separate ballast) are the preferred version (as opposed to the screw base, retrofit CFLs with integral ballast). CF lamps are already near their peak efficacy (approx. 75 lpw) and are inherently lower in efficacy compared to their linear counterparts. However, contrary to linear types, the CF lamps will probably not have a place in NZEB due to several competing technologies – low wattage HID and LED.

Fluorescent ballasts have also been improving over the last decade, with the new High Efficiency types delivering efficiencies of approx. 93%. It is felt that this is also at a practical limit. Slight improvements are possible but would cause an increase in cost and have a questionable return on investment.

High Intensity Discharge (HID) Lamps and Systems

Again, there has been significant improvement of these sources and systems over the last decade. From a building perspective, most of the weight would be carried by Metal Halide (MH) types, with High Pressure Sodium (HPS) used mainly outdoors for area and roadway lighting. The other main member of this family, mercury lamps, has been basically outlawed in recent energy legislation due to low efficacy.

Improvements in ceramic arc tubes, electrode designs, fill materials, and electronic ballasts have all contributed to improvements in efficacy of MH lamps and systems. There are still numerous areas within the HID family that could, with continuing research and development, bring about improvements in lamp and system efficacy and in lamp operating characteristics.

The areas of improvement that would make HID a viable option for Net Zero Energy buildings are:

- Instant or near-instant starting
- Dimmability to 25% of full output
- Low cost, high efficiency dimming ballasts
- High efficacy low wattage lamps (>=175 lpw) for higher ceiling/mounting applications
- Long life with good lumen maintenance and color stability (20,000+ hours)
- Luminaires with a combination of high efficiency, glare control, and low cost

The most significant technology gaps to overcome are:

- Improved electrode designs and materials to allow low level dimming
- Improved electronic dimming ballasts
- New ceramic arc tube materials and designs to improve life and color stability
- New radiating materials for environmentally friendlier lamps (no mercury or other toxic materials)

Where do HID lamps fit in the Zero Energy puzzle? High wattage lamps (either HPS or MH) are still needed for applications such as roadway, area lighting, façade lighting, sports stadiums, and the like. For interiors, areas such as atria, small auditoriums, gymnasiums, or any area with higher ceilings would be candidates for low wattage MH. For these areas, improved MH may be advantageous due to potentially better optical control, heat tolerance, and probable lower system cost.

Solid State Lighting (SSL)

The table below illustrates the energy saving potential of SSL.

Table 2.2: Energy Savings of Continued Adoption of SSL Products

SSL Performance Scenarios	Low Improvement Conventional Technology	Medium Improvement Conventional Technology	High Improvement Conventional Technology
Reference (Quads for lighting in 2030)	8.70 Quads	8.26 Quads	8.10 Quads
LED Scenario (Quads *saved* in 2030)	2.42 Quads	2.05 Quads	1.89 Quads
OLED Scenario (Quads *saved* in 2030)	1.77 Quads	1.51 Quads	1.39 Quads

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. February 2010.

Following are discussions about the various types of SSL products that will probably play a major role in zero energy buildings.

Light Emitting Diode (LED)

A large part of the solution to achieving NZEB will surely be LED technology. Pros and cons are quite well known and summarized here:

Pros:

- Good system efficacy
- Easy to dim
- Insensitive to on/off cycling
- Inherently directional
- Can be directly powered by photovoltaic sources
- Long life
- For RGB arrangements, color can be "tuned" to match other light sources and/or daylight
- No toxic materials

Cons:

- High cost per lumen
- Significant thermal control requirements (heat sinking) for higher output types; luminaire designs more challenging for high output types
- Color and light output consistency (the binning issue) both initially and for replacement
- Inherently directional
- Potentially higher glare – decreased visual comfort

It is felt that the efficacy of LEDs would need to be in the area of 250 lpw in order to significantly reduce overall lighting energy to the levels needed in a NZEB. Although the range in efficacy for commercial LEDs is currently 76-132 lpw, research in a variety of areas should be able to increase the efficacy to the required target. This target will need to be reviewed as time goes on since the relative contributions of the other building systems may require that the target be higher (or perhaps lower, in which case, resources could be put to work on other issues).

With LEDs, whatever performance increases are needed will, in almost every case, increase the cost. Higher efficacy, longer life, improved color, more advanced controls (dimming, interface to other building systems), higher light output – all will have a cost penalty. The question remains if manufacturers will be able to offset cost increases with improved manufacturing processes and sales volume.

LEDs typically have a different pricing model compared to traditional products – it costs more to produce more light. Lumen-based pricing may facilitate more innovative lighting designs. Existing lighting is largely based on luminaire cost and not lumen output (at least for most interior lighting applications). Due to this, there may be resistance to the LED pricing structure, which could slow acceptance.

Instead of listing all the details of required improvement areas for LEDs and the technology gaps, the reader is referred to a recent document prepared for Lighting Research and Development group, Building Technologies Program, Office of energy Efficiency and Renewable Energy of the U. S. Dept of Energy titled "Solid State Lighting Research and Development: Manufacturing Roadmap", dated July 2010. The link is (http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_manuf-roadmap_july2010.pdf)

This document gives a very complete picture of the necessary steps to improve LED performance. It sets targets out to the year 2015 – the range of efficacies being 184 lpw to 215 lpw for warm and cool color temperature LEDs respectively. While these targets are somewhat less than the 250 lpw noted earlier, it is felt that continuing improvements will lead us to our target within the required timeframe.

Organic Light Emitting Diode (OLED)

OLED technology, while similar in concept to LED technology, is different in execution. OLED lighting is typically in planar, diffuse form as opposed to the point source nature of LEDs. This makes OLED sources more applicable to general lighting, where a diffuse source is usually preferred and advantageous. Laboratory efficacies for OLEDs are beginning to surpass efficacies of conventional technologies. Currently, 50-60 lpw is possible for white light OLED panels, with 70-90 lpw on the horizon. Lifetime at these higher outputs, however, still needs improvement.

OLEDs have several unique characteristics: due to their planar nature, surfaces can become sources, e.g., walls, partitions, ceiling panels. They can potentially be flexible to adhere to surface contours or even be rolled up and transported to another task location. They can be integrated into clothing, although this is not necessarily an energy saving feature. Summarizing:

Pros:

- Potential efficacy can surpass most traditional sources
- Design flexibility due to planar form factor
- Physical flexibility

- Dimmability
- Insensitive to on/off cycling
- Can be directly powered by photovoltaics
- Simple luminaire design
- Inherent low glare (diffuse source)
- No toxic materials

Cons:

- Very high cost per lumen
- Color and light output stability
- Not directional
- Short life (<10k hours)
- Susceptible to moisture

Like LEDs, OLEDs' light output may be directly proportional to the area of the light emitter. Thus, OLEDs will likely have similar pricing structures to LEDs (i.e., more lumens mean higher cost). OLEDs may take advantage of lessons learned and policy changes that will be driven by the adoption of LEDs. Accordingly, when OLEDs are ready for commercial applications, their adoption may be more rapid as a result of LEDs paving the way.

While OLEDs are currently used in small display applications (e.g., cell phones) and in small, high end televisions, their application to the lighting market is still not realized. Ongoing research needs to continue being supported to fully realize the potential of this technology for creating efficient white light. If the efficacy and life can be significantly improved, there is likely a place for this in zero energy buildings.

Other Technologies

Another technology for saving energy and improving efficiency is to eliminate energy conversion wherever possible, i.e., converting AC to DC and vice-versa. An example is the use of DC voltage circuits tied directly to photovoltaic power sources.

A simple but effective "technology" that is highly effective in reducing energy use is the "task-ambient" lighting design. Use of highly efficient task lighting can bring a concomitant reduction in the amount of energy used for ambient lighting. While this is not a new concept, its application in zero energy buildings is required.

The art and science of lighting design can also benefit from technological advancements. Improvements in lighting design software by taking advantage of more accurate modeling of the occupied space could produce additional energy savings. New lighting design techniques and software would also be needed to take advantage of new and upcoming developments in light sources, luminaires, and the incorporation of daylighting.

Other areas of concern

Advancing energy efficient lighting may need efforts on several fronts, policy, education, research and development and standardization. From a policy perspective, this may include building codes, policies for government facilities, ASHRAE/IES standards, and other building standards. Likewise, light level requirements may also need to be re-evaluated to reflect the more stringent requirements and advanced lighting design techniques of the future.

More thought needs to be given to lighting efficiency legislation. The current push for continued reduction in source lpw and longer and longer lifetimes can be counterproductive. For example, setting the Energy Star lifetime requirement for LED lamps at 25,000 hours may increase the cost of the lamps, thus slowing adoption. In addition, continued use of lpw or W/sq.ft (watts per square foot) as a metric for energy efficiency is too restrictive from a design standpoint and also will likely produce a building with poor *quality* lighting. Unintended consequences will certainly ensue.

An energy-based metric (as opposed to a power-based one) will allow flexibility in the design process while preserving the desired outcome – limiting the energy used for operating a commercial building. After all, this project is called "Net Zero Energy" not "Net zero Power".

Additional policy changes that could accelerate development and adoption of energy efficient lighting would be simpler accounting/tax treatment of the expenditure for lighting upgrades. The Federal incentive for energy efficiency provides, after extensive and expensive verification, for accelerated depreciation of a portion of the cost of the lighting system. This system highlights the difficulty with lighting, as the benefit of lighting accrues to the maintenance budget while the expense is a capital expenditure. This often splits the decision for lighting upgrades to two competing areas of a commercial venture. Merging the cost and the benefit, for example, by allowing the cost of lighting upgrades to be immediately expensed rather than as a capital asset that is depreciated, can move the financial aspects of energy efficient lighting to the same decision maker.

Additionally, the use of energy performance contracting needs to be evaluated to assure that it is providing the desired reductions in energy consumption. Energy performance contracts often put a premium on the payback period of the efficiency upgrade. This approach typically does not take into account maintenance costs, light quality, proper illumination levels and distribution or environmental consequences of a lighting technology. Incorporating these measures into the performance metrics of an energy performance contract can also accelerate the adoption of, and therefore, the development of, advanced lighting technologies.

From an education standpoint, building owners and operators, lighting designers, architects, engineers and contractors need to be educated about emerging technologies and designs that maximize the use of these technologies. All of these stakeholders need to be educated about how the emerging technologies can drive changes in behavior that can further reduce energy consumption from lighting.

Research and development of both basic technologies and manufacturing technologies has already been mapped out by the DOE.

Standardization can lower costs which can speed adoption but premature standardization can impede development. Furthermore, forcing emerging technologies into existing standards can place artificial constraints on the development of these technologies. Moving forward in a new direction, not limited by the A19, PAR, BR or other form factors, may be the only way to optimize a lighting system around an emerging technology.

Another aid to change behavior is to provide energy usage feedback. If building occupants are aware of the energy they are using and how easy it is to turn lights off when not being used, they are more likely to change their behavior. Visible and immediate access to energy usage through smart metering or personal information displays can provide such feedback.
Adoption of minimum standards such as ANSI/ASHRAE/IES 90.1-2010 or ANSI/ASHRAE/USGBC/IES Standard 189.1 will go a long way toward achieving the goal of net zero energy buildings. Concurrently, it is paramount that buildings are properly commissioned and maintained throughout their life to insure continued compliance and maximum energy savings.

Summary

Barriers – Product based

- Metal Halide lamp performance – need longer life and improved efficacy in low wattage (< = 150W)
- Cannot dim MH below 50%
- MH electronic ballasts need improved performance and low level dimming capability
- LED (white light) efficacy is too low
- OLED (white light) life and efficacy are too low
- Inadequate standards for SSL

Barriers – non-Product based

- Inadequate adoption and enforcement of building codes and standards
- Building owners may not accept cost increases associated with zero energy buildings
- Proper light levels (illuminance) in zero energy buildings are not established
- Lighting design software and techniques not adequate for zero energy buildings
- Building operating personnel not familiar with sophisticated systems
- Prescriptive approach to energy efficiency

Recommendations

- Research program to improve performance of Metal Halide lamps including dimming capability and improved, performance-matched electronic ballasts
- Development effort to improve efficacy and color stability of LEDs

- Study needed to determine ultimate capability and applicability of OLEDs. If positive, then research will be needed to achieve goals of longer life and higher efficacy.

- Development of new, valid life test methods is necessary. The market will not wait for traditional life test results of very long life sources.

- Establish ANSI/IES standards for performance and electrical compatibility of SSL

- Need for “outcome-based” approach for energy efficiency, i.e., move away from prescriptive approach (power-based, product-specific) and toward an energy-based system based on building type.

- Building owners need to be convinced of the value of zero energy buildings. A demonstration project would allow owners to evaluate the concept. The idea would be to show that zero energy buildings are, for example, attractive to tenants, that rental rates ($/sq.ft.) could be higher, tenants would be willing to sign longer term leases, and the financial aspects would be attractive due to severely reduced operating costs.

- Fund research to determine appropriate illuminance for these types of buildings, i.e., buildings with major amounts of daylighting, lighting dimming controls, etc. Also, it would need to be determined if occupant comfort and safety are adequate for the tasks.

- Develop new modeling software to assist in optimizing lighting designs

- Develop new lighting design techniques to account for the changes in lighting systems, e.g., how to handle transition areas from daylighting to electric lighting, new control strategies, etc.

- Establish training programs for building operators and require that certain levels of training are required in order to work in a zero energy building (perhaps a licensing approach).

- Establish a particular building code or codes as a *national* minimum. States or municipalities can always be more stringent based on local needs and conditions.

Conclusion

Some final thoughts:

- Traditional light sources do have a place in Zero Energy Buildings, but to a limited extent. High efficiency fluorescent systems for general lighting and improved performance metal halide for higher ceilings, atria, small auditoriums, etc. should be considered as part of an overall lighting design

- The major portion of the lighting work will need to be done by some form of improved solid state lighting due to its high efficacy, long life, and controllability

- New lighting design techniques and software will ensure the significant lighting demands of zero energy buildings are met
- The “way home” will depend heavily on improved designs and application of Daylighting and Control Systems
- “Buy in” from building owners is paramount, using either a carrot or stick approach (preferably the carrot). It is, however, likely that legislative power will be needed to initiate the transition from traditional to zero energy buildings
- Even though the target is 2030, product development cycles will dictate that the real timeline is shorter, perhaps 2020 or 2025. New technologies require extensive testing both at beta test sites and under real world conditions.

Daylighting

Introduction

Daylighting use for lighting building interiors for the purpose of energy savings and occupant comfort is not a new concept. In fact, using daylight (as opposed to electric light) to illuminate building interiors is a very old concept, older than the use of electric lighting. In the times of cheap and plentiful energy, it has not been a necessary strategy. In addition, cost, complexity, and maintenance issues made this an unattractive investment. Now, however, it is mandatory if we are to achieve huge leaps in building energy efficiency.

The general objectives of this section on daylighting for today and the future are:

- Support net zero energy goals by significantly reducing use of electric lighting through daylight distribution and management, as well as integration with lighting control systems. This should be achieved without compromising other aspects of building envelope performance including managing direct solar heat gain and heat transfer through other building envelope materials.
- Measure and report actual building energy performance (BTU/sf/yr). Simulated and installed equipment data is not enough.
- Improve occupant comfort, productivity, and well-being through access to natural light.
- Support architectural design and aesthetic intentions through use of natural light to enliven building form, interior spaces, and materials.

Current State of Daylighting – Standard Practice/Best Practice

Design—(massing, orientation, window-to-wall ratio (WWR), window placement)
WWR has become a significant and controversial topic lately—some believe that WWR must be reduced significantly to reduce energy use, other advocate greater flexibility depending on climate, building type, and facade configuration to encourage daylighting. The current trend with codes and standards is to reduce WWR. One problem with this trend is that once a building's WWR has been established, it is unlikely to be modified in future renovations even though technologies may be developed that could make a higher WWR more energy efficient. For horizontal buildings—skylights also become an important component for providing daylighting.

In many buildings perimeter spaces deprive interior spaces of daylighting—for example perimeter offices block light to interior office space, perimeter hospital rooms block light from interior staff work spaces. There are some buildings that are an exception and are well-planned for daylighting, but they are a small exception. To some extent, this is the result of the very limited use of daylighting analysis and the limitations of current analysis tools. Better, more widely adopted methods would better inform codes, policy measures, standards, and design guides.

Low tech interior daylight management elements include manual venetian blinds and roller shades. High tech strategies include automated interior and exterior daylight redirection and management systems. Mid tech/hybrid strategies include fixed and manual daylight redirection and management systems, split vision/daylight configurations.

Lighting control systems are typically not well-integrated. Although this topic is being explored by another sub-group, it is a big area of potential and obviously intersects with the topic of daylighting. Energy savings from daylighting is not possible without well-integrated controls. Proper use by building managers and building users is a challenging issue.

Products in early stages of commercialization such as electrochromic glazing have recently become commercially available, but have not yet been widely adopted. Such dynamic fenestration products are on the DOE's roadmap for ZEB and in combination with daylighting controls have the capability of significantly reducing energy use in buildings and turning the building envelope into an energy positive element. The normal compromises and tradeoffs designers make between solar heat gain and having enough visible light transmission to provide adequate daylighting are substantially overcome. More glass area can be installed without energy penalty. Prices are currently high, but are expected to fall with economies of scale. Prices will fall faster and become more accessible to a wider range of buildings/budgets, and have a greater impact on the broader energy performance of buildings if market adoption is accelerated. It is important to find mechanisms that break down the barriers to adoption of new technologies. One can imagine incentives for adoption, funded demonstration projects which prove out benefits, removal any code barriers, etc.

Vision: Daylighting Buildings in 2030-2050

- How much are buildings likely to evolve—including uses, types, and scale? Will this have implications on daylighting?
  Buildings will likely be very similar to today's buildings in their general configuration, but the uses and tasks within them may be significantly different. For example, recent and current use of computers and monitors drives many decisions regarding the building envelope, window coverings, and electric lighting systems. Future computers, monitors, and/or equivalent devices for work tasks are likely to be significantly different.
- Most of the effective design principles that will make a difference in the next 20-40 years are already known. In new buildings, minimum codes need to acknowledge these effective principles and require better design. Energy performance codes also need to be enforced, which will require that states dedicate money in their budgets.
  EUI based codes and metrics will speed adoption of lighting controls and daylighting. (We are currently at the point where the only way to lower LPD results in insufficient lighting unless daylighting is employed.)
- Building Design—including the implications of massing, orientation, window placement, -scale and floor-plate depth play a significant role in the effectiveness of daylighting. Narrower floor plates as seen in European buildings can increase the amount of floor area that can be effectively daylit. Building scale also impacts daylight availability—buildings that have three or few stories can be daylit from skylights as well as windows. To allow deeper daylight penetration, enclosed offices at the perimeter are likely to become less common.

- New buildings—lots of questions:
  How will daylighting be incorporated and managed for the major building uses/types? (office, residential, retail, civic, healthcare, education, manufacturing, research)
  Nearly all types require daylighting and have significant potential. In 20-40 years energy and daylighting should be strong drivers in building planning and design.
  What role will daylight play in building energy use?
  Where is the greatest potential to support the goal of net zero energy use?
  What role will daylight play for building users comfort, productivity, and well-being?
  What kind of interaction will there be between building users and daylight?
  What are the most significant hurdles?
- Existing buildings:
  What approaches are most likely to be taken to retrofit existing buildings to improve daylighting conditions?
  Highly tinted glass (which prevents light from penetrating) will be replaced with high transmission low E glazing, glazing with a high light to solar gain ratio (LSG), and dynamically controlled mechanical shading or dynamic glazing systems which will be used to manage heat gain and glare.
  Replacing glazing and window systems is quite expensive so it can be challenging for improved performance to show a reasonable cost benefit. The impact is also limited by the existing skin of the building—if the windows are small (20% WWR) and positioned low on the wall, good daylighting isn't possible. This could be an issue in the future due to the current trend in codes toward lower WWR. Current codes should take into consideration current performance as well as the flexibility to upgrade the building envelope in the future to realize better daylighting and overall energy performance.
- Retrofitting or adding skylights with appropriately controlled systems will also provide significantly more daylight to horizontal buildings.
- To achieve net zero (or near net zero) with existing buildings, swapping the exterior glass, while expensive, is not as expensive as other technologies. The glass can be replaced within the existing framing system. Also, there are varying degrees at which the building skin can be affected. One option is to change the entire framing system; another is to keep the framing system and change the infill. For existing buildings the apertures are already fixed.
- What role will daylight play in building energy use?
  Where is the greatest potential to support the goal of net zero energy use?
  What role will daylight play for building users comfort, productivity, and well-being?
  What kind of interaction will there be between building users and daylight?
  What are the most significant hurdles?
  Buildings from the 60's and 70's typically were not planned for daylighting and have a very thick floor plate. New strategies and technologies can improve perimeter conditions. Moving natural light deeper into the interior and core areas is possible, but difficult and expensive and thus less likely to be realized.
  New York City has demonstrated that a City government can play a role in building improvement when they passed a local law that requires all buildings larger than 50,000 sq.ft. to be upgraded and brought up to current code by the year 2025. These sorts of policy instruments are likely needed to make a real difference in the existing building stock, as we have seen relatively few

buildings take advantage of currently available tax incentives. Incentives are good, but there is rarely enough money in them to make it attractive to a large audience.

Vision: Available technology in 2030-2050

- Low tech interior daylight management systems (manual venetian blinds and roller shades) can be very effective, but require more careful space planning around patterns of light, sky conditions, and building uses.
- High tech/mid tech/hybrid—fixed and operable daylight redirection and management systems, split vision/daylight configurations
    - Remote daylight redirection systems—heliodons
    - Exterior daylight redirection/management systems
      Automated exterior venetian blinds can be very effective at redirecting daylight, managing glare and managing solar heat gain. In temperate climates (like Seattle) they can keep solar heat loads low enough that it is possible to eliminate cooling systems. In this scenario, overall costs can be reduced. Because they are dynamic, they open for more daylighting on overcast days. They also inherently adjust as needed to optimize daylighting for each solar orientation. Exterior venetian blinds have significant potential for sunny and warm climates. Testing at LBNL on exterior venetian blind systems has shown up to an 80% reduction in solar heat gain. Maintenance and durability are concerns for exterior venetian blinds. They must automatically retract in high winds to avoid damage. One option is to use them within a double-skin assembly, although this is rather expensive. Exterior venetian blinds are fairly common in Europe and have been used over the past 40 years.
      Accurate energy simulations for dynamic systems are particularly challenging because they are dependent on good control algorithms. EnergyPlus has the capability, but the algorithms need to be developed further. COMFEN is an interface for EnergyPlus developed by LBNL that allows comparative studies of facade configurations.
    - Interior manual and automated systems can effectively redirect daylighting, manage glare, and minimize direct solar radiation on occupants, but do not reduce solar heat gain through the glazing
    - Dynamic glazing systems can be effective for optimizing heat gain and light levels as a function of changing exterior daylight conditions and can be used in conjunction with separate daylight redirection elements. As such they have the capability for achieving significant energy saving performance (reference LBNL work) without obstruction of view and without the maintenance required to keep dynamic exterior and interior mechanical shading solutions working well.
    - Light tube and similar daylight redirection configurations can be effective, but require physical space to move light and thus can be expensive and impractical.
    - Fiber optic daylight systems can also be used to redirect daylighting.
- Integration with control system (will primarily be covered in Controls Section)
- Integration with lighting system
- Measurement and verification—actual building energy use (in Wh/sf/yr or kBTU/sf/yr) should be measured and reported, not just the installed power of the equipment. Poor performing buildings should be penalized.

Process and Tools – Current practices and vision for the future

Design and Simulation Tools

- How many buildings currently use daylight simulation tools for design and decision-making? Not even 20%, probably about 2%.
  How is this likely to change over the next 20-40 years? Is there a need for a middle ground—pragmatic methods that don't offer a full sophisticated analysis (such as Radiance) but provide good guidance?
  Sub-committee members noted that because 80% of daylighting analysis is fairly straightforward, common simulations sequences can be used to identify rules of thumb to develop a pattern book approach to daylight. The Seattle Integrated Design Lab, NBI, and University of Idaho are currently working on this. There is also a need for rigorous investigation and simulation of building specifics like occupant behavior, shading and other site specific factors, and controls to realize the maximum performance benefit from daylighting.

  The technology that the consortium is exploring can and should include daylighting design and simulation tools that support the goal of net-zero energy use. What are the gaps? What is missing and needed to get beyond the current 2% of buildings that engage a daylight analysis process? More training? More trustworthy results? What drivers in the design and documentation process need to be addressed?
  Many tools are available, funding could help train more users of daylight analysis. Development of tools that "incorporate the expert" is also needed.
- Many of the existing tools provide illuminance levels, but what is challenging and really needed are luminance levels and daylight quality metrics. Often quality issues over specific time period are a priority that must be addressed (prerequisite) before energy implications can be considered. Glare is particularly difficult to define and measure. Multiple view points are needed which significantly increase the light vectors that must be analyzed. Many pieces of the basic tool box are in place—but no one has put it all together yet.

  One of the issues with simulation output is the viewing devices which limit user feedback. Typical monitors don't have the ability to show the actual high dynamic range (HDR) analyzed by simulation tools. Improved display devices are beginning to become commercially available, including one recently acquired by DOLBY which has a range of 20,000 to 1 or greater. With a HDR monitor a virtual mock-up can be viewed for analysis.
- In the meantime, simple methods can be developed as short term proxies for understanding patterns of light utilizing tools such as SketchUp. Existing tools can be used better than they currently are. Although currently daylight analysis images don't tell you everything, guidelines can help provided a better understanding.

- Daylighting needs may conflict with other building envelope strategies for achieving net-zero buildings, particularly solar control and insulative properties. It is important to understand the balance needed and tradeoffs required. Perhaps future technologies can diminish the tradeoffs that currently exist.

- It would be useful to have a better developed rules of thumb regarding trade-offs. For example: the daylighting benefit of windows vs. thermal losses. The trade-offs may offer opportunities for emerging technologies—such as daylight redirecting surfaces, efficient lighting and control systems. Dynamic daylight systems are also a challenge for analysis—better simulation tools and rules of thumb would be beneficial. New technologies are needed to develop simulation tools that can accurately simulate actual materials. The current ASHRAE advanced design guides do not include dynamic systems.

- The right tools can provide a feedback loop for both design and operations. The cycle is indirect, not direct. Many tools are not easy enough to use and thus are limited to large building projects where the costs of energy simulations are not a huge part of the total budget. Tools need to become accessible to all buildings so that various design choices can be explored and trade-offs can be made in a systematic fashion, say between the building envelope design and the mechanical and electrical equipment.

- Overall—the vision is for tools and methods to be developed that allow a significantly higher percentage of buildings to benefit from daylighting analysis.

Daylighting metrics

- LEED criteria for daylighting (Daylight factor—DF)is very simplistic. Glare metrics exist, but they are complex and there isn't an agreed upon standard. Quality of daylighting is important in addition to quantity of daylight. What is good daylighting? Fraunhofer has developed a glare metric and a tool to calculate it (evalglare). Heshong Mahone is working on a daylight sufficiency metric. Although it is challenging, to develop a comprehensive metric, the two need to somehow be rolled together. Because there are multiple daylighting goals (including energy performance and human factors) it is important for to articulate the goals to guide the process of identifying and measuring the appropriate metrics.

Physical Testing

- There is often a chasm between daylighting objectives, decision-making, and daylight conditions in completed buildings. In part this is because there is seldom compensation for evaluating actual conditions. Are buildings actually living up to daylighting objectives?
  Control systems are often installed but may not be well designed or properly commissioned to actually realize daylighting energy savings potential. If skylight or other glazing is added but controls don't work properly the energy use may actually be higher.
  It would be useful to identify the general specifications and calibration required to realize performance potential. Operating sequences are often not clearly or accurately specified for control systems.
  SPOT (Sensor Placement Optimization Tool) is a simulation tool developed by Zack Rogers and others that is currently available and uses an annual daylight simulation and correlation analysis, with actual measured sensitivity of photo sensors to optimize their placement and operation. Proper design, specifications, and commissioning of control systems are critical to actually realizing energy savings from daylighting. Inadequate design of control systems and sensor placement typically leads building users and operators to frequently (or permanently) override the control system.
  Another sensor optimization tool is under development by Rick Mistrick at Penn State that uses

a daylight coefficient approach via DAYSIM. The project is being funded by Samsung and is (or was) under wraps for one year, but will be available for download soon (if it isn't already.)

Delivery (Construction/Installation)

- Contractual obligations may need to change. Today, contractors are "rewarded" (as measured in terms of their income) by lowest initial cost, which leads them to try to break any high performance specification. This path does not lead to net zero energy performance, so we need to change the contractor's metric to something else, such as life cycle cost. Contractors will have to be responsible for the on-going operational efficiency of the building, not just the initial cost. An example is the NREL RSF building which has performance requirements that are tied to incentives in the design build contract.

Post occupancy measurement, surveys, and dashboards

- These methods and tools measure and report actual conditions and can help gauge the impact of daylighting on occupants. They can also provide feedback to building occupants to help them fine-tune the operation of their building for better lighting quality with the least possible energy use.

A Process/Method of the Future (proposed by Kyle Konis)

- How can the knowledge ("lessons learned") from buildings in operation be fed back to improve the design metrics for new buildings? How can this process work within a firm, across firms, across the profession, and between researchers, professionals, government, green building organizations, and clients?
    - What is the design intent? (what are the daylighting goals? Energy, but what else?)
    - What are the design metrics being used to zero in on that intent?
    - How are the selected metrics interpreted at each stage in the design process as a decision support tool?
    - How are the metrics applied to the building in operation to assess performance and make adjustments if needed?
    - In reality, does compliance with metrics equate to satisfied occupants and low energy?

  If the design and evaluation of every new building followed this method it would be easier to resolve the transfer of knowledge between groups.

- Starting point: Make Intent Clear
    - If you scrutinize the design of most current high performance buildings, the daylighting goals are stated in vague terms that make it difficult when doing a POE to compare performance in reality to the designer's intent... simply to see if the design was able to deliver the anticipated environmental conditions

- Then there is the follow up question if the metrics are met, "does the environment result in satisfied occupants?" and "does the building really use low lighting energy?" And, is reduced lighting energy at the expense of increased heating or cooling loads?

- Tools to Improve Guidance
  Relative to the five steps outlined above, it would be useful to map out what tools are currently available and used to make decisions including when they are used in the process. This could point toward more effective use of the tools over the next 20-40 years, how the tools should be developed, and what new tools are needed.

Key Barriers

Product/system technology

- Need for higher performance films and coatings for glazing
- Inefficient or cumbersome daylight distribution systems
- Need for improved building envelope materials (insulation, infiltration)
- High cost of daylighting systems

Software and design techniques

- Inadequate design tools
- Need for improved simulation software
- Need education programs for design professionals

Market Acceptance

- Cost / reliability / practicality
  Many building owners and design team members do not believe that lighting control systems are reliable yet. This may well be a misconception, and perhaps a function of how well commissioning is done. We need to find a way to demonstrate reliability of such systems so that they are widely accepted and their efficacy is proven.
- Dynamic products are typically more expensive, less available, and require commissioning and maintenance. (Price and availability are a function of adoption. Dynamic glazing can be less expensive than automated exterior venetian blind systems. Economies of scale and availability are a function of market demand. Within 10 years, availability should not be a limitation as investment will be there assuming rising market demand.)
  Reliable performance can help convince owners and design team members. Government support is needed to incent building owners.
- Occupant comfort and safety – building occupants may not feel comfortable working under new lighting systems

Recommendations

- Policy—significant shifts in regulation are likely to be needed. A carbon tax and other policies or incentives to adopt could push the development and adoption of net-zero strategies including daylighting. (Carrot, stick, or both?)
- Market acceptance—we need to find ways to reduce the perceived risk to owners/designers in adopting new products, technologies or implementation strategies.
- Design and documentation process—daylighting analysis could be better integrated into this process. The daylighting designer needs to be at the table earlier in the process and needs to interact with the building envelope designer and the interior designer.

- Identification of performance potential and priorities for new and existing technologies
  A single comprehensive study or a series of coordinated studies documenting the theoretical and actual performance potential of overall building configuration and envelope systems on daylighting, energy use, and human factors would be very valuable. The study should include literature reviews of each topic, simulations of representative configurations, and measurements of representative buildings in use. This study should also include the implications of the building envelope (insulative properties, infiltration, etc) as well as HVAC and other related building systems. The conclusions could include applications to both new construction and renovations. The study would be most valuable if the results should are made readily available and updated on a regular basis.
- New technologies—building materials and systems
  There is a need for increased research and development of building materials and systems to improve daylighting distribution and glare management. This should include exterior systems, interior systems, films and coatings applied to glazing, and systems that are installed within glazing units. The national labs and academic institutions should play a primary role in defining and prioritizing the performance needs and desired function as well as testing prototype products. Funding should also go to support industry R&D projects that have the potential to meet performance criteria.
- New technologies—digital tools to support design, engineering, construction, commissioning, and operation of buildings to optimize daylighting performance.
  (See also discussion in Section V.) There is a need for both breadth and depth. Broadly accepted rules of thumb would be a significant help for early decision-making in a significant percentage of projects. Easy to use daylighting tools which simulate both static and dynamic products would be useful for early design decisions and could also be broadly applied. Advanced tools are also needed for specialist use. NREL and LBNL are developing tools such as the Window 6 software, EnergyPlus, Radiance, and COMFEN. Further research and development of digital tools is needed.
- Smarter applications of known existing, effective, low tech strategies should be supported and promoted over the next 20-40 years. Those strategies should be identified and the performance benefits quantified through simulations, chamber tests, and measurements in operating buildings. Detailed case studies can be an effective means of showing performance benefits to help building owners make good decisions about daylighting and overall building performance.
- Performance of existing buildings—coordinated research studies should be conducted to better document how buildings are actually performance and seek to identify potential for retrofits and/or new buildings.

- Existing buildings—retrofit and fine-tune
  Develop sophisticated programs to improve performance of individual buildings fine tuned to climate, building type, building configuration, construction type
- Professional Education— is a need for strong degree programs and effective continuing education emphasizing daylighting and overall building performance in architecture, engineering, building science, construction, real estate, and building operations.
- Policy, codes, and standards can effectively drive daylighting applications in buildings. They should be based on the best forward-looking research to balance the multiple interrelated factors that drive overall building performance.

Lighting Controls

Introduction

In today's buildings, lighting accounts for 38% of the building site electrical use, which is more than any other building system, and 20% of the site energy use (1) Although recent advances in energy codes and the accelerated adoption of sustainable design practices for Federal buildings, have slightly improved the penetration of lighting controls in new construction, their full energy-saving potential is far from being realized in all construction types. According to the U.S. DOE, three-quarters of the Nation's buildings were built before 1979, before the introduction of energy efficient control technologies, such as automatic-off controls and electric digital dimming ballasts. All these buildings are unnecessarily consuming huge amounts of electricity, costing billions of dollars each year, and burdening an antiquated electrical transmission and distribution system. Despite the availability of today's cost-effective lighting control technologies, most buildings have not been upgraded or have been improved only marginally. According to the EIA's 2003 CBECS report[(1)], only 7% of the commercial building floor space utilizes energy management and control systems for lighting, and only 4% of the floor space utilizes daylight sensors.

Implementing lighting control technologies that exist today, can reduce lighting electrical use by 40% to 60%, or more, as shown in Figure LC-1. This graph illustrates the typical energy savings of a lighting control solution that integrates various lighting control strategies. The bar on the far left represents the energy performance of the lighting system in the baseline design based on ASHRAE 90.1-2007. Working from left to right on the graph, operating hours are reduced by incorporating occupancy sensors over basic time clock control in as many spaces as possible in the building. Next, during commissioning, light levels can be "tuned" to the exact design criteria intended in each area of the building, reducing energy consumption. In the perimeter areas of the building, daylighting controls are used to reduce the electric light output in response to available daylight, and in appropriate spaces, individuals are able to control their own lighting and further reduce energy consumption, while maintaining visual comfort. This example shows that integrated lighting control strategies that exist today, can already significantly reduce lighting energy consumption in a commercial building. Furthermore, using lighting controls benefits whole-building energy performance because as electric light output and energy are reduced so is the overall cooling load on the buildings HVAC system.

To reach net-zero goals, first we need to make major strides with penetrating the market using today's technologies that work and save energy, then increase use of technologies that work today, but are limited in acceptance and application, and dedicate research and demonstration resources for proving the effectiveness of new technologies that can have a major impact.

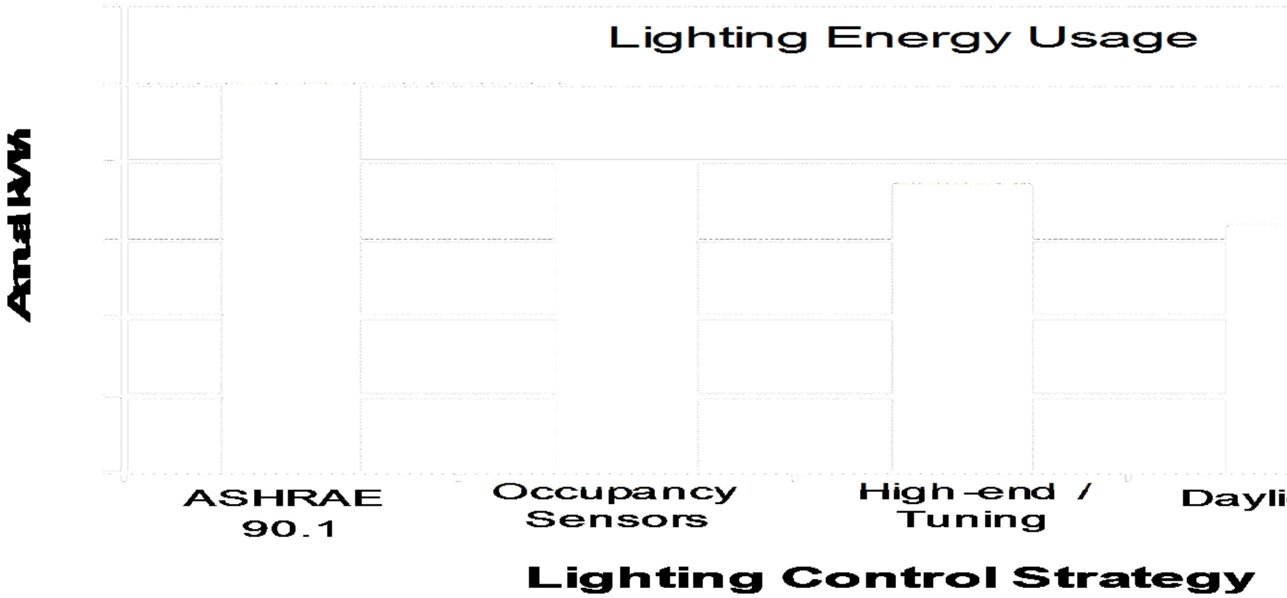


Figure LC-1. Possible Energy Savings from Lighting Control Strategies

Vision 2050

By 2050 we envision that the majority of the existing building stock will be retrofitted with new lighting and control technologies, and all new construction will use the latest lighting and control technologies and strategies. Elements of the lighting system will be "smart" and energy use will be monitored at the device, room, and building level. Control devices will consume little-to-no power. All buildings will use automatic lighting controls for turning lighting off or reducing lighting power when not needed in all interior and exterior spaces, will provide personal controls for office and workstation occupants, and will have seamless capability for reducing lighting system load upon demand. Sensors will be embedded in the environment to learn user's preferences, and the system will anticipate user's needs and personalize the environment by adapting light scenes for activity type, time of the day, room temperature, occupancy, day light, glare, eye sight, and mood. Applied systems and technologies will vary, depending on whether a building has been retrofitted, is newly constructed, or is designed to optimize daylight. Building energy performance will be evaluated based upon annual energy use per square foot, rather than using prescriptive measures for specific building systems and envelope.

Technology Assessment – Lighting Controls

There are a number of lighting control strategies that are used today for optimizing the energy performance of lighting systems, and for integrating with other building control and energy systems. The control strategies and technologies, together with their gaps and barriers are summarized in this section.

Automatic time- scheduling

Most automatic-off time scheduling control technologies are widely accepted into today's market, and include programmable lighting control relay panels, controllable circuit breakers and contactor panels. Programmable lighting control relay panels, controllable circuit breakers and contactor panels are offered by many manufacturers, are proven to work, and most have become commodities. They commonly control large lighting zones, typically at the circuit level, and are programmed to automatically dim or turns lights off at certain times of the day. Astronomical timeclocks are used to provide a building lighting sweep at night so that lights are turned off or set to a low dimmed level at certain times, saving energy and preventing light pollution. Astronomical timeclocks are preferable to standard time-of-day timeclocks because they can automatically adjust lighting based on astronomical events such as sunrise or sunset, ensuring lights are not wasting energy when they don't need to be on. Few buildings operate on 24-hour schedules, and many are empty during the overnight and weekend hours. For the most part, these controls are typically employed for meeting mandatory energy code requirements at the lowest cost, rather than by end-user desire to maximize energy savings, integrate control, or provide personal control for occupants.

Scheduling algorithms can reduce lighting energy use by approximately 10% to 35%. They are best used when the hours of use of a space are known, and when time-based control is desired by the owner. There are few gaps and barriers preventing the use and application of schedule-based systems. Their energy savings benefits aren't fully realized unless they are applied in combination with a hi/lo strategy, for example, in an outdoor parking lot or corridor, when it is unsafe or not desirable to turn lighting completely off in an area.

Occupancy Sensing

Occupancy sensors are set apart from common scheduling technologies, because they enable lighting control at the room level, and further improve energy savings beyond common scheduling strategies, especially when they are integrated with personal controls. These sensors can reduce lighting-electricity use from 15% to 60%, depending on the use and size of the space, by simply turning lights off when a space is unoccupied. Traditionally, passive infrared, ultrasonic, or a combination of the two technologies, are used for detecting motion. More recently, radio frequency (RF) technology has been embedded into occupancy sensors and switches, allowing them to be installed in minutes with no additional wiring and making them an ideal choice for retrofit applications. Microwave sensing technology is beginning to emerge as well. A microwave occupancy sensor can be mounted within a luminaire, out of view, thereby making it an excellent solution for controlling exterior luminaires.

Daylight Sensing

Daylight harvesting automatically dims, or turns off, electric lights when enough daylight is present. A daylight harvesting system can typically reduce lighting energy use by 10% to 60%, depending upon the time of year, hours of daylight, and size of the controlled lighting load. Although photocell sensing materials have not changed much over the years, the latest evolution of sensors use photodiodes that provide spectral sensitivity that's similar to that of the human eye. This means that the photocell "sees" similar wavelengths as the human eye and ensures that the photocell is responding to light, rather than nonvisible energy such as heat (infrared) or ultraviolet energy. Photosensors haven't been very "smart." They have traditionally used a photodiode for sensing daylight, which sends a signal to a ballast for either dimming or turning lights off in response to daylight.

Gaps and Barriers – Occupancy and Daylight Sensors

Both occupancy and daylight sensors are still often misapplied and incorrectly installed and commissioned, which leads to occupant and building owner complaints. A 2009 survey of 184 facility managers(1)showed that about half of the facility managers used scheduling for automating lighting, about a quarter used occupancy sensors, and under 5% used daylight sensors. This might be explained because when not applied, installed, or commissioned correctly, lighting controls, specifically occupancy and daylight sensors, are often disabled by building occupants or the maintenance personnel that have to field their complaints. Photosensors are taped-over, blinds are left permanently closed, occupancy sensor sensitivities and time delays are maxed out, and sensors are disabled or even removed. Additionally occupancy and photosensor placement is deemed an "art form" by designers because there is no industry-standard method for reporting product performance or application of the products. Often, insufficient quantities of sensors are supplied leading to lack of coverage and dissatisfaction at the owner end.

These sensors are highly effective when applied correctly, however, their application and use is primarily limited by cost and application barriers. Although the cost of the photosensor is not prohibitive, it must operate with a dimming ballast, which is the most expensive component in the system. Another barrier to use is determining sensor location along with set-up and commissioning. Guidance for placement varies among manufacturers and products, and manufacturer guidelines must be strictly followed to ensure performance. Most products require set up during at least one day and one night time site visit, which can be a burden on construction man-hours, and on design team time. Furthermore, systems often need to be "tweaked" to account for seasonal variation, or to suit occupant preferences, and this usually requires additional site visits, typically after construction is complete and the building has been occupied for some time. To overcome these barriers, a new "dual loop" photosensor has recently emerged. This technology embraces the benefits of both closed and open loop control, while employing self-calibrating algorithms that negate the need for recalibration and manual commissioning.

Tuning

Lighting electricity usage can be reduced by 20% or more through high-end trim or tuning, which sets the maximum light level for each space. For example, the human eye can barely distinguish between a 100% light level and an 80% light level – but setting lights to 80% reduces energy use by about 20%. Tuning is typically accomplished using programmable systems, or digital addressable ballasts.

Personal or individual control

Personal light control, allows users to control general lighting directly over their workstations. The ability to vary lights to the appropriate level for the job at hand can improve productivity and reduce eyestrain and glare while saving energy. In fact, research by lighting researcher and human factors expert Peter Boyce showed that “people with dimming control reported higher ratings of lighting quality, overall environmental satisfaction, and self-rated productivity.” Personal controls are not widely used because they are viewed as a superfluous expense, rather than as an energy saving tool. Although the energy saving benefits of personal control has been fairly well-documented (cite NCAR, NRC, LRC) their energy-saving benefit and overall value has not been well understood, or communicated to owners and end users.

Digital lighting controls

Networked digital lighting systems are in the market today that are smarter, easier to connect than traditional wiring, self-commission, report on usage, and save more energy. Digital lighting control systems utilize either digital dimming ballasts or digital room controllers for integrating and processing control signals. The digital dimming ballasts and/or controllers are the building blocks of lighting systems that are fully controllable and scalable, from small stand-alone spaces to multiple rooms or areas, to whole floors, entire buildings, and even whole campuses. With digital systems, light fixtures can be directly networked with time clocks and occupancy sensors – not to mention daylight sensors, wall controls, handheld remote lighting controls, window shades, building management systems, and each other. Since they’re digital, they can be easily reconfigured, so that, as spaces change, lights can easily be regrouped into different zones or to work with different sensors without rewiring. Furthermore, digital systems allow users to monitor and report on the energy usage and functionality of each luminaire.

Emerging Technologies

Emerging technologies include the “next generation lighting controls” that have not yet fully demonstrated their potential for saving energy and helping to reach net-zero goals, and are not completely accepted by the market. These technologies include products such as net zero energy devices, intelligent lighting controls and advanced sensors, wireless control, demand management systems, solid-state lighting controls, DC micro-grid, smart grid enabled lighting systems, and plug load controls.

Net Zero Energy Devices

Many lighting control devices such as power packs, sensors, LED drivers, or any device using an illuminated indicator light, draw power when operating, and when in stand-by mode. Eliminating, or minimizing, the power consumption of these devices, is critical to the success of net zero buildings. This requires a combination of effective energy harvesting techniques, such as micro fuel cells or photovoltaics, coupled with storage technologies such as batteries. These technologies need to be developed further to address long lifetime and cost effectiveness aspects. Coupled with these, power conversion circuits and systems with high efficiency and long lifetime will need to be developed.

Intelligent Lighting Controls and Advanced Sensors

Intelligent, networked control systems that enhance the quality, reliability and efficiency of lighting systems, provide continuous feedback on system operation, and integrate with other building systems are essential for maximizing energy savings and occupant comfort, and minimizing building operating and management costs. These systems require a software platform and communication backbone, together with intelligent sensing and switching devices.

It is widely acknowledged that maximum value for building owners, operators and occupants can be extracted if all of the building components and subsystems (e.g. lighting, HVAC, shading, climate control, audiovisual subsystem, access control, security, onsite power generation, plug-in hybrid electric vehicles, and emergency response) are fully integrated and jointly optimized. This whole-buildings integrated approach involves radically new interdisciplinary activities across planning, design, equipment and material selection, construction, commissioning, operation and maintenance to make optimal use of natural (e.g. daylight) and human made systems. The benefits of user comfort, enhanced productivity, energy efficiency, sustainable resource utilization, cost-effectiveness, return-on-investment and lifecycle value offered by integrated controls of all the subsystems needs to be fully explored and quantified.

The progress on software development, which is vital for designing sophisticated systems that can be reliably installed in buildings and achieve significant energy savings, has been very slow due to industry fragmentation and lack of agreement on one or more industry-accepted communication platforms. Legacy 0-10v analog and DALI dimmers haven't been able to make a dent in the commercial building market mainly due to higher costs and commissioning complexity. Penetration of DALI as a lighting control protocol has also been inhibited by the fact that it is designed primarily for dimming ballasts, not for sensors and it requires additional wiring which increases the cost. Sophisticated control systems tend to be complex and require highly skilled installers, commissioning engineers and labor intensive processes which add to the overall cost and slow down adoption. Developing self-configuring standardized protocols and advanced tools would make the process of installation and commissioning friendly to non-experts, and easy for electricians.

Networked Lighting Controls

Building-wide networked lighting control systems are starting to emerge on the horizon but yet to find a foothold in the market. Leveraging commercial of the shelf technologies (e.g. LAN and IP) to address the connectivity challenges would entail economics of scale, availability of skilled manpower and compatibility with existing IT infrastructure thereby fostering the market adoption. Obtaining buy-in from the building IT management is crucial for having LAN and IP-based control solutions accepted.

Extending the networked control paradigm beyond one building would facilitate enterprise-wide lighting management systems and services deployed over the internet. Enterprise-wide lighting controls spanning across the geographical boundaries would fundamentally alter the way lighting controls are designed, developed, operated and managed in the future. However, further investment in research and development is needed to explore these value propositions in commercial building landscape.

Initial efforts can be directed towards development of tools, strategies, framework and pilot projects for integrated closed-loop lighting, HVAC and shading systems compatible with the smart grid. In parallel, the implementation of demand response and load shedding strategies over integrated building management systems should be undertaken to be followed later by larger scale integration of other subsystems, demonstrations and market transformation strategies.

Wireless

Despite many virtues of wireless technologies (e.g. cost-effective deployment in legacy building where rewiring could be cost prohibitive), the lighting control industry has been slow with embracing it due to reliability interference, and cost concerns. Availability of open standards, software protocol stacks and chipsets haven't been able to accelerate the market uptake. Breakthroughs in high performance low-power radios and scalable network architecture could expand the coverage of wireless lighting controls networks to the entire building. Large scale wireless lighting control demonstration projects would help alleviate scalability and integrity concerns and establish wireless technology as a reliable solution for connectivity. Proven cost-effective wireless technology, improvements in energy harvesting sensors and advances in battery technology are needed to make wireless a viable choice for lighting controls.

Demand management

Development of novel demand management strategies and simulation tools focusing on lighting controls and pilot programs quantifying their performance would strengthen the role of lighting controls. In parallel, the sensitivity of demand management strategies to changes in weather, daylight and occupancy dynamics should be investigated. Research and cooperation among stakeholders are needed to define the information models for real-time information exchange between lighting systems, utilities, and smart grid. .

Performance monitoring, tracking, reporting and profiling

Determining the standardized methods for measuring the performance of lighting control technologies over time is critical for auditing, benchmarking, performance comparisons, reporting and documentation. In the near term, the focus should be on development of continuous performance monitoring tools, sensors, algorithms, and metrics that would enable detailed metering, performance analysis and optimization. In addition to that decision support tools need to be developed for load prediction, strategy optimization and demand response planning purposes.

In the future, automated continuous commissioning tools would be designed to track real-time performance of lighting system, detect anomalies causing energy wastage, identify any faults and diagnose any system level problems. To further improve overall system control and operations, the optimal operational parameters, strategies and schedules would be decided based on actual facility needs, current occupancy requirements, weather conditions, onsite power generation and demand management policies. Maintenance crews would be automatically alerted by the system to reduce system downtime. Lamp runtime tracking and battery level monitoring would facilitate scheduled maintenance. Thus, the paradigm will shift from reactive maintenance to cost-effective proactive maintenance.

A national repository should be created for storing life cycle performance and cost assessments of representative lighting and energy management technologies operating in a range of building types and climate zones. Public and private sector initiatives for on-going benchmarking, verification of savings and validation of control strategies would boost the adoption of latest lighting control technologies.

Plug Load Control

Minimizing energy used by plug loads is crucial for meeting net zero energy goals. For lighting, this means controlling task lights and other plug-in portable lamps. Few technologies exist today that elegantly turn plug loads off when not in use, or needed.

Controls for Solid State Lighting

Widely anticipated penetration of SSL requires development of novel digital control methodologies which can not only enable dimming but also scene setting, color temperature control and desired distribution within the space while maintaining energy efficiency and lamp life. Longevity of SSL brings about the need for long lasting drivers and control gear. New technologies are needed for designing reconfigurable systems that can be easily adapted to changes in layouts and usage patterns over its lifetime. In the long run, penetration of SSL in commercial buildings will permanently change the lighting control landscape.

DC micro-grid

Today the power is supplied to lights and control equipments in the form of AC. Given the proliferation of laptops, computers, servers and networking equipments, emergence of SSL, rise of solar power and the expected growth in electric vehicles, all of which are inherently DC driven, it would be beneficial to develop DC micro-grids for commercial buildings. DC micro-grids would fundamentally change the way power is supplied in commercial buildings, eliminate DC-AC-DC conversions, simplify equipment designs and layouts, and save energy. Technical assessment of the requirements is needed to derive the specification of DC micro grid. The micro-grid architecture needs to address emerging lighting (SSL) as well as internet connected appliances while clearly pointing out the benefits in terms of energy savings, lifecycle cost savings and flexibility.

Simulation tools

Because field measurements and demonstrations are expensive and time consuming, simulations will play key role in studying energy, economic, environmental impact of integrated lighting control systems. Existing simulation tools are inadequate to handle the complexities of the advanced lighting control technologies and interdependencies among integrated systems. More R&D is needed to fill these gaps and to develop a comprehensive simulation tool that can perform the complete life cycle impact assessment of not only lighting control systems but also include the broader impact on other building subsystems (e.g. HVAC).

When used in a real building, such a tool can utilize the real-time information about the building subsystems, occupancy and weather condition to produce necessary visual feedback to the facilities manager and send control signals to actuators to further optimize the overall system performance.

Standards

Lack of universal standards for integrated lighting controls has already lead to a fragmented market full of high cost, proprietary and incompatible solutions, and the shortage of skilled professionals. The vision of fully integrated commercial building would not be realized without scientifically sound standards that support ‘plug and play’ interoperability. It is unlikely that one standard would address all the requirements hence, a suite of standardized protocols, data structures, control parameters, interfaces and interoperability profiles for communications and information exchange between individual components and subsystems throughout a building needs to be developed. Strategic partnerships, collaboration and cooperation cutting across industry domains, academic and governmental institutions, regulators and policy makers are essential to undertake this endeavor.

Design, Application, and Installation Barriers

Selecting the right product, or system, for a project, and ensuring correct installation, set-up and commissioning are all crucial to the successful implementation of lighting control systems. Some of the biggest barriers to successful applications are faced in these areas.

Owner issues

Despite encouragement and recommendations to make decisions based upon life cycle costs, owners continue to make decisions based upon first cost and simple payback. This mindset encourages selection of component-based solutions, rather than on complete systems which integrate system operation and optimize energy performance. It is prevalent in the leased space, where the building owner chooses lowest cost solutions over energy-optimized solutions because they pass the electricity costs on to the tenant. In owner-occupied buildings, owners also are hesitant to hire specially trained personnel, or to train existing personnel, to ensure that lighting control systems continue to operate effectively. Furthermore, owners and operators are typically unaware of how energy is used by various components of their buildings or where energy is being wasted. This perpetuates an “out of sight, out of mind” mindset, and results in lost opportunities for furthering energy savings. Owners also fail to commission, or recommission their lighting control systems. Commissioning is viewed as prohibitively expensive and frequently not performed; which results in occupant complaints and owner disappointment.

Design/Specification issues

Design and specification obstacles prevent lighting controls from being fully utilized, which ultimately limits the magnitude of achievable savings. For example, there are eight possible energy codes in use by each State (four IECC versions and four 90.1 versions). Consequently, designers spend their time researching energy codes for their projects, rather than spending time designing the most effective, and efficient solution. On the design side, principles have not been firmly established regarding occupant acceptance of the level and rate of dimming. This issue is then in conflict with the concern that manual controls will be used too often, thereby minimizing energy savings, for the sake of occupant comfort.

Technical system performance issues such as lamp/ballast compatibility and efficacy remain major concerns. For example, for the same lamp types, dimming ballasts draw more power when lighting is at full light output, than non-dimming ballasts, because extra power is needed for heating lamp cathodes during dimming. There is no industry consensus about which strategy is best for saving energy (continuous or stepped dimming), while also considering cost and occupant preference. Furthermore, despite market preference and industry recommendations for using program-start ballasts when controls are used, low-cost instant start ballasts continue to be shipped as standard with most fluorescent luminaires. Therefore, specifying the optimum ballast for control/luminaire system performance adds additional costs for additional assembly and manufacturing, which extends economic payback.

Installation Training/Commissioning issues

Most lighting control systems are connected using low-voltage wiring, and commonly employ multiple sensors of multiple types (i.e. occupancy and photosensors), manual controls at the wall, personal controls, and a relay switching or dimming module. All of the components are wired together, in a specific way, to achieve a sequence of operation to suit the owner’s needs. Consequently, the wiring is often complex, especially when there are many control zones tied to multiple sensors and switches. Newer control technologies exist that mitigate wiring complexity, and minimize installation and set up time (digital control, wireless); however, the benefit of these technologies is not widely known. Furthermore, installation of lighting controls in a retrofit is limited due to perceived wiring barriers.

Recommendations

Research, Development and Demonstration Program Recommendations

- Develop comprehensive applied research program, using sound research practices and methods, to quantify and demonstrate occupant satisfaction and energy savings by individual control strategies and combinations of strategies for new and existing buildings, using full-scale demonstrations and living laboratories. Publish results in case study format, make available through a web-based technology transfer program, and inform stakeholders of availability.
- Develop comprehensive behavioral research program to quantify behavioral benefits and value of individual and combinations of lighting control strategies for current and future technologies.

- Establish an Emerging Lighting Control Technologies category within the Department of Energy's Buildings Program. Establish steering committee with industry representation, and focus on the development of next-generation lighting control systems and technologies for getting to Net Zero, such as smart sensors and systems. This Program would evaluate the energy savings and occupant acceptance of advanced lighting control systems such as:
    - Demand response and load shedding strategies over integrated building management systems
    - Self-calibrating, self powered (energy harvesting), zero-energy sensors and controls
    - Photosensor configurations that provide the best daylight tracking and electric lighting control to achieve energy savings while satisfying occupants. Develop software to permit users to evaluate and model system performance.
    - Multi-function sensors for sensing occupancy, daylight, glare, etc
    - Building-wide networked lighting control systems and technologies such as IP-based systems, digital communications, wireless technology and software-based platforms, and
    - DC micro-grid infrastructure and digital lighting control for SSL systems
    - integrated lighting, HVAC and shading control systems
- Establish a Smart Grid Lighting Integration Panel (SGLIP) comprised of all stakeholders. This group will work with the SGIP for ensuring that all relevant characteristics of existing and future lighting and control systems are built into a lighting information model for integration with Smart Grid

Codes Recommendations

- National adoption of energy code and high performance buildings standard to ensure consistency and optimized energy efficiency performance for new and existing construction
- Enhancements to existing 90.1 energy standard to include, but not limited to, the following:
    - Mandate pre- and post-commissioning for lighting control systems in all buildings
    - Require on-going benchmarking performance/measurement/verification of savings/performance for lighting and other building systems
- National and Statewide programs for energy code enforcement with penalties for non-compliance

Standards

- Develop a suite of standardized protocols, data structures, control parameters, interfaces and interoperability profiles for communications and information exchange between individual components and subsystems. Strategic partnerships, collaboration and cooperation cutting across industry domains, academic and governmental institutions, regulators and policy makers are essential to undertake this endeavor.

Market Based

- Require utilities to include lighting controls in incentive programs to increase market adoption.

- Financial incentives for building owners and developers for installing “beyond code” lighting control technologies and systems

Design and Specification Tools

- Develop lighting controls design and application software integrated with common lighting design software. This software would work with current lighting calculation and modeling software and Building Information Modeling systems to calculate and model lighting control system energy performance, impacts on other building systems, and economics.
- Develop a suite of consensus based, best practice documents explaining which technologies are most appropriate given (i) the application, (ii) where they are to be installed and (iii) the desired features. These documents must include guidelines on installation and commissioning and must differentiate between market segments and space type. Link to published research and case studies and show the economic and visual benefits of lighting controls, as well as compliance with codes and sustainable design criteria.
- Develop an industry-accepted one stop web portal for finding lighting control solutions, technologies and applications.

Education Programs

- National and education program for utility demand side management program developers, code development organizations, government procurement groups and ESCOs, on the value and benefits of lighting controls
- National Training and outreach program for educating building owners and developers. Include occupant education and training with building commissioning to train building occupants about the installed energy-saving control technologies and features. Ensure complete understanding of their value, and the costs involved with short-circuiting them. Obtain feedback on occupant satisfaction and be responsive to problems.
- Require passage of an Energy Code and sustainable design exam for all professional practitioners to maintain licenses and certifications.

References

1. CBECS, Table 44

2. Reference for 2009 TFM article at http://www.aboutlightingcontrols.org/education/papers/2009/2009_enlighten_america.shtml)

3. Frost and Sullivan 2008 Market Report