PROPOSED LEED CREDIT FOR ELECTRICAL LOAD SHEDDING

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ABSTRACT

The cost of energy is a significant percentage of the operating expense for most buildings. Energy used within buildings is supplied primarily by electricity. Demand for electricity used in industrial and agricultural applications is frequently leveled by shifting portions of peak loads to non-peak periods. Leveling electrical loads reduces the utility's carbon footprint and the cost of generating power. Resulting savings are commonly shared with customers through economic incentives. Similar techniques can be applied to control the energy demand of buildings, with benefits for both the electrical utility and electricity users. This paper provides an overview of electrical load-shedding techniques, outlines some of the benefits and problems associated with each, and discusses how some of these techniques are currently being applied to reduce the total electrical load for buildings. The paper also proposes a LEED credit which provides an incentive for owners and tenants to incorporate one or more load-shedding systems into LEED certified buildings to lower peak electrical demand.

KEY WORDS

LEED credit, load-shedding, peak load

INTRODUCTION

LEED (Leadership in Energy and Environmental Design) is a rating system developed by the U. S. Green Building Council (USGBC) helped in part by a grant from the U.S. Department of Energy (DOE). The catalyst for LEED development was an increased demand for buildings which were healthy places to live and work while at the same time minimizing environmental impact. LEED is intended as a guide to building project teams when they seek to incorporate sustainable construction into new structures or sustainable operation into existing buildings. The LEED rating system encourages and accelerates sustainable building and development practices through the creation and implementation of standard and accepted tools plus performance criteria. LEED is the nationally recognized benchmark in the United States for design, construction and operation of sustainable structures.

LEED is a whole building, integrated approach to design and construction. Owners who build structures based on the LEED rating system can be awarded points in seven areas (sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design and regional priorities). In the LEED-NC 2009 Edition, a maximum of one hundred ten points is available. There are four levels of LEED certification: certified, silver, gold and platinum. LEED places a significant degree of emphasis on a building's energy performance. Energy efficiency is the single largest LEED-NC credit category and represents thirty-five percent of the total points available under the current LEED-NC rating system (USGBC, 2009). The previous edition of LEED-NC edition (2005) had only twenty-seven percent of its total points awarded for energy efficiency. The increase demonstrates USGBC's commitment to improve the energy efficiency of buildings. The 2009 LEED-NC requires that ASHRAE Standard 90.1 be exceeded by ten percent under Prerequisite 2. The previous edition required only compliance with ASHRAE Standard 90.1. As this requirement is found in a prerequisite versus a credit, design and construction of an energy-efficient building is mandatory to earn any level of LEED-NC certification.

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LEED ENERGY CREDITS

The LEED-NC prerequisites and credits in the 2009 Edition that deal with energy efficiency include the following:

EA Prerequisite 1: Fundamental Building Systems Commissioning

This prerequisite has the intent of ensuring that the installation and calibration of building equipment and systems occur as designed and intended.

EA Prerequisite 2: Minimum Energy Performance

This prerequisite requires that the building be designed, at a minimum, to meet the local energy code or exceed ASHRAE Standard 90.1-2007 (ASHRAE, 2007) by ten percent, whichever is more stringent.

EA Prerequisite 3: Fundamental Refrigerant Management (Chlorofluorocarbon Reduction)

This prerequisite requires zero use of Chlorofluorocarbons (CFCs) in building heating, ventilating, air-conditioning and refrigeration (HVAC & R) systems.

EA1: Optimize Energy Performance—19 credits

This section is the basis for comparing how well a sustainable building design performs compared to a baseline building defined in ASHRAE 90.1-2007. Alternatively, it is possible to earn up to one credit by complying with ASHRAE Advanced Energy Design Guidelines or up to three credits by complying with New Buildings Institute's (NBI) Advanced Buildings Core Performance Guide.

EA2: Renewable Energy—7credits

LEED encourages the use of renewable energy for buildings and provides for on-site or site-recovered renewable energy credits in order to reduce environmental and economic impacts associated with the use of fossil fuel energy.

EA3: Additional Commissioning—2 credits

LEED places considerable emphasis on building commissioning. Two additional points can be earned by going beyond the minimum commissioning requirements for EA Prerequisite 1. Beginning commissioning early in the design process and executing additional activities after systems performance verification is completed will earn an additional point.

EA4: Ozone Protection—2 credits

This credit calls for zero use of hydrochlorofluorocarbon (HCFC) refrigerants and halons in buildings. Its intent is to reduce ozone depletion while minimizing direct contributions of these gases to global warming.

EA5: Measurement and Verification—3 credits

This credit requires the development and implementation of a measurement and verification (M&V) plan in compliance with the International Performance Measurement and Verification Protocol (IPMVP), Volume III, Options B or D. A corrective action process must also be developed if the M & V plan indicates that energy savings are not being met.

EA6: Green Power—2 credits

This credit encourages the development and use of grid-source, renewable energy technologies on a net zero pollution basis.

Energy consumption remains the single most critical factor in determining building operating expenses, not only because of the current cost of energy, but also because of the probability of significantly higher energy costs in the future. Building energy consumption can be reduced through efficiency and related measures that are incorporated into every LEED building design. Benefits of reduced energy consumption will, of course, be greatest during periods of highest energy demand.

Load shedding is a strategy that was developed to reduce energy consumption on electrical networks during periods of peak demand. Various load shedding techniques are widely used by industry and the electric utilities, but load shedding has only been applied to buildings in a relatively few instances. This paper explores the possibility of adapting some common load shedding techniques for use in public, residential and commercial building applications.

BACKGROUND

Industrialized nations have long depended on electricity as the primary source of energy within buildings. Electricity is used to provide heat, light and ventilation, to power machinery for many industries, and to operate communications systems. The widespread use of computer technology has made it essential that virtually all businesses have uninterrupted electrical power to conduct their daily tasks. Reducing energy use within buildings presents a major challenge for architects and engineers.

Buildings consume a large portion of all energy resources. In the United States, buildings account for about sixty-five percent of the total electrical energy consumption (USGBC, 2009). Summer is the period when energy usage is at its peak. Peak load commonly occurs in the afternoon, especially during the summer months, when the air conditioning load is highest. Commercial air conditioning, representing fifteen percent of peak load, and commercial lighting, representing eleven percent of peak load, are the largest electrical demands during a peak load period (Wilson et al., 2002). The increased demand associated with peak load puts stress on the electric grid, which can result in rolling blackouts. Reducing energy demand (from any and all sources) during this critical peak period is the key to avoiding blackouts, saving money and reducing greenhouse gas emissions.

In an electrical grid, consumption and production must balance at all times; any significant imbalance can cause grid instability or severe voltage fluctuations, which often result in failure. Problems with power distribution in California in 2000 and 2001 and in the northeastern United States and Canada in 2003 have highlighted the need to effectively manage electrical energy at the national level. Computer technology allows systems (lightning, cooling, heating, outside air, etc.) in newer buildings to be analyzed continuously, allowing building designers to reduce peak demand by balancing building systems, particularly air conditioning and lighting, while continuing to provide a comfortable indoor environment for occupants.

In deregulated markets, energy is commonly billed at varying rates for different times of the day, with the rate showing a significant price increase near times of peak demand. During summer months a kWh of energy consumed between noon and 8:00 pm costs approximately 90% more to produce than a kWh of electricity used between midnight and 8:00 am. At times of peak demand, the cost of purchasing an additional watt of power can be as much as one dollar (Fanney, 2006). A supplemental charge is often billed for maximum power consumption recorded during a month (peak demand), even though the duration of such a peak may be very short.

Load shedding disconnects all or part of an electrical load during periods of peak demand; this action reduces the total load on the electrical distribution network and reduces the total quantity of electricity required. Load shedding is not a method of reducing energy consumption; rather it is a method of reducing the cost of providing power at times of peak electrical demand. Load shedding also helps to relieve transmission line congestion and the need to transport electrical power from one region to another; hence it reduces the inefficiencies associated with the transmission of power and the need for extra capacity to cover contingencies such as the loss of transmission lines. Load shedding techniques could be used to a much greater extent than they currently are within buildings to transfer a percentage of the peak load to non-peak hours. The premise of this paper is methods or systems that transfer a specified percentage of peak electrical load to non-peak hours should qualify for LEED credit.

METHODOLOGY

The methodology used to develop the proposed LEED standard was to first review the literature including journal and magazine articles related to various load shedding techniques.

Energy usage (typically expressed in kWh) is equivalent to actual power consumption (kW) multiplied by the duration (hours) of operation. Various strategies under different applications have been developed to minimize energy usage during peak load periods. The more common techniques that are currently used for load-shedding include:

- Demand Side Management Programs
- Load-shed Algorithms
- Load-shed Ballasts
- Variable Air Volume Systems
- Radiant Cooling
- Pre-Cooling and Thermal Mass
- Thermal Energy Storage
- Building Automation Systems

These techniques were then evaluated with regard to their potential to contribute to peak demand reduction for buildings. A draft proposal for LEED credit with the intent, requirements and submittals was then developed and is included later in this paper.

LOAD-SHEDDING TECHNIQUES

Demand Side Management (DSM) refers to programs implemented by utilities to modify customer load profiles. A DSM program provides customers with monthly credit for allowing the utility company to interrupt power during demand peaks or emergencies. Many demand management schemes offer lower rates for customers who sign up for demand management, and also provide credit depending on how much of their load a customer designates as available to be interrupted. Customers willing to share in "available risk" derive economic benefit by participating in controlled outage programs. Participation in demand management programs is voluntary and compensation for participation is an integral part of any DSM program (Faranda et al., 2007).

Such programs have a variety of methods and objectives:

- Energy-efficiency programs reduce energy use, both during peak and off-peak periods, typically without affecting the quality of services provided. Such programs substitute technologically more advanced equipment to produce the same (or a higher) level of services (e.g., lighting, heating, cooling, drive power, or building shell) with less electricity.
- Peak load reduction programs focus on reducing load during periods of peak power consumption on a utility's system or in selected areas of the transmission and distribution grid. This category includes interruptible load tariffs, time-of-use rates, direct load control, and other load management programs.
- Load shape flexibility can be achieved by programs that modify prices, cycle equipment, or interrupt service in response to specific changes in power costs or resource availability. These approaches include real-time pricing and time-of-use rates for pricing periods that have flexible hours. They also may include interruptible load tariffs, direct load control, and other load management programs when those activities are not limited to peak load periods.
- Load building programs are designed to increase use of electrical equipment or shift electricity consumption from peak to off-peak hours, thereby increasing total electricity sales. This category includes valley filling programs that increase load during off-peak periods and programs that introduce new electric technologies and processes (Johnson and Thomas, 2006).

Providing service packages that include generation, management of the price risks associated with competitive generation markets and demand-side services help attract and retain customers in a competitive market. The future of DSM will be determined by the choices that consumers, utilities, other service providers, regulators, and legislators make with regard to the increasing cost of electricity.

In 2006, electricity providers reported total peak-load reductions of 27,240 MW resulting from DSM programs, a six percent increase from the amount reported in 2005 (Energy Information Administration, 2006). Reported DSM costs increased to $2.1 billion, a 6.7% increase from costs reported in 2005. DSM costs can vary significantly from year to year because of business cycle fluctuations and regulatory changes. These programs can be very effective at reducing peak demand for electricity.

LOAD-SHED ALGORITHMS

A load-shed algorithm is designed to minimize peak demand over specified periods (usually of fifteen minutes each). When load shedding is required to reduce an excessive demand, loads are examined and selectively shed on an increasing priority basis as required, based on the operational parameters and status of each load for the then prevailing load level condition.

The methods employed by common load-shed algorithms include:

1. The target peak demand for a month is determined as the average historic peak demand of that month during the previous four years, multiplied by a target savings factor based on the predicted potential peak savings.

2. The fifteen minute demand period is divided into a number of decision periods.
3. At the start of each decision period, the following parameters are determined:
   - The shed-ability status of each piece of equipment, based on the status of its internal parameters and on the limitations defined to maintain its primary functions.
   - The current kVA level of each piece of equipment.
   - The maximum time duration, for which the equipment can be kept in the off state, starting from the current state.
4. The predicted kVAh for the demand period is calculated based on the predictions. This is subtracted from the target peak demand for the month to obtain the required kVAh to be shed during the remainder of the period.
5. Equipment that has become unsheddable based on internal status parameters is switched on again.
6. If the kVAh required is positive, the algorithm will identify equipment for shedding, based on a priority level allocated to each type of equipment. For equipment with the same priority level, the algorithm would first select equipment which can be shed for the longest time duration.
7. If the kVAh required is negative, the algorithm will identify loads which have been shed and which could be switched on again.
8. If the target peak demand is exceeded during the course of the month, the target peak would be adjusted upward to the maximum actual demand level attained at that point in time (Hoffman, 1998).

Estimation of the expected kVAh contribution of each type or piece of equipment shed requires a model describing the expected thermal and electrical behavior of the equipment based on its current internal temperature, its existing thermal load and other parameters describing its internal state. Load-shed algorithms are compounded by the implementation of pre-defined load priority tables that are executed sequentially to curtail blocks of load, regardless of the dynamic changes in system loading, generation, or operating configuration.

LOAD-SHED BALLASTS

Lighting is a voracious consumer of electrical energy. Electric lighting in commercial buildings accounts for fifteen percent of the total energy used and over twenty-five percent of the electricity consumed by commercial buildings (Lighting Research Center, 2003). Lighting commercial buildings in the United States consumes about 3.7 quadrillion British Thermal Unit (BTU) a year, equivalent to the output of over 175 power plants. According to an estimate by Myers (2005), if buildings could automatically dim the electric lights in daylighted spaces and building occupants could manually dim local lighting according to their preference, U.S. energy savings could amount to more than half a quadrillion BTUs per year—about fourteen percent of annual energy use for lighting in commercial buildings.

Light is a dynamic element of the building environment, but its availability fluctuates daily in both time and quantity. Using natural light or daylight for illumination is one of the hallmarks of a sustainable building. As more windows are added to commercial projects, more daylight enters into the space. Developing an effective day-lighting strategy can be a complex undertaking due to trade-offs that must occur between admitting light and cooling (or heating) the building. In order to realize the potential benefits of natural illumination, light must be managed effectively by a combination of both dimming and shading systems.

In most office spaces, lighting has traditionally been designed to provide equal amount of illumination for all occupant spaces. However, lighting may not be needed in all spaces; part-time occupancy and daylight eliminate specific lighting needs. Individual worker's needs and expectations also vary. New lighting controls allow individuals more flexibility in setting light levels for their space. Various strategies such as "task tuning" and "occupancy control" are currently available to accomplish more efficient usage of electric lighting. Each of these strategies reduces the "on-time" of lighting and/or reduces the power consumption at a particular moment in time. Task tuning allows light levels to be adjusted to suit the particular task at hand.

The Illuminating Engineering Society of North America (IESNA) publishes a comprehensive series of design guides, practices and standards that recommend an appropriate level of illumination for specified tasks in any type of interior work area. Occupancy control can be installed to ensure that certain areas are lit only when they are in use. A typical occupancy controller turns off the lights approximately ten minutes after it has last detected activity (Hoffknecht, 2003). Occupancy can be monitored in various ways including use of infrared or ultrasound sensors.

Daylight harvesting is a strategy employed to reduce energy consumption when designing interior lighting. Daylight harvesting measures incoming natural light; level of illumination of interior lights is increased or decreased accordingly. As the natural light in an area increases, the level of interior illumination decreases, maintaining an identical level of illumination while saving energy.

Load shedding lighting control systems can reduce electrical loads when emergencies or congestion threaten grid reliability or when market conditions raise cost. Using a building's lighting system to shed electric load has few drawbacks when done properly. Load shedding can employ a smooth and gradual reduction in illumination levels to a degree that is not generally noticeable by building occupants. The load reduction is almost immediate (occurring in less than a few minutes), which makes this method useful for emergency load-shedding

Dimming control varies the light output to provide the desired level of illumination. Dimming systems require electronic dimming ballasts, which are better suited to offices, schools, and areas where deskwork is being performed. Ballasts allow a utility or building manager to shed electric load quickly by sending a signal to a building's lighting system. An instant-start ballast with dimming control is connected to a signal receiver for automated dimming response. The ballast works by reducing the electricity supplied to the lamps, thereby decreasing illumination levels by thirty to sixty percent. Reduction in lamp current reduces electrical power demand.

Digital Addressable Lighting Interface (DALI) uses direct/indirect intelligent light fixtures that integrate occupancy and daylight sensor intelligence into each fixture. With new advances in digital lighting technology such as the DALI protocol, the benefits of integrated lighting controls are slowly being realized in newly constructed buildings. The key to deploying integrated lighting controls in existing buildings is a lighting control solution that does not require additional control wiring. One additional benefit of intelligent lighting is that it has already been used in LEED design, providing credit in the categories of energy management, control, and resource reduction.

A study conducted in Southern California Edison (SCE) Service Territory found that the majority of peak load during the year (top 600 hours) occurred between 1:00 p.m. and 4:00 p.m. during weekdays. The combined lighting demand of three SCE customers represented ten percent of total energy consumption. To demonstrate the effects of demand reduction through dimming on the power network, the three largest customers were equipped with dimming ballasts throughout their facilities. The ballasts were dimmed by thirty-three percent between 1:00 p.m. and 4:00 p.m. during weekdays only. The results show demand reductions of 100 kW to 200 kW, up to two percent of the peak demand during the highest 1,000 hours of the Load Duration Curve (LDC) (Kingston and Stovall, 2005). Peak demand reduction of two to four percent in energy consumption is a significant achievement by itself. If the same procedures were more widely implemented, greater savings in both energy consumption and costs would result.

Lighting control standards are designed to ensure a desirable level of lighting energy efficiency by defining requirements in two areas. First, they define maximum allowable lighting loads for given applications by setting limits on the design watts per square foot. Second, the standards mandate the use of time clocks and occupancy sensors. To earn credits toward LEED certification, a proposed design must significantly exceed the energy performance requirements mandated by ASHRAE 90.1-2007. In striving for LEED certification, dimming controls offer the greatest potential to optimize the energy performance of the lighting system. Dimming technologies provide infinite adjustment options of lighting levels throughout the day. Building owners can save energy while creating a near optimal lighting level within their facilities. Appropriate lighting levels can be based on available daylight, each individual's personal preference or the task at hand.

A project can earn LEED credits by introducing daylight and views into the design of occupied areas of the building. Daylighting strategies that incorporate dimming controls offer elegant and acceptable performance and are a significant contributor toward obtaining LEED credits for optimizing energy performance (Myers, 2005). It should also be noted that ASHRAE Standard 90.1-2007 allows for a ten percent credit for the cooling load attributable to lighting from using dimmable light fixtures and an additional ten percent for the use of occupancy sensors. This often results in smaller air-conditioning equipment and a lower initial cost. Using lighting control strategies such as daylighting, tuning, and the integrated control of daylight and electric lighting, a project can optimize energy performance by reducing the amount of electricity used for lighting, thereby reducing the waste heat produced and subsequent load on the building's HVAC system.

VARIABLE AIR VOLUME SYSTEMS

One major consumer of energy in buildings is the air distribution system, comprised of air handlers, electric motors, ductwork, diffusers, energy and humidity exchangers, control boxes and associated control systems. Use of "Variable Air Volume" (VAV) systems is a design option for improving energy efficiency. A VAV system varies the quantity of cooled air delivered to each zone to maintain the appropriate room temperature. A separate dehumidification system is used in humid climates. Heating is typically provided by a separate system such as a fintube, due to restrictions on the use of reheat. Pressure drops are kept low because of the relatively low air velocities. The low pressure and air volume that more closely matches the cooling load allows for lower energy use and improved occupant comfort (Janis and Tao, 2005).

VAV systems are designed to provide acceptable air quality at reduced airflow rates. The volume of air supplied to a building space is changed in order to maintain a set temperature. Many fans in VAV systems do not operate at full capacity even under normal conditions. The optimum combination of fan speed, quantity of air supplied and degree of cooling is infinitely variable for each space, building and HVAC system (Kinney et al., 2001).

VAV is not a unique system, but rather an air delivery strategy in which the rate at which air is delivered to a space is proportional to the cooling loads. VAV systems reduce energy use at the direct expense of ventilation. Ventilation reduction is the primary cause of IAQ problems (Lentz, 2004). Because of these characteristics, simultaneously complying with the requirements of both ANSI/ASHRAE Standard 62.1-2007, "Ventilation for Acceptable Indoor Air Quality," and ANSI/ASHRAE/IESNA Standard 90.1-2007, "Energy Standard for Buildings Except Low-Rise Residential Buildings" when using VAV systems can be a difficult design challenge.

ANSI/IESNA Standard 90.1 promotes the use of variable air volume for its energy use reduction. In addition to requiring minimum equipment efficiencies, Standard 90.1 also limits fan system horsepower and mandates the use of energy recovery in specific situations. The use of reheat is prohibited under Section 6.5.2.1 of Standard 90.1-2007, and is allowed only under limited exceptions, so most VAV systems commonly use a separate system to satisfy the heating load. In VAV re-heat systems, the amount of airflow permitted to be reheated is no more than the greater of 30% of device design flow, 0.4 cubic feet per minute per square foot of area served, or the amount of outdoor air required to satisfy the space ventilation needs as computed in accordance with Standard 62.1-2007. These restrictions have significant implications for the design of VAV systems.

VAV systems provide important control and measurement qualities which can be beneficial for any HVAC system. In addition to improving thermal comfort and providing more localized control, these systems are capable of actively managing ventilation requirements at the individual room level.

RADIANT COOLING

Radiant cooling uses actively cooled surfaces to absorb excess thermal energy and remove it from a space. Thermal energy flows from the occupants, equipment, lights, and other surfaces in a room to the actively cooled surface. Once thermal energy has been absorbed by the actively cooled surface, heat is removed by water flowing through a hydronic circuit. Since there are typically internal latent loads (humidity) from occupants and infiltration plus sensible and latent loads associated with outside ventilation air, radiant cooling is often part of a hybrid system that includes conditioning of ventilated air to address these loads.

The basic radiant cooling system types are chilled slabs and panels. While panels have advantages related to installation flexibility, responsiveness and control, slabs have advantages of lower cost per unit area of active surface and better coupling with the thermal mass of the building structure. An actively controlled surface is considered a "radiant panel" if at least 50% of the design heat transfer is by thermal radiation (ASHRAE, 2007).

Research conducted at the Center for the Built Environment by Moore and others (2006) suggests that, on average, radiant panel cooling might save thirty percent of overall cooling energy for applications across a range of representative climates in North America. The same research indicated that potential energy savings would range from approximately seventeen percent in cool, humid regions to forty-two percent in hot, arid regions. This range reflects both the relatively larger latent load in humid regions and the smaller sensible load in cool regions. Conversely, hot, dry climates where the preponderance of cooling load is sensible have the greatest potential for savings with radiant systems.

The key is to decouple the cooling and heating functions from the ventilation function by using a hydronic-based radiant cooling and heating system. The advantage of this approach is that, for heating and cooling, it takes a lot less energy, space and equipment to transport water around the building than it does air. Energy saved by radiant cooling results from thermal energy being transported more efficiently by water than by air. Depending on the building and HVAC design, the electrical energy required to move one unit of thermal energy by pumping water can be less than five percent of that required to move the same quantity of thermal energy through fans (Moore et al., 2006).

In radiant cooling systems where thermal mass facilitates nighttime or off-peak pre-cooling, chillers can be operated more efficiently as a result of improved heat rejection. Coupling radiant cooling systems with building mass, either directly through a radiant system water loop or via radiant exchange between exposed surfaces, facilitates reduction and/or shifting of peak loads. Depending on thermal lag, slab systems have some capacity for off-peak operation to reduce peak demand and for nighttime chiller operation to improve chiller efficiency (Moore et al., 2006). Even without direct coupling to thermal mass, however, research at the Center for the Built Environment suggests a twenty-seven percent reduction in peak power demand for a system of suspended aluminum panels. The reduced demand is thus a function of reduced fan energy and more effective cooling of the building mass by radiant exchange. The cooling of building mass would undoubtedly be somewhat more effective with a direct-coupled hydronic system in the slab.

One of the barriers to radiant cooling is the perceived need for temperature controls for each room. These are necessary for an air system because space temperature is sensitive to transient changes in thermal load. A radiant slab, however, has massive storage capacity and is only minimally affected by transient heat loads, so individual room controls are rarely necessary.

PRE-COOLING AND THERMAL MASS

Pre-cooling involves maintaining zone temperatures at the lower end of the comfort region during the occupied period until about 2:00 pm. Beginning at 2:00 pm, zone temperatures are allowed to float to the high end of the comfort region. With this strategy, chiller power usage was reduced by 80–100% (1–2.3 W/ft^2) during normal peak hours without causing any thermal comfort complaints (Xu et al., 2004). The thermal mass of the building can also be used to reduce the peak load. In summer, the building mass can be cooled during non-peak hours in order to reduce the cooling load during peak hours. As a result, the cooling load is shifted in time and peak demand is reduced. The building mass can be cooled most effectively during unoccupied hours because it is then possible to relax the comfort constraints.

Thermal mass control strategies differ in the way each stores and releases heat. The building mass may be cooled by natural or mechanical ventilation, with or without mechanical cooling. Pre-cooling can be performed either during the unoccupied hours or during the occupied non-peak hours, usually in the morning. In climates with a large diurnal temperature swing, it may be possible to pre-cool the building mass without mechanical cooling. If there is sufficient pre-cooling and the daytime cooling load is relatively low, it may be possible for the indoor air temperature to remain within the comfort range during the peak hours without any mechanical cooling. Cooling energy stored in the mass can be discharged during the peak hours by either demand limiting the cooling plant and distribution system or by zonal temperature reset.

Using computer simulation, Keeney and Braun (1990) demonstrated 10–35% peak load reductions and 10–50% cost savings from a series of pre-cooling strategies. In a recent simulation study, intensive night ventilation and standard cooling effectively reduced peak demand by 43%–56% (Xu et al., 2004). Forty to fifty-one percent of the cooling peak load was shifted to the off-peak hours. About 18% of the load was shifted from day to night with no comfort complaints. The study demonstrated there is a high potential to reduce peak cooling loads with thermal mass control.

A study was conducted on an 80,000 ft^2 governmental office building located in Santa Rosa, California in which zone temperature set-points were adjusted prior to and during occupancy. Significant peak demand savings were observed for pre-cooling strategies. At 2:00 pm, when the zone temperature set-points were reset to 78ºF, the cooling plant shut off automatically because cooling demand fell to zero; the whole building electric load dropped by one watt per square foot (Xu et al., 2004).

The pre-cooling and zonal temperature reset strategies that were tested shifted eighty to one-hundred percent of the electric load attributed to the cooling plant from on-peak to off-peak period without comfort complaints, even with relatively high outside temperature (90ºF). The invariable reduction in demand in response to increases in set-point indicates that the observed peak demand reductions were a result of the changes in operation rather than changes in solar gain or occupancy. The building thermal mass was effective in limiting the variations in the zone temperature. The average rate of change of zone temperature was about one degree per hour (Xu et al., 2004).

Although the peak load was reduced significantly in this test, the benefits of nocturnal pre-cooling in other locations and climates are unclear. There is insufficient evidence to demonstrate that extended pre-cooling has any significant effect on the peak demand, especially in more humid climates. Further work is needed to improve understanding of pre-cooling and its role in reducing peak demand. There is a need to quantify the relationship between peak demand reduction and discomfort risk for different buildings and for HVAC system types in different climates.

THERMAL ENERGY STORAGE

HVAC systems are responsible for forty to sixty percent of the energy consumed in the U.S. by residential and commercial buildings (US DOE, 2008). According to Aliant Energy (2008), chillers are the single largest energy users in commercial buildings, consuming about twenty percent of the total electrical energy generated in North America. Chillers also characteristically increase their power consumption as the day progresses, thereby contributing directly to peak demand. Consequently chillers are responsible for large portions of peak power charges for many commercial and industrial customers.

Active thermal storage such as ice production and chilled water storage can leverage the price differential between peak and off-peak electrical rates to significantly reduce peak hour cooling costs. The medium for the storage of cooling energy, ice or chilled water, is produced during off hours when rates are low. When electrical loads are high, the stored energy is called upon to help meet the load. Ice storage is an environmentally benign method that has been utilized to shift air conditioning power loads to off-peak times and rates. Depending on the geographic location, ice produced during winter may be sufficient to meet cooling needs throughout summer. If the stored ice has been depleted, an air conditioner can be operated at night to produce chilled water in a bin and hot water in a water heater. This type of system results in little or no chiller or water heater operation during periods of peak electrical demand.

Air conditioning systems with supplemental ice storage and cooling capacity can create and store ice in pipe assemblies or in an ice storage tank. The condensing unit can be operated at night when energy is less costly. During the day when the thermostat calls for cooling, a cooling medium (generally a water/

anti-freeze mixture) is circulated through coils in the ice. The cooling medium then flows through the building's air-conditioning system to provide immediate, efficient cooling. An ice storage system can significantly reduce the largest day-time electrical load and lower the cost of air-conditioning by shifting consumption to lower cost, more efficient off-peak hours. This enables users to significantly reduce their electricity costs and the utilities to reduce peaks and fill valleys, thereby improving system load factors, reducing reliance on peaking strategies, and increasing utilization of base-load units.

The ice storage cooling system at Credit Suisse lowered the facility's peak energy use by 900 kilowatts and reduced overall electric usage by 2.15 million kilowatt-hours annually (Valenta, 2008). At the Morgan Stanley facility in Westchester County (New York) an ice storage system reduced peak energy use by 740 kilowatts and overall electricity usage by 900,000 kilowatt-hours annually (Valenta, 2008).

Many studies, most notably one by the California Energy Commission (1996), have demonstrated that it requires less fuel to produce an off-peak kWh of electricity. Some of the main reasons include:

- Off-peak, base-load plants are much more energy efficient than on-peak plants, with 7,900 to 8,500 Btu/kW (8335 to 8970 kJ/kW) heat rates typical for base-load plants.
- Line losses are less at off-peak times because much less power is transmitted at night.
- Spinning reserve requirements are lower. Spinning reserve refers to power plants that are spinning turbines at night, without generating power, so that each is prepared to meet the next day's peak load requirements. Lower peak power requirements translate into less waste from spinning reserves.

The results of the California Energy Commission's study showed that for the two major California utilities, 10% to 30% less energy was required to create and deliver power off peak. In addition to the reduction in emissions from using less fuel, peak power plants that are the last to come on-line during a hot summer day normally are often among the worst pollution sources with the highest carbon emissions (MacCracken, 2004).

Figures 1 and 2 show the load profiles of a building designed without thermal storage. Figure 1 shows a building design to meet ASHRAE Standard 90.1. Figure 2 shows a building with many energy-saving features (better windows, external shading, variable speed pumps, etc.) that is predicted to use 20% less energy than Standard 90.1 requires. Even with all the energy saving features, the load factor (the average load divided by the peak load) is about 53% for both designs. When thermal storage system is added (Figure 3), the load factor increases to 88%. The peak load of the building dropped from 1,500 kW to under 900 kW by shifting the need for cooling energy to off-peak hours.

FIGURE 1. Base building is the ANSE/IESNA Standard 90.1 Non-storage electrical profile (load factor is 53%). (from MacCracken, 2004)

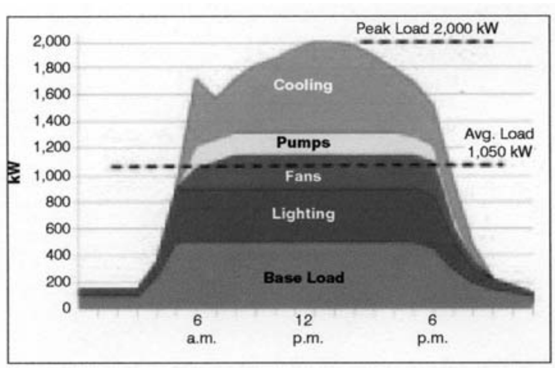


FIGURE 2. Base building with 20% less energy use than the ANSE/IESNA Standard 90.1 Non-storage electrical profile (load factor is 53%). (from MacCracken, 2004)

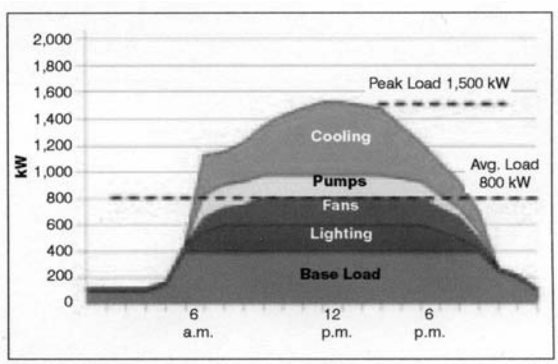
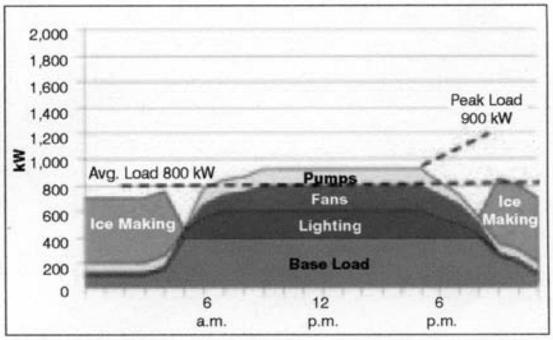


FIGURE 3. Base building with 20% less energy use than the ANSE/IESNA Standard 90.1 minimum full storage electrical profile. A 40% peak load reduction is realized (load factor is 88%). (from MacCracken, 2004)



Thermal storage is a natural method to more evenly balance the immediate needs of any system with its average needs. Thermal storage shifts HVAC loads to off-peak hours by decreasing the peak electrical demand. Lower electricity demand reduces energy cost and minimizes the environmental impact of cooling for everyone.

BUILDING AUTOMATION SYSTEMS

Building Automation Systems (BAS) include a variety of energy management systems used to coordinate, manage, and automate control of diverse environmental, physical, and electrical building subsystems, particularly HVAC, climate control and sometimes lighting systems. A BAS, using computerized monitoring and control, commonly optimizes the operation of HVAC equipment in large commercial buildings (Herrmann, 2005).

A BAS can be set to control HVAC equipment so that it doesn't operate when the building is unoccupied. Fifteen minutes in advance of the work period is normally sufficient, although initial morning recovery may take longer at higher exterior temperatures. HVAC compressors can be turned off before the work area is vacated because the thermal inertia of walls will maintain near ambient temperature for several hours. A BAS can also be programmed to turn off unused equipment during breaks (Gonzalez, 2006).

A BAS can also be used to provide a larger range of individual user control options over all environmental conditions (temperature, airflow, lighting, ventilation, etc.), which can yield significant improvements in worker productivity. Energy code features such as Zone Thermostatic Controls, Automatic Shutdown, Setback Controls, Optimum Start/Stop Controls, Zone Isolation, Demand Controlled Ventilation, Air and Water Economizers, Humidification, VAV Fan Speed Controls as well as VAV Static Pressure Reset could not be performed efficiently without the use of networked, digital BAS controllers (Posson and Rios, 2004).

A BAS can control each piece of equipment separately, but integrating the separate pieces of the equipment into one network provides a more energy-efficient building. In a truly integrated system, a building's cooling, ventilation, lighting and other systems are communicating with one another throughout the day. A BAS can be integrated into a building as a single system, which eliminates much of the wiring required to control multiple types of hardware.

Building commissioning provides documented confirmation that building systems function in compliance with criteria set forth in the project documents to satisfy the owners' operational needs. BAS is one of the systems that must be verified for proper operation to ensure its compliance with the design intent. BAS incorporates the tools necessary for collection, storage/retrieval, analysis and visualization of equipment and system operating performance. BAS diagnostics and data visualization tools can be specified to be capable of supporting continuous commissioning.

LEED-NC EAc5 requires an owner to provide metering equipment for major end-users within the building in order to provide ongoing accountability and optimization of building energy consumption over time. Credit 5 also requires an owner to develop a Measurement and Verification (M&V) plan which incorporates the monitoring measurement and control parameters from the sensors and metering equipment. The M&V plan is required to follow the 'International Performance Measurement & Verification Protocol' (IPMVP) Volume 1: Concepts and Options for Determining Energy and Water Savings. The IPMVP provides a methodology to accurately catalogue baseline conditions, verify proper operation and confirm the quantity of energy savings. LEED-NC EAc5 requires a building owner to follow M&V Options B or D within the IPMVP, which requires sub-metering to confirm the energy savings obtained.

Permanently installed metering tied to the BAS provides the best opportunity to fully integrate the M&V plan. Measurement and verification will play a key role in being able to optimize BAS. M&V is simply a precursor to what ultimately is needed in BAS: a reliable predictive control function. The M&V data gained provides the much-needed information on how systems are utilized and performing so that the BAS can be programmed to react to real-time scenarios. This data can be utilized by a BAS to enable the system to know when to shed non-critical loads, to diagnose system/equipment inefficiencies and to improve overall system performance.

A BAS can be designed to measure and control the use of energy in any combination of or all the following systems (Herrmann, 2005):

- Lighting systems
- Building electric and natural gas utility meters
- Chilled water system efficiency at various loads
- Cooling load
- Boiler efficiencies
- Constant and variable motor loads
- Variable frequency drives
- Air-distribution systems

A BAS can play many roles in the effective and efficient operation of a building. Any dynamic aspect of a building's operation which fluctuates or is influenced by external forces and must respond or adjust to changing environmental conditions is a prime candidate for BAS technology. The U.S. Green Building Council has recognized the importance of BAS in sustainable design by including within the various LEED Green Building Rating Systems prerequisites and credits that rely heavily on BAS and its functions. Building automation systems are eligible for credit under EAc1 'Optimize Energy Performance' and EAc5 'Measurement and Verification' criteria of the LEED-Energy and Atmosphere criteria.

SUMMARY

Demand side management is exclusively at the discretion of the utility and hence is not recommended as a strategy to qualify for LEED load-shedding credit. Load shed algorithms appear to be more directly applicable to industrial equipment rather than to infrastructure. Load-shed (dimming) ballasts already qualify indirectly for points under EAc1, Optimize Energy Performance, as do VAV systems. Radiant cooling appears to have significant potential for load-shedding within buildings as does pre-cooling, but quantifiable data concerning the benefits of either is still being developed. Thermal storage systems appear capable of offering significant energy and environmental benefits. EAc1 and EAc5 in the LEED system rely heavily on building automation systems to achieve specified levels of performance before credit is awarded.

Of the eight load-shedding strategies examined in this paper, all but demand side management and load-shed algorithms have been incorporated into at least few buildings in an attempt to reduce overall energy consumption. Reducing overall energy consumption is important to both occupants and owners. However, with minimal changes, most systems installed to reduce overall consumption can be concurrently used to shift percentages of peak load to non-peak hours, thereby leveling the demand for electrical energy.

Leveling the demand for electrical energy benefits owners and building occupants economically plus society in general by lowering carbon emissions from peak demand generation of electricity. Responsible energy use is enhanced by energy conservation systems being used simultaneously to reduce peak power demand. The LEED rating system contains other areas where strategies overlap and credits can be earned in more than one area for incorporation of a system for product. By incorporating load-shedding criteria and credit(s) into the LEED system, the USGBC can provide benefits for owners and occupants while promoting sustainability within the electric power generation and distribution industry. Awarding credit for synergistic use of energy is consistent with the holistic approach embodied in the LEED rating system.

PROPOSED LEED CREDITS FOR LOAD SHEDDING STRATEGIES

Peak Demand Reduction Strategies

The proposed standard for load shedding could be included in Credit EAc1 under the 'Optimize Energy Performance' based on shifting electrical loads (calculated based upon cost) from peak to non-peak periods. Compliance will result in credits being awarded under the LEED Energy and Atmosphere category for new construction and major renovations.

1 point—Reduction of peak load by at least 10%
2 points—Reduction of peak load by 20%

Intent

To optimize energy performance by reducing the amount of energy used for lighting and by reducing the load on the building's HVAC system during periods of peak electrical demand.

Requirements

Reduce peak demand period electrical load by 10% (or 20%) compared to the energy cost budget for a combination of lighting and HVAC systems described in the requirements of ASHRAE/IESNA Standard 90.1-2007, as demonstrated by a whole building simulation using the Energy Cost Budget Method.

Submittals

- Provide a LEED letter template that includes a quantitative summary table showing the energy-saving strategies incorporated in the building design and the expected reduction in peak demand.
- Demonstrate via summary printout from energy simulation software that the design peak energy cost is at least 10% (or 20%) less than the basic energy cost as defined in ASHRAE 90.1 - 2007, Section 11, during peak demand periods.

CONCLUSIONS

Buildings consume a significant portion of the total electric energy generated each year and drive peak demand electrical energy pricing strategies. High peak summer loads drive capital expenditures for the electrical generation industry. The industry meets peak loads with low-efficiency power plants using gas turbines, which have lower capital costs but higher fuel costs and significantly higher carbon emissions. Several methods already exist for reducing peak energy consumption in other applications. Some of these methods are already being incorporated into buildings to reduce total electrical load. Load shedding helps to relieve transmission congestion and the need to transport electrical power from one region to another; hence it reduces inefficiencies associated with the transmission of power and the need for extra capacity to cover contingencies such as the loss of transmission lines.

Lighting is an ideal load to shed because it is so pervasive and there is little impact on building occupants or operations if control is done correctly. Lighting also provides a predicable quantity of load to shed. Load-shedding ballasts can eliminate much of the hassle associated with the use of building's lighting system to reduce peak electric load and maintain workers' productivity. VAV systems, radiant cooling, thermal mass and precooling can all make significant contributions toward reducing the quantity of energy used. Thermal mass and precooling appear to offer the greatest potential for shifting portions of peak energy demand to off-peak periods.

A kilowatt-hour of electricity can be produced at night for much lower cost than the same unit produced during the day. Rather than using a conventional air conditioning system during the hottest times of the day when performance is degraded and energy consumption is high, thermal energy can be stored before being used to cool a building. Ice (or chilled water) can be created at night and stored for use during peak demand hours. Ice provides excellent cooling performance independent of the outside temperature. Using thermal storage to shift HVAC loads from peak to off-peak hours allows a BAS to select the time when energy is used for greatest economy.

The LEED building rating system recognizes the importance of energy efficiency by making the highest percentage of total credits available in the Energy and Atmosphere category. The proposed LEED credit(s) would extend the benefits of LEED building certification to electrical utility systems, helping to level out electrical energy usage while enhancing the environment through reduced carbon emissions and lowered building operating costs.

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