COMMERCIAL LIGHTING RETROFITS: A BRIEFING REPORT FOR PROGRAM IMPLEMENTERS

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CONTENTS

SUMMARY

Lighting accounts for more than 40% of commercial sector electricity consumption in the United States. Lighting programs to date have achieved tremendous savings through lamp and ballast replacements. Largely through the success of these efforts, energy-efficient T8 lamps and electronic ballasts, compact fluorescent lamps (CFLs), and light-emitting diode (LED) exit signs have become standard practice in some regions for fluorescent lighting in new buildings and most lighting retrofits. Newer programs have turned their attention toward lighting design as a means of realizing the additional possible savings potential. While lighting design improvements can yield significant energy savings, transforming the market for lighting design will require a tremendous investment of time and program staff to reach the diverse and fragmented market. In the meantime, additional savings opportunities are available from the use of improved lighting equipment in several key market segments. Examples include one-lamp linear fluorescent fixtures in offices, high-intensity fluorescent lamps and fixtures in warehouse and industrial spaces, metal halide spot lamps in retail, and simple controls. These fixture replacements and lighting upgrades can take advantage of newer technology that is increasingly available off-the-shelf. These efforts can also play an important role in reaching those customers that are reluctant to utilize the services of sophisticated lighting design professionals.

We recommend that demand-side management (DSM) program operators increase or shift program emphasis to promote new "super" T8 lamps and high-efficiency ballasts, lighting fixture replacements—particularly high-performance one-lamp fixtures (for use with T5, T8, and "super" T8 lamps), high-intensity T5 fluorescent systems, ceramic metal halide lamps, and occupancy sensor controls. Specific program recommendations are outlined at the end of this report.

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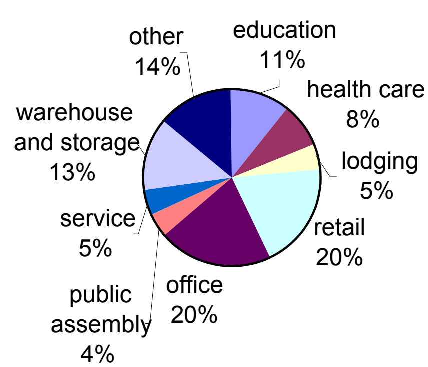
BACKGROUND

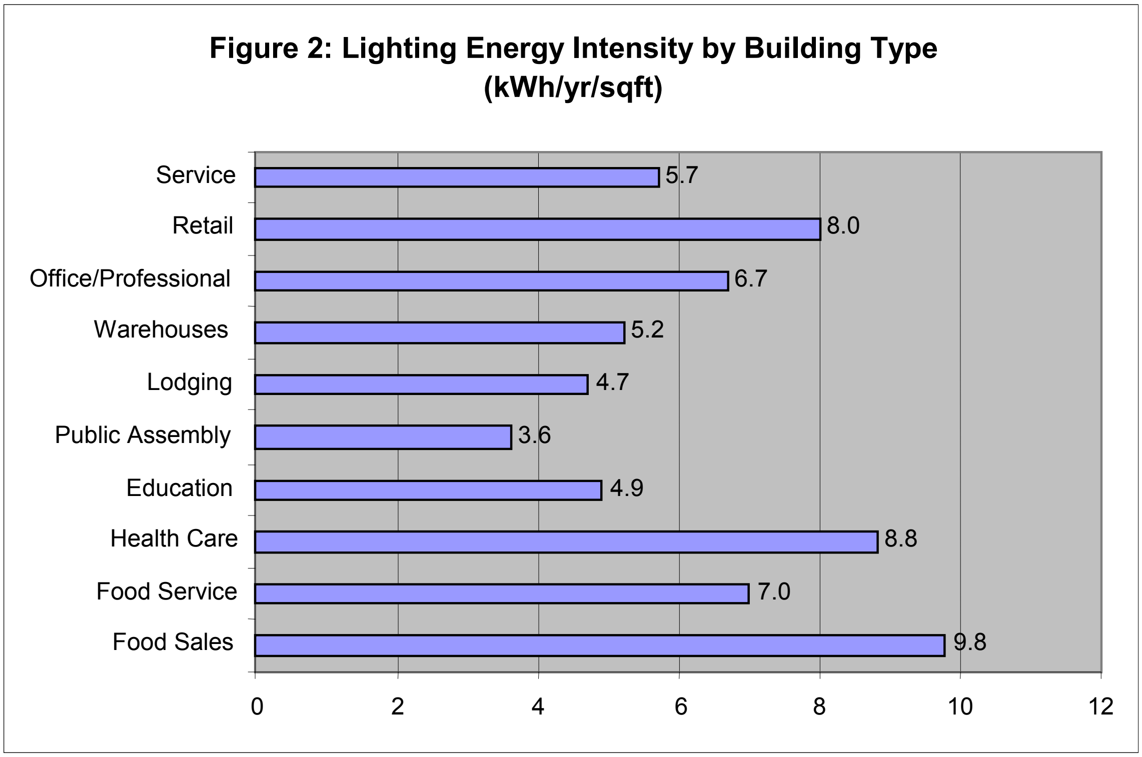
According to a recent analysis of the U.S. lighting market (DOE 2002a), lighting accounts for more than 40% of commercial sector electricity consumption in the United States, a total of 391 terawatt-hours (TWh) per year (DOE 2002a). Offices, retail, and warehouses are the largest contributors to commercial lighting energy use, as shown in Figure 1. The intensity of lighting energy use in commercial buildings averages 5.8 kilowatt-hours per foot squared (kWh/ft$^{2)}$ but varies widely by building type. The average lighting intensity for a number of different building types is presented in Figure 2. In terms of energy intensity, grocery stores, health care facilities, and retail stores use the most lighting energy due to their sheer size and long hours of operation.

Fluorescent lamps are by far the largest source of lighting energy use in commercial buildings, accounting for 56% of lighting energy use (77% of lamps and 78% of lumen output), followed by incandescent lamps, which account for 32%f lighting energy (22% of lamps and 8% of lumen output), and high-intensity discharge (HID) sources, which use 12% of lighting energy (2% of lamps and 14% of lumen output) (DOE 2002a).

Figure 1: Lighting Energy Use by Building Type



Source: DOE 2002a



Source: DOE 2002a

TECHNOLOGY DESCRIPTION

New lighting technologies provide high-quality, energy-efficient lighting options for a variety of building types. Although some components of energy-effective lighting have become increasingly common in new buildings and major renovations, many commercial and institutional buildings do not have upgraded lighting systems. Other new technologies offer additional energy savings and performance benefits, but are not yet in widespread use in new construction or existing buildings. Current off-the-shelf lighting systems offer significant energy savings with relatively short-term paybacks for these customers. The leading technologies for these lighting retrofits include:

- *"Super" T8 lamp systems.* New "super" T8 lamps with high-efficiency ballasts represent a simple strategy to save energy.
- *One-lamp linear fluorescent fixtures.* High-performance recessed and suspended indirect fixtures take advantage of new guidelines for appropriate general lighting levels and are often used with appropriate task lighting. New CFL fixtures for task lighting also present strong savings opportunities.
- *High-intensity fluorescents.* T5HO linear fluorescents replace HID lamps in high- and medium-bay applications.
- *Ceramic metal halides.* These lamps are an energy-saving alternative to halogen PAR lamps, particularly in retail and other display applications.

- *Simple lighting controls.* Automatic shutoff controls and occupancy sensors are straightforward retrofits.

These technologies are gaining acceptance in new construction and major remodels and are beginning to catch on in some standard lighting retrofits. As a result, many of the lamps, fixtures, and controls discussed here are widely available off-the-shelf and a growing number of lighting contractors have the skills to successfully install the equipment. In this report, we focus on relatively simple retrofit and remodeling projects that can be undertaken by a range of lighting contractors. In other words, we focus on lighting retrofit projects that do not require the services offered by more sophisticated lighting design professionals. It is important to recognize that lighting designers can add to the success of a project and possibly identify additional opportunities for energy savings, but we would like to draw attention to those measures for which designers are not essential. Furthermore, the strategies presented here target the largest consumers of commercial lighting electricity—offices, retail spaces, and warehouses.

"Super" T8 Lamp Systems

New 800-series super T8 (or premium) lamps are high-lumen, extended-life replacements for standard 800-series F32T8 lamps. When used with new reduced-power electronic ballasts, system wattage can be reduced by 15 to 20% relative to conventional T8s and electronic ballasts. In older systems using T12 lamps and magnetic ballasts, the savings are even greater. As an added benefit, improved phosphors reduce lumen depreciation so the super T8s continue to deliver more lumens per watt over their lifetime. Table 1 compares standard T8 lamps and electronic ballasts to super T8 lamps with new reduced-power electronic ballasts.

Table 1: Comparison of Standard T8 and Super T8 Systems

Lamp/Ballast	Initial Lumens	Ballast Factor	Lamp Life (hours)	System Wattage
Standard F32T8 with electronic ballast	2,850	0.88	20,000	1-lamp fixture: 30 W 2-lamp fixture: 58 W 3-lamp fixture: 87 W 4-lamp fixture: 114 W
Super F32T8 with reduced-power electronic ballast	3,200	0.78	24,000	1-lamp fixture: 25 W 2-lamp fixture: 48 W 3-lamp fixture: 73 W 4-lamp fixture: 96 W

Source: Walerczyk and Liebel 2002

The higher lumens and improved lumen maintenance (i.e., 88 to 92% end-of-life lumens) of the super T8 lamps allow them to provide the same light levels with a reduced-power ballast. New high-efficiency ballasts are available with ballast factors of less than 0.78. The super T8's higher CRI values mean improved lighting quality in sensitive applications. This strategy is a simple lamp and ballast replacement and requires no other changes in equipment or layout. Super T8s present an additional opportunity for energy savings in delamping retrofits when used with high-power ballasts (i.e., 1.00 to 1.20 ballast factor, also known as “max output” ballasts), yielding energy savings of up to 30%.

One-Lamp Fluorescent Fixtures

One-lamp fixtures for linear fluorescent lamps (both T8 and T5) can reduce electricity consumption while providing more appropriate lighting levels and improved lighting quality. These fixtures are particularly well suited for small or oddly dimensioned offices, spaces with some daylighting, and offices where computer-oriented tasks are predominate. In many buildings, general lighting levels are the same as those originally established for largely paper tasks—typically over 50 footcandles. In others, levels are set to meet the needs of the most demanding tasks performed in the space. This practice often results in excessive light levels and excessive energy use. Research demonstrates that overlighting can have detrimental impacts on worker comfort and productivity. The Illuminating Engineering Society of North America (IESNA) has recognized these problems in its latest lighting design handbook. In typical office applications with desktop computers, the new guidelines recommend reduced ambient lighting levels (20 to 30 footcandles) augmented by task lighting and the use of average illuminance values (IESNA 2000). High-performance fixture efficiencies typically exceed 65% and can exceed 80% in some cases (NBI 2001). With efficient fixtures, 20 to 30 footcandles can be achieved with one-lamp fixtures and task lighting can be used when additional lighting is required. This approach also allows ballasts to be wired in tandem to power multiple fixtures, further reducing overall equipment costs and energy use. Typical energy savings possible with this approach are approximately 0.3 watts/ft^2 or 25% of the lighting energy use common in new office space.

Shifting from older general lighting systems to an approach based on lower ambient light levels with a task lighting complement introduces further energy savings opportunities by allowing some degree of occupant control over lighting levels. Research shows that individual preferences for lighting levels vary widely and that allowing individuals some control over their own lighting not only increases user satisfaction and productivity, it also results in measurable energy savings (Boyce, Eklund, and Simpson 2000). The use of task lighting also allows for adaptation of lighting in a space as end-uses or occupants change. Many types and configurations of task lighting are available to meet user preferences and needs, including under-cabinet lights, table lamps, and floor lamps. Task lighting typically uses a fluorescent or compact fluorescent source. Improvements in CFL technology have made dimmable lamps increasingly common and some specialized fixtures are taking advantage of these developments, such as CFL torchiere lamps and the award-winning “Berkeley Lamp.”

High-Intensity Fluorescent Replacements for HIDs

High-intensity fluorescents are an energy-efficient alternative to high-intensity discharge lamps in many medium- and high-bay applications including retail outlets, industrial facilities, and warehouse and storage space, among others. New high-intensity fluorescent lighting systems incorporate high-output linear T5 (T5HO) fluorescent lamps with high-efficacy fixtures to maximize light output in the space. Each of the system components confers advantages over traditional HID fixtures. Advantages include: lower energy consumption; lower lumen depreciation over the lifetime of the lamp; better dimming options; faster start-up and restrike (virtually "instant-on" capability); better color rendition; higher pupil lumens ratings (translating into improved worker productivity and performance); and less glare (given fixture design and the more diffuse nature of the fluorescent light source) (Rogers and Krepchin 2000). Many lighting designers recommend a mix of high-efficiency HIDs (e.g., pulse-start metal halides with electronic ballasts) and high-intensity fluorescents to maximize cost-effective energy savings (Rogers and Krepchin 2000; Walerczyk and Liebel 2002).

Under similar operating conditions, high-intensity fluorescent replacements yield 50% electricity savings over standard metal halide HID. For a typical application, this translates to annual energy savings of more than 900 kWh per fixture. The use of dimming or on/off controls, which are impractical with most HID systems, can increase savings substantially. The first high-intensity fluorescent systems suitable for medium- and high-bay applications were introduced in 1996. Since that time, the number of fixture manufacturers has grown to more than a dozen and prices have dropped dramatically. In addition, the number of contractors experienced with installation of the systems has grown.

Ceramic Metal Halide Lamps

Advancements in metal halide technology have produced ceramic metal halide lamps with improved color rendering characteristics. For example, the use of ceramic arc tubes in metal halide lamps provides the warm tones desired in retail applications and the concentrated beams required for accent lighting both in retail and other architectural applications. Furthermore, these lamps represent an attractive alternative to the halogen PAR lamps commonly used in these applications because ceramic metal halide lamps have a much longer life and use just over half of the energy. Table 2 compares product characteristics of ceramic metal halide and halogen PAR lamps. All major lamp manufacturers offer ceramic metal halide spot lamps.

Table 2: Comparison of Ceramic Metal Halide and Halogen PAR Lamps

Lamp Type	Watts	Initial Lumens	Average Life (hours)
Halogen PAR	100	1,400	2,000
Halogen-IR PAR	100	2,070	3,000
Ceramic metal halide	39	2,200–2,400	9,000–10,000

Source: GE 2002; Philips 2002

Simple Control Solutions

In the appropriate applications, controls such as occupancy sensors and automatic timers can yield significant energy savings. Here we focus on these basic types of controls because they are relatively easy to install and maintain compared to more complicated dimming control systems. The controls widely available today outperform the products available 10 years ago. Occupancy sensors are generally appropriate in areas that are unoccupied for up to two hours on most days or in spaces where the lights are likely to be left on inadvertently. Examples include private offices, classrooms, and common areas without permanent occupants such as restrooms, copy rooms, conference rooms, break rooms, and warehouses. Shared spaces with multiple occupants, such as open offices, may be more suited to automatic time clock devices that switch lights off at a set time of day. Table 3 summarizes the preferred control strategies for common room types in commercial buildings.

Table 3: Appropriate Control Strategies for Different Room Types

Room Type	Recommended Control Options
Classroom	Ceiling or wall-mounted occupancy sensor
Open office	Personal occupancy sensor Time clock device
Private office	Ceiling or wall-mounted occupancy sensor Personal occupancy sensor Time clock device
Conference room	Ceiling or wall-mounted occupancy sensor
File/storage/copy room	Ceiling or wall-mounted occupancy sensor Timer
Break/lunch room	Ceiling or wall-mounted occupancy sensor
Hallway	Ceiling or wall-mounted occupancy sensor Time clock device
Library reading room	Ceiling or wall-mounted occupancy sensor
Library stacks	Ceiling or wall-mounted occupancy sensor Timer
Exterior lighting	Time clock device
Restroom	Ceiling or wall-mounted occupancy sensor
Warehouse	Ceiling or wall-mounted occupancy sensor Time clock device

Source: NBI 2001

Daylight dimming—incorporating photosensors and dimming controls to take advantage of natural light in a space—can yield substantial energy savings. Savings are typically estimated in the range of 25 to 50% in feasible applications. The technology to provide daylight dimming is increasingly available and cost-effective. However, we will not cover this technology in greater depth in this report because (1) the technology is particularly suited for new construction or major rehabs; (2) proper installation and operation require the input of a lighting designer experienced in daylighting; and (3) time constraints. Due to the complexity of these systems and the greater applicability for new construction, we have not included any further information or analysis.

Market Structure

The lighting market is complex. Table 4 summarizes the various supply-side players active in the commercial building lighting market. Customers can approach any of these different actors to get assistance with lighting projects.

Table 4: Supply-Side Lighting Market Actors

Manufacturers	Distributors	Designers	Installers
Lamp Ballast Luminaire	Lighting supply Electrical supply Industrial supply Manufacturers' reps	Lighting designers ESCOs Architects Engineers Electrical contractors Distributors' reps	Electrical contractors ESCOs Lighting management firms End-users/facility managers Integrated suppliers

Note: ESCO = energy service company
Source: NEEA 2000

Large building owners and developers often work with professional lighting designers, architects, and engineers to design lighting systems for their new construction or retrofit projects. Smaller building owners, on the other hand, are more likely to work with electrical contractors and lighting suppliers when developing or retrofitting their lighting design. To illustrate, a study of the New England lighting market found that 50% of all remodeling and renovations used lighting designers; however, only one-third of medium-size end-users were likely to use design services in their projects (Stone et al. 1997). Another study in New York State found that small commercial customers were most likely to work with electrical contractors on lighting retrofits. Of those surveyed, 66% worked with electrical contractors on their lighting upgrade, 37% with a general contractor, 30% with their landlord, 21% with an architect, 19% with a facility or property manager, and 18% with a lighting designer (NYSERDA 2000). Even in situations where the lighting system is specified by a lighting designer, architect, or engineer, it is common for the electrical contractor installing the equipment to make last-minute substitutions in order to use products currently in-stock or in response to cost-cutting pressures from building owners.

The lighting technologies covered in this report are widely available off-the-shelf from a large number of manufacturers and lighting suppliers. Many lighting equipment manufacturers offer computer software, web-based calculators, worksheets, and other tools to help contractors and end-users select the appropriate equipment for their application.

MARKET BARRIERS

There are several barriers to the adoption of the energy-efficient lighting technologies covered in this report. Major barriers include: (1) a lack of awareness about recent developments in energy-efficient lighting by end-users; (2) the higher first costs associated with improved lighting equipment and lighting design; (3) lack of skills and knowledge by electrical contractors, suppliers, and others involved in lighting retrofits; (4) limited readily available information on lighting technologies and systems; (5) concerns about technology performance; and (6) split incentives between renters and landlords in lease properties and between operating units in institutional buildings. In addition, public agencies and small commercial customers face unique barriers related to financing and limited services.

ENERGY SAVINGS AND ECONOMICS

The opportunities for energy savings from lighting retrofits are significant. Although it appears that much of the low-hanging fruit has been harvested, the fixture and control strategies discussed above present the potential for lighting energy savings of 5 to 50% with simple paybacks of 5 years or less. Maintenance cost savings can further improve the project economics.

"Super" T8 Lamp Systems

Upgrading standard T8 lamp systems with super T8 lamps and reduced-power ballasts decreases energy use by 15 to 20% for savings equivalent to replacing T12 systems with T8s. For a typical two-lamp fixture, the super T8 system saves approximately 37 kWh per year; for a four-lamp fixture the super T8 system saves 66 kWh per year.[1] The super T8 lamp costs about $1 more than a standard T8 and the reduced-power ballast averages $3 for an incremental system cost of $4. The resulting payback is 1.3 years for two-lamp fixtures and less than one year for four-lamp fixtures.[2]

One-Lamp Fluorescent Fixtures and Task Lighting

Task-ambient lighting approaches, as described above, yield energy savings in three ways: (1) by locating the light source closer to the task, thereby more efficiently matching the illumination required to the task at hand; (2) by reducing the level of ambient light required—typically 33 to 67% of that in general lighting scenarios—and removing the need for uniform lighting levels throughout the space; and (3) by reducing the amount and duration of task lighting since some occupants will not use their task lights, and also task lights in unused or temporarily unoccupied spaces generally will not be lit. This approach is particularly well suited for major remodeling projects, but is often too involved for standard lighting retrofits.

One example of this approach is installation of two one-lamp F32T8 fixtures and one task lamp employing a 30 W CFL instead of two two-lamp F32T8 fixtures. This system reduces the power requirement from 134 to 92 W for an annual energy savings of 153 kWh or 33%.[3] Moreover, the worker in this space has additional control over the system and may choose to turn off the overhead lights (especially if there is a window) for additional savings. In buildings where T12 lamps are replaced, savings will be greater. High-efficiency one-lamp fixtures are roughly comparable in costs to two-lamp fixtures (i.e., $60 to $250); standard CFL task lighting costs $40 to $60 (for example, for a CFL torchiere or desk lamp), but can run much higher for new or specialty products (LightCorp 2002; National Grid 2002; Vorsatz et al. 1997).

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[1] Assumes 3,650 hours per year operation based on DOE (2002a) reported daily lighting energy use in offices of 10 hours.
[2] Assumes electricity cost of $0.0796 per kWh (DOE 2002b).
[3] Assumes 3,650 hours per year operation (DOE 2002a).

Despite the new IESNA lighting guideline recommendations of 20–30 footcandles of ambient light for office space, many contractors and designers are reluctant to install less than 30 footcandles of ambient lighting. Thirty footcandles of lighting can be attained with one-lamp fixtures in several ways, for example: (1) installing one-lamp indirect fixtures with T5HO lamps—this can also reduce glare and improve light distribution; (2) using super T8 lamps with high-output electronic ballasts (ballast factors of 1.18 to 1.26); or (3) using closer spacing of one-lamp fixtures with standard T8 lamps (i.e., 8' x 6' rather than 8' x 8' spacing). Table 5 provides energy savings and simple payback for several scenarios.

Table 5: Savings and Payback for One-Lamp Fluorescent Systems in Remodeling

Lighting System	Power (watts)	Energy Use (kWh/yr)	Energy Savings (kWh/yr)	Annual Savings	System Cost	Incremental Cost	Simple Payback (years)
Base case: two 2-lamp fixtures, F32T8 lamps, electronic ballast	134	489			$320		
Option 1: two 1-lamp fixtures, F32T8 lamps, electronic ballast, CFL task light	92	336	153	$12.18	$350	$30	2.5
Option 2: two 1-lamp fixtures, super-premium T8 with high-power electronic ballast	78	285	204	$16.24	$335	$15	0.9
Option 3: two 1-lamp indirect fixture with T5 lamp	86	314	175	$13.93	$410	$90	6.5

Sources: GE Lighting 2002; LRC 2002; Philips Lighting 2002; lighting distributors
Note: Options 2 and 3 provide approximately 30 footcandles of ambient light with standard 8' x 8' spacing. Option 1 provides approximately 21 footcandles of ambient light and includes the power consumption and cost of the supplemental task lighting.

High-Intensity Fluorescent Replacements for HID

High-intensity fluorescents can save almost 50% of electricity consumption compared to HID. For example, a standard 400 W metal halide with magnetic ballast has a system energy use of 455 W compared with 234 W for an equivalent T5 system incorporating four 54 W T5HO lamps and an electronic ballast. The T5 system saves 907 kWh per year or 48% relative to the metal halide lamp. In new and remodeled facilities, high-intensity fluorescent and HID systems are comparable in cost. In retrofit applications, investment costs are approximately $195 per fixture ($150 for fixture, $20 for ballast, and $25 for installation cost); the lamp costs are roughly equal to the metal halide (EBN 2000; 1st Source Lighting 2002; Rogers 2000; Thorpe 2002). Case studies have also found reduced maintenance costs resulting from the use of multi-lamp fixtures—unlike HID fixtures, the fluorescent fixture continues to provide sufficient light in most applications even when one lamp fails. As a result, lamp replacement can be delayed until several lamps fail, at which time the entire fixture (typically 4–6 lamps) can be changed out (Rogers 2000). In a remodeling situation, the above example yields an almost instantaneous payback given the comparable system costs. For retrofits, a $195 investment per fixture yields annual energy savings of approximately $72 for a simple payback of 2.7 years per fixture.[4]

Ceramic Metal Halide Lamps

Ceramic metal halide lamps use approximately half the energy of halogen-IR PAR lamps to produce the same number of lumens. In addition to energy savings, ceramic metal halides last three to four times as long as halogen PAR lamps (9,000 to 12,000 hours versus 3,000 hours) and can reduce the number of fixtures required to illuminate a space. In a typical retail application, replacement of each 100 W halogen-IR PAR lamp with a 39 W ceramic metal halide (lamp plus ballast uses 44 W) saves roughly 260 kWh per year. For retrofits, an investment of $175 per fixture yields a simple payback of 7.5 years. In a retrofit of an entire store, where existing fixtures can be replaced with fewer ceramic metal halide fixtures, the payback is shorter. For remodeling projects, the payback drops to just over 6 years.[5]

Simple Control Strategies

Recent studies on scheduling controls demonstrate savings of 20 to 60% in controlled spaces depending on the application. The *Advanced Lighting Guidelines* (NBI 2001) estimated overall building lighting energy savings of 5 to 20% from the most minimal control strategies. Table 6 presents the range of savings for a number of common applications.

Table 6: Electricity Savings from Occupancy Controls in Various Applications

Application	Annual Electricity Savings
Private office	45%
Open office	35%
Classroom	50%
Restroom	60%
Break room	30%
Conference room	50%

Source: NBI 2001

Based on these estimates, a typical 100 ft^2 office with one occupancy sensor would save approximately 300 kWh per year or $24.[6] Occupancy sensors range in price from $60 to $250

[4] High-efficiency metal halide systems (pulse-start metal halide lamps with electronic ballasts) also offer energy savings over standard metal halide systems and can be used in conjunction with high-intensity fluorescents to maximize cost-effective energy savings in some applications (for example, to augment high-intensity fluorescents during shorter periods when higher light levels are required in large spaces). Pulse-start metal halides with electronic ballasts save approximately 125 W per fixture compared to standard probe-start 400 W MH systems.

[5] Assuming ceramic metal halide system cost of $175 per luminaire ($50 for lamp, $50 for ballast, and $75 for fixture) and halogen-IR PAR lamp cost of $10 and fixture cost of $25, and annual operating hours of 4,680.

[6] According to DOE (2002a), a typical office uses 1.8 W/ft^2. Assumes 3,650 hours per year of operation and electricity cost of $0.0796/kWh.

based on the sophistication of the functions performed (National Grid 2002; NBI 2001). For a typical occupancy sensor used in a private office costing $100, the simple payback for this case is approximately 4 years.

PAST AND CURRENT EFFORTS TO PROMOTE LIGHTING RETROFITS

Over the years, lighting retrofits have been the mainstay of many utility energy efficiency programs. For example, in 1992, approximately 1,659 gigawatt-hours or 70% of the savings from utility demand-side management spending in the commercial sector came from lighting programs (Eto et al. 1995). Further efforts, such as the EPA's Green Lights program, resulted in additional energy saving from lighting upgrades. Much of the gains in market share for efficient technologies brought about by these efforts have been locked in through codes and standards, such as the minimum-efficiency standard for fluorescent ballasts set to take effect for most applications in 2005. As a result, utilities and other efficiency program administrators have turned their attention from T8 lamp and electronic ballast replacements to newer technology upgrades and design-oriented market transformation programs. Some of these efforts are summarized here.

National Grid

National Grid (formerly called New England Electric) has operated a lighting incentive program for about 15 years. Except for small customers (less than 50 kW peak demand), it stopped providing incentives for standard T8 lamps and electronic ballasts several years ago, as "free rider" levels were high. The current program emphasizes new efficient fixtures, generally requiring fixtures to meet efficiency guidelines and use T8 lamps and electronic ballasts. Incentives are generally $15 per fixture for troffers, $20 for low-glare fixtures, and $30 for indirect low-glare fixtures. Incentives for fixtures with just T8 lamps and electronic ballasts (and that do not meet fixture efficiency requirements) are limited to customers with average demand less than 50 kW, and also exclude chain accounts. National Grid also has incentives for high-intensity fluorescent fixtures (designed to replace HID lighting systems) of $22–30 per fixture. And National Grid provides incentives for metal halide track lighting ($130 per fixture) and remote-mounted occupancy sensors ($75 per control). It has also just added prescriptive incentives for super T8 systems.

New York State Energy Research & Development Authority

Through the New York Energy$mart programs funded by the state's system benefits charge, the New York State Energy Research & Development Authority (NYSERDA) administers a program targeting small commercial spaces. This market transformation program seeks to promote energy-efficient lighting in small commercial buildings through dissemination of design tools, lighting guidelines, incentives, and an information campaign (Richards 2002). Financial incentives for efficient lighting equipment are also offered through NYSERDA's Smart Equipment Choices program. These incentives were originally based on the National Grid program discussed above, but have since deviated in some small respects. With regards to lighting, NYSERDA's new construction program is also very similar to National Grid's. Eligibility levels are very similar although incentives are generally somewhat lower as NYSERDA has a limited budget for its statewide program.

Efficiency Vermont

Through its Commercial Energy Opportunities Program, Efficiency Vermont runs programs for commercial new construction, renovation, remodeling, and equipment replacement covering most of the state (Efficiency Vermont 2002). For lighting, its program is very similar to the National Grid's. However, many of the advanced lighting measures discussed in this report are rebated on a custom-measure basis and not with prescriptive incentives. With regards to occupancy sensors, Efficiency Vermont does provide prescriptive incentives—$75 for remote-mounted controls and $30 for wall-mounted controls.

Pacific Gas & Electric

Pacific Gas & Electric (PG&E), as well as the other California utilities, run the Express Efficiency program for retrofit measures for small and medium-sized nonresidential customers with monthly aggregated maximum demand of more than 500 kW (for larger customers it has a performance contracting program). Included in the Express Efficiency program are several of the advanced lighting measures discussed in this report: interior high-output T-5 fixtures ($75 incentive when replacing lamps of 400 W or more) and occupancy sensors ($8.25 for wall-box sensors and $22 for wall or ceiling-mounted incentives). PG&E is also offering rebates of $2.30 to $4.25 for super T8 lamps ($0.30 to $0.50 higher than incentives for standard T8 lamps).

Northeast Energy Efficiency Partnerships—Design Lights Consortium

The Design Lights Consortium (DLC) works to make high-quality energy-efficient lighting common practice in commercial buildings. A regional collaboration between utilities and other stakeholders administered by the Northeast Energy Efficiency Partnerships, DLC targets small business owners and lighting practitioners with information and tools to improve lighting design in a range of building types. To that end, DLC has sponsored market research, customer and contractor education, development of technical guidelines, demonstration projects, and support for enhanced building code requirements. DLC has published a series of lighting design guides that provide model layouts and specify preferred lighting technologies for schools, small retail, office, warehouse, and industrial buildings. The guides serve as templates for lighting practitioners and highlight lighting quality and energy efficiency.

OTHER MEASURE SCREENING DATA

Measure Life

The measure life for fixture replacements is based on the time the fixtures remain in place. A typical estimate of lighting fixture life is 20 years (PEA 2001). Lifetimes for control measures are difficult to predict because they are dependent on the durability of the sensors and equipment. National Grid uses an estimate of 10 years for occupancy sensors.

Non-Energy Benefits

The use of improved lighting technologies yields many benefits beyond energy savings. Better lighting equipment can increase productivity by reducing absenteeism and improving worker satisfaction. In lease properties, improved lighting can increase the investor's bottom line by reducing vacancy rates, lowering operating and maintenance costs, and enhancing lease rates. These benefits vary from site to site and are difficult to quantify. However, they can be significant. For example, studies show that tenant turnover is an expensive proposition for landlords, costing as much as 30 to 40% of the 5-year lease value of office space (Haasl and Sharp 1999).

Approximate Stock and Annual Sales

Opportunities for lighting upgrades exist in many existing commercial buildings. In a study for the Pacific Northwest (PEA 2001), it was estimated that as much as 25 to 50% of commercial floorspace in the region had not undergone even basic lighting upgrades. A recent study of nonresidential remodeling and renovation in California found that 3 to 7% of total floorspace undergoes renovation or remodeling activity each year depending on building type and ownership (CEC 2002).

Opportunities also exist in newer buildings where the increased speed of construction and emphasis on rapid completion often reduces the time devoted to good, space-specific lighting design. Many of the spaces have lighting systems that were not designed to take advantage of natural light levels (by considering building orientation and window size and placement), lighting in surrounding spaces, and different uses of the space (NEEA 2000). As a result, many newer buildings could benefit from lighting retrofits emphasizing delamping, task lighting, and controls. As noted above, new premium and super-premium T8 lamps and high-output electronic ballasts offer attractive retrofit opportunities even in buildings with relatively new lighting systems.

Savings Possible in the United States

Savings estimates for each of the technologies presented are discussed below and summarized in Table 7.

Super T8 Lamp Systems

This simple lighting upgrade can yield energy savings of 15% or more. Linear fluorescents account for 53% of all commercial sector lighting electricity use (DOE 2002a). Replacing 75% of these lamps with super T8s and reduced-power electronic ballasts would yield national energy savings of 23 TWh per year.[7]

One-Lamp Fluorescent Fixtures and Task Lighting

As outlined above, these retrofits offer energy savings of approximately 33% in typical office applications. Assuming feasibility in 30% of office building space (generally in private offices and some meeting spaces), we calculate a national energy savings estimate of 4.47 TWh.[8]

High-Intensity Fluorescent Replacements for HID

Based on the discussion above, these systems offer electricity savings of almost 50% compared to conventional HID equipment. According to the recent *U.S. Lighting Market Characterization* (DOE 2002a), commercial lighting electricity consumed by HID sources is approximately 12% of the total or 47 TWh per year. Three of the leading contributors to HID electricity consumption—retail (7.5 TWh), warehouses (8.6 TWh), and educational facilities (6.0 TWh)—present good opportunities for high-intensity fluorescent upgrades. Retrofitting 50% of the lighting in these applications would result in total annual U.S. energy savings of 11 TWh. The large opportunity for this technology in industrial applications would yield substantial additional energy savings.

Ceramic Metal Halide

Ceramic metal halide lamps and fixtures can save approximately 50% of the energy required for halogen lamps in retail applications. Approximately 30% of the 47 TWh of annual retail lighting electricity use is consumed by incandescent sources (DOE 2002a). Assuming that halogen lamps account for 50% of incandescent use in retail, annual savings from replacing halogen PAR lamps with ceramic metal halides would total 3.5 TWh.

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[7] Savings based on upgrade from standard T8 to super T8 lamps; upgrades in facilities still using T12 lamps would increase savings.

[8] According to DOE (2002a), office lighting electricity consumption is 80.7 TWh per year and 56% of office lighting electricity comes from fluorescent sources. We multiple this portion by the electricity savings and feasible applications to arrive at an annual savings estimate for the United States.

Simple Control Strategies

As outlined above, the use of occupancy sensors for fluorescent lighting in commercial buildings can yield energy savings of up to 20%. Fluorescent lighting accounts for 56% of the 391 TWh per year of commercial lighting electricity use. Assuming that occupancy sensors can be installed on 30% of all fluorescent lighting, national annual savings would total 13.1 TWh.

Table 7: Summary of U.S. Savings Potential

Lighting Technology	Savings Potential (annual TWh)
Super T8 lamp systems	23.0
One-lamp fluorescent fixtures	4.5
High-intensity fluorescents	11.0
Ceramic metal halide	3.5
Simple control strategies	13.1

RECOMMENDED PROGRAM STRATEGIES

Commercial and industrial lighting incentive programs have achieved good participation rates and savings over the years. However, as measures become increasingly popular, the risk grows of high levels of "free ridership." For some of these measures, incentives could be lowered (and eventually phased out) and use of these technologies would continue to grow. Measures that fall into this category include standard T8 lamps, electronic ballasts (now up to 53% market share nationally according to the U.S. Census Bureau), LED exit signs (national market share of about 63% according to EPA), HID lighting fixtures without two-level switching, and compact fluorescent lamps and fixtures. We recommend that program operators place less program emphasis on these measures (perhaps restricting incentives to certain "hard-to-reach" market segments) and to put more emphasis on the more advanced lighting technologies as discussed in this report. Specifically, based on the experience of the programs discussed above, we recommend the following incentives:

- $3 to $8 per fixture for super T8 lamps with high-efficiency ballasts. This incentive level, similar to the PG&E program, reflects typical lamp and ballast costs and will help offset the incremental cost of the system.
- $25 to $60 per fixture for one-lamp fixtures. We recommend a $25–$35 incentive for high-efficiency fixtures (efficiency greater than 83% for prismatic lensed and greater than 75% for parabolic lensed fixtures) and a $40–$60 incentive for low-glare fixtures (meeting IES Standard RP-1 and also having an efficiency greater than 60%). The eligibility levels come from the National Grid program. To be eligible, fixtures must use electronic ballasts and either T5 or T8 lamps. The incentive levels are designed to offset some of the incremental cost of a one-lamp system including required use of task lights, more expensive indirect fixtures, or closer spacing between fixtures (and hence larger fixture quantities).

- $75 to $140 per high-intensity fluorescent fixture designed to replace HID lighting in high-bay and low-bay applications. For fixture wattages of less than 220 W, we recommend a $75–$90 incentive. An increased incentive of up to $140 is suggested for higher wattage fixtures of 220 W or more. The incentive levels are based on the PG&E and National Grid programs.
- $100 per fixture for ceramic metal halide spot lights of up to 70 W. These lamps are a good energy-saving replacement for halogen lamps used for display lighting. The 70 W cap comes from National Grid's program. The incentive is based on the typical cost of ceramic metal halide luminaires. A similar incentive level is under consideration by the Energy Trust of Oregon (Benya 2002).
- $30 to $75 incentives for occupancy sensors. We recommend incentive levels similar to those paid by Efficiency Vermont and National Grid—$75 for remote-mounted sensors and $30 for wall-mounted sensors.

In addition to the financial incentives outlined above, we also suggest the following program components:

- Develop educational and promotional materials about the target measures focusing on energy and cost savings, non-energy benefits, and product availability. Simple tools and calculators to help customers and contractors understand the benefits of each technology for their application can be useful.
- Work with other financing entities to secure customer financing for the customer portion of the cost share on measure and installation costs. An example of this strategy is a loan program that allows customers to repay loans for retrofits through their monthly utility bill.
- Market the program to customers, electrical contractors, lighting suppliers and distributors, and others involved in lighting retrofit decision-making. Work with these parties and with manufacturers to disseminate information on energy-efficient lighting products, particularly those covered by the program. It may also be useful to work with web-based vendors, such as www.earthsavers.com.
- Consider offering small and medium-sized customers assistance determining the appropriate measures for their facilities by providing assistance in completing pre-installation worksheets or through a basic scoping study. The study would serve to identify opportunities for lighting retrofits and reduce the risk to the customer by outlining the financial viability of the project upfront. Such a study should be feasible for a cost of $0.01/ft^2 or less and may be sufficient for use as a basis for developing an agreement with a contractor or ESCO to complete the project (NBI 2001).
- Coordinate with other lighting programs at the regional and national level on outreach to manufacturers, distributors, and lighting designers.

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