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Lighting Business Case

A Reporting Analyzing Lighting Technology Opportunities with High Return on Investment Energy Savings for the Federal Sector

C. C. Jones, IALD, LC
E. Richman, LC

September 2005

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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1.0 Executive Summary

Lighting in buildings remains a huge energy savings opportunity that is highly competitive with other Federal energy savings opportunities in terms of return on investment. The US Department of Energy's Federal Energy Management Program (DOE FEMP) is challenged with executive and legislative goals that are increasingly difficult to meet as energy efficiency becomes more challenging in the Federal market. Given these challenges FEMP must be selective when making programmatic investments; there must be a high probability of success and a clear path toward meeting energy savings goals. It is with these things in mind that the Lighting Business Case has been developed.

Lighting technology is evolving at a rapid pace and yet standard practice with respect to lighting in Federal facilities has not similarly evolved. Federal facilities are generally slow to embrace new and emerging technologies due to a series of complex factors. The best lighting efficiency opportunities are underutilized in both retrofits and new construction largely because energy efficiency contractors are not sufficiently motivated or able to try new and unfamiliar strategies. This is not from lack of interest; their best intentions are thwarted by market barriers and obstacles such as lack of awareness, expertise, excessive risk, high costs, and procurement challenges. Intervention is necessary to realize energy savings and meet the legislated goals.

This report presents analysis and data that has been used to determine high value energy savings opportunities, and provides a series of candidate (suggested) tasks to implement the opportunities indicated by analysis. Candidate tasks are shown to address market barriers and have performance metrics provided for measurement of progress against the goals. Analysis included detailed information about four specific high-value lighting technologies and their usages, projected market penetration into the Federal building stock, and the potential energy savings shown against FEMP goals.

The results of the analysis show that the effect of strategic Federal efforts towards deployment of new and emerging lighting technologies is to almost double the natural penetration rate by the year 2014. The cumulative savings of the four lighting technologies is 14,000 Btu's per gross square foot as of 2014. This represents 72 percent of the overall goal of 2 percent per year across all Federal agencies, as directed by the Energy Policy Act of 2005. Return on investment information is presented for each of the four technologies.

The Lighting Business Case provides solid support for programmatic investment decisions and the basis for a multiyear lighting master plan. Execution of selected tasks will bring FEMP significantly closer to meeting legislative energy savings goals. Recommendations include maintaining an ongoing cognizant FEMP program manager to oversee a core capability in lighting, planning and implementation activities. It will be important to leverage internal and external partnerships to achieve the greatest results in the most cost-effective manner.

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2.0 Background

Lighting tasks have been supported by FEMP for quite some time, but a data based approach was lacking. As the need for FEMP to support new and emerging technologies increased in priority, it became necessary to objectively view lighting-related tasks in the context of goals and other program activities. The Lighting Business Case report has been developed to meet that need. What follows is background on the status of lighting in the Federal sector, which sets the context for the subsequent analysis and recommendations.

2.1 The Mythology of the "Low Hanging Fruit"

In the energy efficiency community lighting has earned the dubious honor of being dubbed "low hanging fruit" because it has historically provided the largest energy savings opportunities. The tremendous wave of T8/electronic retrofits over the last decade has created the erroneous perception that everything that *should* be done in lighting *has* been done, or is being done. The result is a persistent mythology that the "low hanging fruit" has been picked. The lesser-known truth is that significant lighting efficiency opportunities are still available but underutilized. The standard[1] T8-electronic retrofit falls far short of energy savings potential from the most recent commercially available lighting technologies and design techniques. The sheer size of the opportunity provides a compelling case for a strong and proactive investment to fundamentally shift standard lighting practice in the Federal sector.

2.2 All Is Not Well

Contrary to popular opinion, lighting that is typically and currently being implemented in most Federal buildings is not considered acceptable per the lighting standards of the Illuminating Engineering Society of North America (IESNA) and the most recent lighting research. Some examples follow:

- The use of specular reflectors is still common, in spite of the fact that research has shown that high brightness overhead glare conditions are uncomfortable for workers (Ngai and Boyce, 1999).
- Retrofit practices continue to focus on creating a greater amount of light in a downward distribution, which may sound sensible with respect to increasing fixture efficiency, but is contrary to good lighting design practice. These types of retrofits create major problems with respect to uniformity across work surfaces (Jones 1998).
- The "cave effect" is a problem in troffer[2] retrofit projects—the light is taken away from the vertical surfaces in the interest of horizontal desktop illuminance, creating work environments that appear gloomy and dark and reduce worker satisfaction. This is in direct opposition to IESNA guidelines (IESNA 2000).

[1] The standard T8 electronic retrofit uses 700 series lamp technology and early generation electronic ballasts. Newer and much more efficient lamp/ballast technologies are available now but are poorly understood and underutilized. This will be expanded upon later in the document.

[2] A troffer is a type of lighting fixture. Most commonly, troffers are recessed into standard grid ceilings with parabolic louvers or acrylic lenses and are found in sizes of 2 ft x 4 ft, 1 ft x 4 ft, or 2 ft x 2 ft.

- Lighting controls are underutilized in the Federal sector. Controls represent an energy opportunity that is often significant as the retrofit practices, and yet only the most rudimentary controls are included in typical projects.

In summary, the Federal sector is consistently far behind private sector projects with respect to the most energy efficient equipment, as well as design practices that meet current industry standards. The opportunities in this report would propel the Federal sector forward from a lagging to a leading position relative to the private sector.

2.3 Lighting Presents Unique Challenges

Lighting presents unique challenges as compared to other building systems (HVAC, envelope, etc.), which require additional thoughtfulness and expertise.

- While other building systems have new technology opportunities, they are not as prevalent and do not change as rapidly as lighting technologies.
- There are infinite combinations of lighting technologies (light sources, ballasts/power supply, fixtures/distribution systems, lighting controls), and this adds another level of complexity and challenge.
- Technologies and design solutions vary significantly from one application to the next—the solutions differ for a warehouse, aircraft hanger, office, commissary, or hospital.
- Changes in lighting can impact human beings and performance towards missions, positively or negatively (health, comfort, satisfaction, productivity).

These unique challenges require technical and programmatic support; it is not feasible for Federal agencies to meet these challenges on their own. FEMP has a core capability in lighting technology and application and can serve the agencies well with continued programmatic support.

3.0 Overview

The goals and process of this document are detailed below.

3.1 Goals of the Lighting Business Case

- Use analysis and data to determine high value energy savings opportunities.
- Design a program with candidate tasks that implement the opportunities indicated by analysis.
- Develop performance metrics for the tasks.
- Provide discrete recommendations that can be used in programmatic and strategic planning to help FEMP meet its mission.

3.2 The Process

- Analyze the technology opportunities and barriers.
- Analyze the Federal buildings stock in light of the technology opportunities and highlight high impact opportunities in the various agencies.
- Develop a portfolio of technologies whose penetration into the Federal sector is supported in varying degrees.
- For each of the market barriers, determine what tasks and activities would break down these barriers to increase deployment, and specify how to measure the success of the tasks.

3.3 The Strategy

The essence of the strategy underlying the candidate tasks at the end of this document is that investment decisions should be based largely on the potential for return on investment. The lighting technologies analyzed in this report offer a high value for a relatively low investment. Reasons for this are listed below:

(1) Lighting is a large portion of the energy used in a building. Lighting represents 24% of the end-use consumption of commercial buildings (see Figure 1), the clear leader among the various end-uses (DOE-EERE).[3]

(2) Lighting technologies offer a high level of energy savings, and are extremely cost-competitive as compared to other building energy technologies.

(3) Solutions are targeted to agencies based on applications, missions and infrastructure.

(4) Portfolio planning in terms of tasks and technologies are geared towards FEMP goals (Btus per square foot by agency).

[3] Because lighting contributes approximately 42% of the cooling load in commercial buildings, more efficient lighting will also decrease peak electricity demand and its associated high costs (LBNL 1998).

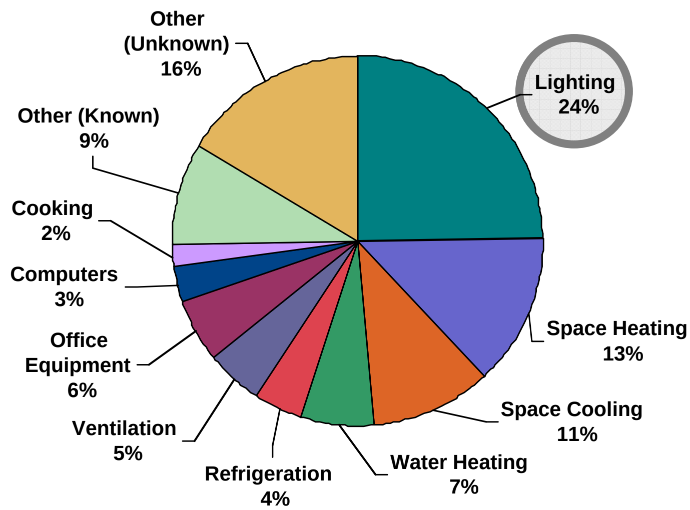

Figure 1. U.S. Commercial Buildings, Primary Energy End-Use Splits

3.4 Federal Market Deployment

What does it take to deploy advanced lighting technologies and accomplish a Federal sector market transformation? Once goals are established, the tasks must break down the barriers to implementation. There should be effort in numerous arenas, including technical information, training and education, outreach and visibility, direct technical project assistance with agencies, direct work with agencies to revise specifications, procurement strategies, and development of contractor and utility capabilities and standard practices, to name a few. There is no "silver bullet" that will create a shift in the Federal market. Rather, it is the sensible balance of a variety of thoughtfully selected tasks that will collectively result in change. Consider the following examples (Figure 2).

Figure 2. Tasks must break down barriers to deployment.

These are only simplistic examples to illustrate that there must be a clear logic flow to show how specific tasks will create a market shift. These tasks need to result in actual implementation and actual change, and the performance metrics should be designed to track progress.

3.5 The Continuum of Energy Savings

Finding energy saving technology is only the beginning of the process (Figure 3). The design and application of lighting technology is also a critical element in maximizing energy savings. The operation and maintenance of equipment is necessary for continued energy savings. Specific examples of lighting application and operation include the following list:

- T5 lamp technology – The T5 lamp is widely perceived as the latest and greatest light source technology. It has specific advantages but energy savings are largely dependent on luminaire photometrics and layout, and glare issues are a significant concern.
- Task-Ambient design – The use of task-ambient design strategies allow a lower overall light level while the task light effectively puts light where it is needed. However, the luminaire layout (quantity of rows of fixtures and on center spacing) requires careful attention to ensure reduced ambient light levels and achieve savings.
- High Performance "Super T8" systems (HPT8) – In applying high performance T8 technology it is important to note that the output of the ballast is a critical factor in the ability to save energy. The choice between low, normal and high ballast factor in relationship to fixture spacing and light levels must be considered to save energy.
- Lighting Controls Operations and Maintenance (O&M) – The installation of simple and advanced controls can be a useless expense if the controls are not properly commissioned and maintained.

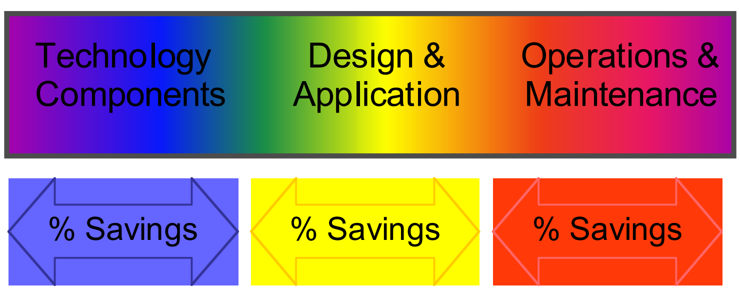

Figure 3. Continuum of Energy Savings. Bridging the chasm between hardware and people is the essence of market transformation.

3.6 Portfolio Planning

Different lighting technologies often require a variety of tasks and activities to achieve market penetration. For example, a procurement strategy may be an appropriate choice for one type of technology but a wasted effort for another technology. Lighting technologies are often application-specific, some are more readily incorporated into building spaces than others, and some are still being fine tuned for maximum use.

These varying characteristics present a need to phase various technologies into the market when they are ready in a manner that ensures success. The application of high performance T8 technologies is one of the simplest technology areas, the easiest to implement, and mature enough to implement with confidence. Task-ambient and intelligent lighting systems are emerging as effective and mature technologies but require more specific application guidance and will follow high performance T8s chronologically. Scotopic lighting as a concept and technology is still emerging and being validated in the field, and may be the last technology to be embraced by the market.

Figure 4 illustrates how degree of effort should be varied over time[4]. There should be a significant initial emphasis on high-performance T8 systems, followed closely by task-ambient technology. A lesser amount of funding and effort should be put towards intelligent lighting and scotopic lighting in the beginning, but some smaller early efforts (market conditioning) will lay the groundwork for more significant progress at a later time.

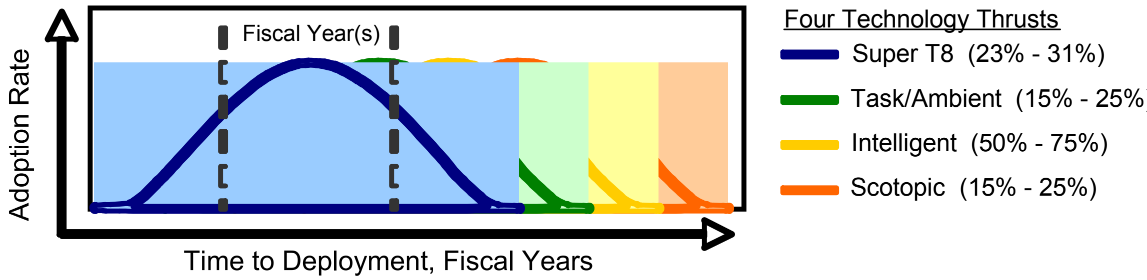

Figure 4. Technology Deployment Scheduling

[4] Each technology shown is exclusive from the other; technologies and savings do not overlap.

4.0 Lighting Technology Opportunities

While there are as many lighting solutions as there are buildings and tasks, it is nonetheless possible to characterize the most significant opportunities by analyzing the Federal building stock in light of new technology opportunities.

4.1 Four Technology Thrusts

When considering the square footage of the different Federal agencies and the occupancy types of their buildings, certain technology solutions offer the greatest promise for Federal sector energy performance improvements;

- *High Performance Fluorescent T8 systems* – High performance T8 (HPT8) lamps and electronic ballasts (sometimes called "Super T8" systems) go well beyond the most commonly used T8 retrofit strategies. Four-foot lamps are the workhorse of Federal lighting so the large majority of projects would be able to apply this technology at an estimated 23% to 31% savings over standard T8 technology.

- *Task-Ambient Design* – The use of advanced luminaire[5] technologies and lower ambient (room) light levels in combination with localized task lighting offers savings in Federal office areas of 15% to 25%, with scientifically measured occupant comfort improvements of 10% to 16% (Boyce, et al. 2003).

- *Intelligent Lighting* – The most progressive energy efficiency technology solution in lighting is a combination of workstation-specific direct-indirect lighting with personal control—this offers an impressive energy savings of 50% to 75%, and has been shown in research to improve worker motivation and performance on tasks (Boyce, et al. 2003).

- *"Scotopic" Lighting* – The term scotopic refers to a form of vision that occurs in the human eye under certain lighting conditions. The use of lamps with more blue in the spectrum is geared toward scotopic vision and can result in improvements in visual acuity. This improved visual performance provides an opportunity to reduce overall light levels resulting in energy savings of 15% to 25% across many commercial and industrial applications.

These technologies are often not well understood and typically are not applied on Federal facilities and projects. Such advanced technologies are not traditionally offered because they are not as simple as one-for-one component lighting retrofits. *Without FEMP assistance, these opportunities will continue to languish*.

[5] Luminaire is the technical term for a lighting fixture with the lamp and ballast included. Efficiency of a luminaire includes the fixture efficiency (e.g., photometric performance) (+) lamp efficacy (+) ballast efficiency.

4.2 Technology Thrusts Support DOE EERE Goals

Of these four technologies, three have been supported with DOE Energy Efficiency and Renewable Energy (EERE) funding out of the Building Technology Program:

(1) Task-Ambient Luminaires and Design

(2) Intelligent Lighting (Advanced Lighting Controls)

(3) Scotopic Lighting

By supporting the deployment of these advanced technologies in Federal buildings, FEMP would be leveraging previous DOE investments.

4.3 High Performance T8 Fluorescent Lamp and Ballast Technology

It surprises many people to learn that the typical T8-electronic retrofit falls far short of the commercially available energy savings potential. The newest T8 lamp/ballast systems offer improvements over commodity products, yet are still under-utilized. The typical retrofit is to replace T12 lamps and magnetic ballasts with T8 lamps and electronic ballasts. Unfortunately, the components used in most retrofits are the standard 700 series T8 lamp and early generation electronic ballast.

The newer high performance fluorescent T8 systems (HPT8) have improvements in both the lamps and ballasts. The lamps offer more light output for the same amount of nominal wattage, along with better lumen maintenance (greater than or equal to 94 percent, or 2900 mean lumens), improved color rendering, and longer life (20% better) than standard T8 products. Ballasts have improved efficiencies and are offered in low, normal and high outputs.

In applying HPT8 technology it is important to note that the output of the ballast is a critical factor in achieving energy savings. The choice between low ballast factor (0.77), normal ballast factor (0.88), and high ballast factor (1.15) in relationship to fixture spacing and light levels must be considered to save energy. The choice of ballast effectively “tunes” the amount of light and energy used so it is appropriate for the application.

For instance, if the current light levels are adequate with a standard T8 system, a premium T8 retrofit should consider the use of a low output ballast because the HPT8 lamp has a higher lumen output. In relighting situations using indirect lighting, the use of a high ballast factor to slightly increase the light output may allow a greater distance between rows of fixtures, thereby eliminating a row or rows.

Energy Savings Estimate—High Performance Fluorescent T8 System

Efficiency comparisons of typical sample products indicate a 23% savings over common T8 systems with the use of a programmed-start premium ballast, and a 70% savings over the older T12 magnetic ballast systems. Instant-start premium ballasts save even more energy at 31% over standard T8, but care should be taken to not pair instant-start ballast with occupancy sensor controls (Sardinsky 2003). For the purposes of this energy analysis, the savings estimate will be 23%.

Table 1. Fluorescent Lamp Technology Characteristics

Technology Description	*Light Output (MLPW[a])*	*% Efficacy[b] Improvement*	
		Over T12	*Over Generic T8*
T12 - 34 watt w/Magnetic Energy-Saving Ballast	54	None	N/A
Generic T8 32 watt 700 series w/rapid-start elec ballast	75	39%	N/A
"Super" T8 32-watt 800+ series w/programmed-start electronic ballast	92	70%	**23%**
"Super" T8 32-watt 800+ series w/instant-start electronic ballast	98	81%	**31%**

[a] Light output in mean lumens per watt.
[b] Efficacy is the correct technical term for efficiency of a lamp. The term efficiency can be applied to fixtures and luminaires.

Improvements in efficacy of a "Super T8" system compared with the most popular standard lamps and ballasts. (Sardinsky 2003)

As shown in Table 1, the HPT8 system provides greater light output with ballasts that are more efficient, resulting in more light for less wattage than a standard T8 system. While these new T8s carry a small price premium, their long-lived energy savings cost-effectively outpaces the standard T8s. *Even the vast square footage of commercial and industrial space that has already been retrofitted or designed with standard electronically ballasted T8 lighting systems can benefit from these efficiency upgrades.*

Barriers—High Performance Fluorescent T8 System

- Unfortunately this savings opportunity is not yet widely known or well understood. The recent excitement in the marketplace about T5 lamps has obscured to some degree the significant savings available with this high performance system.
- One of the distinctions between the HPT8 opportunity and the mass retrofits of the last decade is that this typically should *not* be a one-for-one replacement using normal output ballasts because it will waste the increase in additional light output and efficiency and vastly reduce the cost-effectiveness of the opportunity. The ballast choice is a critical factor in saving energy—the ballast must be chosen carefully to adjust the amount of light that comes out of the lamps. A HPT8 system retrofit requires design and engineering consideration that is not typical for most Federal facility projects.
- There is a small increase in cost for this product, and it has not fully penetrated the distribution system, creating pockets of demand that can be a concern on fast track projects.
- Because this can be retrofitted into existing T8 applications, there is concern about "snapback"[6] when lamps are replaced (maintenance staff may revert to standard T8 lamps).

[6] The term snapback is used in the market transformation literature and refers to the phenomenon when an energy efficiency measure is installed but not maintained. An example of this is the use of

4.4 Task-Ambient Design

The most common lighting design for commercial buildings and spaces is direct-only overhead lighting, where a typical lighting fixture is laid out in a grid pattern to produce relatively uniform illumination throughout the space. In these designs, the lighting levels must be high enough to illuminate task work in any place it may occur in the space – an obviously inefficient use of lighting energy. The careful design and application of effective direct-indirect or semi-indirect[7] lighting systems with task lighting provides the means of harvesting the lighting energy that is currently wasted on transition areas and other non-task areas.

Task-ambient design departs from typical lighting by using indirect[8] lighting fixture technologies and lower ambient (room) light levels in combination with localized task lighting to provide energy savings in offices in the range from 15% to 25%. The ambient lighting illuminates the majority of the space to about 30-35 footcandles (300-350 lux), which is significantly less than the required task lighting level. Direct-only designs using recessed parabolic or lensed troffers typically provide between 50 and 60 footcandles of illumination (500 to 600 lux) throughout the space including transition areas.

Local task lighting is provided to supplement the ambient lighting in the workstations. Under-cabinet task lighting supplements the ambient light levels in the workstations and provides illumination for vertical partitions and the adjacent portion of the horizontal surface. If there are work surfaces or task areas without under-cabinet lighting, moveable compact fluorescent desktop task lights can be provided upon request.

The indirect systems that provide this occupant-friendly lighting are much more affordable than they were 4 to 5 years ago[9]. The use of steel rather than extruded aluminum in semi-indirect fixtures allows for aesthetically pleasing and energy efficient fixtures at an installed price point that is competitive with recessed parabolic troffers. Mergers and acquisitions in the lighting industry have greatly reduced the cost and increased availability of these types of fixtures. In the private sector they are becoming more prevalent as a result. This increases the economic viability of using both aesthetically pleasing and energy efficient fixtures in the Federal sector.

Importantly, new breakthrough lighting fixtures have been made commercially available for low ceiling applications, greatly improving the opportunities for usage in Federal facilities. Previous to this evolution, a minimum of nine feet of ceiling height was required to allow sufficient suspension of the fixtures below the ceiling. Now it is possible to suspend a fixture by only 4-12 inches, allowing installations in ceilings as low as eight feet.

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screwbase compact fluorescent lamps that are installed to save energy, until users revert back to A-lamp incandescents because of dissatisfaction or low replacement costs.

[7] Semi-indirect fixtures have a very small amount of downlight, less than 10%. Direct-indirect fixtures have downlight in an amount greater than 10%, usually in the range of 15-20%. Often, direct-indirect fixtures will have an open downlight component allowing a direct view to the lamps through a baffle. This requires a stronger housing (structural) than semi-indirect which can increase the costs.

[8] Lighting fixtures with an indirect component are suspended from the ceiling on pendants or cables and emit light upwards, using the ceiling as a large reflector.

[9] 5-10 years ago, the cost of extruded aluminum direct-indirect type fixtures ranged from $45 to $55 per linear foot. Today, semi-indirect and direct-indirect fixtures are commonly available at a price point of between $18 and $25 per linear foot.

The use of suspended fixtures to create aesthetically pleasing uplight on ceilings is distinctive because it actually provides a tangible benefit to the end user. Most often energy efficiency measures are invisible, and don't noticeably impact the workers. By contrast, task-ambient systems offer a value-added solution above and beyond efficiency. Research shows that occupant comfort increased by 10% to 16% when direct-indirect systems were used in comparison with direct-only troffer systems (Boyce, et al. 2003).[10] The *IESNA Lighting Handbook, 9th Edition* (IESNA 2000) specifies that room surface brightness is of primary importance in office spaces, and troffer fixtures can be problematic in this regard.

Energy Savings Estimate—Task-Ambient Design

For the purposes of estimating the savings associated with task-ambient lighting systems point-by-point lighting calculations were completed to represent technology application and usage accurately (see Appendix B). The comparison shown in Table 2 is against the baseline of current typical design, the standard parabolic lighting system.

Table 2. Standard and Task-Ambient Lighting System Comparison

Description	Footcandles	Watts per Sq. Foot	% Savings in W/Sq Ft	% Savings kWh
Baseline: T8 Parabolic troffers, semi-specular, 3-in. deep, 18-cell, three-lamp standard T8s, standard electronic ballasts, 8- by 10-ft. grid spacing[11]	55	1.03	NA	NA
Task-Ambient: Suspended direct-indirect, one-lamp "Super T8", premium instant start electronic ballast, high output ballast factor, 10ft.-0 in. on center spacing	39	0.80	22%	**22%**

This task-ambient comparison modeling shows that this technology could reduce office space lighting energy use by 22%, and this is the number used in the energy savings analysis. As a point of reference, this baseline is quite conservative when compared to recent energy codes. The power density limit for open plan offices in the ASHRAE/IESNA/ANSI 90.1-2001 is 1.3 watts per square foot (ASHRAE 2001).[12]

[10] A research study by the Light Right Consortium (Boyce, et al. 2003) measured the impacts of different types of lighting on occupants and reported that lighting designs that provide direct-indirect lighting and wallwashing were rated as comfortable by 81% to 85% of participants. By comparison, designs that provide only downlight (2x4 troffers) were rated as comfortable by only 69 to 71% of participants.

[11] The footcandles of the baseline case are slightly higher than the IES requirement, which is common when this common type of system is used, and is in fact one of the reasons that this standard solution is not optimal for energy savings. The typical A&E relies heavily on this cookie-cutter parabolic (and often lensed) solution.

[12] The power densities in ASHRAE/IESNA/ANSI 90.1-2001 are used as the baseline in the Energy Policy Act of 2005 (EPAct 2005) when determining tax credits for lighting energy efficiency.

Barriers—Task-Ambient Design

- Most engineers and ESCOs are inexperience in designing indirect lighting systems, and they are reticent to change from their tried and true troffer solutions. There is concern about the design costs that may be incurred to learn how to use these systems.
- There is a significant barrier related to the *perceived* high cost of this type of lighting. Certainly it will have higher first costs than a component retrofit, but it is competitive compared to troffers when new fixtures are an option. This is still largely misunderstood in the Federal market.
- The cost of installation of indirect lighting is actually less than that of recessed systems because of the reduction in power feeds. However, contractors often try to charge more because they think they can get away with it. Historically higher pricing may be seen by installers as a chance to treat it as a "high end" job.
- Historically, most indirect lighting systems have required relatively high ceilings (9 ft.-0 in. or greater) to achieve wide spacing between fixtures and keep the energy consumption low. Recent breakthroughs in semi-indirect technologies finally allow indirect lighting in ceilings as low as 8 ft.-0 in., but this is not widely known in the Federal sector.

4.5 Intelligent Lighting

Lighting for buildings is typically designed to provide a "blanket of light" throughout the space sufficient to perform all tasks. Clearly, if light is provided only where it is needed and when it is needed, significant potential for energy savings exists. One method of doing this is to use "intelligent" lighting systems.[13] These systems are characterized by individual direct-indirect lighting fixtures (usually four feet or eight feet in length), which are specifically located at each workstation. The direct (downlight) component allows for personal control by the occupant as well as workstation-specific occupancy sensors (even in open plan areas). The indirect (uplight) component is not under control by the user. This ensures that the ceiling plane has a pleasant appearance of brightness without excessive contrast and also allows for centralized control of the uplight component for peak load shedding, lumen maintenance, and perimeter daylight dimming.

Intelligent lighting also offers the greatest ancillary (non-energy) benefits when compared to any other lighting system. A research study by the Light Right Consortium (Boyce, et al. 2003) measured the impacts of different types of lighting on occupants and reports that intelligent lighting has the highest comfort rating of all of the systems; the systems with dimming control of the overhead lighting at each workstation are rated as comfortable by 91% of participants. This was a 20% improvement in rated comfort when compared to direct-only troffer systems, which was only rated as comfortable by 69% to 71% of occupants.

In addition to the comfort ratings, the study also found that the presence of personal control had a measurable impact on the motivation of office workers to perform on tasks. Normally, the persistence and vigilance of office workers will decline over the course of a workday. However, the presence of personal control of their lighting increased subject motivation allowing workers to sustain their performance—they persisted longer on difficult tasks and were more accurate on a task requiring sustained attention.

[13] The use of the term "intelligent" is meant to describe lighting with advanced controls including addressable ballasts that can be controlled and programmed by computer or similar device.

Energy managers often assume that when occupants have control, they will maximize their light levels. Actually, research shows that the opposite is true. In the Light Right study, subjects using the dimming control showed a wide range of desktop light level preferences. On average, people with dimming control chose ambient light levels that were approximately 25% lower than current practice. Another study that tested dimmable ceiling lighting found that subjects who had controllable lighting were more satisfied with the lighting, felt more comfortable in the room, rated the tasks as less difficult and rated the lighting quality as higher than the subjects who did not have control (Boyce, et al. 2000). In that study the control system produced a 35% to 42% decrease in electrical consumption. There is also a psychological benefit of personal control over lighting. A Canadian study found that subjects who had control of their lighting experienced a greater sense of control in general through the day (Veitch and Newsham, 1998).

The combination of such significant energy savings, along with the positive influence on workers, makes a compelling case for this technology.

Energy Savings Estimate—Intelligent Lighting Controls

The combination of reduced connected load, user control of the downlight, facility control of the uplight and occupancy sensors leads to a dramatic energy savings that ranges from 50% all the way to 75% when compared to a standard direct-only, constant light level, constant-on design.

For the purposes of estimating the savings from intelligent lighting controls for this analysis, a point-by-point lighting calculation analysis was made to accurately represent the reduced connected load for this technology application (see Appendix B). Additionally, metered data were used to determine the savings over time from the use of these advanced controls (Suvagau) (see Appendix C). The comparison shown in Table 3 uses a baseline of current typical design, the standard parabolic lighting system. The baseline case is developed at a lighting power density lower than the average for office spaces to be conservative in estimates of potential savings.

The potential energy savings available from intelligent lighting is presented in Table 3. The savings in watts per square foot is 24% and the savings in kilowatt hours (kWh) is 67%. The kWh savings reflects additional savings over time from the multiple types of advanced controls.

Table 3. Intelligent Lighting Comparison Modeling Results

Description	Footcandles	Watts per Sq. Foot	% Savings in W/Sq Ft	% Savings kWh
Baseline: T8 Parabolic troffers, semi-specular, 3 in. deep, 18-cell, three-lamp standard T8s, standard electronic ballasts, 8 by 10 ft. grid spacing[14]	55	1.03	NA	Not Applicable
Intelligent Lighting: Workstation-specific direct/indirect, three-lamp T8, dimming electronic, centered over each workstation	Varies per user choice	0.79	24%	**67%**

[14] The footcandles of the baseline case are slightly higher than the IES requirement, which is common when this common type of system is used, and is in fact one of the reasons that this standard solution is not optimal for energy savings. The typical A&E relies heavily on this cookie-cutter parabolic (and often lensed) solution.

Barriers—Intelligent Lighting

- Intelligent lighting is considerably more expensive than standard lighting systems.
- Commissioning is complex and requires expertise and a commitment to maintenance over time.
- Coordination is required by the industry to ensure reliable data protocols and intelligent communication between the various types of control components.

4.6 Scotopic Lighting[15]

The term 'scotopic' refers to a type of vision that occurs in the human eye under certain lighting conditions. The use of lamps with more blue in the spectrum is geared towards scotopic vision and can result in improvements in visual acuity. This improved visual performance provides an opportunity to reduce overall light levels resulting in energy savings of 15% to 25% across many commercial and industrial spaces. Lamps that deliver light with more blue in the spectrum are considered scotopically enhanced and are also called 'Spectrally Enhanced Lighting' (SEL).

Research supported by DOE Building Technology Programs and performed by Sam Berman and Lawrence Berkeley National Laboratory indicates that under this blue-rich ambient light, the rods allow the observer's depth of field and visual acuity to be increased compared to other 'warmer' light sources (LBNL). The "2003 Advanced Lighting Guidelines" (NBI 2003) describes the effect well:

> "The pupil size is primarily determined by the stimulation of the rods outside of foveal vision. Because the rods are more sensitive to bluer light than the cones, for the same level of illumination, the pupil is smaller for ambient light sources that are richer in the blue spectrum. Research indicates that under blue-rich ambient light, smaller pupils tend to increase the observer's depth of field and visual acuity compared to blue-deficient ambient light. Because of this interaction with pupil size, light sources with more blue, such as daylight or high correlated color temperature fluorescent sources (4000K to 6500K) seem to appear brighter to observers. This work suggests that for the same level of illumination, observers will see things more acutely under ambient light sources that are richer in blue light."

A point of controversy in the lighting design and engineering community is the fact that illumination recommendations based on lumens and footcandles don't completely account for spectrum specific characteristics of normal vision. Some researchers have made use of factors called scotopic/photopic ratios (S/P ratios) that are independent of light level and express the extent to which a lamp favors scotopic effects. Sources with larger S/P ratios (such as high color temperature fluorescent lamps) may permit a greater depth of field and better acuity than those with smaller S/P ratios. Table 4 demonstrates that lamps with higher S/P ratios exhibit higher "efficiency" when considering the factors of visual acuity and depth of field. By taking advantage of this effect, lower ambient light levels could be used, which translates to a reduction in energy use.

[15] Scotopic lighting is also referred to as "scotopically enhanced", "spectrally enhanced", and "blue-rich" lighting. All of these terms generally refer to the enhancement of the typical interior lighting spectral distribution with light from the blue end of the spectrum.

Table 4. Characteristics of 40 Watt Fluorescent Lamps

Lamp Type	Photopic lumens	Scotopic lumens	S/P Ratio	"Scotopic" Efficiency (Lumen/Watt)
Warm-white fluorescent (WW)	3200	3100	1.0	78
Cool-white fluorescent (CW)	3150	4630	1.46	106
Narrow-band phosphor fluorescent (5000K)	3300	6468	1.96	139
Scotopic rich narrow band (SR-NE)	3000	7500	2.47	153

This technology has potential application in many Federal spaces. However, it is important to note that the research in this area is rapidly evolving and design recommendations associated with scotopic lighting have not yet been developed by the IESNA. Until design and applications recommendations are provided, it is important to consult with an expert who is up-to-speed with the latest research and can support effective application of this technology.

Energy Savings Estimate—Scotopic Lighting

Energy savings potential with scotopic lighting is related to the effective visual efficiency differences between standard and scotopically enhanced lamps as shown in S/P ratios. Data from reports of work done by S. Berman for common fluorescent (cool white) and scotopic products (5000K) indicate a potential savings of 25% (LBNL). A recent field study was completed in California that achieved 20% energy savings and documented user acceptance (Afterimage + Space 2004). For the purposes of this energy savings analysis, 20% energy savings will be used.

Barriers—Scotopic Lighting

- Some occupants may be resistant to the very “cool” appearance of the scotopically enhanced lamps, especially in applications that have a very well-established norm for color temperature.
- There continues to be controversy in the scientific field with respect to the physiological mechanism underlying spectral vision effects and its impact on visual acuity under photopic lighting conditions.

5.0 Federal Facility Lighting Energy Savings Potential

The many buildings used by the various Federal agencies present a tremendous opportunity for lighting energy savings using the four technologies described in this report. Development of an estimate of the energy saving potential includes the following information: (1) Federal facility square footage, (2) Federal energy use intensities, (3) Application of technologies to the Federal sector, (4) Estimates of technology savings, (5) Development of savings potential estimate.

The following describes the methodology of the analysis, defines the inputs and their sources, and presents the results as yearly and cumulative estimates of the potential lighting energy savings in Federal buildings.

5.1 Federal Facility Square Footage

Federal facility square footage data is available from several sources. The FEMP Geographic Information System (GIS) for 2001 (Chvala 2002) was found to provide the most complete and detailed data and was chosen for this analysis. The GIS accesses Federal facility data sources including the annual reports to congress. The data was split into general building type categories to help match the application of the four technologies as shown in Table 5.

Table 5. Federal Agency Square Footage by Agency and Facility Use Type (Million ft^2)

Bldg Type	Federal Agency[16]				
	DOD	VA	USPS	GSA	Other[17]
Housing	627.1	4.6	0.0	0.2	40.1
Office	181.4	7.5	154.0	178.9	50.5
Service	429.7	4.5	5.2	3.1	35.6
Storage	348.9	5.5	1.9	31.9	44.0
School	125.7	0.7	1.4	0.1	18.8
Hospital	39.3	95.4	0.0	0.0	6.7
Industrial	59.9	0.1	0.0	0.1	53.8
Prison	3.4	0.0	0.0	0.0	36.3
R&D	71.2	3.6	0.0	0.0	71.7
All Other	106.9	14.4	0.0	4.5	40.8
TOTAL	1993.6	136.4	162.6	218.8	398.3

[16] Acronyms for various Federal agencies are used throughout this report as follows: Department of Defense (DOD), Veterans Administration (VA), United States Postal Service (USPS), General Services Administration (GSA).

[17] Other category includes: The Departments of Agriculture, Commerce, Energy, Health and Human Services, Housing and Urban Development, Interior, Justice, Labor, State, Transportation, and Treasury. Also the Federal Communications Commission, Federal Emergency Management Agency, Federal Energy Regulatory Commission, Federal Trade Commission, National Aeronautics and Space Administration, National Archives and Records Administration, Nuclear Regulatory Commission, Railroad Retirement Board, Social Security Administration, US Information Agency, Tennessee Valley Authority.

5.2 Federal Energy Use Intensities (EUI)

Energy use intensities for Federal facility building types are important in providing a baseline reference for applying savings percentages. The most appropriate set of yearly whole building intensities is available from the 2003 Buildings Energy Databook representing 1999 data. These data are regularly compiled for the DOE Building Technologies Program, Office of Energy Efficiency and Renewable Energy (DOE-EERE 2003).[18] Estimates of the fraction of whole building energy provided by lighting was also available from the 2003 Databook but only as an aggregate for all building types at 24.7% based on 2001 data. The application of the lighting percentage to the whole building intensities provides a reasonable and recent set of energy use intensities for this analysis.[19] These end use intensities form the baseline lighting energy use against which technology savings is measured.

Table 6. Estimated Commercial Lighting Yearly Energy Intensities by Principle Building Type

Building Type	**EUI (MBtu/ft2/yr)**
Office	0.054
Service	0.085
Storage	0.021
School	0.033
Hospital	0.083
Industrial	0.071
Prison	0.034
R&D	0.071
Other	0.071

5.3 Application of Technology Thrusts to Federal Facilities

A further input in the estimation of energy savings is the assessment of where each technology might be effectively installed. This involves considering market readiness, ease of use, cost, and applicability of each type of lighting system. The applications of lighting technologies to Federal

[18] A set of intensities based on the Commercial Building Energy Consumption Survey (CBECS) from the Energy Information Administration (EIA 1998) was considered for the basis of this analysis. The data does include potentially useful estimates of energy use broken down by delivered end use energy consumption by building type. However, the data used in the 1998 report is from 1995 and is considered too old to be a fair representation of current energy use conditions considering the changes in equipment and energy code adoption since that time.

[19] It should be noted that there is a higher margin for error when looking at the energy savings totals for each building type (found in Appendix A), due to the lack of recent data on delivered energy end use data. The data is more accurate when viewed in aggregate as this reflects the nature of the information that was used to develop the savings estimates. The values shown in Table 6 are based on these data and are considered the most accurate set of available intensity values.

building types are indicated by checkmarks in Table 7 based on the following considerations for each technology.[20]

- *High Performance Fluorescent T8 Systems* refers to the HPT8 and ballast technology that is available on the market but underutilized. Applications for this technology are based on the understanding that this technology could be applied in any space where linear fluorescent technology is employed.

- *Task-Ambient Systems* involve the use of suspended linear fixtures where lower ambient lighting levels are supplemented with local task light. The uplight component requires clean and highly reflective ceilings, therefore this technology is limited to building types where a reasonable fraction of activity is office based.

- *Intelligent Lighting Systems* apply where fixtures can be oriented over workstations allowing users to have individual control and individual occupancy sensors. This is most applicable in office settings where workspace is well-defined with a consistent size.

- *Scotopic Lighting* is a technology that could be applied as a direct replacement of existing lamp type technology with associated reduction in power requirements. Therefore, scotopic lighting is considered potentially appropriate to most fluorescent lighted spaces and spaces with High Intensity Discharge (HID) lamp technologies.

Table 7. Applications of Lighting Technology to Federal Building Types

Facility Type	HPT8 Systems	Task - ambient	Intelligent Lighting	Scotopic
HOUSING				
OFFICE	√	√	√	√
SERVICE	√	√		√
STORAGE	√			√
SCHOOL	√	√		
HOSPITAL	√	√		
INDUSTRIAL	√			√
PRISON	√			√
R and D	√	√		√
OTHER	√			

[20] It is understood that while multiple technologies may be effective in many building and space types, it is unlikely that more than one would be applied to each situation. Therefore, it has been assumed that there is no overlap of technologies. More information about the percentage of use per technology for each building type can be found in Appendix A.

5.4 Technology Savings Estimates

A final input to the analysis is a determination of what percentage of energy savings exists for each technology upon its typical application. These have been developed from various sources, as described in the earlier section of the report, and are summarized in Table 8.

Table 8. Estimated Lighting Energy Savings Potential for Typical Applications

High Performance T8 Systems	Task-Ambient	Intelligent Lighting	Scotopic
23%	22%	67%	20%

5.5 Potential Total Savings Estimate Development

The combination of these factors produces estimates of potential technical lighting energy savings in Federal facilities shown in Table 9 derived using the following:

$$\text{Energy Savings} = \frac{\left(\text{Federal square footage} \times \text{Lighting EUI}\right)}{\text{Building Type}} \times \text{Savings Percentage}$$

Table 9. Estimated Technical Potential Savings by Technology and Agency
(million Btu, site energy)

Federal Agency	Lighting Technology				Totals (MBtu)
	HPT8 Systems	Task-Ambient	Intelligent Lighting	Scotopic	
DoD	11,318,000	3,930,000	1,643,000	2,128,000	19,019,000
VA	1,544,000	764,000	68,000	29,000	2,405,000
USPS	867,000	582,000	1,395,000	103,000	2,947,000
GSA	1,169,000	657,000	1,621,000	135,000	3,582,000
Other	3,495,000	707,000	457,000	490,000	5,149,000
Totals	18,393,000	6,640,000	5,184,000	2,885,000	33,102,000

This estimate of the technical potential energy savings is calculated against the Federal energy reduction goals as of the drafting of this report.[21] The goal that was set forth in the National

[21] The new Energy Policy Act of 2005 (EPACT 2005) requires a new annual energy baseline be established using 2003 reporting data and a new annual energy reduction goal of 2% per year. However, that data was not yet published as of the writing of this report.

Energy Conservation Policy Act of 1978 (NECPA 1978) and the Executive Order 13123 (Executive Order 1999) was to achieve a 35% reduction from 1985 based energy by the year 2010. Table 8A in the FEMP Annual Report to Congress for Fiscal Year 2001 (latest data reported, DOE 2004) notes that for fiscal year 2001 the energy reduction for standard Federal facilities towards the 2010 goal, relative to the base year of 1985, is 23.3%. Progress through FY2004 can be estimated (based on continued progress at the same rate through 2004) at approximately 27.7%. This leaves an additional 7.3% reduction remaining to meet the 35% goal. This is estimated to be just over 31 trillion Btu (31,167,793 Million Btu) remaining to be saved between 2005 and 2010 for Federal facilities as a whole.

5.6 Lighting Technology Penetration Factors

It is reasonable to expect that each technology will have an initial limited entrance into the market because of natural cost and user acceptance factors. Penetration rates have been assumed for each technology to reflect achievable results in the face of these factors. These penetration rates assume that that FEMP would provide technical assistance geared towards breaking down Federal market barriers in order to increase deployment of these technologies.

Future penetration rates of technology are difficult to predict because they can be affected by many external factors. It would be instructive to look at historical data of similar technologies (where available) to help derive estimates of potential penetration. However, in spite of the many changes in lighting technology over the years, there is limited definitive data available that characterizes lighting technology penetration or accurately attributes the penetration to natural or external market transformation efforts. The general trends and rates over time are minimally instructive as upper and lower bounds of potential new technology penetrations. Some available information collected on historical lighting technology penetration provides some conclusions and potential effects but is not definitive enough to provide an analytical basis for comparison.[22]

- Lighting technology (electronic ballasts and CFLs) penetration across the nation from all natural and external effects has an historical upper bound through 2001 of 4.3% per year. Early penetration rates were found as low as less than 1%. (Xenergy 2000)
- External market transformation efforts for these same technologies in one state (California) have been credited with increasing natural penetration rates by 35% to 40%. Combined penetration from all factors has been found to increase by an upper bound of 1000%. A potential lower bound penetration effect from published recommended design guidance has been reported as an 8% to 15% increase in sales and use of indirect fixtures. (Xenergy 2000)

It is also appropriate to note that compact fluorescent lamp (CFL) penetration is primarily into the residential market. Consumer usage of CFLs as a replacement for incandescent A-lamps should not be readily compared to commercial and industrial penetration.

A more useful metric in developing penetration rates is the life of the technology equipment itself. This information can provide an estimate of naturally occurring technology changes. These values provide an estimate of unassisted penetration for technologies where newer technologies are installed as a replacement for old equipment. The life of most commercial and

[22] Several additional sources providing penetration rate data over time are included in Appendix A as reference points of interest.

industrial lighting equipment is considered to be approximately 20 years. While there are always some early adopters, the shift towards advanced technologies is usually seen at the end of the useful life of existing equipment. Under typical conditions this equates to an equipment replacement cycle of approximately 5% per year, on average. Therefore, this was used as the baseline for unassisted penetration rates in the analysis.

A thorough understanding of advanced lighting technologies and their application leads to several other key expected effects.

- Technologies are expected to see initially moderate penetration rates that ramp up to maximum penetration over several years. At some point the technology's saturation and the penetration of other technologies will cause a declining penetration effect.
- Penetration rates of each technology are not expected to overlap as users are unlikely to retrofit their lighting more than once in a 10-year period.
- The HPT8 technology (primarily component retrofits) is expected to ramp up more quickly than other technologies due to the relative familiarity among users. Its penetration is expected to fall off in the out years as more complicated and complete relighting technologies become more common.
- Task-ambient technology utilizing advanced lamp and ballast components as well as new fixture configurations is expected to have a slower ramp up as Federal facility fixture infrastructure will be stable for many facilities for several more years.
- As the more advanced control driven intelligent lighting systems become more mainstream, task-ambient applications are expected to start to fall off.

A final useful and necessary factor in technology penetration development is a thorough understanding of each technology's appropriate application and the potential roadblocks to acceptance. This understanding fills in the gaps left from other limited data. Previously in this report the market barriers for each of the four technologies were listed. The last section of this report provides candidate (recommended) tasks that are strategically designed to break down specific market barriers wherever reasonable, practical and affordable. It is this direct market intervention that will speed up deployment in the Federal market.

5.7 Derived Penetration Rates

The penetration factors described above were used to develop the rates used in the analysis and are shown in the table below. Each technology starts to penetrate the Federal market slowly and is eventually partially overtaken by another more advanced option as it becomes easier to apply and therefore more mainstream. The individual yearly technology rates are conservative compared to the available historical data for both natural and market transformation assisted rates of similar technologies that are noted above at 4.3% and 15%.

Overall, the cumulative rate of penetration for each of the four technologies ranges from 2% to 13% per year over the 10-year period. The total cumulative penetration for the 10-year period is 93% for all technologies combined and represents the expectation that the deployment program will assist in incorporating lighting improvements twice as fast as compared to the natural equipment turnover rate of 20 years.

Table 10. Lighting Technology Expected Penetration Rates

Year	HPT8 Systems		Task-Ambient		Intelligent		Scotopic		Total	
	Annual	Cum-ulative	Annual	Cum-ulative	Annual	Cum-ulative	Annual	Cum-ulative	Annual	Cum-ulative
2005	1%	1%	1%	1%	0%	0%	0%	0%	2%	2%
2006	2%	3%	1%	2%	0%	0%	0%	0%	3%	5%
2007	4%	7%	2%	4%	1%	1%	0%	0%	7%	12%
1008	4%	11%	3%	7%	1%	2%	1%	1%	9%	21%
2009	4%	15%	3%	10%	2%	4%	2%	3%	11%	32%
2010	3%	18%	3%	13%	2%	6%	2%	5%	10%	42%
2011	3%	21%	4%	17%	3%	9%	3%	8%	13%	55%
2012	2%	23%	4%	21%	3%	12%	3%	11%	12%	67%
2013	2%	25%	3%	24%	4%	16%	4%	15%	13%	80%
2014	2%	27%	3%	27%	4%	20%	4%	19%	13%	93%

5.8 Lighting Energy Savings Estimate Towards Federal EUI Reduction Goals

Applying these penetration rates to the yearly estimated energy savings provides an estimate of the potential contribution of lighting savings to meeting the energy goal by year for each technology. This is shown in Figure 5 as yearly savings and cumulative savings are shown in Figure 6. For example, in Figure 5, the high performance fluorescent T8 system shows a penetration that starts strong but drops off in later years representing its eventual saturation in the building stock with an energy savings contribution in Year 2014 approaching 5 million MBtu. The simplest and most easily applied technology – high performance fluorescent T8 – shows a penetration that starts strong but drops off in later years representing its eventual saturation in the building stock. Other technologies, because of their complexity, take longer to become standard design practice and are not expected to reach maximum penetration much before 2014.

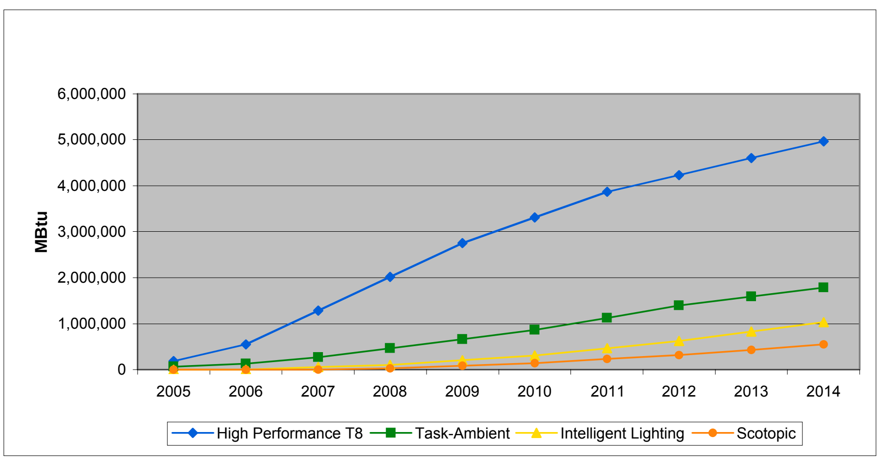

Figure 5. Estimated Yearly Lighting Energy Savings by Technology

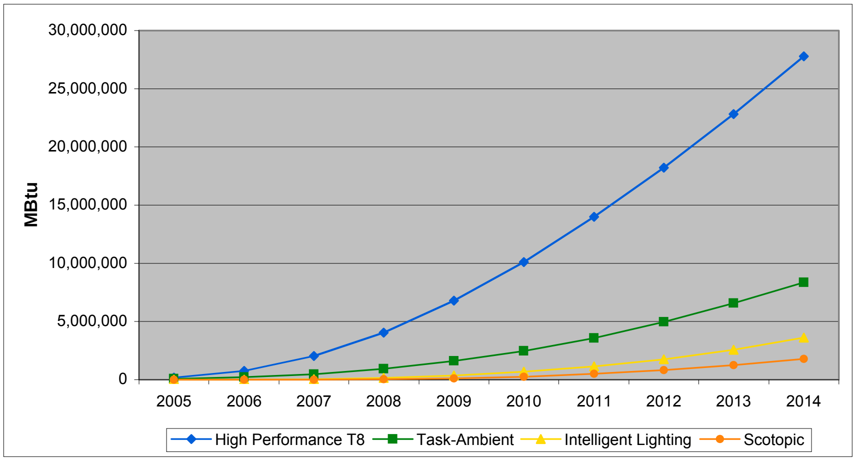

Figure 6. Estimated Cumulative Lighting Energy Savings by Technology

These results are shown as cumulative contributions of savings in the chart below (Figure 7). This representation provides a visual comparison of the relative contribution of the four different technologies based on the application and potential savings factors described previously. It is clear that the high performance fluorescent T8 system will provide the most savings because of the widespread application opportunities in existing facilities. A companion Figure 8 relates the savings to the Federal EUI metric in Btu/GSF (base of 2001 square footage).

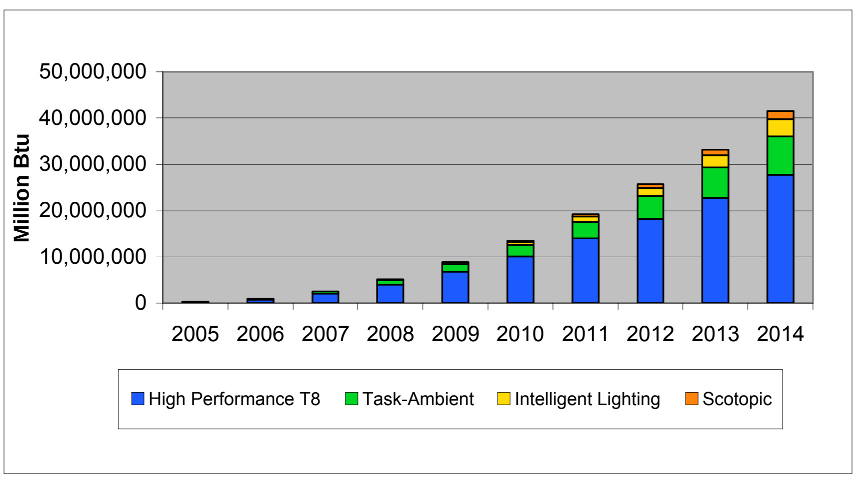

Figure 7. Cumulative Energy Savings Contributions by Lighting Technology per Year

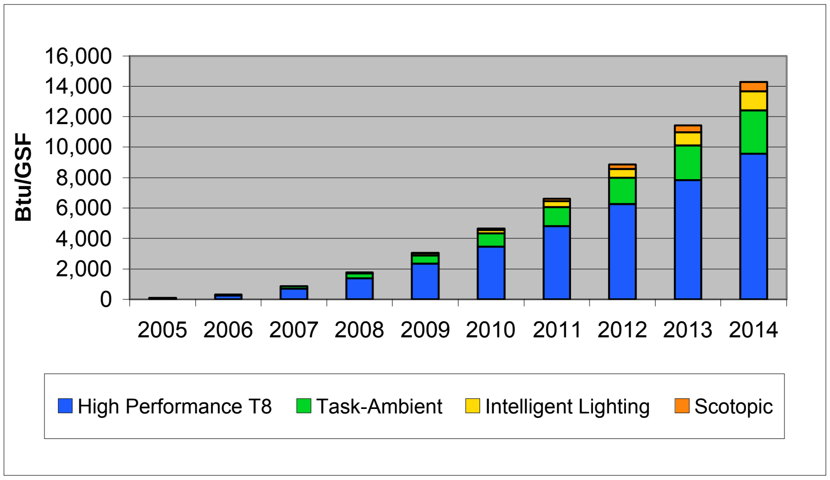

Figure 8. Cumulative EUI Reduction Contributions by Lighting Technology per Year

The Energy Policy Act of 2005 (EPACT 2005) introduced a new goal to reduce Federal energy use by 2 percent per year. It stipulates that a new baseline be established using 2003 reporting data (not yet published) as a basis for an annual energy reduction goal of 2% per year. For the purposes of showing savings against this new goal, the latest reported data from 2001 was used (DOE 2004) in conjunction with estimated progress through 2004 (the same rate of progress was assumed for the purposes of developing this revised baseline). This provided a starting point to determine the potential for savings in the Federal sector against the 2 percent per year goal (Figures 9 and 10). A revision to these charts would be appropriate once actual reported data has been used to determine the 2003 baseline. These charts present this view graphically showing the relative amount of yearly 2% savings achievable through lighting alone in actual energy and Federal EUI. The cumulative savings of the four lighting technologies is 14,000 Btu's per gross square foot, which represents 72 percent of the overall goal as of 2014.

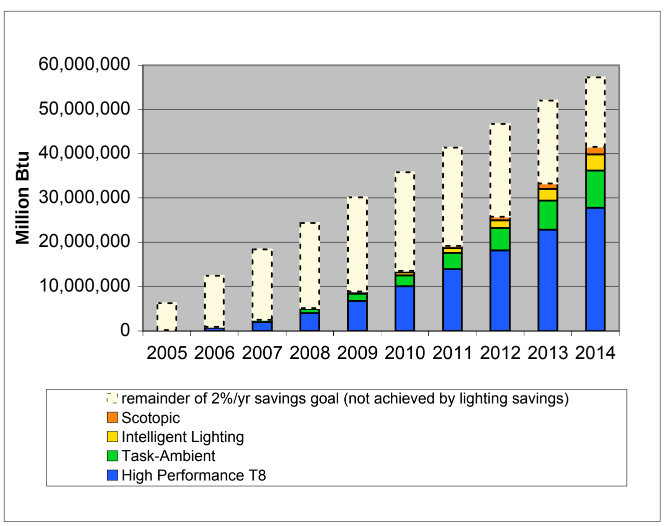

Figure 9. Cumulative EUI Savings Contributions by Lighting Technology Towards a 2% per year all Agency Energy Savings Rate (per Thousand Square Foot)

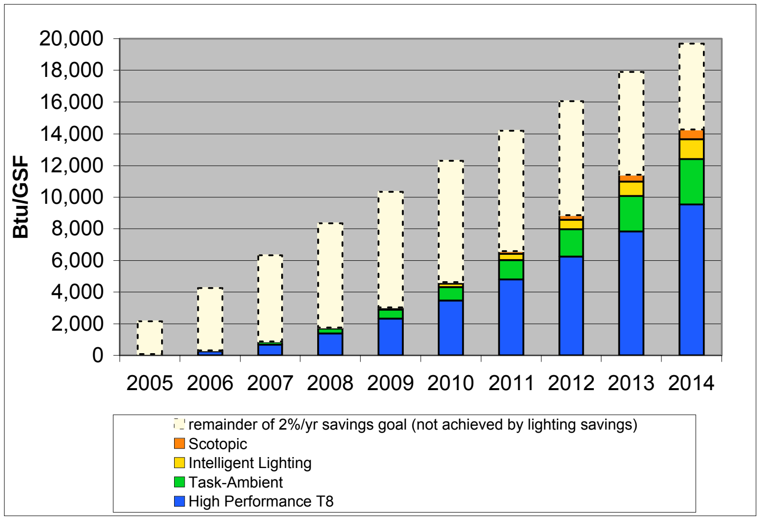

Figure 10. Cumulative EUI Savings Contributions by Lighting Technology Towards a 2% per year all Agency EUI Reduction Goal (Btu/thousand SF)

As a basis for determining return on investment, FEMP program investment to achieve these energy savings are presented in Figure11. Anticipated investment is based primarily on the expected cost for FEMP lighting related program tasks (details on recommended tasks and activities are found later in this document) as well as historical funding levels. Investment starts relatively low and increases as the opportunity to penetrate into the buildings market increase, and then drops off as saturation is approached.

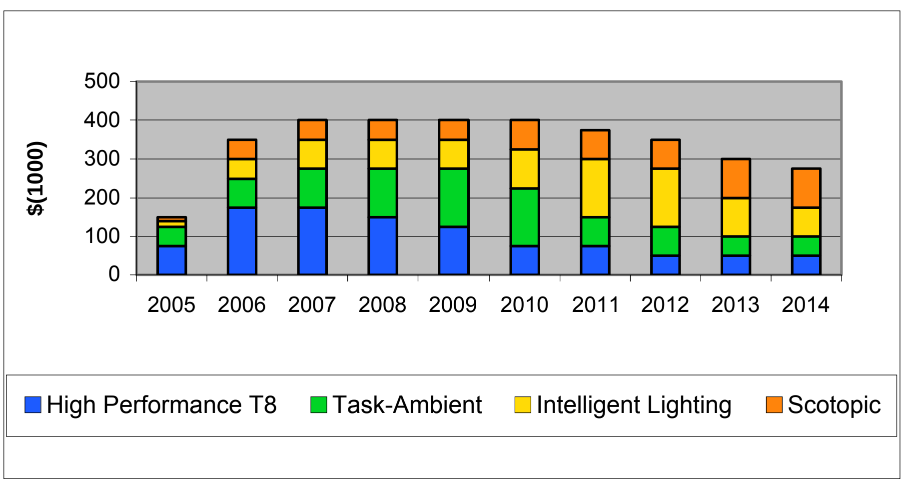

Figure 11. FEMP Program Investment, Projected Contributions per Year

Relating these investments to expected savings produces the savings per investment values in Table 12 below. As expected, the high performance T8 system is the easiest to implement and therefore has the least relative cost.

Table 11. Federal Lighting Energy Savings per Investment Dollar

Mbtu saved per $ investment - Cumulative through 2010			
High Performance T8	Task-Ambient	Intelligent Lighting	Scotopic
13.05	3.78	1.73	0.91
Mbtu saved per $ investment - Cumulative through 2014			
High Performance T8	Task-Ambient	Intelligent Lighting	Scotopic
27.77	9.30	4.19	2.82

The information on energy saved per dollar spent is valuable for determining where programmatic investments should be made to achieve goals. When compared to other technologies, lighting is likely to show a much higher return on investment.

5.9 Projected Impact of FEMP Program Tasks vs. Natural Penetration

As stated previously, the natural penetration of new lighting technologies is quite slow and is typically based on the turnover of lighting equipment due to equipment failures and naturally occurring tenant fitouts due to relocation and churn factors.

This business case shows that the effect of strategic Federal efforts towards incorporating advanced lighting technologies is to almost double this penetration rate by the year 2014. A comparison of the expected 5% per year natural penetration discussed above and the assisted penetration suggested in this report is shown in Figure 12. This increase in lighting advancements can provide the energy savings needed to help achieve the energy reduction goals all agencies are faced with.

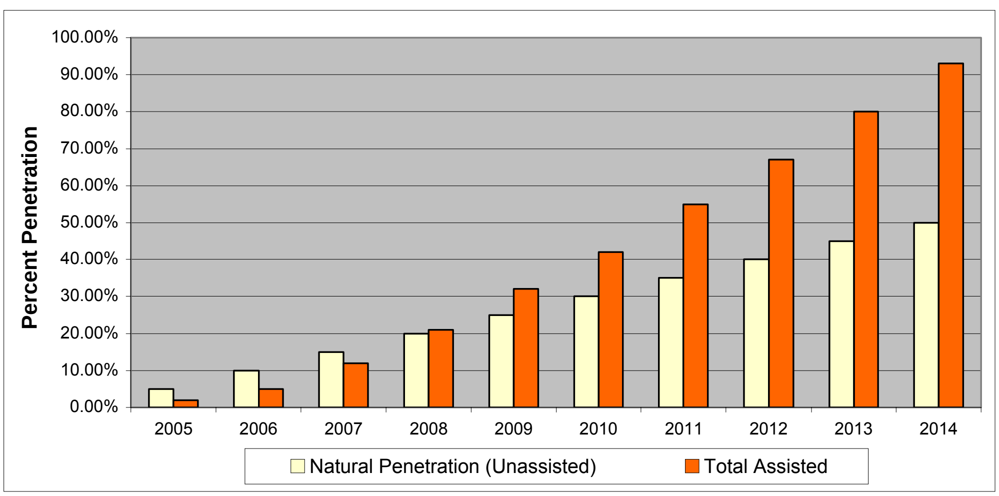

Figure 12. Natural Unassisted Federal Market Penetration of Thrust Lighting Technologies vs. FEMP Assisted Federal Market Penetration

6.0 FEMP Candidate Tasks and Activities

Given the potential energy savings opportunities, the goal is to make these savings a reality. The tasks shown below in Tables 12 through 15 have been developed with the following objectives in mind.

(1) Tasks must break through the barriers listed in the technology descriptions above.

(2) Tasks must have a high likelihood of success and avoid high risks.

(3) Tasks must have well-defined performance metrics with decision points and off-ramps.

(4) Tasks must be cost-effective and achieve significant benefits, providing the most impact for the lowest amount of spending.

Table 12. High Performance "Super T8" system tasks

Technology Barriers	Candidate Tasks	Performance Metrics
Poor visibility, lack of awareness	Article in FEMP Focus and energy trade publications	Number of articles, circulation rates
	Case study one-page write up, similar to New Technologies Demonstration Program (NTDP) documents	Completion of one-pager and quantity of distribution
	Participate in Consortium for Energy Efficency[23] (CEE) working group as they develop performance specification for HPT8 systems. Present performance specification to Federal Utility Partnership Working Group (FUPWG) meeting	Meeting minutes of CEE working group conference calls. Presentation of performance specification at FUPWG meeting.
	Create a "Virtual Lighting Working Group" of energy managers to share challenges and lessons learned via phone on a quarterly basis.	Meeting minutes of phone calls

[23] The Consortium for Energy Efficiency is a national market transformation organization with primarily utility membership that has formed a High-Performance Commercial Lighting Working Group in 2004. Their first project was to produce a standard specification on high performance T8 systems for use in utility incentive programs. Information and a copy of the specification can be found on their website at http://www.cee1.org/com/com-lt/com-lt-main.php3.

Technology Barriers	Candidate Tasks	Performance Metrics
	Proactive Distribution of E-Source publication to ESCO's, FUPWG, Inter-Agency Task Force (IATF), and select agency distributions	Quantity distributed
Need for design and application expertise (not a one-for-one replacement)	30-45 minute web-based online technology-specific learning module	Course content for the modules provided to DOE web contractor. Number of students who complete learning module tracked via the web.
	Lighting Pattern Tool for high performance T8 systems	Completion of document, quantity of distribution
Cost and availability	Highly visible procurement program to get reduced price, guarantee availability	Track sales and product prices related to procurement program
	Insert product into all relevant Federal catalogues and supply schedules	Track inclusion of technology and pricing information in Federal supply catalogues and schedules.
Snapback	Long-term price breaks and incentives through Federal supply catalogues and schedules	Compare standard T8 sales with HPT8 sales over time
	Insert high performance T8 specifications into Federal agency contract language, design manuals and guidelines, make it the standard	Number of agencies that make changes to their documentation and practices, and square footage impacted by these changes (annual data collected via email and phone interviews)

Table 13. Task-Ambient Technologies

Technology Barriers	Candidate Tasks	Performance Metrics
Lack of design experience with indirect lighting	Office Lighting Pattern Tool for Task-Ambient Lighting	Completion of document, quantity of distribution
	30-45 minute web-based online technology-specific learning module	Number of students who complete the learning module racked via the web

Technology Barriers	Candidate Tasks	Performance Metrics
Cost and availability (including installation cost issues)	Case study installation detailing equipment and installation costs with NTDP write up of results	Completion of document, quantity of distribution
	Increase incentive to install task-ambient lighting by quantifying improvement in occupant satisfaction with the *Light Right Consortium* web-based survey tool	Survey data
	Insert representative product into all relevant Federal catalogues and supply schedules	Track inclusion of technology and pricing information in Federal supply catalogues and schedules.
Low ceiling conditions are typical	Demonstration using breakthrough low ceiling technology. Document results in a case study NTDP-type document.	Completion of demonstration, case study document, quantity of distribution
Poor visibility, lack of awareness	FEMP Focus article about case study and Task-Ambient Lighting Pattern Tool	Completion of article and distribution

Table 14. Intelligent Lighting

Technology Barriers	Candidate Tasks	Performance Metrics
Equipment cost	This barrier cannot be addressed until usage has increased enough to allow Federal sales to influence pricing.	Not applicable
Complexity of commissioning	Case study installation detailing commissioning process with NTDP write up of results	Completion of document, quantity of distribution
	Increase incentive to install intelligent lighting by quantifying improvement in occupant satisfaction with the *Light Right* web-based survey tool	Survey data

Technology Barriers	Candidate Tasks	Performance Metrics
Cost and availability	Insert representative technology into all relevant Federal catalogues and supply schedules	Track inclusion of technology and pricing information in Federal supply catalogues and schedules.
Integration of advanced control systems	This issue will be resolved by industry efforts and research organizations.	Not applicable

Table 15. Scotopic Lighting

Technology Barriers	Candidate Tasks	Performance Metrics
Very "cool" appearance of lamps	This can only be addressed once there is more data about occupant preference (will vary by application).	Not applicable
Scientific controversy	Partnership with EERE to perform field demonstration in office environments to support resolution of controversy.	Completion of tasks funded by FEMP in the field study.
	Demonstration in an industrial or warehouse environment to measure value-added aspects of scotopic lighting (visual acuity, apparent brightness).	Completion of demonstration and publication of findings
Poor visibility, lack of awareness	FEMP Focus article about scotopic lighting after completion of field demonstration(s).	Completion of article(s) and distribution
Cost and availability	Insert representative technology into all relevant Federal catalogues and supply schedules	Track inclusion of technology and pricing information in Federal supply catalogues and schedules.

7.0 Conclusion and Recommendations

FEMP is increasingly committed to strategic planning and investment-to-impact criteria as a means to establish programmatic priorities. This Lighting Business Case provides information and analysis that provides a basis for FEMP program investment decisions. It is clear that lighting is a worthwhile program investment, which will languish without attention. The complexities of lighting technology, its application, and Federal market obstacles are significant enough that intervention is necessary to realize energy savings and meet the legislated goals.

Given the structure of the FEMP program, it is clear that some of the lighting tasks should reside in existing programs. However, some tasks that are proposed above do not have a programmatic "home." Importantly, to take advantage of this opportunity there needs to be a lighting master plan against which task activities are selected and progress is measured. If there is no centralized oversight and if a core capability and staff are not maintained, these various activities cannot be integrated where necessary, and strategically important tasks may fall in-between the cracks.

The conclusion of this report is that lighting is strategically significant enough to the achievement of FEMP goals that it merits continued attention. The most logical direction at this time is to have it be an ongoing activity within the Technology Deployment (Emerging Technologies) program area.

Recommendations:

- Maintain an ongoing cognizant FEMP program manager to oversee a core capability in lighting.
- Establish and maintain an overall master lighting plan based on the findings of this report to guide investment decisions. The lighting plan should include tasks that measure progress against goals and be modified as necessary to stay current.
- Maintain the core lighting capability in the Technology Deployment / Emerging Technologies program area. Where appropriate, some tasks may be performed under other FEMP program areas.
- Leverage internal and external partnerships to achieve the greatest results in the most cost-effective manner.

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APPENDIX A

Appendix A

Energy Savings Analysis

This analysis involves several data inputs and developed assumptions that support the primary energy savings estimates. These are described here to provide more complete documentation of the analysis.

Building Type Energy Intensities

A set of yearly whole building intensities is available from the 2003 Buildings Energy Databook shown below in Table A-1 representing whole building energy use from 1999 data (DOE-EERE 2003, Table 1.3.7, 1999 Commercial Primary Energy Consumption Intensities, by Principle Bldg Type).

Table A- 1. Primary Whole Building Energy Usage Intensities

Bldg type	Primary Building EUI (MBtu/sqft/yr)
Office	0.22
Mercantile	0.17
strip malls	0.17
other	0.16
Education	0.14
Warehouse/storage	0.09
Healthcare	0.34
inpatient	0.39
outpatient	0.19
Service	0.20
Lodging	0.19
Public assembly	0.17
Food service	0.47
Food sales	0.53
Public order/safety	0.14
Vacant	0.04
Other	0.29

Because only lighting energy is of interest in this analysis, an estimate of the lighting only portion of building energy was needed. An estimate of the fraction of whole building energy provided by lighting was available from the 2003 Buildings Energy Databook at an aggregate for all building types at 24.7% based on 2001 data (DOE-EERE 2003, Table 1.3.3, 2001 Commercial Energy

End-use Splits, by Fuel Type- Quads). The lighting percentage of 24.7 was applied to the whole building values to calculate the lighting only energy use intensities.

The final step in the development of energy intensities was a matching of building types. The building types with whole building energy use data provided in the Buildings Energy Databook do not match one-for-one the building types represented in the Federal facility square footage data used in the analysis. A matching of building types was completed between the two sets to ensure the most reasonable application of energy intensity values. The combination assumptions and the resulting lighting only energy intensities are shown in Table A-2.

Table A- 2. Estimated Commercial Lighting Yearly Energy Intensities by Principle Building Type

Federal Bldg Type	Lighting ONLY EUI (MBtu/sqft/yr)	NOTES
Office	0.054	
Service (see note)	0.085	Avg of Food Service, Food Sales, Mercantile and Service
Storage	0.021	Direct match
School	0.033	Direct match
Hospital	0.083	Direct match
Industrial	0.071	Based on Other
Prison	0.034	Based on Public Order and Safety
R&D	0.071	Based on Other
Other	0.071	Direct match

(Source: 1999 Commercial Primary Energy Consumption Intensities)

Application of Technologies

The report presents a table indicating where each of the four lighting technologies is considered to be applicable to each of the major building types in the Federal sector. This ensures that energy savings are only estimated where there is a likely application.

For the analysis it was necessary to make assumptions about the percentage of each building type that could make use of each technology. The percentages are shown below in table A-3. While multiple technologies may be effective in many building and space types, it is unlikely that more than one will ever be applied to each situation. Therefore, the application percentages add to no more than 1.0.

While these are reasonable assumptions, it is certainly possible, even likely, that actual penetration will vary from what is shown here. So for instance, scotopic lighting is only shown as being used in 5% of offices. That assumption is based on the possibility that there may be some resistance to the very cool lamp color in offices. If user acceptance is higher than assumed, then it is possible that scotopic lamps may be utilized more, and take the place of some of the HPT8 systems. Importantly, this would have very little impact on the overall energy savings shown in the body of the report because three of the four technologies have a very similar savings.[24]

Table A- 3. Percentage of Lighted Federal SQFT by Bldg Type That is Applicable to Each Lighting Technology

Facility Type	High-Performance T8 Systems	Task - Ambient	Intelligent Lighting	Scotopic
OFFICE	0.40	0.30	0.25	0.05
SERVICE	0.50	0.30		0.20
STORAGE	0.80			0.20
SCHOOL	0.60	0.40		
HOSPITAL	0.60	0.40		
INDUSTRIAL	0.80			0.20
PRISON	0.80			0.20
R and D	0.70	0.20		0.10
OTHER	1.00			

Development of Savings Potential

The report shows potential energy savings by technology and Federal agency. These are summations of the individual calculations of potential savings by building type and by year based as shown in tables A-4 through A-8. The analysis behind these summaries starts with a calculation of maximum potential energy savings in a typical year by building type for each of the technologies within each agency (based on square footage of building stock). The following tables show these yearly estimated savings for each of the four technologies by building type.

As stated in the body of the report, the end use intensity for lighting is estimated at 24.7 percent for all buildings based on 2001 data (DOE-EERE 2003). More accurate delivered end use data were not available by building type in a recent data set. This suggests that there may be a higher margin for error when looking at the savings on a per agency basis. However, even with the possibility of a high variance there are still some obvious conclusions that can be drawn by looking at the percent of usage by technology and facility. The following examples are provided for the purpose of programmatic planning to illustrate where emphasis can be strategically placed.

- DOD shows 43% energy saved in service facilities as compared to the other facility types. Thus, outreach to DOD should include suggested solutions for service areas. Scotopic lighting savings is also very heavy in service areas at 11% (as compared to the other agency-specific charts of 1%, 3% and 4%). This suggests that the use of scotopic lighting in high bay areas, which are typical of service areas, should be emphasized.
- For the VA, 77% of the energy saved is in hospitals. HPT8 systems and task-ambient systems show the greatest potential with savings of 64% and 32% respectively as compared to only 4% for the other two technologies.

[24] As a reminder, HPT8 systems are estimated at 24%, task-ambient systems are estimated at 22%, and scotopic lighting is estimated at 20%.

- The majority of energy savings potential at the USPS is in offices, showing at 94%. This indicates that there should be support for intelligent lighting with a savings of 46%, followed by HPT8 and task-ambient.
- GSA buildings are primarily offices so the energy savings opportunities are found in intelligent lighting at 45%, HPT8 systems at 33%, followed by task-ambient at 18%.

Table A- 4. DOD Yearly Potential Energy Savings (MBtu)

Facility Type	HP T8 Systems	Task - Ambient	Intelligent Lighting	Scotopic	Facility Type Totals	Facility Type Percent
OFFICE	942,000	647,000	1,643,000	98,000	3,330,000	18%
SERVICE	4,370,000	2,404,000	0	1,457,000	8,231,000	43%
STORAGE	1,425,000	0	0	297,000	1,722,000	9%
SCHOOL	604,000	369,000	0	0	973,000	5%
HOSPITAL	471,000	288,000	0	0	759,000	4%
INDUSTRIAL	816,000	0	0	170,000	986,000	5%
PRISON	22,000	0	0	5,000	27,000	0%
R and D	848,000	222,000	0	101,000	1,171,000	6%
OTHER	1,820,000	0	0	0	1,820,000	10%
Technology Totals:	11,318,000	3,930,000	1,643,000	2,128,000	19,019,000	100%
Technology Percent:	60%	21%	9%	11%	100%	

Table A- 5. VA Yearly Potential Energy Savings (MBtu)

Facility Type	HP T8 Systems	Task - ambient	Intelligent Lighting	Scotopic	Facility Type Totals	Facility Type Percent
OFFICE	39,000	27,000	68,000	4,000	138,000	6%
SERVICE	46,000	25,000	0	15,000	86,000	4%
STORAGE	22,000	0	0	5,000	27,000	1%
SCHOOL	4,000	2,000	0	0	6,000	0%
HOSPITAL	1,144,000	699,000	0	0	1,843,000	77%
INDUSTRIAL	1,000	0	0	0	1,000	0%
PRISON	0	0	0	0	0	0%
R and D	43,000	11,000	0	5,000	59,000	2%
OTHER	245,000	0	0	0	245,000	10%
Technology Totals:	1,544,000	764,000	68,000	29,000	2,405,000	100%
Technology Percent:	64%	32%	3%	1%	100%	

Table A- 6. USPS Yearly Potential Energy Savings (MBtu)

Facility Type	HP T8 Systems	Task - ambient	Intelligent Lighting	Scotopic	Facility Type Totals	Facility Type Percent
OFFICE	799,000	549,000	1,395,000	83,000	2,826,000	96%
SERVICE	53,000	29,000	0	18,000	100,000	3%
STORAGE	8,000	0	0	2,000	10,000	0%
SCHOOL	7,000	4,000	0	0	11,000	0%
HOSPITAL	0	0	0	0	0	0%
INDUSTRIAL	0	0	0	0	0	0%
PRISON	0	0	0	0	0	0%
R and D	0	0	0	0	0	0%
OTHER	0	0	0	0	0	0%
Technology Totals:	867,000	582,000	1,395,000	103,000	2,947,000	100%
Technology Percent:	29%	20%	47%	3%	100%	

Table A- 7. GSA Yearly Potential Energy Savings (MBtu)

Facility Type	HP T8 Systems	Task - ambient	Intelligent Lighting	Scotopic	Facility Type Totals	Facility Type Percent
OFFICE	929,000	639,000	1,621,000	97,000	3,286,000	92%
SERVICE	32,000	18,000	0	11,000	61,000	2%
STORAGE	130,000	0	0	27,000	157,000	4%
SCHOOL	0	0	0	0	0	0%
HOSPITAL	0	0	0	0	0	0%
INDUSTRIAL	1,000	0	0	0	1,000	0%
PRISON	0	0	0	0	0	0%
R and D	0	0	0	0	0	0%
OTHER	77,000	0	0	0	77,000	2%
Technology Totals:	1,169,000	657,000	1,621,000	135,000	3,582,000	100%
Technology Percent:	33%	18%	45%	4%	100%	

Table A- 8. All Other Agency Yearly Potential Energy Savings (MBtu)

Facility Type	HP T8 Systems	Task - ambient	Intelligent Lighting	Scotopic	Facility Type Totals	Facility Type Percent
OFFICE	262,000	180,000	457,000	27,000	926,000	18%
SERVICE	362,000	199,000	0	121,000	682,000	13%
STORAGE	180,000	0	0	37,000	217,000	4%
SCHOOL	90,000	55,000	0	0	145,000	3%
HOSPITAL	80,000	49,000	0	0	129,000	3%
INDUSTRIAL	733,000	0	0	153,000	886,000	17%
PRISON	239,000	0	0	50,000	289,000	6%
R and D	854,000	224,000	0	102,000	1,180,000	23%
OTHER	695,000	0	0	0	695,000	13%
Technology Totals:	3,495,000	707,000	457,000	490,000	5,149,000	100%
Technology Percent:	68%	14%	9%	10%	100%	

The totals for each lighting technology from the five agency groups, as shown in the report and repeated here, are shown in Table A-9 and are used as the basis for estimates of actual potential savings.

Table A- 9. Estimated Savings per Year by Technology and Agency (MBtu)

Federal Agency	Lighting Technology				
	High-Performance T8 Systems	Task-Ambient	Intelligent Lighting	Scotopic	TOTAL
DoD	11,318,000	3,930,000	1,643,000	2,128,000	19,019,000
VA	1,544,000	764,000	68,000	29,000	2,405,000
USPS	867,000	582,000	1,395,000	103,000	2,947,000
GSA	1,169,000	657,000	1,621,000	135,000	3,582,000
Other	3,495,000	707,000	457,000	490,000	5,149,000
TOTAL	18,393,000	6,640,000	5,184,000	2,885,000	33,102,000

The penetration rates described in the report for years 2005 through 2014 are then applied to these yearly values to calculate actual expected energy savings by year. These are calculated as yearly and cumulative values. These are the values that directly populate the summary tables in the report. The savings estimate by year along with their associated penetration rates are shown in Tables A-10 through A-13 for each technology with totals reported in Table A-14.

Table A- 10. Expected High Performance T8 Fluorescent Savings by Year (MBtu)

Year	Total Yearly Savings	Estimate Cumulative Penetration	Yearly Savings	Cumulative Savings
2005	18,393,000	0.01	184,000	184,000
2006	18,393,000	0.03	552,000	736,000
2007	18,393,000	0.07	1,288,000	2,023,000
2008	18,393,000	0.11	2,023,000	4,046,000
2009	18,393,000	0.15	2,759,000	6,805,000
2010	18,393,000	0.18	3,311,000	10,116,000
2011	18,393,000	0.21	3,863,000	13,979,000
2012	18,393,000	0.23	4,230,000	18,209,000
2013	18,393,000	0.25	4,598,000	22,807,000
2014	18,393,000	0.27	4,966,000	27,773,000

Table A- 11. Expected Task-Ambient Savings by Year (MBtu)

Year	Total Yearly Savings	Estimate Cumulative Penetration	Yearly Savings	Cumulative Savings
2005	6,640,000	0.01	66,000	66,000
2006	6,640,000	0.02	133,000	199,000
2007	6,640,000	0.04	266,000	465,000
2008	6,640,000	0.07	465,000	930,000
2009	6,640,000	0.10	664,000	1,594,000
2010	6,640,000	0.13	863,000	2,457,000
2011	6,640,000	0.17	1,129,000	3,586,000
2012	6,640,000	0.21	1,394,000	4,980,000
2013	6,640,000	0.24	1,594,000	6,574,000
2014	6,640,000	0.27	1,793,000	8,366,000

Table A- 12. Expected Intelligent Lighting (advanced controls) Savings by Year (MBtu)

Year	Total Yearly Savings	Estimate Cumulative Penetration	Yearly Savings	Cumulative Savings
2005	5,184,000	0	0	0
2006	5,184,000	0	0	0
2007	5,184,000	0.01	52,000	52,000
2008	5,184,000	0.02	104,000	156,000
2009	5,184,000	0.04	207,000	363,000
2010	5,184,000	0.06	311,000	674,000
2011	5,184,000	0.09	467,000	1,140,000
2012	5,184,000	0.12	622,000	1,763,000
2013	5,184,000	0.16	829,000	2,592,000
2014	5,184,000	0.2	1,037,000	3,629,000

Table A- 13. Expected Scotopic Lighting Savings by Year (MBtu)

Year	Total Yearly Savings	Estimate Cumulative Penetration	Yearly Savings	Cumulative Savings
2005	2,885,000	0	0	0
2006	2,885,000	0	0	0
2007	2,885,000	0	0	0
2008	2,885,000	0.01	29,000	29,000
2009	2,885,000	0.03	87,000	115,000
2010	2,885,000	0.05	144,000	260,000
2011	2,885,000	0.08	231,000	490,000
2012	2,885,000	0.11	317,000	808,000
2013	2,885,000	0.15	433,000	1,241,000
2014	2,885,000	0.19	548,000	1,789,000

Table A- 14. Combined Savings for ALL Agencies by Year (MBtu)

Year	Yearly Savings	Cumulative Savings
2005	250,000	250,000
2006	685,000	935,000
2007	1,605,000	2,540,000
2008	2,621,000	5,160,000
2009	3,717,000	8,877,000
2010	4,629,000	13,507,000
2011	5,689,000	19,195,000
2012	6,564,000	25,759,000
2013	7,454,000	33,213,000
2014	8,344,000	41,557,000

Historical Lighting Penetration Data

For reference and comparison, examples of historical lighting market penetration results are provided here. Unfortunately there is a lack of data for commercial lighting market transformation efforts although some data was found related to electronic ballasts and indirect lighting. The majority of information is about programs supporting the deployment of compact fluorescent lamps in the residential market. Results indicate varying degrees of increased market penetration depending on the particulars of the target market and the strategies deployed.

The comparison of electronic vs. magnetic fluorescent ballast production and shipments in the US in past years is one metric of typical commercial new technology lighting penetration. Data from the 2005 E-Source Lighting Technology Atlas, Section 4, page 84 shows the change in total sales percentage of electronic ballasts rising fairly steadily from 10% in 1991 to about 53% in 2001 (E-Source 2005). This represents a steady 4.3% penetration rate. This rate would include penetration from natural market factors as well as utility, environmental, and energy advocacy programs.

An E-Source report on indirect lighting published in 2001 discusses the role indirect fixtures play in meeting the recommendations in the IESNA *RP-1 Practice for Office Lighting* publication (IESNA 1993). The author believes that this in part is the driver for an 8% to 15% increase in sales of this type of fixture since the early 1990s (E-Source 2001).

Data from the 2002 ACEEE paper "2001—A CFL Odyssey: What Went Right?" collected by Regional Economic Research includes sales data from major lamp retailers during the very early years of modern CFL technology production (Calwell 2001). The data shows relatively slow but fairly steady penetration of screw-in CFLs across the nation of about 0.1% per year from 1998 through 2000. At about this time there were some efforts to increase CFL use through procurements aimed at reducing the cost, which was considered the biggest roadblock to acceptance and use. In 1999 the Energy Star labeling program was started (for testing and verification of performance) and in 2001-2002 EPA launched the Change a Light program further promoting the use of CFLs. At a point between these two federal programs (sometime in 2000) the percentage of CFL sales began to increase and rose to a rate of about 1.6% per year by the end of 2001.

The ACEEE 2000 paper "Green Lights and Blue Sky: Market Transformation Revealed" separated the effects on electronic ballast sales in California of Utility rebate and price reductions vs. the Green Lights Partnership and other market transformation programs. The data indicated that 35 to 40 percent of the market effect was attributable to the Green Lights and other market programs (Horowitz 1999).

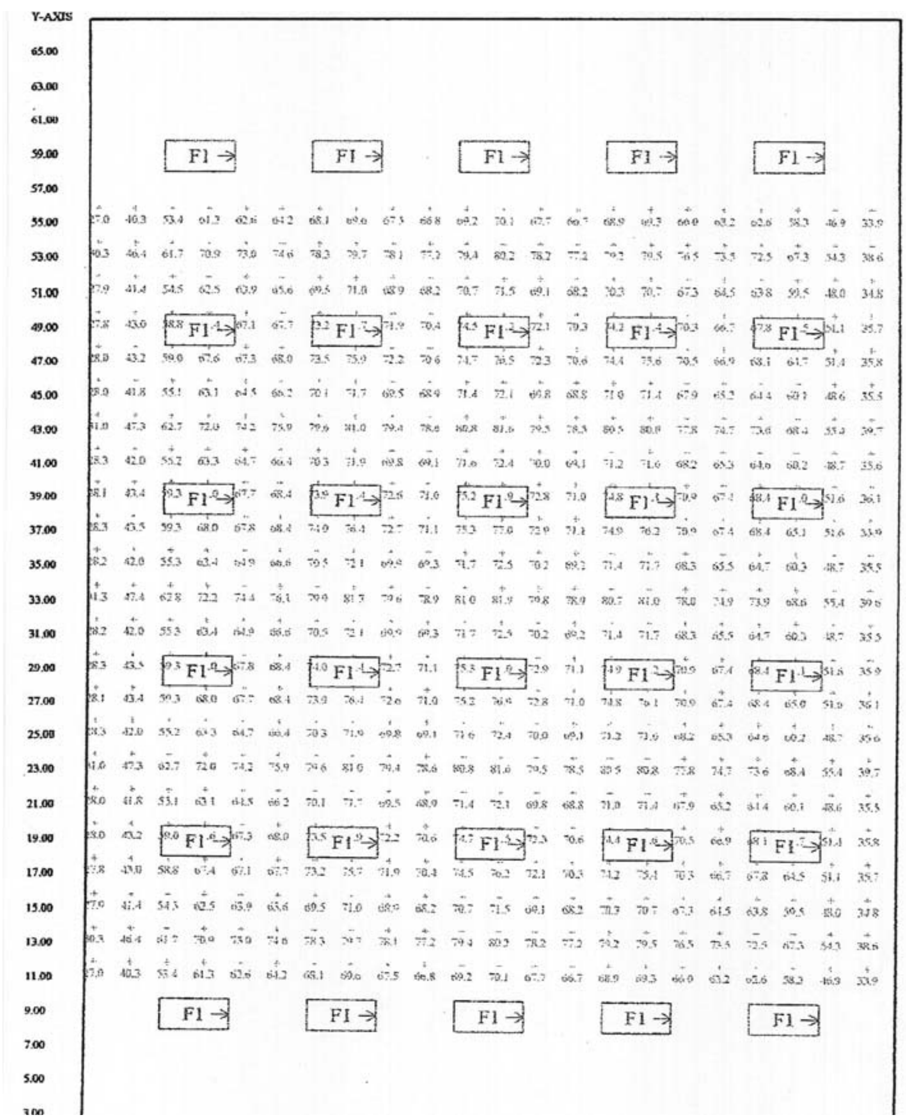
E-Source Tech report ER-03-11 "Compact Fluorescent Light Programs Shine Through the West Coast Power Crisis" published in 2003 provides data on the California CFL penetration with and without the support of market transformation programs. This data shows a 10-fold increase in CFL lamp market share with the aid of market programs (steadying to about 5%). Before this, the penetration was at a fairly steady (but slowly rising) 0.5% to 1% (E-Source 2003).

APPENDIX B

Appendix B

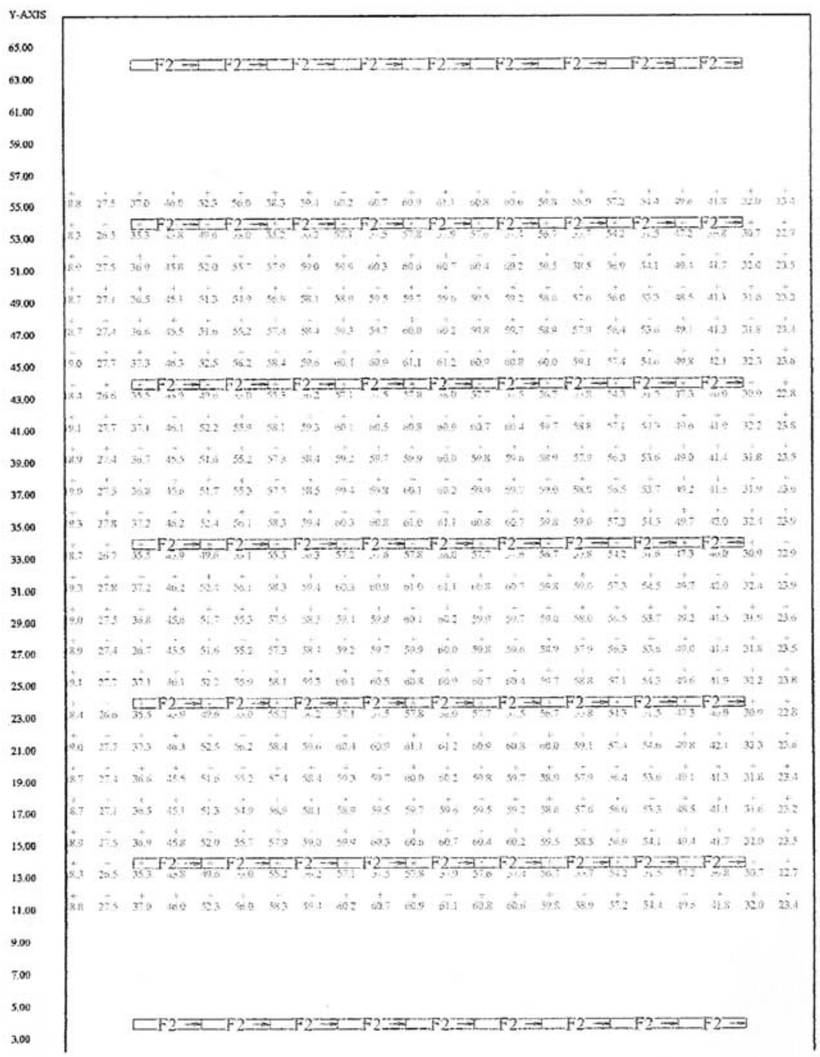
Point-by-Point Lighting Calculations for Direct-Only Baseline

Design Description:	Baseline, direct-only: T8 Parabolic troffers, semi-specular, 3-in. deep, 18-cell, three-lamp standard T8s, standard electronic ballasts, 8- by 10-ft. grid spacing.			
Calculated Footcandles: *(LLF included)*	Minimum 28.5 fc	Maximum 86.4 fc	Average 68.2 fc	Avg Less Partition Factor (.80) **54.6 fc**
Room Reflectances:	Ceiling – 0.80	Walls – 0.50	Floor – 0.20	
Light Loss Factors (LLF):	Ballast Factor (Normal Output) 0.88	Lamp Lumen Depreciation 0.94	Luminaire Dirt Depreciation 0.97	Total LLF 0.80



Point-by-Point Lighting Calculations for Task-Ambient Design

Design Description:	Task-ambient: suspended direct-indirect, one-lamp "Super T8", premium instant start electronic ballast, high output ballast factor, 10ft.-0 in. on center spacing.			
Calculated Footcandles: *(LLF included)*	Minimum 18.3 fc	Maximum 61.2 fc	Average 49.1 fc	Avg Less Partition Factor (.80) **39.3 fc**
Room Reflectances:	Ceiling – 0.80	Walls – 0.50	Floor – 0.20	
Light Loss Factors (LLF):	Ballast Factor (High Output) 1.15	Lamp Lumen Depreciation 0.94	Luminaire Dirt Depreciation 0.95	Total LLF 1.03



APPENDIX C

Appendix C

Analysis of Savings Over Time Using Metered Data

The intelligent lighting technology system is characterized by individual direct-indirect lighting fixtures, which are specifically located at each workstation. The system allows for personal control of the direct (downlight) component but the indirect (uplight) component is not under control by the user. This system has very high energy savings potential because the connected load savings is augmented by many types of advanced control producing additional savings over time. This makes it critical to use metered data with realistic load profiles to accurately estimate savings. To accomplish this, actual metered data is used from a case study of an installation of intelligent technology at the B.C. Hydro offices (Suvagau).

The study provides a control area as well as a technology area for comparison, which provides a good basis for analysis as long as the test areas are equal in their energy-effecting characteristics. In this case, the areas were found to be reasonably similar with few specific differences that are not considered to be typical.

- Figure C-1 (weekday profile) and Figure C-2 (similar effect) in the case study show the lights in the reference area are on all weekend. This is referred to in the study text as an effect from occupants (workers/cleaning) calling for light and the system having to turn it all on all day long. However, the same data indicates that no one calls for light in the test case (intelligent lighting) area during the weekend. While this may be an actual effect of the metered data, it is not considered reasonable for an equitable comparison of similar spaces and activities
- The text indicates that the reference area is on a 6 to 6 schedule (on/off), but that the test area was put on a 7 to 5:30 schedule. However, the profiles in Figures C-1 and C-2 do not show this. What the profiles do show is a schedule for the reference area that is from at least 9 to 8 PM (11 hours). This may be realistic for a system where entire floors/areas are centrally controlled but not realistic for areas with more local (switch) control as in banks of lights activated by wall switches

These two observations are results of the actual space operations but the differences they set up between the reference and test areas cannot be considered typical of otherwise similar average spaces. They will also tend to have the effect of over-estimating the savings benefits of the installed technology. Therefore, to be conservative in estimates of potential energy savings, an adjustment is made to the case study results to account for the non-typical differences shown in the BC Hydro.

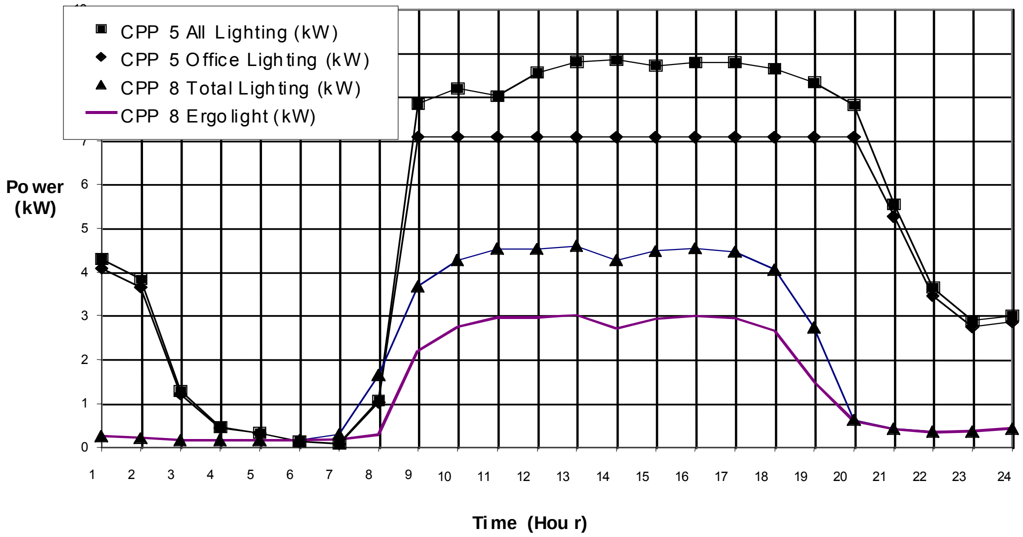


Figure C- 1. Weekday Average Lighting Demand

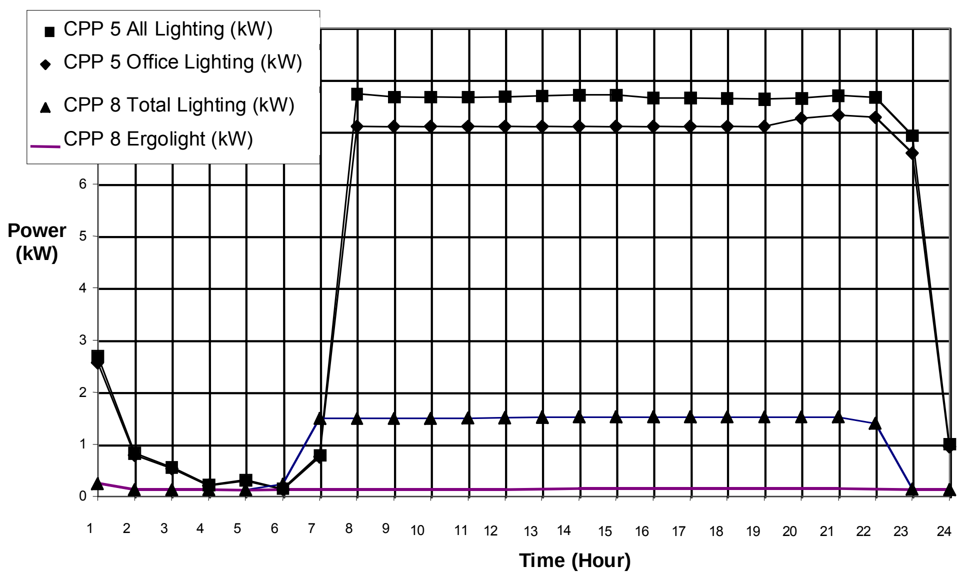


Figure C- 2. Weekend Average Lighting Demand

It is generally not typical to apply complete weekend full on lighting to a reference or test case. This is seen in commonly applied Energy use profiles such as those offered in the ASHRAE Handbooks. Other regional metered data (DOE 1989) shows little weekend lighting use. For a truly conservative energy savings analysis, it is more reasonable to ignore this weekend lighting for both cases primarily because it is often an unknown and will be much more variable that occupied weekday lighting.

At the same time, an 11-hour typical weekday for a reference or any other case is generally more than what might be considered normal for a typical office environment. It is possible that this is likely a product of the auto central building system control used in this building. However, it is not realistic to assume this type of control (all on or all off) exists for all buildings. It is more reasonable and conservative to assume a profile that accepts a slightly modified weekday schedule and completely discounts the weekend one (not representative of "typical"). The weekday schedule is effectively 11 hours at full power and approximately 4 hours at 50% power. A more typical schedule might be 10 hours at 100% power and 4 at 50% for weekdays with 0 hours on weekends (DOE 1989).

Therefore an adjustment of the data was applied as follows:

(1) Take the assumed reasonable 10-hour data at 100% and 4-hour data at 50% and calculate a weighted weekday average (10 hr * 100% + 4 hr * 50%) / 100% = 12 hours at 100%.

(2) Use this and the "metered" 15 hours at 100% (from Fig 6) to determine a weekly weighted average adjustment factor for a full combined week of reference area energy. This is (12 hr * 5 days) / (12 hr * 5 days + 15 hr * 2 days) = 2/3.

(3) Apply this to reference office area consumption numbers in Table 1 from the case study.

(4) Recalculate the savings percentages for each month and take an average of these. The average does not include August, where a software error in the Ergolight power management software disabled the dimming functions, keeping the lights at 100% on during working hours for a week. Therefore the month of August was excluded from all average calculations but was kept for various energy consumption profiles.

The results of this modification are shown in Table C1 below.

Table C- 1. Modified BC Hydro Hours on Data and Resulting Percentage Savings Values

B.C. Hydro cases study paper Table 1. values							
Reference Open office kWh:							
June 01	July 01	Aug 01	Sept 01	Oct 01	Nov 01	Dec 01	Jan 02
3345	3441	3312	3514	3492	3317	3374	3442
Same values adjusted by 2/3							
2230	*2294*	*2208*	*2343*	*2328*	*2211*	*2249*	*2295*
Intelligent Lighting (test) Open office kWh:							
657	777	1067	732	756	767	683	848
Adjusted % savings of test vs. reference values:							
70.5%	66.1%	51.7%	68.8%	67.5%	65.3%	69.6%	63.0%
Average savings from reasonable typical profile of use (not including August):							67%

The resulting average value is **67%** savings over a "reasonable and typical" profile. This value falls well within the 50% to 75% estimates often offered as typical for this type of system and is therefore found to be reasonable.