Efficient Lighting Design and Office Worker Productivity

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ABSTRACT

Energy efficiency advocates have long known the importance of ancillary or non-energy benefits in achieving market transformation. Energy efficiency measures must meet a range of needs and business objectives to have an enduring impact. New research presents an exciting value proposition for commercial office buildings. A recent in-depth study of lighting quality and office worker productivity shows that realistic changes in lighting can measurably increase worker comfort, motivation, persistence and vigilance. The research points to two profound market opportunities that deserve serious attention by the energy efficiency community.

The first paradigm shift is from standard direct-only troffers to task-ambient lighting. Energy savings result from an optimized lighting layout with lower ambient light levels in the room, the use of task lighting where needed, and more efficient components (for example, T5 linear fluorescent lamps and high performance T8 lamp-ballast systems).

The second paradigm shift is to workstation-specific personal control using "intelligent"[2] technologies. Dramatic energy savings result from fewer fixtures overall, occupancy sensors tuned to individual workstations, daylight dimming at the perimeter, peak load demand response, and personal control by the user.

This paper provides an overview of the research findings that will be used as the basis for changing customer buying behaviors and a recipe for success for lighting solutions that will yield both energy savings and non-energy benefits. The lighting energy savings of these new systems compared to strategies of the past is analyzed, along with a recommended market penetration strategy using market research and the dynamics of the construction market.

Ancillary Benefits

One of the key lessons of the past 25 years of efforts to improve energy efficiency is that *non*-energy benefits are often the key to adoption of higher efficiency products. Except when energy prices are high, energy efficiency is typically not a driving force for adoption of new technologies. Products need to provide other benefits or attractions to consumers and businesses. For those that are uninspired by energy efficiency measures, non-energy benefits can be a powerful motivator.

For example, the ubiquitous and energy-intensive halogen torchiere floor lamp has been largely eliminated from hundreds of college campuses around the country not primarily because of energy concerns, but due to safety concerns. Halogen lamps operate at a temperature high enough to burn any cloth or other flammable material that happens to come into contact with the lamp. Compact fluorescent torchieres provide a safe, functional, and highly energy-efficient alternative. Another example is front-loading clothes washers, which have become very popular

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[1] Pacific Northwest National Laboratory is a multi-program laboratory of the U.S. Department of Energy.

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

in the US over the past several years. This is a product that would seem to contradict the accepted wisdom that consumers will adopt only those energy efficiency measures that make clear economic sense, i.e., that "pay back" the incremental cost in a reasonable time frame. Front-loading clothes washers cost two to three times as much as standard top-loading machines and, except in the areas of the country with the highest electricity and water rates, would take many years to pay back the extra cost through utility savings. Nonetheless, by 2000, they achieved about 10% market penetration nationwide and closer to 20% in the Northeast and Pacific Northwest. (Hewitt, Pratt & Smith 2001). Why? A combination of promotional programs and financial incentives contributed to this increased market presence, but front-loaders have since become a "desired" product, featured in home design magazines, and touted for their better cleaning performance.

In the commercial office building market, technical advances in fluorescent lighting technology have allowed dramatic increases in lighting energy efficiency. Moving from outmoded T12s and magnetic ballasts to 700 series T8s with instant start electronic ballasts yields approximately 39% energy savings. High performance T8 lamps and ballasts can increase efficiency by about another 23% (Sardinsky and Benya, 2003). But making improvements in lamp and ballast technology within the existing office lighting paradigm does very little to improve lighting conditions for occupants. High performance T8s have marginally better color rendering and color temperature compared to standard T8s, but if installed in traditional recessed troffer downlight-only applications, they will not improve occupant comfort or performance. To increase the penetration of energy efficient technologies the lighting and energy efficiency communities need to shift focus from the utility bill to the people working inside the office, and the costs and productivity they represent.

Lighting accounts for about 28% of total electricity consumption in office buildings (EIA 1998), so improving lighting efficiency will certainly decrease utility bills. However, the cost of utilities is small, relative to other costs of running an office. Salaries and benefits make up more than 75% of the cost of doing business in an office setting, while all utilities combined are typically less than 2% (BOMA 2000). The impact of lighting on worker productivity and labor-related costs has the potential to be a more important driver of change in office lighting than the energy-related impacts.

A review of previous research points to measurable effects of lighting on workers' comfort and performance. For example, studies by researchers in the U.S. and Canada (Boyce, Eklund & Simpson 2000; Veitch & Newsham 1998) indicate that individual control over lighting levels results in workers feeling more satisfied with the lighting and experiencing a greater sense of control in general. Researchers have found that headaches are reduced and task performance increases when energy efficient electronic ballasts are used rather than magnetic (Wilkins et al. 1989 and Veitch & Newsham, 1998.).

Research Program Description

The *Light Right Consortium* is a project sponsored by the US Department of Energy (DOE), National Electrical Manufacturer's Association (NEMA), New York State Energy Research and Development Authority (NYSERDA) and other industry and energy efficiency organizations.[3] The project is managed by Pacific Northwest National Laboratory, operated by Battelle for the US DOE. The purpose of *Light Right* is to perform research that provides a basis for market transformation towards high-quality, energy-efficient lighting for offices and commercial spaces. The research includes qualitative and quantitative measurement of aesthetics and psychological processes, visual performance and energy consumption. The prevailing hypothesis is that well-designed lighting can provide a range of benefits in the office environment, including improved worker comfort and performance; fewer worker complaints related to eyestrain, glare, or other visual discomfort; improved energy efficiency; and energy and maintenance cost savings. *Light Right*'s mission is to improve both the quality and energy efficiency of office lighting. To accomplish this mission, research is conducted to define the benefits of improved office lighting and to communicate these benefits to decision makers involved in office lighting. The research program was begun using a laboratory methodology and will be continued using field study methodologies.

Light Right decided to focus on office lighting for several reasons including the potential for significant impact, the opportunity for relatively near-term results and multiple benefits, and the opportunity to build upon earlier related research. Lighting accounts for close to one third of total electricity consumption in office buildings, so improved lighting energy efficiency can save companies money on utility bills and decrease energy-related pollution. Since lighting contributes approximately 42% of the cooling load in commercial buildings (LBNL 1998) more efficient lighting will also decrease peak electricity demand and its associated high costs.

The research conducted by *Light Right* and the solutions that are recommended are appropriate for both existing buildings and new construction. While new construction offers exciting opportunities for progressive integrated sustainable design including daylighting, the huge base of existing stock is by far the largest and most immediate target and opportunity for energy savings. The content of this paper makes a compelling argument for a vigorous nationwide effort to relight our buildings with advanced lighting technologies as the most powerful near-term way to dramatically reduce end use consumption.

Study Description

The choice to study room surface brightness and personal control was guided by numerous well-known researchers. Several earlier studies had pointed to these variables as key attributes in the effect of lighting on office workers. These two factors can be adjusted to improve conditions for office workers, and have an impact on energy efficiency.

The first study in the program and the topic of this paper was a controlled laboratory study completed in 2003 in a field setting in Albany, NY (Boyce et al. 2003). By starting with a laboratory methodology it was possible to isolate the impact of the various lighting measures on the participants in the study. The lab methodology allowed researchers to tightly control external factors that could impact workers' performance, and to ensure the testing results were comparable across different lighting scenarios. The use of a linked mechanisms methodology allowed the researchers to determine the causal impact of the independent variables. The linked

[3] In addition to the organizations listed, the *Light Right* Board of Directors includes Steelcase, Johnson Controls, the Illuminating Engineering Society of North America (IESNA), the International Association of Lighting Designers (IALD), the Alliance to Save Energy, and the International Facility Management Association (IFMA).

mechanisms model allows the researchers to isolate the intervening mechanisms and state with precision the effects of different lighting scenarios on the participants.

The study took place in a typical office building in downtown Albany, NY. An office was furnished as a typical open plan workplace for nine workers, including cubicles, a conference room, hallway, reception area, and kitchen. Experiments were conducted with six different lighting conditions. There were provisions for changing the lighting conditions in random order for the data collection process but the appearance was that of a permanent lighting installation. The researchers collected data from temporary office workers, who were hired to work under one of the lighting scenarios for a complete day.[4] During that day the participants carried out various clerical and cognitive office tasks, and evaluated both the physical environment and their moods.

Two experiments were conducted. In Experiment 1, there were four lighting installations[5], detailed below[6]:

- Base Case 1: This installation was designed to represent the most common approach to office lighting in use today. It consisted of a regular array of three lamp, 18 cell, 3 inch deep, semi-specular, recessed parabolic-louvered luminaires, mounted on 8 ft by 10 ft centers. Each luminaire contained three T8, 32W fluorescent lamps.[7] This installation provides a typical illuminance on the working plane (558-611 lux) that meets *horizontal* illuminance standards but tends to produce dark walls and ceilings. Its strongly downward directional light distribution also tends to produce shadows and veiling reflections.
- Best Practice 1: This installation was designed to provide a similar illuminance on the working plane (528-601 lux) as the Base Case installation yet produce brighter walls and ceiling and reduce shadows and veiling reflections while meeting IESNA recommended luminance ratios (IESNA/ANSI, RP-1-1993). The design consisted of runs of continuous direct/indirect luminaires suspended 16 inches below the ceiling. The luminaires contained one row of 54W, T5 high output fluorescent lamps. The walls of the area containing the cubicles were illuminated by a wall-washing system using track-mounted linear luminaires with each luminaire containing one 50W 24 inch twin tube compact fluorescent lamp. The hallway area was lit by three sets of four, 8 feet long indirect luminaires, arranged in a square shape, and suspended 16 inches from the ceiling. The conference room was lit in a manner consistent with the cubicle area.
- Switching Control: In this installation, the lighting of the hallway and conference room was the same as in the Best Practice lighting. In the cubicle area, the ambient lighting (including wall-washing on the perimeter walls) was the same as the Best Practice installation. In addition, each cubicle was fitted with a freestanding desk lamp with a luminous shade placed on the unobstructed work surface. Each desk lamp contained one

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[4] There were some repeaters in the experiment but the majority of the data was for subjects that only saw one of the designs. The full experimental design included both between and within subjects data.

[5] Lighting equipment was supplied by Birchwood Lighting, Cooper Lighting, Day-Brite Lighting, Engineered Lighting Products, General Electric, Ledalite, Lightolier, Lutron, Osram Sylvania, Peerless, and Philips.

[6] Photographs of all installations can be found at www.lightright.org under the research tab.

[7] All of the lamps in the study had a correlated color temperature (CCT) of 3,500K and a CIE General Color Rendering Index (CRI) of 82. The fluorescent lamps were operated from electronic dimming ballasts. Under cabinet lighting common to each of the designs illuminated the vertical partitions and reduced overhead shadows.

40W 2D compact fluorescent lamp, which could be mechanically switched to three different light outputs, equivalent to 11W, 19W and 35W (500-1169 lux). This lamp also had a CCT of 3,500K and a CRI of 82. Moving and switching this desk lamp provides an element of control to the lighting of the cubicle.

- Dimming Control: This installation had direct/indirect luminaires suspended above each workstation, with the same wall-washing as the "Best Practice" installation. Each luminaire contained three 54W T5HO fluorescent. The fixtures had an opaque baffle that separated the three lamps so that one contributed only to the indirect component, while the other two contributed primarily the direct component. The light output of the indirect component was fixed, but the light output of the other two lamps could be dimmed from zero to full light output (280-1040 lux) from the computer in the cubicle using a simple on-screen interface. The transition area between the cubicles and the elevator was lit by thirteen compact fluorescent downlights, each luminaire containing a four-pin, 32W triple tube compact fluorescent lamp of CCT of 3,500 K and CRI of 82.

Experiment 2 was undertaken for two reasons. First, to provide another test of the hypothesis that better quality lighting will enhance the health, well-being, and task performance of office workers. Second, to provide a comparison between a different form of Base Case lighting and a variant of the Best Practice lighting used in Experiment 1. The Base Case 2 lighting used in Experiment 2 was designed to study lensed troffers, another common approach to office lighting. The Best Practice 2 lighting used in Experiment 2 was the same as Experiment 1, but with the direct/indirect luminaires dimmed to provide a lower illuminance on the desks. It is a common practice to reduce the ambient (general) design illuminance when using indirect lighting in conjunction with desktop task lights. Experiment 2 contrasted two lighting installations:

- Base Case 2: This installation was a regular array of recessed prismatic luminaires with the same layout as the Base Case parabolic lighting used in Experiment 1. It consisted of a regular array of three lamp, recessed prismatic luminaires, mounted on 8 ft by 10 ft centers. Each luminaire contained three T8, 32W, fluorescent lamps. This installation provided an adequate illuminance on the working plane (514-567 lux) but the luminaire could be seen as bright from a wide range of positions. This made it more likely that the installation would create high luminance reflections visible on the screen of the computer monitor, although not every workstation had this characteristic.
- Best Practice 2: This installation was designed to provide a lower illuminance on the working plane (398-431 lux) than the Base Case 2 installation while still providing the perception of brightness at the walls and ceiling. The luminaires, lamps and layout were identical to those used for Best Practice 1, but the direct/indirect luminaires in the cubicle area were dimmed to produce a lower illuminance on the working plane, more typical of contemporary installations with direct/indirect systems. All other areas were lit in the same manner as for Best Practice Experiment 1.

Research Findings

The Albany study found that occupants felt better and worked more effectively under certain lighting conditions. Specifically, the researchers found the following:

- Participants were asked if they agreed with the statement, “Overall, the lighting is comfortable.” In the base case lighting scenario, 69 to 71% of participants agreed with the statement. Under the lighting designs that provided direct/indirect lighting and wall washing, 81 to 85% of participants agreed with the statement. The most preferred design provided direct/indirect lighting, wall washing, and occupant dimming control of the overhead lighting for their workstation. This design was rated as comfortable by 91% of the workers.
- Satisfaction with the office lighting influenced other areas of preference. People who were more satisfied with their lighting also rated the space as more attractive and said they were happier, more comfortable and more satisfied with their environment and their work. This is the first time that this complete path has been demonstrated.
- The presence of personal control over light levels had a measurable impact on the motivation of office workers to perform on tasks. Normally, the persistence and vigilance of office workers declines 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. This was determined using a proven research tool with a basis in psychology research and subsequently applied to research about the built environment.
- When using the dimming control, subjects showed a wide range of light level preferences. On average, people with dimming control chose lower levels than current practice. The majority of participants chose light levels around 375 lux, well below the industry standard of 500 lux. However, the *diversity* of preferences suggest that if a lower fixed ambient room illuminance is chosen, it must be supplemented with some means of providing higher local light levels for those who prefer them.

It is worth noting that there were many measures that showed no impact of the lighting designs. The strength of the linked mechanisms approach is that a large amount of data is collected—the primary causal mechanisms are not presumed at the start of the research. The researchers did not anticipate findings across all of the measures. As an example, the lighting designs did not make a statistical difference for clerical tasks such as typing speed and accuracy. This is consistent with other short-term experiments, in which visibility was high and no condition was uncomfortable, and in which participants might be motivated to work hard for the one day regardless of conditions.

Research on the quality of the built environment has evolved significantly, but is generally not well understood beyond the research community. There are often questions about the methods of measuring productivity in an office environment. In an industrial setting, productivity is defined in economic terms as output produced per unit of labor (or other factor of production). When it comes to productivity in a non-industrial setting such as offices, the definition of productivity extends beyond worker output per labor hour to include numerous aspects of individual and organizational success, such as the quality of the output, occupant satisfaction, employee attraction and/or retention, health and comfort of workers, company image, and financial success.

An emerging approach to studying knowledge worker productivity focuses on mental building blocks and psychological processes—those skills and abilities that are characteristic of information processing work in general. Examples of these mental building blocks include attention, vigilance, memory, creativity, mental computation and comprehension. Examples of relevant psychological processes include motivation, persistence and effort. Researchers from several different scientific fields have developed measurement tools for assessing these various skills and processes.

This study did have breakthrough findings showing that the presence of personal lighting control increased the motivation of workers over the day and that they persisted longer on difficult tasks. This statement is likely to be much more compelling to today's white collar office manager as compared to output measures like typing speed. Motivation, persistence and vigilance are important aspects of performance in the office workplace and can be generalized across many tasks.

Just as important, the comfort findings have great potential for changing standard practice in the marketplace. Market research funded by the *Light Right* in 1999[8] found that end user decision makers were far more interested in employee satisfaction than was previously believed by the research community. A surprising 99% of the respondent set said that employee satisfaction was considered when making decisions about the quality of the built environment. Now for the first time we are aware that standard office lighting is rated as comfortable by only 70% of office workers. Should we be satisfied with this, knowing that 30% of workers are not comfortable? Consider the ANSI/ASHRAE Standard 55-1992, which states "The purpose of this standard is to specify a thermal environment that is acceptable to at least 80% of the occupants." Lighting is no less important than thermal comfort, and awareness of this new finding can leverage change in standard practice. It is important to consider the opportunity for energy savings when decision-makers relight their environments for the comfort of their workers.

Recipe for Success

The results of the Albany study point to a need to shift from traditional office lighting layouts to direct/indirect or task-ambient lighting designs. We can now see that providing a "blanket of light" from troffers in the ceiling has significant limitations. In addition to the concerns about comfort, there are additional constraints on energy savings with a direct-only system. When a single system such as downlight-only troffers is used the lighting must be designed to give everyone at least 500 lux, even those who don't need that much light.

The two-fold advantage of task-ambient lighting design with advanced lighting equipment is that energy can be saved while increasing occupant comfort by 10-15%. The direct/indirect lighting system can provide lower general light levels closer to 350-400 lux, while a desktop moveable task light provides additional local light levels for a reduced energy cost. It is important to note that traditional under-cabinet lights are insufficient to meet the task needs of the occupant in a design with reduced ambient light levels. Under-cabinet lights are still needed,

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8 Conducted by Ducker Research Company, Inc. Bloomfield Hills, MI.

but they are usually insufficient for supplementing horizontal light levels for the full workstation. In fact, one of the most important reasons for under-cabinet lighting is to reduce contrast and shadows by providing light on the vertical partitions. This function should be achieved with lower wattage lamps providing further energy savings. Providing personal control over the overhead light levels further increases occupant comfort. With the use of intelligent lighting this can be achieved through individual dimming control of the overhead direct lighting component.

Energy Savings Analysis

For the purposes of estimating the savings associated with task-ambient lighting systems and intelligent lighting controls, point-by-point lighting calculations were performed to ensure that the layouts met design objectives and the energy costs were compared (Table 1). The energy comparison was only made between the baseline and the two designs that resulted in increased occupant satisfaction and/or motivation. 'Base Case 1' represents the status quo of lighting installations, the standard parabolic lighting system. The comparison designs represent two advanced options from the study that provide energy savings as well as improved lighting quality. The savings for the direct/indirect design are a result of the reduction in connected load. The savings for the intelligent lighting system is also shown in % savings in kilowatt hours to reflect the additional savings over time due to the multiple types of advanced controls.

Table 1. Comparison of Energy Savings

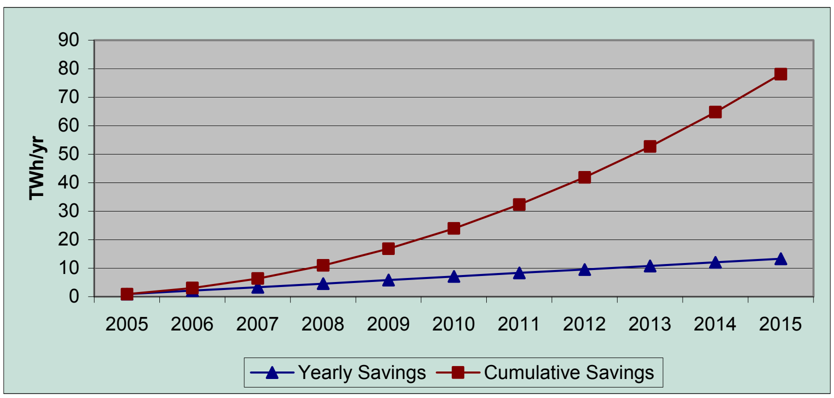
Description	Footcandles	Watts per Sq. Foot	% Savings in W/Sq Ft	% Savings kWh
Base Case 1: T8 Parabolic troffers, semi-specular, 3" deep, 18-cell, 3-lamp standard T8s, standard electronic ballasts, 8 by 10 foot grid spacing[9]	55 (550 lux)	1.03	NA	NA
Best Practice 2: Suspended direct-Indirect, 1-lamp "super" T8, premium instant start electronic ballast, high output ballast factor, 10'-0" on center spacing	39 (390 lux)	0.80	**22%**	22%
Dimming Control: Workstation-specific direct/indirect, 3-lamp T8, dimming electronic, centered over each workstation[10]	Varies per user choice	0.79	24%	**67%**

Table 1 shows that task-ambient technology would reduce office space lighting energy use by 22%. Implementation of this can have a relatively fast penetration rate due to its

[9] The footcandles of the baseline case are slightly higher than the IES requirement, which is not uncommon 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. It is possible to use a low output ballast to reduce both the output and the footcandles, but the practice of "tuning" light levels with the ballast factor is still mostly limited to expert lighting designers. The typical A&E relies heavily on this cookie-cutter parabolic (and often lensed) solution. If the light levels for the parabolic system were "tuned" to 50 footcandles, this would still not resolve the issues related to comfort and performance.
[10] The kilowatt hour savings are based on metered data from a project at BC Hydro. "Performance Evaluation of Intelligent Personal Controls for Open Office Lighting." Cristian Suvagau, Roy Hughes.

reasonable cost and because it can easily be absorbed into existing infrastructure. An estimate of this includes the effects of natural penetration plus that driven by productivity benefits. A conservative estimate of natural retrofit penetration is 5% of the equipment stock in place in a typical year. This corresponds to a complete stock retrofit cycle of 20 years (5% for 20 years = 100% replacement) that relates well to a typical fixture lifespan. As the benefits of worker productivity and satisfaction from improved lighting in office environments are both more thoroughly quantified and become better understood, these benefits are likely to become a market pull for better quality lighting in later years causing an increased yearly penetration rate. The savings associated with non-energy benefits is conservatively estimated at a rate of 2% of equipment stock. Applying these data to the current level of lighting energy use in U.S. offices produces the projected yearly and cumulative energy savings estimate shown in Figure 1.

Figure 1. Potential Task-Ambient Energy Savings in U.S. Offices

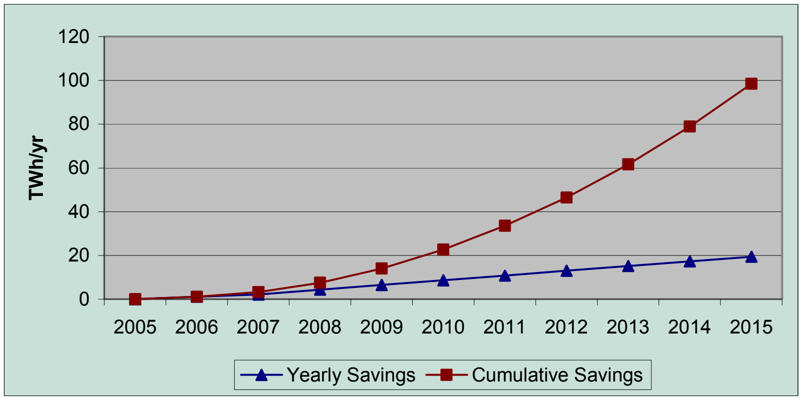


Source: Pacific Northwest National Laboratory 2004.

The savings estimate for the workstation-specific intelligent lighting system from Table 1 is approximately 67%. These systems are potentially applicable to the majority of spaces in office type buildings and are conservatively assumed to apply at a rate of 75% of the office building space in the US. However, due to the more complex nature of control systems, and their application as well as the current elevated cost of intelligent lighting systems a lower penetration rate of 2% per year through 2008 is considered more reasonable. By 2008, we project that the cost of the systems will drop and applications will become standardized. As the benefits of worker productivity and satisfaction from advanced personal control systems are more thoroughly quantified and become better understood, these benefits are likely become a market pull for advanced controls causing an increased yearly penetration rate into the building stock. The increased use of controls technology can be projected to increase up to 4% of equipment stock per year. Applying these data to the current level of lighting energy use in U.S. offices produces the projected yearly and cumulative energy savings estimate shown in Figure 2.

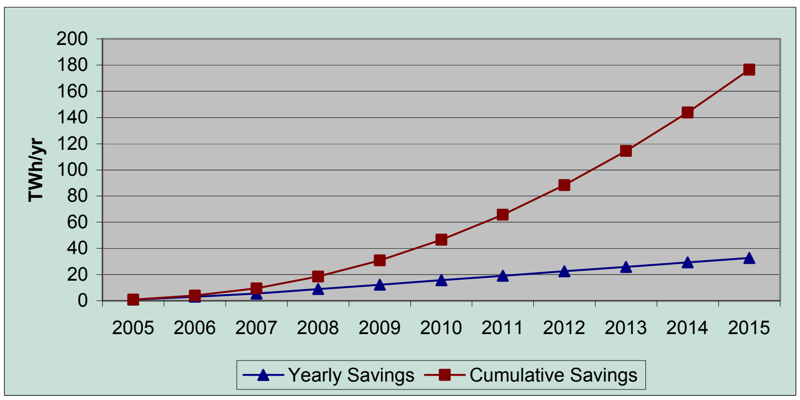
Taken together, the energy savings of the task-ambient and intelligent lighting systems represents a significant energy savings opportunity. These estimated combined savings are shown in Figure 3. The total estimated cumulative savings by the year 2015 is 159 TWh or .54 quads. These estimated combined savings are shown in Figure 3. The total estimated cumulative savings by the year 2015 is 159 TWh or 0.54 quads of site energy. Penetration of these win-win energy efficient technologies is an achievable near-term contribution to national energy savings.

Figure 2. Potential Advanced Controls Energy Savings in U.S. Offices



Source: Pacific Northwest National Laboratory 2004.

Figure 3. Total Potential Task-Ambient + Controls Energy Savings in U.S. Offices



Source: Pacific Northwest National Laboratory 2004.

Market Penetration Strategy

Light Right's hypothesis, that changes in lighting layout would affect worker comfort and performance, has been confirmed through the laboratory study. Further study in actual office settings is needed and is in the planning stages (2004-2005), but the initial results are encouraging and build upon earlier studies. Lighting systems incorporating task-ambient fixtures and wall washing have been shown to increase occupant comfort by 10-15%, with an estimated energy savings of 22%. Adding personal control technologies increases occupant comfort by another 6% while increasing estimated energy savings by another 52-57%. Now how do we begin to effect change in the commercial office building marketplace to realize these benefits in actual buildings?

Market research funded by *Light Right*[11] examined the roles and influence of various decision makers in lighting design and installation (refer to Table 2). The research identified the well-known problems in the construction industry delivery system. As would be expected, their findings indicated that lighting designers naturally place a high value on quality lighting and

[11] Conducted by Ducker Research Company, Inc. Bloomfield Hills, MI. The project involved an analysis of the purchase/specification process for lighting & in-depth phone interviews with corporate decision-makers.

have a high authority level because they create the specification. However, they are not intensely involved (if at all) during the construction phase resulting in a low frequency of contact with the project when products are procured and installed. The general contractor does not value lighting highly, and does not officially have authority over the lighting, but has a significant and frequent contact with the project—they have control over budget and schedule and thus have a significant influence on the lighting that is actually installed. The only group that has both high authority and frequency of contact with the project is the owner/tenant. However, owners generally place a low value on lighting quality. Similarly, architects have a relatively high level of influence on lighting decisions and a high incidence of involvement in design decisions, but place a relatively low value on lighting quality, compared to other architectural features.

This market research points to an important opportunity to inform and educate building owners and architects about the benefits of more effective lighting. Owners and tenants, followed closely by architects, are the only decision-makers that can truly create change in market dynamic. So this is our challenge: to educate building owners and managers about the benefits of high quality lighting to their bottom line.

Table 2. Market and Delivery System Dynamics

Decision-Maker	**VALUE** (Derived Importance—from 1-5; 5=highest)	**AUTHORITY (Level of Influence with Lighting Decisions)**				**INCIDENCE** (Frequency of contact with the project)
		New		Renovations		
		TO	OO	TO	OO	
Owner	1 (TO) or 2 (OO)	5	5	3/4	5	5
Architect	2	3	4	3	3	4
Engineer	1/2	3	4	3	3	4
General Contractor	1	2	2	2	2	5
Lighting Designer	5	4	5	4	5	2
Interior Designer	4	3	4	3	4	1
Facilities Manager	4	3	4	3	4	3/4
Electrical Subcontractor	3	1	1	1	1	4
Occupant	5	1	1	4	1	1

Key: TO = Tenant occupied. OO = Owner occupied.
Scale for all is 1-5, with 5 being highest level of importance, influence, and incidence.
Importance refers to the derived value the decision-maker places on lighting quality.
Influence refers to the authority the decision-maker has over lighting decisions.
Incidence refers to frequency with which the decision-maker is involved in design decisions.

With this understanding the ultimate goal is to strategically influence high-level decision-makers. Likely avenues are through building owners, asset managers, human resources professionals, and business units. To that end, *Light Right* is creating a web-based survey tool to allow building owners and managers to gauge their employees or tenants' comfort and attitudes about lighting. This tool will be free and publicly available. Designers, manufacturers, and utilities can offer this tool to owners, managers, clients and customers to leverage the *Light Right* comfort results into action. Ultimately, with sufficient use and quantity of data, this web-tool can become a national benchmarking tool to promote best practices in lighting and leverage fundamental change in the market.

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