DERIVING POWER BUDGETS FOR ENERGY-EFFICIENT LIGHTING IN NON-RESIDENTIAL BUILDINGS

David B. Goldstein
Robert K. Watson
Natural Resources Defense Council
90 New Montgomery Street, Suite 620
San Francisco, CA 94105

ABSTRACT

Lighting constitutes the largest end use of electricity in a non-residential building, and a large, low-cost resource of conserved energy. Much of this resource is languishing, in part because of a lack of written information on what products are available, in part due to a lack of sufficiently ambitious targets or standards to encourage innovative lighting designs for energy efficiency, and also due to the absence of facilities to test proposed lighting solutions visually before a designer commits a whole building to them.

This paper reviews commonly applicable equipment currently available for minimizing energy use and life cycle cost, and provide recommendations for optimum lighting power limits based on the achievement of illuminance recommendations of the Illuminating Engineering Society with the most efficient equipment. The methodology for calculating these power budgets is presented, and representative results are displayed.

The computed optimum power budgets are typically 50% to 85% lower than current practice and imply a technical potential for saving over 100,000 megawatts of peak electric power over the next 30 years. But such ambitious targets may not achieve acceptance from designers unless representative spaces that meet them can be visualized. A lighting mockup facility described in a companion paper is suggested as a solution to this problem of acceptance.

DERIVING AND TESTING POWER BUDGETS FOR ENERGY EFFICIENT LIGHTING IN NON-RESIDENTIAL BUILDINGS

David B. Goldstein and Robert K. Watson
Natural Resources Defense Council

OVERVIEW

Lighting (directly through luminaires, and indirectly through increased air conditioning and ventilation loads) accounts for more than one-half of the total commercial electricity consumption.[1] This paper shows how savings of approximately 75 percent of the electricity used for commercial lighting can be achieved by installing more efficient lighting equipment and lighting controls and by employing better lighting design strategies. These technologies and methods, despite their exceptionally low cost, are not being deployed widely in the United States.

One type of market barrier is the lack of information about state of the art technologies and designs for efficient lighting, and the absence of sufficiently ambitious targets or recommendations. This paper discusses the most widely applicable technologies and design strategies for reducing lighting energy consumption, and estimates the effect of applying all feasible and cost effective measures to a wide range of building types.

The second section reviews the most promising technologies for increasing lighting efficiency and reducing costs, emphasizing those measures with widest applicability among building types and users. The third section summarizes the effect of applying these technologies by calculating optimum lighting power budgets: the amount of energy one would project should be used, by building type, if all of the applicable efficiency improvements were employed. We conclude with a comparison of these levels with current standards and practices. This section points out the potential role of lighting education and research facilities in allowing the practical confirmation of the calculational results presented in this paper, and for overcoming market barriers to implementation. Such a facility is under construction in Seattle, and is described in Holt & Campbell.[2]

---

1 The Rocky Mountain Institute calculates that lighting, directly and indirectly, accounts for 60-65% of commercial building energy consumption. Amory Lovins, "State of the Art Monograph: Lighting" Rocky Mountain Institute, Old Snowmass, CO, August 1986, pp.2-3. The Electric Power Research Institute estimated that lighting energy accounts for 420 billion kwh/yr directly and an unspecified additional amount indirectly (N. Lihach, "Evolution in Lighting," EPRI Journal, June 1984). With residential lighting consuming some 90 billion kwh of this, non-residential lighting uses 330 billion kwh compared to commercial electricity sales at 575 billion kwh, or some 55 - 60%, considering only direct usage.

2 Additional market barriers to the use of efficient lighting technologies, and proposed means for overcoming them, are discussed in E. Holt & D. Campbell, "A Commercial Lighting Education and Research Facility for the Pacific Northwest," presented at this conference.

STRATEGIES FOR IMPROVED LIGHTING EFFICIENCY

An increasing number of products has become available over the last decade to improve the energy efficiency of lighting systems and reduce life cycle costs. This section discusses several of the most promising technologies and design opportunities, selected for their wide applicability and generally favorable economics.

Many of these options have been employed in specific energy efficient building designs. But a survey of the most efficient lighting designs in the United States failed to disclose a single building in which all of the cost effective opportunities were exploited.[3]

Three categories are used for describing technologies to reduce electrical energy for lighting:

(1) More efficient lighting equipment
(2) Lighting controls.
(3) Better design strategies to provide appropriate illumination for the task.

More Efficient Lighting Equipment

Solid State Ballasts. Solid-state (or electronic) ballasts have been in mass production for over five years. Developed by Lawrence Berkeley Laboratory, electronic ballasts now comprise roughly 2.5 percent of the ballast market. Solid-state ballasts reduce energy consumption of the lighting system by 25 to 40% depending upon how one counts a number of savings factors such as reduced sensitivity of light output to lamp temperature and voltage fluctuations, lower lamp temperatures (which allow higher on-site efficiency), etc. Solid-state ballasts can run from one to four lamps and some have continuous and step dimming capability.

Dimming capability allows power usage to be adjusted to the actual needs of a space, allowing low energy usage equivalent to the output of, say, one-third of a light fixture.

A representative solid state ballast reduces energy consumption by approximately 20% compared to an efficient core and coil ballast at the level currently required by federal legislation effective in 1990. Costs of solid-state ballasts vary widely depending on the size of order, among other factors, but mid-range projections of cost suggest a $15 cost premium compared to efficient core and coil ballasts, resulting in a payback period of less than four years.[4]

---

3 See "Commercial Lighting Demonstration Scoping Study; Phase 1A, Seattle City Light, Natural Resources Defense Council, Northwest Conservation Act Coalition, Roger Williams Architects, AIA, July, 1987; Appendix D.

4 D. Goldstein, et. al. "A Comprehensive Assessment of Proposed Appliance Efficiency Standards for the Commonwealth of Massachusetts," prepared for the Massachusetts Executive Office of Energy Resources by the National Resources Defense Council, San Francisco, 1986.

High Efficacy Lamps. Two improvements in design allow fluorescent lamps to obtain higher efficacies than in the past. First, improved phosphors in lamps currently available from all major manufacturers allow an improvement in color rendition as well as luminous efficacy by providing enhanced light output in frequencies corresponding to the three primary colors seen by the eye. In addition, the "T-8" or "T-10" lamps with these phosphors are smaller in diameter than conventional lamps, allowing greater fixture efficiency because the amount of light reflected back to the lamp and reabsorbed is smaller. The resulting luminous efficacy exceeds 100 lumens per watt assuming the use of a solid state ballast, compared with 60 lumens per watt for a conventional fluorescent lamp and low efficiency ballast.[5]

The combination of solid state ballasts and high efficiency lamps appears to have the most widespread applicability for new commercial buildings. Most illumination in non-residential buildings is provided by fluorescent lamps, and there appear to be very few circumstances in which the 100 lumen per watt combination is not feasible and cost effective. Thus, it is used for calculating the optimum energy targets for all uses of fluorescent lighting computed below.

High Intensity Discharge (HID) Lamps. HID lamps can be used in indirect lighting systems for ambient light. Indirect systems reflect light off the ceiling from upward facing fixtures which can reduce glare but may also reduce overall efficiency. The applicability of this technology hinges on lighting design, so it is not used the basis of our energy target calculations.

High Efficiency Fixtures. A number of options are available to improve the performance of lighting fixtures, to provide increased amounts of light and more useful patterns of light distribution for the same power input. The efficiency of a fixture refers to the gross amount of light coming out of the fixture compared to the total light produced by the lamp. Compilations of luminaire efficiency performed in the development of the ASHRAE 90.1 standard found that typical fixture efficiencies are in the neighborhood of 60 to 65%.

A second measure of the effectiveness of a fixture is the "coefficient of utilization" (CU). This parameter is the ratio of luminous intensity (footcandles) on the task to the lumens emitted by the fixture per square foot of area illuminated. In most cases, the CU is a more practical measure of the "efficiency" of the fixture, because it is the ratio of the desired output (i.e. illuminance on the task) to energy input.

One cannot conclude that higher coefficient of utilization or higher fixture efficiencies are necessarily better. For example, bare bulbs have higher efficiencies and CU than conventional office lighting fixtures that direct the light downward, but the latter are generally more effective designs because they reduce glare and are more attractive. On the other hand, high CU's do not entail poorly controlled light distribution; the highest CU fixture in the Illuminating Engineering Society Lighting Handbook is a highly directional floodlight.

5 Source: "Fixture Comparison Data", table compiled by the Sylvania Lighting Center, Danvers, MA and personal communication with Jerry Frank, Sylvania Lighting Center, 7/31/87.

Because of the inter-relations between lighting design considerations and the technologies for improvement of fixture efficiency, the most effective and energy conserving choices for fixtures cannot be specified in general, but are most likely to be found by experimentation. Facilities for providing such experimentation are described in Holt & Campbell. However, some generic methods that raise fixture efficiency and CU and generally allow for better lighting quality include parabolic reflector fixtures and specular imaging reflectors. Parabolic reflector fixtures are largely replacing prismatic lens fixtures in new commercial structures, particularly where lighting energy codes are in effect. The CU of such products can be as much as 30% higher than that of conventional lensed fixtures.[6]

Specular reflectors can provide substantially greater CU's because the fixture efficiency increases: diffusely reflected light that might otherwise undergo several internal reflections before emerging from the fixture or be reabsorbed on the lamp, instead contributes to useful illumination. Simulations of the effect of specular reflectors show that they direct the light more tightly downward than other types of fixtures. This can be beneficial or detrimental depending on the placement of the fixtures relative to the tasks.

Replacements for Incandescent Lighting Incandescents are widely used for decorative lighting in commercial applications, particularly in the retail sector. Most current applications of incandescents, such as downlights or area lighting, can be replaced by a variety of more efficient technologies.

PL's and Equivalent. PL lamps are small, twin or quad tube fluorescent lamps that range in size from 5 to 25 watts or more. They are available with adapters that allow them to screw into Edison sockets in direct replacement of incandescent light bulbs. Because of their tube-like shape, PL lamps frequently cannot always be used as direct replacements for incandescents for aesthetic reasons. However, fixtures and diffusers designed around PL lamps are becoming more widely available. Also, a rapidly increasing number of floodlight and downlight fixtures are becoming available for PL lamps. Dimming capability is only available in one compact fluorescent system, but more are expected to be available in the near future.[7]

Fixtures and flood lamps designed for use with PL lamps can play an important role in improving efficiencies in non-residential buildings. A large number of incandescent lamps currently are in use for down lights, task lights, and display lights in such applications are hallways, lobbies, restaurants, hotels, and retail stores. Not only can these incandescent sources be replaced with PL lamps, but the cost of conserved energy is often negative. This effect comes about because the long life of the fluorescent PL lamps (typically rated between 7,000 and 10,000 hours) provides savings in equipment and labor for lamp replacement that more than equal the additional first cost of installing the fixture.

PL lamps and their fixtures and flood lamp adapters may have different distribution of light than the lamps they are replacing, and this effect can either

6 F. Berryman & J. Kelly, "Office Lighting Analysis Summary" California Energy Commission, November 1982.

7 Rocky Mountain Institute, Competitek Series "State of the Art:Lighting" pp. 96 & 277.

improve or degrade lighting designs. Practical experience with individual specimens of these products in each application may be necessary to achieve the best results.

SL lamps and Equivalents. SL lamps are compact fluorescent light bulb that screw into conventional Edison sockets like incandescents. They are produced by a number of manufacturers, and presently are all in the 15-20 Watt range. All of the current lamps are somewhat larger than standard incandescent bulbs, but still fit into many conventional fixtures. Color rendition is generally comparable to incandescent lamps. SL bulbs include integral ballasts, which must be discarded when the lamp burns out. Currently, none can be operated with dimming; however, this may change with further development.

Tungsten-Halogen Spotlights (also known as Quartz-Halogen): This emerging incandescent technology provides greater control over light distribution than conventional lamps, and produces energy savings through reducing the area illuminated by the spotlight to the area desired for illumination. Applications include retail display lighting and task lighting.

These lamps have two serious limitations for energy conserving practice. First, the level of illumination they provide may be greater than is needed to achieve the desired luminance ratio with surrounding areas. Second, while these lamps have superior characteristics for lighting control, their actual efficacy is no higher than incandescent lamps. Thus, if they are used to illuminate relatively large areas, they wind up providing the same distribution of light that could be accomplished with PL flood lamps at much higher cost.

More Efficient Incandescents. Improvements in bulb coatings, filament design and materials and interior gases have increased the efficiency of conventional incandescents by 5 to 10 percent. One type of incandescent achieves 50% savings by coating the lamp surface with an infrared reflector that redirects non-visible light back to the filament, reducing electricity needed to maintain the desired temperature.

Lighting Controls

Lighting controls can substantially reduce the amount of energy consumed by lighting systems by shutting off unneeded lights and by maintaining illuminance levels while taking advantage of daylighting. The major control strategies are listed below:

Occupancy Sensors. These controls employ infrared light or ultrasonic energy to detect motion in the controlled area; they turn off lights after an adjustable time lag during which no motion is sensed, and turn the lights back on when they detect motion. They allow for lighting to be shut off in unoccupied offices, conference rooms, storage areas, etc., and are estimated to save 30% or more of typical energy costs.[8]

8 The California Energy Commission adopted a 10% savings factor based on field studies of occupancy sensors. The same credit has been endorsed by ASHRAE, the U.S. Department of Energy, and the Northwest Power Planning Council.

Lumen Maintenance and Daylighting Controls. Typical illumination systems are designed with a "light loss factor" of about 0.7 or less; the light loss factor is the ratio of light output delivered to the task under the worst design conditions, such as old lamps, dirty fixtures, etc., to light delivered when the system is new. Lighting systems are designed to meet illuminance targets at these worst design conditions. This means that typical lighting systems are over-designed by about 43% to account for reductions in the amount of light output over the life of the equipment. Lumen maintenance controls reduce the need for this over-sizing by turning up the intensity of illumination as the efficacy of the lamp deteriorates and the lamp and fixture become dirtier. These controls save approximately 10-15% over their life.[9] Daylighting controls dim the illumination in zones near windows, skylights or other sources of daylight. However, these controls must be quite sophisticated to provide pleasing light over a wide range of outdoor lighting conditions.

Energy Management Systems (Centralized Controls). A wide variety of these systems are available. System features include the ability to turn lights and building systems on and off in different parts of the facility according to a pre-arranged schedule. In addition, manual override of the central control is often an option.

Manual Controls and Multi-Level Switches. These include manual-on and automatic-off switches for task lighting and manual dimming capability. Multi-level switching allows occupants to have their lights off or at 1/3, 2/3 or full power. This switching configuration is currently required by the California Energy Commission's Title-24 standards and the Northwest Power Planning Council's Model Conservation Standards.

<u>Design Considerations</u>

Design considerations are distinguished from the other strategies because they involve rearranging lighting equipment and tasks, as opposed to replacing less efficient equipment with that of higher efficiency. Most of these strategies are used only in a tiny percentage of current building designs, despite being recommended by the Illuminating Engineering Society (IES) as good energy conserving design practice.

Serious Task Lighting. The IES recommends that footcandle levels of 30 and higher be provided only on tasks, with the remainder of the room illuminated to no more than one-third of the illuminance of the task (but generally not less than 20 footcandles). This has been recommended by the IES for almost a decade, yet it is almost never attempted seriously by lighting designers. Buildings surveyed for methods of achieving low energy use cited lighting levels that almost always exceeded IES recommendations;[10] A serious task lighting design would attempt to provide recommended levels of illumination only on the visual tasks and approximately a third as much light in the surrounding area. The remaining space

9 <u>Usibelli et al.</u>, <u>Commercial Sector Conservation Technologies</u>, Lawrence Berkeley Laboratory, Berkeley, CA., 1985, at 6-63.

10 See note 3; also buildings described in <u>Lighting Design & Application</u> list illuminance levels that generally exceed IES recommendations.

should be illuminated at 1/9 the task intensity (but generally at least 10 footcandles).[11]

Task lighting design can reduce glare and increase visual comfort, as well as save energy. This sort of lighting design will be facilitated by the availability of a mock-up facility (see Holt & Campbell).

More Careful Display and Highlighting of Retail Stores. Many retail stores over-illuminate the general merchandise to the degree that the featured displays are almost washed out. The IES document "Recommended Practice for Retail Lighting" discusses the importance of reducing general illumination levels and concentrating the customer's attention on the merchandize and on special displays. These methods improve the visual effectiveness of the store as well as saving energy.

Brighter Colors. The illuminance of a visual task depends not only on the efficiency of the fixture, but also on the reflectivity of the walls and floor of the work space. Substantial gains in system efficiency can be obtained by using more reflective color schemes. Dark colors absorb light, requiring higher illuminance levels to avoid a "gloomy" appearance. Lighter colors require less power to achieve the same appearance of brightness.

Grouping of Tasks. Where there is a variety of tasks at different illuminance levels, it saves energy to group similar tasks together so that areas requiring more intense illumination are isolated. The remainder of the facility then can be illuminated to lower levels without providing unacceptable variations in luminance ratios. This strategy is frequently mentioned, but very seldom employed.

Serious daylighting. Serious daylighting is distinguished from ordinary daylighting in that a conscious attempt is made to design the fenestration systems of the building to produce the desired lighting effect, as opposed to simply turning out lights when there is sufficient natural illumination. Technologies to increase the useful amount of daylight in a building bring large reductions in electric lighting consumption, when combined with control technology. These strategies include: light shelves or diffuse reflecting panels located above eye level to project light from the side of the building into the interior, better interior distribution, tracking concentrators, and carefully planned window systems and shading devices.

RECOMMENDED ENERGY CONSERVING POWER BUDGETS FOR NEW BUILDINGS

The technologies described in the previous section can be applied in combination to achieve the lowest life cycle cost from a lighting system. This has very seldom been done in practice.[12] This section attempts to calculate optimal levels of "adjusted" lighting power density that would result from the application of

11 See "IES Recommended Procedure for Lighting Power Limit Determination" IES LEM-1-1982, Illuminating Engineering Society of North America, 1982, pp. 19-21.

12 See Note 3 for a survey of low energy use lighting systems, all of which ignored one or more obviously cost effective technologies described above.

cost effective technologies and design methods.[13] These optimum lighting power budgets are intended to represent targets for designers who wish to minimize costs for their clients. Thus, they are also appropriate targets for utility incentive programs or other programs attempting to encourage least cost investments in energy efficiency.

The results are summarized in Table 1, which is formatted analogously to the table of required maximum adjusted lighting power densities in ASHRAE proposed standard 90.1P (and also the parallel Department of Energy proposed standard.) The actual power budget for a room is taken by multiplying the values in the table by an area factor that accounts for the drop in CU as one goes from an infinitely large room to a room of finite dimensions. These area factors are always greater than 1, and range up to about 1.5 for small spaces such as 100 square foot enclosed offices.

The recommended power budgets are calculated using the "Lumen Method" which is based on Equation 1:

$$\text{Power Budget } (w/ft^2) = I_{wa} x CF/(CUxLExLLF) \quad (1)$$

where:

I_{wa} is the weighted average illuminance of the space.

CF is a correction factor that accounts for lighting control credits and other factors unique to the space in question.

CU is the coefficient of utilization as discussed above.

LE is the luminous efficacy of the lamp and ballast combination.

LLF is the light loss factor used for design calculations.

Input to the calculation are described below.[14]

Illuminance. Illuminances are based on the recommended categories of illuminance established in the IES Lighting Handbook, 1981 Applications Volume. They are based on the degree of difficulty of the visual task, as well as recommendations for illuminances in each of the types of task area described in Table 1.

Correction Factor. The correction factor primarily includes the effect of control credits, that are appropriate in the space. Spaces with transient occupancy such as conference rooms are assumed to make use of occupancy sensors. Most

13 Adjusted lighting power densities refer to the average power that is in operation over the course of the day rather than the total connected power. They include power adjustment credits for lighting controls.

14 Calculational details are presented in "Detailed Comments of the Natural Resources Defense Council on the Department of Energy's Conservation Voluntary Performance Standards" August 4, 1987. This document also adds more occupancies to those displayed in Table I.

fluorescent-lit facilities are assumed to make use of lumen maintenance controls, because the use of such controls allows reduction in the installed power as well as energy use, resulting in first cost savings along with operating cost savings.[15] The correction factor may also include heuristic adjustments for other specific characteristics of a room type.

Coefficient of Utilization. The CU's used in computing Table 1 are based on a roughly 10% increase from the levels required in ASHRAE Standard 90-75, which was designed in the mid-1970's. These figures provide some minimal account for the improvements in fixtures efficiency and CU that would obtained from using reflector fixtures.

Luminous Efficacy. Several categories of luminous efficacy are selected for the Table 1 calculations, based on the technologies described in Section II. The variations in LE by occupancy type are based on perceptions of the need to use incandescent lighting in that type of room. For occupancies in which lighting can be all fluorescent, the value of 100 lumens per watt, corresponding to the most efficient (but economically justified) ballast-lamp combination described above. For other occupancies, a ratio of incandescent lumens to fluorescent lumens is derived from the mix assumed in IES LEM-1[16], which provides recommended limits on installed power for building code purposes. LEM-1 was written in the mid-1970's, so the fraction of lumens that should be optimally derived from fluorescent today would be higher due to the following factors:

- Fluorescent lamps have greatly improved color rendering qualities, so cases in which incandescents were chosen solely for their color rendering ability may now find fluorescents acceptable.
- The cost of electricity has increased, giving efficiency relatively more weight over aesthetics today than in the 1970's.
- Because of increased efficiency since 1975, the operating cost advantage of fluorescent lighting over incandescent is larger.

In addition, for each occupancy type, we projected the extent to which compact fluorescent lamps -- which were not available at all when LEM-1 was written -- could be substituted for incandescent lighting. For different occupancies, assumptions were made that 0, 50%, or 100% of the incandescent lighting could be replaced with compact fluorescents at an assumed efficacy of 40 lumens per watt.[17]

Light Loss Factor: For conventionally well managed fluorescent lit occupancies, a light loss factor of 0.8, compared to typical practice of .7, is used. This increase results from two factors: 5% of the 30% light loss in the IES

15 This effect occurs because Equation 1 is used to size the lighting system and determine the number of fixtures as well as to compute energy budgets. Clearly, if LLF is increased, the number of fixtures needed to be installed is reduced.

16 See note 10 above.

17 Actual LE's for compact fluorescents range from 40 l/w to 60 l/w (Usibelli, et. al. note 9 above, page 5 - 1), so a choice of 40 l/w is conservative.

Handbook[18] is due to temperature and voltage fluctuations, and solid state ballasts are much less sensitive to these.[19] In addition, lamp lumen degradation is responsible for over 10% of the light loss. Both temperature and voltage effects and lamp aging effects can be compensated by lumen maintenance sensors. To compute LLF, we divide the conventional LLF by .95 for temperature and voltage and .9 for the use of the lumen maintenance sensor.

For uses that rely more heavily on compact fluorescents, the conventional .70 is used because of lack of experience with these lamps being used with lumen maintenance controls. For incandescents, a .8 or .85 light loss factor is used, because the lumen output of these lamps degrades much more slowly than that of fluorescents.

18 IES Lighting Handbook, 1981 Application Volume, page 4-22.
19 See R.P. Verderber "Electronic Ballast Improves Efficiency" Electrical Consultant, November/December, 1980 p. 23.

TABLE I. Selected Optimum Lighting Power Budgets vs. Current Practice

Occupancy Type/Activity	Optimum Power Budget (w/ft^2)	Current Practice[20] (w/ft^2)
Auditorium	0.38	1.1
Corridor	0.50	0.6
Classroom/Lecture Hall	0.55	2.2
Fast Food/Cafeteria	0.25	2.8
Leisure Dining/Bar	0.65	2.1
Kitchen	0.87	1.7
Stairway	0.23	0.6
Toilet/Washroom	0.12	0.7
Library: catalog & record file	0.45	3.2
reading	0.45	2.2
Lobby	0.25	1.0
Storage & warehouse: active storage, medium & bulky	0.17	0.4 - 0.6
Offices, enclosed, reading, filing, typing	0.60	2.2
drafting	1.69	4.7
accounting	1.10	3.2
Airport, Bus, Rail, Station		
baggage room	0.45	1.3
ticket counter	1.07	2.2
waiting lounge	0.25	0.8
Hotel - guest room	0.50	1.4
lobby	0.53	1.1
Bank: banking activity area	1.19	4.7
customer area	0.34	2.3
Church & synagogue congregation	0.65	2.3
Retail stores: merchandise areas	0.94-1.46	3.8

DISCUSSION

The optimum lighting power densities in Table I entail reductions in energy use of 50% to 85% compared to current practice. This implies a national lighting efficiency resource from new buildings over the next 30 years of some 100,000

20 Current practice is represented by the recommendations in LEM-1, which is comparable to the ASHRAE/IES Standard 90A-1980 that is the basis of building codes in most states. This assumption is employed in the Pacific Northwest Laboratory analysis, see note 21.

megawatts.[21] When one adds existing buildings, these figures increase by roughly 25%.

But such figures, based on calculations, rather than actual lighting designs, are received with skepticism by the lighting design community, whether or not there is any objection to the specific calculational parameters on which they are based. These recommendations are not likely to achieve acceptance in the real world unless they can be seen and experienced by the lighting designer before they become the design basis for the building and its HVAC system.[22] This is one of the major motivations behind the lighting education and research facility described in Holt & Campbell, of which the authors of this paper are co-sponsors. Physical mock-up is necessary because computer simulations are not available to project the visual effect of a lighting system to sufficient accuracy before it is built, and designers are unwilling to accept the prospect of such large changes in energy consumption without feeling completely assured that the design will be aesthetically acceptable. Computer simulation will be inadequate for the near future for two reasons. First, while there are programs available to calculate the distribution of footcandles throughout a room, they are only used by expert lighting designers and they still do not allow visualization of what the space will look like.[23] Perhaps even more significantly, the programs are based on very simple rectangular geometries in an idealized room, and are unable to calculate the effect of three-dimensional objects such as desks, furniture, computer terminals, or more complicated variations from the norm, such as wall decorations and plants.

CONCLUSIONS

Analysis of the effect of existing state of the art efficient products for commercial lighting and calculations of their cumulative effect suggest potential savings of 125,000 megawatts nationwide from increased lighting efficiency. The realism of these calculations is subject to confirmation by practical demonstration. The least risk approach to such validation is by constructing sample designs for different spaces as mock-ups, and confirming their visual acceptability as well as energy savings. Since there is no metric for lighting quality or performance, visual inspection is necessary to confirm these calculations.

---

21 From the Building Energy Use Data Book (Oak Ridge National Laboratory, ORNL-5552-ED-2, pp. 9-57 and 9-65) 1988 square footage of commercial buildings is approximately 50 billion. Projecting to 2020, assuming year 2000 ORNL projections and a lower 3% growth rate thereafter forecasts about 145 billion square feet in 2020. Thus, new growth exceeds 100 billion ft2 Energy savings average about 1 W/ft2 or more, comparing current practice (taken from Pacific Northwest Laboratory's analysis of energy use (in progress) for the Northwest Power Planning Council) to targets taken from Table 1. Thus, savings in new buildings exceed 100,000 mw. Savings from existing buildings are perhaps half of 50 billion ft2 x 1 W/ft2.

22 Since in the building design process the HVAC design is usually completed before the lighting design (which often waits until a space is sub-divided and leased), the HVAC designer will not base his loads calculation on an estimate of improved lighting systems unless he has confidence that an acceptable system can be designed within the energy constraint.

23 Lawrence Berkeley Laboratory and others such as Lighting Technologies in Colorado are developing sophisticated computer graphics programs using ray- tracing algorithms to graphically simulate lighting conditions in offices. Unfortunately, these programs are not available yet to the public and require very sophisticated computer equipment to generate.