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ABSTRACT

There have been many new lighting products introduced since the 1973 energy crises. The products that entered the market most rapidly were based on existing technologies and relied primarily on reducing light levels to reduce electrical power use. These systems worked for retrofitting existing spaces that were over-illuminated. In the mid-70s, new products employing new technologies were developed that increased the efficacy of producing and distributing visible light. These included the high-frequency operation of fluorescent lamps, replacement of incandescent light sources, and effective management of lighting. These technologies will be described and their present status, with regard to their current use, will be discussed. Their impacts on energy use and on the quantity and quality of illumination will be presented. The results will provide evidence that proposed lighting power densities of 1.5 watts per square foot for lighting can be realized.

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INTRODUCTION

It has been more than 10 years since the 1973 oil crisis spurred the lighting community to develop energy-saving devices and improvements. This paper will review the various groups that have influenced the industry during this period, and will discuss the many new products that have emerged since 1973.

The roles that government, utilities, and industry have played in making lighting more efficient will be described. One section will discuss the influence of professional societies on the changes in lighting design philosophies. Another section will describe new lighting products, which can be separated into two categories: advances in existing technologies and new lighting technologies. These products will be discussed with respect to their capacities to meet present lighting requirements. The potential of these products to meet projected targets for lighting systems will be discussed, as will the means to accomplish needed improvements.

RESPONSE TO CRISIS

Government

A modest national lighting program was initiated in 1976 to determine whether the energy consumed by illumination could be reduced. The program's primary role was to help accelerate the introduction of energy-efficient lighting products. The program included support for developing these products and for conducting on-site demonstrations.

Federal and state agencies also established power density requirements for lighting. Initial values were established at about 2.2 watts per square foot (W/ft^2). Today, some agencies have proposed limiting average power densities for commercial office space to 1.5 watts W/ft^2. There is some doubt that this goal can be met. Some lighting designers within the Illuminating Engineering Society (IES) organizations claim this will require above-average costs for equipment; some also say that the analysis did not account for the quality of illumination.

Utilities

Lighting consumes about 25% of the total electrical energy supplied by utilities. This amounts to 450 billion kilowatt hours (BkWh) annually; at an average price of $0.07 per kWh, the cost of lighting is more than $30 billion. The bulk of lighting use occurs during the day, when commercial and industrial use is highest, which contributes to the peak power demands. So, although reducing the energy used for lighting will reduce utilities' revenue, the utilities realize that improving the efficacy of lighting systems will reduce the need for capital expenditure for new power plants. Thus, many utilities have developed effective programs to encourage the use of efficient lighting systems. They have also been active in several of the national lighting program's on-site demonstrations. Through their research arm, the Electric Power Research Institute, they have initiated a lighting program to study the performance of new lighting products that have reached the marketplace, as well as to monitor buildings having energy-efficient lighting systems.

Industry

The lighting equipment market represents approximately $5 to 6 billion per year. As energy costs increase, it is reasonable for the industry to add costs to its products in order to improve performance (i.e., efficacy), which will, in turn, reduce operating costs. But, although the industry is competitive, the lamp and ballast market is dominated by two or three companies, and the companies that have large market shares are reluctant to make drastic changes in their products. Thus, the major innovations using new technologies in this area are being introduced by small companies or companies new to the lighting industry. One exception is lighting management systems. Because there are virtually no lighting controls in place, the lighting industry views this as a new potential source of revenue.

Lighting Design Concept

The conservative nature of the lighting industry influences lighting design. Prior to 1973, general lighting design practice was to provide uniform illumination throughout a space and to make certain that illumination levels were adequate for workers' tasks. The amount of light required for the most demanding visual tasks was supplied to the entire space. In addition, because electrical energy costs were low, designers tended to err toward higher illumination levels. The prevailing philosophy was, "more light is better".

After 1973, the increasing cost of electrical energy created concern about the operating costs of lighting systems. Although previously the lowest initial cost had served as the primary criterion for selecting a competitive bid, building operators became concerned with the operating cost for lighting in existing sites as well as in new construction. For example, a four-lamp fluorescent fixture with a ballast might have cost $100 originally and, at $0.01 per kWh, cost $8.00 to operate for a year. Today, at $0.07 a kWh, the cost is $56 per year. Over the life of the fixture and ballast (10 years), the operating cost is $560, more than five times the initial cost. This operating cost is more important to the building operator than is the initial cost. Hence operating cost is emerging as a decision factor.

NEW LIGHTING PRODUCTS

Since 1973, many new lighting products have been introduced. The new products and concepts were developed in response to the following situations:

1. Many spaces were over-illuminated.

2. The new IES recommended lighting levels were lowered and broadened and freed from limitation to a single value.[1,2]

3. Non-uniform lighting designs became acceptable.

4. The cost of a product could be increased if the product was more efficient.

Two types of products were introduced, one type to reduce illumination levels in existing systems (retrofit), and the other based on making more efficient and effective use of lighting (replacement and new construction).

Existing Systems

Table I lists several new concepts and products introduced during the past ten years that are improvements to existing lighting technologies and practices.

Table I. Some major concept, product changes.

Efficacy Increase	
(0)	IES lighting standards
(0)	Delamping/impedance monitors(phantom tubes, thriftmate, add-on controls)
(0)	34-W F40 lamps
(7%)	Lite-white phosphor
(10%)	Energy-efficient core-coil ballasts
(18%)	32-W T-8 lamp, EE ballast
(18%)	Non-heated filaments, rapid-start lamps, EE ballast

In the previous section, the changes in the IES recommended light levels were discussed. For example, in the past a typical average maintained light level in an office space was 70 to 100 footcandles (fc); today many designs aim to maintain an average of 50 fc.

Many over-illuminated spaces can be delamped, which means removing one or two lamps from three- and four-lamp fixtures, respectively. Several types of impedance monitors could be installed in fluorescent fixtures to reduce light levels by 30 to 50%. New lamps have been introduced that use less power (and provide less light) with existing ballasts, and/or that have more efficacious phosphors. Finally, rapid-start lamp systems have been introduced that remove filament power after the arc is ignited. In combination with more efficient magnetic ballasts, these changes have resulted in greater system efficacies. Table II lists the input-output performance of these components in detail. The standard Certified Ballast Manufacturer (CBM) two-lamp F40, T-12, rapid-start cool-white system serves as the basis of comparison. Delamping, impedance monitors, and special tube replacement can reduce the power used by as much 30 to 67%; however, light output is reduced by 30 to 75%.

Table II. Fluorescent two-lamp systems.

Ballast	Ballast Factor (%)		Power (W)	Light (lm)	Relative Change Power (%)	Relative Change Light (%)
CBM	95	F40/CW	95	5980	0	0
Phantom Tube		F40/CW	31	1500	-67	-75
Impedance Monitors			67/48	4200/3000	-30/-50	-30/-50
Delamp		F40/CW	48	2990	-50	-50
CBM	87	34W/F40/CW	77	4960	-19	-17
CBM	87	34W/F40/LW	77	5300	-19	-11
CBM	95	F40/LW	95	6460	0	+8
CBM(EE)	87	34W/F40/LW	70	5300	-26	-11
CBM(EE)	95	32W/T-8	70	5520	-26	-8
CBM(EE)	95	28W/LW	60	4840	-37	-19
CBM	87	32W/T-12	73	5080	-23	-15

The energy-saving lamp with the cool-white phosphor reduces light output by 17%. This same lamp with a light-white phosphor reduces light output by 11%. Note that the ballast factors for these energy-saving lamps were 87% with CBM ballast, compared to 95% for the F-40 lamp. One lamp was introduced that increased light output: the F-40 lamp with the light-white phosphor. Other new lamps were introduced, all having a reduced rated light output and, when used with an energy-efficient (CBM,EE) magnetic ballast, lowering input power by as much as 37% with respect to the standard CBM F-40, two-lamp systems.

However, all the systems described in Table II, except for the F40/LW lamp, achieve a major portion of power reduction by reducing light output. Thus, all are most effective in retrofit or replacement applications to reduce the light levels in over-illuminated areas; they may not be the most cost-effective choices for renovation or new construction.[3] The technologies and practices most suitable for retrofit applications are those that have the lowest installation costs, e.g., delamping, some impedance monitors, and energy-saving lamps.

Another characteristic of these products is that their shape and form are virtually identical with the products they replace. Hence, their introduction has involved a minimum of capital cost for new plant and manufacturing equipment. These products represent a rapid and economical means to reduce operating costs of lighting systems in spaces that have been over-illuminated.

New Lighting Technologies

The past 10 years have seen a rapid development in three new lighting technologies that have achieved large increases in efficacy and energy savings. The new lighting technologies are listed in Table III along with the increased efficacy and energy savings they achieve. All three systems are based on amending existing technologies developed for applications other than lighting systems.

Table III. New lighting technologies.

	Efficacy Increase
Solid-State Ballast	20-25%
Compact Fluorescent 40 to 60 lumens/watt	62-75%
	Energy Savings
Lighting Controls	15-50%

The solid-state ballast is a switching power supply that converts the 60-Hz input power to a high frequency (20 to 30 kHz). Fluorescent lamps operated at high frequencies increase system efficacy by 20 to 25%.[4] The compact fluorescent lamp is one of several new efficacious light sources that can replace an incandescent lamp in many applications.[5] It is listed in Table III because it is the only technology that is available today. This technology combines new fluorescent lamp design with a solid-state ballast. The lamp provides good color (similar to that provided by an incandescent lamp) and a substantial increase in efficacy (60 lumens per watt--lm/W) compared to the 75-watt incandescent it would replace (16 lm/W). Other equally effective systems are being developed, including a miniature metal halide lamp, a coated filament lamp, and the electrodeless fluorescent lamp.

Finally, lighting control systems are being introduced that alter the amount and distribution of the illumination in a space, compatible with the activity in that space. Several demonstrations have shown that lighting controls can reduce the amount of energy consumed by lighting from 15 to 50%.[6,7,8]

MEETING LIGHTING GOALS

We will next examine whether the new products that have been introduced can meet the conservation goals being considered by federal agencies. The present voluntary standards established in many states are about 2 W/ft^2 for office buildings. As stated earlier, the new, more stringent figure of 1.5 W/ft^2 has been proposed.

In a previous paper,[3] a lighting layout using a standard CBM ballast, F-40, cool-white lamps, and ordinary four-lamp fixtures was designed. For a room cavity with a maintenance factor of 0.7 and a maintained average illumination level of 70 fc, the installed power density was calculated to be 2.8 W/ft^2.

Table IV lists the results of calculating the power densities for the same layout and fixtures, replacing the ballast and/or the lamps with the improved lighting system. Combining both the new reduced lighting level (50 fc) and the improved efficacy of the ballasts and/or lamps, we can easily meet the present 2 W/ft^2 targets. However, the proposed 1.5 W/ft^2 target is just barely met by the CBM energy-efficient magnetic ballast and the efficient fluorescent lamp with no filament power.

Table IV. Lighting layout.

Luminaire: 4 lamps
RCR: 1
Maint. Factor: 0.7

Lamp System	Power Density (W/ft^2)		
	100 fc	70 fc	50 fc
CBM/F40/CW	4.0	2.8	2.0
CBM(EE)/F40/CW	3.7	2.6	1.9
CBM(EE)/35W/LW	3.4	2.4	1.7
CBM(EE, No Fil.)/ 28W/LW	3.0	2.1	1.5

Table V lists the results of calculating the power densities for the same layout based on the use of solid-state ballasts, energy-efficient lamps, and lighting controls. Maintaining a 50-fc light level, the solid-state ballasts with energy-efficient lamps clearly met the proposed standards. Using these ballasts, and considering that lighting controls are 20% effective in reducing installed loads, we can meet the new proposed standards at a maintained illumination of 70 fc and, at 50 fc, the loads are more than 30% below the limit. This simple exercise suggests that if the new lighting technologies are universally adopted, the power densities proposed for 1987 can be met with standard four-lamp fixtures. With existing technology, more expensive fixtures, e.g., efficient one- and two-lamp fixtures, would be required to met the 1.5 W/ft^2 power densities.

Table V. Lighting layout.

Lamp System	Power Density (W/ft^2)		
	100 fc	70 fc	50 fc
CBM/F40/CW	4.0	2.8	2.0
Solid-State/F40/CW	3.0	2.1	1.5
Solid-State/F40/LW	2.7	1.9	1.4
Solid-State/F40/LW, No Filament Power	2.6	1.8	1.3
Controls (20% effective)	2.0	1.4	1.0

CONCLUDING REMARKS

This paper has provided an overview of the roles of government, industry, utilities, and professional groups in bringing about changes in the illumination of spaces. New, more efficient systems have reduced the energy used for lighting by reducing illumination levels in existing over-illuminated spaces. In 1976, the national lighting program's goal was to reduce the energy used for lighting by 50% by the mid-1990s. The new products, based on existing lighting technologies and the application of the new recommended illumination levels, have reduced power densities by 18% and 28% for 70-fc and 50-fc levels, respectively (see Table II). The present common standard of 2 W/ft^2 power density can be achieved. The products and concepts based on new lighting technologies offer still greater reductions through efficacy improvements of 25 to 75% with respect to the products they replace (see Table III).

Although these systems have been under development for more than eight years, and have been tested in applications, those who procure lighting systems are conservative and still exhibit a reluctance to employ them. Thus, market penetration has been slow. It is important that their use be accelerated to meet our nation's goals and to reduce the need for additional electrical generating capacity in the 1990s. A continuing coordinated effort is needed among the lighting community, the government, and the utilities: i) to provide standards of operation to assure the reliability and performance of these new technologies; ii) to provide suitable performance information so that they are used in the proper applications; iii) to collect and disseminate information on case studies of these products; and iv) to continue to support controlled on-site demonstrations. In the past, lighting components were almost all the same in form and performance and had well-established track records. The new technologies differ in performance, are more efficacious, provide various light outputs, will cost more initially, will have reduced operating costs, may last longer, and will vary significantly in the above categories depending on the manufacturer. An effort directed toward controlled studies of the new components will provide confidence and establish a track record for these technologies so that a rational basis can be established for comparing and selecting these new products and concepts.

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