Energy, Incandescent Lighting, and 100 Years

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Abstract—**1979 was the centennial year of light. 100 years ago Edison invented the first practical incandescent lamp. Since then the lamp industry has taken giant steps in developing and perfecting more efficient and diverse light sources. However, the incandescent light source 100 years after its invention continues to keep pace with the industry, providing the backbone to the lighting industry. The history of incandescent lamp development, many diversified applications of incandescent lighting, simple schemes to achieve energy savings, and the latest developments in incandescent light sources are discussed. In a myriad of applications, it is most unlikely to be replaced with any other source.**

INTRODUCTION

THE YEAR 1979 was the centennial year of incandescent light. Exactly 100 years ago, Edison invented the first practical incandescent lamp. Since then, the lamp industry has taken giant steps in developing and perfecting more efficient and more diverse light sources. The incandescent light source 100 years after its invention continues to keep pace, providing the backbone to the lighting industry. In a myriad of applications, it is not likely to be replaced with any other source.

Since the energy shortage in 1974 intensive efforts to achieve energy conservation by the lighting industry have been centered on more efficient sources, such as high-pressure sodium. Not many users realize that new designs continue to be introduced in the incandescent field to address this shortage. Direct substitution of the newly developed energy-saving lamps in one's incandescent lighting can effectively save energy without compromising the unique quality and preferred color rendition of incandescents. This paper is intended to bring to the user's attention some old as well as new incandescent devices. It is concerned with incandescent lamps and simple energy-saving schemes, and outlines new and potential incandescent applications.

HISTORY OF INCANDESCENT LAMP DEVELOPMENT

On October 19, 1879, after innumerable experiments, Thomas Edison finally put a carbonized filament to the test. It was made from no. 9 cotton sewing thread. This time the lamp burned steadily, giving out after 40 hours only when Edison turned up the voltage to see what it could withstand. He then broke the bulb. Therefore, the original incandescent lamp no longer exists.

The activity of Westinghouse in the lamp business actually dates back 102 years. In 1878, the United States Electric Lighting Company and Electro-Dynamic Light Company of New York were organized to promote the patents of Sawyer and Man, which covered filaments made from carbonized fibrous materials. In 1882, the Consolidated Electric Light Company acquired the patents and property of both the Electro-Dynamic Company and the Eastern Company. In 1887, the Westinghouse Electric Company acquired control of Consolidated & Sawyer-Man Companies and in 1889, secured by lease the control of the United States Company, thus bringing under its control both the carbonized fibrous filament patents and the carbonized cellulose patents. The early work of the Westinghouse Company was with carbonized silk.

For a dozen years after the initial success of the carbon lamp, relatively little attention was paid to filament development. The Edison lamp was found to excel in length of life and uniformity of performance, but it consumed more energy than any other make tested for an equal amount of light output. The tests showed the average efficiency of the standard Edison lamp around 1885 to be 4.47 W per spherical candle (2.8 lm/W) and that of the competing lamps tested to range down to 3.45 W per spherical candle (3.65 lm/W). The lower efficiency of the Edison lamp made it less economical than many competing lamps despite its long life (up to 2000 h). It became clear that the optimum balance of lamp efficiency and life required replacement after burning 600–1000 h.

By 1904, several different individuals and groups were attempting independently to make tungsten filaments for incandescent lamps. Progress in lighting with tungsten filament lamps was rapid in Europe. The General Electric Company (GE) introduced its tungsten filament lamps into the United States in 1907. Successful production of ductile tungsten wire was achieved in the GE Research Laboratory in 1910. A patent covering this specific process was granted in 1913.

The introduction of inert gas fillings into lamp bulbs had the important gettering effect of decreasing filament decomposition and bulb blackening. The next major technological development was a cheaper method of producing large tipless lamps. Another noteworthy change in the design of the incandescent lamp was the introduction of inside frosting. Only a few significant changes in fundamental incandescent lamp design were made after 1926. The desirability of increasing the effective diameter of the filament in the gas-filled lamp to reduce heat loss led to a recoiling of the once-coiled filament. The coiled-coil filament was introduced in 1936. With that improvement, the efficiency of the 60-W lamp was increased from 12.5 to 13.8 lm/W, and that of

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the 100-W lamp, from 15.3 to 16.01 lm/W. The introduction of vertical filaments further increased the efficiency of the 100-W lamp to 17.1 lm/W. In the late 1950's the halogen lamp was introduced into the incandescent families. It has many advantages including high efficacy, compactness, thermal shock resistance, and almost constant light output throughout life. In general, there have been no appreciable efficiency advances for many years. However, a great many new types of incandescent lamps have been developed for special applications since 1912, including various decorative lamps, numerous miniature lamps, reflector, and parabolic aluminized reflector (PAR) lamps. Most of these lamps were introduced by GE with the collaboration of Westinghouse. Families of lamps have grown up by applications and many of these general incandescent groups can be defined briefly as follows.

TYPES AND CLASSES OF INCANDESCENT LAMPS

A. General Lighting Lamps: The most commonly used filament lamps are those ranging from the 15-W A-15 to the 1500-W PS-52, designed for 120-, 125-, and 130-V circuits. For lamps of 200 W and below, inside frost lamps are standard. White lamps are popular in the home because they achieve maximum diffusion of light from the filament without glare or harsh shadows.

B. Vibration Service and Rough Service Lamps: Lamps designed with added strength to the filament can provide lasting service in areas where shocks or rough handling are normal. Rough service lamps have more supports than the vibration service types.

C. Special Household Lamps: Ones such as a three-way can provide versatility in home lighting. It has two filaments which provide three levels of illumination through the use of a special base and socket combination. The "Bug-A-Way" lamp which has a yellow coating to minimize the attraction of insects is another example.

D. Reflectorized Lamps: These lamps can provide controlled lighting in a wide range of indoor and outdoor applications. The primary types are the PAR for outdoor service and the R for indoor service. They are available in both wide and narrow distribution patterns, and their wattages range from 25 to 1000. PAR and R lamps combine in one unit a light source and a highly efficient sealed-in reflector consisting of vaporized aluminum or silver applied to the inner surface of the bulb.

E. Sign and Decorative Lamps: Sign lamps are used where color and brilliance are desired outdoors. Translucent and transparent coatings are available with weather resistance. Decorative lamps are available in an assortment of shapes and finishes to meet decorative needs.

F. Appliance and Indicator Lamps: They are generally in small bulbs with candelabra or intermediate bases. Applications include vending machines, refrigerators, range ovens, and other appliances where pilot lights are required. Some are designed to withstand the extremes of both heat and cold.

G. Street Lighting Lamps: These lamps are designed to adapt to specific fixture requirements for accurate light control. Street series lamps are commonly rated in lumens and amperes instead of the watts and volts of multiple-type lamp ratings.

H. Signal Lamps: These lamps are used for marine, railway, and traffic signals. Marine and railway use involves a compact filament in S-8 and S-11 bulbs. Traffic signal lamps, generally in an A-21 bulb, can provide a durable long life and consistent signal control.

I. Precision Design Lamps: These are used in studio spotlights and applications where precise optical control of the filament is required. Prefocus or bipost bases are used to assure proper location of the filament in its fixture.

J. Aviation Lamps: They are used for aviation needs such as beacon, marker and signal lights. Special designs exist in the "T," "A," and PAR shaped bulbs to meet these needs.

K. Lumiline and Showcase Lamps: They are long tubular types approximately 1 in in diameter. Showcase lamps use standard screw bases whereas Lumiline lamps require an electrical connection at both ends through disk-type bases.

L. Infrared Lamps: These lamps are designed to operate at a low termperature resulting in much less light and more infrared than lamps for lighting purposes. These lamps are usually in R-40, G, and T bulbs. The tubular quartz lamps are very compact and high in thermal shock resistance. Their wattages range from 300 to 5000.

M. Tungsten Halogen Lamps: They are designed for general lighting as well as for numerous other applications. The halogen lamp features a regenerative cycle which keeps the bulb wall free from normal tungsten blackening. They are available in a wide range of wattages and varieties.

N. High- and Low-Voltage Lamps: Their design voltages are considerably higher or lower than the common 120 V. High-voltage lamps are designed at specific points between 208 and 300 V. Low-voltage lamps are generally classed from 6 to 64 V and are more efficient than the popular 120-V types.

APPLICATIONS OF INCANDESCENT LIGHTING

Downlighting

Luminaires producing direct lighting from a single source are called downlights. They can be fixed or adjustable, surface or recessed types. They are used to provide a higher level of controlled illumination at the merchandising level.

General service incandescent lamps in reflectors, or PAR and reflector lamps, are commonly used as sources. The light pattern may be circular, rectangular, triangular, or spread. Where radiant heat from lamps would damage merchandise or compromise human comfort, reflector lamps with special dichroic filters on the reflector can be used.

Luminaires should be inconspicuous both by design and location. Very low surface brightness in the normal line of vision is the primary consideration.

Spotlighting

The principal function of spotlighting is to accent feature displays with higher brightness, to create highlights and sparkle. Dramatic shadows and color are often developed. For vertical surfaces of the display, spotlights should be located such that their beam axes strike the important parts of the display from an angle of 25 to 30 degrees from the vertical. This assures natural highlight-shadow patterns. Since point sources, when controlled by reflectors, can be easily adjusted to create brightness in any direction, they are ideal lighting elements for providing the flexibility necessary in department stores. The wide variety of spotlighting equipment available includes those employing both reflector and PAR type lamps. They may be fixed or adjustable in position, recessed in the ceiling, surface mounted, or suspended. Track lighting provides a new dimension in spotlighting as well as many other applications with unparalleled flexibility.

Floodlighting

Incandescent lamps are often used because the light from their compact filaments is easily controlled by reflectors and lenses. While they are low in efficiency in terms of lm/W, they still can be efficient in relation to light reaching the surface. The "whiteness" of incandescent lamps increases with higher wattage lamps. The 1500-W floodlight and tungsten halogen lamps, when properly operated, will appear significantly "whiter" than the familiar 150-W PAR38 lamps. PAR and R lamps have their own built-in reflectors to provide light control. The beam of the PAR lamps is always more accurately controlled and provides higher candlepower than the corresponding R lamps. The R lamps are less expensive, less critical in aiming, but have less control in directing light to a specific area. Small buildings and monuments often use PAR or R lamps for grazing and accent floodlighting. Outline building lighting may be accomplished using general service incandescent lamps or sign lamps. For facade lighting, PAR and R lamps may be used. Tungsten halogen lamps are used to produce rectangular beam patterns.

Supplementary Lighting

It is used to provide a certain brightness or color, or to permit special aiming or positioning of light sources to produce or avoid highlights or shadows to best portray the details of the task. It becomes a valuable industrial lighting tool. Many machines, assembly, and inspection operations involving difficult seeing tasks may call for more illumination or a different type of illumination than can be provided economically by general lighting alone. General lighting in an industrial plant, if based on high-pressure sodium lamps, often requires some supplementary incandescent lighting for color identification tasks.

Studio Lighting for Television

There are two aspects of lighting for television production. The first has to do with controlling the light in terms of quantity, color, and distribution to produce a technically good picture. The second has to do with the design of lighting to produce a dramatic and artistic visual effect for broadcasting. In high-ceiling studios and in television theaters, the lighting units are supported either from fixed pipe grids or on counter weighted pipe battens. Here again, the most satisfactory light source is incandescent or tungsten halogen.

Miscellaneous Applications

A. Light in Horticulture: The light requirements for plant growth varies with plants. It has been found that all portions of the visible spectrum are effective to some degree, but the regions of maximum effectiveness lie between 560 and 720 nm in the orange-red region. The incandescent lamp, taking all factors into account, is a most satisfactory light source for day-length control. Reflector lamps and general service incandescent lamps in industrial reflectors are most commonly used.

B. Infrared Energy: Infrared radiant energy may be used for any heating application where the principal product surfaces can be arranged for exposure to the heat sources. Tungsten lamps ranging from 250 to 500 W are all rated for 115-125 V operation. The 250- and 375-W sizes are also available in the R-40 type with internal reflectors, and G bulb lamps require external reflectors. Quartz lamps with clear or diffusing surfaces are now in extensive use among the line sources for producing infrared energy. These lamps are available with effective heating length up to 50 in and permissible arrangements will provide energy density up to 75 W/in^2. External reflectors and special lamp holders are recommended, permitting final assembly in confined areas.

C. Airport Lighting: Most of the lighting installed on the landing areas of land and water airports is signal lighting. Such lighting conveys the necessary information to the pilot by means of its color, location, flash characteristic, or configuration, rather than by the illumination of areas or objects. Exceptions to this occur around the perimeter of the landing area, where service areas are floodlighted and wind direction is indicated by an illuminated wind cone. In all types of running lights, incandescent lamps are used as the light source.

THE EFFECTS OF ENERGY COSTS ON INCANDESCENT LIGHTING

Strangely enough, while Edison was toying with the incandescent lamp, he also invented the entire system of electric generation and distribution which carried his "magic" first to cities, then to rural areas, and finally throughout the world. The continuing improvements in the efficiency of the generation and distribution equipment during the early years of incandescent lighting helped drive the energy costs down steadily. Significant reductions in energy costs have been achieved which would have more than halved the cost of electric lighting since 1913, even if lamp performance had not improved at all. Table I indicates how steadily residential electric rates have been reduced in the U.S. This trend only reversed itself since the energy shortage in 1974.

To bring together all the factors affecting lighting cost, one must consider what has happened to the average cost of obtaining a given amount of light. This takes into account the reductions in energy cost, the reductions in lamp price, the increase in lamp efficiency, and the increase, if any, in lamp life. The record of Edison Electric Institute shows that the lighting costs in 1945 were 1.3 percent of what they were in 1882. About 60 percent of the saving since 1923 is attributable to reductions in the cost of electric energy, about 30 percent to increase in lamp efficiency, and about 10 percent to reductions in lamp prices.

Cheap energy in the United States has been a most influential factor in the flourishing incandescent lighting industry for several decades. However, since the recent energy crisis, the lighting industry has been facing one of its toughest

TABLE I
RESIDENTIAL ELECTRIC RATES

Year	Average Cost in Cents Per kWh
1913	8.70
1915	8.00
1920	7.45
1925	7.30
1930	6.03
1935	5.01
1940	3.84
1945	3.41
1950	2.88
1955	2.64
1960	2.47
1965	2.25
1970	2.10
1975	3.21
1976	3.45
1977	3.78

challenges to date. On one hand, light plays an important role in every walk of life and should be allowed to perform its intended function. On the other hand, the lighting industry has been called upon to make contributions to energy conservation. The lamp and lighting industries have responded exceedingly well. In the last five years, many new energy-saving light sources have been developed and made available to the users. Although intensive efforts have been centered in the high-intensity discharge (HID) light sources, especially high-pressure sodium, there are also many new developments and new ideas for energy saving in the incandescent lighting which are worth mentioning.

ENERGY SAVING IDEAS IN INCANDESCENT LIGHTING

Energy saving can be accomplished with incandescent lamps, and a variety of choices are available:

a) use of lower wattage lamps where less light is acceptable;
b) use of shorter life higher efficiency lamps;
c) use of reflectorized lamps in place of standard lamps;
d) use of transformer fixtures which accommodate low-voltage lamps.

The least effective way of saving energy with incandescents is a direct change to a lower wattage. In this type of substitution, a loss in light output in approximately the same proportion as the reduction in wattage must be acceptable in the lighting situation. The effects on task performance may not be acceptable. However, the variety of wattages available with direct interchangeability make this approach a consideration which should not be passed over.

A basic characteristic of incandescent lamps is the interrelationship between life (how long they last) and lumens (how much light they produce). Generally speaking, if one wishes to have more of one of these in a specific lamp design he must give up part of the other. This seesaw effect can be more visually demonstrated in Table II.

TABLE II
LUMEN COMPARISON CHART: AVERAGE LIFE IN HOURS

Wattage	Std.	2500 Hrs.	3500 Hrs.
40	480	415	400
60	890	740	670
75	1210	1000	-
100	1710	1480	1280
150	2850	2350	2150
200	3900	3250	2890

When a 100-W lamp at 355-h life design is replaced, an equal amount of light can be obtained from a 75-W lamp of 850-h life design. An energy saving of 25 W and a cost saving of $4 per year will result, assuming a 4000-h burning and $0.04 c/kWh cost.

A more important aspect of these energy-saving ideas, beyond energy and dollar savings, may be the necessity to comply with government regulations. Hence the incentives for a quick and simple change may be numerous.

Reflectorized lamps are available in a variety of styles and wattages. They provide a very versatile lighting tool. Based on a recent standard from the American National Standards Institute (ANSI), eight categories of beam spread ranging from extremely narrow spot to very wide flood attest to their versatility. Reflector (and PAR) lamps are designed to put the light on the work surface efficiently. With time, the reflector surface of a standard fixture may deteriorate in reflective ability for a variety of reasons. Although there is a loss in output over the life of a reflector lamp, a clean new reflector surface is provided with each new lamp. In addition, the filament is positioned optically within the reflector during lamp making to further maximize the efficiency of this source. In many instances, a reflector lamp of only half the wattage of a standard lamp can be quickly substituted with very nearly the same lighting results on the work surface. Fig. 1 provides a direct substitution guide for this energy saving scheme.

Low-voltage lamps are inherently more efficient than standard voltage design with equal life values. These gains vary by wattage and range in the vicinity of 10 to 30 percent. A relatively simple and inexpensive method is available to switch to low voltage. A change to track lighting could be the answer. Many track lighting fixtures with built-in transformers accommodate reflector low-voltage lamps, thus providing efficiency gains in two ways.

NEW DEVELOPMENTS IN INCANDESCENTS AND THEIR APPLICATIONS

Recent developments in incandescent sources prompted primarily by the energy shortage have occurred in the following areas:

a) new wattage sizes,
b) new bulb shapes,
c) new coatings,
d) basic design modifications.

Although a variety of wattages has been available for some

Present Lamp	60A (1000 hr)	60/99IF (2500 hr)	75A (850 hr)	75R30/FL (2000 hr)	100A (750 hr)	100/99IF (2500 hr)	150PAR FL (2000 hr.)	150R/FL (2000 hr.)	200A (750 hr.)
Substitute	30R20 (2000 hr.) 50R20 (2000 hr.)	50R20 (2000 hr.) 55PAR/FL (3000 hr.)	50R20 (2000 hr.) 60A (1000 hr.)	55PAR/FL (2000 hr)	75R30/FL (2000 hr) 75PAR/FL (2000 hr) 75ER30 (2000 hr.)	75PAR/FL (2000 hr) 75A (850 hr.)	100PAR/FL (2000 hr)	100PAR/FL (2000 hr)	150PAR/FL (2000 hr.)
Light Level*	100% 200%	200+% 200+%	175% 75%	150%	125% 200+% 200%	200+% 80%	70%	150%	200+%
Watts Saved	30 10	10 5	25 15	20	25 25 25	25 25	50	50	50
Annual Energy Cost Savings Per Socket**	$4.80 $1.60	$1.60 $ .80	$4.00 $2.40	$3.20	$4.00 $4.00 $4.00	$4.00 $4.00	$8.00	$8.00	$8.00

*Expressed as % of present level. Specific cases may vary depending on conditions. **Based on 4.000 hours/year and $0.04/KWH.

Fig. 1. A direct substitution guide.

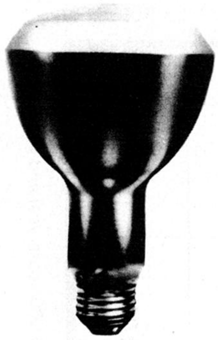

Fig. 2. Typical ER-30 lamp.

time in standard lamps, this has not been the case in PAR reflector types. The recent introduction of the lowest wattage PAR-38 for standard voltage, a 55-W now provides an energy-saving alternate where 75-W lamps are in use. Similarly, a 100-W is available to replace the popular 150-W size. Until recently there was no alternative to the use of 300-W PAR-56 lamps often used in high-ceiling lighting. Now a 200-W size can cut energy consumption by one third.

To maximize the utilization of light, a new elliptical bulb shape (ER) has been added to the reflector family. Three wattages of 50, 75, and 120 are currently available as replacements for existing parabolic ray reflector lamps. The beam pattern developed by the ER is ideally suited to the constraining action of well baffled fixtures. Much of the reflected light will initially converge, crossing at a point near the bottom of the fixture. Thus a minimum of light, i.e., energy, is trapped by the fixture. The mirror projection action of an ellipsoidal reflector is well-known. It has been applied to produce a concentration of light for theater and similar projectors for decades. However, these and other commercial applications have been principally in lighting equipment rather than lamps. This lamp is designed with a heat reflector disk to reduce base and socket temperature. The development of ER was an effective collaboration of application and engineering design. The resultant lamp has quickly demonstrated its unique characteristics in retrofit installations by gaining wide acceptance as a rational method of increasing energy optimization and permitting simplified visual comfort achievement. Fig. 2 shows a typical ER-30 elliptical reflector lamp.

The use of special bulb coatings designed to be selective to specific wavelengths of energy has resulted in a number of new incandescent products in recent years. The same basic concept is now being tried to improve the efficiency of incandescent lamps. The work now being conducted by a number of lamp manufacturers is designed to drive the infrared heat portion of the lamp energy back onto the filament to make better use of the energy originally generated by the tungsten wire. Success in this area of development may greatly improve the energy effectiveness of incandescent lamps for a great variety of applications.

Incandescent lamps are generally filled with Argon gas. Use of the heavier Krypton gas in recent years has resulted in small improvements in lamp efficiency. This gain occurs only if the majority of the gas fill is Krypton and the lamp was designed for efficiency improvement rather than some other benefit such as long life. A variety of Krypton lamps are currently available from several manufacturers for general lighting purposes.

A compact reflector bulb called PAR-36 has been known for its high efficiency. Up until a recent development, lamps of this type were confined to low voltage. Now a standard voltage 75-W lamp is on the market and brings with it compactness as well as high utilization of light from the source. This new lamp is used most effectively in a track light fixture as a medium level floodlight in commercial areas and in the home.

CONCLUSION

It is recognized that there have been no appreciable efficiency advances for many years. The opportunities for further increases in incandescent lamp efficiency seem to lie primarily in the economical use of gas fillings of Krypton and Xenon, in metallurgical advances in the uniformity and density of tungsten, and in advancements in the use of coatings. The possibilities are limited and there is little chance that incandescent light can rival the efficiencies of modern HID lamps. However, due to its unique simplicity in application and superiority in color rendition, even in today's climate of energy saving, incandescent lamps will have their place in the lighting industry.

After observing the 100th birthday of the incandescent lamp, one may get the feeling that occurs at New Year's Eve. The old is passing on and it is time to bring in the new. The incandescent lamp has a long future ahead. This paper is designed to help users of incandescent lamps who find them to remain the most practical for their lighting needs. New developments in incandescents will spring for many a decade to come.

REFERENCES

[1] *A Practical Guide to Westinghouse Incandescent Lamps*, 1968.
[2] A. A. Bright, Jr., *The Electric Lamp Industry*. New York: MacMillan, 1949.
[3] *IES Lighting Handbook*, 5th ed. New York, NY: Illuminating Engineering Soc., 1972.
[4] *Edison Electric Institute Bulletin, Operating Data & Ratios*, 1978.
[5] M. W. Evans, F. F. LaGiusa, and J. M. Putz, "An evaluation of a new ellipsoidal incandescent reflector lamp," *LD & A*, pp. 22–25, Mar. 1977.
[6] K. Chen, M. C. Unglert, and R. L. Malafa, "Energy saving lighting for industrial applications," *IEEE Trans. Ind. Appl.*, vol. IA-14, July/Aug. 1978.
[7] A. L. Hart, "Cutting lighting costs by applying energy efficient light sources," *Plant Engineering*, pp. 141–144, Mar. 8, 1979.

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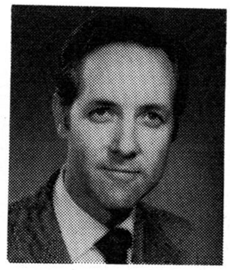

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Lighting Controls, Patterns of Lighting Consumption, and Energy Conservation

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Abstract—**Some of the important areas of the lighting energy conservation research program currently being carried out at the Division of Building Research, National Research Council of Canada, are described. The major emphasis of the program is to monitor present patterns and levels of lighting consumption in offices and schools and then develop and encourage cost-effective control systems to reduce the hours of use of lighting power loads. A new device to measure lighting energy consumption is described. Time-lapse photography is being employed to obtain detailed information regarding patterns of lighting use in offices and schools. This information is used to develop cost-effective manual- and automatic-control devices. The savings measured with a daylight-linked automatic system installed in a typical office are discussed.**

I. INTRODUCTION

THE DIVISION of Building Research (DBR), National Research Council of Canada, initiated a research program in January 1977 to investigate means of reducing lighting energy consumption in office and school buildings. Present estimates attribute 17 percent of the total lighting energy consumed in the U.S. to office and school buildings [1], and this same figure is generally assumed to be appropriate for Canada. The uncertainty in this estimate, however, becomes of academic interest to those owning and operating office and school buildings where lighting is often found to be one of the major consumers of energy, accounting for anywhere between 25 and 50 percent of total energy consumption in the building [2].

Lighting energy (E) is calculated as the product of two independent variables, power (p) and time (t):

$$E = P \times t.$$

Power is normally expressed in kilowatts and time in hours. This seemingly simple fact has been overlooked on many occasions by those involved in lighting energy conservation to the extent that their attention has focused entirely on reducing lighting levels (with an expected commensurate reduction in the installed or demand lighting load) as a sole means of achieving their goal.

Research at the DBR has taken a different approach. A major goal has been the development of a method of ensuring that lights are on when required and off when they are not. The alternative approach of advocating a general reduction in lighting levels is beset with difficulties. The choice of the "correct" or "adequate" lighting level is arbitrary, and its implementation often creates controversy and dissatisfaction. In addition, a reduction of lighting levels may lead to a lowering of productivity and increased absenteeism. Although evidence for this is not extensively documented, there is considerable laboratory data to indicate that reductions in productivity could be expected. Setting an upper limit to the installed

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