INDUSTRIAL AND PRACTICAL APPLICATION OF ENERGY CONSERVATION IN ELECTRICAL ENGINEERING

By

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I. ENERGY-SAVING LIGHTING FOR INDUSTRIAL APPLICATIONS

Steps to Achieve Energy Saving in Lighting

In many industrial lighting systems, significant energy savings can be accomplished by taking the following steps.

a) Reduce the number of lamps in the existing fixtures. This practice will result in reduced light output and quality, and may even create unsafe working conditions.

b) Replace existing lights with energy saving lamps. This approach will preserve the lighting distribution but does usually reduce the lighting level. Therefore, careful consideration must be given to the effect on safety and productivity. Since the energy crisis, several lamp manufacturers have introduced energy saving lamps. Replacing existing lights with these lamps can best be applied where the lighting level is higher than the recommended level. These lines include incandescent, fluorescent, and mercury vapor. Besides reducing the amount of electrical energy consumed by the lighting system, energy saving lamps can lower the power cost by helping maintain adequate power factor of the overall system. Economic comparison of conventional and energy saving lamps is given in Table I.

c) The most effective energy saving method is to update or modernize the present lighting system with high-efficacy, high-intensity discharge light sources. Table II is a useful guide in selecting light sources. Table II is a useful guide in selecting light sources for cost and energy savings.

Generally speaking, high-pressure sodium (HPS) lamps can replace mercury lamps with substantial savings. In some cases HPS lamps can also be used to replace fluorescent lamps with cost and energy, savings. In spite of the many merits of the high-intensity discharge (HID) light sources, it must be recognized that they do not relight instantly. An HPS lamp may take 45 x 1 min to relight, a mercury vapor up to 5 min, and a metal halide lamps as long as 15 min. Color rendition will vary depending on the HID source.

However, these factors are not generally of overriding importance for industrial applications. The lights are usually turned on once per day. Should power interruption occur, supplementary or emergency lighting is generally available in the area. Because of its poor color rendition, the low-pressure sodium light source is generally considered not satisfactory for industrial lighting application.

Criteria of Industrial Lighting

To create a quality lighting system for an industrial plant that provides both general and task illumination, a lighting engineer must consider many factors in choosing a particular light source. In analyzing the visual task in the area to be lighted, the appropriate equivalent sphere illumination (ESI) must be determined. A standard footcandle meter tells very little about our ability to see a given task. Depending on the effect desired, fixtures either having a wide spread or providing a precise beam pattern may be chosen. The color rendering quality of the lamp is essential. The efficacy of the lamp affects the cost of lighting from energy usage and maintenance considerations. Conditions present in the installation, such as ceiling height and line voltage are also important factors in selecting the type of lighting which will be most suitable. Some of the more important considerations for the application are discussed in the following sections.

A. *Color Perception*

Incandescent lighting has been considered as the artificial light source under which various colors are rendered in most natural appearance. There has been a concern with the HID lamps as to whether their color rendition of safety colors warrants their exclusion for industrial application. Study has indicated that there is little difference in the ability of the human eye to identify safety colors under incandescent, warm deluxe mercury metal halide, or high-pressure sodium lighting. Safety colors prescribed by OSHA are red, orange, yellow, green, blue, and purple. Test results show that overall color rendering properties of high pressure sodium lighting is satisfactory.

B. *Maintenance*

Maintenance is another important consideration during initial selection of a lighting system. If the cleaning cycle is chosen during the design stage, fewer luminaires can be used to achieve the desired footcandle level. A case study comparing high-pressure sodium versus mercury vapor, both with 12-month and 36-month cleaning cycles, indicates that the high-pressure sodium with a 12-month cleaning cycle has the lowest annual owning and operating cost per footcandle.

C. *Spacing*

The ratio of luminaire spacing to height of the luminaire above the work plane is a critical consideration in industrial lighting design. This relation is known as the spacing to mounting height ratio (S/MH). The value of S/MH in lighting fixture manufacturer catalogs is the maximum spacing that will result in relatively uniform lighting at the work plane. This spacing will provide good overlap of light between adjacent fixtures, regardless of interference from workmen or equipment. The wider the fixture spacing, the greater must be the light output from each fixture.

TABLE I

ECONOMIC COMPARISON OF CONVENTIONAL AND ENERGY SAVING LAMPS

Lamp	*Power Consumption (watts)*	*Rated Initial Output (lumens)*	*Rated Average Life (hours)*	*Power Cost Savings (dollars)*
Incandescent, Industrial Service				
Conventional	60	670	3500	
Energy Saving	54	590	3500	0.63*
Conventional	100	1280	3500	
Energy Saving	90	1090	3500	1.05
Conventional	150	2150	3500	
Energy Saving	135	1790	3500	1.59
Fluorescent, 48" RS/CW				
Conventional	40	3150	20000+	
Energy Saving	34	2800	20000	3.60
Fluorescent, 96" CW				
Conventional	75	6300	12000	
Energy Saving	60	5220	12000	5.40
Mercury Vapor, Clear				
Conventional	400	21000	24000+	
Energy Saving	300	14000	16000+	48.00
Mercury Vapor, Deluxe White				
Conventional	400	23000	24000+	
Energy Saving	300	15700	16000+	48.00

* (6 x 3500)/1000 x $0.03 = $0.63.

TABLE II

LIGHT SOURCE CHARACTERISTICS

Type	*LPW*	*Life x 1000*	*Lumen Maintenance*	*Color Rendition*	*Operating*
Incandescent	15-25	0.75-12	Fair to Excellent	Excellent	High
Self-Ballasted	20-25	16	Good	Good	Above Average
Fluorescent	55-85	7.5 -24	Fair to Excellent	Good to Excellent	Average
Mercury	50-60	16-24	Very Good	Poor to Excellent	Average
Metal Halide	80-100	1.5-15	Good	Very Good	Below Average
High Pressure Sodium	75-130	20-24	Excellent	Good Gold White	Low
Low Pressure Sodium	Up to 180	16	Excellent	Poor	Low

High intensity discharge lamps are available in lumen output sizes that span a range of more than ten to one. Initial cost of a lighting system will be lower if larger lamps and fewer luminaires are used. But using large lamps and spacing luminaires far apart can produce unsatisfactory. A good rule of thumb is to maintain a spacing to mounting height ratio of 1:1 or less. The overlap of light from adjacent fixtures and lamp shielding will be good, and reflector brightens will be within acceptable limits. When the mounting height is equal to the spacing between fixtures, the area covered by each luminaire is equal to the square of the mounting height. Multiplying the square of the mounting height by twice the desired average maintained light level yields a good approximate value for required initial lamp lumens.

D. *Economics*

In order to visualize the power required by various light sources to provide a given lighting level, we shall examine the results of a study taken on a common basis to deliver a maintained lighting level of 100 fc over a 10,000-ft^2 factory area. The following tabulation (Table III) provides a sense of the relative position among the light sources chosen. The data would also hold true for other similar interior lighting applications provided there were sufficient ceiling height for proper mounting of the fixtures.

Another example is lighting design for a factory area of 200 ft by 100 ft with a 27-ft mounting height for a maintained 100 fc level. Included in this study are mercury vapor, metal halide, high-pressure sodium, and fluorescent light sources. Economic comparison of the lighting systems proposed are as indicated in Table IV.

TABLE III

COMPARISON OF POWER REQUIREMENT

Lighting System	Fluor Super-Hi Sodium F962T12/CW	High Pressure Sodium 400W	Metal Halide 400W	Mercury Deluxe "Twins" 400W	Inc. 100W
No. of fixtures	73	40	65	59	70
Power Required (KW)	33.2	19	30	52	70
Relative Power Requirement (%)	175	100	158	274	368

TABLE IV

COMPARISON OF COSTS

Lighting System	400 HPS	400 MH	400W Mercury	1000W MH	1000W Mercury	F96T12/ CW Fluor.
Relative Initial Investment Per fc	1.29	1.54	1.92	1.0	1.73	1.49
Relative Annual Operating Costs Per fc	1.0	1.73	1.45	1.67	2.24	1.79

II. ENERGY CONSERVATION IN THE DESIGN OF BUILDING ENVIRONMENTAL SYSTEMS

Energy Consumption

Crude oil consumption for electricity in 1976 expected to cost 1.8 billion pesos.

Electricity usage in Meralco service area approximately 450 million kilowatt hours per month, equivalent to 700,000 barrels valued at 83 million pesos.

Consumption by seventeen (17) largest users of electricity in the hotel and commercial buildings sector as 105 million kilowatt-hours (=24 million pesos) in 1974.

Annual average for these 17 buildings: 6.2 Mkwhrs
1.4 million pesos

Energy Wastage

Recently reported studies by such American agencies as the Federal Energy Administration and the National Bureau of Standards have confirmed that waste is due to

(a) Inadequate construction
(b) Poor operating practice
(c) Inefficient equipment
(d) Unnecessary lighting and cooling levels

Energy Conservation Codes for New Buildings

In recognition of the need to conserve energy, energy conservation codes pertaining to the design of new buildings have been adopted in more than twenty American states and most of the others are contemplating the imposition of performance standards.

The greatest potential for reducing the amount of energy used in buildings lies in existing building themselves because these are, quite obviously, more numerous.

Impact of Application of Conservation Standards

The adherence to performance standards in the design of new buildings is expected to have a broad impact on the design and construction industry. The construction and operation of buildings will be beneficially affected.

Consider, for instance, that a future typical building which attains a reduction in its operating cost of only ten percent can save the owner 140,000 pesos annually—at present-day cost of energy. This can be expected to double in 5 to 7 years, notwithstanding the discovery of oil-bearing strata in the Palawan area.

Potentially, the survey can be substantial—up to 50 percent?

1. Impact on Building Energy Consumption.
   —Every effective in reducing annual energy consumption in all building types
2. Impact on Physical Characteristics
   —Exterior glass—glass area (percent fenestration) reduced

—Exterior walls—reduction in glass area balanced by increased net wall area
—Insulation—Additional insulation required
—Lighting—Reduction in lamps and fixtures
—Airconditioning and ventilation—Reduction in cooling plant capacity, reduction in sizes of fans, pumps, towers, etc.

3. Impact on Building Economics
   —Percent savings in annual energy cost appreciable. Initial construction cost for energy-modified buildings less than those of conventional" buildings
4. National Energy Consumption
   —Can reduce national consumption substantially, may help slow down energy-usage growth rate.
5. Impact on Building Materials
   —Increase demand for building materials such as insulation and double glazing but reduce markets for equipment and building AC systems.
6. Impact on Key Industry Participants
   —Requires additional design effort involving more calculations, technical evaluation, interactions among design team members, liaison with code authorities.
   —Requires use of electronic computer programs and services Problems of implementation and enforcement.
7. Impact on Building Habitability
   —Increased importance of indoor air pollution sources.

The IES 12 recommendations

1. Design lighting for expected activity (light for seeing tasks with less light in surrounding nonworking areas).
2. Design with more effective luminaires and fenestration (use systems analysis based on life cycle).
3. Use efficient light sources (higher lumen per watt output).
4. Use more efficient luminaires.
5. Use thermal-controlled luminaires.
6. Use lighter finish on ceilings, walls, floor and furnishings.
7. Use efficient incandescent lamps.
8. Turn off lights when not needed.
9. Control window brightness.
10. Utilize daylighting as practicable.
11. Keep lighting equipment clean and in good working condition.
12. Post instructions covering operation and maintenance.

TABLE 1. *Characteristic of basic lamp types*

Characteristics	*Incandescent (Including Tungsten Halogen)*	*Fluorescent*	*High-Intensity Discharge (HID)*		
			Mercury-Vapor	*Metal-Halide*	*High Pressure Sodium*
Wattages (lamp only)	15 to 1500	40 to 219	40 to 1000	400, 1000, 1500	75, 150, 250, 400, 100
Life (hours)	750 to 12000	9000 to 30000	16000 to 24000	1500 to 1500	10000 to 20000
Efficacy (lumens per watt, lamp only)	15 to 25	55 to 88	20 to 63	80 to 100	100 to 130
Color redition	Very good to excellent	Good to excellent	Poor to very good	Good to very good	Fair
Light direction control	Very good to excellent	Fair	Very good	Very good	Very good
Source size	Compact	Extended	Compact	Compact	Compact
Delight time	Immediate	Immediate	3 to 5 minutes	10 to 20 minutes	Less than 1 minute
Comparative fixture cost	Low because of simple fixtures	Moderate	Higher than incandescent, generally higher than fluorescent	Generally higher than mercury-vapor	Highest
Comparative operating cost	High because of relatively short life and low efficacy	Lower than incandescent; replacement costs higher than HID because of greater number of lamps needed; energy costs generally lower than mercury- vapor	Lower than incandescent; replacement costs relatively low because of relatively few fixtures and long lamp life	Generally lower than mercury-vapor; fewer fixtures required, but lamp life is shorter and lumen maintenance not quite as good	Generally lowest; fewest fixtures required

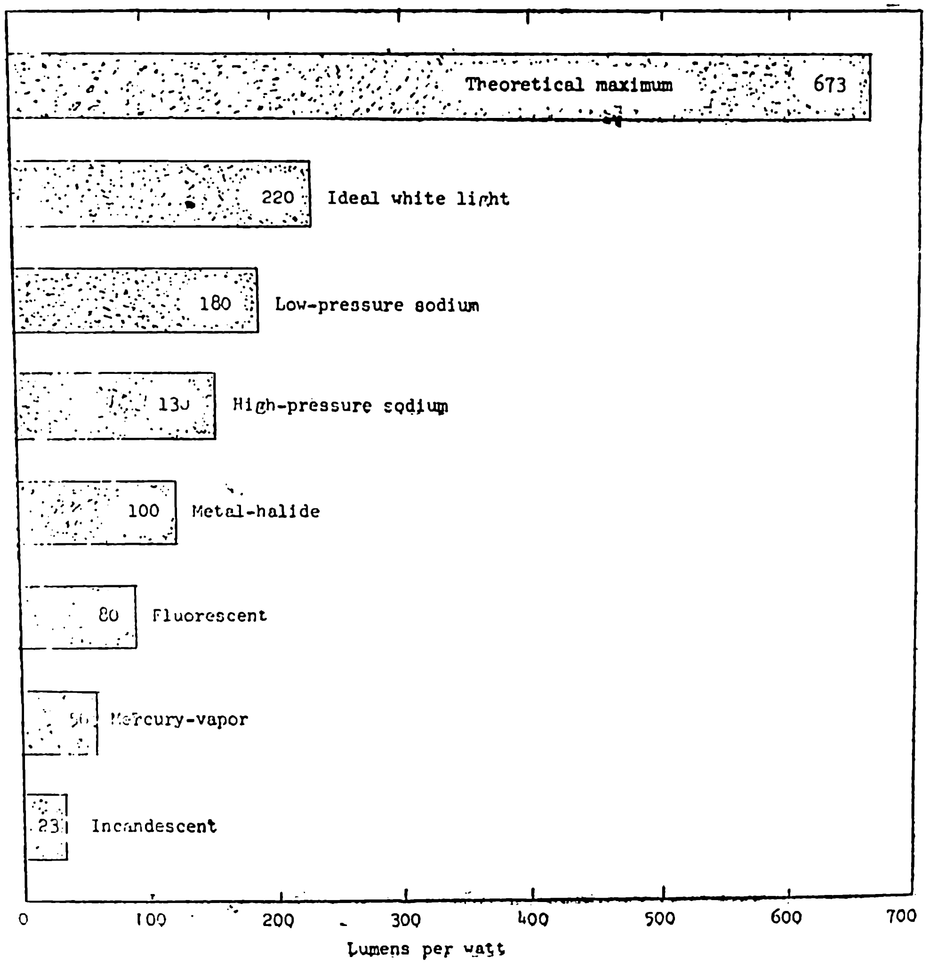


FIG. 1.—*Relative Efficacies of Lamp Sources.*

III. *LIGHT SOURCES*: *A PRIMER*

Incandescent: The efficacy of light production by incandescent filament lamps depends on the temperature of the filament—the higher the temperature, the greater the portion of radiated energy that falls in the visible region. And, although early incandescent lamps used carbon, osmium, and tantalum filaments, tungsten's high melting point (3655°K) and low vapor pressure permit higher operating temperatures and, as a result, high efficacies. Because filament configuration is also a factor —coils increases efficacies—past improvements in incandescent lamps have involved changes in filament shape. Recent improvements, however, are primarily a result of changes in the atmosphere inside the glass bulb that encloses the filament. Although early incandescent sources were manufactured with evacuated bulbs to prevent filament burn-up, the discovery that inert gases retard evaporation of the filament made it possible to design lamps for higher filament temperatures. Today, most incandescent lamps use a fill mixture of argon and nitrogen; however, Superman's anathema, krypton, is also used, for much the same reason that it's found in reduced-wattage fluorescent sources; improved efficacy and lumen maintenance because of the reduced filament heat loss.

Tungsten-halogen lamps are a variation of incandescent filament sources. A halogen additive in the bulb reacts chemically with the tungsten, removing deposited tugnsten from the bulb and redepositing it on the filament. This results in a lumen maintenance factor of close to 100 percent. (Lumen maintenance refers to the ability of a lamp to maintain a constant light output. In an ordinary tungsten filament lamp, light output is reduced by the sublimed tugnsten that collects on the inner surface of the bulb). However, such a lamp does have a definite life, usually a maximum of 3000 hours. Although important in general lighting, these characteristics of tugnsten-halogen have meant significant changes for specialized applications like stage and studio lighting. The smaller size, good optical control, and high color temperatures of tungsten-halogen lamps, as well as a continuous spectrum, fit theatrical lighting needs.

The most popular incandescent lamps are general service (GS) ones, which range from the 15-watt A-15 to the 1500-watt PS-52 types and are designed for 120-, 125-, and 130-volt circuits. (The letter prefix refers to the lamp shape—for example, PS is a pear straight neck; A is the standard incandescent shape. Other common designations are G for globe and PAR for parabolic aluminized reflector. The number following the letter prefix is the bulb diameter in eights of an inch.)

Higher-wattage GS lamps are more efficient than lower-wattage GS ones. For example, one 100-watt GS lamp produces more light than two 60-watt lamps (1750 lumens versus 2 times 860 lumens, or 1720 lumens.)

For the same wattage, GS lamps (750 to 1000 hours of life) are more efficient than extended service (FS) lamps (2500 hours of life). ES lamps—for use where replacement costs are relatively high, such as hard-to-reach locations—achieve long life by use of a filament that is stronger, but less efficarious. A 100-watt GS lamp produces 17.5 lumens per watt, whereas a

100-watt ES lamp produces 14.8 lumens per watt. For equal lighting results in this instance, 18.2 percent more lamps and energy are required when using the ES lamps, but in many applications, the actual level of illumination is not of significance, and the longer socket life offers economies.

Because of its versatility, the incandescent lamp survives in spite of its poor economics and efficacy, the interchangeability of many types and ratings in the same socket, easy dimming, and a variety of shapes and kinds all contribute to the lamp's popularity.

Fluorescent. Fluorescent lamps offer three to five times the efficacy of incandescent sources and compare favorably with most HID sources. Efficacies vary with lamp length, lamp loading, and lamp phosphor coating.

This lamp uses an electric-discharge source, in which light is produced predominantly by fluorescent powders activated by ultra-violet energy generated by a mercury arc. The fluorescent lamp cannot be operated directly from the nominal 120-volt ac source because the arc discharge would not be established, and —even if it were—current would rise until the lamp was destroyed. As a result, it must be operated in series with a ballast that limits the current and provides the starting and operating lamp voltages.

Fluorescent lamps are tubular bulbs of small cross-sectional diameter. Two electrodes are hermetically sealed into the bulb, one at each end. Electrodes for flow or "cold cathode" operation operate at a current in the order of a few hundred milliamperes, with a high cathode fall-over voltage of 50 volts, the more common arc mode or "hot cathode" electrode is usually constructed from tungsten wire coated with a mixture of alkaline earth oxides. During lamp operation, the coil and coating reaches temperatures of approximately 1100°C, at which the coil/coating combination thermally emits large quantities of electrons at a low cathod fall-over voltage of 10 to 12 volts. Because of the lower cathode fall-over voltage of the hot cathode fluorescent lamp, more efficient lamp operation results; consequently, most fluorescent lamps are designed for "hot" cathode operation.

Both geometric design and operating conditions of a fluorescent lamp affect the efficacy with which electrical energy is converted into visible radiation. For example, as lamp diameter increases, efficacy increases, passes through a maximum, then decreases. The length of the lamp also influences its efficacy: the longer it is, the higher the efficacy.

The starting process occurs in two stages: once a sufficient voltage exists between an electrode and ground, ionization of the gas (mercury plus an inert gas) in the lamp occurs; then, a sufficient voltage must exist across the lamp to extend the ionization throughout the lamp and to develop an arc. Three basic types of ballasts—preheat, instant start, and rapid start—provide means of starting.

Early lamps were all of the preheat variety, which required a starting switch. As the name suggests, the electrodes are heated before the application of high voltage across the lamp—usually by means of the automatic switch, which places the lamp electrodes in series across the output of the ballast. (As ambient temperature decreases, starting of all fluorescent lamps becomes more difficult.) Arc initiation in instant start lamps depends entirely on the application of a high voltage (400 to 1000 volts) across the lamp, which ejects electrons by field emission. These electrons ionize the gas and initiate arc discharge, which provides electrode heating. The rapid start principle makes use of electrodes that are heated continuously by means of low-voltage windings built into the ballast. A power-saving feature of rapid-start circuits is that the lamps show little change in rated life as a result of frequent on/off/on cycles. And, at a time when consumers are urged to turn off the lights to save energy, this feature has particular significance. In instant-start and preheat circuits, the electrodes erode during the starting and burning cycle; consequently, rated life decreases if the lamp is turned on and off with great frequency.

Although widely used in offices, schools, stores, and industry, fluorescent lamps have had limited acceptance in residential applications because of their shape and color; however, the energy crunch may change this. Because of their long life and high efficacy, fluorescent lamps in utility areas like kitchens and bathrooms can reduce wattage requirements in the home.

In addition to improvements in light output and life, progress in color rendering ranks high in fluorescent lamp developments, as evidenced by intensive research into new phosphors. Infrared phosphors, for example, are a possibility and already exist in some lamp types. Most users, though, are most concerned with the shade of white that is best for a specific environment.

Mercury. Mercury lamps, which were widely used in street lighting in the early 1960s and are now popular choices for lighting commercial interiors, use argon gas to ease starting because mercury has a low vapor pressure at room temperature. When the lighting circuit is energized, the starting voltage is impressed across the gap between the main electrode and the starting electrode, which creates an argon arc that causes the mercury to vaporize. The lamp warm-up process takes 5 to 7 minutes, depending on ambient-temperature conditions. Most mercury lamps are constructed with two envelopes—an inner one that contains the arc, and an outer one that shields the arc tube from outside drafts and changes in temperature. The outer envelope usually contains an inert gas that prevents oxidation of internal parts and maintains a high breakdown voltage across the outer bulb parts, as well as providing an inner surface for the coating of phosphorus.

The pressure at which a mercury lamp operates accounts in part for its characteristic spectral power distribution: within the visible range, the mercury spectrum results in greenish-blue light at efficacies of 30 to 65 lumens per watt. Nevertheless, as Fig. 1 indicates, the mercury lamp is far from being an efficacious source, and it ranks between incandescent and fluorescent lamps in lumen-per-watt output. Economics favor mercury where burning hours are long, service is difficult, and replacement labor is high. However—all other factors considered equal—a fluorescent system tends to be less costly because of its higher efficacy. But this hardly rules out use of the mercury lamp, which is still very much alive and well.

Low-wattage mercury lamps, for instance, have replaced less-efficient incandescent lamps in small luminaires. There have beeen improvements in color rendering as well. New phosphors improve color, increase light output, and reduce surface brightness. A "warm deluxe white" mercury produces an apparent color temperature of 3300°K and can be used in indoor commercial applications in place of fluorescent lamps.

A challenge for manufacturers is improvement in high-output depreciation characteristics. Many mercury lamps lose as much as 50 percent of their initial output during their rated life of 24,000 hours or more.

Another challenge to manufacturers of mercury lamps is the health hazard resulting from eye and face burns suffered by those exposed to radiation from broken mercury lamps used in gymnasiums. The inner quartz arc tube of the lamp continues to burn for up to 100 hours, and, without the outer glass to absorb excess radiation, a dangerous level of ultraviolet rays are emitted. The U.S. Bureau of Radiological Health has asked the major lamp manufacturers to supply information about the radiation characteristics of their lamps, and it presented a report to the Technical Electronic Product Radiation Safety Standards Committee in September. Meanwhile, at least one manufacturer has developed a mercury lamp with an arc tube that extinguishes repidly after air enters the ruptured outer bulb.

Other developments in the mercury category includes a 300-watt self-ballasted lamp that incorporates solid-state starting and higher efficacy. The solid-state circuit is "potted" in the base and acts as a voltage doubler. This eliminates the need for a bimetal switch on the 120-volt lamp and provides a high degree of reliability throughout the 16,000 hours of rated life. In addition, the ratio of arc-tub watts to ballast watts is increased. These lamps can be used where high temperatures are likely to damage external ballasts and where insertion in incandescent luminaires provides an increase in illumination.

Derated mercury lamps are also available. They yield lower lumen outputs for a lesser corresponding reduction in energy consumed, for example, a 300-watt mercury lamp is available that operates on either 400-watt constant wattage or regulated output ballasts.

Metal-halide — Metal-halide lamps are similar in construction to the mercury lamp, except that the arc tube contains various metal halides in addition to mercury. When the halide vapor approaches the high-temperature, central core of the discharge, it disassociates into the halogen and the metal, with the metal radiating its appropriate spectrum. As the halogen and metal move near the cooler arc tube wall by diffusion and convection, they recombine and the cycle repeats itself. This cycle has to advantages: metals that cannot be vaporized at the temperatures that a fused silica arc can withstand can be introduced into the discharge by disassociation of the halides, which vaporize at much lower temperatures; and other metals that react chemically with the arc tube can be used in the form of a halogen, which does not readily react with the fused silica.

These lamps generate light with more than half the efficacy of the mercury arc, offer a small light-source size for optical control, and provide good color rendition as compared with clear mercury. They have been applied in nearly every type of interior and exterior lighting application because they offer an efficient "white" light source.

Like mercury lamps, metal-halide sources produce less light in certain burning positions than others. For example, mercury lamps may produce from 3 to 11½ percent less light when operated horizontally instead of vertically. The most extreme case is the 1500-watt metal-halide lamp, for which an angle of 70 degrees from the vertical or 20 degrees above the horizontal can produce a drop of as much as 25 percent. Part of the reason for this loss is that the arc stream in the horizontal operating lamp is bowed into an arc within the arc tube by convection currents from the hot fill gases. A newly designed arc tube, arched so that the arc stream flows through the center of the quartz tube, provides lumen gains of 10 percent (the 175-watt lamp) and 25 per cent (the 400-watt lamp) over its vertical-operating counterparts.

Sodium — Low-pressure sodium (LPS) lamps have been used in public lighting for some 40 years and are seen most frequently in Europe, where they are used for roadway lighting. Because of their distinctive monochromatic, deep yellow color, they are also used in the United States for lighting tunnels and toll plazas, as well as industrial areas where security is more important than color rendition. HPS lamps which became available in 1965, are used in many U.S. cities for roadway and sidewalk illumination and offer more suitable color rendition characteristics. With either lamp, sodium is particularly suitable because most of its radiation is concentrated in a wavelength interval where the sensitivity of the human eye is high. It also has a relatively low excitation energy.

Light from the LPS lamp is emitted from a long, U-shaped arc tube placed inside an outer tubular glass enclosure. A vacuum surrounding the arc tube—along with a heat-effecting coating on the other bulb—conserves heat and improves luminous efficacy. It is the most efficient commercial light source, with an efficacy of 10 lumens per watt in the largest size of 180 watts. It looks somewhat like an oversized fluorescent tube, but because of its length, does not fit into a compact luminaire as do other sources.

In both low- and high-pressure sodium sources, light is produced by electricity passing through sodium vapor. In the LPS lamp, a starting gas of neon produces a red glow when the lamp is initially ignited. As heat is generated, the sodium metal vaporizes, and the emitted light turns into the characteristic yellow color. The vapor pressure of the sodium must be in the order of 5 x 10^{-3} mm of mercury to achieve the maximum efficacy. This corresponds to an arc tube bulb wall temperature of about 260°C (500°F), which is why the arc tube is enclosed in a vacuum.

The HPS lamp is constructed with two envelopes—the inner being polycrystalline alumina, which is resistant to sodium attack. The arc tube contains xenon as a starting gas and a small amount of sodium-mercury amalgam. The outer borosilicate glass envelope is evacuated and protects against chemical attack of the arc tube and maintains the arc tube temperature.

HPS sources are compact, yet have high efficacies (up to 140 lumens per watt) and high lumen maintenance characteristics. They radiate energy across the visible spectrum and produce a golden-white color. They are available in sizes from 70 to 1000 watts, with the low-wattage sources finding application in residential street-lighting and shopping-mall illumination.

HPS lamps have five times the efficacy of incandescent sources, more than twice that of mercury, and 50 percent more than metal-halide—which is one of the reasons for their popularity at a time when energy is both scarce and expensive.

One manufacturer has introduced a family of HPS lamps for use in existing mercury liminaires. This lamp can increase illumination in certain installations by 70 percent and reduce energy consumption by10 percent. A tungsten glow coil wound around the arc tube enables this lamp to operate without the usual high-voltage starting aid. When power is applied to the lamp, the tugnsten coil heats the tube to the required 300°C temperature, and two bimetallic switches remove the heater from the circuit at full light output. This permits a standard 400-watt, 240-volt mercury reactor or lag-type transformer to be used with the HPS lamp.

Because of its high efficacy, the HPS lamp is finding application in areas other than roadway lighting. Not only is it being specified for industrial interiors, but several manufacturers have used this HID source in office areas. "Streetlights" in offices may sound extreme, but the lamps used ranged from only 100 to 400 watts, and special lenses and reflectors were used to achieve a broad light distribution appropriate for low-ceiling applications.

TABLE I

THERMAL EFFICIENCY IN POWER GENERATION

Prime Mover	*Thermal Efficiency*	*Energy Lost*
Gas Turbine		
1) Simple	24 - 30%	70 - 76%
2) Regenerative	28 - 36%	64 - 72%
Steam Turbine	25 - 35%	65 - 75%
STAGE—Unfired (steam and gas turbine combination)	25 - 34%	66 - 75%
STAG—Fired	50 - 60%	40 - 50%

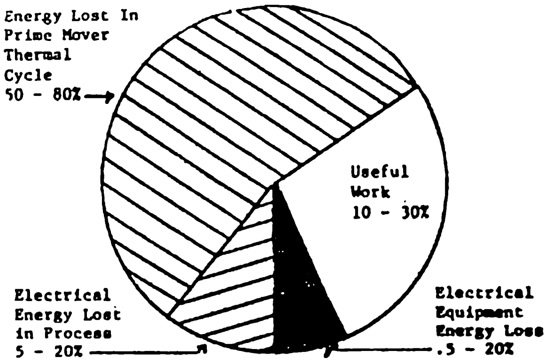


Fig. 1. Consumption of energy in industrial process.

TABLE -II

RANGE OF LOSSES IN POWER SYSTEM EQUIPMENT

Component	*% Energy Loss (full load)*
A. Outdoor Circuit Breakers (15 to 230 KV)	.002 – .015
B. Generators	.09 – 3.50
C. Medium Voltage Switchgear (5 & 15 KV)	.005 – .02
D. Current Limiting Reactors 600V to 15 KV)	.09 – .30

E. Transformers	.40 –	1.90
F. Load Break Switches	.003 –	.025
G. Medium Voltage Starters	.02 –	.15
H. Busway (480 V & Below)	.05 –	.50
I. Low Voltage Switchgear	.13 –	.34
J. Motor Control Centers	.01 –	.40
K. Cable	1.00 –	4.00
L. Motors		
a. 1 – 10 hp	14.00 –	35.00
b. 10 – 200 hp	6.00 –	12.00
c. 200 – 1500 hp	4.00 –	7.00
d. 1500 & up	2.30 –	4.50
M. Rectifiers (large)	3.00 –	9.00
N. Static Variable Speed Drives	6.00 –	15.00
O. Capacitors (watts loss/var.)	.50 –	2.00
P. Lighting (lumens/watt)	3.00 –	9.00

LOSS DATA

Generators

Losses for 3600 r/min 13.8 kV industrial generators are as follows.

KVA	*P.F.*	*Cooling*	*% Eff.*	*% Loss*
5 000	.8	Direct Air	97.2	2.8
7 500	.8	" "	97.2	2.8
9 375	.8	" "	97.6	2.4
12 500	.85	" "	98.1	1.9
18 750	.85	" "	98.3	1.7
29 412	.85	" "	98.3	1.7
44 118	.85	" "	98.3	1.7
29 412	.85	30# – H_2	98.7	1.3
64 000	.85	" "	98.7	1.3
90 000	.9	" "	98.9	1.1
115 000	.85	" "	98.9	1.1
150 000	.9	" "	99.0	1.0
175 000	.9	" "	99.1	.9
196 000	.9	" "	99.1	.9
220 000	.9	45# – H_2	99.0	1.0
246 000	.85	" "	99.0	1.0
300 000	.85	" "	99.0	1.0

Note: Losses include windage and friction but not seal and bearing losses as per standard ANSI C50.10.

Medimum-Voltage Switchgear-5 and 15 Kv

Estimated full-load losses for both 5 and 15 kV are

Breaker Units (amperes)	*Air Magnetic (watts)*	*Vacuum*
1200	1000	500
2000	1500	750
3000	2500	1250

Auxiliary compartment average 500 W for air magnetic and 300 for vacuum. The bus duct includes losses:

1200 A	75 W/ft.
2000 A	100 W/ft.
3000 A	175 W/ft.

Notes

1) Above losses are for indoor units. For outdoor units add 500 W/unit for heaters if air magnetic and add 300 W/unit if vacuum.
2) Losses are approximately the same for an alumnium or or copper bus.
3) Losses very as the square of the current throughout range.

The percent energy losses of breaker units with load at 0.9 PF for all ratings are

Voltage (kilovolts)	*Efficiency (percent)*	*Losses (Percent)*
2.4	99.98	0.02
4.16	99.99	0.01
13.8	99.994	0.006

Transformers

Representative energy losses in transformers at self-cooled rating, rated kVA, and 55°C rise are as follows.

1) Load Center Type-three-phase, oil, or Pyranol. For a 2.4, 4.16, 6.9, 12, 13.2, or 13.8 kV delta primary 480, 480Y/277 V delta or wye.

Oil-Air Rating (kVA)	*No-Load Loss (watts)*	*Total Loss (watts)*	*Loss (percent)*
750	1940	15 670	1.79
1000	2660	16 170	1.60
1500	3390	22 910	1.51
2000	3850	27 100	1.34
2500	5220	31 960	1.27

2) Substation Type-three-phase, oil, or Pyranol for a 2.4, 4.16, 6.9, 12, 13.2, or 13.8 kV delta primary 480, 480Y/277 V delta or wye secondary,

Oil-Air Rating (kVA)	*No-Load Loss (watts)*	*Total Loss (watts)*	*Loss (percent)*
750	1950	9 300	1.38
1000	2500	11 800	1.31
1500	3400	16 300	1.21
2000	4400	21 000	1.17
2500	5200	24 700	1.10

3) Power and lighting transformers for 480 to 120/240 V single phase or 480 to 208/120 V three phase are shown.

Single Phase	*Watt Loss*	*Three Phase*	*Watt Loss*
1	60	9	295
2	90	15	460
5	190	30	1400
7.5	240		
10	290		
15	350		
25	430		

Motors

Energy losses are shown for motors at rated load. Losses in small motor (induction type, three-phase, type K, 875, 1165, 1750, and 3550 r/min at rated load, 115, 230, or 460 V) follow.

		Horizontal Dripproof		TEFC	
HP	Syn. *Speed*	*% Eff.*	*% Loss*	*% Eff.*	*% Loss*
1/2	3600	69.0	31.0	69.0	31.0
	1800	69.0	31.0	69.0	31.0
	1200	70.5	29.5	70.5	29.5
	900	62.5	37.5	62.5	37.5
1	3600	74.5	25.5	74.5	25.5
	1800	75.0	25.0	75.0	25.0
	1200	73.0	27.0	73.0	27.0
	900	70.0	30.0	70.0	30.0
2	3600	79.0	21.0	79.0	21.0
	1800	79.5	20.5	79.5	20.5
	1200	78.5	21.5	78.5	21.5
	900	70.0	30.0	70.0	30.0
3	3600	80.0	20.0	75.5	24.5
	1800	80.5	19.5	80.5	19.5
	1200	76.0	24.0	78.0	22.0
	900	74.0	26.0	74.0	26.0
5	3600	83.0	17.0	80.5	19.5
	1800	84.0	16.0	84.0	16.0
	1200	79.0	21.0	78.0	22.0
	900	78.0	22.0	78.0	22.0
7½	3600	84.5	15.5	79.0	21.0
	1800	82.0	18.0	82.5	17.5
	1200	84.5	15.5	83.0	17.0
	900	79.0	21.0	79.0	21.0
10	3600	84.5	15.5	82.5	17.5
	1800	83.0	17.0	83.0	17.0
	1200	84.0	16.0	82.0	18.0
	900	81.0	19.0	80.0	20.0
15	3600	86.0	14.0	82.0	18.0
	1800	86.5	13.5	86.5	13.5
	1200	85.0	15.0	87.0	18.0
	900	82.0	18.0	83.0	17.0

20	3600	87.0	13.0	86.0	14.0
	1800	87.5	12.5	87.5	12.5
	1200	87.0	13.0	85.0	15.0
	900	85.0	15.0	85.0	15.0
30	3600	87.0	13.0	86.5	13.5
	1800	89.0	11.0	89.5	10.5
	1200	88.5	11.5	89.0	11.0
	900	88.0	12.0	90.0	10.0
40	3600	88.0	12.0	86.5	13.5
	1800	88.5	11.5	90.5	9.5
	1200	89.0	11.0	90.0	10.0
	900	88.0	12.0	90.0	10.0
50	3600	89.0	11.0	88.0	12.0
	1800	89.5	10.5	91.5	8.5
	1200	90.0	10.0	91.5	8.5
	900	89.0	11.0	90.0	10.0
75	3600	90.5	9.5	90.5	9.5
	1800	91.0	9.0	92.0	8.0
	1200	91.0	9.0	92.0	8.0
	900	91.0	9.0	92.0	8.0
100	3600	91.5	8.5	91.5	8.5
	1800	92.5	7.5	93.0	7.0
	1200	91.5	8.5	91.5	8.5
	900	92.5	7.5	93.5	6.5
150	3600	92.0	8.0	91.5	8.5
	1800	93.0	7.0	93.0	7.0
	1200	91.5	8.5	93.5	6.5
	900	92.5	7.5	92.5	7.5
200	3600	91.5	8.5	92.0	8.0
	1800	94.0	6.0	93.0	7.0
	1200	93.0	7.0	93.5	6.5
	900	—	—	—	—
300	3600	92.5	7.5	93.5	6.5
	2400	93.0	7.0	93.0	7.0
	1200	—	—	—	—
	900	—	—	—	—

Power Factor Correction Capacitors

Energy losses per kvar for 2400 V and above open stack rack capacitors units are

1) paper/pyranol 2 W/kvar;
2) magvar 0.5 W/kvar.

Notes

1) Watt losses are based on rated voltage and vary as the square of the voltage. Capacitor life is in part a function of temperature and goes down rapidly with over-voltage because of it.
2) For enclosed outdoor units, add 0.1 W/kvar for bus, switch, and fans.

Since there is no through energy in a capacitor bank losses cannot be expressed as a percent but must be added and weighted against savings due to improvement of power factor and energy.

CHECK LIST OF POSSIBLE SAVINGS

The main purpose of this paper is to point power system engineers in the direction of where energy losses are or where to go to start plugging energy leaks. We would miss an opportunity, however, not to provide a simple check list of ideas on possible energy savings. Their worth may vary considerably from plant to plant. To convert ideas to actual dollar savings is a specific study for each application.

A) Quite naturally, the place to start is in the power generation area. Efficiency improvements in converting fuel energy to electrical energy can be dramatic. The days of low pressure boilers and steam turbines or low efficiency simple cycle gas turbines as drivers for small generators are fading fast under today's high fuel energy cost. Power companies exist because they can deliver a kilowatt-hour of energy at your plant even with all of their transmission system at a cheaper cost than you could generate it because of better cycle efficiency and larger generating units.

B) Examine cable sizes in your distribution system, particularly in the low voltage area of 208 and 480 V. The code says that a feeder circuit should have no more than 3 percent voltage regulation. New economic factors may say that in actual practice this should be no more than 1½ percent.

C) Reduce lighting loads by the following

   1) Use more efficient light sources such as sodium in place of mercury vapor on structures and towers. In cost per million lumen hours, the lighting of a 400 W high-pressure sodium lamp is 31¢, a 100 W incandescent source is $2.26, and a common candle is $3000.
   2) Use more efficient laminaires.

3) Use lighter colors on walls, structures, etc., to reflect more light.

4) Keep lighting equipment clean.

5) Cut down footcandle levels of lighting, particularly in nonworking areas such as cat walks, halls, etc. The Federal Energy Administration recently passed a guideline for

workstations and desks	50 fc
general work area	30 fc
halls and corridors	10 fc

This guide, though not mandatory yet, will generally cut present levels in half. In building interiors, a secondary savings is in decreased air conditioning load.

6) Cut wasted light. Put lighting on timers or photoelectric controls. In general it has been estimated that potential savings in lighting loads with the same lighting effectiveness are

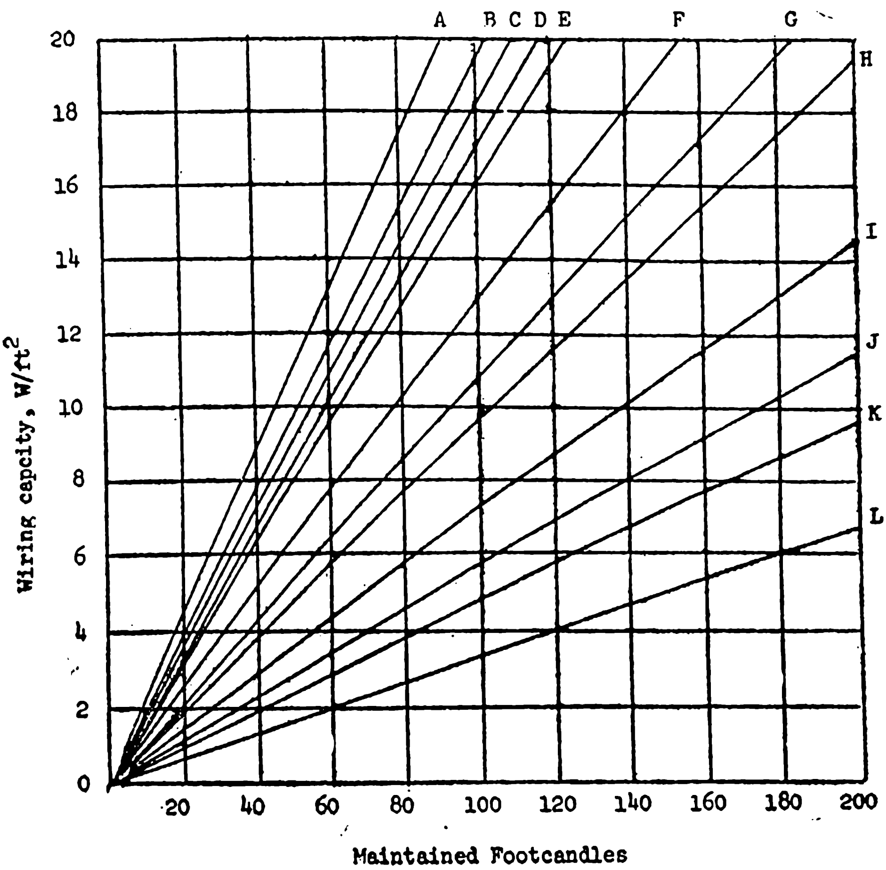
residential	10-20 percent
commercial	15-35 percent
industrial	5-20 percent.

D) Use power factor correction capacitors to reduce system losses. Normally we think of capacitors being installed to improve power factor, release system capacity, and lower billing demand charges. They also produce an important savings in energy losses. The resultant improvement in power factor may result in an annual gross return in less energy of as much as 20 percent of the annual capacitor equipment investment. Capacitors in reducing reactive currents reduce the I in I^2R system losses. Since current is reduced in direct proportion to power factor improvement, losses are inversely proportional to the square of the power factors:

$$\text{kW losses} \propto \left[\frac{\text{original PF}}{\text{improved PF}}\right]^2$$

$$\text{loss reduction} = 1 - \left[\frac{\text{original PF}}{\text{improved PF}}\right]^2$$

$$= \frac{\text{ckvar (2 kvar-ckvar)}}{\text{kVA}^2}$$



Mountained Footcandles

Figure 2. Maintained illumination levels for a variety of luminaires based on their wiring capacity expressed in watts per square foot. Efficient fixtures produce a greater amount of light on the task with less wattage. Approximate wiring capacity to provide a given maintained level of illumination is by means of: A-indirect, incandescent filament (silvered bowl); B-direct, incandescent filament (with diffuser); C-direct, incandescent filament; E-direct, incandescent filament (lens); F-direct, incandescent filament (industrial, and indirect, flourescent (cove); G-indirect, fluorescent (extra high output); H-direct, fluorescent (extra high output, louvered); I-direct, fluorescent (ouvered); J-luminous ceiling, fluorescent; K-direct, fluorescent (lens), and direct, HID (mercury); L-direct, semidirect, fluorescent (industrial).

To this savings, the kilowatt losses of the capacitors, usually about 1/4 of 1 percent of the kvar rating, must be deducted.

E) In applying reactors, remember the following.

1) Keep them out of main power flow if possible such as shown in Fig. 2. The total losses in feeder reactors as in Fig. 2(a) is 1/3 of those in a main incoming line reactor as in Fig. 2(b).

2) Keep magnetic clearances given on reactor drawings. When these are below recommended distances they incur losses in magnetic materials that show up as additional reactor energy losses.

3) Make sure there is no loop of magnetic materials such as continuous reinforcing bar or structural steel around reactor. This too adds to reactor losses.

F) In applying motors note the following.

1) Motors increase efficiency as they get larger. Note that in the preceding data a 500 hp, 1775 r/min induction motor at 2300 V has 1.4 percent less energy loss than 2-250 hp motors of the same rating. This adds to the trend of going to larger unit sizes in compressor drives.

2) Motors decrease efficiency as voltage goes above 4000 V. A 500 hp motor at 13.2 kV will have 1.3 percent more losses than at 4000 V.

3) Motor efficiency can be improved by design. There is generally a price adder for this, and it may be accompanied by a change of one or more other characteristics such as starting current, power factor, and starting, pull-in and pull-out torques. It is well worth the effort to investigate for each particular application. There is a growing trend to pay the price added and get premium efficiency, which at times in large motors may be as much as 1.5 percent.

4) In selecting new motors remember that synchronous motors are usually 0.5-3.0 percent better in efficiency than induction motors.

5) In replacing older or failed motors consider replacement with new premium high efficiency motors, which in integral sizes

offer a savings in losses of from 1-15 percent. The smaller the motor the greater will be the savings. Motors operating continuously from 1/2 to full load are good targets for savings by replacements, whereas those of intermittent duty such as valve operator motors are not.

G) In applying transformers, it is well to remember that transformers increase in efficiency as they go up in size for a given type. On a per kVA basis, a 2000 kVA transformer with a 480 or 2400 V secondary has about 18 percent less in losses than a 750 kVA. A 40 000 kVA, 69 kV primary, 13.8 kV secondary transformer has about 22 percent less in total losses/kVA than two 20 000 kVA units with each at full load.

H) In outdoor switchgear, it is frequently a benefit to move the line-up indoors and dehumidify it. Besides the price adder saving/unit in outdoor construction, there is 300 or 500 W of energy per unit saved in deletion of heaters. With a fully loaded power bus, it may be worth the price adder to go to the next higher bus ampacity rating for the reduction in energy loss. New vacuum-type switchgear has half the losses than that of the older air magnetic type.

I) It must be remembered that in decreasing the loss in a piece of equipment, particularly in the utilization area, its direct savings on that equipment reflects in small but significant reduction in losses in other components up through the power system to the source.

J) Where variable speed drives are found that operate very much of their time below rated speed, a dc variable voltage or ac variable frequency drive should be investigated in lieu of a constant speed motor and hydraulic or hysistersis coupling. A constant speed motor and coupling operating at half speed, for instance, throws away half of its consumed energy in heat losses.

K) In process applications involving motor driven centrifugal pumps with throttling valves to control flow or pressure, considerable savings in throttling loss energy can be achieved by using a variable speed motor drive controlled by a flow or pressure sensor eliminating the throttle valve loss along with its cost and high maintenance.