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ENERGY CONSIDERATIONS IN FIXED AND VEHICULAR LIGHTING

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ENERGY CONSIDERATIONS IN FIXED AND VEHICULAR LIGHTING

INTRODUCTION

National concern has been focused on energy consumption and conservation. While energy consumption resulting from operation of fixed and vehicular lighting represents only a minute percentage of United States energy use, every effort should be made to reduce consumption by these factors as well as others involved in this national effort.

Over the past several years, a substantial number of papers have been presented concerning energy efficiencies and benefits of fixed roadway lighting. Comparatively speaking, practically no papers have discussed the energy efficiencies of vehicular lighting systems. It is the purpose of this report to summarize the results of past studies relating the energy consumption and benefits of fixed roadway lighting and vehicular lighting. The emphasis of this circular will be on the current benefit status of these two modes of roadway lighting with recommendations for implementation of the most energy efficient system.

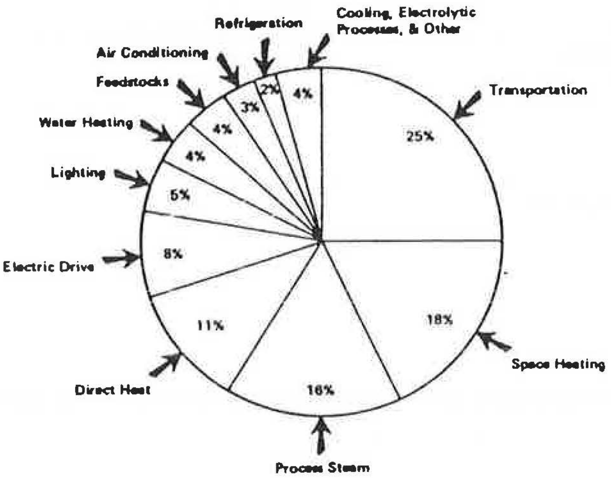
ENERGY USE IN THE UNITED STATES

In 1973, one-fourth of the total gross energy consumption in the United States was expended in the transportation sector, primarily for motor vehicles and aircraft. In the non-transportation sector, space heating and process steam accounted for 18 and 16 percent, respectively, of the total gross energy consumption in 1973. Figure 1 shows a breakdown of U.S. gross energy and uses by various use categories (latest figures available).

Figure 2 shows U.S. gross energy consumption by sectors for the years 1960 to 1975. Electrical energy accounts for some 28% of the 1975 total energy used. Table 1, electric utility sales, and Table 2, other sales, indicate the percentage of energy used in providing street and highway lighting in the United States (termed "fixed lighting" in this report)

Using the 1976 figures of over 1800 billion total kilowatt hours (kwh) sold, of which 14.4 billion kwh were used for fixed lighting, it is readily seen that less than 0.8% of electrical energy is consumed in operating fixed lighting. To further place that figure in the proper perspective, this 0.8% is part of the 28% of total energy represented by electrical energy or 0.2% of total U.S. energy consumed.

FIGURE 1: U.S. gross energy end uses, 1973 (total gross energy use: 74.7 x 10" Btu). (Source: U.S. Energy Prospects: An Engineering Viewpoint, National Academy of Engineering, 1974, p. 26.)



The above figures represent streets and highways in many different areas such as residential streets, alleys, rural intersections, commercial streets, boulevards and freeways. Specific data on any one class of roadway is not available except for the lighted freeways which are part of the U.S. Interstate Highway System.

Relating the energy used in fixed lighting to the U.S. Interstate Highway System, the following data have been made available by the Federal Highway Administration (FHWA) (1).

Lighting on the Interstate System

1. Continuous, interchange, rest area, and sign lighting:

Total connected load:	181,000 Kw
Energy consumed/year:	727,000,000 Kwh
Cost of energy/year:	$24,000,000
Cost of energy per capita per year:	$0.1150
Power consumed per capita per year:	3.4 Kwh

Breakdown of type of light-source is as follows:

Source	Number of Units	Total Connected load (kw)
Mercury vapor	282,000 (72.8%)	148,000 (81.7%)
Metal halide	10,000 (2.6%)	10,000 (5.7%)
High-pressure sodium	24,000 (6.2%)	12,000 (6.4%)
Fluorescent	63,000 (16.2%)	7,000 (4.0%)
Other	9,000 (2.2%)	4,000 (2.2%)

The fluorescent source listed above is principally used for sign lighting:

2. Tunnel lighting:

Total connected load	5,500 kw
Energy consumed/year:	34,000,000 kwh
Cost of energy/year:	$1,200,000
Cost of energy per capita per year:	$0.0054
Power consumed per capita per year:	0.2 kwh

The total electric energy consumed in operating all lighting equipment installed on the Interstate System is approximately 761,000,000 kwh per year. This is, apportioned over the entire population of the United States, equal to 3.5 kwh, or 12 cents per capita per year.

To equate these values with some readily available figures, the following illustrations are offered.

If all electricity were produced from oil, based on an energy conversion rate of 545 kwh per barrel of #2 oil, the yearly consumption of oil used in lighting the Interstate System would be about 1.4 million barrels, or about 3800 barrels per day. In 1974, approximately 18.8 percent of all electrical power was generated by the use of oil, and 18.8% of 3800 barrels is about 720 barrels of oil per day. This compares with a total daily consumption of about 18 million barrels of oil in the United States, and is 0.004% of U.S. daily oil requirements.

Vehicular lighting consumption of energy can be arrived at by using some overall average figures

FIGURE 2: U.S. gross energy consumption, by sector, 1960-75. (Source: U.S. Bureau of Mines, 1976.)

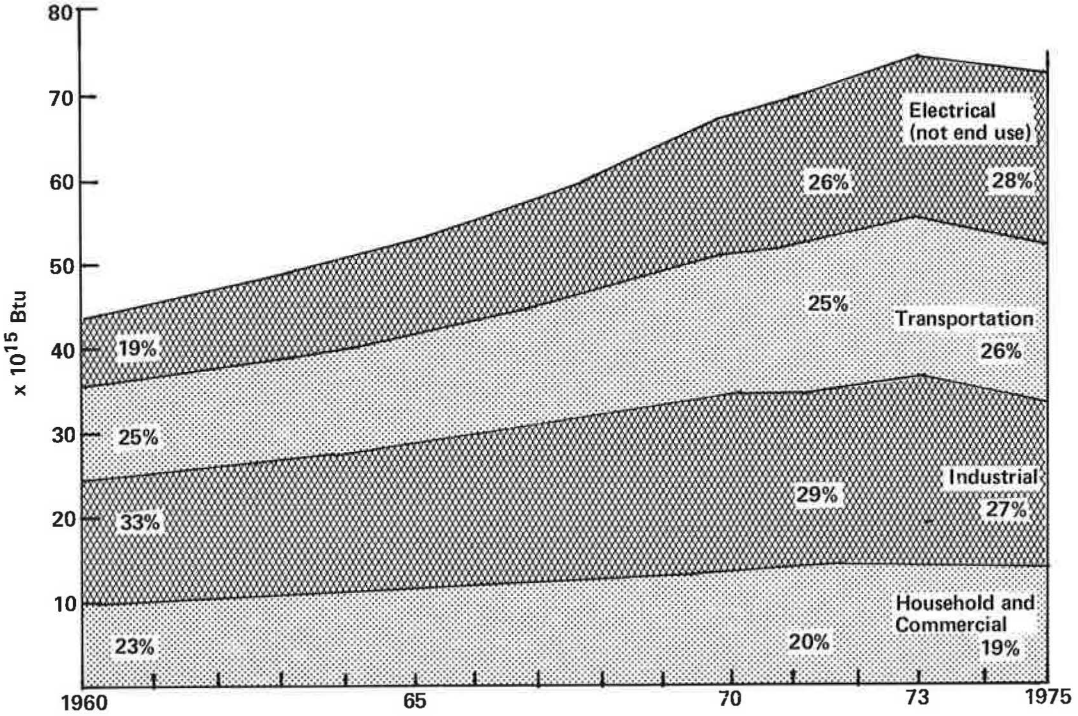


TABLE 1: Electric utility sales (billions of k-Wh).

Year	Residential	Industrial	Commercial	Other	Total	% Change
Sales						
1968	367.7	518.8	265.2	50.6	1202.3	8.6
1969	407.9	557.2	286.7	55.4	1307.2	8.7
1970	447.8	572.5	312.8	58.3	1391.4	6.4
1971	479.1	592.7	333.8	60.9	1466.4	5.4
1972	511.4	639.5	361.9	65.0	1577.7	7.6
1973	554.2	687.2	396.9	54.9	1703.2	8.0
1974	555.0	689.4	392.7	63.7	1700.8	-0.1
1975	586.1	661.6	418.1	67.2	1733.0	1.9
1976	613.1	725.2	440.6	70.8	1849.6	6.7
1977	652.3	757.2	469.2	72.1	1950.8	5.5
1978	679.2	782.1	480.7	75.8	2017.8	3.4
Forecast						
1979	702.5	813.8	493.3	78.4	2088.0	3.5
1980	725.8	821.9	500.7	81.2	2129.6	2.0
1981	765.7	874.3	525.7	83.9	2249.6	5.6
1982	802.5	925.4	549.4	86.7	2364.0	5.1
1983	845.0	952.5	572.5	89.7	2459.6	4.0
1984	886.7	977.3	595.4	92.7	2552.0	3.8
1985	929.2	1006.2	619.2	95.8	2650.4	3.9
1986	972.9	1034.0	643.3	99.1	2749.2	3.7
1987	1015.0	1067.4	667.8	102.4	2852.6	3.8
1988	1058.0	1104.5	692.5	105.9	2960.9	3.8
1989	1101.0	1142.5	717.4	109.6	3070.5	3.7
1990	1141.8	1183.2	742.5	113.3	3180.8	3.6
1995	1340.8	1404.3	892.8	134.3	3772.2	3.4

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TABLE 2: Other sales (billions of k-Wh).

Year	Street and Highway Lighting	Other Public Authorities	Railway and Railroad	Interdepartmental	Total
Sales					
1968	10.3	32.2	4.5	3.6	50.6
1969	10.8	35.9	4.5	4.2	55.4
1970	11.2	37.8	4.6	4.7	58.3
1971	11.7	39.8	4.5	4.9	60.9
1972	12.2	43.2	4.4	5.1	64.9
1973	12.8	42.3	4.2	5.5	64.8
1974	13.3	40.7	4.3	5.4	63.7
1975	13.9	43.6	4.3	5.4	67.2
1976	14.4	45.6	4.3	6.4	70.7
1977	14.4	46.2	4.2	7.2	72.0
1978	14.8	49.5	4.3	7.1	75.7
Forecast					
1979	15.2	51.0	4.4	7.8	78.4
1980	15.6	52.8	4.5	8.4	81.3
1981	15.9	54.6	4.5	8.8	83.8
1982	16.3	56.5	4.6	9.2	86.6
1983	16.8	58.5	4.7	9.7	89.7
1984	17.2	60.6	4.8	10.2	92.8
1985	17.6	62.7	4.8	10.7	95.8
1986	18.0	64.9	4.9	11.2	99.0
1987	18.5	67.1	5.0	11.8	102.4
1988	18.9	69.5	5.1	12.4	105.9
1989	19.4	71.9	5.2	13.0	109.5
1990	19.9	74.5	5.3	13.7	113.4
1995	22.5	88.4	6.0	17.4	134.3

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for energy consumption. Using low beam headlight rated at 80 watts (0.08 kw) and an annual headlight use of 100 hours (3000 avg. night driving miles/ 30 mph avg. speed = 100 hours), and allowing 4.3 kwh per gallon of fuel, one can arrive at an annual consumption of 1.86 gallons, (100 hours x 0.08 kw x 1 gal/4.3 kwh = 1.86 gal.) of fuel per vehicle per year. U.S. vehicle registration is 149,000,000 currently; thus, the total annual fuel consumption for headlights is 277,140,000 gallong (1.86 x 149,000,000.) Using the figure of approximately 21 gallons of fuel to be obtained from one barrel (bbl) of oil, or 50% of the 42 gallons of oil in each barrel we can determine that 6,600,000 bbls of oil are consumed annually for headlight energy. This is 18,032 bbls of oil per day or 0.1% of the total daily U.S. consumption. Total fixed lighting oil requirements would amount to 14,740 barrels per day

(15.6 billion kwh/545 x 1/365 x 18.8%) or 0.082% (14,740/18,000,000) of U.S. daily oil requirements. Headlighting and all fixed lighting together, then, represent about .2% of total U.S. daily oil consumption.

ENERGY VERSUS BENEFITS - FIXED LIGHTING

Although fixed roadway lighting uses only 0.2% of the total U.S. energy requirements, it produces substantial benefits for the public.

Safety Benefits

Studies of the effectiveness of roadway illumination in reducing accidents are quite numerous. It is a phenomenon of motorized societies that a disproportionately large number of accidents and resultant casualties occur during the hours of darkness. By "disproportionately large" is meant large in relation to the exposure of road users, measured by the vehicle miles travelled in the hours of darkness (2). The number of fatalities occurring at night is likely to approach or exceed that by day (3, 4, 5). By comparison only about 25 percent of vehicle miles are travelled during the hours of darkness (estimates range from 17 to 32 percent) (6).

Accidents at night are generally more severe in their consequences and more likely to produce fatalities than by day (4, 7). Multiple vehicle accidents increase in severity and pedestrians are particularly vulnerable (7).

The pattern of increase in night accident rates and accident severity extends not only to urban traffic routes but the whole system of streets, rural roads (pedestrians largely absent) and freeways (generally superior in design) (6, 8, 9).

The location of accidents within the road system will reflect the degree of urbanization and the usage of the road system (8). In general, a larger proportion of accidents will occur in urban areas than in rural areas; in urban areas pedestrians involved accidents may predominate whereas in rural areas it may be single vehicle accidents (7, 10).

The absolute volume of traffic and numbers of accidents are in general growing with time. There is some evidence that both the proportion of casualties occurring at night and the night accident rate, relative to the day rate, are also increasing (8, 10).

A recent International Commission on Illumination, (Commission Internationale de l'Eclairage or C.I.E.) publication (2) has documented thoroughly the causes of night accidents and the value of road lighting as an accident countermeasure. Lighting studies on various types of roadways, including urban and rural traffic routes, pedestrian crossings, intersections and freeways, indicate a reduction in night accidents on well lighted roads as compared with unlighted roads. A brief summary for arterial roads indicates that in all cases, except one in Australia, effective reductions in night accidents are reported. Several studies in Australia (11) and Great Britain (9) are of such large scale that the results have a high level of statistical significance.

While there are variations in the reported reductions, as a generalization it can be stated that: Where no or poor lighting is replaced by good lighting,

1. Pedestrian-involved casualty accidents are reduced about 50 percent and those to vehicle occupants are reduced by at least 20 percent.
2. Fatal accidents are reduced by about 50 percent and injury accidents by approximately 20 percent.
3. All casualty accidents to all road users are reduced by about 30 percent.

Similar improvements elsewhere can be expected only when good fixed lighting is installed, in conformance with Illuminating Engineering Society (I.E.S.) Standards, where either there was none before or the existing lighting was grossly inadequate (below I.E.S. Standards.) Upgrading good illumination to even higher levels may not improve accident experience.

Cost benefit studies have been conducted in many areas. The Box Study (6) indicates a cost benefit ratio of 2.3 for a 4-lane freeway, 1.4 for a 6-lane freeway and 1.7 for an 8-lane freeway. Turner (12) conducted an accident study of 65 miles of a lighted roadway and determined a cost benefit ratio of 3.8. The City of Milwaukee (13) found a cost-benefit ratio of 1.2 as a result of a relighting program for its streets.

Current societal losses (14) due to motor vehicle accidents are running about $38 billion annually. In 1975, 46,800 motor vehicle fatalities occurred at a cost of $13.44 billion. It is estimated that 53% of these fatalities occurred during the night time hours at a cost of 7.12 billion dollars.

The aforementioned statistics provide strong indication that substantial benefits may accrue in terms of reduced accidents and improved night safety with the provision of fixed roadway lighting.

Economic Benefits

Roadway lighting has proven to be a balancing factor and therefore of benefit to private businesses and other agencies which generate electric power. Since roadway lighting is basically an off-peak electrical load and an all-night electrical load, it tends toward improving the generating load factor. Generating agencies can select the least expensive and most energy conserving methods of power generation to supply this type of load.

A recent article (15) brought out an interesting aspect of the reductions in the night time electrical loads in order to save oil. The following is quoted from this article:

> In the typical electrical system all-night lighting loads are considered essential to a well balanced operation. Because as fast as the lighting loads have developed, they have not been able to offset the growth of other uses that combine to produce peak demands in the early evening hours.
>
> In addition to the more efficient use of generating and distribution facilities, the utilities are finding that the reduction of night loads, of whatever type, is creating severe problems in the operations of their coal burning plants.
>
> It has been found that in today's mammoth pulverized coal boilers a drop below 50% of rated input results in an explosive type of operation as opposed to the desired steady combustion. The practical remedy for this situation is to supplement the coal with oil which can be burned at these reduced levels without fear of a destructive explosion. Obviously, this is a situation that is counter productive to the conservation of oil, one of the most critical sources of energy.

Crime Prevention

Roadway lighting has long played an important role in crime prevention. An exhaustive study (16) of the impact of street lighting on street crime was made in high crime commercial and residential areas of Kansas City, Missouri before and after upgrading of street lighting. Results indicated that crimes of violence -- robbery and assault -- were significantly reduced. The study recommended a continual upgrading of street lighting to deter crime.

To attract customers who previously felt unsafe in poorly lighted areas many commercial areas dependent on pedestrian traffic have significantly upgraded street lighting. New high-efficacy light sources (efficacy of light sources: the ratio of the total luminous flux (lumens) to the total power input (watts or equivalent) make it possible to increase lighting levels above I.E.S. recommendations and to reduce energy consumption concurrently.

ENERGY VERSUS BENEFITS - HEADLIGHTING

Accident reduction potential for vehicular headlighting has not been widely investigated. On rural roads and unlighted or poorly lighted roads, headlights are a necessary source of illumination to reveal the cues needed by drivers in guiding their vehicles. No one has seriously suggested that headlights be eliminated on such roads and that is perhaps the reason that no general studies of the cost effectiveness of headlights have been found.

Headlights typically provide adequate illumination for detecting a pedestrian size target while adequate stopping distance still remains for vehicles traveling at the legal speed limit on a generally straight, dry road and where there is only an occasional opposing vehicle (17). The problem comes when the complex traffic situation adds vehicular and pedestrian traffic from the side, beyond the reach of headlamp illumination. Fixed illumination has been shown to increase sight distance about three-fold over that available from vehicular systems alone. It is particularly important where off-axis viewing is required or where the level of opposing traffic is such that glare is no longer limited to an occasional encounter. Hemion (18) attempted a cost benefit study of the headlight glare problem. He could find only very scant data on glare as a causative factor in highway accident reports, but estimated that headlight glare could contribute to up to 4% of night vehicular accidents. More investiagion of the benefits to be obtained from headlighting is desirable.

ENERGY CONSERVATION OPTIONS - FIXED LIGHTING

Replacement of Inefficient Light Sources

The most immediate practical conservation item which is now in the process of being implemented by many transportation agencies is the replacement of inefficient lamps with new "high-efficacy" sources (such as high-pressure and low-pressure sodium.)

It is estimated that today there are approximately 12,000,000 roadway lighting units installed in the United States. Approximately 8,000,000 are owned by the larger utility companies. Of these, 14% use filament light sources, 84% use mercury and the balance of 2% use high pressure sodium. The remaining 4,000,000 units are owned by the state highway department, municipal, Rural Electrication Systems, and city owned lighting systems such as New York, Chicago, Philadelphia, Pittsburgh, Washington, D.C., etc. A breakdown of the light sources used in this category is not readily available, but it is safe to assume that the major portion of these use the mercury lamp.

The opportunity for energy conservation by converting these units to today's much more efficient light sources is obvious. The filament lamps in service deliver only about 20 lumens of light for each watt consumed; the mercury units about 55 lumens per watt. The newer high pressure sodium lamps deliver 100 to 140 lumens per watt. From this it can be seen that the use of the more efficient light sources allows for maintaining the same footcandle light levels at a great reduction in energy consumed.

The majority of the roadway luminaires in use today are with the 400 watt mercury lamp having an initial lumen output of about 22,000 lumens. Without the need of changing pole locations, mounting heights, etc., luminaires utilizing the 200 watt high-pressure sodium lamp having an initial lumen output of 22,000 lumens could be substituted for the mercury luminaires at a saving of approximately 200 watts per pole location. Table 3 and Table 4 indicate the expected energy savings in dollars for various electric rates from such a conversion.

The reduction in lamp watts consumed constitutes only a part of the potential savings in energy consumption. The majority of the 400 watt mercury luminaires used today in roadway lighting use isolated-winding regular type ballasts for starting and operating the lamp. Each of these ballasts consumes approximately 60 watts. Reactor type mercury ballasts are available for operating those lamps which only consume approximately 35 watts - an additional savings of 25 watts per fixture. Most of the new high pressure sodium luminaires installed use a magnetic-regular type ballast. In the case of the 200 watt high-pressure sodium lamp, this ballast has approximately 54 watts loss. A reactor type, 200 watt high-pressure sodium ballast is available which has only 30 watts loss.

DESIGN CONSIDERATIONS

There are a number of factors influencing the lighting system design and operating economics. These are type of light source, optical system, lighting system geometry and pavement reflectance characteristics. In view of the need for energy conservation in the vehicular transportation system, standards and practices of lighting design and operating methods should be closely reviewed. The major factors for justification of roadway illumination are safety and road capacity. Much information has been assembled by various researchers (19) indicating clear evidence that good illumination effectively reduces the night accident rate and severity. Evidence of the illumination effect on road capacity is scarce, but traffic monitoring and field observations (20) indicate that vehicle distribution on the lanes is more even at night on illuminated roads compared with those of non-illuminated facilities.

As an integral component of a traffic system, roadway lighting is of interest to traffic, planning, design and operating engineers. In order to incorporate it into the traffic system and use lighting in the most effective way, the descriptive terminology of illumination should be based on clear and concise principles, compatible with a system engineering approach. At the present time, the light quantity needs in North America are described by light density falling on the pavement, measured in foot candles or lux. However, many researchers and practicing engineers point out that such a description is inadequate and does not reflect the visibility conditions experienced by the driver. They state that a more relevant format for describing visibility is the assessment of illumination based on luminance, uniformity and glare control. In the future, it may be possible to assess visibility directly, but at the present this may be too complex.

The energy requirements to achieve optimum luminance values may be influenced by a number of

TABLE 3: Energy savings realized when mercury equipment is replaced by high-pressure sodium lamps, excluding cost differential of lamps.

Lamp Changeover (k·Wh)		Energy Cost ($/k·Wh)											
Mercury	High-Pressure Sodium	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060	0.065	0.070
250	150	5.16	6.88	8.60	10.32	12.04	13.76	15.48	17.20	18.92	20.64	22.36	24.08
400	150	15.36	20.48	25.60	30.72	35.84	40.96	46.08	51.20	56.32	61.44	66.56	71.68
400	200[a]	13.20	17.60	22.00	26.40	30.80	35.20	39.60	44.00	48.40	52.80	57.20	61.60
400	250	9.18	12.24	15.30	18.36	21.42	24.48	27.54	30.60	33.66	36.72	39.78	42.84
700	310[a]	25.74	34.32	42.90	51.48	60.06	68.64	77.22	85.80	94.38	102.96	111.54	120.12
700	400	19.20	25.60	32.00	38.40	44.80	51.20	57.60	64.00	70.40	76.80	83.20	89.60
1000	400	37.08	49.44	61.80	74.16	86.52	98.88	111.24	123.60	135.96	148.32	160.68	173.04

Notes: Energy savings ($) per year per luminaire as a result of replacing mercury equipment with high-pressure sodium of similar lumen ratings; does not include cost differential of lamps.
Average annual burning time = 4000 h.

[a] Estimated values.

TABLE 4: Energy savings realized when mercury equipment is replaced by high-pressure sodium, including cost differential of lamps.

Lamp Changeover (k·Wh)		Energy Cost ($/k·Wh)											
Mercury	High-Pressure Sodium	0.015	0.020	0.025	0.030	0.035	0.040	0.045	0.050	0.055	0.060	0.065	0.070
250	150	0.88	2.60	4.32	6.04	7.76	9.48	11.20	12.92	14.64	16.36	18.08	19.80
400	150	10.61	15.73	20.85	25.97	31.09	36.21	41.33	46.45	51.57	56.69	61.81	66.93
400	200[a]	8.22	12.62	17.02	21.42	25.82	30.22	34.62	39.02	43.42	47.82	52.22	56.62
400	250	4.20	7.26	10.32	13.38	16.44	19.50	22.56	25.62	28.68	31.74	34.80	37.86
700	310[a]	23.49	32.07	40.65	49.23	57.81	66.39	74.97	83.55	92.13	100.71	109.29	117.87
700	400	16.72	23.12	29.52	35.92	42.32	48.72	55.12	61.52	67.92	74.32	80.72	87.12
1000	400	35.20	47.56	59.92	72.28	84.64	97.00	109.36	121.72	134.08	146.44	158.80	171.16

Notes: Energy savings ($) per year per luminaire as a result of replacing mercury equipment with high-pressure sodium of similar lumen ratings. Figures include cost differential of lamps (per FSC-6240 electric lamps; Contract No. 95-00S-03941) based on a four-year replacement period.
Average annual burning time = 4000 h.

[a] Estimated values.

factors. These are briefly discussed in the following sections.

Light Sources: Commonly used light sources on the North American continent for roadway lighting are mercury vapor, high pressure sodium and low pressure sodium. Two main factors should be assessed when the light source is appraised with respect to its efficacy and effectiveness. The first is lumen output per watt and the second is its optical controlability. In other words, it is not only important to appraise the efficacy of light source but also what part of its output will actually contribute to the establishment of a desired luminance level.

A light source having a high efficacy may result in a less effective lighting system if the luminaire optical control system is inadequate. Concentrated source lamps will produce highest effective lumens on the road and target compared with tabular and globe shaped lamps.

Road Reflectance: The detection of hazardous objects on the road surface is mainly affected by the contrast between objects and their background. In most cases the contrast sensitivity of the eye will depend upon the luminance level of the pavement. The road pavement luminance, on the other hand, will depend not only upon the density of the incident flux, but also on the directional and tested reflective properties of the road surface. The pavement reflectance for typical North American road surfaces is of the order of 5 to 20%. New bituminous pavement may reflect as little as 5% of incident light, and a new concrete road surface may reflect as much as 20%. However, these properties do not remain so in service. For example, asphalt increases to approximately 7% and concrete decreases to 10 to 12% (21). In order to achieve the same luminance level on black, rough surfaces, as on concrete, considerably more light is required. Utilizing the white aggregates, such as quartzite, asphalt pavement reflectance can be considerably improved, thus reducing the energy requirements accordingly.

Lighting System Maintenance: Dirt accumulation on the luminaire exterior and deterioration of the reflector surface, as well as a reduction in lamp lumen output due to aging, may result in reduced system efficiency down to 50% of its initial level, or lower. Waste of energy due to dirt accumulation is perhaps one of the least excusable factors in the energy conservation program.

Energy Conservation in Existing Installations: Due consideration should also be given to the energy effectiveness of existing installations. A program of turning out every other light or turning out continuous lighting except at ramps or intersections must be carefully evaluated. Illumination conditions under these circumstances may not provide minimum visibility and may in some cases provide a visual scene worse than that with no illumination. The cost of reducing illumination and the increase in costs of traffic accidents may well exceed the energy savings. Studies in Virginia (22) and Texas (23) indicate that turning out lighting on urban freeways results in increased accident rates and costs.

Summary: It is evident from the foregoing that there are many areas in lighting system design that should be assessed and evaluated if optimal utilization of energy in highway illumination is to be achieved.

Difference in light source efficacy, effective light control by the luminaire, the influence of pavement reflective characteristics and uniformity of object detection complicate the design problem. For major projects a thorough study of comparative lighting systems is justified before a commencement of design. In short, selection of more efficient light sources, improved lighting system geometry, well planned maintenance programs and a better understanding of the driver's visual performance process should lead to the most effective use of energy without sacrafice or traffic safety needs.

REDUCED HEADLIGHT USE

Another energy reduction possibility lies in the option of reduced headlight use in urban areas where fixed roadway lighting is in itself adequate. Contrary to popular belief, the use of present vehicle headlights in conjunction with adequate fixed lighting often reduces visibility, produces unnecessary glare, and wates energy (17, 24).

The need to resolve the problem of urban fixed lighting and vehicle lighting is long overdue. Since energy conservation has become important, it should help focus attention on the need for developing a more effective and efficient combination of fixed and vehicle lighting.

A great deal of effort has been devoted to improving vehicle headlighting for rual roadway. However, no special effort has been made in North America to improve vehicle lighting for roadways with fixed lighting. The low beam headlights designed for glare reduction in vehicle meetings on rural roadways have been assumed to be quite satisfactory for roadways with fixed lighting. Two points have often been overlooked. First, present headlights and fixed lighting are often not compatible. Second, vehicle lighting on roadways with fixed lighting should produce delineation rather than illumination. The combination of improved parking lights such as the wrap-around design with good fixed lighting produces the most effective and comfortable nighttime visual driving environment (17, 25).

The low beam headlights require 80 to 100 watts. The vehicle alternator is very inefficient compared to central power station generators. For example, at $1.00 per gallon for fuel, one kilowatt-hour costs $.28 at 50 mph vehicle speed and $.34 at 35 mph. Although streetlighting rates vary widely depending on geographical and other conditions on average rate of $.04 per kilowatt hour would represent current cost from the utilities. Consequently, only a portion of the energy cost savings from the reduced use of headlights would be required to upgrade fixed lighting for urban areas where inadequate fixed lighting presently exists.

Potential Reduction in Energy Costs

Estimates of the present use and future potential savings in energy for fixed and vehicle lighting are indicated in the tables that follow.

The table below indicates the type, quantity, and energy consumption of fixed-lighting equipment currently installed, and the energy consumption if high-pressure sodium lamps were used exclusively.

Energy Consumption - Current Fixed Lighting vs. High-Pressure Sodium (HPS)

Type of Fixed Lighting Currently Installed	Luminaires (Millions)	Annual kwh billions	*Annual kwh-billions Using HPS
Filament (300 watt avg)	2.4	2.88	.96
Mercury (300 watt avg)	9.0	11.88	6.48
High Pressure Sodium (350 watt avg)	.6	.84	.84
TOTAL	12.0	15.6	8.28

*NOTE: Using a hypothetical average of 100 watts for high-pressure sodium in replacing filament luminaires and an average of 180 watts high pressure sodium in replacing mercury luminaires.

This table indicates an annual savings of 7.32 billion kilowatt-hours (15.6 - 8.28) by replacing filament and mercury luminaires with high-pressure sodium.

The capital cost of this replacement would vary from under $100 to over $200 per unit depending on the type of replacement, area of country, size of lamp and luminaires, and various other factors. Experience has shown that recovery (via energy cost savings) of the initial capital investment for this type of project has been in a period of approximately eight years.

The table that follows estimates the possible savings of oil by not using low beam headlights in urban areas.

Vehicle Headlight Energy Use in Urban Areas

1. Average annual headlight use (Urban)	55 hours*
2. Low beam headlight wattage	80 watts
3. Total annual urban headlight energy per vehicle (1) x (2)	4.4 kwh
4. Total number of vehicles	149,000,000
5. Total annual millions of kwh to operate low beam headlights (4) x (3)	655,600,000
6. kwh generated in motor vehicle alternator by 1 bbl of oil	180 kwh
7. Total annual oil consumed by low beams (5)/(6)	3.64 million bbls

*Urban-only average use of headlights for the whole vehicle population.

The next table considers the combined potential savings energy from the elimination of low beam headlights in urban areas and replacement of mercury and filament fixtures with high pressure sodium including a 20 percent upgrading of current lighting levels.

A 20% upgrading of lighting levels is deemed to be necessary to provide the margin of safety required to assure adequate visibility from fixed lighting alone. The extinguishing of low beam headlights would be proposed for urban lighted roadways only. There are some cities that already have their road system illuminated to levels of 20% or more above recommendations and have converted to HPS. Other urban locations will require conversion and upgrading. Therefore, the cost of this upgrading is difficult to estimate due to the existing wide variation in lighting levels. Assuming an average cost of $150 per fixture, a rough estimate for conversion and upgrading would be approximately 1.7 billion dollars:

Energy Savings by Eliminating Low Beams and Upgraded Lighting

1. Annual kwh current use	15.6 billion-kwh
2. Annual kwh by conversion to HPS	8.28 billion-kwh
3. Annual kwh using HPS and upgrading 20% (2)x1.20	9.936 billion-kwh
4. Annual kwh saving using HPS (1)-(3)	5.664 billion-kwh
5. kwh generated by one barrel of oil	550 kwh
6. Percent of oil used for	18 percent
7. Annual bbls of oil saved using (HPS) upgraded fixed lighting((4)/(5))x (6)	1.85 million bbls
8. Annual oil consumed by low beams	3.64 million bbls
9. Total annual oil saving by not using headlights and conversion of fixed lighting to HPS (7) + (8)	5.49 million bbls

In addition to the annual oil savings as shown in item 9, there is an additional savings in oil equivalent by changing to HPS, of approximately 8.5 million bbls per year (4)/(5) x (1.00-(6).

The savings in total energy indicated above - 8.5 million bbls of oil equivalent plus 5.49 million bbls of oil or a total of 14 million bbls of oil and oil equivalent annually-represents a substantial reduction in overall energy consumption. As indicated in the introduction, fixed lighting consumes about 0.2% of all U.S. energy whereas transportation generally consumes 26% of all U.S. energy. The 0.2% for fixed lighting can be reduced by approximately 36% while still improving lighting levels. Overall transportation energy can be reduced by 3.64 million bbls of actual oil, a small but significant savings.

The above analysis represents a possible method of reducing energy consumption. This technique of reduced vehicle lighting in areas where fixed lighting is present has been used in Europe and therefore is not an untried experiment. However, a great deal more study and research is required to eliminate the problems encountered where reflectorized materials are used for traffic identification and direction. These materials now widely used must be compensated for and all legal requirements satisfied.

Also, the problem of identifying the appropriate areas for turning off headlights must be considered. A system must be developed, further, such that motorists will be alerted to the use of headlights where adequate fixed lighting is not present. This may require some automatic type of equipment since the motorists may be required to act rather quickly as he leaves a lighted area.

The cost of providing the operational expenses required for all night operation of fixed lighting should be weighed against the traffic volumes served. It certainly could be shown that, if at some early morning hours no vehicle traffic existed, fixed lighting could be reduced or turned off during that period. However, the safety of a few pedestrians or motorists should not be neglected for small economic gain.

The seriousness of an impending fuel shortage, however, may be all that is required to provide the proper impetus for this concept.

SOLAR ENERGY

One of the energy sources being considered for supplying part of the electrical energy needs for fixed lighting is solar energy.

A recent study (26) for the U.S. Department of Energy's Federal Photovoltaic Utilization Program concluded that highway and street lighting is a type of energy use application which is standardized and therefore may be suitable for solar photovaltaic systems. Their study of conventional street lighting systems in two cities indicated that advanced technology, predicted to be available in the mid 1980's, could possibly reduce the relative cost of photovoltaic cells, storage batteries and other appurtenances to such an extent that a solar energy system might be competitive with conventional power installations. Solar photovoltaic cells have been proposed as the source of energy for high mast (100 ft. or more poles) lighting (27). A concentration of lighting units at fewer locations and adequate provision for collector arrays is inherent in the highway interchange type of high mast lighting installation. Collector arrays require considerable area.

The application of photovoltaic cells in tunnel entrance illumination needs has been proposed (28). The highest energy requirements occur during the daytime when solar energy availability is greatest.

The use of photovoltaics for street lighting requires large arrays of photovoltaic cells as well as large numbers of storage batteries resulting in high costs for maintenance. The installation and maintenance costs of such systems are not economically feasible at this time.

RECOMMENDATIONS

Decreasing U.S. natural fuel supplies require corrective action in those areas of energy conservation where known solutions are at hand and the initiation of long range programs as soon as practical. The following items are suggested for both immediate and long range implementation:

1. Current levels of fixed lighting as specified by the American National Standards Practice for Roadway Lighting should be retained or modified in accordance with further research (6) (25). Lighting equipment should not be deactivated without a thorough study of the costs and accident potential that might result.
2. Existing fixed lighting installations should be reviewed for updating and revisions using more efficient equipment. The optimizing of equipment location for maximum visibility at lowest energy consumption should be implemented. (Energy savings of over 50% may be attained by these revisions).
3. Development of test sites to research the interaction between fixed lighting and headlights in urban areas is very desirable. (Fuel savings to motorists along with improved visibility will be an encouragement for compliance with turning off headlights in urban areas).
4. Research projects using solar energy, wind energy and other sources for fixed lighting should be designed and demonstration projects built. Efficient cost effective systems cannot be attained without operational experience.

5. New fixed lighting installations should meet the latest standards for fixed lighting design and energy efficient equipment.
6. Research should be continued in several areas such as:
    - a. Higher efficacy light sources,
    - b. More efficient luminaires,
    - c. Motorist visibility requirements,
    - d. Automatic headlight dimming systems,
    - e. Development of new energy sources for lighting,
    - f. More sophisticated control of lighting equipment,
    - g. Highly reflective pavement materials,
    - h. Increased vehicle conspicuity and,
    - i. Effectiveness of traffic control devices without headlighting.

Implementation of the recommendations above should provide a basis for further reduction and more efficient use of energy in the United States.

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