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ALTERNATIVES FOR ENERGY CONSERVATION IN ROADWAY LIGHTING

by

Marvin H. Hilton
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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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SUMMARY

From a review of some of the possible methods of conserving energy in the operation of roadway lighting, with due consideration being given to traffic operations and safety under the current energy scenario, it was concluded that the most favorable conservation measure would be to replace the existing mercury vapor luminaires with the more energy-efficient high pressure sodium (HPS) luminaires. Replacement of the existing mercury vapor lighting systems could lead to a savings of up to 50% of the power currently being consumed. Following a discussion of this conclusion by the Department of Highways and Transportation's Special Roadway Lighting Advisory Committee, it was decided to inventory all of the interstate lighting currently in operation and to estimate the savings that could be achieved through conversion to HPS luminaires. The results of the inventory and analysis indicated that the conversion of 4,752 interstate system luminaires could yield a present worth savings to the Department of $1.2 million over the average remaining service life of the various installations, assuming the use of the available 90% federal funding. It was further determined that it would take only 7 1/2 months for the Department to recoup its 10% investment and 9.9 years to break even on the total investment. Based on these data, the recommendation to convert all the interstate mercury vapor lighting to the HPS type was approved by management. Currently, approximately 75% of the original inventory is nearing the contract stage for conversion.

Other alternatives for conserving energy in existing roadway lighting systems are discussed and placed in order of preference in the report.

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INTRODUCTION

Approximately 4% to 5% of the energy consumed in the United States goes for the operation of residential, commercial, industrial, and public lighting systems. Considering the vast amount of energy consumed in the nation, this surprisingly low percentage consumed by lighting nevertheless represents a significant quantity. Obviously, the percentage of all energy consumed in street and highway lighting alone is quite small, but the quantity of power consumed is substantial. If measured in terms of operational costs, the power consumed by roadway lighting can be quite significant to those paying the bill, and is a matter of concern as energy costs continue to rise.

Prior to the oil embargo of 1973-74, there had been a gradual increase in the use of lighting on many highways, interchanges, and freeways in both urban and suburban areas. Beginning with the oil embargo, however, roadway lighting became one of the first items to be cut back in order to conserve energy and to reduce the cost of operating transportation systems. With the easing of the energy crisis, much of the lighting in many areas was restored to the original levels but some was not. As a result of this reduction in roadway lighting, considerable controversy on the part of both the public and highway and transportation officials arose in different parts of the country. It has been reported, for example, that turning off the lighting on some freeways in Utah resulted in protests by citizens who felt that their safety was being jeopardized.[1] A number of complaints about the lack of lighting were reported in Wisconsin after the energy crisis atmosphere changed in the mid-seventies.[2] On the other hand, there has been a general feeling on the part of some officials that highway lighting is unnecessary and should be turned off entirely.[3]

In the period since the 1973-74 energy crisis methods of reducing the energy consumed by highway lighting have appeared to vary from one extreme to the other. The lighting systems on some roadways have, at various times, been turned off entirely, been partially turned off, or been operated at normal levels. In some instances, in order to reduce operational costs (as well as energy consumption), some highway organizations have reduced roadway lighting levels at some locations or turned the lighting off entirely at others.[2] Recent trends, however, suggest that many organizations are converting their existing lighting systems to the more energy-efficient, high pressure sodium lamps while maintaining equal or better illumination levels.[2,4,5,6,] Obviously, there are a number of approaches that can be taken to reduce energy consumption in roadway lighting. The question, of course, is which of the options is the best for a given situation considering all the factors involved. At one extreme a severe energy shortage might dictate that roadway lighting be turned off entirely. On the other hand, considerations of safety and of traffic operations may demand that lighting be provided. Between these two extremes, there are a number of options for reducing both energy consumption and power costs.

PURPOSE AND SCOPE

The purpose of this report is to review and present the various alternatives available to the Virginia Department of Highways and Transportation for reducing its energy consumption and costs in the operation of its highway lighting. Since the majority of the lighting controlled and operated by the Department is installed on highways, interchanges, and freeways, rather than on streets in urban areas, the review is generally limited to consideration of these types of installations.

The scope of the report includes: (1) A brief review of the need for roadway lighting, (2) a review of possible techniques that could be applied to reduce energy consumption in roadway lighting, and (3) an evaluation of the most desirable energy-saving alternatives under the prevailing energy and operational situation.

THE EFFECTIVENESS OF ROADWAY LIGHTING

The use of the term "roadway lighting" normally implies the general use of lighting on streets, highways and freeways as well as on interchanges and at intersections. The purposes served by roadway lighting differ depending upon the specific type of facility being lit. Street lighting in cities and urban areas improves visibility for both drivers and pedestrians, reduces the crime rate, and enhances commerce and community values. On the other hand, continuous roadway lighting on freeways serves the main function of providing improved visibility for the driver. Regardless of the specific type of roadway lighting, one of the main advantages of its use is to aid in preventing nighttime accidents. Numerous studies and reviews in the United States and foreign countries have shown that street, intersection, and general highway lighting reduces the nighttime accident rate.[5-18] Although some early studies were inconclusive,[19-23] some more recent studies of continuous freeway lighting have indicated its effectiveness in reducing the nighttime accident rate.[24-26] A recent study by the writer showed that a section of continous freeway lighting in Virginia was highly effective in reducing the night accident rate during the winter months when heavy traffic volumes occur during the early hours of darkness.[27] During the March through May period when the hours of daylight are longer, the number of accidents reported was not sufficient to provide statistical significance to the results, but the data suggested that the lighting might not be as effective in reducing the night accident rate in the spring and summer months. For the full 6-month study period, however, it was concluded that the lighting was effective in reducing the night accident rate.

The results reported by Richards indicate that in addition to reducing the nighttime accident rate, lighting generally tends to make those accidents that do occur less severe.[26] This latter finding was substantiated in the Virginia study where, when the lighting was off, 39% of the total number of accidents involved injuries, as compared to 25% when the lighting was on.[27]

In summary, there remains little doubt that roadway lighting is effective in enhancing the safety of nighttime traffic operations. Under normal traffic conditions, i.e., when the unavailability of fuel or other constraints do not severely affect normal traffic volumes, even freeway lighting appears to be effective in enhancing the safety of traffic operations. Probably the only questionable case is that involving the use of freeway lighting during the off-peak periods when traffic volumes are low.

ENERGY CONSUMPTION IN ROADWAY LIGHTING

The costs of all forms of energy are rising. Consequently, everyone is interested in conserving energy in order to minimize its cost in their overall operations. While the costs of operating roadway lighting are considerable, only a small portion of the total electrical energy consumed annually in the United States is used for this purpose. The total electricity consumed over the past few years along with a forecast of use to 1990 are indicated in Figure 1.[28] The corresponding curve for the electricity consumed in roadway lighting is shown in Figure 2. These data can be used to calculate that in 1977 and 1978, only 0.74% of the total electric utility sales were derived from the operation of roadway lighting. This figure is projected to decrease to about 0.72% in 1979 and 1980.

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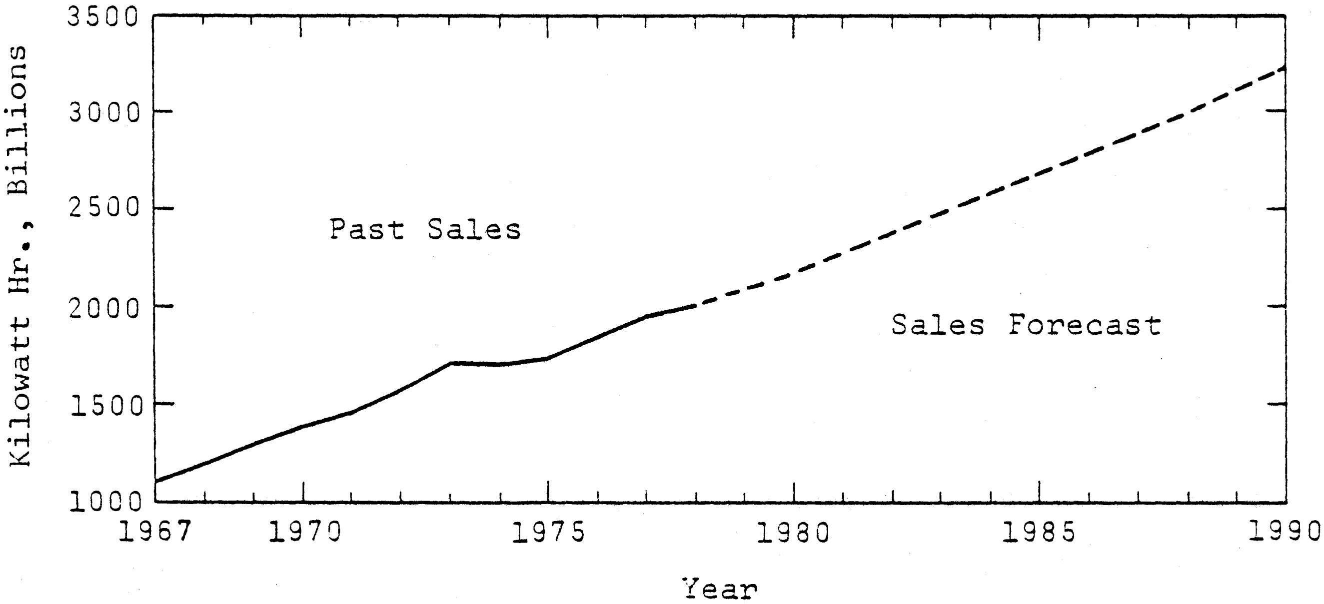

Figure 1: Actual and projected electricity consumption in the U. S. — 1967-1990. Source: Reference 28.

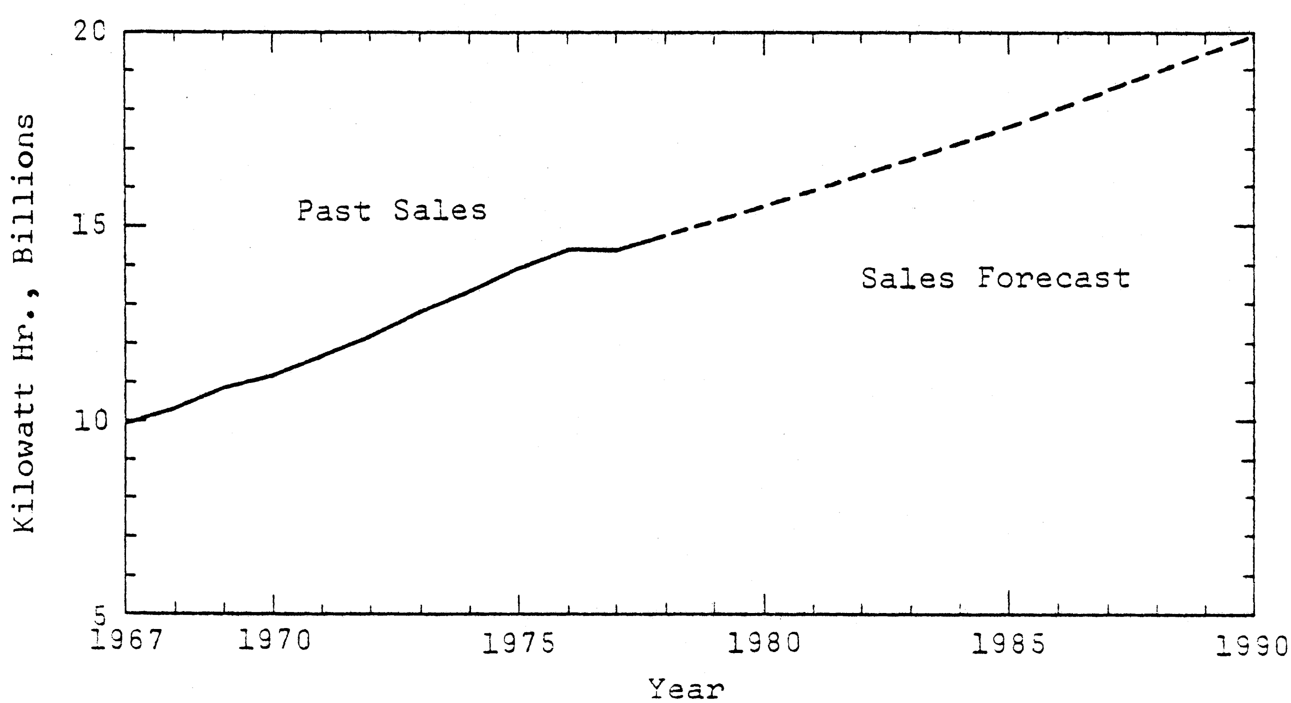

Figure 2: Actual and projected electricity consumption by roadway lighting in the U. S. — 1967-1990. Source: Reference 28.

The growth rate in total electricity consumption was interrupted after the oil embargo period of 1973 and then resumed its upward trend after 1975. Beyond 1978 continued growth is being forecast, but probably at a much lower rate than would likely prevail had not the sharp and continuing increases in fossil fuel prices been imposed after the original embargo. By way of contrast, the rate of increasing electricity consumption in roadway lighting remained relatively constant between 1976 and 1977, and a lower rate of increase is forecast for the future as compared to the rate of growth that prevailed prior to 1976. The constant rate of consumption between 1976 and 1977 indicated in Figure 2 was probably due to a combination of reduced lighting and a switch to more energy-efficient light sources — a subject discussed in more detail later.

While the various fuels used to generate electricity are increasingly costly, the use of oil is probably of greatest concern since most of that used by electric companies is currently imported. The proportion of oil that is used to generate electricity is constantly changing due to such things as nuclear plant startups, shutdowns, etc. On the average, however, oil is used to generate between 16% and 18% of the electrical power produced in the United States. If one assumes that an average of 17% of the electricity produced in 1977 was derived from oil, it can be determined that 4.7 million barrels of oil per year were used to power street and highway lighting. This is the equivalent of 12,923 barrels of oil per day (see Appendix A for calculations). While this is a large daily quantity of oil, it is only 0.07% of the more than 18 million barrels per day consumed in the United States during 1977. Viewed in a slightly different manner, the quantity of oil used to power street and highway lighting for one year is roughly equal to that consumed in one-fourth of a day at the overall daily consumption rate.

The proportion of power generated from oil in the state of Virginia is slightly different from the national average. In a recent speech by a Virginia Electric and Power Company official, it was stated that 24% of the electricity produced by his company was generated from oil. This particular company generates the majority of the power used in Virginia — particularly in those areas having the largest populations and thus the greater share of the roadway lighting.

Most of the roadway lighting in Virginia is not under the direct control of the Virginia Department of Highways and Transportation since the lighting facilities are located within the various municipal jurisdictions. All of the interstate highway lighting, however, is controlled by the Department. At present there are approximately 5,000 luminaires in service on the interstate system in Virginia. If it is assumed that the average power (including losses) consumed by each lamp is 500 watts and that each operates for 11 hours per day, 27,500 kilowatt-hours of electrical energy would be used each day. With 24% of Virginia's power being produced from oil, this would translate to an average of 12.7 barrels of oil per day used to power the interstate highway lighting in Virginia. Could 12.7 barrels of oil per day be saved if all the interstate lighting were turned off? Presumably, this would be the case since a lower demand would be placed on the power plant generators. Whether the potential savings could actually be realized or not, however, is unknown to the writer. Since the lighting is being used mostly during the off-peak demand period,turning the roadway lighting off would be of little aid to the utilities in reducing the amount of generating capacity required at their plants. It is probably more fruitful at this time to think in terms of conserving electrical energy to reduce its cost in roadway lighting. As the electric utilities find ways to store their off-peak capacity through pumped storage or possibly other means, much of the electrical energy conserved (and thus oil conserved) by consumers during the off-peak periods could then be stored for later use. In terms of the total electrical energy consumed by the Virginia interstate highway lighting, the equivalent of 53 barrels of oil per day would be required to supply 27,500 kWh of electricity. At a rate of $0.035 per kWh, the annual cost of this power would be $351,312.50. With the increasing costs of power that are likely in the future, considerable monetary savings could be realized through a reduction in the energy consumed by the interstate lighting alone, as will be analyzed in more detail later. It should be noted that the interstate highway lighting is only about 5% or less of all the roadway lighting in operation. Therefore, a reduction in the power consumed by all roadway lighting could be translated into substantial savings.

ENERGY SAVING ALTERNATIVES IN ROADWAY LIGHTING

Turning Roadway Lighting Off Entirely

The most obvious way to reduce energy consumption in roadway lighting is to simply turn sections of lighting off entirely. In the literature cited earlier, however, the vast preponderance of the information indicates that under the normal operating conditions for which the roadway lighting was intended to serve, simply turning lighting off may increase the traffic accident rate. Even on controlled access freeways, several of the recent studies cited earlier have indicated that turning lighting off entirely may result in increased accident rates and degree of severity of those accidents that occur. Thus, the "lights out" alternative does not appear to be an acceptable one under normal traffic and operational conditions. Only in an austere energy situation would this alternative appear to be justified at this time. In a severe shortage of energy, it is likely that traffic operations would be markedly different and would not constitute the normal (or near normal) conditions for which a lighting system may have been designed.

Partial Lighting

A procedure that has been used to reduce energy consumption by roadway lighting consists of turning off some of the lighting. Schemes have varied from turning off every other light on continuous sections to turning off all lighting between interchanges while leaving the interchange lighting on. In some instances interchange lighting has been partially reduced. Obviously, there are many variations of this approach to reducing energy consumption.

Partial reductions in lighting have been applied in a number of ways for varying periods of time at a number of locations in Virginia and elsewhere. To the writer's knowledge, no evaluations of any one particular reduction technique have been made to determine the effects of the change on accident statistics or on driver behavior. Reductions in lighting such as that effected by turning off every other light violates several initial design standards such as those required for uniformity and average maintained levels of illumination. Therefore, the effects of these types of conservation efforts are difficult to ascertain without resorting to a research study conducted over an adequate period of time. National Corporative Highway Research Program (NCHRP) research in this area has been proposed but no investigations have been conducted as yet. A recent NCHRP problem statement concerning partial interchange lighting has been submitted to the Transportation Research Board (TRB) jointly by Illinois and Virginia. This statement suggests that research funds be designated to study partial lighting situations at interchanges.

In the absence of adequate data concerning its effects, the partial reduction of lighting on existing systems does not appear to be a desirable alternative under normal traffic and operational conditions. It should be noted that this conclusion pertains primarily to existing systems. Design approaches to new systems could be handled in a more orderly fashion to minimize any negative aspects of lower illumination levels.

Seasonal Lighting

Another austerity type strategy might be to cut off the roadway lighting on certain projects during the weeks of the year having the longer hours of daylight. This approach could be used for approximately half of the year — late spring, summer, and early fall. Some support for this possible approach is seen in the results of a study cited earlier, where it was found that lighting might not be as effective in reducing the night accident rate during the seasons of the year having the longer hours of daylight.(27) This result, it should be noted, applied only to continuous freeway lighting situations. Furthermore, the data available for the study were limited; so it would be desirable to have substantiating data from future studies. In a statistical sense, however, there would appear to be a lower chance of adversely affecting the nighttime accident rate if, under a severe energy shortage situation, the lighting on urban and suburban freeways were used only during periods when the heaviest traffic volumes occur during the early hours of darkness. This alternative could be applied primarily between April and October to all freeway lighting and, possibly, other roadway lighting that serves a function similar to that of freeway lighting, i.e., lighting in areas with little or no pedestrian traffic, few intersections, etc.

One of the disadvantages of turning roadway lighting off for extended periods of time might be the potential development of functional problems associated with nonuse of the hardware. This could involve, for example, problems with moisture accumulation in the luminaires, rusting, etc., that could cause operational problems when the lights are reactivated. These types of potential problems, however, might prove to be minimal on some lighting systems.

Heavy Traffic Volume Lighting

A variation of the seasonal strategy might be to activate the lighting only during the hours of darkness, when the heaviest traffic volumes are on the roadway. During the longer hours of darkness in the winter, for example, certain sections of lighting might be used for only 3 to 4 hours in the early evening and again for 3 to 4 hours in the early morning, when the traffic volumes are highest. This approach could be combined with the seasonal approach such that the lighting would be phased out entirely during the seasons having the longer daylight hours.

The disadvantages of this alternative would be similar to those discussed for the seasonal lighting possibility. In addition, the lighting would have to be virtually manually controlled each day. On some lighting systems this might involve a number of different circuits and a number of people to perform the daily tasks efficiently. From an operational viewpoint the implementation of this alternative would, in most instances, be unattractive.

Conversion to More Energy-Efficient Lamps

Most of the roadway lighting in service in Virginia is provided by mercury lamps. The mercury vapor lamp has been the most widely used light source for roadways for more than 20 years. Until several years ago it was also one of the most efficient light sources in addition to having reasonably good color and a long, dependable life span. In addition, the mercury lamp is small enough for good optical control of the light distribution. In recent years considerable improvement in the development of the high pressure sodium (HPS) vapor lamp has increased its service life to the point that it compares with that of the mercury vapor lamp. While it is still not the most efficient light source available today, the HPS vapor lamp is much more energy-efficient than the mercury lamp. The luminous efficacy of the HPS lamp can be as high as 140 lumens per watt compared to 65 for the mercury.(3) Accordingly, the HPS lamp can provide approximately the same amount of light as the mercury lamp while using half the power. Thus the replacement of the mercury lamps with HPS lamps would allow lighting systems to be operated in a normal fashion while using only half the power, in many instances, as used previously.

The conversion of existing mercury lighting to HPS lighting would normally involve more than simply replacing the lamps. To obtain the necessary electrical control, special ballasts are required for the most efficient HPS lamps. HPS lamps are available that can be directly retrofitted into some conventional mercury luminaires having certain types of ballast. However, the rated average life, as well as the efficiency of these lamps, is about 25% lower than that of the ballast and lamp retrofit. Compared to the mercury lamp, the HPS lamp is also more expensive.

The most energy-efficient lamp currently available is the low pressure sodium (LPS) lamp, which has a luminous efficacy of up to 183 lumens per watt.(30) This lamp cannot be retrofitted to existing mercury luminaires due to its large size. Because of its large size, optical control is difficult to achieve and installation of the hardware is more expensive than with the HPS lamp. It also produces a monochromatic color which is not desirable for most street and highway situations. Where color and optical control do not take precedent over the efficiency of the lamp, it can be a good, efficient source of light. Tunnel lighting, for example, might be an application for LPS lighting.

In an environment where the conditions that initially warranted a lighting system still exist, the most logical step would be to convert to HPS lamps to reduce energy consumption while maintaining illumination levels equal to or superior to those of the original systems. In the case of new lighting systems, they should be designed utilizing HPS vapor lamps wherever possible.

Automatic Energy Control

For many hours during the operation of a roadway lighting system, the total amount of illumination being provided is not needed. There are several reasons for this. First, lighting is over designed initially to allow for subsequent depreciation in the lumen output of the lamps. Secondly, illumination levels are affected by dirt accumulation on the luminaire over a period of time. In addition, full illumination levels are not normally needed when lighting is first activated in the early evening nor before it is turned off in the early morning. As a result of these factors, considerable energy is wasted in providing light that is not needed. This is particularly true during the first two years of operation of a lighting system and again when the system is cleaned and the lamps replaced. With automatic energy control devices, this wasted energy could be saved.

Automatic energy control, simply stated, allows only enough power input to the system to deliver the design level of illumination. As the lumen output of the lamp gradually declines with age, the power input increases to maintain the desired level of illumination. The input is determined by an automatic energy control device that compares a preset value with the level of illumination provided by a strategically located photocell sensor. The energy controller then sends a signal to the ballasts, which increase or decrease the power input to achieve the prescribed illumination level.

Energy savings can be obtained from the use of automatic energy control but it is difficult to estimate the amount of savings, largely because of the variation in the lumen output of the lamp during the early part of its life cycle. During this period, savings on the order of 25% might be realized, but the percentage would likely decline significantly as the lamps age. The costs of an automatic energy control system, as well as the potential savings resulting from its use, would require thorough analysis.

More Efficient Management

The activation of roadway lighting is normally controlled by time clocks or photoelectric cells. These control units should be checked periodically to ensure that they are operating properly. It has often been observed that roadway lighting in some areas is activated before it is needed in the evenings and not deactivated soon enough in the mornings. Luminaires that are controlled by time clocks, for example, need constant adjustment to keep them in tune with the changing hours of daylight and darkness. Controls that malfunction should be corrected as soon as possible to ensure maximum efficiency and reduce energy waste.

Luminaire maintenance— particulary routine scheduling for cleaning and replacement of the lamps — can greatly promote efficiency of operation of a lighting system.

SUMMARY AND CONCLUSIONS

Although the energy situation is at times quite critical with gasoline and diesel fuels in short supply, traffic operations in the areas where the majority of the roadway lighting is located have continued at or near expected levels. Therefore, from an operational and safety viewpoint the most logical alternative of those reviewed here would be to convert as much of the mercury lighting to HPS lighting as would be practical. Reductions in energy consumption on the order of 50% can be achieved through this step alone. In addition, implementation of this alternative does not preclude the possible subsequent implementation of one or more of the other options available for reducing energy consumption further in the event of severe energy shortages.

The Department's ability to make the conversion to HPS lighting has been greatly enhanced by the FHWA's policy which now makes the cost of the replacement of existing mercury luminaires on federal-aid systems eligible for federal funding. Lighting on the interstate system, for example, could be converted to use HPS luminaires with 90% of the costs being covered by federal funding.

Color rendition is often cited as an objectionable feature of HPS lighting and is sometimes a factor that complicates the decision-making process. This feature is less of a factor now than it was several years ago, because the HPS light source is now widely accepted by the public and transportation officials. In a recent survey of public acceptance of changes in some street lighting in Canada, the respondents said they were pleased with both the mercury and HPS lighting. There were few differences in the respondents' ratings of the mercury vapor and HPS lighting.(31)

The next most logical alternative would appear to be that of turning the lighting off at a certain hour of the night as determined by traffic volumes and prior experience with nighttime accident rates. This strategy has the advantage of maximizing the benefits of the lighting when the heaviest traffic volumes are on the roadway as well as reducing overall energy consumption. It would be most applicable to continuous freeway lighting or other similar situations where the effectiveness of the lighting in reducing the nighttime accident rate appears to be more related to traffic density than to other factors. A negative aspect of this alternative would be the cost of switching the lighting on and off.

Turning roadway lighting off on a seasonal basis, i.e., during the seasons having the longest hours of daylight, would be a less desirable alternative. In addition to the risk of possibly increasing nighttime accident rates, there would be a tendency for the lighting system components to deteriorate if not in regular use. These two problems would be considerably magnified if lighting systems were switched off entirely. At present, the following ordering of energy-saving alternatives in roadway lighting appears to be reasonable.

1. Convert existing mercury vapor lighting to the more energy-efficient HPS lighting.

2. Provide for an efficient field management program that will ensure adequate maintenance and reduce energy waste due to malfunctioning lighting controls.

3. Install automatic energy control equipment to reduce power consumption when full level illumination is not needed.

4. Activate the lighting only during the hours of darkness when the heaviest traffic volumes are on the roadway.

5. Use partial lighting. It should be noted that the reference to partial lighting here pertains to the partial utilization of the lighting on existing systems.

6. Deactivate the lighting on a seasonal basis when the hours of daylight are the longest and where experience indicates that accident rates would be the least affected. This alternative would apply, in most cases, to continuous freeway lighting.

7. Turn the roadway lighting off entirely.

IMPLEMENTATION

After a discussion of some of the alternatives by the Department's Special Roadway Lighting Advisory Committee, it was decided to inventory all of the interstate system lighting currently in operation and to estimate the savings that could be achieved through converting the mercury lighting to HPS lighting. The interstate system was chosen because all of this lighting is under the direct control of the Department, whereas much of the lighting on other highway systems is controlled by local jurisdictions.

An initial inventory of all the mercury vapor luminaires in service on Virginia's interstate system was completed by J. R. Youell, former senior electrical engineer, and is presented in Table 1. At the time of the inventory, a total of 4,752 luminaires were in service in the eight highway districts that were candidates for conversion from mercury to HPS lighting. A present worth analysis for replacing these luminaires with HPS lamps is given in Appendix B.

Table 1

Mercury Vapor Luminaires

Interstate System

District	No. Luminaires
Bristol	211
Salem	91
Lynchburg	0
Richmond	1,150
Suffolk	900
Fredericksburg	97
Culpeper	2,273
Staunton	30
Total	4,752

The present worth analysis assumes an interest rate of 10%, a cost of power of $0.04 per kWh, and a 20-year life for the lighting hardware. As an example of the annual savings in power costs, the conversion of a 400-watt rated mercury system to a 200-watt rated HPS system would yield annual savings of $33.29 per luminaire. With the 1978 cost of converting estimated at $192.50 per luminaire and the difference in the cost of an HPS lamp as opposed to a mercury vapor lamp estimated at $20, it was determined that it would take only 7-1/2 months for the Department to break even on its investment when 90% funding is supplied by the FHWA. Assuming no participation by the FHWA (100% state financing), it would take 9.9 years to recover the initial investment. Over a 20-year period, the present worth of accumulated savings resulting from the proposed conversion would be, $247.96 and $74.71 with and without federal participation, respectively. In either case, the initial investment is cost-beneficial. Perhaps more importantly, approximately 50% of the energy currently consumed will be saved after the proposed conversion.

Since 90% federal funding is available for conversion of the lighting on the interstate system, it is estimated that present worth savings of $1,245,072 in power costs can be realized by the Department over the remaining 20-year life of the lighting systems. The remaining life calculation is based on an assumed conversion to HPS after the existing system has reached an average age of 6-2/3 years. It should be noted that the estimated savings is probably conservative since power costs are likely to increase beyond the per kWh costs used in the analysis. In addition, the analysis assumes no salvage value of the mercury luminaire components that would be replaced.

Based on the interstate lighting inventory and the analysis of the power and cost savings that could be achieved, it was recommended that the conversion to HPS be undertaken. This recommendation was made to the Department's management by R. A. Mannell, chairman of the Special Lighting Advisory Committee, and was approved by Deputy Commissioner & Chief Engineer Leo E. Busser III on June 16, 1978.

IMPLEMENTATION STATUS

In a report to the newly formed Energy Research Task Group, R. P. Stockdell, senior electrical engineer, stated that as of May 11, 1979, 3524 mercury vapor luminaires were being scheduled to be replaced with HPS lamps. Of this total, 2632 of the units are at or near the contract stage. As can be noted in Stockdell's summary shown in Table 2, some non-interstate system lighting is also being scheduled for conversion to the HPS type. Approximately 75% of the original inventory, however, is nearing the conversion stage.

Table 2

Status of Converting From
Mercury Vapor to High Pressure Sodium Lighting
(Data furnished by R. P. Stockdell, senior electrical engineer, of the Department.)

At or Near Bid Stage

Route No.	Area	No. Lamps
17	James River Bridge	232
I-64	Richmond	75
I-85	Dinwiddie County	100
I-95	Richmond-Petersburg	197
I-395	Shirley Highway	2,028
	Subtotal	2,632

In Initial Stage

Various	Suffolk District	892
	Total	3,524

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The author thanks J. R. Youell, former senior electrical engineer; R. P. Stockdell, senior electrical engineer; and R. A. Mannell, chairman of the Special Lighting Advisory Committee; for their efforts in inventorying the lighting systems involved, analyzing the cost data, and achieving the implementation of the Committee's recommendation.

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REFERENCES

1. "Modern Highways News Report", Rural and Urban Roads, May 1976.

2. Special Report: "Switch to Energy-Efficient Lighting, Lower Wattages Saves Highway Dollars", Better Roads, September 1977.

3. "Highway Lighting Systems: Are They Really Necessary?", Better Roads, December 1977.

4. "City Doubles Illumination at Half the Power Cost", Rural and Urban Roads, October 1977.

5. Wyatt, Francis D., and Edmund Lozano, "Effect of Street Lighting on Night Traffic Accident Rate", Highway Research Board Bulletin 146, Highway Research Board, Washington, D. C., 1957.

6. Schrenk, Louis J., "Effect of Light Changes on Traffic Accidents Shown in Detroit Lighting Report", Illuminating Engineering, Vol. 42, No. 9, Nov. 1947.

7. "Street Lighting— Accident Reduction Pays for Lighting", Rural and Urban Roads, April 1969.

8. Tanner, T. C., "Reduction of Accidents by Improved Street Lighting", Light and Lighting, Vol. 51, No. 11, Nov. 1958.

9. Turner, H. J., "The Effectiveness of the N.S.W. Street Lighting Subsidy Scheme", paper presented to the National Road Safety Symposium, Canberra, Australia, March 1972.

10. Janoff, M. S., B. Koth, W. McCunney, M. Freedman, C. Duerk, and M. Berkovitz, "Effectiveness of Highway Arterial Lighting", Report No. FHWA-RD-77-37, Federal Highway Administration, Washington, D. C., July 1977.

11. Janoff, M. S., B. Koth, W. McCunney, M. J. Berkovitz, and M. Freedman, "The Relationship Between Visibility and Traffic Accidents", Journal of the Illuminating Engineering Society, Vol. 7, No. 2, January 1978.

12. Lipinski, M. E., C. G. Meador, A. L. Gilbronson, M. L. Traylor, W. D. Berg, C. L. Anderson, and R. H. Wortman, "Summary of Current Status of Knowledge on Rural Intersection Illumination", Highway Research Record No. 336, Highway Research Board, Washington, D. C., 1970.

13. Jorgenson, Roy and Associates, "Evaluation of Criteria for Safety Improvements on the Highway", Roy Jorgenson and Associates, Gaithersburg, Maryland, 1966.

14. Blythe, J. D., "Highway Lighting and Accidents in Indiana", Highway Research Board Bulletin No. 146, Highway Research Board, Washington, D. C., 1957.

15. "A Study of the Benefits of Suburban Highway Lighting", Illuminating Engineering, Vol. 64, No. 4, pp. 359-363, April 1969.

16. Vey, A. H., and C. S. Pope, "The Relation of Highway Lighting to Highway Accidents", Highway Research Board Proceedings, Vol. 14, Part I, Highway Research Board, Washington, D. C., pp. 429-441, 1935.

17. Christie, A. W., "Research on Street and Highway Lighting with Particular Reference to Their Effect on Accidents", paper presented to the Annual Conference of the Institution of Municipal Engineers, June 1966.

18. Lefevre, P., "The Influence of Lighting on Traffic Accidents", Automobilismo e Automobilismo Industriale, No. 3, May 1962.

19. American Association of State Highway Officials, Traffic Safety Committee, "Highway Design and Operational Practices Relating to Highway Safety", Feb. 1967 (71 pp.)

20. Johnson, Roger T., and Thomas N. Tamburri, "Continuous Freeway Illumination", State of California Highway Transportation Agency, Traffic Department, May 1965.

21. Huber, Matthew J., and Joseph L. Tracy, "Effects of Illumination on Operating Characteristics of Freeways", NCHRP Report 60, Highway Research Board, Washington, D. C., 1968.

22. Yates, John G., and Richard L. Beatty, "Relationship Between Lighting and Accident Experience Between Interchanges", Highway Research Record No. 312, Highway Research Board, Washington, D. C., 1970.

23. Stark, Richard E., "Studies of Traffic Safety Benefits of Roadway Lighting", Highway Research Record No. 440, Highway Research Board, Washington, D. C., 1973.

24. Box, P. C., "Relationship Between Illumination and Freeway Accidents", Illuminating Engineering, Vol. 66, No. 5, 1971.

25. Box, P. C., "Freeway Accidents and Illumination", Highway Research Record No. 416, Highway Research Board, Washington, D. C., 1976.

26. Richards, Stephen H., "The Effects of Reducing Continuous Roadway Lighting to Conserve Energy: A Case Study", Safe Journal, Vol. 9, No. 1, Spring Quarter, 1979.

27. Hilton, Marvin H., "Continuous Freeway Illumination and Accidents on a Section of Rte I-95", Virginia Highway and Transportation Research Council, Report #79-R4, August 1978.

28. "The 29th Annual Electrical Industry Forecast", Electrical World, September 15, 1979, pp. 62-76.

29. "Energy Impact Analysis Resource Information", U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., June 1976.

30. Roadway Lighting Handbook, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., August 1978.

31. Herlihy, Dan G., and Douglas F. Smith, "Attitudes to Street Lighting in a Residential Area: High Pressure Sodium and Mercury Vapour Lighting Compared to Incandescent Lighting", Ministry of Transportation and Communications, Ontario, October 1978.

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APPENDIX A

Calculation of the Quantity of Oil Used for the Generation of Power Consumed by Roadway Lighting (Source: Reference 29)

Year: 1977

Power Consumed: 14.4 Billion kWh_e*

Power Produced From Oil: 17% (national average)

Units:

1 bbl. oil = 5,800,000 Btu

1 kWht = 3,412 Btu

1 bbl. oil = 1,700 kWh_t

1 kWh_e = .305 kWh_t

1 bbl. oil = 519 kWh_e

Barrels of Oil Consumed Daily to Power Roadway Lighting:

$$\frac{0.17 \times 14.4 \times 10^9}{519 \times 365} = 12{,}923 \text{ bbls. per day.}$$

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* Notations:

kWh_t = The intrinsic thermal energy value of oil in kilowatt hours.

kWh_e = The electrical energy produced from oil after losses during generation, transmission, and distribution.

APPENDIX B

COMPARISON OF NEW 400 WATT MERCURY VAPOR LUMINAIRE WITH NEW 200 WATT HPS LUMINAIRE AT 240 VOLTS

This analysis assumes an interest rate of 10% and an electricity rate of $.04/kWh. The cost of the 400 watt MV luminaire is excluded, as the analysis assumes the luminare has just been installed and is being considered as a candidate for replacement with no salvage value. This assumption is slanted in favor of retaining the mercury luminare.

<u>Luminaire Savings</u>

$$\frac{(460-246)}{1000}\ \text{kW} \times \frac{10\ \text{Hr}}{\text{Night}} \times \frac{365\ \text{Nights}}{\text{Yr.}} \times \frac{.04\$}{\text{kWh}} = \frac{\$31.24}{\text{Yr.}}$$

<u>Line Savings</u>

$$\frac{(15.6 \times (2.0-1.1))}{1000}\text{kW}\ \frac{10\ \text{Hr}}{\text{Night}} \times \frac{365\ \text{Nights}}{\text{Yr.}} \times \frac{.04\$}{\text{kWh}} = \frac{\$2.05}{\text{Yr.}}$$

<u>Total Savings</u>

$$= \frac{\$33.29}{\text{YR}}$$

BREAK EVEN TIME FOR DEPARTMENT @ 10% INTEREST

<u>No FHWA Participation</u>

$$\$192.50^{*} + \frac{\$20.00^{\dagger}}{1.1^{6.66}} = \frac{1.1^{n}-1}{.1(1.1)^{n}} \quad (\$33.29)$$

$$n = 9.9\ \text{yrs.}$$

<u>90% FHWA Participation</u>

$$\$19.25 = \frac{1.1^{n}1}{.1(1.1)^{n}} \quad (\$33.29)$$

$$n = .625\ \text{yrs.}$$

*Cost of changing one mercury luminaire to a HPS luminaire.

†Present worth of replacing lamps at 6-2/3 yrs. with HPS costing $20 more than MV.

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TOTAL 20-YEAR SAVINGS IN PRESENT WORTH

No FHWA Participation

$$\$33.29\ \frac{(1.1^{20}-1)}{.1(1.1)^{20}} - \$192.50 - \frac{(\$20.00)^{a}}{1.1^{6.66}} - \frac{\$20.00)^{b}}{1.1^{13.33}} =$$

$$\$283.42 - \$142.50 - \$10.60 - \$5.61 = \$74.71$$

90% FHWA Participation

$$\$283.42 - \$19.25 - \$10.60 - \$5.61 = \$247.96$$

TOTAL ESTIMATED PRESENT WORTH SAVINGS FOR REMAINDER OF 20-YEAR LIFE

90% FHWA Participation

$$\frac{500}{400}\left[33.29\left(\frac{(1.1)^{13.33}-1}{.1(1.1)^{13.33}}\right) - 19.25 - 10.60\right] \times 4752 = \$1,245,072^{c}$$

[a]Replacing lamps at 6-2/3 yrs.

[b]Replacing lamps again at 13-1/3 yrs.

[c]Assumes conversion after system is 6-2/3 yrs. old.