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Lighting Energy Management: In the case of road lightings in Negara Brunei Darussalam

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Abstract: In the feasibility study to manage energy consumption of road lightings in Brunei Darussalam, flux regulation technique had been used to perform the energy-saving task of the lightings involved in trial. A 40 A, 3-phase regulator was used to regulate flux on 400 W high-pressure sodium road lightings throughout the trial period. Flux of lighting was regulated by the steady lowering of the output voltage from the regulator from normal operation to the minimum allowable voltage for high-pressure sodium bulbs. Twenty-six lightings had been involved in the study at the suburban area of Brunei. The findings from the trials had demonstrated that as much as 92.7 kWh or 38.7% of electrical energy can be saved from the implementation of the method with an illumination's reduction of 52.6% respectively recorded at the end of lightings' lines. The associated energy-cost savings was B$3,337.20 per annum. The method will also help reduce as much as 29.4 tonnes of CO_2 emission annually.

Keywords: Lighting energy management,Flux regulation, Energy consumption, Energy saving, Average horizontal illumination.

Introduction

Road and street lighting or more specifically termed as public lighting, plays an important role in the development of many urban, suburban and rural areas. It enhanced the night-time hours with artificial lighting whereby, increased comfort, convenience, efficient traffic operation and safety of night traffic are achievable. Besides, it also helps to reduce crime and accident occurrence. In the past, poor road and street lighting design can be compensated by increased lighting levels [1]. However, since the energy crisis of the 1970's, the awareness on energy conservation has created a need to use energy wisely of which, exterior lighting, road lighting in particular, is one area where energy can be conserved. The efficient and effective use of outdoor lighting can offer a major energy and cost savings.

The history on lighting energy management of road lighting has gone a long way since its beginning. Lighting experts kept on formulating new bulb invention in the pursuit for a better light output yet with a significant reduction on the bulb's energy consumption. The continuous efforts from the researchers tended to aim on the increasing awareness of energy issues besides providing a better quality of lighting for roads. International Lighting Review [2] indicated from statistics that, street lighting accounts for far less than 1% of our energy requirements, yet, as in all other areas of energy consumption, there are constant pressures to reduce costs in both the existing and future installations. The answer to providing a standard public lighting while ensuring the safety of persons and property as economically as possible, in an era when energy costs will continue to rise, lies in the use of modern, energy-efficient light sources. As time passed by, the management's trend has changed dramatically in scope and sophistication. Owing to the needs by the lighting utilities and municipalities both in terms of conserving energy resources and cutting down their operational cost, products through the innovative idea from lighting experts and researchers that can be found in the market nowadays, are able to provide the solutions. The emergence of the state-of-art systems such as public lighting automation, flux regulation and dynamic dimming have helped to perform energy-saving measures to lightings on roads according to the utilities' managing strategies.

Owing to the reformations made from the replacement programs of 250 W to 400 W high-pressure road lightings at most major roads and highways by an Independent Power Producer (IPP) company during the mid nineties, Brunei has seen a drastic increase on its annual energy consumption of road lighting. As reflected by the statistical data report from Research and Development, Department of Electrical Services (DES), Negara Brunei Darussalam [3] on energy production and energy consumption for Brunei, energy consumption for road lighting had risen drastically to 41.4 GWh in 1996 as compared to 11.6 GWh the year before. The consumption's figure in 2002 was 48.9 GWh. This has caused concern to the Department of Electrical Services (DES), being an organization responsible for the operation and maintenance of all road lightings throughout the country. As a Government body, the cost for performing all these operations are supported and allocated to the DES by the Brunei Government. The current road lighting installation at major roads and highways are seen to be over-lit and consumed more energy as the lamps used are of 400 W type. It was observed that much energy was wasted especially after midnight.

The past few years had seen DES's concern on the increased use of energy and hence the operating costs for road lightings. Some lighting management strategies such as involving the switching off of lightings alternately were found to be ineffective. The absence of many nighttime activities such as nightclubs has made Brunei roads quieter especially after shops' closing time at 10:00 p.m. This, indirectly, strongly supports the need to save energy consumption of road lightings especially after this period. The use of nighttime lightings on the roads thus serves to only a small portion of the population after that period.

This study is therefore conducted as an attempt to find the energy saving solutions for the current situation on the energy consumption of road lighting in Brunei. However, the study would not attempt to make estimation on the amount of road lighting energy that can be saved from all the 400 W luminaries statewide through the method used in the study. It will focus only onto the experimental result from the method's implementation at a selected site in Brunei. It is hoped that the success from the field trial would be made as a role model to implement lighting energy management to the roads and highways throughout the state in the future.

Methodologies

The method, the equipment and the experimental set-up used in the research.

Flux regulation method, a similar technique that was used by IREM [4], was employed to investigate the energy-saving task for road lightings in Brunei Darussalam throughout the research's work. In this method, the lightings on the roads were dimmed by subjecting them to underpowered condition. By doing so, the flux was regulated to the desired level and thus achieving a substantial amount of energy saving. In carrying out the research study, reference is made to the basic concepts and methodology as guided by International Performance Measurement and Verification Protocol (IPMVP) Committees [5] which stated that, energy or demand savings are determined by comparing measured energy use or demand before and after implementation of an energy savings program. Measurement involves the identification of the post-retrofit period. This period may be as short as a one minute test following commissioning of an Energy Conservation Measure (ECM), or as long as the time required to recover the investment cost of the ECM program. Savings are determined by partial field measurement of the energy use of the system(s) to which an ECM was applied; separate from the energy use of the rest of the facility.

A 40 A, 3-phase flux regulator was used to regulate flux of 400 W high-pressure sodium road lightings at a chosen site in Brunei during the trial study. The energy consumption of the lightings involved was monitored by means of a100 A, 3-phase energy kilowatt-hour meter. The flux regulating equipment is connected next to the existing lighting controller as is shown in Figure 1. Only the lighting line under study had been connected to the flux regulator and to the kilowatt-hour meter.

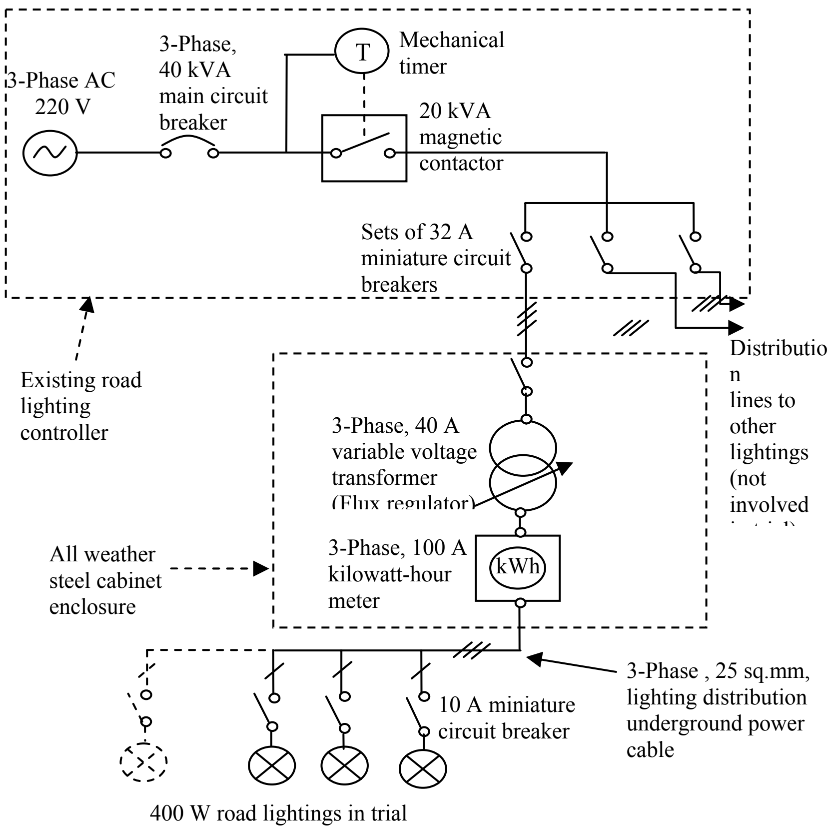

Figure 1. The experimental set up of the equipment that had been used to carry out the energy-saving task on the 400 W road lightings at Muara Road in Brunei Darussalam.

Study site.

One such site where flux regulation had been carried out to manage energy consumption for road lightings in Brunei Darussalam was Muara Road, situated at the suburban area near the capital city of the state. The site has a double lane two way roadway system with 400 W high-pressure sodium road lightings stretching along the median of the road. Commercial buildings, residences, technical college, schools and public buildings can be found within the vicinity of the road. A total number of 26 road lightings had been involved in the case study at this site.

Method procedures.

Lightings with voltage supply's level at normal operation (Before Energy Conservation Measures's Operation)

With the lighting line under study fed with normal power supply and connected to the energy kilowatt-hour meter, the daily energy consumption of the lightings involved at the trial site is monitored overnight and recorded. In addition, the flux emitted at the road section in-between the two lanterns at end of lighting line is measured and recorded.

Lightings with voltage supply's level reduced (After Energy Conservation Measure's Operation)

With the flux regulating equipment connected next to the existing lighting controller at site, it is possible now to perform the energy-saving operation by reducing the voltage supply along the lighting line under study. The output voltage supply from the regulator is set to its minimum level in such a way that the lantern at the end of lighting line receives a minimum allowable working voltage of 175 V [6] as to avoid flickering or switching off of lighting. As the output of the resultant illumination from the implementation of the method is considered a critical issue to the safety of motorists during nighttime driving, the reduced flux emitted at the road section in-between the two lanterns especially at the end of lighting line, is measured and assessed, and is compared with the standard recommended value as laid by the Illumination Engineering Society (IES) [7].

Proposed future road lighting scheme operation based on Energy Conservation Measure's operation.

This section will look into the possibility for the operation of future road lighting scheme based on Energy Conservation Measure's (ECM) operation. It is scheduled according to the lighting energy management strategy by the lighting engineer or manager. ECM's operation will be incorporated into the existing lighting hour operation. For some hours in the evening, from the time when lightings start to operate, lightings will operate via the normal existing voltage supply whereas, for the rest of the evening till lightings were turned off by the timer in the early hours of the morning, they will be fed with the minimum reducing power supply for which ECM will be put into effect. Apart from this, the study will also explore the possibility if ECM's operation were to operate for the entire existing lighting time operation. This will depend on whether the result on the reduced illumination will meet the standard criteria as laid by Illuminating Engineering Society (IES) for the category of area the study site belongs to. For this purpose, management strategy will look into three various lighting scheme operations which are as shown in Table 1.In the table, ECM's operation is considered for lighting energy management scenario 1 and scenario 2 as lower volume of traffic on the roads are expected between the period mentioned.

Table1. ECM's operating schedule for the proposed future lighting scheme operation.

Lighting energy management's scenario	Energy Conservation Measure's (ECM) operating schedule
Scenario 1	ECM's operation starts from 12:00 a.m. till lighting's switching-off time
Scenario 2	ECM's operation starts from 10:00 p.m. till lighting's switching-off time
Scenario 3	ECM's operation starts from lighting's switching-on time till lighting's switching-off time

For each of the ECM's operating schedule as set, the study will look into the amount of electrical energy that would be saved daily if a lighting energy management strategy is to be applied to the lightings at the same site in the future based from the energy-saving data as obtained from the study.

Economic analysis.

To look into the cost-benefit analysis of the technique used at the study site, base year energy consumption, both before and after the intervention of flux regulation technique to the lightings will be used. Base year consumptions are to be calculated from the daily energy consumption as recorded from kWh metering. Energy savings were to be calculated for an assumed annual period of 360 days due to the reasons as follow:

- Not all lightings will light up at all times as some lamps might be faulty.
- Voltage fluctuation.
- Power breakdown.

In the occurrence of the above events, energy consumption will be affected.

Most banks institutions in Brunei normally grant loan to such a project or projects with a maximum repayment period of ten years and an annual interest bank rate of 12% with the exception of an housing loan. Therefore, calculation for each of the economic assessment will be carried out for 10 years operation of the flux regulator in field. Three economic analysis techniques were used to determine the cost effectiveness of the method which are Simple Payback Time (SPT), Net Present Value (NPV), and Internal Rate of Return (IRR). SPT is the time it takes for an initial investment to be recouped. Although the SPT technique is inadequate for ranking investments in the basis of their expected profitability, it was calculated because it is still widely used as a criterion for accepting or rejecting potential investments [8]. The NPV and IRR for the viability of the method's investment will be determined from an energy-saving discounted cash flow calculations.

The NPV technique computes the present value (measured in Brunei Dollars) of an investment *n* years into the future. NPV is calculated using the formula as follows [8]:

$$NPV = \sum_{t=1}^{n} \frac{ACF_t}{(1+d)^t} - I$$

Where ACF_t is the annual cash flow in year *t*, *d* is the discount rate, *n* is the investment time in years and *I* is the initial investment amount. The discount rate used in the NPV calculations was 12.0% as it was the range of returns commonly expected by the lender (bank institution) for such a project loan in Brunei.

Finally, the value of IRR is typically determined through a “trial and error” process. Similar to NPV calculations, IRR takes into account the time value of money by considering the cash flows over the lifetime of a project. IRR analyses simplify part of the NPV calculation by focussing only on the cash flows of the project and solving the NPV equation for the rate that will yield an NPV equal to zero. The calculation approach to determine IRR is as below:

$$NPV = \sum_{t=0} ACF_t(P \mid F, IRR, t) = 0$$

In the above equation, ACF_t is the annual cash flow in year *t* and P/F is the present worth factor. To compute economic analyses using NPV and IRR, Microsoft excel spreadsheet’s program had been used. The operating costs which involve both the electrical energy cost and operation and maintenance (O & M) costs and also for the investment spent on the flux regulator are taken into consideration here. Electrical energy cost for road lightings in Brunei Darussalam is charged at a flat tariff rate of B$0.10 per kWh (B$1.00 is equivalent to 23.20 Baht approximately). There is no maximum demand charge levied to the total energy cost. The cost associated with operation and maintenance of the flux regulator is B$785.10 per annum. The cost is to include the hourly wage of the operator, the fuel on transportation to bring the operator to and fro field site and also, the annual cost to maintain the equipment quarterly. The flux regulator enclosed in an all weather steel cabinet used in the study was purchased for B$3,103.45 (equivalent to 72,000 Baht). Equipment installed at site is referred as a one-time investment only. A 5 percent energy escalation is assumed annually for the energy saving costing to give allowance to the frequent rise of global energy price. Depreciation cost of the flux regulating equipment is also considered here for the continuous future implementation. The salvage value of the equipment is set at B$200.00.

Benefits from the method.

Facts’ and results’ data as obtained from the study site will be used to evaluate valuable benefits from the use of the method in the study. These are:

1. Reduction in energy consumption and energy-cost savings.
2. Environmental benefits.

Reduction in energy consumption and energy-cost savings

Base year energy consumption both before and after the implementation of each of the ECM’s strategy scenario to the site will be used to determine the reduction in energy consumptions and hence the energy-cost savings involved. Both base year energy consumptions before and after the implementation of each of the ECM’s strategy scenario can be obtained from the results of the daily energy-savings.

Environmental benefits

International Performance Measurement and Verification Protocol (IPMVP) Committees [5] pointed out that, energy saving activities may also reduce other costs such as pollution/health care costs through lowering of atmospheric emissions from boilers. This statement has supported the hypothesis that energy saving activities as a result from the use of energy efficient technologies help to reduce pollution emissions to the atmosphere of which, carbon dioxide is part of the pollution emissions. The reduction in the electrical energy consumption by applying flux regulation to the lightings involved in the study will contribute to the reduction of carbon dioxide (CO_2) emission, a greenhouse gas which has contributed to the global climatic changes and global warming. Few studies in the past have related the electricity saved by installing energy efficient lighting systems to reductions in carbon dioxide emissions. Andy Collins et al. [9] pointed out on their project on the Dynamic Dimming of M65 highway in England that, CO_2 emissions was estimated to reduce from 274 tonnes when lightings were at the old scheme state down to 129 tonnes after applying traffic-flow profile to the new lightings. Julian Di Stefano [8] in his study to find out the potential for energy efficient lighting to save energy and reduce CO_2 emissions at Melbourne University, Australia had found that, installing of energy efficient lighting systems at the university has the potential to reduce the CO_2 emissions associated with the university's electricity use by 10%.

As 100% of Brunei's power plants use fossil fuel to generate electricity, the reduction of CO_2 emission from these power plants can be achieved through the reduction of electrical energy consumption from the trial site based on the energy savings from applying Energy Conservation Measure (ECM) strategy's scenarios to the new future lighting scheme operation. Calculation for the reduction in the carbon dioxide (CO_2) emission will be based on the production of 0.0024 tonnes of carbon dioxide from 1 kWh of electricity for Brunei Darussalam as reflected by the release on the latest report from World Resources Institute for 2004 [10], on the total carbon dioxide emission for the country in 2001 as well as on the statistical report by Research and Development DES [3], on the total consumption of electrical energy for Brunei for the year 2001.

Results and Discussion

The resultant daily energy consumption and output average horizontal illumination before and after the intervention of flux regulation to the lightings in trial.

Table 2 shows the results on the energy consumption and the change in the average horizontal illumination before and after the intervention of the flux regulation to the lightings involved at the trial site. With the voltage of operation set in a way that the luminaire at the end of lighting line received a voltage of 175 V during the Energy Conservation Measure, the method is capable of giving an energy consumption's reduction of 92.7 kWh or equivalent to 38.7% with an illumination's reduction of 52.6%. As can be seen from Table 2, the average horizontal illumination as recorded at the road section near the end of lighting line after the intervention of flux regulation

Table 2. The energy consumption and the output average horizontal illumination before and after intervention of flux regulation to the road lightings at study site.

Mode of operation	Energy consumption (kWh)	Average horizontal illumination at road section near end of lighting line (lux)
Before intervention of flux regulation	239.6	21.1
After intervention of flux regulation	146.9	10.0

to the lightings was found to conform with the recommended value as laid by IES. The standard recommended value from IES for the study site's road classification is 6.5 lux. With the illumination level produced during the Energy Conservation Measure is still within IES's specification and standard, the implementation of flux regulation for the voltage level as preset is applicable to be put into effect even for the entire lighting period at site without causing adverse effect to the road-users. As highlighted by Andy Collins et al. [9] in a research made by the Department of Optometry and Neuroscience at UMIST, they found that, reducing the luminance of the overhead light (road lighting in this case) results in a measurable reduction on ocular stress, a stress that was caused at the orbicularis muscle which surrounds the eye. An instrument to measure ocular stress was developed, the UMIST ocular Stress Monitor (OSM). This measures the electrical activity (EMG) of the orbicularis muscle. The research had noted that, a 30% reduction in the lighting level caused a 14% reduction in the EMG value, while a 50% reduction in lighting level gave a 23% reduction in the EMG. The study indicates that significant improvements in driver comfort are obtained where dimmable lighting is installed. While not specifically measurable, it is likely that general road safety is improved by reducing ocular stress, enabling motorists to remain more alert and reduce the risk of accidents. Thus, the case study from UMIST can make a convincing evidence to implement flux regulation as an energy-saving technique for road lightings in Brunei Darussalam, which will assure the improvements in driver's comfort and safety.

Proposed future lighting scheme operation based on Energy Conservation Measure's (ECM) operation.

As the reduced lighting's illumination at the study site was found to meet the reference illumination's standard as laid by IES, therefore, lighting management strategy will look into the implementation of all lighting energy management scenarios (scenario 1,2 and 3) for this site. The new associated daily energy consumption for the future lighting scheme based on ECM's operation from implementing these scenarios at the site, is as shown in Table 3. From the table, it can be seen that, as the ECM's operating hours increases, the amount of energy savings also increased. By applying Energy Conservation Measure scenario 1, 2 and 3 to the lightings, the method gives energy savings of 20.1%, 26.8% and 38.7% respectively.

Table3. New daily energy consumption for the proposed future lighting scheme based on ECM's operation and the associated energy savings accrued from the existing lighting scheme for Muara Road site.

Energy Conservation Measure's scenario	New daily energy consumption for future proposed lighting scheme energy-saving based operation (kWh)	Daily energy saving of future proposed lighting scheme operation from existing system (kWh)	Percentage energy-saving (%)
Scenario 1	191.5	48.1	20.1
Scenario 2	175.4	64.2	26.8
Scenario 3	146.9	92.7	38.7

Annual reduction in electricity consumption.

Based on the information from the energy consumption before the intervention of flux regulation to the lightings and also from the new daily energy consumption developed for the future proposed lighting scheme based on the Energy Conservation Measure's scenario as applied, the base year consumption before and after the implementation was developed and as is shown in Figure 2. As much as 17,400, 23,200 and 33,400 kWh of electrical energy annually can be reduced from implementing lighting energy management scenario 1, 2 and 3 respectively to the trial site.

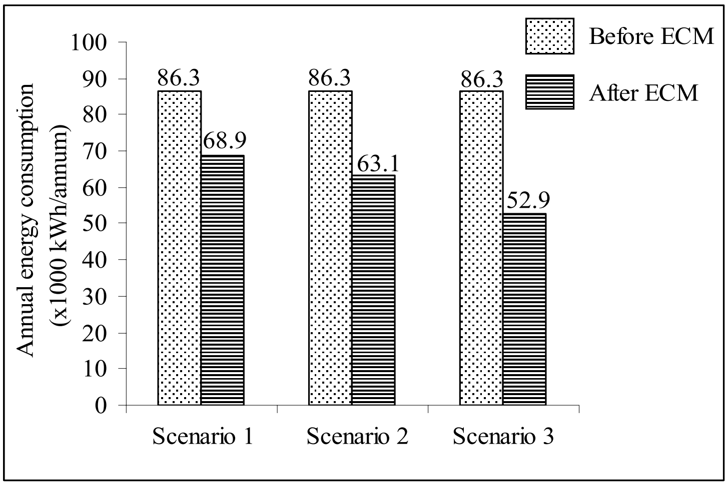

Figure 2. The annual energy consumption before and after the implementation of flux regulation to the road lightings at the study site based on lighting energy management scenario 1, 2 and 3.

Economic analysis.

It can be seen that, from the result on the economic analysis of the method used from Table 4, the IRR (Internal Rate of Return) after the projected regulator's 10 years of operation only gave good return for cases when lighting energy management scenario 2 and scenario 3 were applied to the road lightings at Muara Road site with an IRR of 31% and 121% can be achieved from each management scenario respectively. An NPV of B$1,465.99 can be obtained through the implementation of energy management scenario 2, whereas for the case of scenario 3, the method will give an NPV of B$5,261.67 after the projected regulator's 10 years of operation.

Table 4. The results of economic analysis based on each of the lighting energy management strategy's scenarios for the future lighting scheme ECM 's Based operation.

	Lighting energy management strategy's scenario		
	Scenario 1	**Scenario 2**	**Scenario 3**
SPT (Years)	1.8	1.3	0.9
NPV after 10 years (B$/annum)	-678.23	1,465.99	5,261.67
IRR after 10 years (%)	4	31	121

One of the most notably causes for the unattractive rate of return after the regulator's 10 years of operation as projected in the economic analysis for scenario 1 is due to the low flat tariff rate as imposed on the energy consumption per kilowatt hour of road lighting in Brunei. With B$0.10 per kilowatt hour, energy tariff rate for Brunei is considered one of the lowest in the south-east Asian region. Besides, there is no maximum demand charge imposed in the tariff. In contrast, as pointed out by Julian Di Stefano [8], the price of electricity and the cost of energy efficient lighting technologies can be altered by appropriate government intervention. He also concluded that, low electricity prices represent barriers to the cost effective installation of energy efficient lighting technology.

In contrast, the cost-effectiveness of the method is also determined by the duration of ECM's operating hours as applied to the lightings. Figure 3 shows the effect of ECM's operating hour has on the SPT, NPV and IRR of the method. Note that, the total operating hours of the road lightings at the research study site was 11.5 hours. From Figure 3 it follows that:

1. SPT gets shorter as ECM's operating hours increases. It reduces exponentially as ECM's operating hours increases.

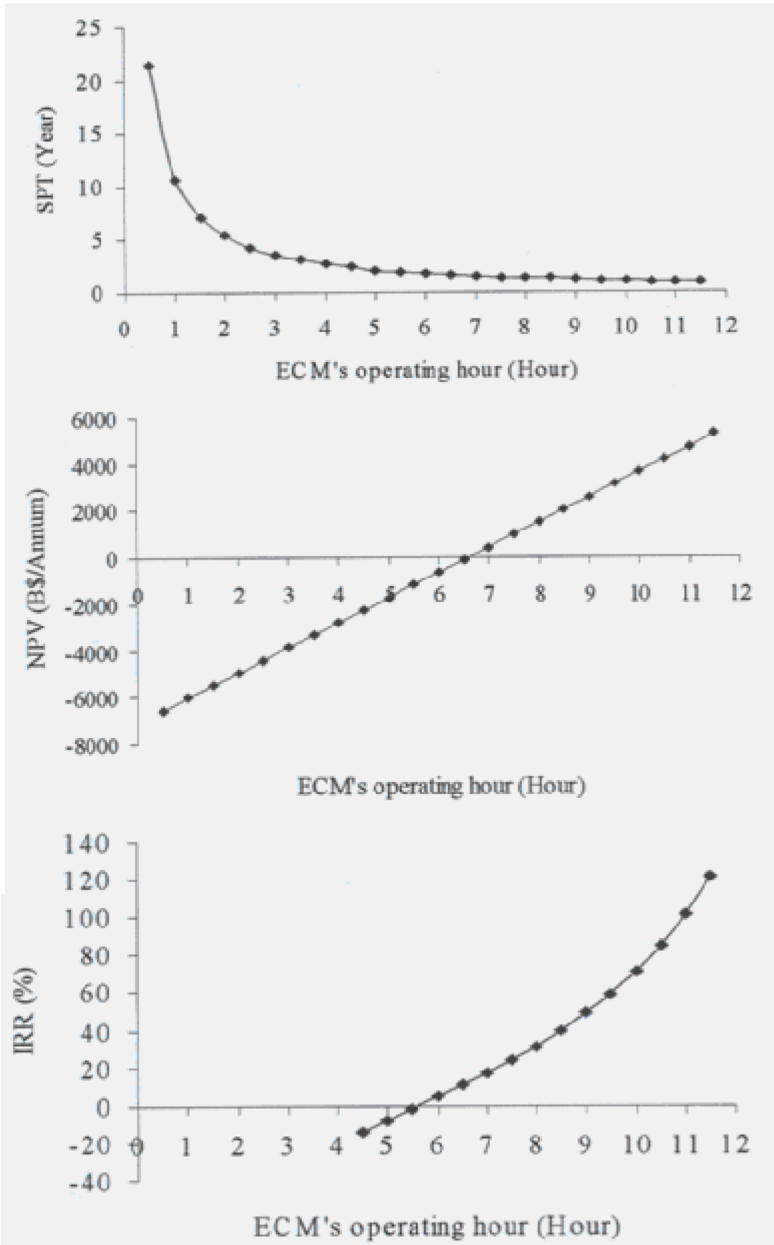

Figure 3. The effect of ECM's operating hours has on SPT, NPV and IRR when ECM's operation was carried out at Muara Road site.

2. NPV increases linearly as ECM's operating hours increases. NPV will have its positive amount when ECM is applied to the lightings between 6.6 hours to 11.5 hours.
3. IRR increases exponentially as ECM's operating hours was increased. The percentage of IRR will be positive when ECM is applied to the lightings between 5.7 hours to 11.5 hours.

Even though the first positive IRR was achieved when the ECM's operation was carried out for 5.7 hours, however, owing to the negative result that was obtained for the NPV of the analysis and also due to the 12% interest rate imposed, the method will show its first good investment when the ECM operation was carried out for 6.6 hours.

Benefits from the method.

Apart from the reduction in the annual energy consumption of the lightings as presented in Figure 2, the method used will also give other benefits to the DES and to the country in general in terms of energy cost savings and helps preserve the country's energy resources. Besides, it contributes to the reduction of global's greenhouse gas emission.

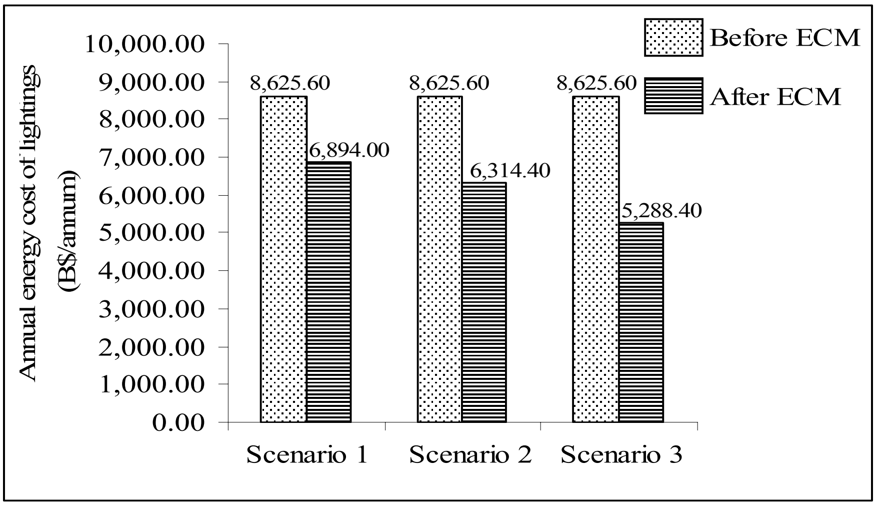

Figure 4. The annual energy costs of road lighting at study site before and after the implementation of flux regulation based on lighting energy management scenario 1, 2 and 3.

As shown in Figure 4, the method can save B$1,731.60, B$2,311.20 and B$3,337.20 in the annual energy costs from the implementation of lighting energy management scenario 1, 2 and 3 to the site respectively.

Through applying all the lighting energy management scenarios as developed for the study also, the method will help reduce the global's greenhouse emissions of carbon dioxide annually by 20.1%, 26.8% and 38.7% respectively. This can be seen from the annual emissions of carbon dioxide both before and after the implementation of flux regulation to the lightings for each of the lighting energy management scenario as shown in Figure 5.

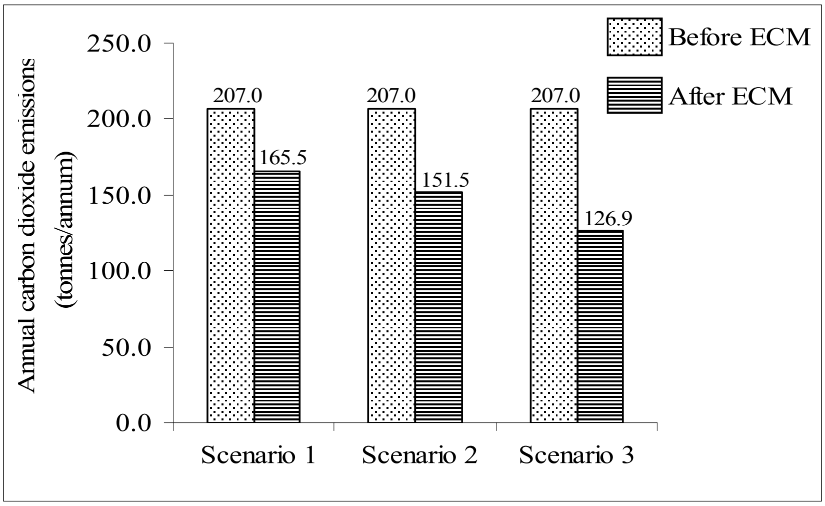

Figure 5. The annual carbon dioxide emissions before and after the implementation of flux regulation to the road lightings at the study site based on lighting Energy management scenario 1, 2 and 3.

Conclusion

The results from the field study have demonstrated the capability of flux regulation to manage the energy consumption for road lightings in Brunei. The study represents both a pioneering achievement and a role model for the future energy saving tasks' management of road lightings on Brunei's roads and highways. With an ever-increasing pressure to save energy and limit environmental damage globally, it is likely that flux regulation on road lighting will become one of the options for the Department of Electrical Services (DES) to implement future energy management's tasks on roads and highways in Negara Brunei Darussalam. In addition, the study has also demonstrated some of the requirements that are needed by such a lighting project manager, be it from a lighting utility or from a municipality, on how to carry out such study or project related to the management of lighting energy on roads or highways.

Apart from showing its potential to manage lighting energy consumption by reducing energy use from the road lightings, the assessment made in the study has also shown that, ECM's operation through the implementation of flux regulation to the lightings involved, helps to reduce atmospheric pollution related to carbon dioxide emissions by as much as 80.1 tonnes annually. The reduction of energy use in the study had also given the opportunity to the DES to cut down its operation cost through energy-cost savings. As much as B$3,337.20 per annum in energy cost can be saved from the method's implementation to the lightings at Muara Road site through energy management scenario 3.

On the other development, the assessment made on the reduced illumination had shown that the method's implementation would not give any negative implication to the road users as the recorded reduced illumination was still within the standard specification as laid by IES. The assessment made makes a convincing evidence to implement flux regulation as an energy-saving technique for road lightings in Brunei Darussalam. This will also assure an improvement in drivers' safety and comfort.

As a concluding remark, the method used in the study is seen as an effective way to manage the lighting energy consumption of road lightings in Brunei Darussalam and therefore, viable to be implemented.

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