Activity 3 Report

CTCN Technical Assistance: Energy Efficient Street Lighting Technologies and Financing Models in Thailand

Techno-economic Study of Energy Efficient Street Lighting Projects in Thai Municipalities

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List of Acronyms

ADB	Asian Development Bank
AECI	Annual Energy Consumption
DLA	Indicator Department of Local
DOH	Administration (DLA) Department
DOR	of Highways (DOH) Department
R EE	of Rural Roads (DORR) Energy
ESC	Efficient
O FL	Energy Service
GWh	Company
HID	Fluorescent lamp
HPS	Gigawatt hour
KPIs	High Intensity Discharge
kW	(HID) High Pressure
h	Sodium (HPS) Key
LE	Performance Indicators
D	Kilowatt-hour
MV	Light-Emitting
M&	Diode Mercury
V	Vapor
O&	Measurement and
M	Verification Operation
PDI	and Maintenance Power
PEA	Density Indicator
	Provincial Electricity Authority

Introduction

The Provincial Electricity Authority (PEA) provides electricity services to more than 1,000 cities and towns throughout Thailand, and more than 65% of all electricity consumed in Thailand is within PEA's service areas. In terms of geographical coverage, PEA distributes electricity to 99% of the country and has more than 900 sub- offices throughout 73 provinces. PEA has partially subsidized electricity expenses for street and outdoor lighting in their service areas for decades and annual electricity consumptions by these street and outdoor lighting applications increased more than two-fold over the past 10 years, from 996 gigawatt hours (GWh) in 2005 to about 2,138 GWh in 2014.

Although PEA has shouldered electricity expenses for street and outdoor lighting in Thailand, its involvements in developing and implementing relevant national energy efficiency standards for street and outdoor lighting have been very limited. In general, installation and maintenance of street and outdoor lighting in PEA's service areas lie with the three following organizations:

- Department of Local Administration (DLA);
- Department of Highways (DOH);
- Department of Rural Roads (DORR).

DLA is under the Ministry of Interior and governs all municipalities in the country, while DOH and DORR are under the Ministry of Transport. These government agencies do not harmonize relevant standards for street and outdoor lighting, and each agency has its own classifications of roads and specify slightly different lighting quality requirements (illumination and uniformity) for each road classification. High Intensity Discharge (HID) technologies, such as High Pressure Sodium (HPS) lamps, Mercury Vapor (MV) lamps, and linear fluorescent lamps (FL) are the common lighting technologies in PEA's service areas, and these conventional lighting technologies are included in the guidelines and regulations issued by DLA, DOH and DORR.

HID and FL lighting technologies commonly used in PEA's service areas need reflectors attached behind the lamps in the luminaires to direct light to where it is needed, and much of the light is lost – at least 20% to 30% for new luminaires[1], and the loss figures are higher for old luminaires. These types of luminaires also produce light pollution in the surrounding area, which leads to inconvenient glare for drivers and pedestrians and may cause roadway hazards. FL luminaires have similar characteristics as of the HID luminaires but fluorescent lamps have poorer efficacy than HPS lamps. It should be noted that over the past few years, Thai municipalities have become familiar with Light-Emitting Diode (LED) technologies, and small-scale installations of LED luminaires and LED tubes have been haphazardly carried out by Thai municipalities. However, overall penetration of LED technologies in the street and outdoor lighting sector in Thailand is still limited.

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[1] Based on technical specifications of HPS luminaires supplied by lighting manufacturers, including but not limited to Philips Lighting Thailand, and Lighting and Equipment Public Company Limited (Thailand).

This report summarizes findings from techno-economic assessment of retrofitting conventional street and outdoor lighting technologies in PEA's service areas with applicable energy efficient street lighting technology design options. The report also provides recommendations on suitable energy efficient technologies for Thai municipalities to minimize operations and maintenance costs of street and outdoor lighting.

PEA's initiatives on energy efficient street and outdoor lighting

PEA has recognized the increasing burdens of subsidies for street and outdoor lighting electricity expenses, and several energy efficiency measures have been piloted since 2004 to pave a way for large-scale implementation of energy efficient street and outdoor lighting in PEA's service areas. These energy efficiency measures include: high efficacy HID lamps, high efficiency reflectors, circuit dimmers and LED.

During the first phase of the project (2004 - 2006), PEA undertook its own investment for equipment purchases. However, PEA could not invest and manage all equipment with a large area of installed street lights throughout the country. The Energy Service Company (ESCO) approach was therefore utilized to implement EE street lighting projects. Under the ESCO approach, PEA has entered into agreements with local ESCOs which provided initial investments and installation of the equipment including operation and maintenance (O&M) throughout the contract duration. ESCOs will then gradually recover the investment cost from the repayments made by PEA through the energy saving gained as per payment terms and conditions agreed to in the contract.

PEA has successfully implemented many energy efficiency street lighting projects using the abovementioned ESCO approach since 2007. Several public and private ESCOs have been contracted by PEA, including Kasetsart University (KU), King Mongkut's University of Technology Thonburi (KMUTT), Burapa University, Philips Lighting and Lighting & Equipment Public Company Limited (L&E). The projects undertaken include the following:

- Installation of energy efficient lighting technologies (electronic dimmers and transformer circuit dimmers) in PEA service area in 2006;
- Installation of power electronics circuit dimmers for HPS in Samutsakorn, Samutsongkram, Ratchaburi and Kanchanaburi – Implemented by the King Mongkut's University of Technology Thonburi during 2007-2014;
- Installation of voltage circuit dimmers in Prachinburi during 2009-2014 – Implemented by the Kasetsart University;
- Delamping with high efficiency reflectors in Samutsakorn during 2010-2015 – Implemented by the Burapa University;
- Replacement of Fluorescent Lamp Street Lighting (2x36W) with HPS SON-T 50W in Ratchaburi, Pattaya and Chonburi during 2010-2023 - Implemented by the Kasetsart University;
- Small-scale demonstration of LED Luminaires in Banpong, Lumpoon, Trang, Nongkhai, Udornthani and Krabi municipalities in 2012;
- Replacement of Mercury Vapor Streetlights in Municipalities in Chonburi during 2013-2018 - Implemented by the Kasetsart University;
- Replacement of 12,000 HPS luminaires with LED luminaires in 4 regions (2014-2019):
    - Group 1 North - Chiengmai, Lampang and Nokornsawan – Implemented by L&E

- Group 2 Northeast - Nakornratchasima - Implemented by L&E
- Group 3 Central - Pathumthani - Implemented by Gero-Philips
- Group 4 South - Phuket and Koh Samui - Implemented by Gero-Philips

PEA has advised DLA, DOH and DORR about the implementations of these energy efficient street and outdoor projects, however there have been limited coordination among these agencies during the implementation phase, and, as a result, there have been neither impact nor improvement of the guidelines and regulations issued by DLA, DOH and DORR.

Small-Scale Demonstration of LED Luminaires in Thai Municipalities

The Government of Thailand received a grant from the Asian Development Bank (ADB) for the implementation of the Mainstreaming Energy Efficiency in Thai Municipalities Project, administered by the Provincial Electricity Authority (PEA). This includes a pilot project on LED street lighting in six municipalities: A total of 100 units of 120W LED roadway luminaires with 5-years warranties were installed to replace 250W HPS and Mercury Vapor lamps in these municipalities from July to September 2011. Post-implementation measurements have shown that the LED luminaires are delivering better illumination, light distribution and hence uniformity, while consuming 40% to 50% less energy.

Figure 1 : LED luminaires in Udonthani (left) and Trang (right) Municipalities in Thailand

The six pilot municipalities have reported good performance of LED luminaires over the past 4 years, and less than 5% of LED luminaires have been reported as malfunctions and failures.

Table 1 : Summary of LED Implementation in Thai Municipalities

Summary of LED Implementation in Thai Municipalities	
Location (City, Country)	**6 Thai Municipalities (Nationwide), Thailand**
Year	2011
Project Size (No. of LED Luminaire)	100
Investments	US$80,000
Electricity Tariff	3.9361 Thai Baht/kWh (US$ 0.11)
Cost Savings	US$8,558 year
Energy Saved	73,350 kWh/ year
Payback Period	9.3 years
Financing Model	Grant+Equity Financing
Implementation Arrangement	Direct Supplier Model
MRV Mechanism	Identical to AMS.II-L for lighting quality

Source: ADB, 2012

Applicable energy efficient street and outdoor lighting technologies in Thailand

As discussed in the previous section, various energy efficient street lighting technologies have been piloted by PEA and most of energy efficient technologies for street and outdoor lighting commercially available in Thailand were demonstrated in those pilots. In view of this, evaluation of applicable energy efficient street and outdoor lighting technologies in this report will consider all energy efficiency technologies that are commercially available in Thailand and can be utilized to replace HID and fluorescent lamps or to improve efficacies of street and outdoor lighting luminaires used in PEA's service areas. Scope of the applicable technologies is shown in table 2.

Table 2 : Available EE Technology Options for Street and Outdoor Lighting in Thailand

Energy Efficient Street Lighting Technology	Applicability to Existing Street Lighting Technology	Note
Dimming Ballast (Step-Dimming Magnetic Ballast and Electronic Ballast)	HID lamp	Applicable for roadways/areas where traffic volumes are low at late night.
Circuit Dimming System	HID lamp with magnetic ballast	Applicable for roadways/ areas where traffic volumes are low at late night.
High efficacy lamp (e.g. HPS, LED tube)	Fluorescent lamp, Mercury Vapor	Generally applicable for roadways with low traffic volumes
LED luminaire (non-dimmable and dimmable)	HID luminaire, Fluorescent luminaire	Applicable for most roadways/areas

Details of each applicable energy efficient street lighting technology are described below.

Dimming ballasts for HID lamps

A dimming ballast, either magnetic or electronic type, is generally capable of controlling one HID lamp. According to the Guidelines on the Application of Dimming to High-Intensity Discharge Lamps (NEMA 2012), HID lamp dimming systems are divided into two basic categories:

1. Step-level (including bi-level) power reduction, typically associated with magnetic ballasts; and
2. Continuous or variable dimming typically associated with electronic ballasts.

The guidelines caution that it is important to confirm compatibility of lamp/ballast combinations, and there may be changes in lamp color temperature, color rendering, and luminous efficacy with dimming. For HPS lamps, there is also an increased likelihood of poor lumen maintenance and shorter lamp life when lamp wattages are dimmed below 50% of rated values for sustained periods. The guidelines also recommend that HPS lamps be started and operated in the full power mode, i.e. at rated wattage for a minimum of 15 minutes before dimming. Shown in Figure 2 is relationship between lumen output and lamp power for HPS lamps.

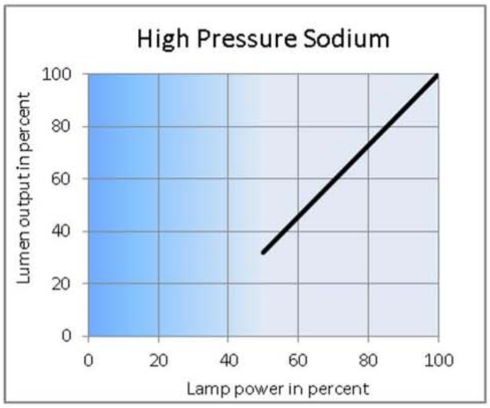


Figure 2 : Lumen Output vs Lamp Power for HPS Lamps

Dimming systems are ideal for saving energy while providing a minimum amount of illumination for safety and security during hours of non-occupancy. In terms of street and outdoor lighting applications, dimming systems may be applicable for roads where traffic volumes are low at late night, for example after midnight. A basic guideline to determine lighting classes for roadways for different traffic speeds and volumes is provided in Appendix 1 of the small-scale methodology for Demand-side activities for efficient outdoor and street lighting technologies, AMS-II.L published by UNFCCC (UNFCCC 2013).

These dimming ballasts for individual lamp have not been included in the previous pilot demonstration projects by PEA; however it is included in the study conducted by Chula Uniresearch[2]. It should be noted that only suppliers of well-known international lighting brands in Thailand have marketed electronic dimming ballasts, and magnetic step-dimming ballasts for HID lamps, as shown in Figure 3. The recent interviews with these lighting suppliers revealed that dimming ballasts for HID lamps are currently not the priority focus compared with other EE lighting technologies, such as LED lighting. However the lighting suppliers confirm that they can supply dimming ballasts in large quantities if requested by customers.

[2]2 In 2011, PEA engaged Chula Uniresearch, a research unit of Chulalongkorn University, in Bangkok, Thailand, to conduct a technical and financial analysis study of various EE street lighting technologies for 250 watts and 400 watts HPS street lighting in PEA's service areas. The study aims at providing PEA with options to improve efficiency of street and outdoor lighting in Thailand.

Figure 3 : Example of Step Dimming Ballast Equipment Set

Consideration for New Installation and Retrofitting

Compatibility between lamps and ballasts should be the primary concern for applying step-dimming ballast for new installation and/or retrofitting projects. Typically, compatible lamp and ballast models from the same lighting manufacturers are recommended. For retrofitting any non-dimmable HID luminaires currently in use with dimming ballasts, uninstalling HID luminaires from lamp posts, and rewiring within the luminaire housing will be required. The total labor cost for retrofitting non-dimmable HID luminaires with dimming ballasts in a large-scale project can be extensive.

Potential Energy Savings

For street and outdoor lighting applications, dimming function can only be activated when traffic speed and volume are low, generally, at late night. Generally lamp power is dimmed to around 50% from 11-12pm to dawn (see Figure 4). Estimated energy savings compared with non-dimmable HID luminaires are around 25% to 30%.

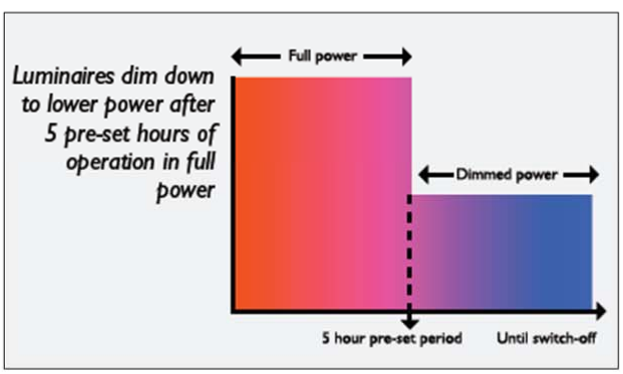


Figure 4 : Operational Profile of Step Dimming Ballast

Circuit Dimming Systems for HID Lamps

PEA implemented several EE street lighting projects utilizing electronic and transformer line voltage dimming systems to dim circuits of 400W and 250W HPS lamps. Each dimmer system supplies line voltage for a circuit of about 30 HPS lamps. Two types of circuit dimmers piloted by PEA, i.e., power electronic dimmer and voltage transformer dimmer, are shown in Figure 5 and Figure 6 respectively. These circuit dimming systems are designed and made to order by local lighting suppliers/ manufacturers in Thailand. One necessary feature of any circuit dimmer is an integration of a bypass switch to ensure that a circuit of street and outdoor lighting can still be powered on/off when the circuit dimmer is malfunction.

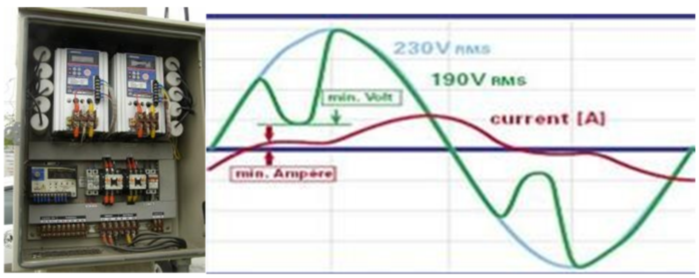


Figure 5 : Power Electronic Dimmer piloted by PEA in 2007

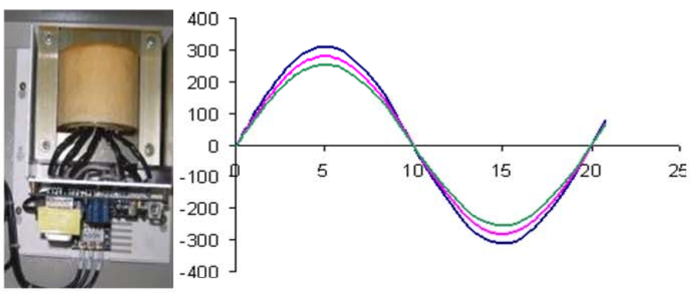


Figure 6 : Voltage Transformer Dimmer piloted by PEA in 2009

Although these circuit dimmers were successfully tested by PEA, they have neither been adopted by other agencies/authorities (such as DOH) nor private sector companies. However the manufacturers of these circuit dimmers indicated that they can still manufacture circuit dimmers if the circuit dimmers are ordered in large quantities.

Consideration for New Installation and Retrofitting

On-off of street and outdoor lighting in Thailand is usually managed through utilization of a daylight sensor and a magnetic contactor controlling a circuit or a string of multiple street and outdoor lighting luminaires (HID or fluorescent lamps). This on-off control approach in Thailand made it easy when performing new installation of circuit dimmers or replacing existing circuit dimmers with new ones. However, the power electronic dimming systems have equipped with centralized power factor correction capacitors and a power factor correction capacitor in each luminaire in the dimming circuit has to be disconnected. These additional rewiring works could lead to requirement of extensive labor costs for a large scale project.

Potential Energy Savings

Similar to dimmer ballast for an individual lamp, dimming should only be activated when traffic speed and volume are low, generally, at late night, and estimated energy savings compared with non-dimmable HID luminaires are around 25% to 30%.

High Efficacy Lamps

Replacement of low efficacy lamps with higher efficacy lamps is probably one of the easiest approaches in improving energy efficiency of street and outdoor lighting systems. In Thailand, HPS lamps are the most common high efficacy lamps used in retrofitting low efficacy lamps, specifically mercury vapor (MV) lamps. In 2010, PEA piloted replacement of dual fluorescent lamp street lighting luminaires (2x36W) with 50W HPS luminaires. LED tubes have recently become a choice of energy efficient lamps for retrofitting fluorescent lamp street lighting luminaires primarily due to attractive unit costs and ease of installation. It should be noted that a high efficacy lamp may not be able to improve the total light output delivered by a luminaire as this depends on the luminaire efficacy.

HPS Lamps LED Tube

Figure 7 : High Efficacy Lamps – HPS Lamps and LED Tubes

Consideration for New Installation and Retrofitting

Similar to dimming ballasts, compatibility between new lamps and existing ballasts (if required) is should be the primary concern when considering high efficacy lamps for new installation and/or retrofitting projects. Fitting new high efficacy lamps with compatible ballasts will not require rewiring within luminaires. In case of LED tubes with integrated ballasts (or drivers), many lighting suppliers offer LED tubes which can directly replace fluorescent tube lamps without disconnecting or rewiring ballast circuits. Assuming that lamps and ballasts are fully compatible, labor costs involved in retrofitting low efficacy lamps with high efficacy lamps (either LED or non-LED lamps) are equivalent to labor costs required for maintenance of street and outdoor lighting luminaires.

Potential Energy Savings

Potential energy savings from retrofitting low efficacy lamps with high efficacy lamps are directly linked with the efficacy improvements. Typically efficacies of lamp-ballast circuits for fluorescent lamps and mercury vapor lamps are about 50 to 70 lumen per watt, while typical lamp-ballast/driver circuits of HPS lamps and LED tubes are about 85 to over 100 lumen per watt. Based on these improvements, estimated energy savings from retrofitting low efficacy lamps with high efficacy lamps for the same luminaire light outputs would be around 35% to 80%[3].

LED Luminaires

LED lighting technology is a fast-evolving technology with significant energy-saving potential. Since the first commercially available LEDs were introduced in 1960, the technology has been constantly improving. The electrical and optical performance of LED lighting is interrelated with its thermal characteristics. Due to the inefficiencies resulting from the imperfections in the semiconductor and in the LED package structure, heat losses are generated. These losses have to be removed from the device in order to keep the operation temperature below the maximum allowed and avoid premature failure of the device. LED chips can have a life span of more than 100,000 hours (Nichia 2002); however the lifetime and performance of an LED luminaire depends on the ability to remove heat from LED chips, the quality of the components (e.g., electronic components, heat sink), the system design, and the operating environment.

Figure 8 : LED Luminaires

[3] Estimation by IIEC based on data from lighting suppliers' catalogues

LED lighting brings a revolution in street and outdoor lighting applications, where every generation of the technology shows remarkable improvement in efficacy, efficiency and lumen. LED lighting technology also produces better colors from objects in comparison with HID technologies. LED luminaires do not require a ballast or a capacitor; instead they convert the supply voltage to low voltage direct current, using a small electronic power supply, called an LED driver. Another key advantage of LED lighting compared with HID or fluorescent lighting is LED lamps do not contain mercury which considered as hazardous substance, however, LED lamps contain electronic waste and other components that need to be disposed of in an environmentally sound manner.

Over the past decade, LED luminaires have demonstrated the ability to provide suitable illuminance levels using significantly lower total light output than the conventional lighting products they have replaced. Superior performance of LED luminaires is accomplished through improved light distribution that reduces over-lighting the target area, improves illuminance uniformity, and produces less wasted light falling outside the target area.

In Thailand, commercially available LED-based technologies for street and outdoor lighting applications range from simple LED luminaires without dimming function, LED luminaires with basic dimming systems, to LED luminaires with intelligent lighting management systems. With rapid development of LED technologies, these commercially available LED luminaires for street and outdoor lighting applications have achieved luminaire efficacies of more than 100 lumen/watt.

Most reputable LED luminaire suppliers in Thailand have provided test reports indicating a projected life of more than 50,000 hours for LED luminaires[4]. With an average of 11-12 operating hours per day, LED luminaires with a lifetime of 50,000 hours will last more than 11 years. In comparison, fluorescent and HPS lamps must be replaced every 1-2 years and 2-3 years, respectively. In practice, the long lifetime performance of LED luminaires remains to be seen, as the early demonstration of LED luminaires by PEA since 2011 has shown mix results. Most LED luminaire suppliers currently provide 3-4 year warranty for their products. The suppliers generally agree to offer extended warranties of up to 5-7 years[5] for an additional cost.

Integrating a light level control system with a LED luminaire in order to save energy appears to be less complicated and more versatile than dimming a HID luminaire. This is basically due to the capability of LED electronic drivers which can be integrated with dimming functions which may include but not limited to step- dimming (bi-level), multi-level dimming and programmable dimming. Note that some suppliers have already introduced LED luminaires with dimming drivers as a standard feature. General approach in LED dimming is similar to HID dimming, i.e., to lower the light levels in accordance with traffic volumes.

[4] Based on technical catalogues published by Philips Lighting Thailand

[5] Based on the procurements under the Mainstreaming Energy Efficiency in Thai Municipalities (2010-2012) and the Promoting Energy Efficiency in the Pacific - Phase II (2012-2015), funded by ADB

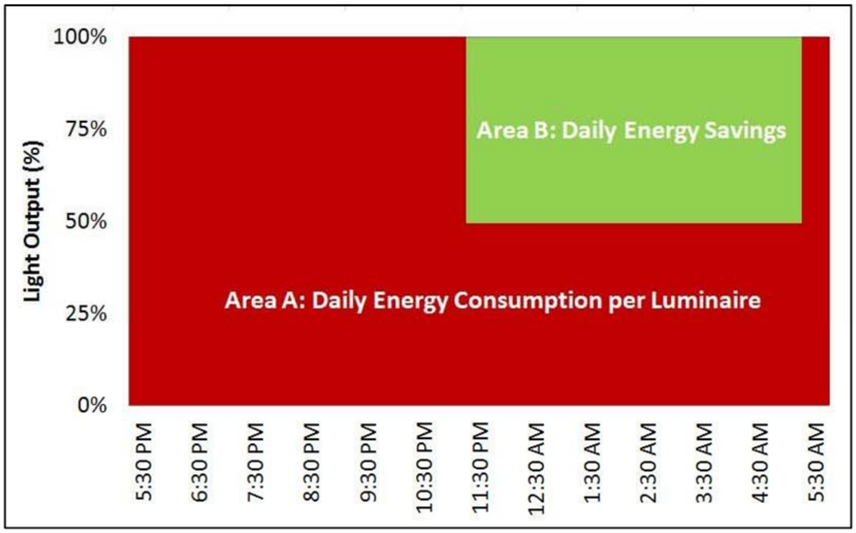


Figure 9 : Typical Dimming Profile for LED Luminaire

Table shows additional annual energy savings from the LED luminaires when applying the dimming profile in Figure 9.

Table 3 : Estimated Annual Energy Consumption of Non-Dimmable and Dimmable LED Luminaires

LED Luminaire Power Consumption (W)	Annual Energy Consumption – Non-Dimmable (kWh)	Annual Energy Consumption – 6-hrs 50% Dimming (kWh)	Annual Energy Saving (kWh)
90	394	295	99
110	482	361	121

Note: Annual energy consumption calculated using 12 hours daily operation and 365 days per year.

Dimmable LED luminaires can also be integrated with more advanced intelligent/smart lighting control systems to provide the city with better control of lighting quality according to different traffic volumes and at different times of night. The system could be enhanced with a remote management feature, enabling faster outage response. Potential energy and cost savings from applications of the intelligent/smart street lighting system are summarized in table 4.

Table 4 : Potential Energy and Cost Savings from Intelligent/Smart Street Lighting System

Feature	Energy and Cost Saving Benefits
Dimming	Operators can schedule lamps to dim as circumstances allow, such as at low traffic volumes, in unpopulated areas in the middle of the night, etc., and appropriate control of light levels can lead to significant energy savings without compromising lighting quality standards.
Reduced Operating Hours	With on/off scheduling capabilities, operators can easily modify street light operation to coincide with changing sunrise/sunset times, reducing lamp operating hours.
Remote Monitoring and Management	The intelligent/smart street lighting system with wireless/GSM control features gives operators visibility into street light operations (for example, how much energy a lamp is using) as well as control over dimming and on/off schedules, reducing the need to unnecessarily run lamps for long periods.
Automatic Outage Detection	The intelligent/smart street lighting system can provide instant outage notification, dramatically reducing the number of calls (and related costs) to the call center and cutting downtime up to 90 percent. With accurate outage information, operators can eliminate administration costs due to false alarms, pinpoint nonworking lamps and quickly dispatch crews to specific lights.

Source: World Bank, 2015

Consideration for New Installation and Retrofitting

New installation of a LED luminaire or retrofit of an existing street and outdoor lighting luminaire with a LED luminaire will require same amount of efforts and it generally involves mechanical installation as well as disconnection and reconnection of power supply. It should be noted that a LED luminaire with a programmable dimming driver may require specific settings if the requirements are different from the factory settings.

Potential Energy Savings

Potential energy savings from retrofitting HPS luminaires with LED luminaires piloted by PEA in 2011 were around 40%-50% with better lighting quality. More recent pilot projects have demonstrated greater potential energy savings of 60%-65%, however these recent pilot projects do not aim to improve lighting quality but to meet the average illumination requirement of 15 lux. Additional 25% energy savings can be achieved through dimming light levels for specific roads where traffic volumes are low at late night, however LED luminaires with dimming drivers have not yet been piloted in a large scale in Thailand.

Table below shows the power consumption per unit of HPS and LED luminaires piloted by PEA.

Table 5 : Power and Energy Saving of HPS and LED Luminaires in Thailand

HPS Lamp Wattage (W)	HPS Luminaire 1		LED Luminaire 2		Power Saving (W)	Annual Energy Saving (kWh)3
	Power Consumption (W)	PF	Power Consumption (W)	PF		
250	287	0.8	86	0.9	201 (70%)	880
250	275	0.7	89	0.96	186 (67%)	815

Note:

1. HPS luminaire power consumptions based on actual measurements by L&E.
2. LED luminaire power consumptions including losses in LED driver based on actual measurements by L&E.
3. Annual energy saving calculated by Author based on 12 hours daily operation and 365 days per year.

Technical and economic analysis of applicable energy efficient street and outdoor lighting technologies

Technical and economic analysis of each applicable technology considers the following aspects:

- Technical analysis and validation of findings from the previous studies and pilot demonstration projects based on the current market situations (price, warranty and availability of local suppliers);
- Comparison of lighting power densities delivered by different energy efficient street and outdoor lighting technologies; and
- Investment cost per luminaire light output ($ per lumen) and investment cost per kilowatt-hours (kWh) saved.

Street and Outdoor Lighting Technologies

In 2011, PEA engaged Chula Uniresearch, a research unit of Chulalongkorn University, in Bangkok, Thailand, to conduct a technical and financial analysis study of various EE street lighting technologies for 250 watts and 400 watts HPS street lighting in PEA's service areas. The study did not discuss energy efficient technologies for some conventional street lighting technologies being used in PEA's service areas, such as mercury vapor and fluorescent tube lamps. The study concluded that electronic and magnetic step-dimming ballasts for HPS lamps and LED luminaires are the most feasible energy efficient street lighting technologies for PEA.

Technical and financial analysis of energy efficient street lighting technologies for PEA

The technical and financial analysis study by Chula Uniresearch discussed pros and cons of various potential energy efficient street lighting technologies commercially available in Thailand in the early 2010s, as listed below:

- Individual dimming using step-dimming magnetic ballast or electronic ballast;
- Circuit dimming using magnetic or electronic ballast;
- High efficacy HID lamp;
- Light-Emitting Diode (LED) luminaire;

The abovementioned energy efficient street lighting technologies were screened for detailed technical and financial analysis, using the following criteria: 1) Meeting the illumination level requirements for different road classifications as specified by the Department of Highway; 2) Meeting relevant technical requirements as specified in the procurement regulations of the Department of Highway; and 3) Delivering at least 20% energy savings.

Based on these criteria, the technical and financial analysis by Chula Uniresearch selected individual dimming, high efficacy HID lamp and LED luminaire technologies for detailed technical and financial evaluations.

In the detailed technical and financial evaluation, individual dimming, high efficacy HID lamp and LED luminaire technologies were qualitatively evaluated against several technical and operational parameters, including, reliability, maintenance requirements, ease of maintenance, adverse effect from failed unit, measurement & verification requirements and life span. It should be noted that life span of the selected technologies is generally based on data provided by lighting suppliers rather than actual operating data. Based on the total technical evaluation scores, LED luminaire was ranked as the best energy efficient street lighting technology, followed by electronic ballast with dimming and step-dimming magnetic ballast. When combined with the financial evaluation scores, the electronic ballast with **dimming technology for HID lamps** was ranked as the best technology, followed by **LED luminaires** and **step-dimming magnetic ballasts**. It should be noted that the financial analysis in this study focused retrofitting 250W and 400W HPS lamps in PEA's service areas with those selected technologies.

It should be noted that the study did not involve any field testing of the identified energy efficient technologies but PEA referenced this study for development of a medium scale project to replace 250 watts and 400 watts with 90 watts to 110 watts LED luminaires in 2014.

Source: Technical and Financial Analysis of Energy Efficient Street Lighting Technologies for PEA Final Report, Chula Uniresearch, 2011

Based on findings from the Chula Uniresearch study and results of the pilot demonstration projects implemented by PEA to date, it can be concluded that all the applicable technologies under section 2 have been able to deliver energy savings while maintaining lighting qualities to meet the roadway requirements. Considering this, the technical analysis in this report will focus on evaluation of other factors that can be verified based on actual implementation experience in Thailand and other countries, and these factors include:

1. Luminaire efficacy;
2. Reliability and maintenance requirements;
3. Useful life; and
4. Industry support over the next 5 to 10 years.

Summary of technical analysis of various applicable technologies is shown in Table 6. It should be noted that dimming technologies are applicable to roads and areas where illumination levels can be reduced, and therefore they should be considered as supplementary measures to the core measures that can deliver better system efficacies, such as high efficacy lamps or LED luminaires.

Table 6 : Summary of Energy Efficiency Options for Street and Outdoor Lighting in Thailand

Technology	Individual Dimming (Magnetic/ Electronic)	Circuit Dimming (Power Electronic/ Transformer)	High Efficacy Lamp		LED Luminaire
			HPS	LED Tube	
Description	Magnetic or electronic dimming ballast one HID lamp 25% -30% energy savings	Power electronic or transformer dimming system for a string/ circuit of HID luminaires 25% -30% energy savings	Most popular HID lamps for street and outdoor lighting in Thailand	Simple retrofit solutions for street lighting luminaires with fluorescent tube lamps	Directional solid-state light source for street and outdoor lighting applications with successful pilot demonstration by PEA Unit costs have been declining over the past decade while luminaire efficacies keep improving
Pros	Easy to install Magnetic ballasts are robust and lifetime has been proven.	Easy to install Transformer dimming systems are robust.	Low initial cost High lamp efficacy (80-130 lm/W)	High lamp efficacy (90-100 lm/w) Good CRI	Specifically designed for street and outdoor lighting applications
	Electronic ballasts deliver high power factor.	Power electronic dimming systems deliver high power factor.	Long lamp life (25,000 – 30,000 hours), low lamp replacement frequency (luminaire maintenance, e.g., cleaning, still required)	Long lamp life (50,000 hours), low lamp replacement frequency (luminaire maintenance, e.g., cleaning, still required) Available off the shelf	Can be integrated with dimming functions and other control systems at extra costs High luminaire efficacy (90-110 lm/w)
				Contain no mercury	Good CRI
					Long lamp life (50,000 hours), low maintenance cost
					3-5 years standard warranty offered by lighting suppliers
					Contain no mercury

Cons	Suitable with roads with low traffic volumes at late night (after 11pm or 12pm) Dimming below 50% of rated values not recommended due to an increased likelihood of poor lumen maintenance and shorter lamp life. Lamps and dimming ballasts must be compatible. Magnetic ballasts need capacitors to improve power factor.	Suitable with roads with low traffic volumes at late night (after 11pm or 12pm) Dimming below 50% of rated values not recommended due to an increased likelihood of poor lumen maintenance and shorter lamp life. Applicable with HID luminaires with magnetic ballasts For power electronic dimming systems, power factor correction capacity in each luminaire must be disconnected.	Poor Color Rendering Index (CRI) Contain mercury Useful lumen outputs depend on Downward Light Output Ratio (DLOR) of luminaires, varying from 60% to more than 80%; lack of proper maintenance can further deteriorate DLOR performance.	Designed for general lighting application (not for street and outdoor lighting) High initial cost compared with fluorescent tube lamps (retail prices of LED tubes are about triple of fluorescent tube lamps for the same lumen outputs.) Useful lumen outputs depend on Downward Light Output Ratio (DLOR) of luminaires, varying from 60% to more than 80%; lack of proper maintenance can further deteriorate DLOR performance.	High initial cost compared with HID luminaire Qualities of LED luminaires vary, depending on brands/manufacturers Long life span of LED luminaires is yet to be confirmed as the first LED luminaire pilot installation was in mid- 2011, and cumulative operating hours to date amount to about 25,000 hours.
Luminaire Efficacy	N/A	N/A	67 lumen/watt 1	60 lumen/watt 2	90-110 lumen/watt 3
Reliability and maintenance requirements	Data not available	Replacement of power factor correction capacitors for power electronic dimming systems needed.	Most HPS luminaires in Thailand use magnetic ballast so they are generally very reliable. Only lamp replacements required every 2-3 years	Data not available	PEA's pilot projects have successfully demonstrated good reliability and no maintenance required. Only replacement of failed luminaires needed.
Useful life	Data not available	PEA's pilot projects have demonstrated 5-7 years	Lamp life: approximately 2-3 years Luminaire: > 5 year	Lamp life: data not available for outdoor applications Luminaire: > 5 year	PEA's pilot projects have shown mixed results of useful life of LED

		useful life of power electronic dimming systems.			luminaires. Some demonstration sites have successfully demonstrated LED luminaire useful lifetime of more than 30,000 hours (around 7 years). While some demonstration sites indicated useful lamp life of only around 10,000 hours.
Support from Local Lighting Industry	Available only from reputable lighting suppliers Not widely adopted by Thai municipalities or private sector	Made-to-order (not available off the shelf) Spare parts and maintenance can be an issue in a long term. Large order quantities needed to stimulate competitive market prices	Lamps at different wattages and accessories available off the shelf from multiple lighting suppliers Many lighting suppliers have shifted their marketing focus toward LED lighting technologies but indicated that they continue support parts and accessories for HID luminaires.	Available off the shelf in most retail outlets	Available from most lighting suppliers

Lighting power density for different road classifications in PEA's service areas

DLA and DOH are the two authorities issuing illumination requirements for different classifications of roadways in PEA's service areas. These requirements however are not fully harmonized as shown in the table below.

Table 7 : Illumination and Uniformity Requirements for Different Road Classifications in PEA's Service Area

Road Classification	Illumination		Uniformity	
	DLA	DOH	DLA	DOH
Arterial	15	9.7 (Rural) 13 (Sub-Urban) 21.5 (Urban)	N/A	Emin/Eav ≥ 1:2.5 Emin/Emax ≥ 1:6
Collector	10	6.5 (Rural) 9.7 (Sub-Urban) 13 (Urban)	N/A	Emin/Eav ≥ 1:2.5 Emin/Emax ≥ 1:6
Intersection	22	15 (Rural) 21.5 (Sub-Urban) 21.5 (Urban)	N/A	Emin/Eav ≥ 1:2.5 Emin/Emax ≥ 1:6
Motorway	N/A	10.75 (Rural) 15 (Sub-Urban) 21.5 (Urban)	N/A	Emin/Eav ≥ 1:2.5 Emin/Emax ≥ 1:6
Local	N/A	2.1 (Rural) 6.5 (Sub-Urban) 9.7 (Urban)	N/A	Emin/Eav ≥ 1:2.5 Emin/Emax ≥ 1:6

The pilot demonstration projects implemented by PEA to date cover all different road classifications outlined in the above table; however the majorities of these road classifications include urban/sub-urban motorways and arterials as well as urban/sub-urban local roads. Characteristics of these roadways based on field measurement reports from various demonstration projects are described below.

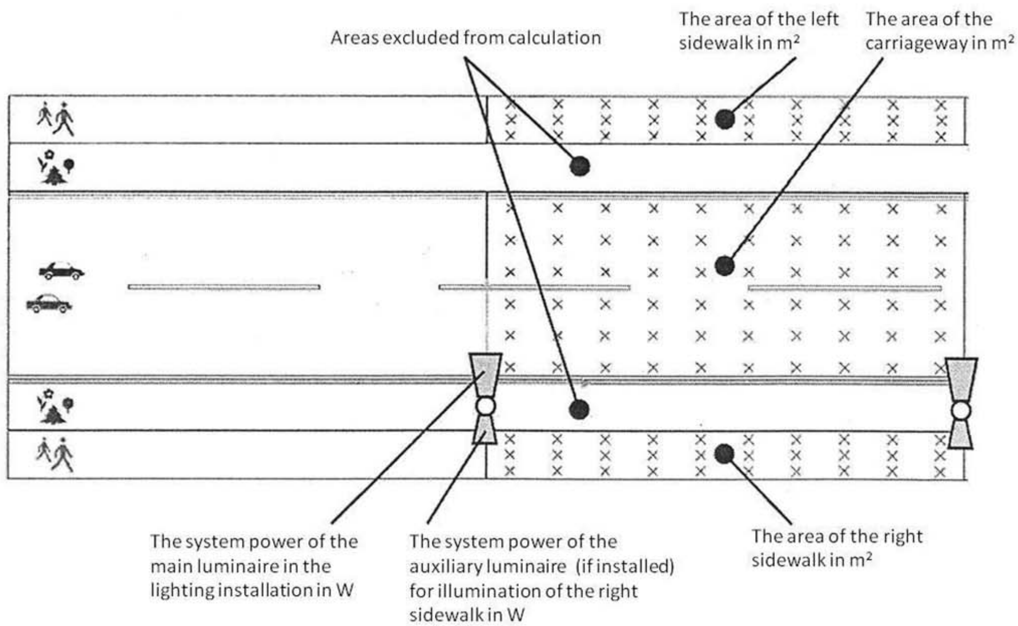
Table 8 : Characteristics of Roadways in PEA's Service Areas

Road Classification	Average Illumination Requirement (Lux)	Road Width (m)	Mounting Height (m)	Pole Span (m)	Installation Layout	Street Lighting Technologies	Measured Illumination (Lux)
Urban motorway	21.5	7-10	9	32-40	Middle island/ double mast arm Single mast arm	250W HID luminaires (HPS, MH) 90W-120W LED Luminaires	22.2 – 33.3.

Sub-urban motorway	15	6-12	9-10	40-50	Middle island/ double mast arm Single mast arm	250W HID luminaires (HPS, MH) 90W-120W LED Luminaires	13.7 – 16.1
Urban arterial	21.5	9	9	20	Single sided/ single mast arm	250W HPS luminaires	29.3

Road Classification	Average Illumination Requirement (Lux)	Road Width (m)	Mounting Height (m)	Pole Span (m)	Installation Layout	Street Lighting Technologies	Measured Illumination (Lux)
Sub-urban arterial	13	6-10	5-9	22-31	• Single sided/ single mast arm	• 70W-250W HID • luminaires (HPS, MV)	5.6 - 17.1
Urban local road	9.7	12	6	35	• Single sided/ single mast arm	• 150W HPS luminaires	5.1 - 7.2
Sub-urban local road	6.5	4-7	6-7	20-40	• Single sided/ single mast arm	• 125W MV • luminaires • 36W • Fluorescent luminaire	1.1 – 2.6

This report uses lighting power density indicator (PDI) in watts/lux/m2 and annual energy consumption indicator (AECI) in kWh/m2 as the Key Performance Indicators (KPIs) for different street lighting technologies in PEA's service areas as the proposed KPIs consider variations of luminaire installation (pole span and mounting height) when comparing different street and outdoor lighting technologies. The proposed KPIs are referenced in EN 13207-5:2015 Part 5: Energy performance indicators – Road lighting. Calculation of PDI and AECI for a generic road profile is shown in the figure below.



Source: Adapted from EN 13201-5: 2015 (European Standard 2015)

Figure 10 : Parameters for Calculation of PDI and AECI

Based on actual measurements, PDIs of different roadway classifications in PEA's service areas are illustrated in the figure below. It can be seen that main traffic routes (motorway and arterial) are relatively efficient compared with sub-urban traffic routes. PDIs of these main traffic routes range from below 0.02 to around 0.05 watts/lux/m2 and lighting technologies typically applied for these classifications of roadways include HPS and

LED. As for the sub-urban traffic routes, PDIs are higher, ranging from around 0.1 to around 0.2 watts/lux/m2, and lighting technologies commonly used include MV and fluorescent tube lamps.

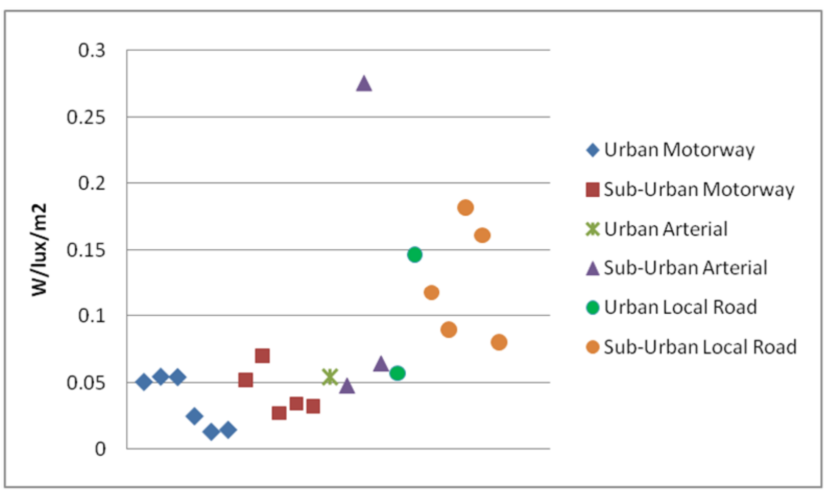


Figure 11 : Power Density in Watts/Lux/m2 of Different Roadways in PEA's Service Areas

Evaluating average PDIs of different roadway classifications against lighting technologies found that LED luminaires are the most efficient option, delivering the lowest PDI with an average PDI of 0.024 watts/lux/m2, followed by HPS luminaires at 0.056 watts/lux/m2. One interesting observation is that retrofitting fluorescent tube street lighting luminaires with LED tubes can reduce PDI more than half, from 0.126 to 0.07 watts/lux/m2. MV is the least efficient lighting technology with an average PDI of 0.211 watts/lux/m2.

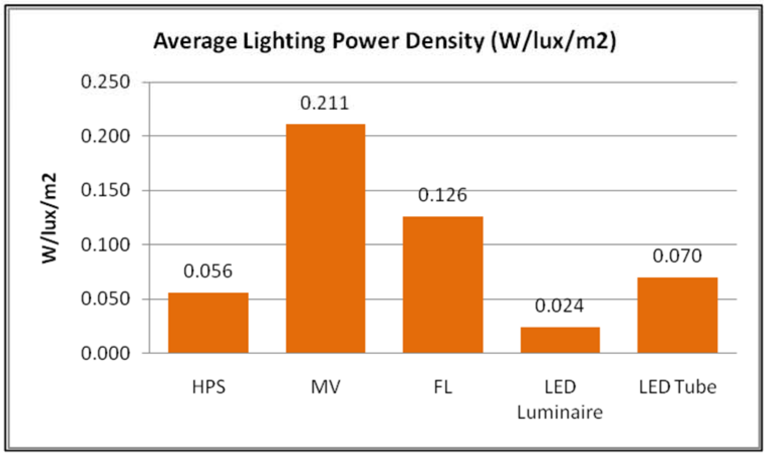


Figure 12 : PDI in Watts/Lux/m2 of Different Lighting Technologies

Table 9 : AECI in kWh/m2 by Different Lighting Technologies for Different Roadway Classifications

Roadway Classification	HPS	MV	FL	LED Luminaire	LED Tube
Urban motorway (21.5 lux)	5.78			2.28	
Sub-urban motorway (15 lux)	3.65			1.59	
Urban arterial (21.5 lux)	7.20			2.28	
Sub-urban arterial (13 lux)	2.82	10.61		1.38	
Urban local road (9.7 lux)		5.69		1.03	
Sub-urban local road (6.5 lux)			1.10	0.69	0.61

AECI in kWh/m2 generally corresponds with selection of lighting technologies to deliver illumination levels required. Shown in Table 9 are annual energy consumption density by different lighting technologies for different roadway classifications, and LED technologies (LED luminaires and LED tubes) are the most efficient options for all roadway classifications.

Potential annual energy savings

Actual measurement and verification (M&V) activities managed by PEA for its pilot demonstration of LED retrofits in 2014 show annual energy savings of about 70% when replacing 250W HPS luminaires with 90W LED luminaires (see Table 3-4). It should be noted that this LED retrofit project aims to deliver an average illumination of 15 lux for sub-urban motorway and arterial roads. The 15 lux illumination level is in accordance with the requirements specified by DLA and DOH, however this illumination level could be higher or lower than the illumination levels delivered by HPS luminaires before retrofitting.

Another approach for the analysis of annual energy savings is to compute better lighting power densities delivered by energy efficient street and outdoor lighting technologies. This approach can estimate annual energy savings when retrofitting the three conventional technologies, i.e., HPS, MV and FL, used in different roadway classifications in PEA's service areas with LED luminaires and LED tubes. The proposed retrofits are based on an assumption that LED luminaires will deliver illumination levels meeting the requirements of DLA and DOH as previously discussed.

As shown in Figure 4-4:, retrofitting HPS with LED delivers annual energy savings of about 30% to more than 60%, while retrofitting MV with LED delivers annual energy savings of more than 80% due to inefficiency of MV lamps. It should be noted that although retrofitting FL with LED tube delivers higher annual savings than LED luminaire, LED tube can only provide the same illumination levels as FLs.

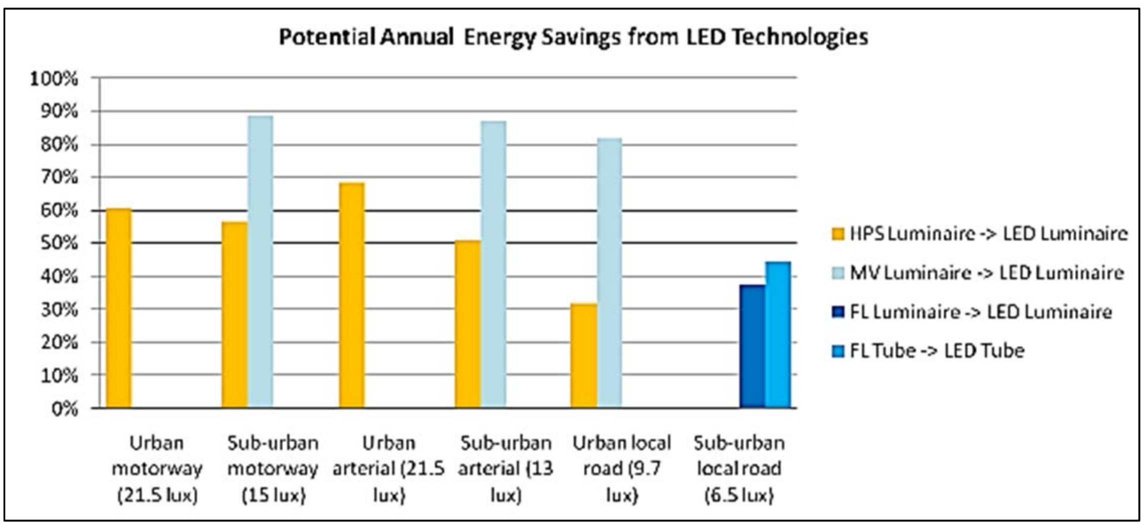


Figure 13 : Potential % Energy Savings from LED Technologies in Different Roadway Classifications

Shown in the table below are potential annual energy savings per m2 in kWh (% in brackets) when retrofitting conventional street and outdoor lighting technologies currently used in different roadway classifications in PEA's service areas with LED technologies.

Table 10 : Potential Annual kWh Savings/m2 from Non-Dimmable LED Luminaires for Different Roadway Classifications

Roadway Classification	HPS Luminaire -> LED Luminaire	MV Luminaire -> LED Luminaire	FL Luminaire -> LED Luminaire	FL Tube -> LED Tube
Urban motorway (21.5 lux)	3.50 (61%)			
Sub-urban motorway (15 lux)	2.06 (56%)			
Urban arterial (21.5 lux)	4.92 (68%)			
Sub-urban arterial (13 lux)	1.44 (51%)	9.23 (87%)		
Urban local road (9.7 lux)		4.66 (82%)		
Sub-urban local road (6.5 lux)			0.41 (38%)	0.49 (44%)

Note that applying dimming LED luminaires will deliver additional 25% savings and potential annual savings of dimmable LED luminaires are shown in Table 11.

Table 11 : Potential Annual kWh Savings/m2 from Dimmable LED Luminaires for Different Roadway Classifications

Roadway Classification	HPS Luminaire -> LED Luminaire	MV Luminaire -> LED Luminaire	FL Luminaire -> LED Luminaire	FL Tube -> LED Tube
Urban motorway (21.5 lux)	4.07 (70%)			
Sub-urban motorway (15 lux)	2.46 (67%)			
Urban arterial (21.5 lux)	5.49 (76%)			
Sub-urban arterial (13 lux)	1.78 (63%)	9.57 (90%)		
Urban local road (9.7 lux)		4.92 (86%)		
Sub-urban local road (6.5 lux)			N/A*	N/A*

**Note: LED luminaires with lower wattage are usually not equipped with dimming functions.*

Economic analysis of priority EE street and outdoor lighting technologies

Based on discussions on applicable EE street lighting technologies and lighting power densities when applying these applicable technologies for different roadway classifications in PEA's service areas, LED luminaires have clearly demonstrated several technical advantages over HPS and fluorescent technologies, and HID dimming systems (individual and circuit dimming). Other factors that underline LED lighting technologies as viable short and long term options for EE street and outdoor lighting implementation in PEA's service areas include the existing capacity of PEA to implement EE street and outdoor lighting and the downward trend of market prices of LED luminaires. Considering this, LED technologies for street and outdoor lighting are considered as priorities for the economic analysis.

Cost of LED technologies for street and outdoor lighting

The cost of LED luminaires for street and outdoor lighting vary widely depending on the make and model selected, light output, the quantity procured, and the warranty period. The most important factor that affects luminaire cost is the light output. Typically, higher light output means greater cost. Note that the relationship between the light output and the luminaire cost is not linear, as most manufacturers have opted to apply a single housing design for a range of light output. However, prices for LED luminaires for street and outdoor lighting have significantly dropped over the past several years and continue to do so.

Declining cost of led luminaires for street and outdoor lighting

The cost of LED street lighting has been decreasing rapidly as the technology matures. Experience from Seattle City Light (SCL) in Seattle, Washington, has shown around 51% reduction of the unit cost of 70W LED luminaires from US$369 in 2009 to US$179 in 2013 (for procurement of more than 2,000 luminaires). It is projected that the unit cost could be further reduced by 30% over the next 5 years. LED street lighting prices in Thailand have followed a similar trend, and unit costs of LED luminaires have dramatically decreased over the past five years, as shown in the figure below.

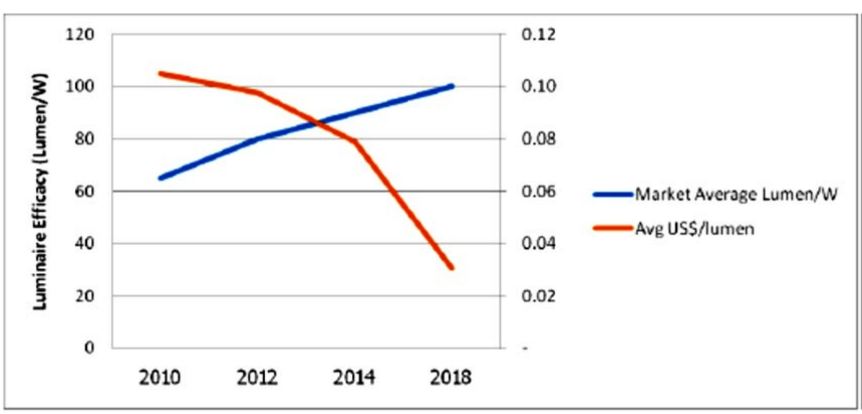


Figure 14 : Average Luminaire Efficacies and Cost per Lumen Output in Thailand, 2010-2018

In terms of future improvement of LED lighting technologies, the Solid-State Lighting 2017 Suggested Research Topics report published by U.S. Department of Energy, efficacy of LED package is projected to exceed 200 lumen per watt by 2020.

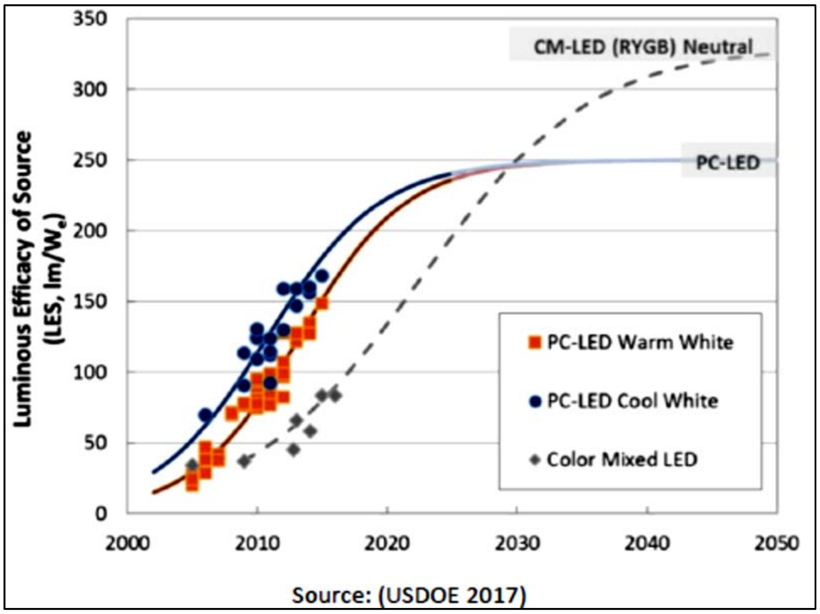


Figure 15 : LED Package Efficacy Projections

Conventional street and outdoor lighting technologies widely adopted by DOH and municipalities in PEA's service areas are HPS and FL technologies. MV used to be the common street lighting technologies for Thai municipalities due to its low initial cost, however it has been replaced by HPS over the past decade. Shown in the figure below are comparison of cost per luminaire lumen output of LED technologies in Thailand against these conventional street and outdoor lighting technologies. The current average cost of LED luminaires is about $0.03 per luminaire lumen output. For the same light output produced by a luminaire, an LED luminaire is about 2.5 times more expensive than a HPS luminaire.

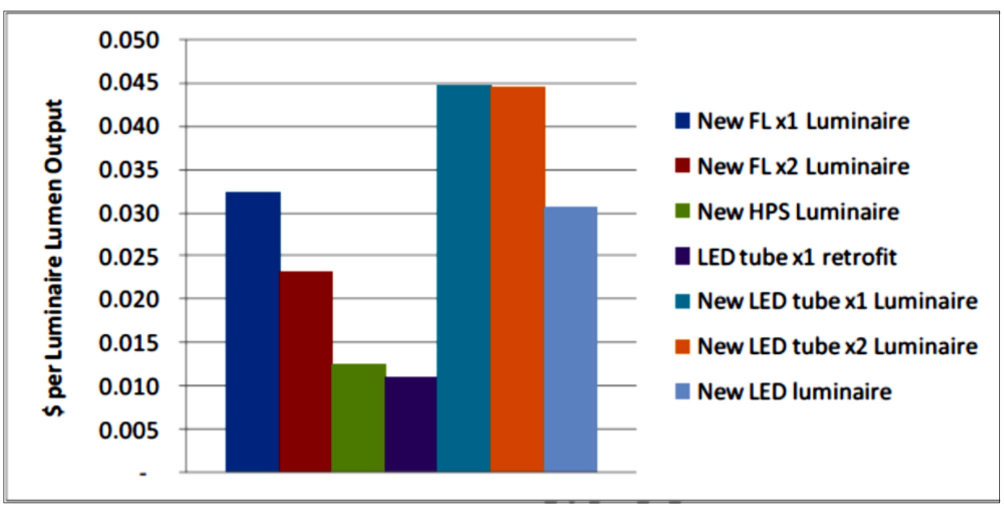


Figure 16 : Cost per Luminaire Lumen Output of Different Lighting Technologies

Source: Thailand market data compiled by IIEC

Conventional street and outdoor lighting technologies widely adopted by DOH and municipalities in PEA's service areas are HPS and FL technologies. MV used to be the common street lighting technologies for Thai municipalities due to its low initial cost, however it has been replaced by HPS over the past decade. Shown in the figure below are comparison of cost per luminaire lumen output of LED technologies in Thailand against these conventional street and outdoor lighting technologies. The current average cost of LED luminaires is about

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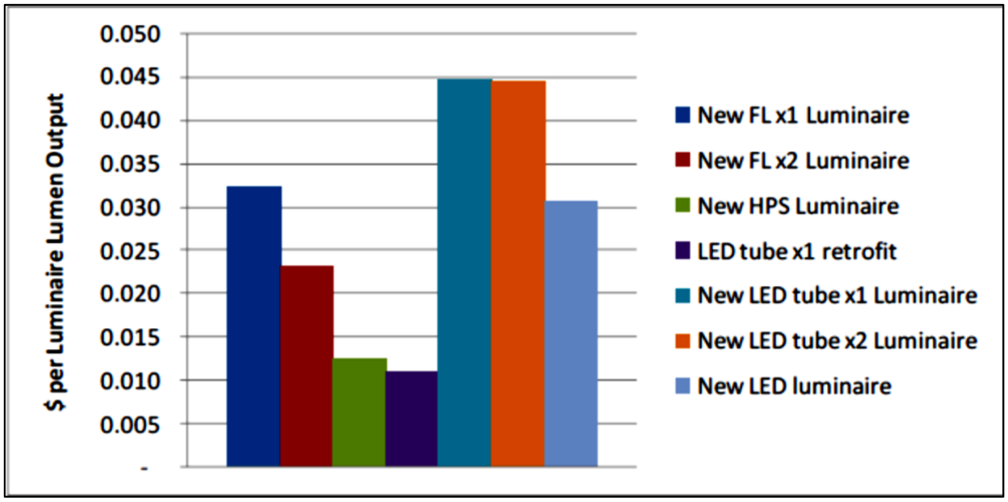

Figure 17 : Cost per Luminaire Lumen Output of Different Lighting Technologies

Economics of LED Lighting Technologies

Economics analysis of LED lighting technologies was based on two approaches i.e.: 1) Economic analysis of LED technologies in delivering lower lighting power density; and 2) Per-unit economic analysis of LED technologies which deliver equivalent light output as compared with common conventional street and outdoor lighting technologies in PEA's service areas.

Economic Analysis of Lower Lighting Power Density

This approach analyzes costs and energy savings when applying LED lighting technologies to lower lighting power densities for different roadway classifications in PEA's service areas. Costs of LED lighting technologies are based on the current market prices compiled by IIEC, and average costs per m^2 for retrofitting conventional street lighting technologies with LED technologies are illustrated in Figure 4-6:. Estimation of potential annual energy savings as a result of lower lighting power densities is described in Section 3.3 and Table 4-5:.

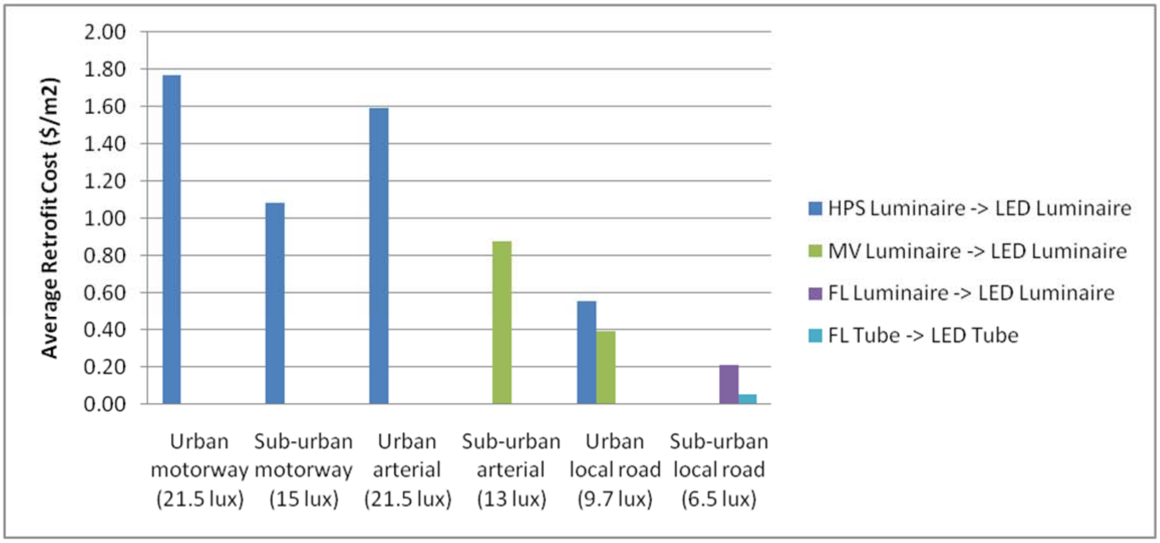

Figure 18 : Average Cost for Retrofitting Conventional Street Lighting Technologies with LED Technologies

Findings from the analysis, as summarized in Table 12 show that payback periods for replacing MV luminaires for sub-urban arterials and urban local roads with LED luminaires are very attractive with the payback period of less than one year. Replacement of FL tubes with LED tubes for sub-urban local roads also offer an attractive payback period of less than one year, however this approach does not improve illumination level for sub-urban local roads. Replacing the whole FL luminaires for sub-urban local roads with LED luminaires has a longer payback period of about 4 year but this approach will provide illumination levels meeting the requirement of 6.5 lux.

Replacing HPS luminaires with LED luminaires gives an average payback period of about 5 years. It should be noted that any simple payback periods of lower than 4 years are the indications that the specific roadway classifications are over illuminated by the conventional street lighting technologies compared with DOH and DLA requirements.

Table 12 : Simple Payback Periods of LED Retrofits for Different Roadway Classifications

Roadway Classification	HPS Luminaire -> LED Luminaire	MV Luminaire -> LED Luminaire	FL Luminaire -> LED Luminaire	FL Tube -> LED Tube
Urban motorway (21.5 lux)	4.05			
Sub-urban motorway (15 lux)	4.21			
Urban arterial (21.5 lux)	2.58			
Sub-urban arterial (13 lux)		0.76		
Urban local road (9.7 lux)	9.25	0.68		
Sub-urban local road (6.5 lux)			4.12	0.90

Per-Unit Economic Analysis of LED Luminaires

Per-unit economic analysis of LED luminaires applicable for replacement of common HPS and FL luminaires was carried out under three scenarios of electricity tariffs for street and outdoor lighting in PEA's service areas, i.e., 2018 electricity tariff at US$0.125/kWh (4 Thai Baht/kWh); medium electricity tariff at US$0.15/kWh; and high electricity tariff at US$0.20/kWh. Per-unit annual energy consumption of existing HPS and FL luminaires and applicable LED luminaires are shown in Table 13: and payback periods for replacement of HPS/FL technologies with LED lighting technologies are shown in Table 14. Results of the per-unit analysis are in line with the lighting power density approach are the payback periods for HPS luminaire → LED luminaire retrofits are about 5 years, FL luminaire → LED luminaire about 4 years, and FL tube → LED tube about 1 year.

Table 13 : Estimated Per Unit Annual Energy Consumptions of HPS/FL Luminaires and LED Lighting Technologies

Baseline	Per Unit Annual Energy Consumption (US$)		
	2018 Tariff (US$0.125/kWh)	Medium Tariff (US$0.15/kWh)	High Tariff (US$0.20/kWh)
36W FL Luminaire	24	28	38
150W HPS Luminaire	94	113	151
250W HPS Luminaire	157	189	252
Non-Dimmable LED Luminaire	Per Unit Annual Energy Consumption (US$)		
LED Luminaire 18W	11	14	18
LED Tube 20W	13	15	20
LED Luminaire 75W	47	57	76
LED Luminaire 125W	79	94	126

Table 14 Per Unit Payback Period for Replacement HPS/FL Technologies with LED Lighting Technologies

Retrofitting Option	2018 Market Price (US$)	2018 Tariff (US$0.125/kWh)	Medium Tariff (US$0.15/kWh)	High Tariff (US$0.20/kWh)
		Payback Period		
36W FL Luminaire -> 36W FL Luminaire	50	4.1	3.4	2.5
36W FL Luminaire -> LED Tube 20W	12	1.1	0.9	0.7
150W HPS Luminaire -> LED Luminaire 75W	300	6.4	5.3	4.0
250W HPS Luminaire -> LED Luminaire 125W	370	4.7	3.9	2.9

It is reported that virtually all the total street lighting luminaires in PEA's service areas are connected with energy meters. However it is believed that there are a number of street lighting luminaires which are unmetered. The practical steps for conducting measurements of energy savings and emission reductions for metered and non- metered lighting points in PEA's service areas based on AMS II.L are described below.

Metered Light Points

This approach relies on periodic recording of energy consumption, which could simply be achieved through coordination and retrieval of data from PEA. Actual readings should be taken from some randomly selected[6] energy meters and compared against the computation recommended for non-metered light points below. Any large discrepancies should be validated and calibration of energy meters should be undertaken as necessary. Calculation of the net electricity savings is carried out by correcting the net electricity savings (NES), based on pre- and post-implementation meter readings, for any leakage and transmission & distribution losses. Emissions reduction is the NES times an Emission Factor (EF) published by the responsible agency in Indonesia.

Non-Metered Light Points

The following M&V approaches are recommended for non-metered light points in PEA's service areas.

- **Determination of Luminaire Power Consumption:** Estimate the nameplate/rated power (Watts) of the baseline (HPS) luminaires and project (LED) luminaires. Conduct bench test measurements, or determine the time-integrated average power if adaptive street lighting controls will decrease lighting power at periods of lower demand: nightly, weekly, seasonally or otherwise. If patterns of variation in parameters such as traffic volume are well known, such as from records of traffic counts, use such records to estimate time-integrated average power based on controls settings.
- **Determination of Operating Hours:** The default value for daily hours of operation of luminaires is assumed to be as follows:
    1. For luminaires controlled with a standard timer, use the number of hours that the timer will be set during the crediting period for operating hours during an average day.
    2. For luminaires controlled by ambient light sensors or astronomical time clocks, use the average number of hours between sunset and sunrise.

Calculation of Electricity Savings: Calculate the gross electricity savings by comparing the total average power of the project luminaires multiplied by project annual hours of operation, with the average power of the baseline luminaires multiplied by baseline annual hours of

[6] AMS.II-L suggests calculation of the sample size to achieve a minimum 90% confidence interval and 10% maximum error margin (which is in line with the International Performance Measurement and Verification Protocol – IPMVP).

operation (daily hours times 365 or another number equal to the number of days per year that the lights are expected to be operated). Calculation of the NES is carried out by correcting the gross electricity savings for any leakage and transmission & distribution losses, and emissions reduction is the NES times an Emission Factor (EF) published by the responsible agency in Thailand.

Lighting Quality

Any lighting retrofits shall provide lighting quality (illumination and uniformity) either: (a) Equivalent to or better than the baseline lighting performance; or (b) Equivalent to or better than the applicable street lighting standard. This proposed EE street and outdoor lighting in Surabaya follows the former approach. For a retrofit project, the measurement of lighting quality should be conducted prior to the luminaire replacement. This provides a quality baseline against which post-installation measurements can be contrasted. The second point at which measurements should be taken is after the installation process. Measurement of lighting quality (or illumination in "Lux" on the area of interest) in this project will utilize the grid measurement approach as outlined in the illumination measurement guideline recommended by AMS II.L. Based on measurement data, average illumination in Lux and uniformity (minimum to average) will be calculated, and post-installation measurements will be compared with the pre-installation measurements as well as any simulations undertaken during the design phase.

Implementation of M&V Activities based on AMS-II.L in the Pacific

`Under the Promoting Energy Efficiency in the Pacific – Phase 2 (PEEP2) project financed by ADB, 11 EE street lighting projects were implemented across the 5 target countries (i.e., the Cook Islands, Papua New Guinea, Samoa, Tonga and Vanuatu). In these projects, MV and HPS luminaires were replaced by LED luminaires. During the design and implementation of these EE street lighting projects, M&V activities based on the AMS-II.L methodology were carried out to verify the project benefits in terms of energy savings and improved lighting quality. Implementation of M&V activities also served as capacity building activities for the implementing agencies in the 5 target countries.

Figure 19 Measurement of Power Consumption and Lighting Quality per AMS-II.L in Papua New Guinea

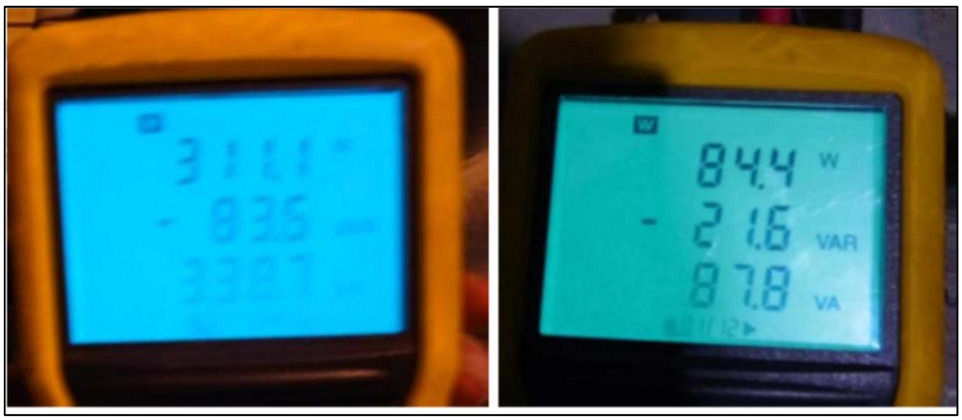

Figure 20 : On-Site Measurements of 250W HPS Luminaire (Left) and 90W LED Luminaire (Right)

Summary of LED Implementation in the Pacific	
Location (City, Country)	5 Pacific Island Countries
Year	2013-2014
Project Size (No. of LED Luminaire)	1,056
Investments	US$562,602
Cost Savings	US$122,937/ year
CO2 Emssion Reduction	1,935 tCO2e (lifetime)
Electricity Tariff	US$ 0.30
Payback Period	4.6 years
Financing Model	Grant
Implementation Arrangement	Direct Supplier Model
MRV Mechanism	AMS.II-L

Source: TA 7798 - REG: Promoting Energy Efficiency in the Pacific (Phase 2) final report, IIEC, 2015; and PEA, 2012

Feasibility of energy efficient street and outdoor lighting in Thai municipalities

According to Tessaban Act 2003, municipalities (or Tessaban in Thai) in Thailand can be divided into 3 classifications as follows:

1. **Tessaban nakhon** are usually translated as city level municipality. Local administration units classified as Tessaban nakhon shall have population more than 50,000 and are able to generate sufficient revenues to perform functions and duties as specified in the Act.
2. **Tessaban mueang** are usually translated as town level municipality. Local administration units classified as Tessaban nakhon shall have population more than 10,000 and are able to generate sufficient revenues to perform functions and duties as specified in the Act.
3. **Tessaban tambon** are usually translated as sub-district level municipality which are the lowest municipality level in Thailand. Local administration units are promoted to be Tessaban tambon by Ministry of Interior.

Previous energy audits undertaken by an ADB funded project[7] have revealed that majority of electricity consumption in Thai municipalities are for street and public lighting services (which account for about 60% to 70% of the total electricity consumption in each municipality), as shown in the figure below. Average annual operating hours of street and outdoor lighting based on continuous monitoring over a 12-month period (from mid-2010 to mid-2011) are about 4,400 hours.

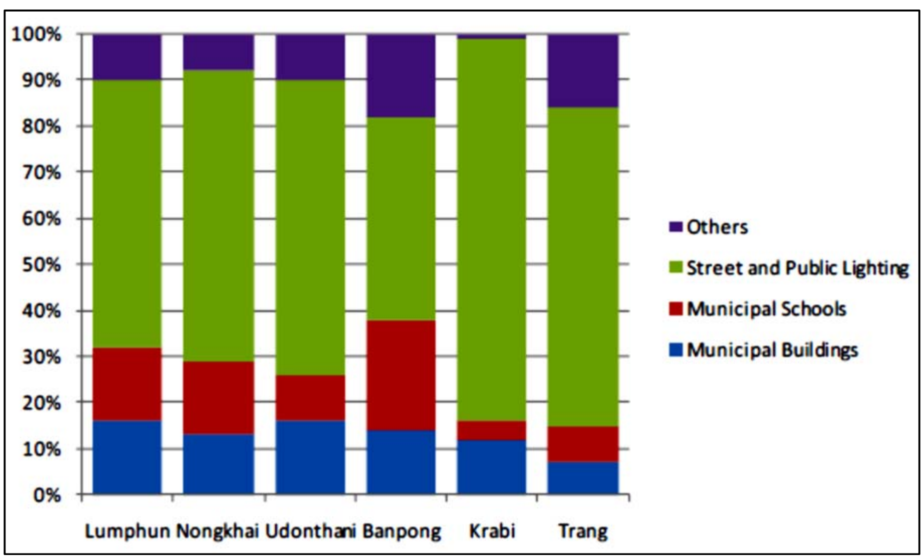

Figure 21 : Breakdown of Electricity End-Use in Thai Municipalities

[7] Mainstreaming Energy Efficiency in Thai Municipalities project funded by ADB and implemented by IIEC in collaboration with PEA from 2009 to 2012.

PEA requested IIEC to conduct feasibility study of energy efficient street and outdoor lighting in the city level municipalities chosen by PEA to implement LED retrofit program using the ESCO model. Details of feasibility studies in Lampang and Nakornsawan municipality are subsequently described below.

Lampang Municipality

Lampang municipality (or Thesaban Nakorn Lampang in Thai) has the total area under responsibility of 22.17 square kilometers with population of around 54,000 people. Figure 22 shows location of Lampang municipality and its jurisdiction area.

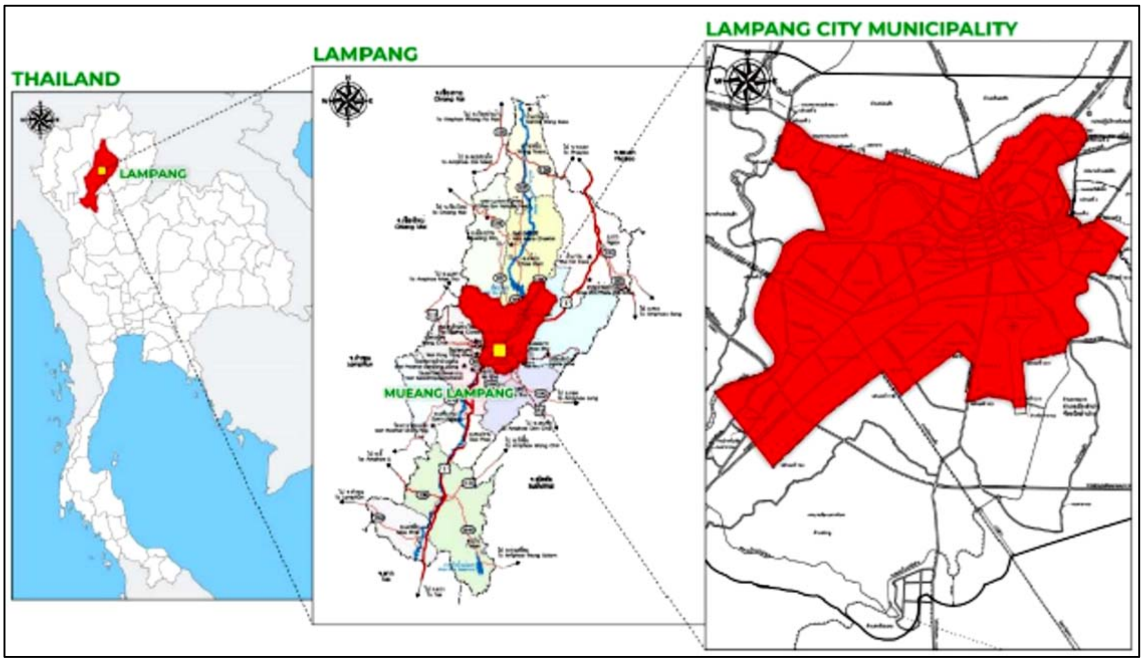

Figure 22 : Location and Jurisdiction Area of Lampang Municipality

Lampang municipality has a total road length of about 224 kilometers, as summarized below.

Table 15 : Type of Road Pavement and Length within Nakornsawan Municipality

Type of Road Pavement	Length (meter)
Concrete	99,181
Asphalt	117,296
Non-Pavement (laterite/gravel)	7,872
Total	**224,349**

Inventory of Street and Outdoor Lighting

Inventory of lamps/luminaires for street and outdoor lighting in Lampang municipality as well as the estimated lighting system power are summarized in the Table 16. It is estimated that these street and outdoor lamps/luminaires cover a total area of 2 million m^2 of roads in the municipality.

Table 16 : Inventory of Lamps/Luminaires for Street and Outdoor Lighting in Lampang Municipality

No.	Type of Lamp/Luminaire	Quantity	Lamp/Ballast Circuit Wattage (W)	Lighting Power Installed (W)	Annual Energy Consumption (kWh)
1	Fluorescent tube luminaire 1x18W	20	21.6	432	1,901
2	Fluorescent tube luminaire 1x36W	44	43.2	1,901	8,364
3	Fluorescent tube luminaire 2x18W	2,954	43.2	127,613	561,496
4	Fluorescent tube luminaire 2x36W	1,854	86.4	160,186	704,817
5	CFL luminaire 25W	419	25	10,475	46,090
6	CFL luminaire 65W	135	65	8,775	38,610
7	MV luminaire 125W	519	143.75	74,606	328,268
8	MV luminaire 160W	24	184	4,416	19,430
9	MV luminaire 250W	1,571	287.5	451,663	1,987,315
10	HPS luminaire 250W	288	287.5	82,800	364,320
11	HPS luminaire 360W	74	414	30,636	134,798
12	MH luminaire 400w	164	460	75,440	331,936
13	MH luminaire 1000W	14	1150	16,100	70,840
14	PAR lamp 38	6	80	480	2,112
15	LED luminaire 90W	825	90	74,250	326,700
	Total	8,911		1,119,772	4,926,997

Figure 23 : Street and Outdoor Lighting in Lampang Municipality

The total installed power for street and outdoor lighting in Lampang municipality is about 1,120 kW, and about 66% of which are HID lighting technologies, followed by fluorescent technologies about 28%. The municipality reported that 825 HPS luminaires were replaced by LED luminaires, accounting for about 6% of the total installed lighting power. Inefficient MV luminaries are still common in Lampang municipality, accounting for about 47% of the total installed lighting power.

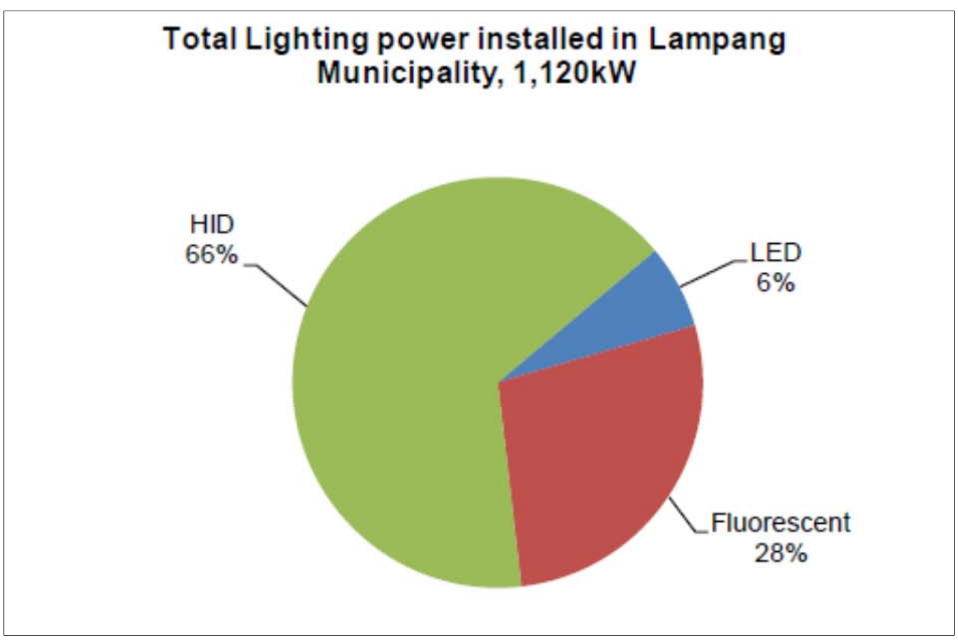

Figure 24 : Street and Outdoor Lighting Technologies in Lampang Municipality

The overall baseline of AECI for street and outdoor lighting in Lampang municipality computed based on various installed technologies and the total roadways area of 2 million m^2 is 2.58 kWh/m^2. Comparing the overall AECI with the average AECI values in Table 17 in previous section found that adoption of more LED lighting by Nakornsawan municipality can further reduce the overall AECI to be lower than 1.6 kWh/m^2, which is equivalent to at least 38% reduction in street and outdoor lighting energy consumption.

Economics of AECI Improvement in Lampang Municipality

Data on street and outdoor lighting inventory and the total area of roadways in Lampang municipality could not be categorized by road classifications per DLA/DOH road guidelines. Considering this, AECI improvement will be estimated using the per unit approach. Based on the investment costs and payback periods of different approaches for AECI improvement, discussed in Section 4, it is recommended that fluorescent tubes, CFLs and MV and Par lamps in Lampang municipality are replaced by LED technologies.

Table 17 : Proposed Energy Efficient Street and Outdoor Lighting Retrofits in Nakornsawan Municipality

No.	Type of Lamp/Luminaire	Quantity	Estimated Investment Cost (US$)	Annual Cost Savings (US$)	Payback Period (Years)
1	LED tube 10W	5928	56,340	37,821	1.5
2	LED tube 20W	3,752	71,318	47,876	1.5
3	LED luminaire 10W	419	11,571	3,457	3.3
4	LED luminaire 25W	135	9,693	2,970	3.3
5	LED luminaire 45W	519	71,663	28,188	2.5
6	LED luminaire 60W	24	4,242	1,637	2.6
7	LED luminaire 90W	1,571	433,842	170,650	2.5
8	LED luminaire 12W	6	221	224	1.0
	Total	12,354	658,890	292,822	2.3

Note:

1. Estimated investment costs based on US$ per luminaire lumen output, as shown in Figure 4-5.
2. Annual cost savings based on 4,400 operating hours per year and electricity tariff of US$0.125/kWh.

As shown in Table 17, the proposed retrofits of existing fluorescent, MV and Par lighting technologies with equivalent light output LED tubes/luminaires are considered to be cost-effective, with the simple payback period for each type of lamp ranging from about 1.5 years to about 3.3 years, and the overall payback period is around

2.3 years. The proposed retrofits will reduce AECI from the baseline of 2.58 kWh/m² to 1.35 kWh/m² (about 48% improvement) with the total investment cost of around US$660,000. Lampang municipality can further reduce its AECI to 1.15 kWh/m² by transforming all street and outdoor lighting in the municipal area to LED lighting, however this will require an extra investment of US$330,000 for additional 8% improvement from the baseline AECI (see figure below).

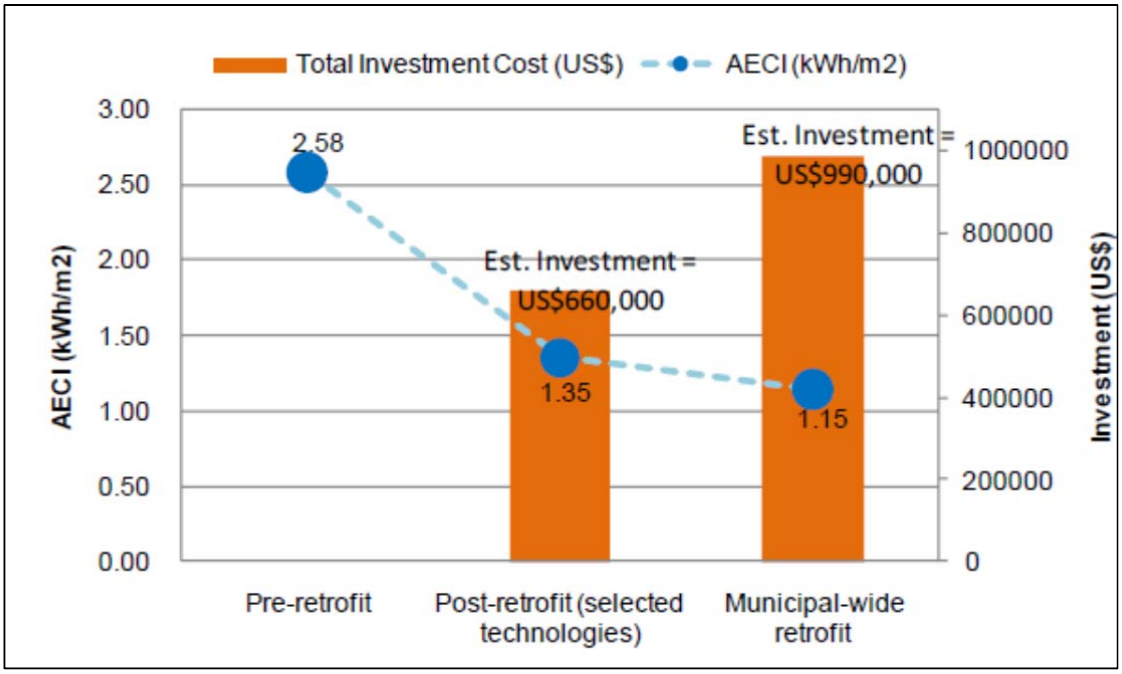

Figure 25 : Summary of AECI Improvements and Investment Required in Lampang Municipality

Nakornsawan Municipality

Nakornsawan municipality (or Thesaban Nakorn Nakornsawan in Thai) has the total area under responsibility of

27.87 square kilometers with population around 90,000 people. Figure 5-6 shows location of Nakornsawan municipality and its jurisdiction area.

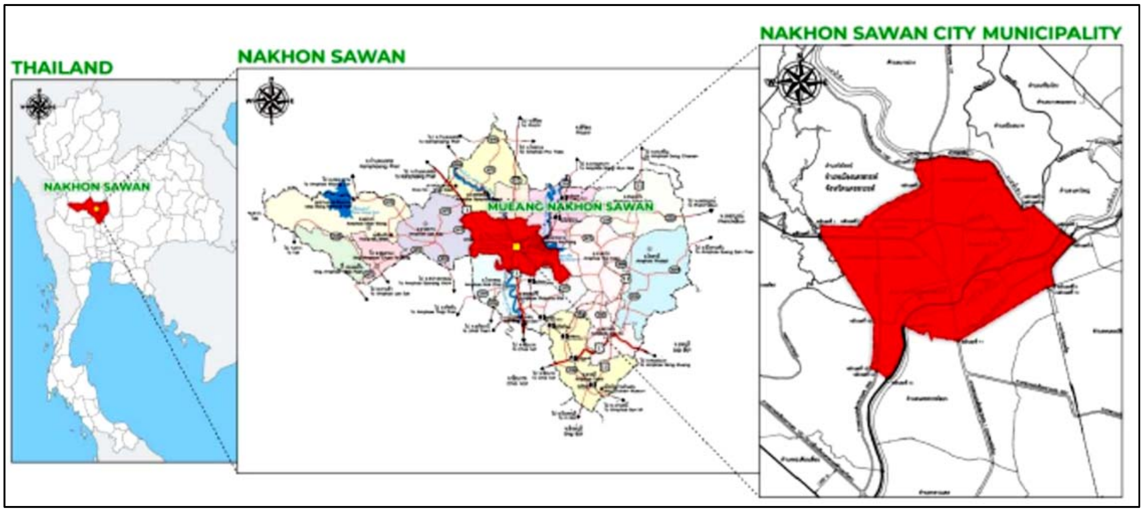

Figure 26 : Location and Jurisdiction Area of Nakornsawan Municipality

Nakornsawan municipality has a total road length of about 126 kilometers, as summarized below.

Table 18 : Type of Road Pavement and Length within Nakornsawan Municipality

Type of Road Pavement	Length (meter)
Concrete	93,690
Asphalt	30,901
Non-Pavement (laterite/gravel)	1,884
Total	126,475

Inventory of Street and Outdoor Lighting

Inventory of lamps/luminaires for street and outdoor lighting in Nakornsawan municipality as well as the estimated lighting system power are summarized in Table 19. It is reported that these street and outdoor lamps/luminaires cover a total area of 1,518,700 m^2 of roads and sidewalks in the municipality.

Table 19 : Inventory of Lamps/Luminaires for Street and Outdoor Lighting in Nakornsawan Municipality

No.	Type of Lamp/Luminaire	Quantity	Lamp/Ballast Circuit Wattage (W)	Lighting Power Installed (W)	Annual Energy Consumption (kWh)
1	LED Luminaire 90W (main traffic routes)	2,165	90	194,850	857,340
2	LED Luminaire 120W (main traffic routes)	85	120	10,200	44,880
3	LED Luminaire 120W (Koh	90	120	10,800	47,520

	Yuan Park)				
4	Fluorescent tube lamp 18W	16	26	416	1,830
5	Fluorescent tube lamp 36W	8,700	44	382,800	1,684,320
6	Metal halide luminaire 250W	14	287.5	4,025	17,710
7	Metal halide luminaire 400W	200	460	92,000	404,800
8	Mercury vapor luminaire 500W	70	575	40,250	177,100
9	CFL luminaire 18W	76	18	1,368	6,019
10	LED Spotlight 200W	189	200	37,800	166,320
Total		11,605		774,509	3,407,840

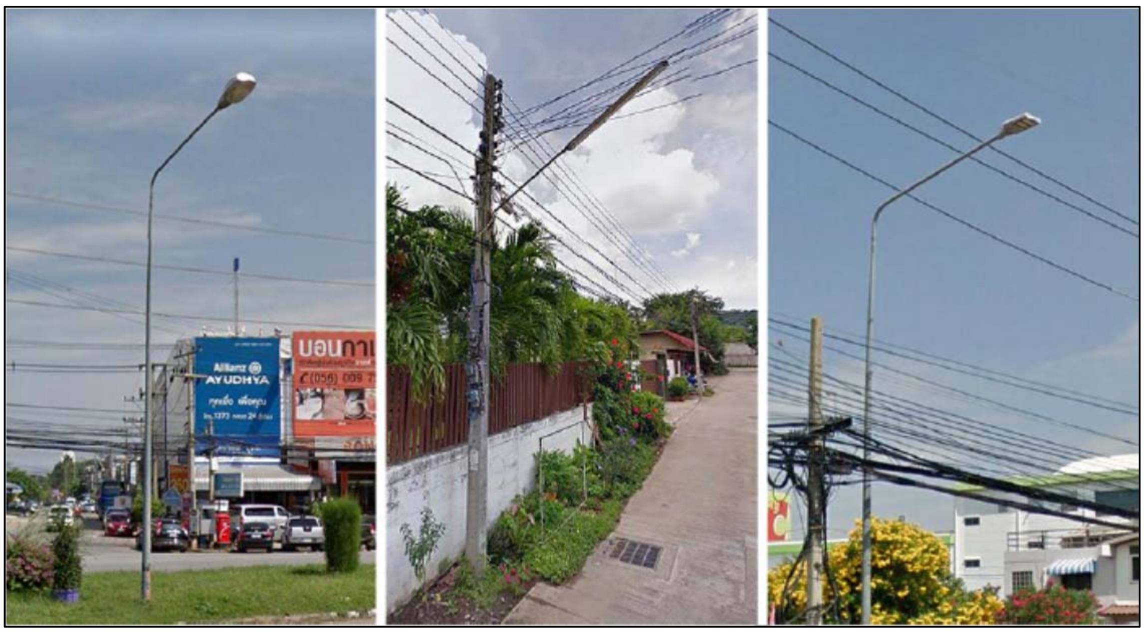

Figure 27 : Street and Outdoor Lighting in Nakornsawan Municipality

The total installed power for street and outdoor lighting in Nakornsawan municipality is about 775 kW, and about 50% of which are fluorescent lighting technologies. The municipality reported that all HPS luminaires were replaced by LED luminaires and inefficient MV luminaries account for only about 5% of the total installed lighting power.

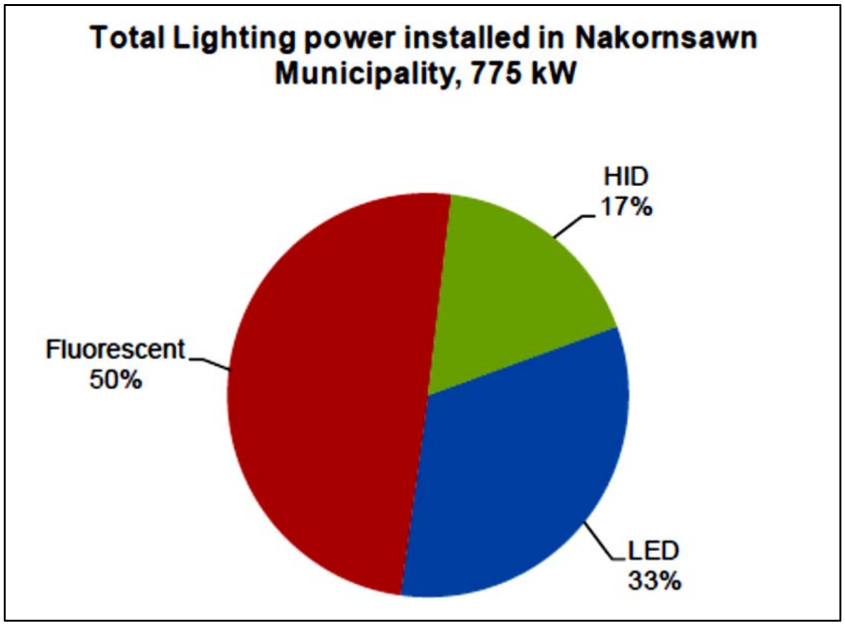

Figure 28 : Street and Outdoor Lighting Technologies in Nakornsawan Municipality

The overall baseline of AECI for street and outdoor lighting in Nakornsawan municipality computed based on various installed technologies and the total area of roadways and sidewalks is 2.24 kWh/m^2. Comparing the overall AECI with the average AECI values in Table 20 in previous section found that adoption of more LED lighting by Nakornsawan municipality can further reduce the overall AECI to be lower than 1.6 kWh/m^2, which is equivalent to at least 30% reduction in street and outdoor lighting energy consumption.

Economics of AECI Improvement in Nakornsawan Municipality

Data on street and outdoor lighting inventory and the total area of roadways in Nakornsawan municipality could not be categorized by road classifications per DLA/DOH road guidelines. Considering this, AECI improvement will be estimated using the per unit approach. Based on the investment costs and payback periods of different approaches for AECI improvement, discussed in Section 4, it is recommended that fluorescent tubes, CFLs and MV lamps in Nakornsawan municipality are replaced by LED technologies.

Table 20 : Proposed Energy Efficient Street and Outdoor Lighting Retrofits in Nakornsawan Municipality

No.	Type of Lamp/Luminaire	Quantity	Estimated Investment Cost (US$)	Annual Cost Savings (US$)	Payback Period (Years)
1	LED tube 10W	16	152	102	1.5
2	LED tube 20W	8,700	165,370	111,012	1.5
3	LED luminaire 200W	70	38,662	14,438	2.7
4	LED luminaire 10W	76	1,511	334	4.5
	Total	8,862	205,695	125,886	1.6

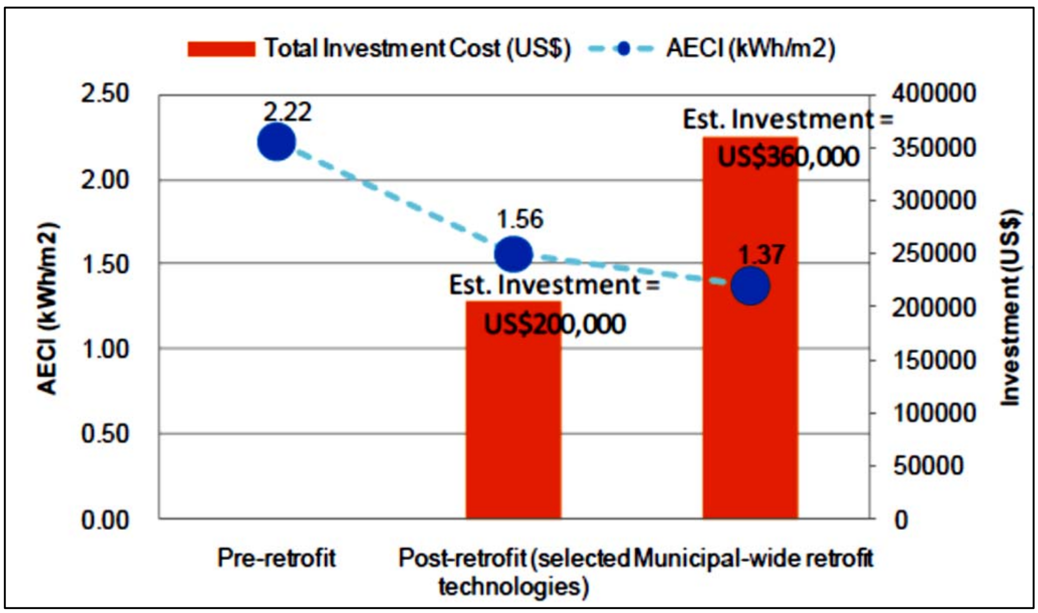

Figure 29 : Summary of AECI Improvements and Investment Required in Nakornsawan Municipality

Pathumthani Municipality

Pathumthani municipality (or Thesaban Mueang Pathumthani in Thai) has the total area under responsibility of 7.1 square kilometers with population around 20,000 people. Figure 5-10 shows location of Pathumthani municipality and its jurisdiction area.

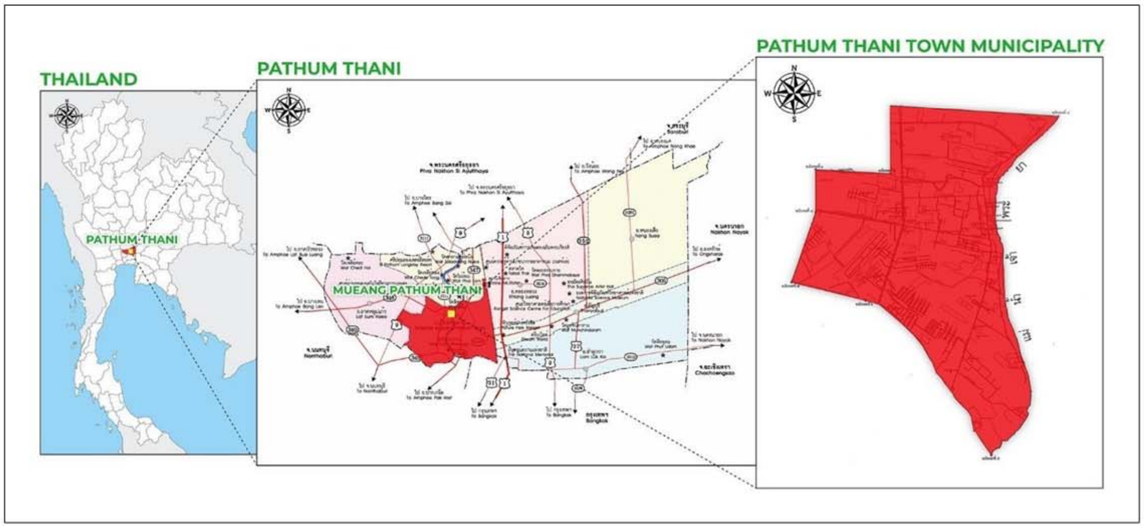

Figure 30 : Location and Jurisdiction Area of Pathumthani Municipality

Inventory of Street and Outdoor Lighting

Inventory of lamps/luminaires for street and outdoor lighting in Pathumthani municipality as well as the estimated lighting system power are provided by the municipal office as summarized in Table 5-8. It is estimated that these street and outdoor lamps/luminaires cover a total area of 310,000 m^2 of roads in the municipality.

There are no published statistics on road classifications and their respective lengths in Pathumthani municipality, however, based on the municipal map provided by Pathumthani municipality, it is estimated that the total road length in Pathumthani municipality is about 41 kilometers, as summarized below.

Table 21 : Type of Road Pavement and Length within Pathumthani Municipality

Type of Road Pavement	Length (meter)
Concrete	40,000
Asphalt	1,000
Non-Pavement (laterite/gravel)	N/A
Total	41,000

Table 22 : Inventory of Lamps/Luminaires for Street and Outdoor Lighting in Pathumthani Municipality

No.	Type of Lamp/Luminaire	Quantity	Lamp/Ballast Circuit Wattage (W)	Lighting Power Installed (W)	Annual Energy Consumption (kWh)
1	Fluorescent tube luminaire 1x36W	807	43.2	34,862	153,395
2	HPS luminaire 70W	57	80.5	4,589	20,189
3	HPS luminaire 250W	162	287.5	46,575	204,930
4	LED luminaire 110W	322	110	35,420	155,848
	Total	1,348		121,446	534,362

Figure 31 : Street and Outdoor Lighting in Pathumthani Municipality

The total installed power for street and outdoor lighting in Pathumthani municipality is about 121 kW, and about 42% of which are HPS technologies. The municipality reported that some 250W HPS luminaires were replaced by 110W LED luminaires (through PEA's ESCO model), and the total LED lighting power installed accounts for about 29% of the total installed lighting power. In terms of number of luminaires installed, fluorescent tube luminaires account for about 60% of the total luminaires installed in the municipality, but the total installed power of fluorescent tubes is only 29%.

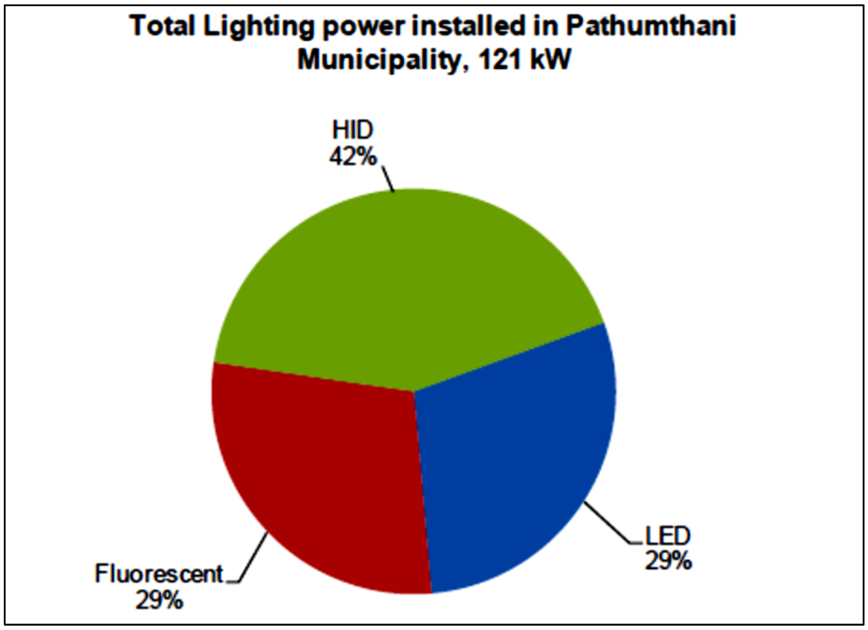

Figure 32 : Street and Outdoor Lighting Technologies in Pathumthani Municipality

The overall baseline of AECI for street and outdoor lighting in Pathumthani municipality computed based on various installed technologies and the total area of roadways is 1.72 kWh/m^2. This low computed AECI is generally influenced by installation of LED luminaires along the main traffic routes and the use of fluorescent tube luminaires in urban local roads. It should be noted that, based on the actual measurements, fluorescent tube luminaires generally deliver an average illumination level of about 2 lux which is much lower than the requirements of 9.7 lux for urban local road per DLA/DOH road guidelines. Considering this, the AECI in Pathumthani municipality cannot be directly compared with Lampang and Nakornsawan municipality.

Comparing the overall AECI with the average AECI values in Table 4-4 in previous section found that adoption of more LED lighting by Pathumthani municipality while maintaining the current lighting quality can further reduce the overall AECI to be around 1.6 kWh/m^2, which is equivalent to at least 6% reduction in street and outdoor lighting energy consumption.

Economics of AECI Improvement in Pathumthani Municipality

Data on street and outdoor lighting inventory and the total area of roadways in Pathumthani municipality could not be categorized by road classifications per DLA/DOH road guidelines. Considering this, AECI improvement will be estimated using the per unit approach. Based on the investment costs and payback periods of different approaches for AECI improvement, discussed in Section 4, it is recommended that fluorescent tubes, CFLs and MV lamps in Pathumthani municipality are replaced by LED technologies.

Table 23 : Proposed Energy Efficient Street and Outdoor Lighting Retrofits in Nakornsawan Municipality

No.	Type of Lamp/Luminaire	Quantity	Estimated Investment Cost (US$)	Annual Cost Savings (US$)	Payback Period (Years)
1	LED tube 20W	807	15,339	10,297	1.5
	Total	807	15,339	10,297	1.5

Note: 1.

1. Estimated investment costs based on US$ per luminaire lumen output, as shown in Figure 4-5.
2. Annual cost savings based on 4,400 operating hours per year and electricity tariff of US$0.125/kWh.

As shown proposed retrofits of existing fluorescent lighting technologies with equivalent light output LED tubes are considered to be cost-effective, with the overall simple payback period around 1.5 years. The proposed retrofits will reduce AECI from the baseline of 1.72 kWh/m^2 to 1.62 kWh/m^2 (about 6% improvement) with the total investment cost of around US$15,400. Pathumthani municipality can further reduce its AECI to 1.11 kWh/m^2 by transforming all street and outdoor lighting in the municipal area to LED lighting, however this will require an extra investment of about US$97,000 for additional 30% improvement from the baseline AECI (see Figure 33). Note that the overall simple payback period for the municipal-wide LED retrofits will be around 4 years.

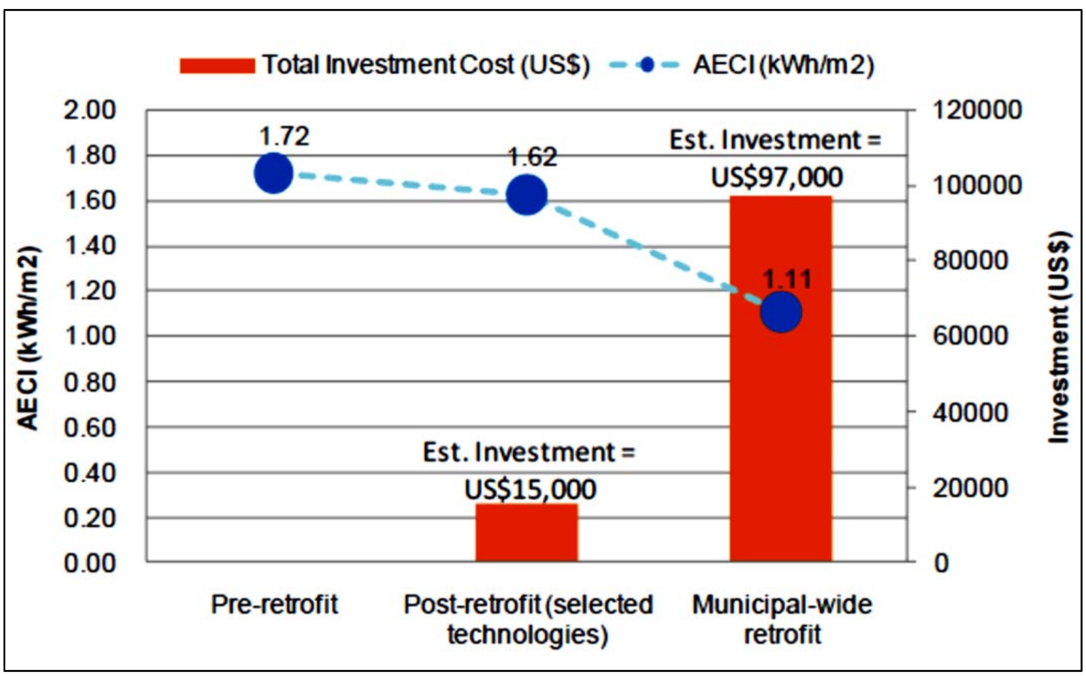

Figure 33 : Summary of AECI Improvements and Investment Required in Pathumthani Municipality

Conclusions and Recommendations

Technical and economic feasibility of LED street lighting

- Pilot demonstrations of LED technologies for street and outdoor lighting by PEA since 2011 have proven their technical viability. However, the key barriers hampering the future scaling-up of LED retrofits for street and outdoor lighting in PEA's service areas include: a lack of proper financial mechanisms; and limited capacity at the local government level to handle large scale projects.
- PEA's pilot projects have shown mixed results of useful life of LED luminaires. Some demonstration sites have successfully demonstrated LED luminaire useful lifetime of more than 30,000 hours (around 7 years). While some demonstration sites indicated useful lamp life of only around 10,000 hours.
- Retrofitting or replacing existing HID/FL luminaires with LED luminaires in PEA's service areas is considered to be cost-effective in meeting the illumination requirements specified by DLA and DOH. The average simple payback periods range from about 3 years to slightly over 6 years, depending on the tariff rate applied. It is envisioned that the payback periods for large-scale LED investment in PEA's service areas will be shorter due to lower unit costs from bulk purchasing.
- Large-scale implementations (installations of more than 10,000 luminaires annually) have also been successfully undertaken internationally. These implementation experiences have also confirmed that the cost of LED street lighting has been decreasing rapidly, and applying a bulk procurement approach could further reduce the unit cost of LED luminaires with extended warranties (5-7 years).
- DLA, DOH and PEA do not have any design guidance or recommendations on EE requirements for street and outdoor lighting. Therefore, there is a need to review international and regional experience and develop product and EE standards for LEDs for street and outdoor lighting, to promote adoption of LEDs by municipalities in the country.

M&V framework

- PEA has a very high metering rate for street and outdoor lighting. Savings from LED street lighting can be monitored through the electricity bills.
- The MRV framework for implementation of the EE street and outdoor lighting in Surabaya can follow the approved CDM methodology AMS.II-L (Demand-side activities for efficient outdoor and street lighting technologies), as it provides guidelines for measuring and calculating energy consumptions for both metered and non-metered light points, emission reduction, and lighting quality.

Impacts on the street lighting KPI

- The key performance indicators (KPIs) for energy efficiency performance street and outdoor lighting in Thai municipalities should address both power installed in watts and annual energy consumption (kWh). The lighting power density indicator (PDI) in watts/lux/m2 and the annual energy consumption indicator (AECI) in kWh/m2 are recommended as KPIs since they consider variations of luminaire installation (pole span and mounting height) when comparing different street and outdoor lighting technologies.
- Thai municipalities that partially adopted LED lighting technologies have AECI lower than 3 kWh/m2. However, replacing fluorescent tube lamps and MV lamps with LED tubes and LED luminaires can further reduce AECI to be lower than 2 kWh/m2. The investment per light point ranges between US$20 – 50 depending on the existing lighting technologies with an average payback period of less than 2.5 years depending on combination of LED technologies and wattages. Based on findings from various pilot demonstration projects, useful lifetime of LED technologies for street and outdoor lighting in Thailand can be up to 7 years.

Recommendations

Results and lessons learned from various pilot demonstration projects and availability of affordable quality LED lighting technologies have pave a way for PEA to scale-up implementation of energy efficient street and outdoor lighting in Thai municipalities. The following ways forward for the implementation are recommended for the consideration by PEA:

- PEA needs to collaborate with municipalities to initiate discussion with the national government (e.g., Ministry of Energy and Ministry of Finance) in creating an enabling environment for implementation of energy efficient street and outdoor lighting in Thai municipalities which will significantly reduce electricity subsidies currently shouldered by PEA.
- Retrofitting fluorescent tube lamps with LED tubes is recommended as the first priority measure for energy efficient street and outdoor lighting in Thai municipalities. A phase-step multi-year implementation plan for energy efficient street and outdoor lighting should be developed with listing of priority municipalities for each phase.
- PEA needs to collaborate with the priority municipalities in the first phase to verify street and outdoor lighting inventories, lengths, areas and classifications of roadways covered by street and outdoor lighting, annual electricity consumptions and lighting quality.

Concerned divisions / project related brief note to be included here

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