DEVELOPMENT OF MINIMUM ENERGY PERFORMANCE STANDARD FOR LED LAMPS IN SRI LANKA

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Degree of Master of Science

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Electrical Installations

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DECLARATION OF THE CANDIDATE & SUPERVISOR

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Prof. N. Wikramarachchi

23rd February, 2017

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D.S.P. Edirisinghe

ABSTRACT

Keywords: LED, Minimum Energy Performance Standard, Sri Lanka, Energy Efficient Lamps

Among the different techniques available for demand side management, replacement of energy inefficient lamps with energy efficient lamps plays a major role.

Due to the huge market competition existing in between the competitors and as a consequence of some manufacturers prioritizing cost reductions over quality, present lighting market of Sri Lanka is flooded with low quality LEDs. At the same time, unlike the star rating system for CFLs, at present there is no proper guideline for the consumers to be used in their buying decision. Hence, this research was intended in developing a Minimum Energy Performance Standard for direct replacement type LEDs sold in Sri Lankan Market.

The market prices of LED lamps required for this study were obtained from a market survey by visiting a few vendors. Coincidence factor required for the cost-benefit analysis was derived based on a theoretical calculation using the available data from sources like SLSEA, CEB, and PUCSL & ADB Household survey on lighting.

Sensitivity analysis carried out during this study show how the minimum efficacy bar varies with the market prices under different coincidence factors.
However, it is suggested to perform a small sample survey to verify the accuracy of the coincidence factor taken.

Major Findings of this research include justification to values of technical parameters such as efficacy and power factor of an LED lamp decided in initiating Minimum Energy Performance Standard by the relevant authorities responsible and the payback period of such a national level replacement project. This study also reveals the cost incurred by an individual consumer per light output (in Lumens) when the inefficient lamps like incandescent bulbs of his household are replaced with LED lamps.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
CCT	Correlated Color Temperature
CEB	Ceylon Electricity Board
CFL	Compact Fluorescent Lamp
CLASP	Collaborative Labeling and Appliance Standards Program
CRI	Colour Rendering Index
CF	Coincidence Factor
C&F	Cost & Freight
DSM	Demand Side Management
EISA	Energy Independence and Security Act
EnMAP	National Energy Management Plan
HFO	Heavy Fuel Oil
HH	Households
IB	Incandescent Bulb
IEA	International Energy Agency
IPP	Independent Power Producers
LECO	Lanka Electricity Company
LED	Light Emitting Diode
LKR	Sri Lankan Rupees
MEPS	Minimum Energy Performance Standard
NCRE	Non-Conventional Renewable Energy
PF	Power Factor
PUCSL	Public Utilities Commission of Sri Lanka
RCL	Regional Center for Lighting
SLSEA	Sri Lanka Sustainable Energy Authority
TWh	Terra Watt Hours
UNEP	United Nations Environment Programme

1 INTRODUCTION

The term ‘Energy Crisis’ is not any more a strange term to the world. The day by day the world is approaching the day when mankind could find the last drop of crude oil. Meanwhile a huge resistance stands against the thermal power generation due to global warming as explain by many environmentalists. On the other hand, power generation through NCRE (Non-Conventional Renewable Energy) sources has become an enormous burden especially to a developing country like Sri Lanka due to the high costs involved. All these incidents imply nothing but the need for the conservation of energy. In this context, energy efficiency plays a major role. In view of this, the issue ‘Energy Efficiency’ stands at the ‘Need for Action’ quadrant (bottom right quadrant) of the Global Energy Map of 2015 prepared by World Energy Council. Those issues have been correctly defined as ‘high-impact and low-uncertainty’ since these issues keep energy leaders in the world busiest. [1]

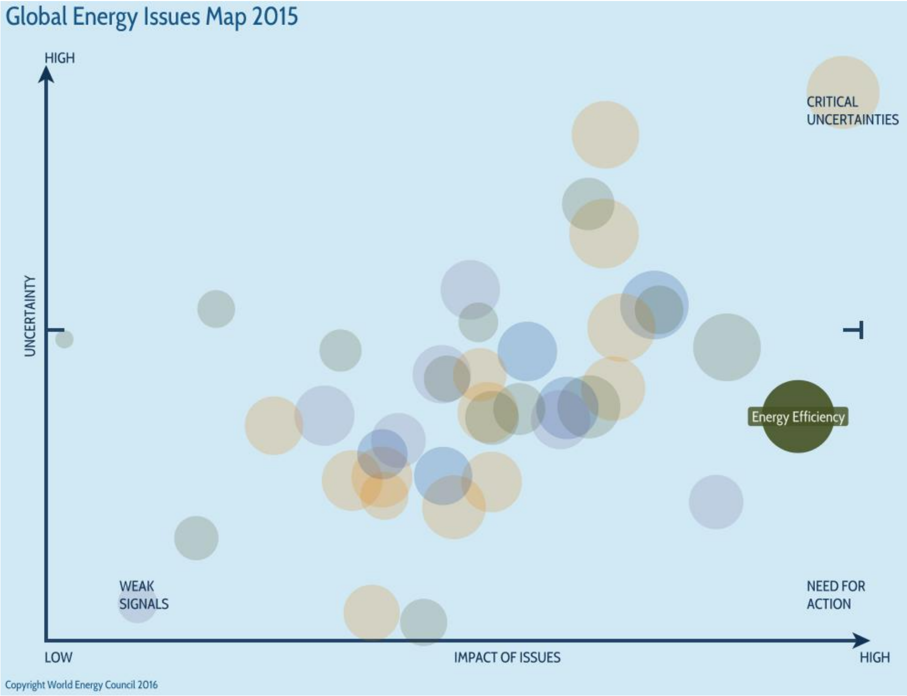


Figure 1.1: The Standing of 'Energy Efficiency' in Global Energy Issues Map 2015

Source: Website of World Energy Council

In order to overcome this challenge, the need of finding a contemporary solution has become crucial. The invention of LED lighting is one of the significant milestones and it has made a revolutionary impact to the world where energy efficiency is a matter of the utmost importance.

Today, LED lighting has become the most energy-efficient and rapidly-developing lighting technologies in the world. Latest developments in the field of LED lighting have been able to surpass the LED chip efficacy level of 150 lm/W.

Primary energy is defined as the energy embodied in natural resources, like coal, oil, sunlight, uranium etc. that has not been subjected to any conversion or transformation process. According to the study report on ‘Life Cycle Assessment study’ done by Osram, primary energy consumption of IB over the entire life (including manufacturing, use and end of life) is around 3302 kWh whereas LED and CFL use around 667 kWh. This implies that over the life of 25,000 hours the IB consumes 1000 kWh, while the CFL and the LED lamp merely consume 200 kWh of electricity, which makes 80% saving in electricity consumption. [2]

According to the United Nations Environment Programme (UNEP) estimation, replacing all the inefficient on-grid lighting globally with innovative, energy efficient alternatives would result in more than 1,000 TWh of electricity savings annually, which is equivalent to the annual electricity use of India and Mexico combined. Further this electricity savings is equivalent to be more than \$120 billion in avoided electricity bills and the reduction of over 530 million tonnes of CO_2 annually[3]

Further, as per the International Energy Agency findings, energy efficiency measures can help countries achieve nearly half of the greenhouse gas emissions reductions necessary to put the world on a $2^{o}C$ pathway by 2020.[4]

Figure 1.2: Different types of LED lamps used in the residential sector

Source: Website of U.S. Department of Energy- http://energy.gov/

Energy efficiency through Demand Side Management (DSM) is a current affair which is taking place globally immensely. DSM is directly linked with energy labeling, performance standards of the appliances used. At present, different countries have adopted & implemented different kind of policies and measures in order to accommodate a better quality, efficient products within their country. Banishment of IBs & introducing of 'Energy star program for solid state lighting' are such initiatives taken by US Environmental Protection Agency, which set platform to strict adherence of energy efficient guidelines within US.

Similarly, 'Energy labelling for electrical lamps & luminaires' has been implemented by EU commission with the objective of energy saving of around 175 Mtoe by 2020 and to help consumers choose energy efficient products.

Further, A performance standard for LEDs & Solid State lighting has already been implemented in countries like China, Japan, Singapore, Switzerland, Mexico etc & label endorsements are being used in nations like Australia, New Zealand, Canada, India etc.

1.1 Introduction to MEPS

MEPS (Minimum Energy Performance Standard) are regulatory measures that stipulate minimum efficiency levels or maximum energy-use levels acceptable for products sold in a particular country or region. For lighting, MEPS contributes to phasing –out of least efficient lamps in a market by setting the minimum levels of energy efficiency that a lamp must meet before it is sold in the market. MEPS for lighting may apply to all lamp products sold in a market, whether imported or manufactured domestically. It can either be technology neutral or technology specific. (Eg: applies only to a lamp technology such as LED). Very often lamp MEPS consists of a requirement relating to luminous output per unit power input, (measured in lm/W). It can also contain parameters like, Colour Rendering Index (CRI), lamp lifetime etc.

One of the key notes to consider in developing a MEPS scheme for a particular product is that it should not become an additional burden to the economy of the country. If a country chooses to adopt MEPS that are not compatible its neighboring markets, this decision could increase cost & restrict the availability of energy efficient lamps. [3] On the other hand, it should not be too loosen to make room for low quality products to enter into the market.

1.2 MEPS in Sri Lankan Context

Sustainable Energy Authority of Sri Lanka (SLSEA) which is the National Energy Agency of the country, has launched many programs and established some regulations in achieving the National targets on energy efficiency within the country.

According to World Energy Council database, ‘Promoting Energy Efficiency Improvement in Sri Lanka’ is one of the official programs launched by SLSEA, in achieving National Targets on energy efficiency.

National Energy Management Plan (EnMAP) from 2012-2016 is an initiative implemented by SLSEA to accomplish the above mentioned National Target. It is targeted in achieving an energy saving equivalent to 20% of the total energy consumption of year 2010, by 2020 through EnMAP. The overall objective of EnMAP is to enhance the economic activity of the country without forcing an additional burden on the energy sector. [5]

The EnMAP launched by SLSEA has 4 facets namely;

I. Regulatory Interventions
II. Energy Efficiency Services
III. Enhancing Awareness on energy conservation
IV. Facilitating Funding Schemes for Energy Efficiency Improvement

the scope of which is to support energy efficiency improvement and conservation in all sectors, namely industrial, commercial and domestic consumer categories. [5]

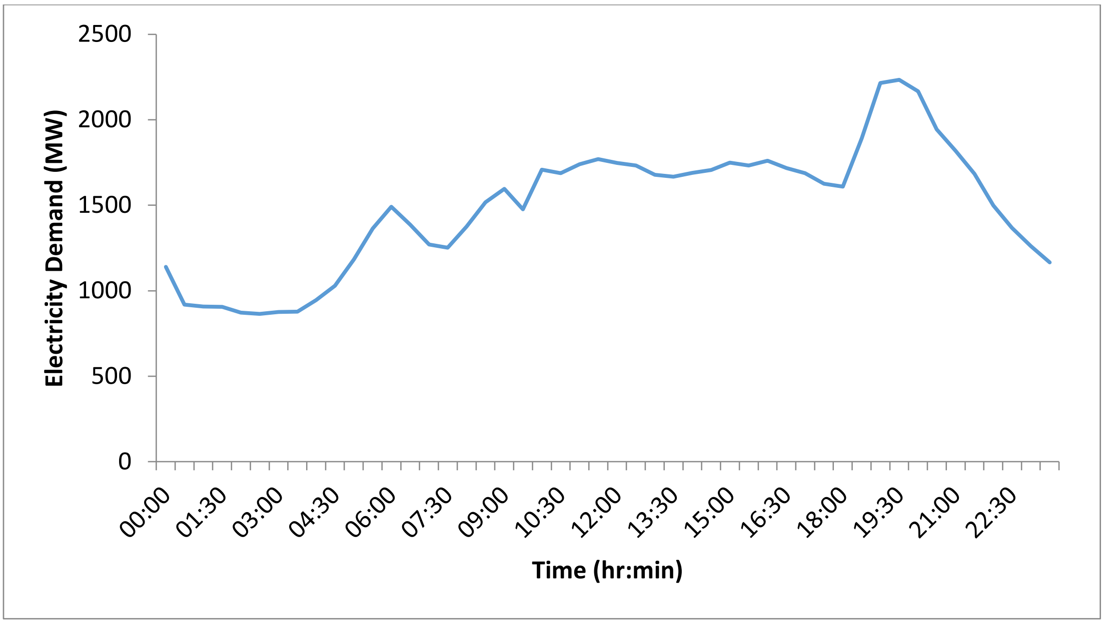


Figure 1.3: Daily Load curve of Sri Lanka (June 2016)

The daily load curve of Sri Lanka (2016- June) is shown in Figure 1.3. The morning peak (between 0500 h and 0700 h) and the evening peak (between 1800 h and 2100 h) of the load curve are mainly dominated by lighting load. Since Sri Lanka is not an industrialized country, around 20% of the morning peak & around 50% of the night peak is contributed by lighting. [6] The total lighting profile of the country basically consists of IBs, Linear Fluorescents, CFLs and LEDs.

A National Survey on Household Lighting was carried out by EnergySolve International (Pvt) Ltd., Sri Lanka with the aid of Asian Development Bank (ADB) in 2011. The national survey covered assessing lighting consumption of over 3000 households in each of the consumption categories (less than 90kWh per month, 90 – 180kWh per month and over 180kWh per month) by type of technology used, location of use, wattage of each lamp and average hours of use per day. [7]

From the data gathered by this survey, the lighting profiles of each consumption category considered (for 2011 year) were developed.

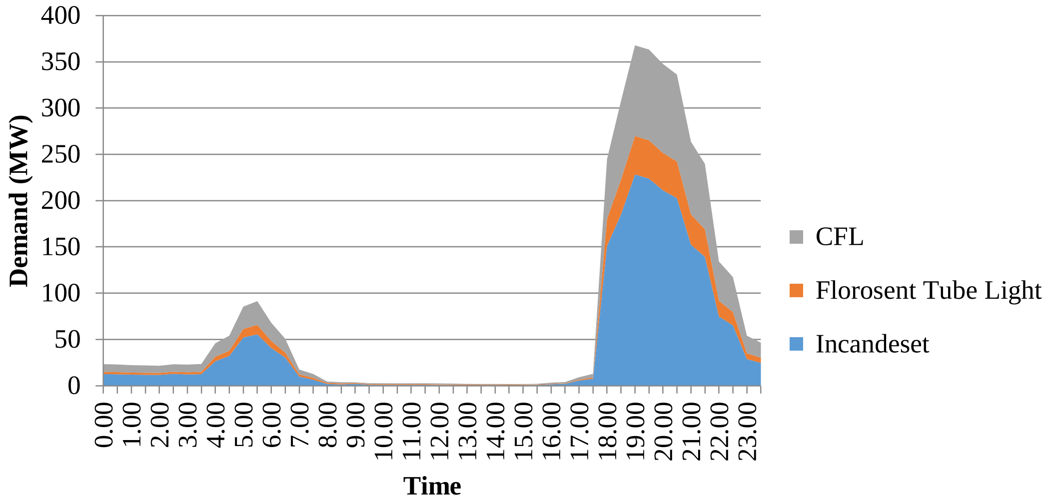


Figure 1.4: Trend analysis on total lighting consumption in residential sector - 2011 (less than 90 units category)

(*Source: National Survey on Household Lighting – 2011)*

Figure 1.4 shows the trend analysis of total lighting consumption of residential sector for the less than 90 kWh per month category. As figure illustrates, in this category, the incandescent lighting dominates both morning & evening peaks.

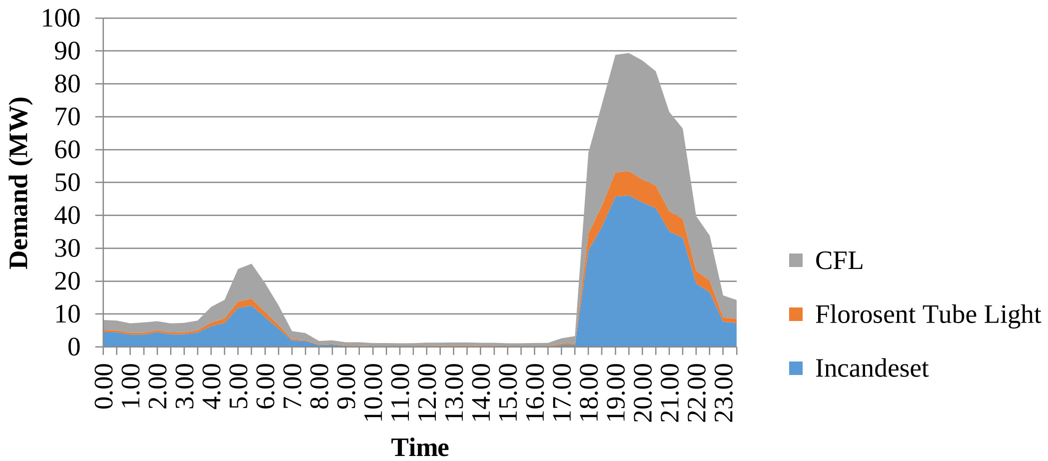


Figure 1.5: Trend analysis on total lighting consumption in residential sector - 2011 (91-180 units category)

(Source: National Survey on Household Lighting – 2011)

Illustration of lighting consumption for the 90 – 180kWh per month category is shown in Figure 1.5. It is seen that for this consumption category, there is an equal contribution from IB & CFL during two peaks.

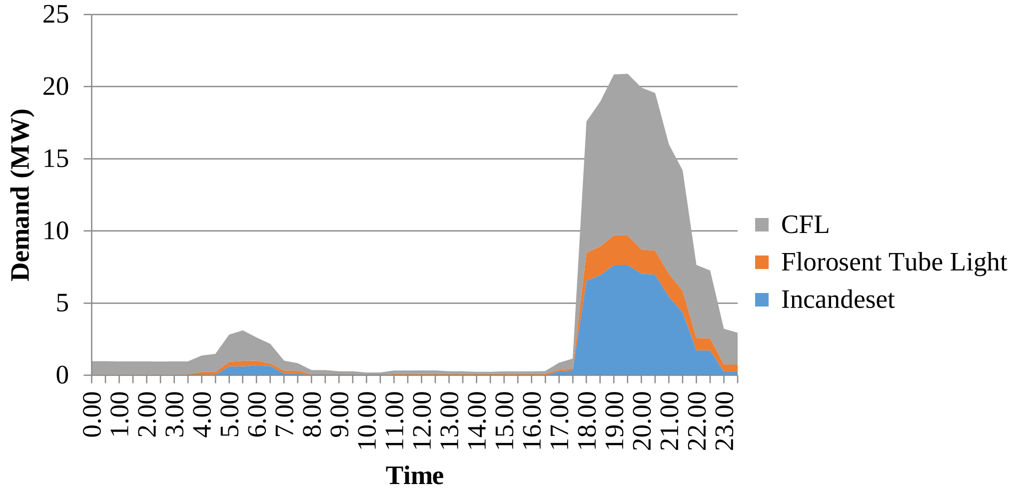


Figure 1.6: Trend analysis on total lighting consumption in residential sector - 2011 (above 180 units category)

(Source: National Survey on Household Lighting – 2011)

Figure 1.6 explains the types of lighting used by consumers belong to above 180 kWh/month consumption category. In this category, CFL is dominating the load as anticipated.

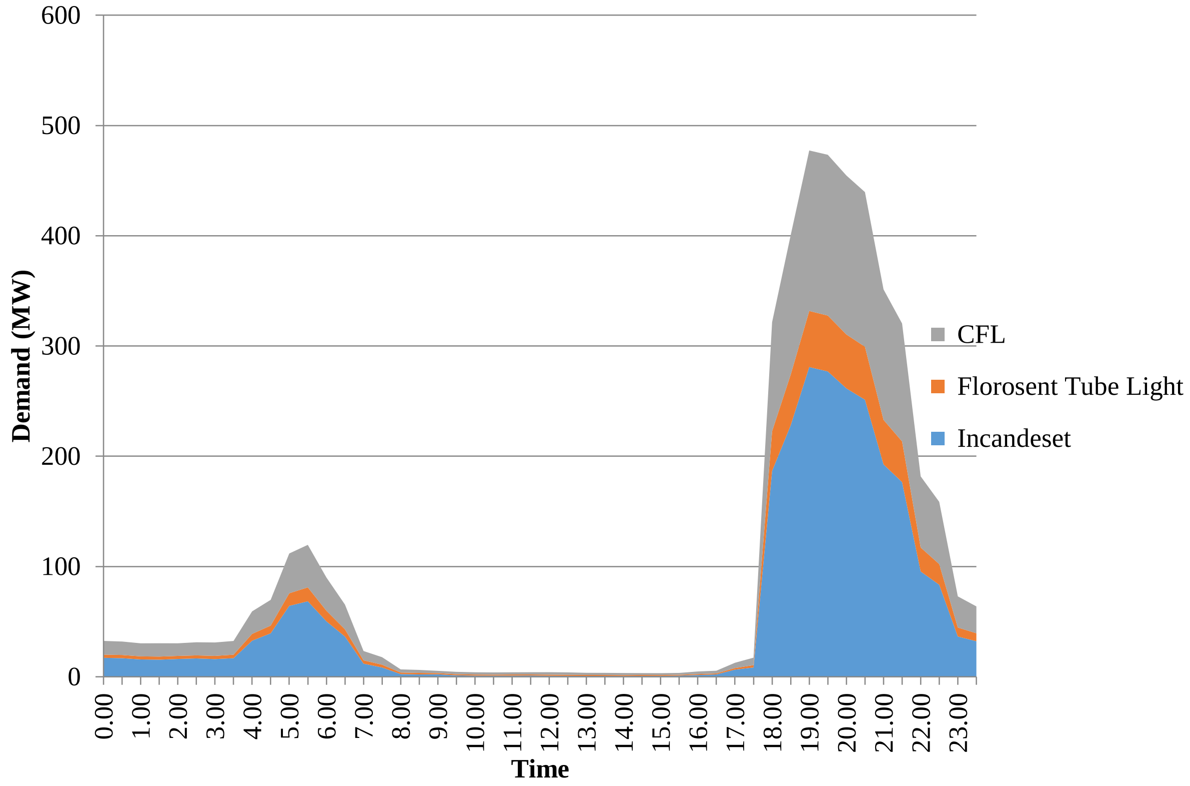


Figure 1.7: Trend analysis on total lighting consumption in residential sector - 2011 (Consolidated)

(Source: National Survey on Household Lighting – 2011)

The overall pattern of use of lighting according to their types is illustrated in Figure 1.7. As the figure shows, the overall contribution of incandescent is still higher than any other technology.

In today's context, the general public is moving towards energy efficient lamps from the inefficient light sources like incandescent lamps whose efficacy is around 10 lm/W. CFL was the most popular energy efficient lamp among Sri Lankans until the latest new comer LED, comes into the picture in late 2013. Nevertheless, a handful of people have moved to LED from Incandescent or CFLs. Despite the high initial cost, the benefits of LEDs are massive. Higher efficacy, longer lifetime, light dispersement (to a specific direction) and ecological friendliness (free of Hg) are a few of them.

In year 2000, energy labeling (Star- Rating System) for CFLs was introduced by Sustainable Energy Authority of Sri Lanka, which was not mandatory at the period of introducing. Government gazette notification No. 1611/10 of July 22, 2009 was published to made the energy labeling for CFLs mandatory and to stipulate 'Minimum Energy Performance Standard' (MEPS) with the product.

1.3 Problem Statement

1.3.1 Need for MEPS

Due to the huge market competition existing in between the competitors and as a consequence of some manufacturers prioritizing cost reductions over quality, present lighting market of Sri Lanka is flooded with low quality LEDs. At the same time, unlike the star rating system for CFLs, at present there is no proper guideline for the consumers to be used in their buying decision. Consumers are generally not well aware of the lamp characteristics and lighting design terminologies. Selection of lamp or luminaire is done on the basis of power consumption (Watts), rather than considering how much illuminance level (lux) they will receive on a given area [8]. Hence introducing a proper guideline to choose LED has become a contemporary need which is urgently needed to be addressed.

Not only that, but also when supporting country's National target of reducing the consumption of 2020 by 20% of 2010 through EnMAP of SLSEA, the introducing of a Minimum Energy Performance Standard Scheme for LEDs has become vital.

1.3.2 Economic aspects of MEPS

This study brings out several conclusions on the benefits of implementing MEPS. Economic analysis done shows the positive outcomes such as reduction of night peak of the load curve that could achieve by phasing out of inefficient lamps through a successful implementation of MEPS scheme for LEDs.

1.3.3 The process of developing MEPS

This study helps the data acquisition & analysis parts required in the intermediate steps 4, 5 & 7of the process developing MEPS in a country. Figure 1.8 illustrates the process in developing & implementing MEPS program in a country.

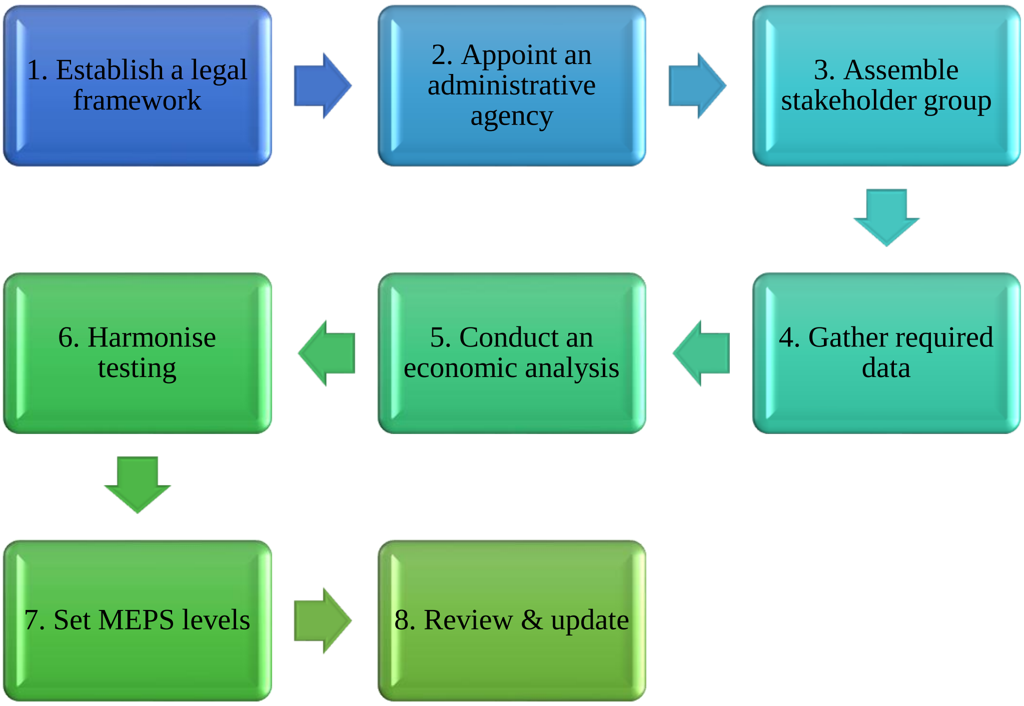


Figure 1.8: Flow diagram illustrating the process of developing lamp MEPS

Source: United Nations Environment Programme, "Developing Minimum Energy Performance Standards for Lighting Products - Guidance note for policy makers", 2015.

Data gathered during the study such as information on the market, technology, engineering & usage of products etc. will be used in step 4 in the above process. Economic analysis conducted in this research will be required in step 5, which implies the cost-effectiveness analysis to determine the appropriate level of ambition for the regulatory measure. Conclusions & findings of this research will help implementing step 7, which suggests determining the technically feasible, economically optimal regulatory level of MEPS.

1.4 Objective

The objective of this study is to develop a suitable MEPS scheme for direct replacement type (E27, E14 and B22 base type) LED lamps which are basically used by domestic consumers in Sri Lanka and validating of the proposed MEPS by economic analysis for a National level replacement project.

1.4.1 Specific Objectives

i. Develop a well-defined set of Minimum Energy Performance Standard (MEPS) for LED Light bulbs to be used in Sri Lanka for general indoor lighting.
ii. Determine the National cost in implementing the above MEPS gradually in discrete steps.
iii. Perform a cost-benefit analysis of implementing MEPS at different performance levels
iv. Suggest using the above results, the most suitable strategy for implementing a MEPS scheme for LED lighting in Sri Lanka.

2 LITERATURE REVIEW

2.1 Role of lighting in today's context

In a century, where the whole world is experiencing the decaying of non-renewable energy sources like crude oil, natural gas and coal, each and every part of the world tries to work align with sustainable development. When addressing this crucial issue, demand side management plays a vital role.

Among the different techniques for reduction in power consumption, replacement of energy inefficient lamps with energy efficient lamps plays a major role [8]. Various studies have revealed that the lighting constitutes a significant portion in the country's total electricity consumption. As per the Swedish Energy Agency report, the lighting portion in the country is around 23% of the total electricity consumption and during the last decade, the electricity used by the households in Sweden has been doubled[9], [10]. Similarly, illumination is the second largest electric power consumption in Malaysia [11]. United States, Department of Energy report describes that in U.S., 18% of the total electricity consumption in 2010 is contributed from lighting. [12]

In Sri Lanka, total contribution to evening peak by lighting will accounts around 44% and the same for morning peak is around 21% [6]

Residential or domestic lighting load majorly contributed by the loads of IBs , CFLs and linear fluorescents and minority from LEDs.

From the survey carried out in 2011, it was observed that in less than 90 kWh/month category in Sri Lanka, 42% of installed lamps are incandescent and the same for the category between 90-180 kWh/month is 40%. The unexpected fact is that, the heavy user category which is the category using more than 180 kWh/month also consumes a substantial percentage, which is 37% from incandescent lighting. [7]

It is obvious that, as at today also there is a considerable no. of IB users exist in all three consumption categories, majority from less than 90 kWh/month category.

Lighting is responsible for consuming a substantial volume of world energy resources. It has consumed 7.2% of the developed world's primary energy resources and hence it was responsible for 430×10^3 kg of CO_2 emission in 2011 [8]

2.2 Barriers for implementing energy efficient lamps & a need for a standard

At present, consumers have a very little knowledge of lighting, lamps and their terminologies (for example lamp efficacy, lamp lifetime and etc). They generally compare the lighting lamps on the basis of power consumption (watts), rather than considering how much illuminance level (Lux) they will receive on a particular area, which could be misleading [8]

In Sri Lanka also, from the National Survey on household lighting which was carried out in 2011, the main reasons for not purchasing energy saving lamps have been evaluated against five major reasons – high cost, not suitable for fittings, low light quality, not reliable and not freely available. Results show that the 'considerable high cost of energy efficient lamp' is the major barrier for 70% households belong to less than 90 kWh /month. 62% from the category between 90-180 kWh/month have given the same answer as their barrier for not purchasing energy saving lamps. [7]

However, it is also important to note that around 4% and 7% from the lower consumption category (<90 kWh/month) have stated that respectively low light quality and the non-reliability (shorter life than claimed) as their reason for not buying efficient lighting products. From the respondents of the category between 90-180 kWh/month, these figures stand at 8% and 15% respectively which are significant values to consider. [7]

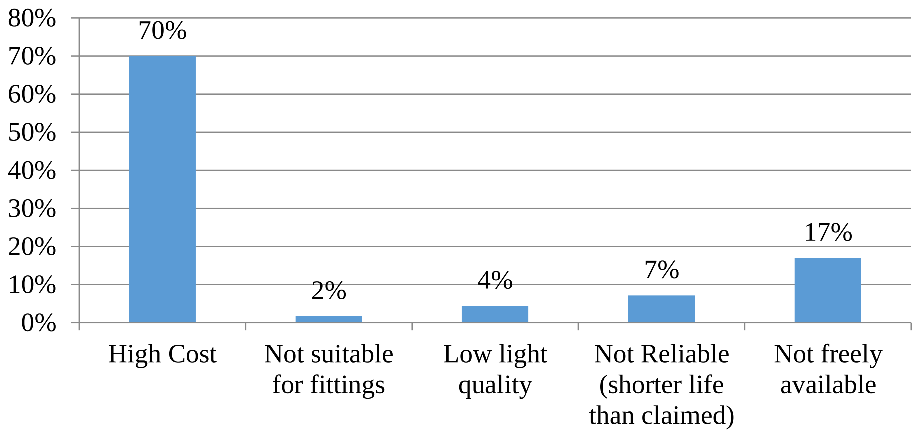


Figure 2.1: Reasons for not purchasing of energy saving lamps in less than 90 unit category

(*Source: National Survey on Household Lighting – 2011)*

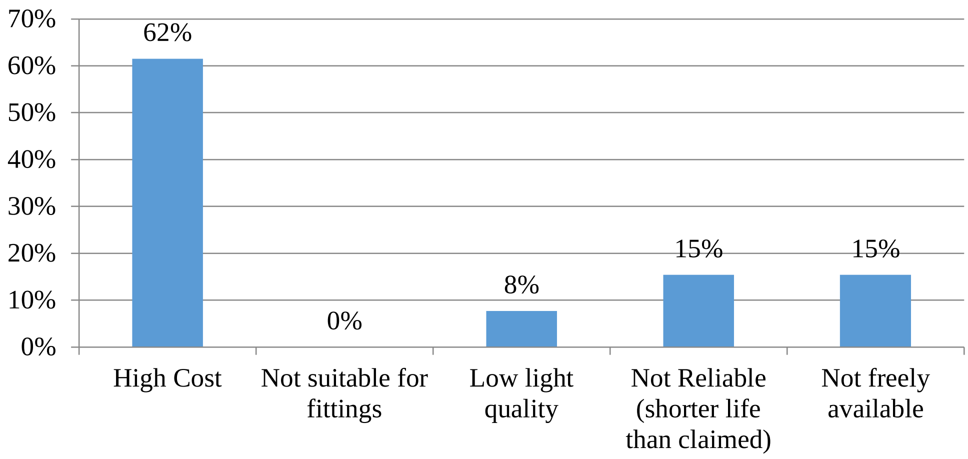


Figure 2.2: Reasons for not purchasing of energy saving lamps in 90-180 unit category

(*Source: National Survey on Household Lighting – 2011)*

2.3 Research work carried out in SL with reference to lighting

When going through the past research work carried out in Sri Lanka with reference to lighting, only a very few literature can be found out.

One such literature describes the use of LED in Street Lighting system in terms of energy efficiency and optimality with the aid of 'lighting reality' software. It evaluates what the most suitable energy efficient lighting system for Sri Lanka is, in street lighting sector with the aid of 'Lighting Reality', simulation software to evaluate better street lighting options. This study has revealed the Sri Lanka's energy consumption of 150 GWh (at 2010) would be reduced by over 1/3 by replacing existing lamps with LED lamps. [13]

The research works based on the title of 'The design of a sustainable efficient lighting program for Sri Lanka' proposes to maximize the usage of existing capacity of lighting by introducing a sustainable lighting program to popularize energy efficient lighting among consumers. The study reveals that the most economically effective method to achieve the objective is to introduce compact fluorescent lamps among the consumers. It is also found that the total saving for CEB would be LKR

12.05 billion, if each consumer has replaced one incandescent lamp in their home with a CFL [14]

Another study has done to suggest energy efficient lighting design for 'National Archives Building of Sri Lanka'. The study has proposed that the luminaries with the T5 fluorescent tube provide the opportunity to reduce electricity consumption & better illumination. [15]

2.4 Worldwide available standards for LED lighting

It is understood that the lighting plays a major role in world electricity consumption. Further reference to support this statement is that lighting is responsible for 19% of the world's electricity consumption and constitutes 7% of global carbon dioxide (CO_2) emissions as per the International Energy Agency (IEA), 2006. Hence, governments obligate to play a pivotal role in adopting energy efficient lighting measures in their countries, including the implementation of more actions around regulatory measures, labeling etc. [16]

Collaborative Labeling and Appliance Standards Program (CLASP) has done a comprehensive review of MEPS and regulatory measures like labeling, performance and quality requirements with regard to LED in regions such as USA, Asia-Pacific, China, Europe, India, Latin America etc.

Program	Performance Standard
China GB/T	GB/T 24908-2010: performance requirements for self-ballasted LED lamps for general lighting; GB/T 24823-2009: performance requirements for LED modules for general lighting;
Efficient Lighting Initiative (ELI)	ELI Voluntary Technical Specification for Self-Ballasted LED Lamps for General Lighting Services
EU	EU 244/2009; EC JRC LED Quality Charter
IEC	IEC/PAS 62612: Performance requirements for self-

	ballasted LED lamps for general lighting
UK Energy Savings Trust	EST LED Lamps and Modules V2.0
US ENERGY STAR	ES Program Requirements for Integral LED Lamps V1.3

Table 2-1: Summary of existing LED related standards and voluntary labelling

(*Source: Assessment of Opportunities for Global Harmonization of Minimum Energy Performance Standards and Test Standards for Lighting Products, CLASP 2011)*

The product scope of all the above mentioned standards focuses on self-ballasted, direct replacement type LED lamps (with standard E27 or B22 type caps) of which rated wattage is up to 60W, out of many different configurations of LED available in the market.

Regarding the wattage requirement, except EU standard and US Energy Star labeling scheme all other standards define a wattage range as $\pm$15% from the rated wattage. UK EST allows up to 25% variation. Similarly for the luminous flux requirement China GB/T, ELI and IEC define a lower bound of 10%; i.e. measured value shall be greater than 90% of the rated value. Both EU standard and UK EST don't specify any limit and US Energy Star defines a minimum initial light output based on the wattage of the lamp.

All standards allow lamps of CCT from 2700K up to 6500K and their color coordinates are of the same as IEC/PAS62612. Almost all the above mentioned standards define a CRI value of greater than 80. Apart from this, IEC requires two measurements for CRI which are taking at initial level and at 25% of rated lamp life. In order to comply with IEC standard, these measurements shall not decrease by more than 5 points from the rated CRI value.

The requirement for the power factor varies from standard to standard. China GB/T specifies the requirement as actual value of PF not to be smaller than rated value by over 0.05 whereas ELI voluntary specification and EU standard requires that the PF to be greater than or equal to 0.5. UK EST defines the PF value depending on the class (basically on voltage level) and it places the most stringent requirements on power factor. Energy Star initiative defines a PF of 0.7 for the lamps of wattage greater than 5W and no PF requirement is specified for lower wattages. In contrast to above all, IEC defines no PF requirement despite of the wattage.

Efficacy outwardly is one of the most important parameter of a light source. The ELI and China GB/T establish a separate efficacy requirement based on the classification of LED lamp products depending on wattage and CCT rating. US Energy Star program defines a minimum value for lamps of wattage greater than 10W and another value for lamps of wattage lesser than 10W. EC JRC quality charter (EU standard) specifies a complex requirement which is related with CRI as well as the directional property of the lamp (based on directional or non- directional). Not only that but also EU standard defines target values for efficacy from 2011 to 2015. (How the efficacy should be improved by 2015). As per the UK EST, LED products shall have a rated wattage no greater than 25% of any lamp it is claimed to replace. Again similar to PF requirement, IEC defines no efficacy requirement too.

In addition to these major parameters, Lumen maintenance, Lamp lifetime, EMC/EMI/Harmonics requirement & Switching withstand test requirements have also been addressed in these standards and voluntary labeling schemes.

3 METHODOLOGY

The methodology which was carried out during the study is illustrated as follows:

1. Collecting of electrical & optical data of available LEDs in Sri Lanka Market
2. Obtaining of the market price of each lamp in the sample
3. Developing of probable set of MEPS bars
4. Calculating the annual cost (to the consumer) per 1000 Lumen for each sample.
5. Calculating the national level cost and the saving of energy by LED lamps at different MEPS bars.
6. Proposing a suitable MEPS scheme using cost benefit analysis
7. Sensitivity Analysis

3.1 Collecting of electrical and photometric data

A database of photometric and electric test data of ninety five samples of direct replacement types (E27, E14 or B22 base) LED lamps which are available in Sri Lankan Market were obtained from Regional Center for Lighting (RCL) of Ceylon Electricity Board. (Appendix 1)

Measured test parameters and some major observations are mentioned in data acquisition & verification chapter (Chapter 4). One such major observation made during the testing of the samples was that the ‘Power Factor’ of the most of the samples is in a very low range. It was observed that more than 50% of the samples are having power factors less than 0.5. (Figure 4.2)

3.2 Estimating the market price

Average price of a direct replacement type LED lamp was obtained by visiting around 15 vendors in the market. It was observed that lamps which possess a better power factor (>0.8), is comparatively expensive. Price of a lamp varies basically with the wattage and the power factor. Branded lamps obviously had a better power factor as well as they were in the high cost range. Prices were in the range of LKR 175.00 – LKR 1,650.00

3.3 Developing of probable set of MEPS bars

When developing this probable set of MEPS bars, initially, a set of MEPS bars were developed tentatively as a baseline for this study.
Following considerations were taken into account.

1. The key objectives of introducing MEPS criteria
2. Quality of light given by an LED lamp
3. Effects to the power quality by introducing the proposed MEPS scheme

It was noted that more than 50% of the tested samples are having very poor power factors. It was also noted that THD of most of these samples (lamps which have got poor power factors) is very high (More than 100%). Hence Power Factor was taken as a key measurement in deciding MEPS Bars.

One of the key objectives of introducing MEPS is to efficiently replace existing inefficient lamps. Hence, efficacy (lm/W) value is another obvious consideration.

Colour rendering Index (CRI) is another important parameter of a light source. It is a measure of a light source's ability to show object colors "realistically" or "naturally" compared to a familiar reference source, either incandescent light or daylight. A CRI of 100 represents the maximum value. Lower CRI values indicate that some colors may appear unnatural when illuminated by the lamp. [17]

It is usually maintained at a minimum of 80, in order to perceive the correct colors and to avoid that some colors may appear unnatural. **Hence, it is suggested to maintain the CRI at value 80 or higher.**

Since the CRI of tested lamps are already within the specified limit, only the **Power Factor** and the **Efficacy** of each tested lamp were checked in order to find qualified samples under 6 different combinations of MEPS bars. The qualified samples under each MEPS bar were sorted out using excel Macro. (Appendix 2)

3.4 Calculating the annual cost (to the consumer)

Annual cost that has to be borne by an individual customer consists of two cost components; capital cost and the energy cost. Based on the market price of the sorted out samples, and also using the average life time of the lamp and the average usage of lamp(in no. of hours), the capital cost was calculated. The energy cost incurred by the customer was obtained using the wattage of the lamp, approved tariff and the average no. of hours of usage of lamp.

Equation 3.1: Annual Capital Cost

$$\text{Annual capital cost} = \frac{\text{Price of LED lamp (LKR)} \times \text{Average no. of hours of burning (hrs.)} \times 365}{\text{Average Lifetime of an LED lamp (hrs.)}}$$

Equation 3.2: Annual Energy Cost

$$\text{Annual energy cost} = \frac{\text{Wattage of LED lamp (W)} \times \text{Average no. of hours of burning (hrs.)} \times \text{Approved tariff} \left(\frac{\text{LKR}}{\text{kWh}}\right) \times 365}{1000}$$

$$\text{Total Annual cost} = \text{Annual capital cost} + \text{Annual energy cost}$$

The variation in Annual Average cost per 1000 lumens (to the individual customer) for different power factors, for a given efficacy bar is shown in Figure 5.7, Figure 5.8 and Figure 5.9

Similarly, the variation in Annual Average cost per 1000 lumens (to the individual customer) for different efficacy bar, for a given power factor is shown in Figure 5.10, Figure 5.11 and Figure 5.12.

3.5 Calculating cost and the saving of energy at different MEPS bars

The National level saving due to introduction of MEPS bars was determined using the data gathered by the National Survey on Household Lighting which was carried out by the aid of Asian Development Bank (ADB) in 2011. The national survey covered assessing lighting consumption of over 3000 households in each of the consumption categories (less than 90kWh per month, 90 – 180kWh per month and over 180kWh per month) by type of technology used, location of use, wattage of each lamp and average hours of use per day. [7]

3.5.1 Obtaining of total lighting load

The sample survey data collected during the household lighting survey was extrapolated to the total domestic consumer cluster for the year 2014 and 2016 using the data in order to obtain the total lighting load of the country. (Table 4-1)

When extrapolating 2011 survey data to 2014 and 2016 following assumptions were made:

i. 30% of incandescent lamps that were available in 2011 have been converted to CFLs by 2014
ii. 40% incandescent lamps that were available in 2011 have been converted to CFLs by 2016

In general, when replacing an existing incandescent lamp with a CFL, people try to match the amount of light (luminous flux) which was already given by the incandescent lamp. Hence in the conversion of incandescent lamps to CFLs, the equivalent CFL was found using the below method:

Equation 3.3: Wattage of CFL

$$\text{Wattage of CFL} = \frac{\text{Luminous Efficacy of incandescent lamp} \times \text{wattage of incandescent lamp}}{\text{Luminous Efficacy of CFL}}$$

The efficacy values of IBs and CFLs were taken from datasheets of a few manufacturers and also from the facts published by Lighting Research Centre (LRC), United States. (Table 4-2 and Table 4-3 show the efficacy values of IBs and CFLs respectively.

3.5.2 Coincidence Factor (CF)

Not every single lamp installed at a domestic consumer's premises is used at a given time, but a few of them. The ratio of the 'Total Lighting Load (domestic)' which is contributed to the system demand at a given time to the 'Total Installed Lighting Load of the domestic sector' at the same time is defined as the term 'Coincidence Factor', CF.

Equation 3.4: Coincidence factor

$$\text{Coincidence Factor} = \frac{\text{Domestic Lighting Load contributed to the System Demand}}{\text{Total Installed Domestic Lighting Load}}$$

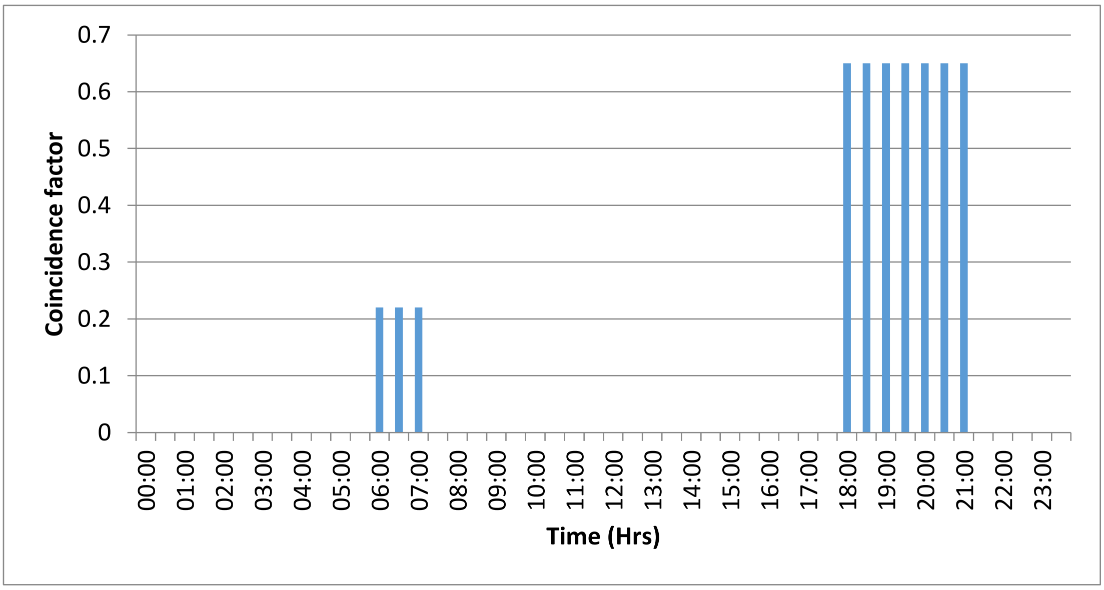


Figure 3.1: CF taken over a day for an average household

The CF can vary depending on each consumption category. Lower consumption category (less than 90 kWh/month category) tends to have a higher CF and a higher consumption category (more than 180 kWh/month category) supposes to have a lower coincidence.

3.5.3 Cost of Supply

In order to find the saving, it is needed to find the cost of supply. Cost of supply is defined as the total cost incurred by the utility to generate, transmit and distribute a unit of electricity to a domestic consumer, and to maintain his account.

This figure was obtained with the aid of 'Decision Document on Electricity Tariff 2011' [18] and the CEB Statistical Digest 2014 [19]

As the SL pricing model by PUCSL which was used in above decision document on electricity tariff 2011 is not used anymore since 2011, 2014 figures were derived assuming the split of the cost for different customer categories will be the same as of 2011. i.e.,

$$\frac{\text{Unit cost of Supply to HH}}{\text{Overall unit cost of Supply}}_{2011} = \frac{\text{Unit cost of Supply to HH}}{\text{Overall unit cost of Supply}}_{2014}$$

Therefore,

Equation 3.5: Cost of Supply to Households

$\text{Unit cost of supply to HH}_{2014} =$

$$\frac{\text{Unit cost of supply to HH}_{2011}}{\text{Overall unit Cost of Supply}_{2011}} \times \text{Overall unit Cost of Supply}_{2014}$$

Similarly, cost of supply to HH in 2016 figure also found using total cost of supply in 2016 value.

Share of costs

The figure 'Cost of Supply to HH' comprised of three different components; namely: Capacity cost, Energy cost and Customer related cost.

Capacity cost is the fixed expense incurred by the utility in order to provide the electricity supply to the customers. For example, Independent Power Producers' (IPP) Capacity payment; Depreciation allowed for CEB Power Plants, Interest payments of the loans obtained, Operational & Maintenance costs of transmission and distribution assets such as Breakdown services in distribution services etc.

Energy cost means purely the cost involved for the energy source. For example; cost incurred in importing coal.

Customer related cost is basically the cost borne by the utility to maintain a customer account. That is, the costs involved in fixing a meter, monthly reading of the meter, issuing of a bill and maintaining the account up to date.

When customers are adopting some measures like implementing of net metering by solar energy during daytime, the cost component which is directly saved by the utility is the 'Energy cost'. Similarly when people practice energy efficiency measures like converting inefficient lighting to efficient lighting such as CFLs, LEDs, it is the energy cost that is directly saved to utility, considering the short term. Even though, when long term is considered, obviously there is a saving in the capacity cost component as well.

Hence, the financial saving gained due to replacement of conventional lamps by LEDs was obtained considering two scenarios of costs. i.e.

1. When considering only Energy Cost
2. When considering both Energy cost + Capacity cost

Inefficient IBs are supposed to be replaced with energy efficient LEDs by matching the lumen output of the IB.

Equation 3.6: Equivalent LED Wattage

$$\text{Equivalent LED wattage} = \frac{\text{Luminous Efficacy of incandescent lamp} \times \text{wattage of incandescent lamp}}{\text{Luminous Efficacy of LED}}$$

This analysis was done for two efficacy bars;

- 70 lm/W
- 80 lm/W

Accordingly, available LED lamp suitable to replace the existing incandescent lamp and existing CFL was obtained. The available LED lamps under each efficacy bar are mentioned in Table 5-3 and Table 5-4.

3.6 Proposing a suitable MEPS scheme using cost benefit analysis

Before MEPS are adopted, cost/benefit analysis must be performed to ensure that the associated regulatory measures provide a positive economic benefit to consumers. [3]

3.6.1 Energy Saving

Energy saving which can be achieved by implementing the MEPS scheme (GWh) was calculated based on the reduction of load in morning peak & night peak (Power saving at night peak). It was determined under three scenarios

- Scenario 1 - 100% Replacement of existing Incandescent Lamps
- Scenario 2 - 50% Replacement of existing Incandescent Lamps
- Scenario 3 - 50% Replacement of existing Incandescent Lamps + 25% Replacement of existing CFL

When finding annual saving of electrical energy due to introducing of MEPS, following parameters are defined.

P_{INC} = Total installed incandescent power

P_{in} = Wattage of Incandescent lamp (n = 25W, 40W, 60W and 100W)

n_{in} = Number of incandescent lamps available in each type of wattage

e_{Inc} = Efficacy of incandescent lamp

P_{ln} = Wattage of LED lamp that replaces incandescent

P_{Ir} = Total replaced incandescent power

P_{LED} = Incoming LED power (Which replaced incandescent)

e_{LED} = Proposed efficacy bar for MEPS of LED

CF = Coincidence Factor

R_r = Lamp Replacement Rate

P = Initial power demand

P_{Ar} = Power demand after replacement

E = Initial daily consumption of electrical energy

E_{Ar} = Daily consumption of electrical energy after replacement

ΔE = Reduction in daily consumption of electrical energy

Equation 3.7: Total Installed Incandescent Power

$$\mathrm{P_{INC}} = \sum P_{in} \times n_{in}$$

Equation 3.8: Total replaced incandescent power

$$\mathrm{P_{Ir}} = \mathrm{P_{Inc}} \times \mathrm{R_r}$$

Equation 3.9: Wattage of LED lamp that replaces incandescent lamp

$$P_{ln} = \frac{P_{in} \times e_{Inc}}{e_{LED}}$$

Equation 3.10: Total incoming LED Power

$$\mathrm{P_{LED}} = \sum P_{ln} \times n_{ln}$$

Equation 3.11: Power demand after replacement

$$\mathrm{P_{Ar}} = \mathrm{P} - (\mathrm{P_{Ir}} \times CF) + (\mathrm{P_{LED}} \times CF)$$

Equation 3.12: Initial daily consumption of electrical energy

$$\mathrm{E} = \int_0^{24} P \, dt$$

Equation 3.13: Daily consumption of electrical energy after replacement

$$\mathrm{E}_{Ar} = \int_0^{24} P_{Ar} \, dt$$

Equation 3.14: Reduction in daily consumption of electrical energy

$$\Delta E = \int_{0}^{24} (P - P_{Ar})dt$$

Annual saving of electrical energy $= \Delta E \times 365$

$$= 365 \times \int_{0}^{24} (P - P_{Ar})dt$$

3.6.2 Financial Saving

Financial saving (in LKR Mn) was calculated using the figure 'cost of supply to HH' (LKR/kWh). When short term is considered, it is 'the cost incurred in importing fuel', i.e Coal, HFO, Diesel etc. is the cost that is going to be saved. Hence, short term saving was calculated using the 'Energy cost' component of the total cost of supply. However, when long-term is considered, reduction in peak loads beneficially affects operation and ageing of the power system elements. Also, mass replacement of inefficient lamps with efficient lamps would lead to the "smoothening" of the power demand daily curves, which would positively affect investment, operational and maintenance costs of whole power system. [20]

Therefore, long term financial saving was calculated by using the cost component 'Energy cost +Capacity cost' of the cost of supply to HH

C_E = Energy Cost

C_C = Capacity Cost

C_{CR} = Customer related Cost

$S_{Rs,E}$ = Financial Saving per year (in terms of energy)

$S_{Rs,T}$
= Financial Saving per year (in terms of capacity , energy & customer related costs)

Equation 3.15: Financial Saving per year (in terms of energy)

$$S_{Rs,E} = \Delta E \times 365 \times C_E$$

Equation 3.16: Financial Saving per year (in terms of capacity energy & customer related costs)

$$S_{Rs,T} = \Delta E \times 365 \times (C_C + C_E + C_{CR})$$

3.6.3 Cost of importing of LEDs

Cost of importing of LEDs was averaged using the prices obtained from different vendors of different brands during the market research carried out. The prices derived using the data gathered are tabulated in Table 4-4: Current market price of LED.

3.7 Payback period

If MEPS are developed and implemented in a way such as an energy label, it is mandatory to specify a minimum warranty period. In order to determine the warranty period that can be requested from the manufacturer, importer, agent etc., a simple payback period can be calculated. It is recommended to request a warranty, at least the period of payback obtained from the simple payback calculation.

Equation 3.17: Simple Payback Period

$$\text{Simple Payback Period} = \frac{\text{Initial Investment in importing/ buying of LED lamps}}{\text{Annual financial saving}}$$

3.8 Sensitivity Analysis

A sensitivity analysis was carried out in order to check the sensitivity of least possible acceptable efficacy bar when the price is varying.

Here, for the ease of calculation, it was assumed that the considered CF is available throughout the average time of burning of a lamp; i.e. 3.95 hrs and during rest of the time no bulb is lit.

The least possible efficacy bar was obtained under different price scenarios, i.e. P0 - P7 which are defined as:

P0 – Original Price (Existing market rate)

P1 – When Price is reduced by 5% from original price ($P_1 = P_0 \times 95\%$)

P2 – When Price is reduced by10% from original price ($P_2 = P_0 \times 90\%$)

P3 – When Price is reduced by 15% from original price ($P_3 = P_0 \times 85\%$)

P4 – When Price is reduced by 20% from original price ($P_4 = P_0 \times 80\%$)

P5 – When Price is reduced by 25% from original price ($P_5 = P_0 \times 75\%$)

P6 – When Price is reduced by 30% from original price ($P_6 = P_0 \times 70\%$)

P7 – When Price is reduced by 50% from original price ($P_7 = P_0 \times 50\%$)

The analysis was performed for different CFs like 0.6, 0.5, 0.4 and 0.3 which represents different types of households. It is obvious that the households which are having higher consumption, may have a small CF like 0.3 (Even though, the total installed load is very high; that is considerable lamp fixtures are fixed, but a few of them are used) and low consuming households (where there are only couple of lamps and no other load) may have a higher CF. The variation of least possible efficacy bar for different pricing levels which is calculated for different CFs are shown in Figure 5.19 to Figure 5.26 considering both energy cost + capacity cost component as well as only the energy cost component.

4 DATA ACQUISITION AND VERIFICATION

4.1 Test data of LED lamps tested at RCL Laboratory.

Photometric and Electric data of 95 Nos. of LED lamps were obtained with the aid of integrating sphere available at Photometric Laboratory of Regional Centre for Lighting (RCL). The integrating sphere works on the principle of multiple diffuse reflections which is used to spatially integrate radiant flux, either from an external or an internal source of radiation.

Figure 4.1: Integrating Sphere

Source: manufacturer's catalogue of Integrating spheres- (Instrument Systems GmbH)

The following test data was available for each and every sample:

- Test Current (mA)
- Power (W)
- Power Factor
- Total Harmonic Distortion (THD)
- Luminous Flux

- Correlated Colour Temperature (CCT)
- Chromaticity X,Y
- Colour Rendering Index (CRI)
- Luminous Efficacy

Major observations of the tested samples are;

- More than 50% are having Power Factors less than 0.5
- More than 60% are having Power Factors less than 0.8
- Wattage is ranging from 1.5W to 18W
- Price of the lamp is ranging from 150.00 LKR to 1300.00 LKR
- Luminous Efficacy is ranging from 35 lm/W to 125lm/W

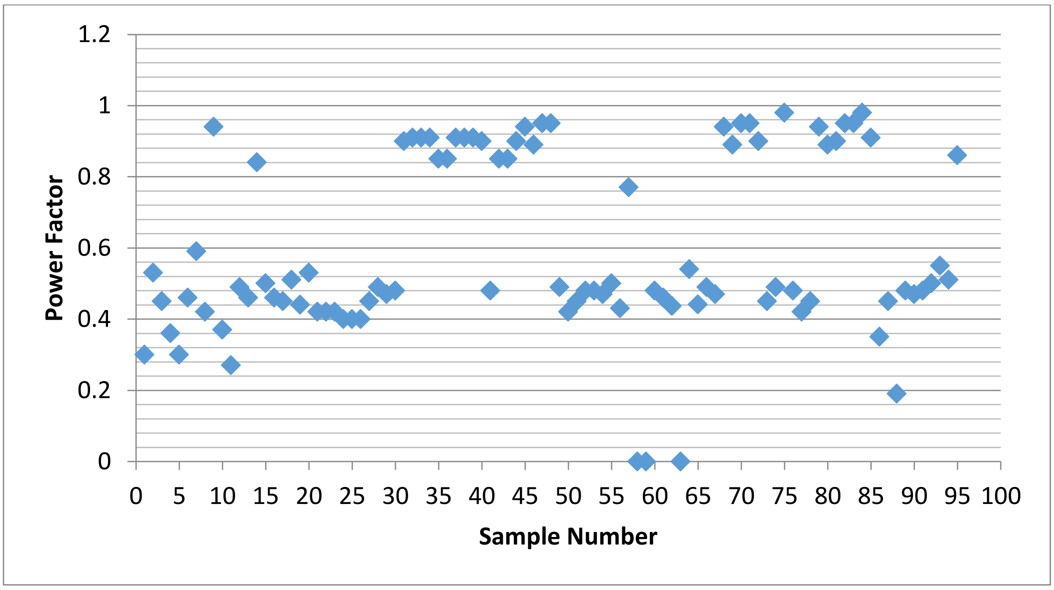


Figure 4.2: Variation of Power factor of the tested samples

As shown in the graph, it is noted that around 60% of the tested samples are within the range of 0.3-0.6 power factor.

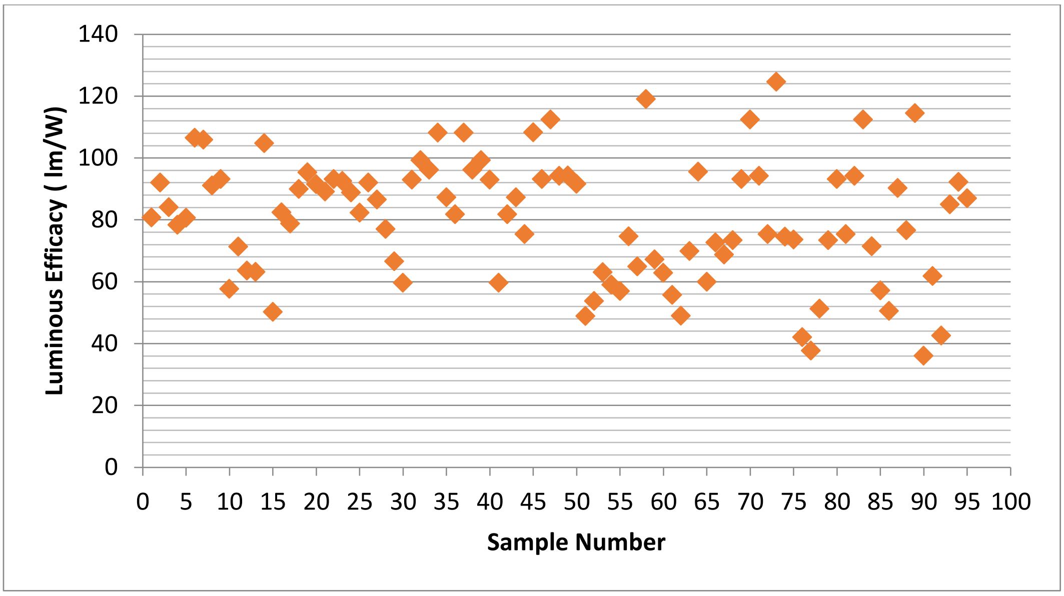


Figure 4.3: Variation of Luminous efficacy of tested samples

Graph shows that around two-third of the tested samples are within the efficacy of 60lm/W – 100 lm/W.

It was noted that more than 50% of the tested samples are having very poor power factors. It was also noted that THD of most of these samples (those who are having poor power factors) is very high (More than 100%). Hence Power Factor was taken as a key measurement in deciding MEPS Bars.

One of the key objectives of introducing MEPS is to efficiently replace existing inefficient lamps. Hence, efficacy (lm/W) value is another obvious consideration. Therefore Power Factor and the Efficacy of each tested lamp were checked in order to find qualified samples under 6 different combinations.

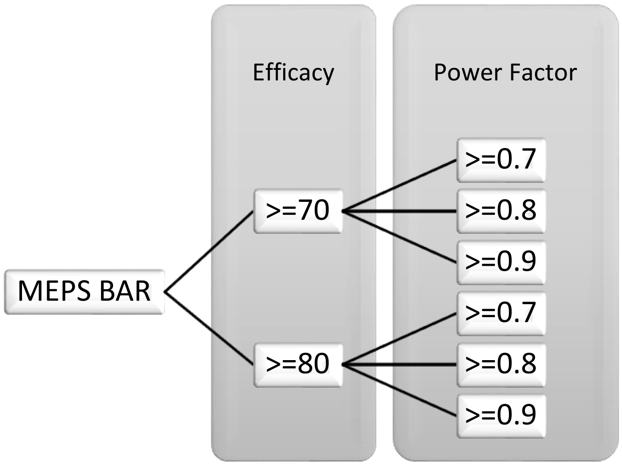


Figure 4.4: MEPS combinations

4.2 Total Domestic Consumer Accounts

In order to extrapolate the sample survey data collected during the household lighting survey, the total domestic consumer accounts for 2014 and 2016 were required.

	2011 (Survey year)	2014	2015	2016 (Forecasted)
CEB (DL1 -4)	4,165,738	4,768,229	4,873,977	5,135,531
LECO (DL5)	412,858	432,027	444,095	457,179
TOTAL	4,578,596	5,200,256	5,318,071	5,592,710

Table 4-1: Variation in Total Domestic Consumer Accounts over the Past Years

4.3 Efficacy of IBs and CFLs

Efficacy of IBs and CFLs were needed during the study in finding;

1. The conversions from IBs to CFLs by year 2014 (30%) and 2016 (40%)
2. In order to find the LED wattage when replacing IBs and CFLs as per the proposed MEPS

Incandescent Wattage (W)	Efficacy (lm/W)
25	10
40	10
60	12
75	12.5
100	15

Table 4-2: Efficacy of Incandescent Bulbs

CFL Wattage (W)	Efficacy (lm/W)
5	45
7	45
8	45
9	45
10	50
11	50
12	50
13	55
14	55
15	55
18	60
20	60
23	60

Table 4-3: Efficacy of Compact Fluorescent Lamps

4.4 Cost of LED

Cost of Importing of LEDs was calculated based on the market research carried out. However, when national level project is concerned, probably a C&F cost of a LED lamp can be considered for the calculation of cost benefit analysis. This was taken into account during the sensitivity analysis.

LED Wattage (W)	Price (LKR)
1-3	400.00
4-5	600.00
6-7	700.00
8-9	900.00
10-15	1,300.00
16-20	2,500.00

Table 4-4: Current market price of LED

4.5 Cost of Supply

The cost of supply to Households for 2014 and 2016 were obtained using the Decision Document on Electricity Tariff 2011 by PUCSL which was last run in 2011.

Table 34- Costs, cross-subsidies and the additional subsidy required in year 2011 with the Approved Tariffs

Customer Category in year 2010 tariffs (and kWh/month for households)	Total Sales (GWh)	Total Cost (LKR million)	Total revenue (LKR million)	Total (Subsidy) or surcharge on customers (LKR million)	Cost of supply (LKR/kWh)	Forecast revenue (LKR/kWh)	Subsidy as a share of cost
LV Retail							
0-30	233	5,487	1,113	(4,373)	23.53	4.77	80%
31-60	756	15,830	3,695	(12,135)	20.94	4.89	77%
61-90	1,018	19,975	5,974	(14,001)	19.61	5.87	70%
91-120	666	11,747	7,075	(4,672)	17.64	10.62	40%
121-180	588	10,363	8,297	(2,066)	17.62	14.11	20%
181-600	492	8,303	10,732	2,429	16.89	21.83	-29%
>600	100	1,472	3,275	1,802	14.79	32.91	-122%
Sub Total	3,853	73,177	40,161	(33,016)	18.99	10.42	45%
Other LV							
Religious	57	1,010	396	(614)	17.77	6.97	61%
General Purpose 1	1,034	15,869	21,549	7,500	15.34	20.83	-36%
Government 1	115		1,820			15.83	-3%
Industrial 1	238	3,169	2,611	(558)	13.31	10.96	18%
Hotel 1	1	19	26	7	15.10	20.23	-34%
Street Lighting	148	2,310	-	(2,310)	15.56	-	100%
Sub Total	1,594	22,378	26,401	4,024	14.04	16.56	-18%
LV BULK							
General Purpose 2	788	9,719	18,175	9,942	12.34	23.08	-87%
Government 2	88		1,486			16.98	-38%
Industrial 2	1,561	19,817	21,763	1,947	12.69	13.94	-10%
Industrial 2 TOU	174	2,147	2,361	214	12.34	13.57	-10%
Hotels 2 TOU	2	26	35	9	11.04	14.64	-33%
Hotels 2 (GP)	73	822	1,122	299	11.19	15.27	-36%
Hotels 2 (IP)	54	653	848	195	12.21	15.85	-30%
Sub Total	2,739	33,184	45,790	12,606	12.11	16.72	-38%
MEDIUM VOLTAGE							
General Purpose 3	201	2,259	4,268	2,347	11.24	21.24	-89%
Government 3	22		338			15.14	-35%
Industrial 3	1,035	10,943	12,526	1,583	10.57	12.10	-14%
Industrial 3 TOU	143	1,373	1,776	403	9.62	12.44	-29%
Hotels 3	8	77	108	31	9.65	13.51	-40%
Hotel 3 TOU	71	629	885	256	8.88	12.50	-41%
Sub Total	1,480	15,281	19,900	4,619	10.32	13.44	-30%
Total	9,666	144,020	132,252	(11,767)	14.90	13.68	8%

Note 1: Customer categories Government 1, 2 and 3 are shown only for information. The respective costs are included under the corresponding General Purpose categories.

Source: Decision document on electricity tariff – 2011 by PUCSL

5 ANALYSIS & RESULTS

Analysis of this study basically consists of finding,

i. The cost that has to be borne by the individual customer when the existing lamps are replaced with LEDs under each MEPS scheme considered. (Micro scale)

   The figure was calculated in LKR/1000 lm. This is due to the fact that, the benefited customer is ultimately paying for the amount of light he is receiving and not for the power (wattage) of the lamp he used.

ii. Cost benefit analysis in National Level (with the aid of total lighting profile of the country)

   This analysis was done with the aid of total lighting profile of the country in order to find out the most viable MEPS scheme.

5.1 The cost to be borne by the individual customer

The results of this analysis show how the cost/lm value that an individual customer bears varies, when the efficacy level and the power factor level of the proposed MEPS scheme is changed. For example, if the MEPS scheme limits the PF value to 0.7 and the efficacy bar to 70 lm/W, cost/lm value that a customer has to pay is different from what, when the PF bar and efficacy bar is limited to 0.8 and 80 lm/W respectively.

5.1.1 Cost of replacing existing lamps with LED (per customer)

Sample calculation under the MEPS bar of Efficacy > 80 lm/W and the Power factor ≥ 0.8 is shown below:

Finding the Annual Capital Cost

Average no. of hours of burning of a lamp per day = 3.95 hrs

(From the report of ADB funded National Survey on Household Lighting 2011 Dec)

Average Lifetime of a direct connected type LED lamp = 15,000 hrs

When the wattage of LED = 8W and

The Price of the considered 8W LED = LKR 900

Annual capital cost = $\frac{900 \times 3.95 \times 365}{15000}$ = LKR 86.51

Finding the Annual Energy Cost

Approved Tariff for Domestic Consumers-2014 (under 121-180 Category) = 32 LKR/kWh

(Statistical digest – 2014 of CEB and LECO)

Annual energy cost = $\frac{8 \times 3.95 \times 365 \times 32}{1000}$ = LKR 369.09

Total cost to be borne (Annually)

= Annual Capital cost + Annual Energy cost

= 86.51+369.09

= LKR 455.60

Total Luminous flux of the considered 8W lamp = 745 lm

Total Annual cost per lumen = 455.60/745 = 0.61154

= <u>LKR 611.54/1000 lm</u>

Under the above proposed (Efficacy > 80 lm/W and the Power factor ≥ 0.8) MEPS scheme, there are only 25 samples out of 95 Nos. of LED lamps tested qualified to be used in the country. And the average cost per lumen is LKR 584.168 /1000 lm

Maximum cost per lumen = LKR 682.69 /1000 lm

Minimum cost per lumen = LKR 490.01/1000 lm

Appendix 3 shows the 'annual cost per 1000 lumen' values for the qualified tested samples under Efficacy > 80 lm/W and the Power factor ≥ 0.8 criteria.

5.1.2 Results – Variation of 'per lumen cost for an individual customer'

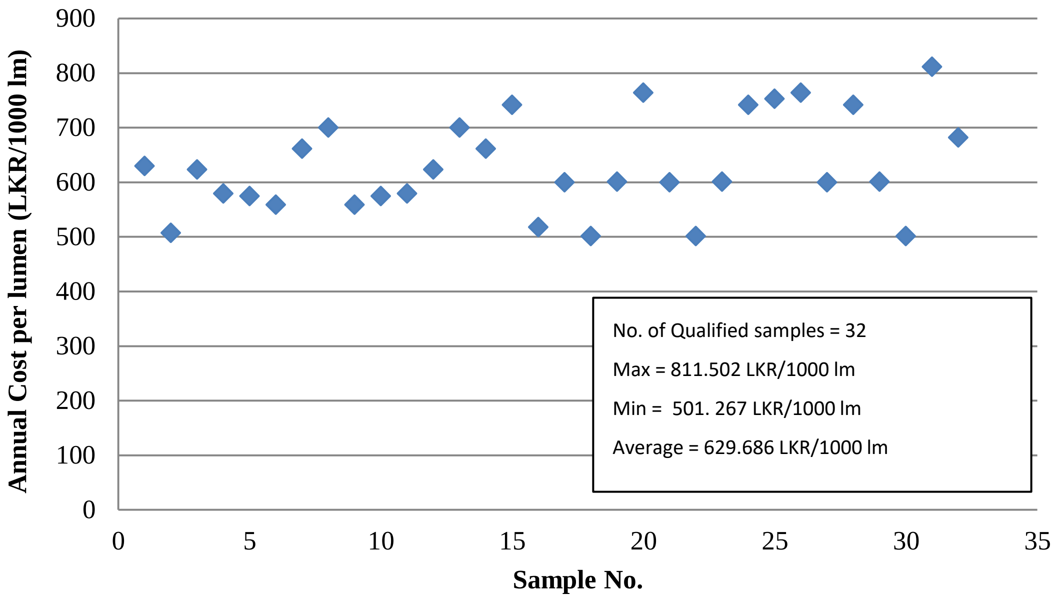


Figure 5.1 : Variation of Annual Cost/1000 lm when Efficacy >= 70%, P.F>=0.7

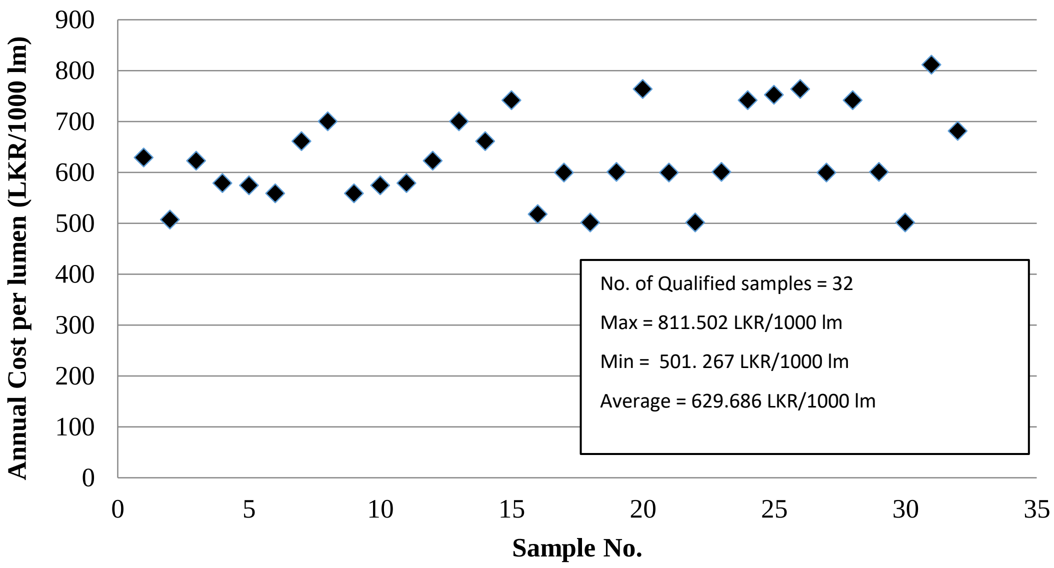


Figure 5.2: Variation of Annual Cost/1000lm when Efficacy >= 70%, P.F>=0.8

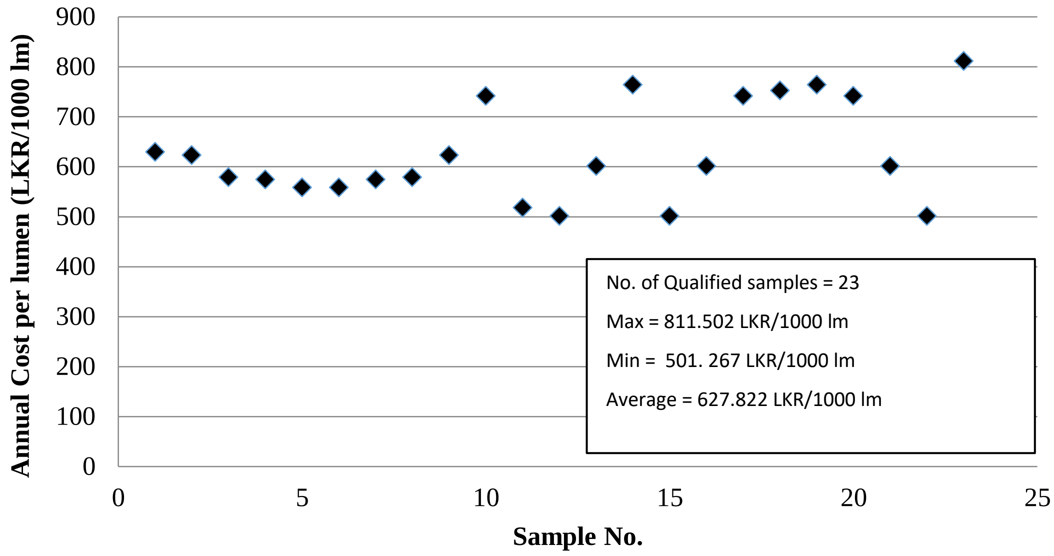


Figure 5.3: Variation of Annual Cost/1000lm when Efficacy >= 70%, P.F>=0.9

As interpreted in above graphs, it can be seen that when the PF goes higher, the no. of qualified samples will become less. However, the average annual cost per lm that an individual customer has to bear decreases from LKR 629.69/1000 lm to LKR 627.82/1000 lm.

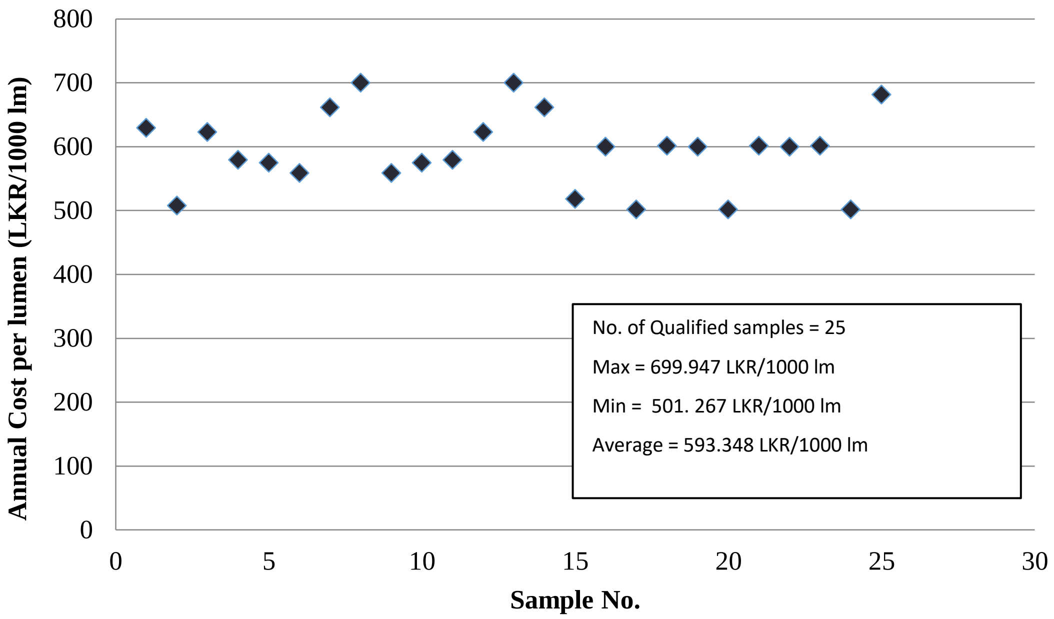


Figure 5.4: Variation of Annual Cost/1000lm when Efficacy >= 80%, P.F>=0.7

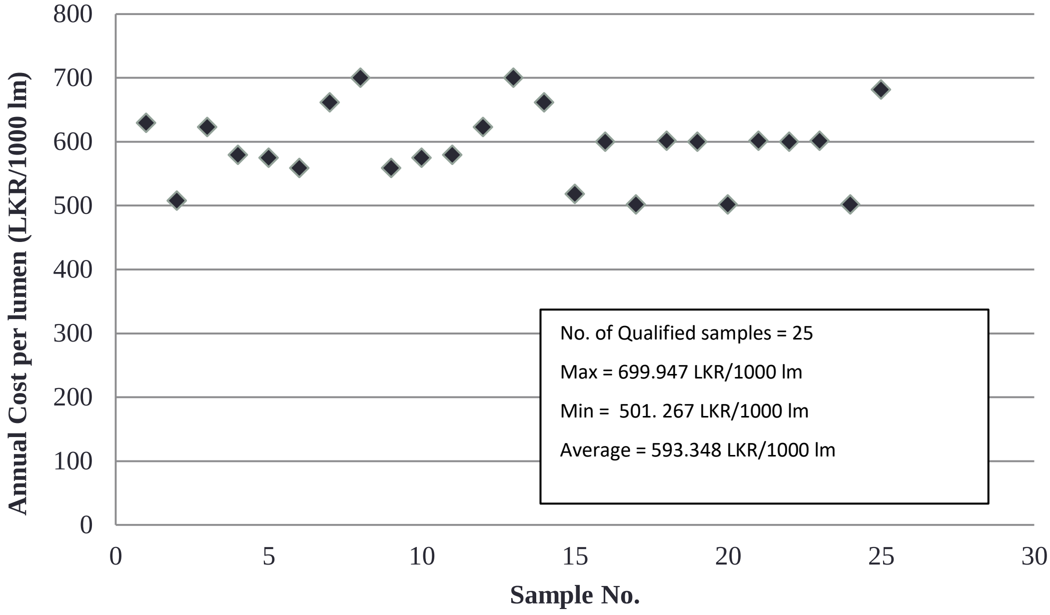


Figure 5.5: Variation of Annual Cost/1000lm when Efficacy >= 80%, P.F>=0.8

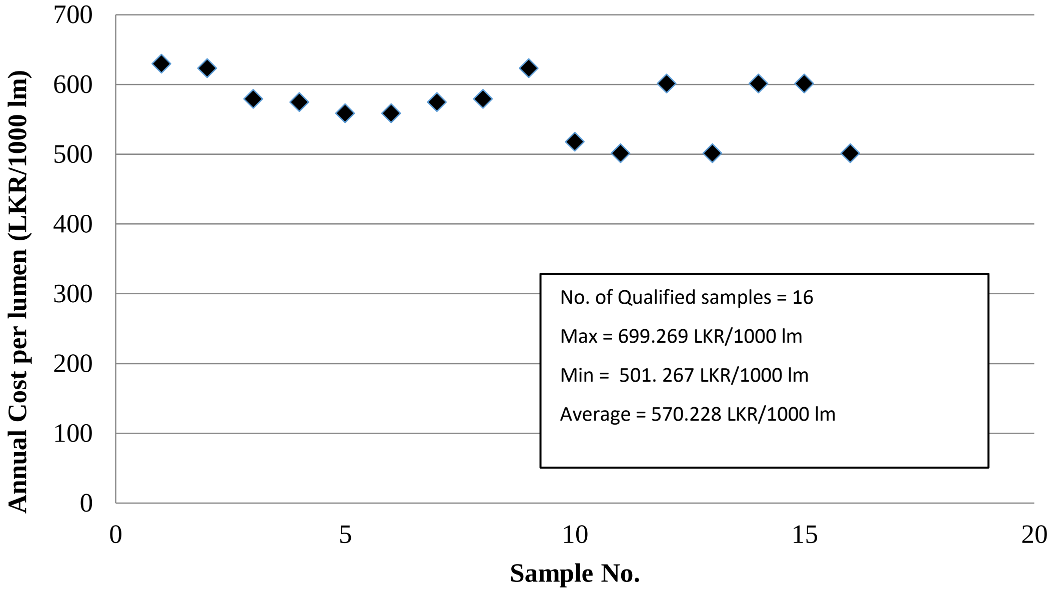


Figure 5.6: Variation of Annual Cost/1000 lm when Efficacy >= 80%, P.F>=0.9

Similar to the variation in the case of 70lm/W efficacy, when the PF goes higher, the no. of qualified samples has been reduced from 25 to 16. As expected, average annual cost per lm has been decreased from LKR 593.35/1000 lm to LKR 570.23/1000 lm.

5.1.3 Variation of annual average cost with the PF (per customer)

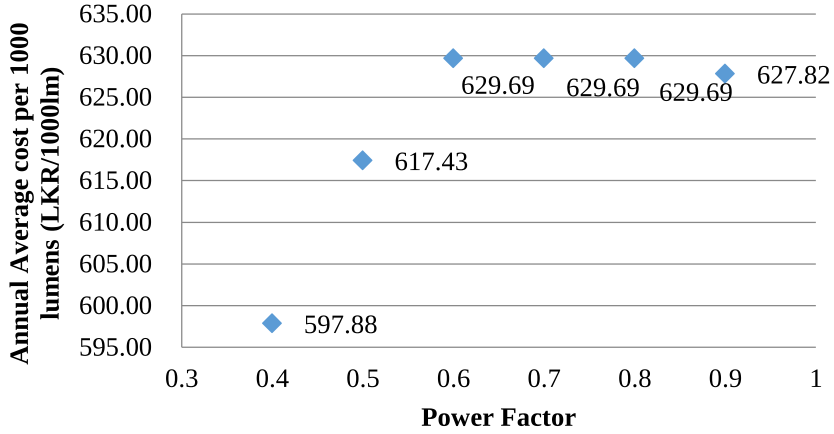


Figure 5.7: Variation of annual average Cost/1000 lm with the power factor when efficacy >= 70 lm/W

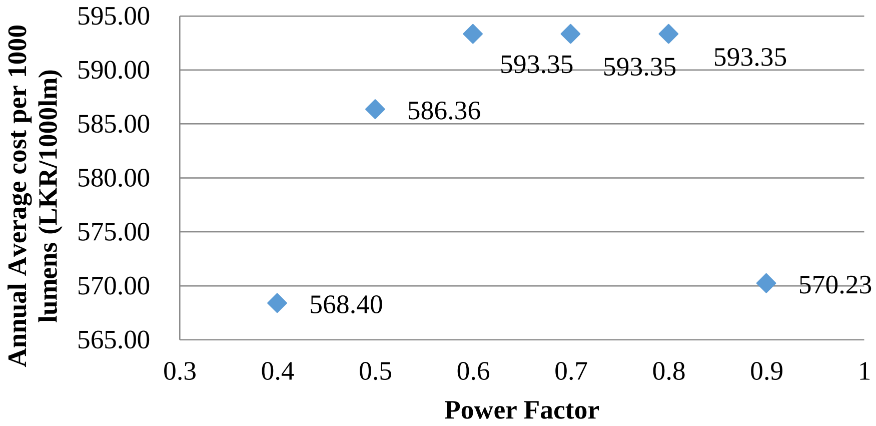


Figure 5.8: Variation of annual average cost/1000 lm with the power factor when efficacy>= 80 lm/W

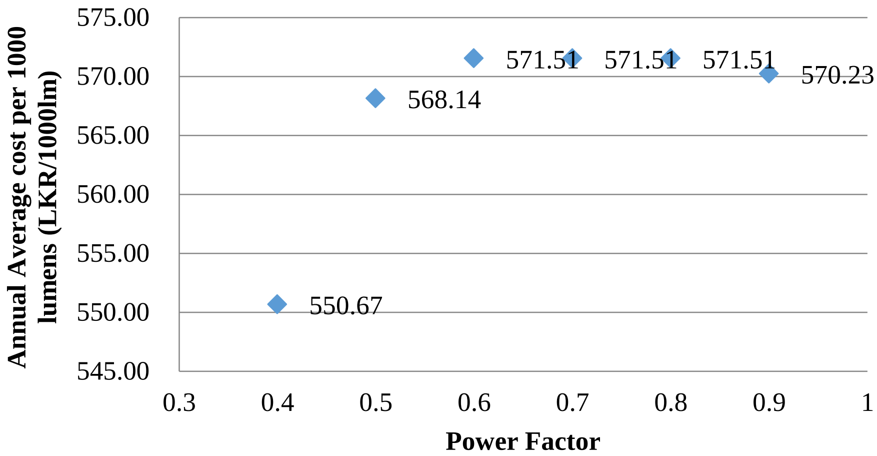


Figure 5.9: Variation of annual average cost/1000 lm with the power factor when efficacy>= 90 lm/W

5.1.4 Variation of annual average cost with the efficacy bar (per customer)

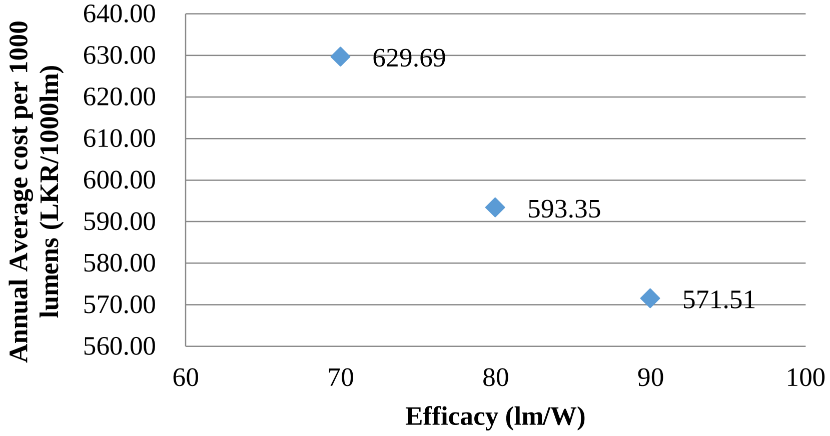


Figure 5.10: Variation of annual average cost/1000 lm with the efficacy bar when PF is 0.7

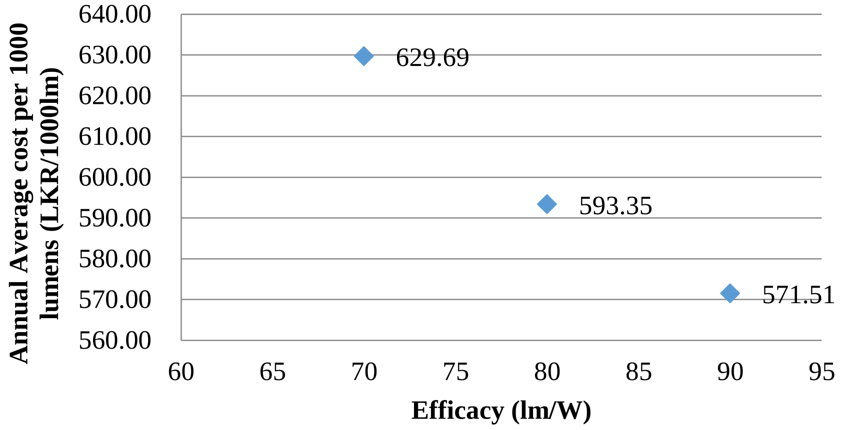


Figure 5.11: Variation of annual average cost/1000 lm with the efficacy bar when PF is 0.8

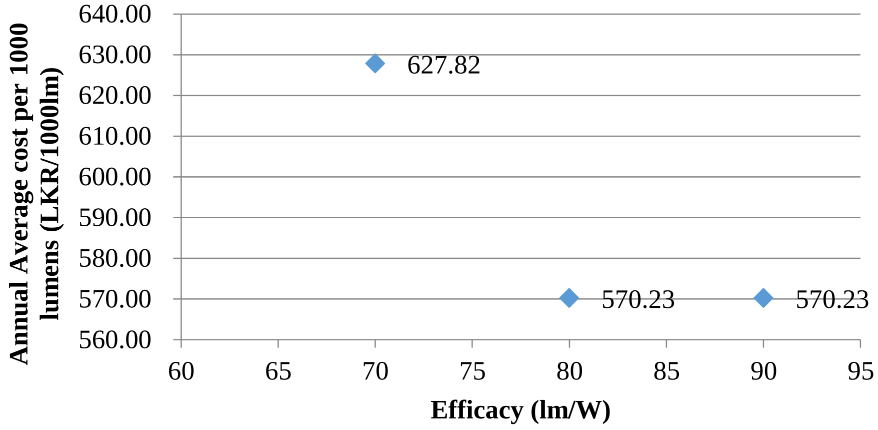


Figure 5.12: Variation of annual average cost/1000 lm with the efficacy bar when PF is 0.9

5.1.5 Comparison of costs with an equivalent incandescent lamp and CFL

Total annual cost of LED can be compared with the equivalent incandescent lamp as well as the equivalent CFL.

Total Annual cost of Incandescent lamp

When the wattage of LED = 8W,

Equivalent Incandescent wattage can be calculated as follows:

Total Luminous flux of the considered 8W lamp = 745 lm

Efficacy of incandescent lamp = 12 lm/W (Assume)

Therefore Equivalent Incandescent wattage = 745/12 = 62.08W ≈ 60W

Finding the Annual Capital Cost

Average no. of hours of burning of a lamp per day = 3.95 hrs

(From the report of ADB funded National Survey on Household Lighting 2011 Dec)

Average Lifetime of an incandescent lamp = 1,000 hrs

The Price of a 60W incandescent lamp = LKR 60

Annual capital cost = $\frac{60\times3.95\times365}{1000}$ = LKR 86.51

Finding the Annual Energy Cost

Approved Tariff for Domestic Consumers-2014 (under 121-180 Category) = 32 LKR/kWh

(Statistical digest – 2014 of CEB and LECO)

Annual energy cost = $\frac{60\times3.95\times365\times32}{1000}$ = LKR 2,768.16

Total cost to be borne (Annually)

= Annual Capital cost + Annual Energy cost

= 86.51+2,768.16

= LKR 2,854.67

Total Luminous flux of the considered 60W lamp = 720 lm

Total Annual cost per lumen = 2,854.67 /720 = 3.96481

= <u>LKR 3,964.81/1000 lm</u>

Total Annual cost of CFL

When the wattage of LED = 8W,

Equivalent CFL wattage can be calculated as follows:

Total Luminous flux of the considered 8W lamp = 745 lm

Efficacy of CFL = 55 lm/W (Assume)

Therefore Equivalent CFL wattage = 745/55 = 13.56W ≈ 14W

Finding the Annual Capital Cost

Average no. of hours of burning of a lamp per day = 3.95 hrs

(Source: Report of ADB funded National Survey on Household Lighting 2011 Dec)

Average Lifetime of a CFL = 6,000 hrs

The Price of a 14W CFL = LKR 450

Annual capital cost = $\frac{450\times3.95\times365}{8000}$ = LKR 81.09

Finding the Annual Energy Cost

Approved Tariff for Domestic Consumers-2014 (under 121-180 Category) = 32 LKR/kWh

(Source: Statistical digest – 2014 of CEB and LECO)

Annual energy cost = $\frac{60\times3.95\times365\times32}{1000}$ = LKR 645.904

Total cost to be borne by the consumer (Annually)

= Annual Capital cost + Annual Energy cost

= 81.09+645.904

= LKR 726.994

Total Luminous flux of the considered 14W lamp = 770 lm

Total Annual cost per lumen = 726.994 /770 = LKR 0.94414/ lm

= <u>LKR 944.14/1000 lm</u>

Lamp Type	Annual Capital Cost (LKR)	Annual Energy Cost (LKR)	Total Cost (LKR)	Cost per 1000 lm (LKR/1000lm)
 **Incandescent**	86.51	2,768.16	2,854.67	3,964.81
 **CFL**	81.09	645.90	726.99	944.14
 **LED**	86.51	369.09	455.60	611.54

Table 5-1: Annual costs of different lamp types

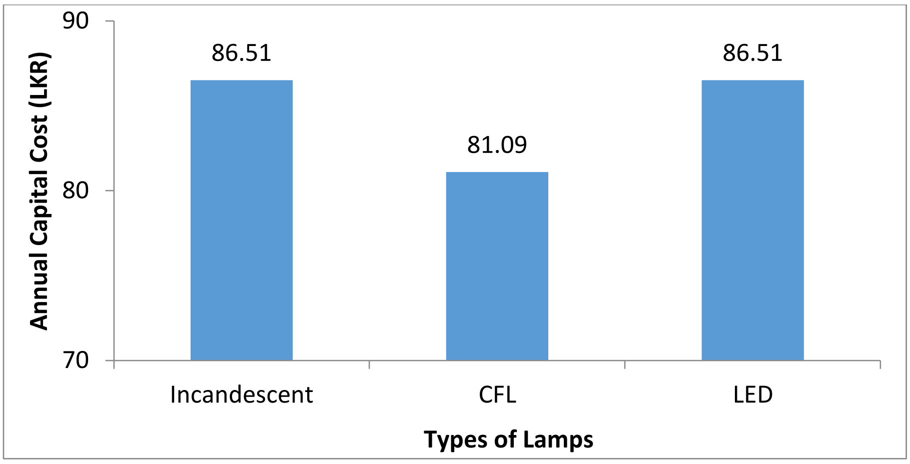


Figure 5.13: Comparison of Annual Capital Cost of different lamp types

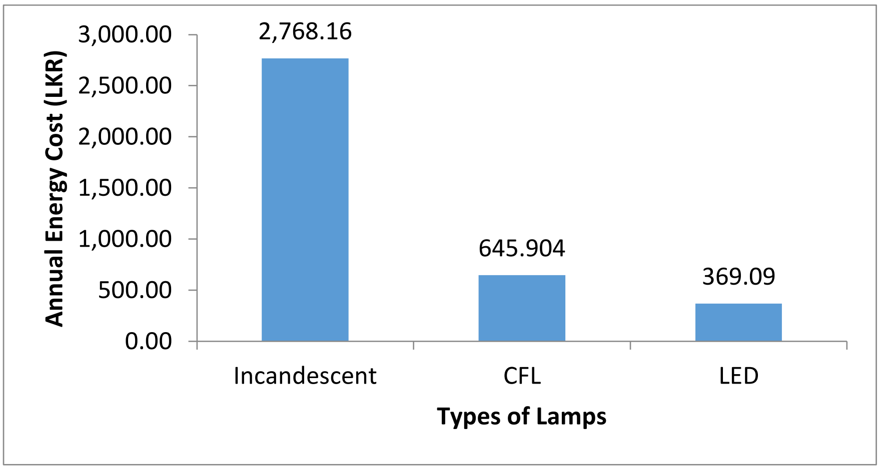


Figure 5.14: Comparison of Annual Energy cost of different lamp types

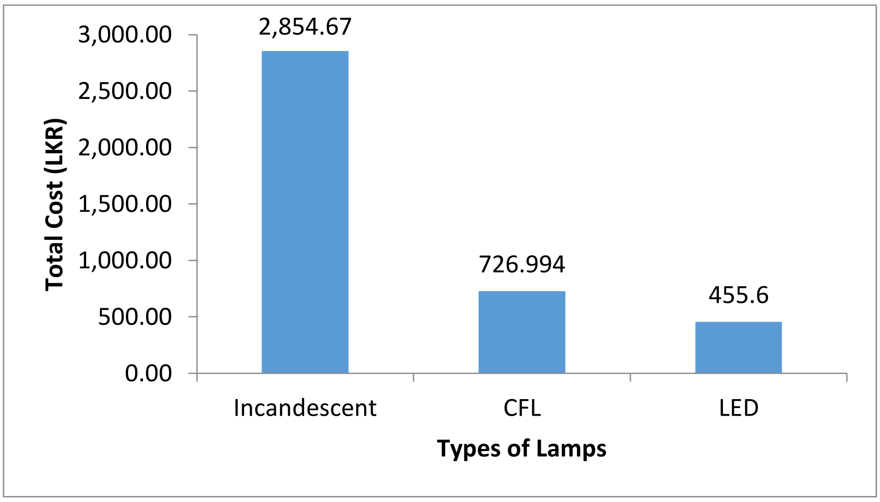


Figure 5.15: Comparison of Total cost of different lamp types

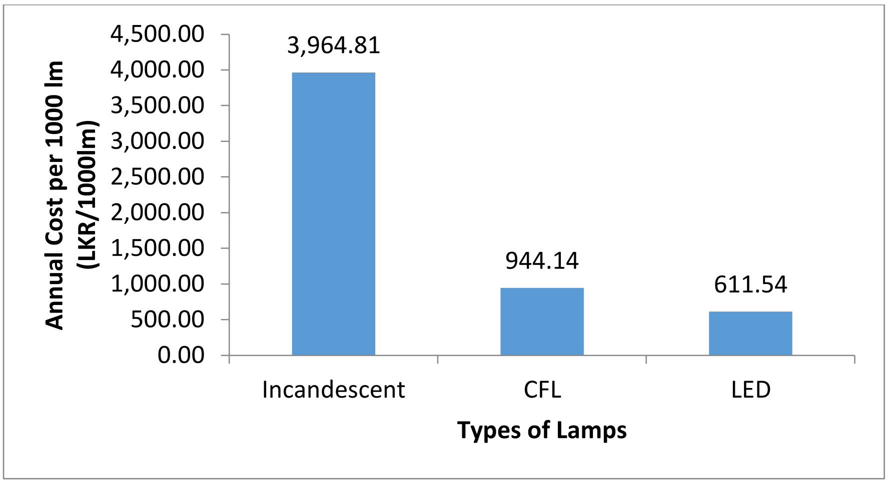


Figure 5.16: Comparison of Annual cost per 1000 lm of different lamp types

5.2 Cost benefit analysis in National Level

Cost benefit analysis in National level was done with the aid of total lighting profile of the country. This was derived using the information collected in National Survey on Household Lighting carried out in 2011 by ADB in its efforts to address the climate change. This sample survey was conducted in Colombo & its suburbs, Galle, Kuliyapitiya, Ampara and Jaffna, covering 3031 consumers in three categories: less than 90 kWh/month (2260 nos. of households), 90-180kWh/month (633 nos. of households) and over 180 kWh/month (138 households).

The results of this analysis show whether a National level project for converting existing inefficient lamps to energy efficient LED lamps is feasible or not under the scenarios considered, for a given CF and the current market pricing.

5.2.1 Coincidence Factor – (Theoretical Calculation)

In order to get an idea for the value of coincidence factor, following method was used. Considered time was the system night peak time of 2014 & morning peak of 2014.

Coincidence factor during night time usage of lighting

$$\text{Total installed lighting load in 2014} = 1229.17\ \text{MW}$$

Source: National Survey on Household Lighting - 2011

$$\text{Average night peak demand of 2014 } = \frac{\sum_{p=1}^{p=365} D_p}{365} = 1{,}867\ \text{MW}$$

D_p = Night Peak Demand of a day

Source: System Control unit, Ceylon Electricity Board

$$\frac{\text{Lighting Load}}{\text{Night Peak Demand}} = 0.43$$

Source: Load Research Report by Sustainable Energy Authority

$$\therefore \text{ Lighting load during night peak demand of 2014 } = 1{,}867 \times 0.43\ \text{MW}$$

$$= 802.84 \text{ MW}$$

$$\therefore \text{Coincidence factor during night peak} = \frac{802.84}{1229.17}$$

$$\underline{\underline{= 0.65}}$$

Coincidence factor during morning time usage of lighting

$$\text{Total installed lighting load in 2014} = 1229.17 \text{ MW}$$

Source: National Survey on Household Lighting - 2011

$$\text{Average day peak demand of 2014 } = \frac{\sum_{p=1}^{p=365} D_p}{365} = 1{,}318\text{MW}$$

D_p = Morning Peak Demand of a day

Source: System Control unit, Ceylon Electricity Board

$$\frac{\text{Lighting Load}}{\text{Morning Peak Demand}} = 0.204$$

Source: Load Research Report by Sustainable Energy Authority

$$\therefore \text{Lighting load during morning peak demand of 2014 } = 1{,}318 \times 0.204 \text{ MW}$$

$$= 268.87 \text{ MW}$$

$$\therefore\text{Coincidence factor during morning peak} = \frac{268.87}{1229.17}$$

$$\underline{\underline{= 0.22}}$$

5.2.2 Saving of electrical energy

Sample calculation shown below is done for scenario 2 (50% replacement of existing incandescent lamps), considering the CF of 0.65 for 3 hrs (1800 hr -2100 hr), CF of 0.22 for 1 hrs (0600 hr -0700 hr) and the efficacy bar of 80 lm/W for the domestic consumer accounts in 2016. The assumption of '40% incandescent lamps used in 2011 were replaced with CFLs by 2016' was also considered.

Number of 40W incandescent lamps counted from the survey (in 2011) = 3707

Extrapolating above data using the no. of consumer accounts data shown in Table 4-1

Total quantity of lamps that are available in 2016 = $\frac{3707}{3031} \times 5{,}592{,}710 \times 60\%$

$= 4{,}104{,}027$ Nos.

$P_{INC\ (for\ 40W)} = 40 \times 4{,}104{,}027$

$= 164{,}161{,}076.63$ W

Wattage (W)	Quantity of lamps	Total Load (W)
25	1,004,141	25,103,536.64
40	4,104,027	164,161,076.63
60	5,977,243	358,634,604.57
75	1,330,737	99,805,240.48
100	1,127,030	112,702,978.16
P_{INC}(MW)		**760.41**

Table 5-2: Total installed Incandescent load in 2016

$P_{Ir} = 760.41 \times 50\%$

$= 380.205$ MW

Using the efficacy data mentioned in Table 4-2 and the 80 lm/W efficacy bar, Equivalent LED lamp wattage that replaces 40W incandescent lamp is,

$P_{LED(40)} = \frac{40 \times 10}{80}$ = 5W

In similar way, equivalent LED wattages of 25W, 60W and 100W incandescent lamps were obtained and subsequently the total incoming LED power was obtained.

Incandescent Wattage (W)	Available equivalent LED lamp Wattage under 80lm/W (W)
25	3
40	5
60	9
75	12
100	19

Table 5-3: Available LED lamp for replacement under 80 lm/W efficacy bar

Incandescent Wattage (W)	Available equivalent LED lamp Wattage under 70lm/W (W)
25	4
40	6
60	10
75	13
100	21

Table 5-4: Available LED lamp for replacement under 70 lm/W efficacy bar

Wattage (W)	Quantity of lamps	Total Load (W)
3	502,070.73	1,506,212.20
5	2,052,013.46	10,260,067.29
9	2,988,621.70	26,897,595.34
12	665,368.27	7,984,419.24
19	563,514.89	10,706,782.93
P_{LED} (MW)		**57.36**

Table 5-5: Total incoming LED power

Considering the demand curve of any particular day of the year and using Equation 3.11 P_{Ar} was calculated. The considered date was 13th June 2016.

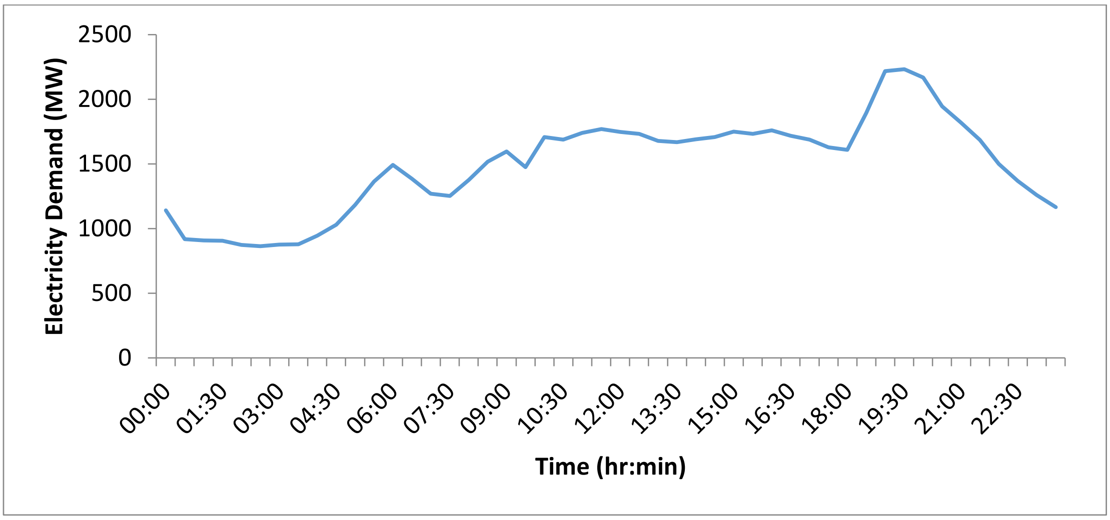
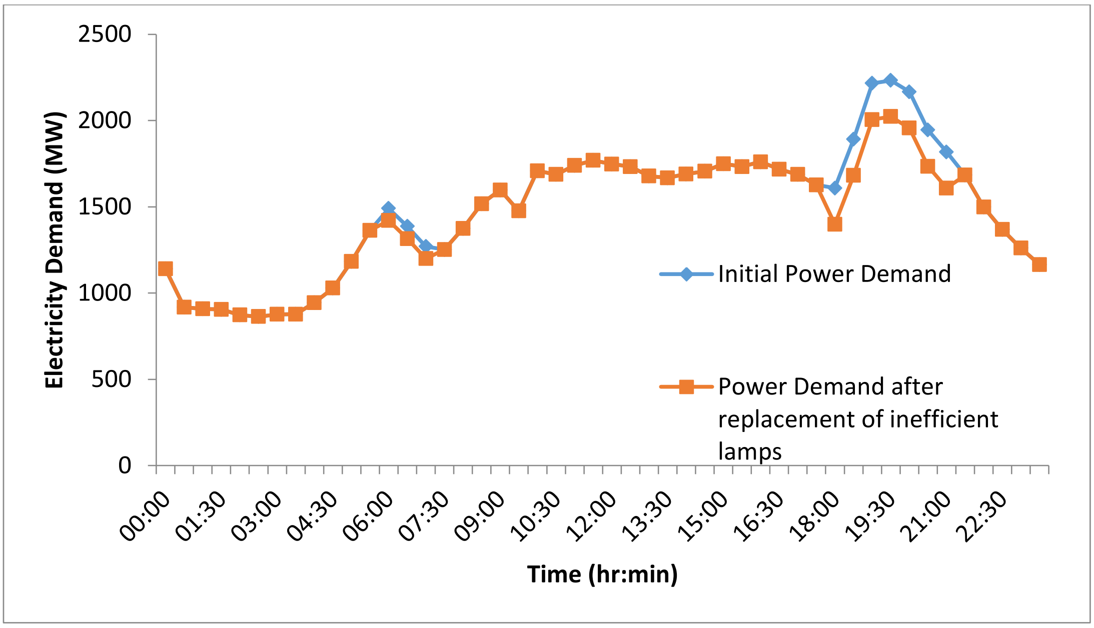


Figure 5.17: Load curve on 13th June 2016



∴ Reduction in daily consumption of electrical energy, ΔE (By Equation 3.14)

ΔE = 35,173.55 - 34,332.52 = 841.02 MWh

∴ Annual saving of electrical energy = 841.02 $\times 365 \times 10^3$ = <u>306.97 GWh</u>

5.2.3 Cost of Supply

Total Cost of Supply$_{2016}$ was obtained using the 'Decision on transmission and bulk supply tariffs – 2016' published by PUCSL

Cost of Supply 2016 = 226,184 LKR Million [21]

Total Sales = 11,985 GWh [21]

Unit cost of supply for 2016 $= \frac{226{,}184}{11{,}985} = 18.87$ LKR/kWh

With the aid of Equation 3.5: Cost of Supply to Households;

$$\text{Unit cost of Supply to HH}_{2016} = \frac{18.99}{14.90} \times 18.87 \quad = 24.06\ \text{LKR/kWh}$$

Share of costs 2011

Capacity cost *(LKR/kWh)*	Energy cost *(LKR/kWh)*	Customer-related cost *(LKR/kWh)*	Total unit cost *(LKR/kWh)*
9.10	9.20	0.51	18.80

Table 5-6: Share of different cost components of the unit cost of supply to HH - 2011

Source: Evaluation of First Tariff Filing– 2011

Assuming the split will be same for 2016,

Capacity cost *(LKR/kWh)*	Energy cost *(LKR/kWh)*	Customer-related cost *(LKR/kWh)*	Total unit cost *(LKR/kWh)*
11.64	11.77	0.65	24.06

Table 5-7: Share of different cost components of the unit cost of supply to HH - 2016

Similarly for 2014,

$$\text{Unit cost of Supply to HH}_{2014} = \frac{18.99}{14.90} \times 19.97 \ = 25.45\ \text{LKR/kWh}$$

Assuming again the split of different cost components to be similar to 2011,

Capacity cost *(LKR/kWh)*	Energy cost *(LKR/kWh)*	Customer-related cost *(LKR/kWh)*	Total unit cost *(LKR/kWh)*
12.32	12.46	0.69	25.45

Table 5-8: Share of different cost components of the unit cost of supply to HH - 2014

5.2.4 Financial Saving

Short term financial saving can be calculated considering only the ‘energy cost’ component of the cost of supply.

By Equation 3.15: Financial Saving per year (in terms of energy),

$$S_{Rs,E} = 306.97 \times 10^3 \times 11.77$$

$$= \ 3{,}613.62\ \text{LKR Mn}$$

In long term, Financial saving per year (in terms of total cost)

$S_{Rs,T} = 306.97 \times 10^3 \times 11.77 \times 24.06$ (By Equation 3.16)

$$= 7{,}384.36 \text{ LKR Mn}$$

The above analysis was repeated for the year 2014 and also for the 70lm/W efficacy bar.

5.2.5 Results

CF considered: 0.22 for 1hr during 0600 hr – 0700 hr

0.65 for 3hr during 1800 hr – 2100 hr

i. ***When efficacy bar is at 70 lm/W (with 2014 household data, no. of lamps and 2014 cost of supply data)- When only energy cost is considered***

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	444.95	650.88	12.46	8,107.65
2. 50% replacement of existing Incandescent Lamps	222.47	325.44	12.46	4,053.83
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	241.86	353.79	12.46	4,406.97

Table 5-9: Results for 2014 data when efficacy bar is 70lm/W (considering only energy cost)

ii. When efficacy bar is at 70 lm/W (with 2014 household data, no. of lamps and 2014 cost of supply data)- when total cost is considered

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	444.95	650.88	25.45	16,567.81
2. 50% replacement of existing Incandescent Lamps	222.47	325.44	25.45	8,283.91
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	241.86	353.79	25.45	9,005.54

Table 5-10: Results for 2014 data when efficacy bar is 70lm/W (considering total cost)

iii. When efficacy bar is at 80 lm/W (with 2014 household data, no. of lamps and 2014 cost of supply data)- when only energy cost is considered

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	455.29	666.01	12.46	8,296.14
2. 50% replacement of existing Incandescent Lamps	227.65	333.00	12.46	4,148.07
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	248.09	362.90	12.46	4,520.51

Table 5-11: Results for 2014 data when efficacy bar is 80lm/W (considering only energy cost)

iv. *When efficacy bar is at 80 lm/W (with 2014 household data, no. of lamps and 2014 cost of supply data)- when total cost is considered*

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	455.29	666.01	25.45	16,952.98
2. 50% replacement of existing Incandescent Lamps	227.65	333.00	25.45	8,476.49
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	248.09	362.90	25.45	9,237.57

Table 5-12: Results for 2014 data when efficacy bar is 80lm/W (considering total cost)

v. *When efficacy bar is at 70 lm/W (with 2016 household data, no. of lamps and 2016 cost of supply data)- when only energy cost is considered*

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	410.17	600.00	11.77	7,063.04
2. 50% replacement of existing Incandescent Lamps	205.08	300.00	11.77	3,531.52
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	228.25	333.89	11.77	3,930.51

Table 5-13: Results for 2016 data when efficacy bar is 70lm/W (considering only energy cost)

vi. When efficacy bar is at 70 lm/W (with 2016 household data, no. of lamps and 2016 cost of supply data)- when total cost is considered

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	410.17	600.00	24.06	14,433.17
2. 50% replacement of existing Incandescent Lamps	205.08	300.00	24.06	7,216.59
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	228.25	333.89	24.06	8,031.92

Table 5-14: Results for 2016 data when efficacy bar is 70lm/W (considering total cost)

vii. When efficacy bar is at 80 lm/W (with 2016 household data, no. of lamps and 2016 cost of supply data)- when only energy cost is considered

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	419.70	613.95	11.77	7,227.24
2. 50% replacement of existing Incandescent Lamps	209.85	306.97	11.77	3,613.62
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	233.02	340.87	11.77	4,012.61

Table 5-15: Results for 2016 data when efficacy bar is 80lm/W (considering only energy cost)

viii. When efficacy bar is at 80 lm/W (with 2016 household data, no. of lamps and 2016 cost of supply data)- when total cost is considered

Scenario	Reduction in night peak (MW)	Annual Energy Saving (GWh)	Cost of Supply of unit of Electricity (LKR/kWh)	Saving (LKR Mn)
1. 100% replacement of existing Incandescent Lamps	419.70	613.95	24.06	14,768.72
2. 50% replacement of existing Incandescent Lamps	209.85	306.97	24.06	7,384.36
3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	233.02	340.87	24.06	8,199.69

Table 5-16: Results for 2016 data when efficacy bar is 80lm/W (considering total cost)

5.2.6 Cost of importing of LEDs

Cost of importing of LEDs for the scenario of '50% replacement of incandescent' by 80 lm/W LED lamps (for 2016 data) is shown below.

Incandescent Wattage (W)	Quantity	Replaced Quantity	LED wattage (W)	Cost of LED lamp (LKR)	Total cost of importing (LKR)
25	1,004,141	502,071	3	400.00	200,828,293.10
40	4,104,027	2,052,013	5	700.00	1,436,409,420.55
60	5,977,243	2,988,622	9	900.00	2,689,759,534.25
75	1,330,737	665,368	12	1,100.00	731,905,096.87
100	1,127,030	563,515	19	2,500.00	1,408,787,226.99
					6,467,689,571.76

Table 5-17: Cost of purchasing of LEDs to replace 50% of existing incandescent lamps

Results

Scenario (for 2014 data)	Cost of importing LEDs (LKR Mn)	
	under 70 lm/W efficacy bar	under 80 lm/W efficacy bar
1. 100% Replacement of existing Incandescent Lamps	16,843.79	14,032.28
2. 50% Replacement of existing Incandescent Lamps	8,421.89	7,016.14
3. 50% Replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	16,676.51	13,973.52

Table 5-18: Cost of purchasing of LEDs under different scenarios- 2014 data

Scenario (for 2016 data)	Cost of importing LEDs (LKR Mn)	
	under 70 lm/W efficacy bar	under 80 lm/W efficacy bar
1. 100% Replacement of existing Incandescent Lamps	15,527.10	12,935.38
2. 50% Replacement of existing Incandescent Lamps	7,763.55	6,467.69
3. 50% Replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	16,641.13	13,950.13

Table 5-19: Cost of purchasing of LEDs under different scenarios- 2016 data

5.2.7 Simple payback period

Simple payback period was determined in order to check the viability of each scenario considered. Sample calculation for '50% replacement of existing incandescent lamps' with LEDs having efficacy of 80 lm/W is shown below. Calculation was done for 2016 year considering the saving only from energy cost component.

Investment (Cost of purchasing of LED lamps having at least 80lm/W efficacy)

= LKR Mn 6,467.69

Annual financial saving = 3,613.62

Simple payback period

$$= \frac{6,467.69}{3,613.62} = 1.8\ years$$

Similarly payback period for each scenario is calculated and tabulated as follows:

Considered year	Minimum Efficacy bar	Scenario	Simple Payback Period (in years)	
			Considering only the saving from energy cost	Considering total saving (capacity+ energy+ customer related cost)
2014	70 lm/W	1. 100% replacement of existing Incandescent Lamps	2.08	1.02
		2. 50% replacement of existing Incandescent Lamps	2.08	1.02
		3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	3.78	1.85
	80 lm/W	1. 100% replacement of existing Incandescent Lamps	1.69	0.83
		2. 50% replacement of existing Incandescent Lamps	1.69	0.83
		3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	3.09	1.51

Table 5-20: Simple payback period in years (for 2014 consumer data & cost of supply data)

Considered year	Minimum Efficacy bar	Scenario	Simple Payback Period (in years)	
			Considering only the saving from energy cost	Considering total saving (capacity+ energy+ customer related cost)
2016	70 lm/W	1. 100% replacement of existing Incandescent Lamps	2.20	1.08
		2. 50% replacement of existing Incandescent Lamps	2.20	1.08
		3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	4.23	2.07
	80 lm/W	1. 100% replacement of existing Incandescent Lamps	1.79	0.88
		2. 50% replacement of existing Incandescent Lamps	1.79	0.88
		3. 50% replacement of existing Incandescent Lamps + 25% Replacement of existing CFL	3.48	1.70

Table 5-21: Simple payback period in years (for 2016 consumer data & cost of supply data)

5.2.8 Sensitivity Analysis

The LED development during the last decade has been done in massive scale. With the rise in research and development activity around LED, performance of LED has increased rapidly & the prices have been reduced drastically. Hence, it is important to check how the level of MEPS is varied with the price.

A sensitivity analysis was carried out in order to check the sensitivity of least possible acceptable efficacy bar when the price is varying.

When considering total cost of supply (including capacity cost and the customer related cost in addition to the energy cost), it is needed that the benefits (the saving gained by the replacement as per the MEPS) are gained within or less than 1 year from the date of initial investment, in order to be a feasible investment. However, if only the energy cost is taken to determine the saving, a period of 2 year or lesser was considered as a feasible period. The accuracy of the viable efficacy bar was determined up to the 1st decimal using MS excel.

					when both energy saving + capacity saving considered			
Price range	*Coincidence Factor*	*Efficacy Bar*	Financial Saving (scen 1)	Cost of importing LEDS	Financial Saving (scen 2)	Cost of importing LEDS	financial saving (scen 3)	cost of importing (scen 3)
P5	0.4	89.2	10,506.79	10,406.85	5,253.39	5,203.42	5,742.89	9,313.46
			Payback Period (Yrs)		Payback Period (Yrs)		Payback Period (Yrs)	
				0.99		0.99		1.62
					when only energy saving is considered			
			Financial Saving (scen 1)	Cost of importing LEDS	Financial Saving (scen 2)	Cost of importing LEDS	financial saving (scen 3)	cost of importing (scen 3)
			5,141.62	10,406.85	2,570.81	5203.423592	2,810.35	9,313.46
			Payback Period (Yrs)		Payback Period (Yrs)		Payback Period (Yrs)	
				2.02		2.02		3.31

Figure 5.18: Determining sensitivity of efficacy bar with the price

Results:

i. ***Sensitivity of efficacy bar with the variation of market price of LED under different CF (When total cost of supply to HH/kWh is considered)***

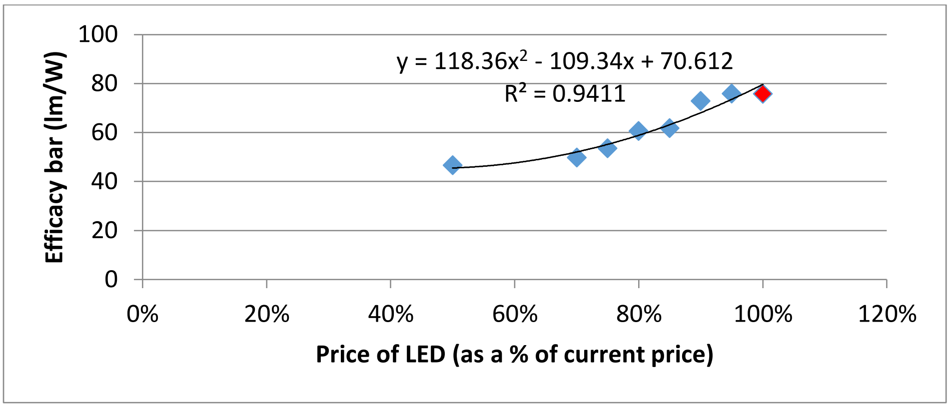


Figure 5.19: Variation of viable efficacy bar vs. price (when CF =0.6)

When the CF is 0.6, at the current market price, the viable efficacy bar (efficacy level which makes payback within 1 year) should be 75.8lm/W. however, if the price is reduced by 20%, the efficacy bar comes down to 60.5lm/W.

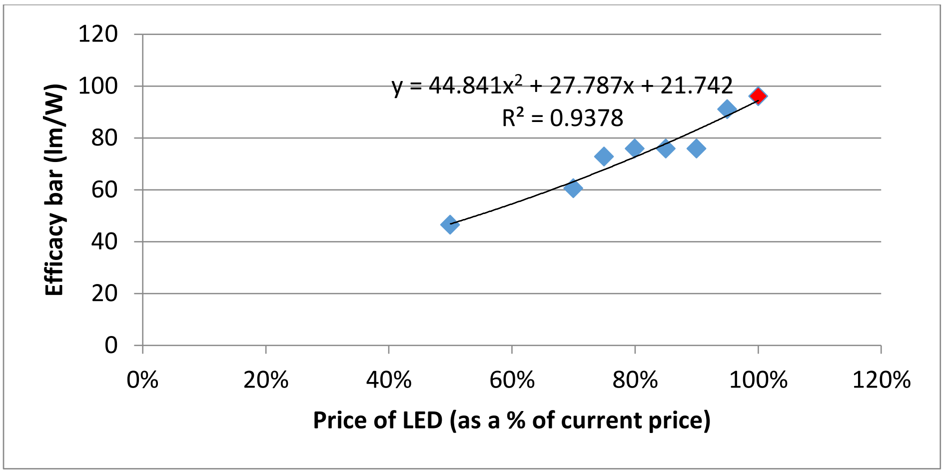


Figure 5.20: Variation of viable efficacy bar vs. price (when CF =0.5)

If the CF is 0.5, at least 96lm/W efficacy bar is required in order to be a viable investment, at the current market price. However, if the price is reduced by 20%, the efficacy bar of 75.8lm/W will be sufficient to pay back within 1 year.

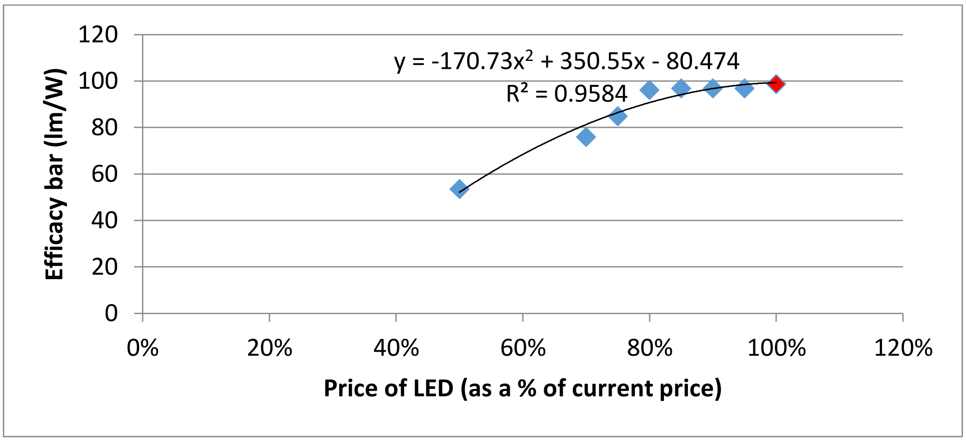


Figure 5.21: Variation of viable efficacy bar vs. price (when CF =0.4)

At the current market price, if the considered CF is 0.4, in order to be a feasible investment, efficacy bar of 98.7lm/W is required. But when the price is reduced by 25%, the viable efficacy bar becomes 85lm/W.

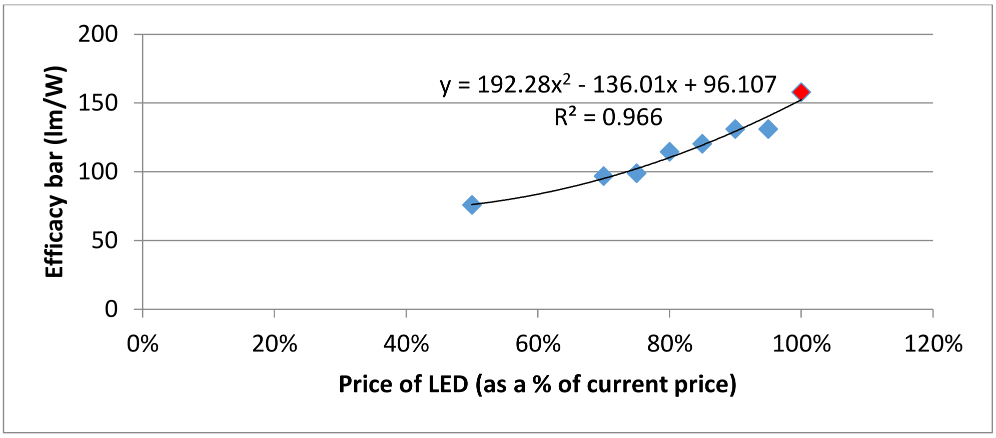


Figure 5.22: Variation of viable efficacy bar vs. price (when CF =0.3)

ii. Sensitivity of efficacy bar with the variation of market price of LED under different CF (When only energy cost of supply to HH /kWh is considered)

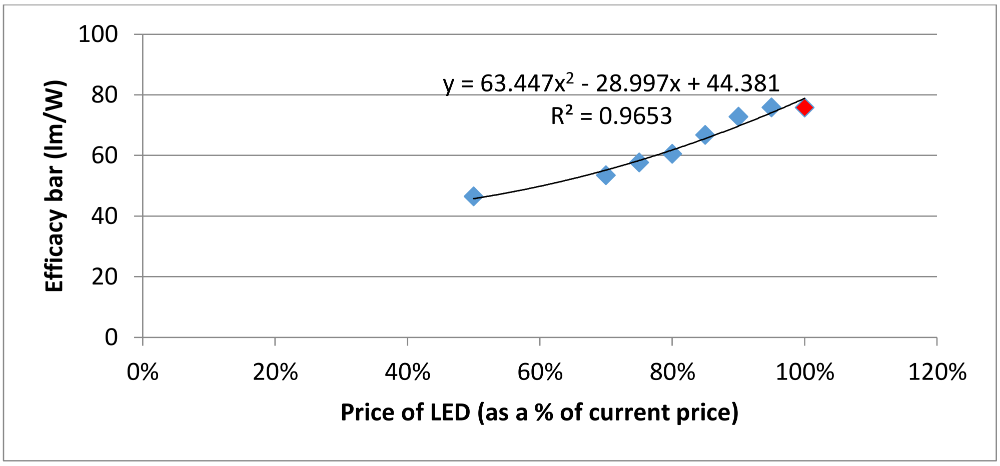


Figure 5.23: Variation of viable efficacy bar vs. price (when CF =0.6)

Similar to the above, Figure 5.23 shows the variation of viable efficacy bar when the market price of the LED varies. The graph has been drawn for 0.6 CF, considering the saving gained only from the energy cost of supply to HH.

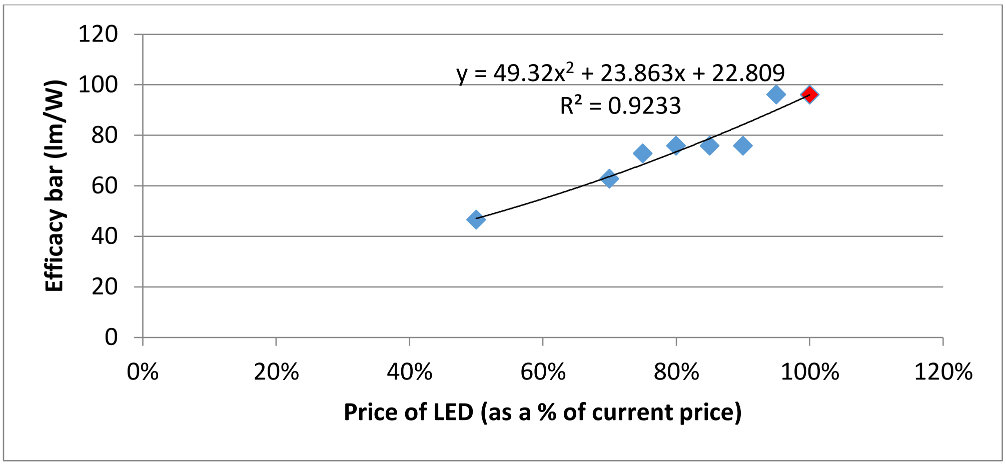


Figure 5.24: Variation of viable efficacy bar vs. price (when CF =0.5)

It is seen that the feasible efficacy bar can be reduced to 75.8 lm/W from 96.1lm/W when the current pricing is reduced by another 20%, under the CF of 0.5.

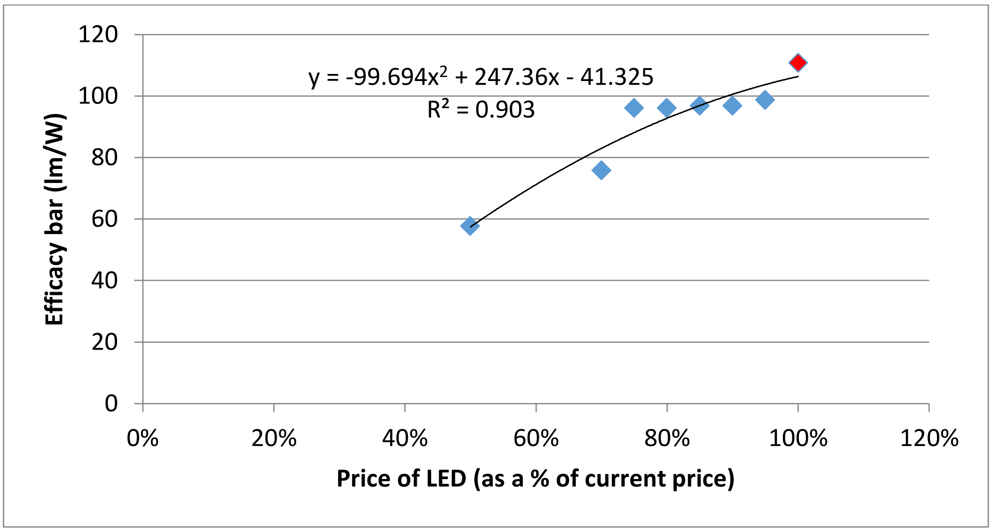


Figure 5.25: Variation of viable efficacy bar vs. price (when CF =0.4)

At the current market price, if the CF is 0.4, at least 111lm/W efficacy bar is required in order to be a viable investment. However, if the price is reduced by 30%, the efficacy bar of 75.8lm/W will be sufficient to pay back within 2 years.

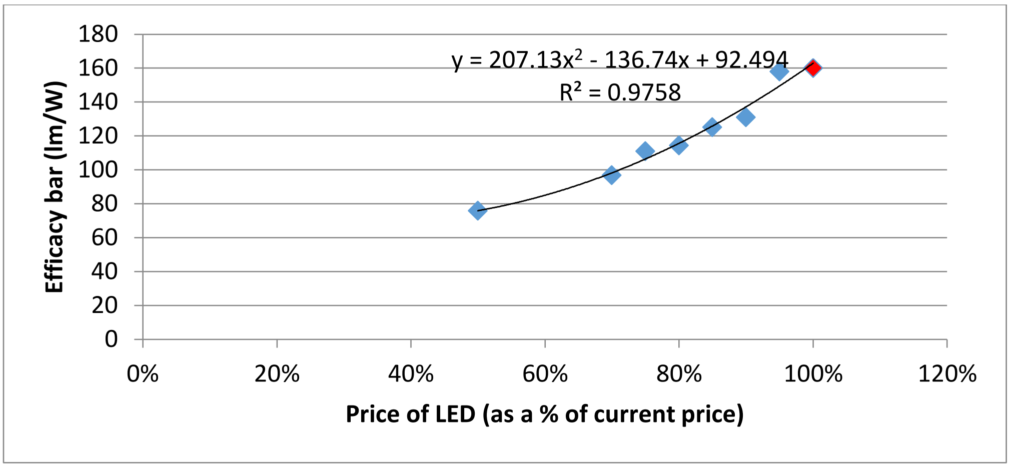


Figure 5.26: Variation of viable efficacy bar vs. price (when CF =0.3)

Eventhough at current market price, in case of 0.3 CF, replacement project is not feasible as the expected efficacy level should be at least 160lm/W. (to be payback within 2 years) however, as LED prices are reducing drastically and also the LED chip efficacy is improving continuously, the above scenario too become feasible within a very few time.

The above graphical interpretations explain how the viable efficacy bar varies with the market price of LED under different CF. As R^2 value is very near to 1, the data are closely fitted with the regression line. Hence, the co-relation between market price and the feasible efficacy bar can be easily obtained.

Results obtained from the sensitivity analysis under two scenarios (only for energy cost saving & considering total cost saving) are annexed at Appendix 4.

6 DISCUSSION AND CONCLUSION

6.1 Discussion

Unlike MEPS of CFL, MEPS for LEDs are still at the developing stage in many countries (despite a few of the developed countries) all over the world. The findings of this study will help policy makers to implement an economically benefited MEPS scheme for LEDs in Sri Lanka.

Many assumptions were taken during the study due to non- availability of data. One such assumption is that, due to unavailability of electricity supply cost data for the considered years (2014 & 2016), it was derived using the available data in 2011, assuming the split of the cost for different customer categories will be the same as of 2011. i.e.,

$$\frac{\text{Unit cost of Supply to HH}}{\text{Overall unit cost of Supply}_{2011}} = \frac{\text{Unit cost of Supply to HH}}{\text{Overall unit cost of Supply}_{2014}}$$

Another assumption was made when finding the total no. of lamps available in each considered year. As 2011 is the last year in which a national level survey on household lighting was conducted, getting the lamp count & their usage pattern for 2014 & 2016 was a challenge. Hence when extrapolating 2011 survey data to 2014 and 2016 following assumptions were made:

i. 30% of incandescent lamps that were available in 2011 have been converted to CFLs by 2014
ii. 40% incandescent lamps that were available in 2011 have been converted to CFLs by 2016

The ratio of the 'Total Lighting Load (domestic)' which is contributed to the system demand at a given time to the 'Total Installed Lighting Load of the domestic sector' was defined as the CF during this study. However finding the CF was another challenge as there was no practical method carried out (sample survey) to evaluate this value. It was obtained only by a theoretical calculation approach, by use of available data from SLSEA, System control centre of CEB and ADB household survey. Even though the CF varies depending on the size of household, an average value was obtained from above theoretical calculation. During the sensitivity analysis, this value was justified by checking the sensitivity of efficacy bar with the variation of market price of LED under different CF.

This study basically finds out

1. The cost to be borne by the individual customer when the existing lamps are replaced with LEDs under each MEPS scheme considered
2. Cost benefit analysis, if a National level replacement project is implemented
3. A sensitivity analysis to check the sensitivity of efficacy bar with the price of the LED

If the MEPS bar is kept at 70 lm/W (efficacy bar) and 0.7 PF bar which was considered as the minimum requirement, an individual customer who is willing to replace his inefficient lighting with LEDs has to pay an annual cost of approximately 630 LKR/1000 lm on average. At this level of MEPS, 32 nos. out of 95 samples tested were qualified which is around 34% of the tested lamps. When the MEPS is placed at a higher standard (Efficacy $\geq$ 80 lm/W and PF $\geq$ 0.9), cost per lm value goes down to a figure around 570 LKR/1000lm. This implies, higher the quality of the lamp, lower the per lumen cost that customer has to be borne. The cost becomes lowest when PF is 0.9. Hence, theoretically PF bar should be kept at 0.9. However at this standard level (Efficacy $\geq$ 80 lm/W and PF $\geq$ 0.9) only 16 nos. of lamps are compiled which makes only 17% of the tested lamps are eligible to be sold, which becomes an unreasonable barrier and a burden to the economy at the initial stage of implementation of MEPS, as this cause restricting too many players out of the field.

It is observed that, if a particular efficacy bar is considered, the average cost/1000 lm figure increases with the power factor up to 0.8 and decreases there onwards.

However, the variation of the average cost/1000 lm figure with the efficacy for a given PF shows a decreasing trend. i.e. higher the efficacy, lower the cost/lm.

In order to justify the minimum efficacy bar that is to be specified, economic analysis was done. This was done with the intention of a national level replacement project covering the whole island. The analysis was done for three replacement scenarios as mentioned in chapter 3.6. It was repeated for 2014 data and 2016 data as well. Simple payback period was obtained again for two cases; when only the saving from energy cost component of the 'cost of supply' is considered and when the total saving (energy+ capacity+ customer related cost) is considered.

Benchmark for the payback period was taken as 2 years when only the saving from energy cost is considered and 1 year when total saving is considered. According to this guideline, minimum efficacy bar requirement is 80 lm/W. However, replacing of efficient lighting like CFL by LED is not viable under the current pricing level.

If it is required that the payback period of the investment to be one year or less, replacing of inefficient lighting such as incandescent lamps is not feasible, if only the energy cost is considered (short term). Nevertheless, benefits are brought within just passed one year even at 70lm/W efficacy bar.

As the prices of LED have been reduced drastically over the last decade, a sensitivity analysis was carried out to check the sensitivity of least possible acceptable efficacy bar when the price is varying. This was done for different CFs & for the above considered two cost scenarios (energy cost & total cost).

According to the analysis, if we consider the saving of total cost and when the CF is 0.6, if the prices have been reduced by 20%, the viable efficacy bar becomes 60.5 lm/W. Similarly, when the CF is 0.4 and if the prices have been reduced by 30%, the feasible efficacy bar drops down to 75.8lm/W from 110.8lm/W. At current pricing level, under the scenarios of CF 0.4 and 0.3 expected viable efficacy bar should be at least 98.7lm/W and 157.8lm/W respectively. Hence, replacement of incandescent lamps by LEDs will not become feasible if the payback time is considered to be 1 year. However, as LED prices are reducing drastically, these scenarios too become feasible as the expected efficacy will fall down to 75.8lm/W if the price has been reduced by 30% and 50% respectively in two scenarios.

If a national level replacement project is implemented, the LED lamp cost will be CIF price. In mass scale purchasing, the cost of a lamp will be even less than half of the existing market price at today. (Appendix 5 contains the wholesale price of a Chinese make LED lamp available at an online store)

6.2 Limitations of the study

This study does not account the variation in lifetime of LED, how the cost varies when the lifetime of LED varies. A fixed lifetime of 15000 hrs was considered when calculating annual average cost incurred by an individual customer.

6.3 Suggestions

- A value for the CF was obtained based on a theoretical calculation. A much fine-tuned figure for "energy saving" can be obtained, if the CF for each time slot (1hr period) has been taken. This can be obtained by conducting a small sample survey covering approximately 300 households.
- It is proposed to consider the lifetime of LED chip and to re-evaluate the variation of cost to improve the results of this study

6.4 Conclusion

1. At the current pricing level, at least 80 lm/W efficacy is needed for LEDs, if it is to be used as an energy efficient replacement. At current market price of LED and the considered total cost of supply to household, a national level replacement project will be paid back within less than a year.

2. When National Level replacement (such as a Government policy) is considered, replacing of inefficient lighting such as incandescent lamps is not feasible, if only the energy cost is considered. When only the energy cost component of the supply cost is considered, payback period is more than a year.

3. However, in long term (including capacity cost), the replacement is viable under 80 lm/W efficacy bar. Even a 70lm/W criteria will bring benefits within almost an year (1.08 years)

4. Under 80 lm/W efficacy bar, when the annual average cost to be borne by an individual customer is considered, it becomes minimum when PF = 0.9. This implies, a high quality & a branded lamp will give you a less per lumen cost when compared to other lamps. i.e., theoretically when the PF bar is kept 0.9, an individual customer gets more benefits. Hence there is no barrier to keep it in such a high value. However if PF is restricted to such a high value like 0.9, only 17% out of the available lamps in the market are qualified, which keeps many players out of the field. Therefore a 0.7 PF is recommended at the initial stage of implementing MEPS and recommended to increase it gradually.

5. Replacing of CFL will not be feasible under any scenario considered as the payback time will be approximately 4 years.

6. The above conclusions were derived based on CFs of 0.65 (during night peak) and 0.22 (during morning peak). However, when the average CF is 0.4, prices need to be reduced by 30% of the current market prices in order to have at least 75.8lm/W efficacy bar. At this CF & current market price, the investment will be viable only for an efficacy bar of 98lm/W.

7. The variation of least possible acceptable efficacy bar against the price of LED lamp under the given CF is closely fitted with the regression line. (R^2 value is close to 1). Hence, for a given CF, the minimum acceptable efficacy bar can be specified depending on the market price of the LED lamp.

7 RECOMMENDED MEPS

- **Scope:**

The proposed Minimum Energy Performance Standard is applicable only to the self-ballasted LED lamps which can be installed as a direct replacement for an incandescent lamp in a standard screw or bayonet (E27, E14, and B22) socket, intended primarily for use in the domestic sector.

- **Efficacy:**

The efficacy of LED lamp should be equal or greater than 80 lm/W in order to be used as an energy efficient replacement

- **Power Factor:**

The Power factor of an LED lamp is proposed to have at least 0.7

- **Colour Rendering Index:**

CRI of an LED lamp should be at least 80

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9 APPENDICES

Appendix 1: LED Lamp test data

Appendix 2: Excel Macro developed to sort out the qualified samples based on efficacy and power factor

Appendix 3: Results of the qualified tested samples under Efficacy > 80 lm/W and the Power factor ≥ 0.8 criteria

Appendix 4: Results of the sensitivity analysis

Appendix 5: Wholesale price of a Chinese make LED lamp available at an online store

Appendix 3

Sample No.	Test Current (mA)	Power (W)	Power Factor	THD	Luminous Flux (lm)	CCT (K)	Chromaticity X	Chromaticity Y	CRI	Luminous Efficacy(lm/W)	Price of LED lamp LKR	Annual Capital Cost - LKR	Cost for energy consumption - LKR	Total Cost (Annual) - LKR	Annual Cost per lumen (LKR/lm)	Annual Cost per lumen (LKR/lm) - Normalized to 1000
9	37.2	8	0.94	0.18	745	2838	0.4481	0.4065	79.75	93.13	900	86.51	369.09	455.59	0.612	611.534
14	45.26	8.79	0.84	0.25	920.2	6053	0.3206	0.3368	70.59	104.69	700	67.28	405.54	472.82	0.514	513.820
31	40	8.48	0.9	0.27	787.7	2966.9	0.4395	0.4054	70.9	92.89	900	86.51	391.23	477.74	0.606	606.498
32	42	8.75	0.91	0.29	868.8	5393.6	0.335	0.351	73.7	99.29	900	86.51	403.69	490.20	0.564	564.221
33	32	6.86	0.91	0.23	659.7	2941.2	0.4411	0.4056	70.7	96.17	700	67.28	316.49	383.77	0.582	581.741
34	33	7.04	0.91	0.23	761.1	5413.2	0.3345	0.3503	73.4	108.11	900	86.51	324.80	411.30	0.540	540.405
35	44	8.64	0.85	0.58	753.3	6008.2	0.3216	0.3349	87.9	87.19	900	86.51	398.62	485.12	0.644	643.993
36	46	8.97	0.85	0.57	732.9	2756.3	0.4544	0.408	80.3	81.71	900	86.51	413.84	500.34	0.683	682.692
37	33	7.04	0.91	0.23	761.1	5413.2	0.3345	0.3503	73.4	108.11	900	86.51	324.80	411.30	0.540	540.405
38	32	6.86	0.91	0.23	659.7	2941.2	0.4411	0.4056	70.7	96.17	700	67.28	316.49	383.77	0.582	581.741
39	42	8.75	0.91	0.29	868.7	5393.6	0.335	0.351	73.7	99.29	900	86.51	403.69	490.20	0.564	564.286
40	40	8.48	0.9	0.27	787.7	2966.9	0.4395	0.4054	70.9	92.89	900	86.51	391.23	477.74	0.606	606.498
42	46	8.97	0.85	0.57	732.9	2756.3	0.4544	0.408	80.3	81.71	900	86.51	413.84	500.34	0.683	682.692
43	44	8.64	0.85	0.58	753.3	6008.2	0.3216	0.3349	87.9	87.19	900	86.51	398.62	485.12	0.644	643.993
45	29	6.31	0.94	0.24	683.3	3122.4	0.4247	0.3929	84.5	108.29	700	67.28	291.12	358.40	0.525	524.513
46	32	6.46	0.89	0.28	601.4	5135.9	0.3418	0.3566	75.2	93.1	700	67.28	298.04	365.32	0.607	607.450
47	44	9.67	0.95	0.27	1087	5147.3	0.3413	0.3523	75	112.41	900	86.51	446.14	532.64	0.490	490.009
48	43	9.46	0.95	0.25	890.6	3160.6	0.4235	0.3948	83.2	94.14	900	86.51	436.45	522.95	0.587	587.190
69	32	6.46	0.89	0.28	601.4	5135.9	0.3418	0.3566	75.2	93.1	700	67.28	298.04	365.32	0.607	607.450
70	44	9.67	0.95	0.27	1087	5147.3	0.3413	0.3523	75	112.41	900	86.51	446.14	532.64	0.490	490.009
71	43	9.46	0.95	0.25	890.6	3160.6	0.4325	0.3948	83.2	94.14	900	86.51	436.45	522.95	0.587	587.190
80	32	6.46	0.89	0.28	601.4	5135.9	0.3418	0.3566	75.2	93.1	700	67.28	298.04	365.32	0.607	607.450
82	43	9.46	0.95	0.25	890.6	3160.6	0.4235	0.3948	83.2	94.14	900	86.51	436.45	522.95	0.587	587.190
83	44	9.67	0.95	0.27	1087	5147.3	0.3413	0.3523	75	112.41	900	86.51	446.14	532.64	0.490	490.009
95	39	7.63	0.86	0.24	663.2	6232	0.3176	0.3297	71.1	86.92	900	86.51	352.02	438.52	0.661	661.222

Annual cost per lumen for each qualified sample under 80 lm/W and PF>=0.8 Criterion