UNEP Collaborating Centre for Energy Efficient Lighting

Southeast Asia
Compact Fluorescent Lamp
Performance and Mercury Content
Testing Report and Analysis

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Acknowledgements
This report was prepared by the Global Efficient Lighting Center for the United Nations Environment Programme (UNEP)–Global Environment Facility (GEF) en.lighten initiative, with the financial support of the Australian Government, as part of the Southeast Asia Efficient Lighting Monitoring, Verification and Enforcement (MVE) project.

About the Global Efficient Lighting Centre
The GELC-UNEP Collaborating Centre for Efficient Lighting was launched in partnership between UNEP and the National Lighting Test Centre (NLTC) in September 2011. GELC is a non-profit organization running as an independent third party. It is a specialized and accredited facility that provides lighting testing, training, advice, quality control and capacity building support to the developing and emerging countries. It has been established to promote the rapid development of the energy efficient lighting technologies around the world.

For more information about GELC, please visit www.gelc.com.

About the United Nations Environment Programme-Global Environment Facility en.lighten initiative
The United Nations Environment Programme (UNEP)-Global Environment Facility (GEF) en.lighten initiative was established in 2010 to accelerate a global market transformation to environmentally sustainable, energy efficient lighting technologies, as well as to develop strategies to phase out inefficient incandescent lamps to reduce CO_2 emissions and the release of mercury from fossil fuel combustion.

The en.lighten initiative serves as a platform to build synergies among international stakeholders; identify global best practices and share this knowledge and information; create policy and regulatory frameworks; address technical and quality issues; and encourage countries to develop National and/or Regional Efficient Lighting Strategies.

The United Nations Secretary General's Sustainable Energy for All (SE4ALL) initiative selected the UNEP –GEF en.lighten initiative to lead its lighting 'Energy Efficiency Accelerator'.

The initiative is a public/private partnership between the United Nations Environment Programme, OSRAM and Philips Lighting, with the support of the Global Environment Facility. The National Lighting Test Centre of China became a partner in 2011, establishing the Global Efficient Lighting Centre and the Australian Government joined in 2013 to support developing countries in Southeast Asia and the Pacific.

In 2015, based on the lessons learned from the en.lighten initiative, UNEP launched the United for Efficiency (U4E) initiative to support countries in their transition to energy efficient appliances and equipment, including room air conditioners, residential refrigerators, electric motors, distribution transformers and information and communication technologies.

For more information about the en.lighten initiative please visit: www.enlighten-initiative.org.

About the Southeast Asia Efficient Lighting Monitoring, Verification and Enforcement Project

The Southeast Asia Efficient Lighting MVE project is being implemented by the UNEP en.lighten initiative with the financial support of the Australian Government. This Project aims at reducing greenhouse gas (GHG) emissions related to lighting in the countries of South-East Asia and the Pacific, by means of strengthening lighting monitoring, verification and enforcement schemes and infrastructure in the region. In addition to lamp testing, a series of capacity building activities have been implemented, including regional and national workshops and consultation, technical training, technical guidance development, and others. The project focuses specifically on six target countries of Cambodia, Indonesia, Lao PDR, Philippines, Thailand, and Vietnam and en.lighten has been collaborating with the Secretariat of the Pacific Community on the development of a Pacific Efficient Lighting Strategy in order to achieve a regional transition to energy efficient lighting

For more information about the Southeast Asia MVE project, please visit: http://www.enlighten-initiative.org/CountryActivities/SoutheastAsiaandPacificMVEProject.aspx

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KEY TERMS AND DEFINITIONS

Amalgam: an alloy of mercury with another metal that is solid or liquid at room temperature according to the proportion of mercury present.

Bayonet cap (base): cap (international designation B) with bayonet pins on its shell which engage in slots in a lampholder.

Chromaticity coordinates: ratio of each of a set of three tristimulus values to their sum.

Colour Rendering Index: measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation.

Correlated colour temperature (CCT): the temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions; unit: K.

Efficacy (of a source): quotient of the luminous flux emitted by the power consumed by the source. Unit: lm/ W Symbol: η_v or η.

Fluorescent lamp: a discharge lamp of the low pressure mercury type in which most of the light is emitted by one or several layers of phosphors excited by the ultraviolet radiation from the discharge.

General lighting: substantially uniform lighting of an area without provision for special local requirements.

Initial values: the photometric and electrical characteristics at the end of the 100 hour ageing period.

Lamp: source made in order to produce an optical radiation, usually visible.

Lamp cap (base): that part of a lamp which provides connection to the electrical supply by means of a lampholder or lamp connector and, in most cases, also serves to retain the lamp in the lampholder.

Luminous flux: quantity derived from radiant flux Φe by evaluating the radiation according to its action upon the CIE standard photometric observer. For photopic vision is the spectral distribution of the radiant flux and V(λ) is the spectral luminous efficiency. Unit: lm $\phi_v = K_m \int_0^\infty \frac{d\phi_e(\lambda)}{d\lambda} \bullet V(\lambda) d\lambda$

Where $\frac{d\phi_e(\lambda)}{d\lambda}$

Luminous maintenance (of a lamp): the luminous flux at a given time in the life of a lamp divided by the initial value of the luminous flux of the lamp and expressed as a percentage of the initial luminous flux.

Maximum mercury content: maximum amount of mercury added to gas discharge lamps to enable their operation.

Mercury (Hg): a metallic element, the only one that is liquid at room temperature.

Minimum energy performance standards (MEPS): regulatory measures specifying minimum efficiency levels acceptable for products sold in a particular country, or region or at the international level. MEPS define what products can be marketed and which ones should be eliminated.

Power: derivative with respect to time t of energy E being transferred or transformed:

$$P = \frac{dE}{dt}$$

Power factor: under periodic conditions, ratio of the absolute value of the active power *P* to the apparent power *S*:

$$\lambda = \frac{|P|}{S}$$

Rated power (of a type of lamp): the value of the power of a given type of lamp declared by the manufacturer or the responsible vendor, the lamp being operated under specified conditions: Unit: W.

Rated voltage or rated voltage range: nominal voltage/range of voltage at which a piece of electrical equipment is designed to operate.

Screw cap (**base):** cap (international designation E) having its shell in the form of a screw thread which engages the lamp holder.

Type: lamps that, independent of the type of cap, are identical in photometric and electrical rating.

1 EXECUTIVE SUMMARY

Introduction

The objectives of this project are to support decision-makers in the six target countries of the Southeast Asia Efficient Lighting Monitoring, Verification and Enforcement Project (Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Vietnam), via a series of capacity building activities, including market review, product sampling, and testing to recognize the importance of energy performance and quality in lighting products. These activities can help to demonstrate the value of strengthening national quality control and testing systems, improve the understanding of energy efficient lamp performance, quality, testing process, interpretation of test results, as well as associated technical issues for national stakeholders, and helping them to establish effective compliance schemes and policies suitable for their particular market conditions.

Compact fluorescent lamps (CFLs) have been selected, along with light emitting diode (LED) lamps[1], as one of the target technologies for this testing activity. The reasons for this selection are:

- Globally, CFLs are currently the most commonly used type of efficient lighting product in the residential sector. They are the most recognized energy efficient alternative to incandescent lamps, as they can use up to 75% less energy and last six to ten times longer.
- Since their introduction, CFLs have been the mainstay of many government lighting energy efficiency programmes, and remain the basis for many energy efficient lighting policies and minimum energy performance standards (MEPS).
- For many countries, the market for CFLs can be considered mature, with large production and/or consumption volumes;, wide availability of manufacturers, products and price range; and retail availability.
- International test methodologies are available for measuring the performance of CFLs, with many well-qualified, experienced independent and national laboratories available.

For these reasons, this study was designed to focus on the parameters that can help to assess the quality of CFLs currently available in the six targeted countries, and to compare their performance to requirements for lamps available in other countries, as well as previous testing results, where possible.

This report provides an overview of the CFL identification, selection and sampling process, describes the testing methodologies used, and summarizes the results from the performance testing conducted on the lamp samples collected from each of the market. It provides a summary and comparison of results across the markets, as well as an analysis of the results for each of the markets. In addition to the technical analysis of the lamp test results by GELC presented here, the UNEP-GEF en.lighten initiative has added an additional observations and recommendations section in order to provide the report with further policy context.

The 80 CFL models selected for testing are integral (self-ballasted), omni-directional, bare lamp (no cover, no reflector) for indoor, general lighting service applications. There are 17 models of high wattage lamps (>=18W, with light output higher than 800 lumens) and 10 models of low wattage lamps (5W, with the light output lower than 450 lumen), representing the CFL models which can

[1] Light emitting diode (LED) lamps were also tested as part of this exercise. The results of this testing are provided in a separate report, *Southeast Asia Light Emitting Diode Lamps Performance Testing and Analysis Report.*

replace the most popular incandescent applications in these markets. It should be noted that the activities documented by these reports are illustrative of the process to identify, sample and test products only, and not a full benchmarking exercise.

Methodology

A total of 80 CFL models were obtained from the six Southeast Asian target countries in this project by the International Institute for Energy Conservation (IIEC), from locations in the six target markets. Lamps models were tested for the most critical parameters related to lamp performance and quality. In addition, lamps were also tested for mercury content. Due to the limited timeframe available, it was not possible to test all of the parameters covered in a typical minimum energy performance standard (MEPS). The performance parameters tested are included below:

- Lamp power,
- Power factor,
- Initial luminous flux (and initial efficacy),
- Correlated colour temperature (CCT),
- Colour rendering index (CRI),
- Standard Deviation of Colour Matching (SDCM) and
- Luminous maintenance at 2,000 hours.

The International Electrotechnical Commission (IEC) standards covering lamp performance parameters are the most recognized and widely adopted by countries, and readily available for CFLs, therefore, all the tests were conducted according to the IEC standard. The testing was conducted in accordance with:

- IEC 60969, *Self-ballasted lamps for general lighting services - Performance requirements*[2].

The mercury content testing was conducted in accordance with:

- IEC 62554, *Sample preparation for measurement of mercury level in fluorescent lamps*[3].
- IEC 62321, *Electrotechnical products - Determination of levels of six regulated substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers)*[4].

As the IEC standards only specify the test methodologies for the performance parameters without specifying their threshold levels, other reference standards available internationally were used to establish minimum requirement levels for CFL performance parameters for comparison purposes. The established performance levels from the following standards were used, representing requirements in a number of major lamp markets globally:

[2] This standard specifies the performance requirements together with the test methods and conditions required to show compliance of tubular fluorescent lamp and other gas-discharge lamps with integrated means for controlling starting and stable operation (self-ballasted lamps intended for domestic and similar general lighting purposes

[3] This standard specifies sample preparation methods for determining mercury levels in new tubular fluorescent lamps (including single capped, double capped, self-ballasted and CCLF for backlighting) containing 0.1 mg mercury or more.

[4] This standard specifies the determination of the levels of lead, mercury, cadmium, hexavalent chromium contained in inorganic and organic compounds, and two types of brominated flame retardants, polybrominated biphenyls and polybrominated diphenyl ethers contained in electrotechnical products.

- EU Regulation No. 244/2009, *Ecodesign requirements for non-directional household lamps* (European Union)
- AS/NZS 4847.2, Self *ballasted lamps for general lighting service Part 2: Minimum Energy Performance Standards requirements* (Australia and New Zealand)
- *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0* (United States)
- *Energy Saving Trust Lamp Specification V7* (United Kingdom)
- GB/T17263, *Self-ballasted lamps for general lighting service* (China)
- *Minamata Convention on Mercury* (United Nations)
- EU ROHS Directive 2002/95/EC (European Union)

In addition to the above reference standards, the results for lamps collected from each country were also compared with the applicable national standards or labelling requirements, as well as with available benchmarking results from a round of United States- and Australia-supported testing from 2010[5], in order to provide the report with further policy context.

Summary of results

A summary comparison between the tested results and the requirements of international standards are provided in Tables ES 1 and ES 2. Further comparison to national standards, where appropriate and available, are provided in the individual country sections.[6] Table ES 1 lists the number of models that did not meet the most strict requirements of the above listed comparison standards, and Table ES 2 lists the number of models that did not meet the lowest requirement of the above listed comparison standards.

Table ES 1. The number of models that did not meet the most strict requirement of the comparison standards

Country	No. of models tested	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	2	6	3	1	7	13
Indonesia	14	0	7	2	0	12	13
Lao PDR	11	0	5	0	2	7	11
Philippines	14	0	5	0	4	11	13
Thailand	14	1	5	0	2	11	14
Vietnam	13	0	7	3	6	12	13

[5] *Testing for Quality: Benchmarking Energy-Saving Lamps in Asia*. USAID, Bangkok, Thailand, April 2010.
[6] It should be understood that the above referenced international standards may have differences in the test methods and sample sizes, therefore these reference comparison standards are only used to provide a general picture of the product quality levels.

Table ES 2. The number of models that did not meet the lowest requirement of the comparison standards

Country.	No. of models tested	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	0	2	3	1	5	2
Indonesia	14	0	0	2	0	3	7
Lao PDR	11	0	0	0	2	4	0
Philippines	14	0	2	0	4	4	0
Thailand	14	0	0	0	2	4	1
Vietnam	13	0	1	3	7	1	3

From these tables, it can be seen that some models of lamps demonstrated high luminous efficacy and good colour characteristics, while other lamps had some problems, mainly on luminous maintenance, SDCM and luminous efficacy. Judging from the number of models not meeting this requirement Luminous maintenance at 2,000 hours is the most challenging parameter for manufacturers if they have to comply with international requirements. Luminous efficacy shows high non-compliance rate when compared with the most strict international requirements, however the standards included two voluntary programmes intended to recognize the best performing lamps in the market (i.e. ENERGY STAR, Energy Saving Trust). As the tested lamps were randomly sampled from local markets, they can serve as indicators for the quality of products for sale in those markets.

Specific to mercury content of lamps, this exercise showed that in some countries there is still a high percentage of non-amalgam (liquid mercury) lamps. As it is harder to accurately control the level of mercury in non-amalgam lamps, Governments may wish to give consideration to this, especially if they intend to adopt the Minamata Convention or harmonize with the stricter requirements.

Additional observations

Currently in many markets, CFLs can be considered a mature product category, with established performance characteristics and benchmarks, and well-known retail and distribution framework. For the six target countries, CFL products generally are available in many locations, with developed retail networks and pricing structures, giving consumers choices in price, brands, and shopping locations. While the retail locations were not broken down by country, the variety of CFL products available, and locations at which they were sold in each of the countries, seem to indicate that the distribution channels for CFLs are quite developed as well in at least five, if not all of the six target countries.[7]

In both pricing and retail distribution, the markets of Indonesia, Philippines, Thailand, and Vietnam seems to fit this categorization, showing a similar range of pricing, and performance, as well as stability (when compared to available 2010 data). For Cambodia, there is no previous data for comparison, but the observed low end of the price ranges for Cambodia are lower than others in the region. This may indicate that consumers and retailers in Cambodia are still focusing on price when selecting products. Similarly, there is no previous data for Lao PDR, but the observed pricing range is quite close to other countries with more developed markets in the region.

[7] It was not possible to link product pricing to performance results, as in the case of the 2010 study.

Because CFLs have been in the market for quite some time, and are widely available currently, many countries have implemented standards or labelling schemes. Therefore it was possible to compare the levels of performance of these products relative to the existing national standards or labelling requirements, and not just international standards or labelling requirements. Table ES 3, below shows the number of tested models and the percentage in each country that met the national requirements (where applicable and/or available). Because the lamps were not fully tested for all of the parameters required by the national standards, the comparison presented here is for informational purposes only.

Table ES 3. Models meeting national labelling or minimum requirements

Country	No. of models	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	NA	NA	NA	NA	NA	NA
Indonesia	14	NA	14	NA	NA	14	NA
Lao PDR	11	NA	NA	NA	NA	NA	NA
Philippines	14	NA	11	NA	NA	13	NA
Thailand	14	NA	14	NA	NA	13	NA
Vietnam	13	NA	12	NA	NA	13	NA

In addition to comparing the current lamps' performance to requirements by international and national standards, it was possible to compare the results from the performance and mercury testing of these lamps to results from an 2010 benchmarking testing effort for Indonesia, Philippines, Thailand, and Vietnam, as shown in Table ES 4. Such a comparison can also provide some indications of market progress in terms of performance or advancements in product designs. This comparison exercise can be only indicative, however, as the sampling methods, the number of samples, and the number of parameters tested may not be comparable. This, only a very broad interpretation can be made regarding any quality and performance trends (for example, no start up or warm up time or switching withstand tests were conducted in 2014).

Table ES 4. Comparison of lamp test results from 2010 and 2014

Country	Average power factor		Average efficacy (lm/W)		Average CRI		Average luminous maintenance (%)		Average mercury (mg)		Maximum mercury (mg)	
	2010	2014	2010	2014	2010	2014	2010	2014	2010	2014	2010	2014
Indonesia	0.60	0.59	55	60	80	82	.92	.88	4.9	2.7	>20	9.6
Philippines	0.58	0.59	58	58	81	83	.77	.86	5.0	2.1	>13	7.0
Thailand	0.58	0.60	56	59	81	82	.90	.86	4.0	1.8	>20	10.9
Vietnam	0.57	0.59	62	58	80	82	.86	.88	7.0	3.1	>20	16.5
Cambodia	NA	0.59	NA	58	NA	82	NA	87	NA	3.1	NA	16.7
Lao PDR	NA	0.59	NA	55	NA	79	NA	87	NA	3.6	NA	13.3

The comparisons seem to indicate that products in Indonesia, Philippines, Thailand, and Vietnam have marginally improved in some areas, such as CRI. Lamps from Indonesia and Thailand show improvements in average lamp efficacy, Philippines' remain unchanged, and Vietnam's showed a slight decline. Lamps from Indonesia, Thailand and Vietnam have declined in average luminous maintenance, while those from the Philippines improved. However, the noted changes are within the typical margin of laboratory error (~3%) for some categories. Specific to efficacy, the changes may be due to MEPS being in place in those countries, as most tested lamps are in compliance with national requirements, so this may indicate that manufacturers are focused more on compliance to established requirements and product consistency, or maintaining parity with competitors, rather than increasing performance.

Most notable are the changes in average mercury content for lamps in each country, which has significantly reduced: lamps from Vietnam showed the most reduction, going from an average of 7 mg in 2010 testing to an average of 3 mg in the lamps tested in this exercise. Average mercury content of lamps from Indonesia, Philippines, and Thailand all showed at least a 50% decline average content. It is also worth noting that not only has the average mercury content of the lamp' declined, but the maximum amount per lamp model found in the lamps in each country has also reduced significantly (Vietnam is the only exception, with a decline of less than 30% in highest content sample). No comparison data is available for Cambodia or Lao PDR. However, the average mercury in lamps for these two markets is in line with the average of other countries in the region for 2014.

Recommendations

It is expected that this report will serve as a good reference to those countries and stakeholders to better understand lamp identification, collection and testing processes and interpretation of results, as well as the availability, performance levels, and overall quality of lamps in their market. While it was not possible to obtain the complete picture of lamp quality without the results of lifetime testing and other parameters important to consumer satisfaction, such as start up and warm up time, there is sufficient information for countries without MEPS or labelling policies to consider the development of these policies, or for countries to consider a range of supporting policies, including monitoring, verification and enforcement (MVE) activities based on the test results.

Countries may consider which measures would be necessary to implement to improve and control lamp product quality, but product testing should remain a priority, so that consumers are protected and receive the expected benefits from the products, and the energy savings promised by efficient lighting are delivered. Even for countries with limited resources, the fact that CFLs are a mature technology in these markets means that there are numerous laboratories in the region experienced in CFL testing methodologies, which can compete to provide support for MVE efforts. Further, the results from this testing show the value of having a regional market picture, which can further inform MEPS development and strengthen MVE activities for each country, as well as the whole region.

Below are a number of policy steps that countries may consider in order to follow up and build upon the successful completion of this region-wide effort:

- **Continue or increase product sampling and testing of national markets**: It can be seen that CFLs have achieved significant penetration in all the markets, with a wide range of model choices, wattages, form factors, and retail locations. More importantly, the overall quality seems to have improved or stabilized over what was available in the region nearly half a decade ago. In large part this is thanks to steps that have been taken by countries to address

this issue. Yet, a comparison of results shows that luminous maintenance, for example, remains low relative to international requirements. A concerted follow up effort to continue the sampling, testing, and publicising results, building on the framework established by this project, and focusing on longer-term testing of products, could go far toward improving verification capacities. Such actions can help to maintain, or to increase product quality for all energy efficient lighting products in the region.

- **Consider more stringent performance standards for CFLs**: Countries may wish to consider the development process of MEPS or labelling requirements for CFLs to include higher performance levels, aligning with international requirements, or comparable to those for LED lamps (or consider High Efficiency Performance Standards (HEPS) in addition to the current requirements). This will help to guide CFL manufacturers by giving them clear indications of future policy directions, increase the focus on quality, while requiring emerging LEDs to meet or exceed performance and quality levels set for CFLs to protect consumers and drive the market..

- **Begin market transition and consumer outreach**: Governments could also consider a roadmap of how the market should transition to LED lamps. While CFLs remain a cost effective efficient option (and generally the lower first cost option), LED lamps can be a more preferable alternative in certain consumer applications, such as in hard to reach and/or long operation hour locations, for operation in a dimming circuit, applications where rapid starting or frequent switching are needed, or where CFL disposal can be an issue. Consumers and manufacturers alike will require more guidance as the new technology enters the market. A campaign to educate consumers about new energy efficient lighting choices may be required. Such a campaign can also help to prepare the market for new or revised MEPS or labelling requirements.

- **Reduce or remove existing CFL incentives:** As CFLs are a mature technology, and the markets are transitioning with emerging efficient technologies, governments currently providing support for CFLs may consider reducing or gradually removing support for CFLs, as appropriate. Alternatively, for countries importing CFLs and other energy efficient technologies, governments may want to consider extending financial advantages, such as VAT tax exemption to all energy efficient lighting technologies.

- **Continue to reduce mercury in lamps through regulations**: As there is still a high percentage of non-amalgam lamps in some markets, countries should consider encouraging the use of amalgam mercury to reduce mercury content and improve recovery rates. This can be accomplished by adding requirements for maximum mercury content for lamps (for example, 2.5 mg for “low mercury” lamps) as well as for run-up time for CFLs (amalgam lamps can be slower to reach steady operating conditions and to provide suitable light output), along with suitable testing and verification schemes to ensure compliance.

- **Consider a collection and disposal strategy for spent lamps:** As CFLs burn out or are broken in normal use, it is imperative that broken and spent lamps are properly handled and disposed of, in order to minimise mercury contamination and accumulation in the environment. Along with efforts to minimise lamp mercury content, governments may also want to consider working with stakeholders to develop a collection and disposal framework

for spent lamps, which may include collection and recycling points around the country, as well as an outreach and educational campaign on proper handling and disposal methods.

- **Embrace regional cooperation**: As shown by the test results, many countries are in the same situation with respect to CFL performance, market development, recycling and disposal challenges, as well as emerging technologies. It could be a good juncture for the region as a whole to cooperate on these issues, building on international experience and establishing best policy practices for the region. Countries can build on the existing network, knowledge base, and international efforts, as well as with the regional exchanges and Asia-specific information networks that have been built to date.

2 INTRODUCTION

As of August 2015, 67 world countries are members of the UNEP-GEF en.lighten Global Efficient Partnership Programme, committing to adopt policies to phase-out inefficient incandescent lamps in their markets. Many will establish minimum energy performance standards (MEPS) to do so. To be effective, these standards need to be reinforced by a monitoring, verification and enforcement (MVE) scheme. The lack of lighting technology knowledge and quality control measures are barriers for those countries seeking to improve access to good quality, efficient lamps in their markets.

The objectives of this project are to support decision-makers in the six target countries of the Southeast Asia Efficient Lighting Monitoring, Verification and Enforcement Project (Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Vietnam), via a series of capacity building activities, including market review, product sampling, and testing to recognize the importance of energy performance and quality in lighting products. These activities can help to demonstrate the value of strengthening national quality control and testing systems, improve the understanding of energy efficient lamp performance, quality, testing process, interpretation of test results, as well as associated technical issues for national stakeholders, and helping them to establish effective compliance schemes suitable for their particular market conditions.

This report provides an overview of the CFL selection and sampling process, describes the testing methodologies used, and summarizes the results from the performance testing conducted on the lamp samples collected from each of the market.[8] It provides a summary and analysis of the results for each of the market, as well as a comparison of results across the markets, and to requirements in other major markets globally. A detailed description of the market review, sample identification, collection process, and lessons learned are contained in a companion UNEP-GEF en.lighten report.[9] It should be noted that the activities documented by these reports are illustrative of the process to identify, sample and test products only. Any market sampling process to support policy development will need to be conducted in such a way that a statistically significant number of samples (representative of the whole market) is collected for testing.[10]

[8] UNEP executed an agreement with the Global Efficient Lighting Centre (GELC) located in Beijing, China In order to deliver the testing and training activities defined under this project. GELC initiated performance testing of a series of lamps purchase in each of the six target countries at the end of 2014.

[9] *Lamp Sampling in Cambodia, Indonesia, Lao PDR, the Philippines, Thailand and Vietnam*, report prepared for the UNEP-GEF en.lighten initiative by the International Institute for Energy Conservation, Bangkok, Thailand 2014.

[10] More information on market sampling can be found in the UNEP-GEF en.lighten initiative guidance note, *Efficient Lighting Market Baselines and Assessment*, and *Product Selection and Procurement for Lamp Performance Testing* .

In addition to the technical analysis of the test results by GELC presented here, the UNEP-GEF en.lighten initiative has added an observations and recommendations section in order to provide the report with further policy context. This additional section provides a summary comparison of the lamp performance parameters against national standards or MEPS, where available, as well as a comparison of the average pricing and results with available earlier pricing and benchmark test results from 2010 for Indonesia, Philippines, Thailand, and Vietnam.[11]

3 METHODOLOGY

3.1 Lamp types

Compact fluorescent lamps (CFLs) have been selected, along with light emitting diode lamps (LED)[12], as one of the target technologies for this testing activity. The reasons for this selection are:

- Globally, CFLs are currently the most commonly used type of efficient lighting product in the residential sector. They are the most recognized energy efficient alternatives to incandescent lamps, as they can use up to 75% less energy and last six to ten times longer.
- Since introduction, CFLs have been the mainstay of many government lighting energy efficiency programmes, and are the basis for many energy efficient lighting policies and MEPS.
- The market for CFLs can be considered mature, with large production volumes, wide availability of manufacturers, products, price range, and quality.
- International test methodologies are available for measuring the performance of CFLs, with many well-qualified independent and national laboratories available.

For these reasons, this study was designed to focus on the parameters that can help to determine the quality of CFLs currently available in the six targeted countries, and to compare their performance to lamps available in other countries where possible, as well as previous testing results, as appropriate. The CFLs selected for testing have the following characteristics:

- **Applications**: These lamps are intended to replace the most popular incandescent lamps (40W – 60W, or 450 – 800 lumens), as well as other typical incandescent applications (25W and 75W or higher);
- **Lamp type:** Integral (self-ballasted); for indoor, general lighting service applications; omni-directional; bare lamp (no cover, no reflector);
- **Rated power:** equal to or greater than 5W and equal to or less than 30W
- **Lamp base:** "Normal" size for typical socket in the country. For example, for a screw base lamp, E26 or E27 base;
- **Voltage:** rated between 100V to 240V; electrical mains voltage (per country requirements);
- **Lamp shape:** Spiral or tubular.

[11] *Testing for Quality: Benchmarking Energy-Saving Lamps in Asia*. USAID, Bangkok, Thailand, April 2010.
[12] Light emitting diode (LED) lamps were also tested as part of this exercise. The results of this testing are provided in a separate report, *Southeast Asia Light Emitting Diode Lamps Performance Testing and Analysis Report*

3.2 Lamp sampling

A total of 80 CFL models were obtained from the six Southeast Asian target countries in this project. The lamps were purchased by the International Institute for Energy Conservation (IIEC), from various locations in these target markets, as shown in Table 1.

Table 1 Country of origin, number of CFL models and lamps collected, apparent condition as received by testing laboratory

Country	Number of CFL models collected	Lamps collected per model[13]	Total number of lamps collected	Number of broken lamps
Cambodia	14	30	420	1 lamp
Indonesia	14	30	420	0
Lao PDR	11	30	330	0
Philippines	14	30	420	1 lamp
Thailand	14	30	420	0
Vietnam	13	30	390	0
Total	80	30	2400	2 lamps

The IIEC representative and the UNEP-GEF en.lighten initiative focal point in each participating country were responsible for collecting the lamps in each market, and for the marking, packing and shipping to GELC for testing. For each unique model, 30 lamps were purchased at random, based on IIEC's initial surveys and country representatives' selection of the most popular models. A total of 80 lamp models (2,400 lamps) were collected for testing.

3.3 Overview of lamp samples collected for performance tests

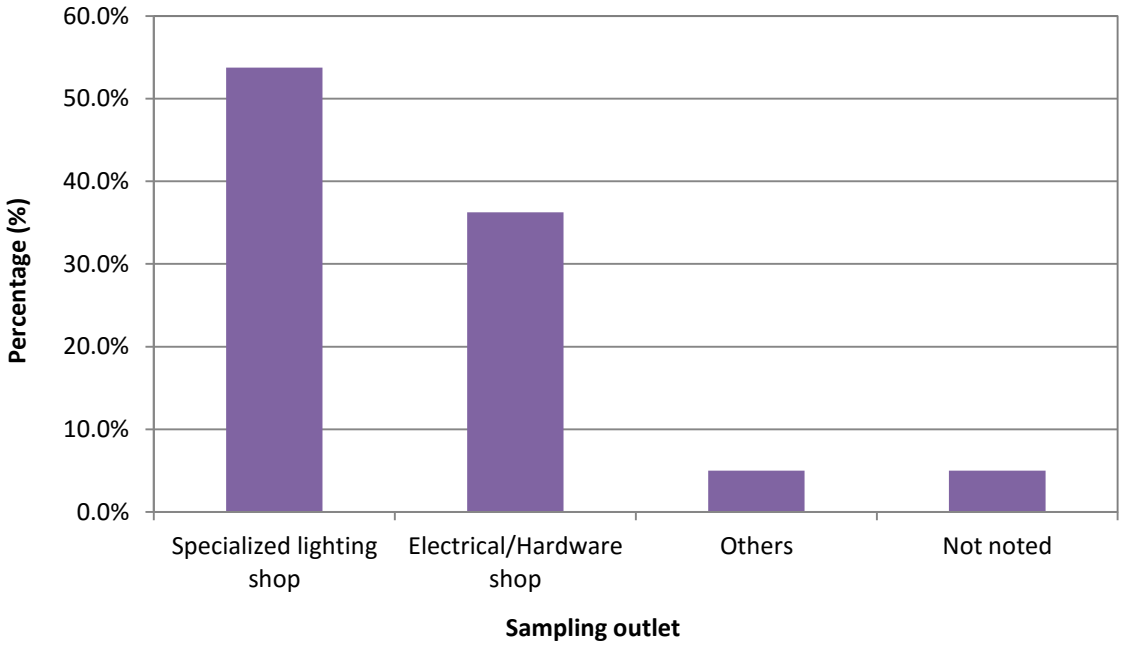
CFL models were identified and collected by IIEC, in coordination with each participating country's representatives, and shipped to GELC for testing. According to the sampling sheets provided by IIEC and participating countries, more than half of the lamps were sampled from specialized lighting shops, 36% were from electrical/hardware shops, and 4% were from others (for example, supermarkets). There were four models where it was not specified from which outlet they were purchased. The origin of the sampled lamps is summarized in Figure 1. Observed lamp pricing is summarized in Table 2. Lamp prices ranged from 0.5 - 5 USD equivalent for CFLs rated less than 11 W to 0.75 -11.5 USD equivalent for higher wattage lamps, with Lao PDR and Cambodia having the widest range and the most expensive (highest relative) price.

[13] In order to insure sufficient lamp samples are available for testing, IIEC purchased twice as many samples per model (15 samples per model were needed, but 30 were purchased).

Table 2 Range of CFL lamp pricing in US dollars (rounded)

Country	CFL < 11W (USD $)	CFL > 11W (USD $)
Cambodia	0.5 - 3	0.75 - 6
Lao PDR	1.5 -5	2.5 - 11.5
Indonesia	1.5 - 3	2 - 5
Philippines	1.5 - 3	1.75 - 6
Thailand	1.5 - 3	2 - 6
Vietnam	0.8 - 2	1.5 - 3.5

Figure 1 Retail channels through which IIEC procured the samples tested

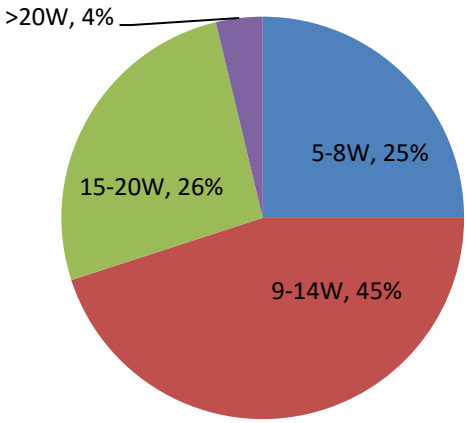


The information documented for each model of CFL included: model number, rated power, rated voltage, rated CCT, lamp base and lamp shape.[14] The information was taken firstly from the lamp itself, however if the information could not be found on the lamp, it was taken from the lamp packaging. During the documenting process, if it was found that for several models, the rated information marked on the lamp was different from the information marked on the package, then the information marked on the lamp was documented.

Of the lamp models received, 60% of them were “stick” shape, and 40% were “spiral” shape. The wattage range of 5 - 8W, accounts for 25% of the total lamps; 45% of the lamps are 9 - 14W; 26% of the lamps are 15 - 20W; and about 4% of the lamps have the wattage over 20W. This is shown graphically in Figure 2.

[14] Performance information from lamp packaging was not collected, therefore no comparisons of claimed versus tested values were undertaken.

Figure 2 Percentage of each wattage range of total models tested



3.4 Testing parameters

Due to the limited timeframe, not all of the parameters covered in the international lighting standards, such as those required by MEPS, were tested under this project, however the most critical parameters related to the lamp performance quality were selected and tested. The performance parameters tested included:

- Lamp power,
- Power factor,
- Initial luminous flux (and initial efficacy),
- Correlated colour temperature (CCT),
- Colour rendering index (CRI),
- Standard Deviation of Colour Matching (SDCM) and
- Luminous maintenance at 2,000 hours.

In addition, the CFLs were also tested for mercury content. Only the China and Australia test standards standards specify a sample size for mercury content testing of CFLs, which is three units. However, due due to the strong international concern and focus on mercury and to ensure a more representative average value is reported, the sample size was increased to five units for this project. The testing parameters and the sample size for each parameter test are summarised In
Table 3.

3.5 Testing reference standards

The International Electrotechnical Commission (IEC) standards are the most recognized and widely adopted by countries, and readily available for CFLs, therefore, all the tests were conducted according to the IEC standard. No variations to the IEC test method were applied.

The performance testing was conducted in accordance with IEC 60969, *Self-ballasted lamps for general lighting services - Performance requirements*[15].

[15] This standard specifies the performance requirements together with the test methods and conditions required to show compliance of tubular fluorescent lamp and other gas-discharge lamps with integrated means for controlling starting and stable operation (self-ballasted lamps intended for domestic and similar general lighting purposes

The mercury content testing was conducted in accordance with:

- IEC 62554, *Sample preparation for measurement of mercury level in fluorescent lamps*[16].
- IEC 62321, *Electrotechnical products - Determination of levels of six regulated substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers)*[17].

Table 3 Testing parameters and sample size

Testing parameter	Sample size (unit)
Power	10
Power factor	10
Initial luminous flux	10
Initial luminous efficacy	10
Correlated colour temperature	10
Colour rendering index	10
Standard Deviation Colour Match	10
Luminous maintenance at 2,000 hrs	10
Mercury content	5
Format of mercury	5

3.6 Comparison standards and performance levels

As the IEC standards only specify the test methodologies without specifying a threshold level, other reference standards available internationally were used to establish minimum requirement levels for CFL performance parameters for comparison purposes, due to the fact that the IEC standards only detail testing methodologies for performance parameters. The established performance levels from the following standards were used:

- EU Regulation No. 244/2009, *Ecodesign requirements for non-directional household lamps* (European Union)
- AS/NZS 4847.2, *Self ballasted lamps for general lighting service Part 2: Minimum Energy Performance Standards requirements* (Australia and New Zealand)
- *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0* (United States)

[16] This standard specifies sample preparation methods for determining mercury levels in new tubular fluorescent lamps (including single capped, double capped, self-ballasted and CCLF for backlighting) containing 0.1 mg mercury or more.
[17] This standard specifies the determination of the levels of lead, mercury, cadmium, hexavalent chromium contained in inorganic and organic compounds, and two types of brominated flame retardants, polybrominated biphenyls and polybrominated diphenyl ethers contained in electrotechnical products.

- *Energy Saving Trust Lamp Specification V7* (United Kingdom)
- GB/T17263, *Self-ballasted lamps for general lighting service* (China)
- Minamata Convention on Mercury (United Nations)
- EU ROHS Directive 2002/95/EC

The performance levels required by these standards are summarised in
Table 4. In addition to the above standards, which represent lamp requirements for major markets around the world, the results for lamps collected from each country were also compared with the applicable national standards or labelling requirements. Finally, the results were compared with available benchmarking results from a round of United States/Australia-supported benchmarking from 2010.[18]

Table 4 Testing parameters and international standards requirements

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th></tr>
<tr><td rowspan="4">Power factor</td><td>EU Regulation No. 244/2009</td><td>≥ 0,55 if P < 25 W</td></tr>
<tr><td>AS/NZS 4847.2 Part 2</td><td>Minimum True Power Factor 0.55</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>Shall not be less than 0.55</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ≥ 0.5.</td></tr>
<tr><td rowspan="4">Initial luminous flux/Initial efficacy</td><td>GB/T17263</td><td>0.55</td></tr>
<tr><td>EU Regulation No. 244/2009</td><td>Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) 0,24√Φ+0,0103Φ</td></tr>
<tr><td>AS/NZS 4847.2 Part 2</td><td>Minimum efficacy in lm/W, 1/(0,24 $\sqrt{\Phi}$ +0,0103 Φ) Where F = initial luminous flux</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7[19]</td><td>See Table 5</td></tr>
<tr><td>ENERGY STAR lamp V1.0[20]</td><td><table><tr><td>Lamp Rated power (watts)</td><td>Minimum Lamp Efficacy (lm/W)</td></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td></tr>
<tr><td></td><td>GB/T17263</td><td><table><tr><td rowspan="2">Power(W)</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour RZ/RR</td><td>Colour RL/RB/RN/RD</td></tr><tr><td>≤5</td><td>36</td><td>38</td></tr><tr><td>6～8</td><td>44</td><td>46</td></tr><tr><td>9～14</td><td>51</td><td>54</td></tr><tr><td>15～24</td><td>57</td><td>60</td></tr></table></td></tr>
</table>

[18] *Testing for Quality: Benchmarking Energy-Saving Lamps in Asia*. USAID, Bangkok, Thailand, April 2010.
[19] *Energy Saving Trust Lamp Specification V7* is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.
[20] *ENERGY STAR lamp V1.0* is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

		≥25	61	64

Testing parameters	Comparison standards	Requirement
Colour rendering index	EU Regulation No. 244/2009	≥ 80
	AS/NZS 4847.2	Minimum CRI 80
	Energy Saving Trust Lamp Specification V7	The measured general colour-rendering index (Ra) shall not be less than 80
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.
	GB/T17263	80
Standard Deviation Colour Match	AS/NZS 4847.2	Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.
	Energy Saving Trust Lamp Specification V7	Within a tolerance limit of 5 steps of MacAdam Ellipses
	GB/T 17263	≤5 steps of MacAdam Ellipses
Mercury content	Minamata Convention	≤5 mg
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W
	EU ROHS Directive	≤2.5mg, for lamp power <30W
	AZ/NZS 4847	≤5 mg
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance
		≤1.5mg, for lamp power ≤ 30W Low mercury
		≤1.0mg, for lamp power ≤ 30W Micro mercury

Table 5 Energy Saving Trust's values for minimum lumens per watt (package claim) by lamp type and wattage (EST Lamp Specification V7) – Class 1

Watts	Stick	Spiral		Watts	Stick	Spiral
5	49	58.3		**21**	59.7	61.2
6	49.8	58.4		**22**	60.2	61.5
7	50.6	58.6		**23**	60.7	61.7
8	51.3	58.7		**24**	61.2	62.0
9	52.1	58.8		**25**	61.7	62.3
10	52.8	59.0		**26**	62.1	62.6
11	53.5	59.1		**27**	62.6	62.9
12	54.2	59.3		**28**	63	63.2
13	54.9	59.5		**29**	63.4	63.6
14	55.6	59.6		**30**	63.7	63.9
15	56.2	59.8		**31**	64.1	64.3
16	56.8	60.0		**32**	64.4	64.6
17	57.5	60.2		**33**	64.7	65.0
18	58	60.5		**34**	65.1	65.4
19	58.6	60.7		**35**	65.3	65.7
20	59.2	60.9				

4 SUMMARY OF TEST RESULTS

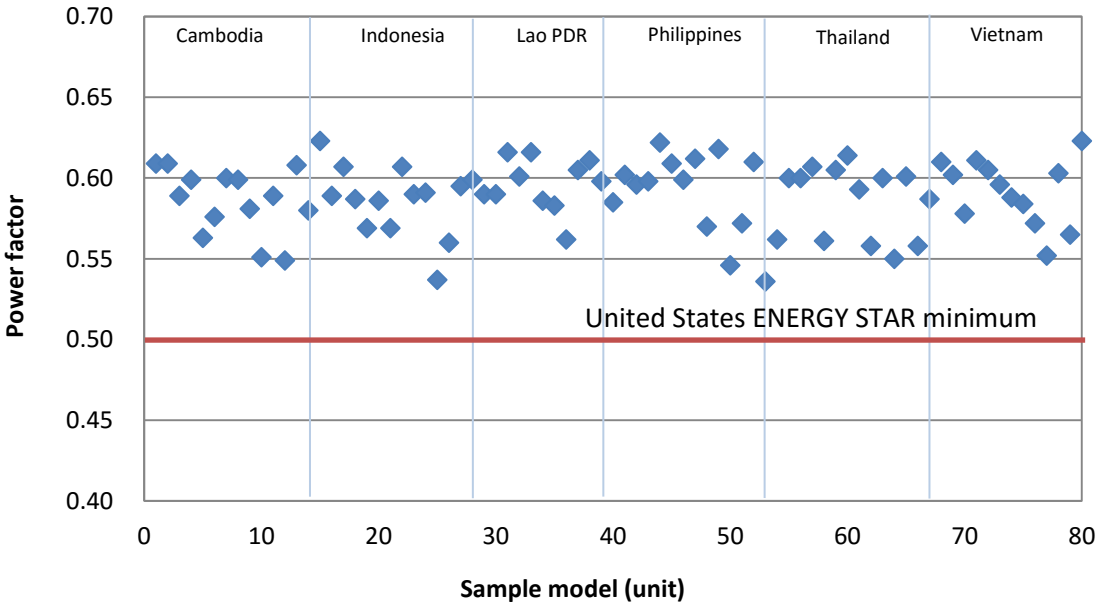
As per the requirements of IEC 60969, the initial performance tests were conducted at the end of a 100 hours ageing period; while the luminous maintenance test was conducted at 2,000 hours. For each model, a sample size of 10 units was tested. Throughout this report, when the result of a particular lamp model is reported, it should be understood that it is the average of the results from all 10 tested samples of that model, and not the result from a single lamp.

The mercury format and mercury content was tested according to IEC 62554 and IEC 62321 for all CFL lamp models. For each model, a sample size of five units was tested.

4.1 Power factor

Figure 3 shows measured average (mean) power factor (PF) test results, all of which were between 0.53 and 0.63, which all met the minimum requirement (of 0.5) specified by the United States ENERGY STAR programme.

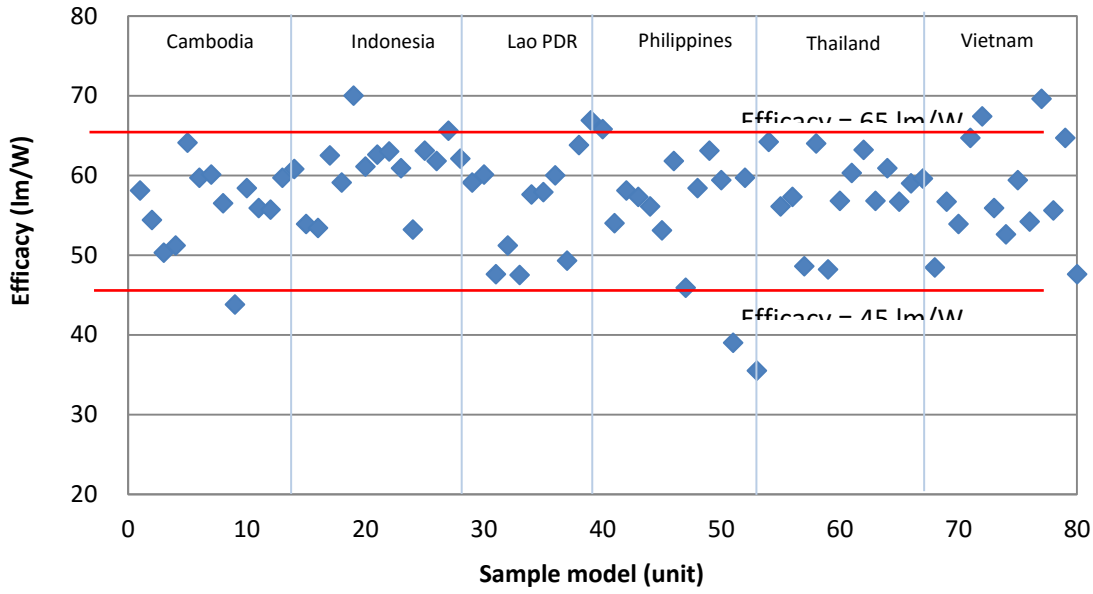
Figure 3 Test results for average (mean, n=10) power factor



4.2 Luminous efficacy

Figure 4 shows the average luminous efficacy results of the 80 models of CFL samples. It can be seen that there are large differences in the efficacy results, the lowest was less than 40 lm/W and the highest was 70 lm/W. Figure 4 also shows that over 88% of the samples were within the range 45-65 lm/W, which falls within the average efficacy range of CFL lamps in general, with only three models (3.75%) falling below the 45 lm/W threshold.

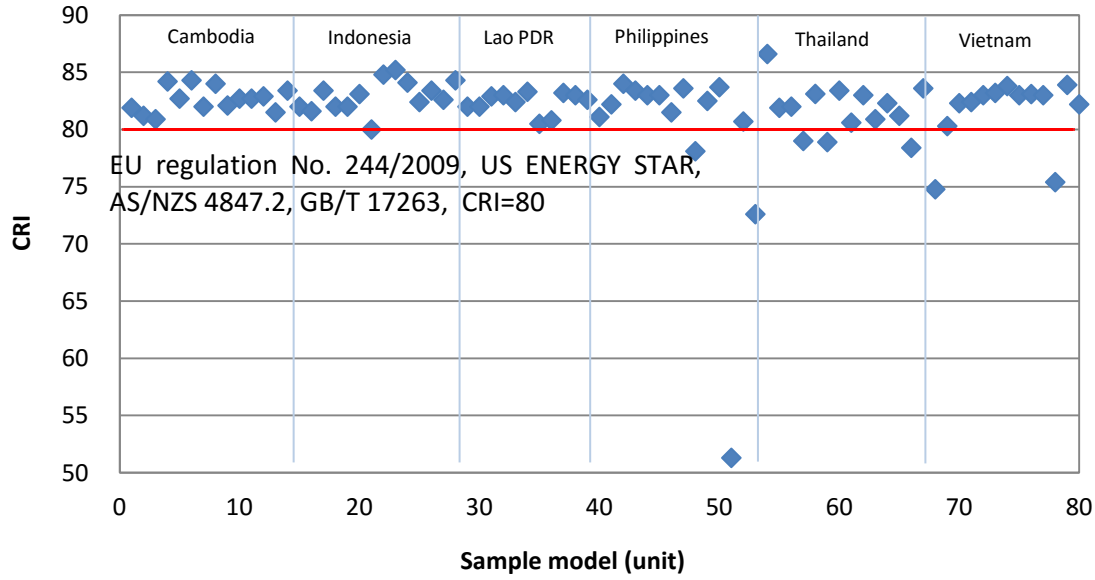
Figure 4 Test results for average (mean, n=10) luminous efficacy



4.3 Colour rendering index

Colour rendering index (CRI), is a measure of a light source's ability to render the colours of an object compared to a reference incandescent source relative to a black body source of the same colour temperature. From Figure 5 it can be seen that the majority of lamps have a CRI of more than 80, which is the minimum requirement for most standards (such as, EU regulation No. 244/2009, UnitedStates ENERGY STAR, AS/NZS 4847.2, GB/T 17263). This is indicated on the graph by a red line. However 10 % of the lamps tested still have a CRI less than 80.

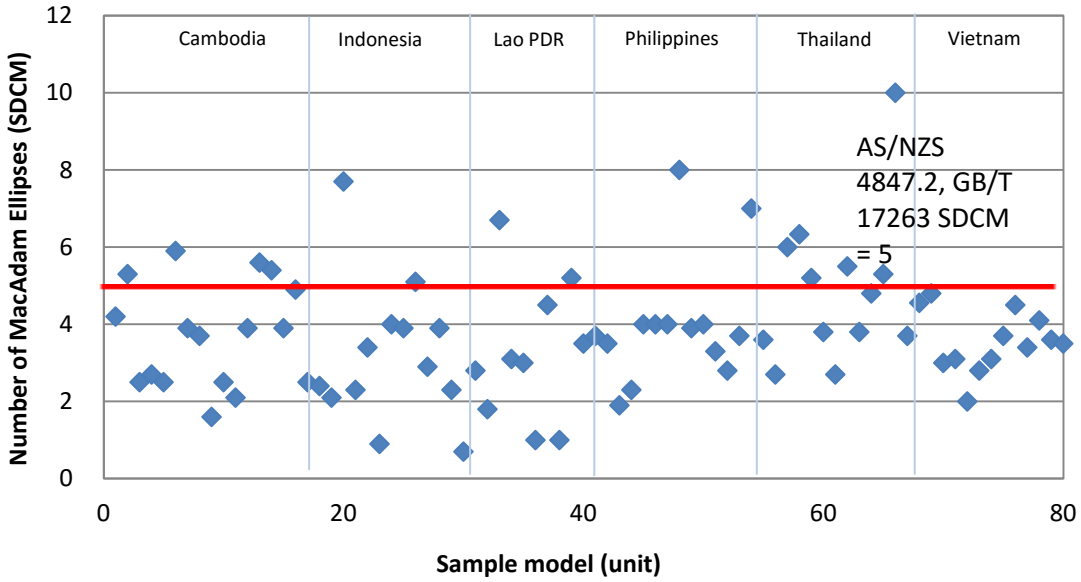
Figure 5 Test results for average (mean, n=10) CRI



4.4 Standard Deviation of Colour Matching

Apart from CRI, Standard Deviation of Colour Matching (SDCM) is another significant parameter that is indicative of the lamp light colour quality. SDCM uses the metric of a MacAdam ellipse to indicate the degree of matching between the actual colour of the lamp and claimed colour temperature of the product. SDCM also gives an indication of the quality control of the lamps and the ability to manufacture to a consistent level. If there is a large SDCM, it means the lamp's colour consistency is poor among the same tested model, and that the lamp's light quality varies between each unit produced. Figure 6 provides the average (mean) results of SDCM for the 80 models of CFLs. From Figure 6, it can be seen that 72% of the lamps had a SDCM under 5 steps, and the highest was up to 10 steps. The maximum allowed requirement from AS/NZS 4847.2 and GB/T 17263 for SDCM is 5 steps.

Figure 6 Test results for average (mean, n=10) SDCM



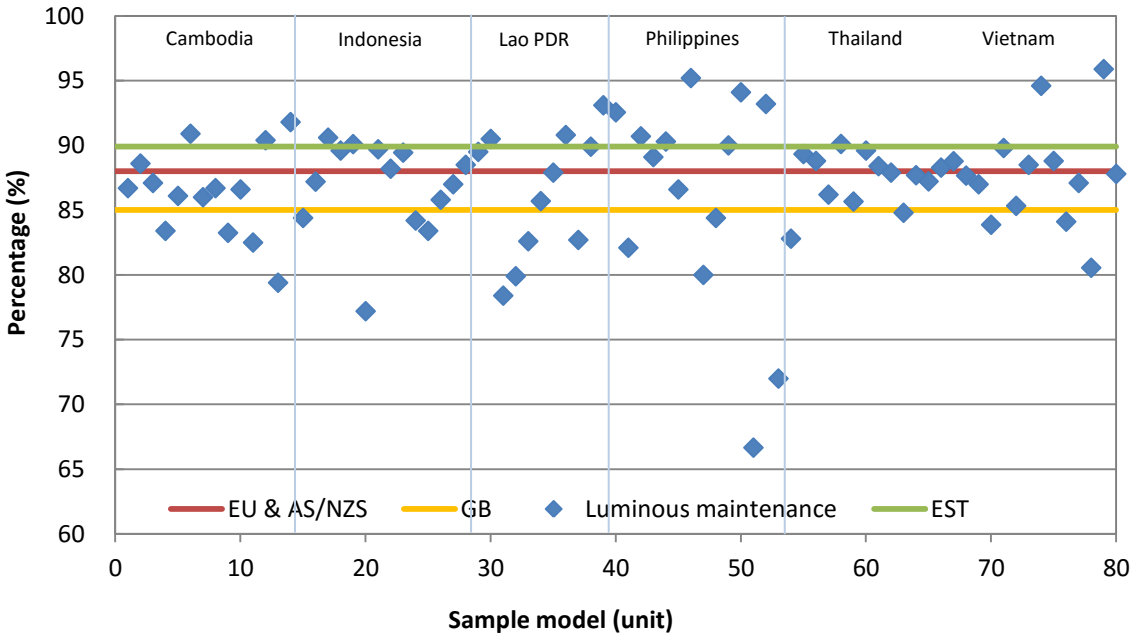
4.5 Luminous maintenance

As the hours of operation of a lamp increase, the luminous flux of the lamp gradually decays, and the light gets dimmer. Luminous (lumen) maintenance is defined as the luminous flux at a given time in the life of a lamp divided by the initial value of the luminous flux of the lamp and expressed as a percentage of the initial luminous flux. Luminous maintenance is an important indicator which is related to the light output over the lifetime of the lamp. In this project, the luminous maintenance test was conducted at 2,000 hours.

Figure 7 shows the luminous maintenance results compared with the different reference standards. However, ENERGY STAR lamp specification V1.0 requires luminous maintenance to be tested at 40% of the rated life time rather than at 2,000 hours, therefore in this report, the luminous maintenance results were not compared with ENERGY STAR lamp specification V1.0. Figure 7 shows that the Energy Saving Trust has the highest requirement for luminous maintenance; the Australia/New Zealand and European Union standard (AS/NZS and EU) follow and then the Chinese (GB) standard is the lowest. Figure 7 shows for the lowest requirement (GB), 21 models out of 80 (26%) did not

comply. The compliance rate for AS/NZS and EU was about 51%. The compliance rate against the Energy Saving Trust specification was about 30%.

Figure 7 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



4.6 Mercury format and content

The element mercury (Hg) mercury is commonly required for discharge lamps as the light emitting substance. At room temperature, the mercury vapour has low pressure which is good for starting discharge lamps. At high temperature, it has higher pressure, which can be helpful for its buffer action. Therefore, in some discharge lamps, mercury plays an irreplaceable role.

However, mercury is a hazardous and toxic heavy metal, and can be harmful to humans and animals. For this reason, countries are increasing efforts to reduce and limit the amount of mercury in lighting products. In October 2013, *The Minamata Convention on Mercury* was issued. The Convention defines a maximum mercury content of 5 mg for CFLs for general lighting purposes (wattage no greater than 30W). In Europe, since 2013, the *Regulations on Hazardous Substances* (RoHS) specifies that the maximum allowable mercury content is 2.5 mg for CFLs for wattages less than 30W. China has the same requirement.

Figure 8 shows the proportions of each mercury format of the CFLs tested. It shows that 71% of the CFLs use the amalgam (solid) technology and 29% of the CFLs use the non-amalgam (liquid) technology. Non-amalgam CFL lamps are normally injected with liquid mercury, which is a greater concern for the release of mercury upon breakage; while amalgam mercury technology uses solid mercury, which is convenient to control the amount of mercury injected into CFLs, and can then be more easily recycled at the end of their useful lamp life.

Figure 8 Test results for mercury format (percent of total lamps tested)

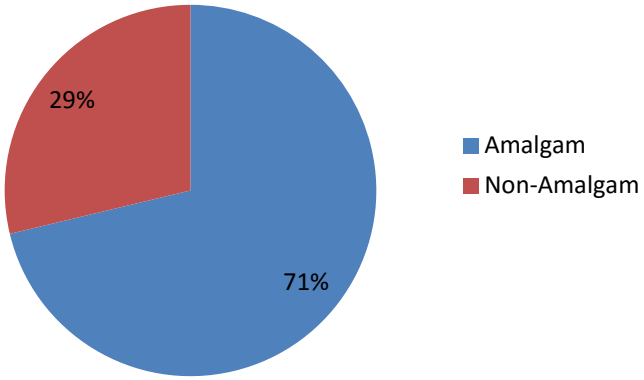
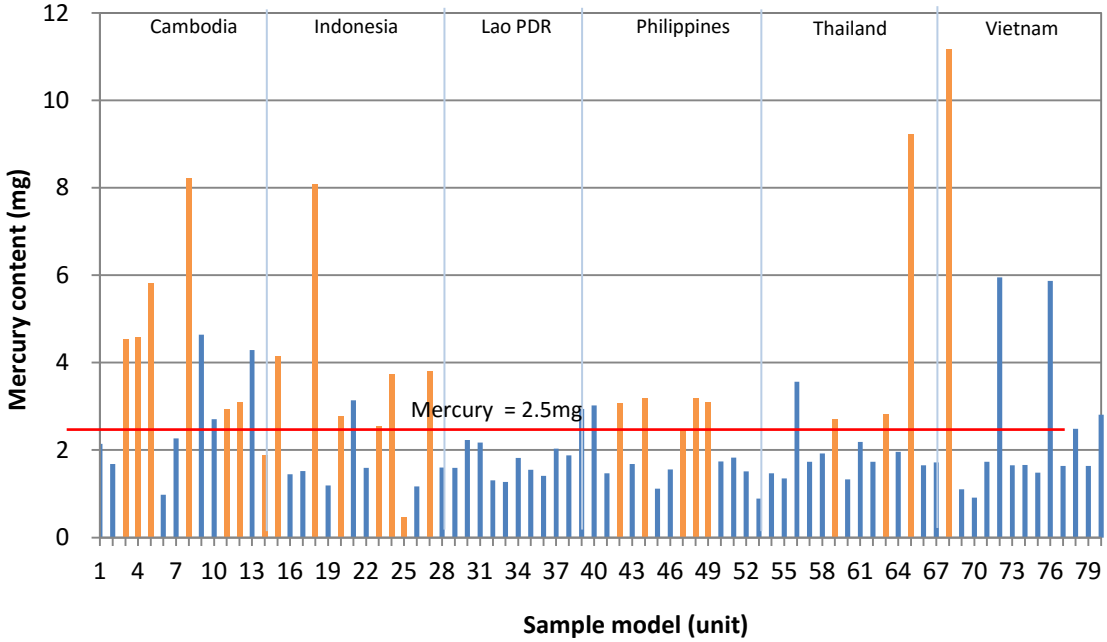


Figure 9Figure 9 shows the average mercury content of each model. The average mercury content was less than 3mg. However the test results shows a very large variation among the tested samples. The lowest mercury content was less than 1 mg and the highest was more than 10 mg. 81% of the amalgam models contained less than 2.5 mg of mercury, but there are still two models which have mercury content over 5 mg. The non-amalgam lamps have an average mercury content of 4.24 mg. Only 13% of these models contained less than 2.5 mg of mercury, and 22% of the models contain over 5 mg of mercury.

Figure 9 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

Figure 10Figure 10 and Figure 11 separate the amalgam (blue bars in Figure 9) and non-amalgam (orange bars in Figure 9Figure 9) lamps to show the proportion of lamps within different ranges of mercury content within each. Of the amalgam lamps tested, 4% contained less than 1 mg of mercury,

23% contained 1-1.5 mg of mercury, 54% contained 1.5 to 2.5 mg of mercury, 9% contained 2.5 to 3.5 mg of mercury, and 4% contained 5 to 10 mg. Of the non-amalgam lamps tested, 4% contained less than 1 mg of mercury, 9% contained 1.5 to 2.5 mg of mercury, 44% contained 2.5 to 3.5 mg of mercury, 22% contained 3.5 to 5 mg, 17% contained 5 to 10 mg, and 4% contained over than 10 mg of mercury. Over 50% of those that do not meet the maximum threshold of 2.5 mg (specified in the European Union and Chinese standards) exceeded this amount by a significant margin. For example, while only three of the CFL models from Vietnam exceeded the 2.5 mg level, these two models contain more than twice the limit. Finally, as can be seen from the Figure 9, Cambodia and Indonesia have the most lamps that exceeded the 2.5 mg level (over 50% of the models from Cambodia, and nearly 50% of the models from Indonesia have over 2.5 mg of mercury).

Figure 10 Ranges of mercury content of amalgam lamps, by percent of lamps tested

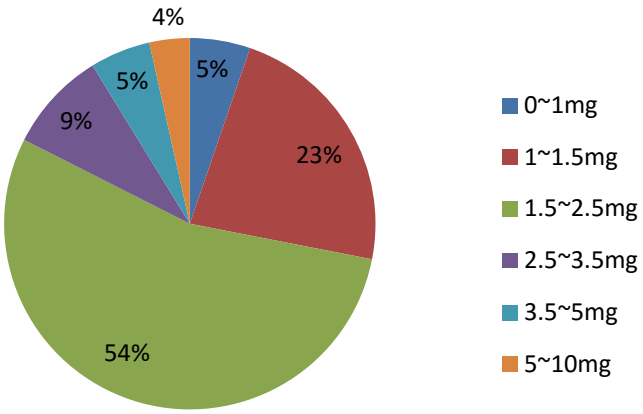
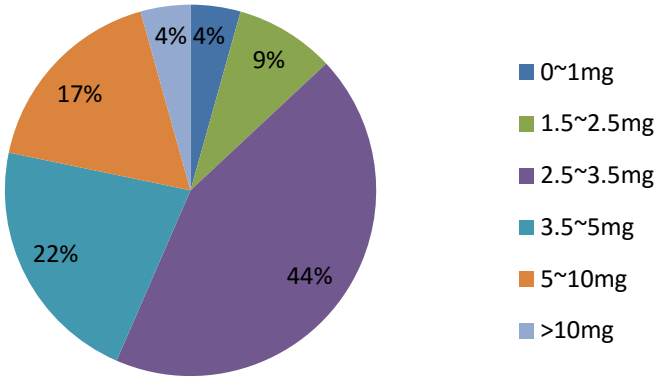


Figure 11 Ranges of mercury content of non-amalgam lamps, by percent of lamps tested



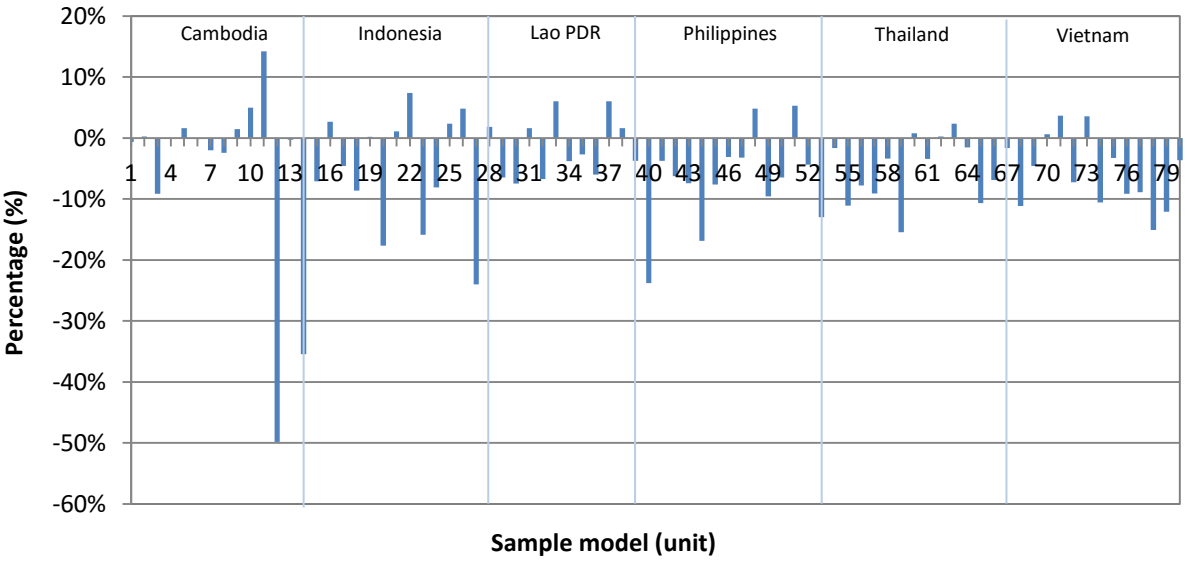
5 SUMMARY AND OBSERVATIONS ON LAMP TESTING RESULTS

80 models of CFLs were sampled for performance testing from six countries. Seven main parameters were tested: lamp power, power factor, luminous efficacy, CRI, SDCM, luminous maintenance at 2,000 hours, mercury format and mercury content. The sections below summarize comparisons between the tested results (measured) and rated (claimed) or average values for these parameters after the lamps have been stabilised (aged). Generally, better quality products tend to have a more stable operation. Therefore, the following comparisons showing how these products performed compared to manufacturers' claims, and to the group average, can provide insight into their quality and likelihood of adoption, as consumers prefer stable-operating products that perform to their expectations. The performance of these products is also compared to the requirements of a number of international as well as national standards where appropriate and available, and are further discussed in the individual country sections.

5.1 Measured and rated power

Figure 12 shows the deviation between measured power and rated power. Among the reference standards being used for comparison (listed in Section 5.1), only two have power requirements: IEC 60969 and GB/T 17263. IEC 60969 requires that the initial wattage dissipated by the lamp shall not exceed 115% of the rated power. GB/T 17263 requires that when working at the rated voltage and rated frequency, the deviations between actual power consumption and rated power shall not be more than 5%+0.5W for lamps with rated power less than 10W, and 10% for lamps with rated power 10W or above. It can be seen from Figure 12 that all the models have a measured power less than 115% of the rated power. However, 15 models did not meet GB/T 17263. The measured values for some of the models were 20% or even 30% less than their rated powers.

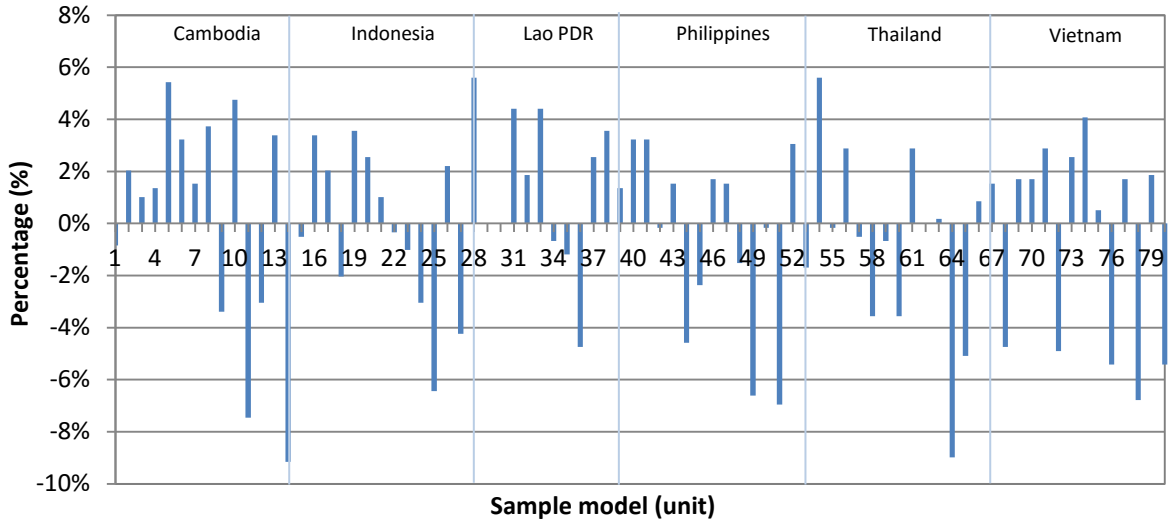
Figure 12 The deviation between measured power and rated power



5.2 Power factor

Figure 13Figure 13 shows the deviations between the power factor of each model and the average value of all models. The average power factor of all models is 0.59. It can be seen that the deviations of each model with the average value were between -10% and 6%. Power factor is an important parameter indicating the actual energy consumption of a lamp on the electrical circuit or system. If the power factor is higher it means there is better utilization of the electricity consumption by the lamps' electrical components.

Figure 13 The deviation between power factor of each model and average value of all models



5.3 Luminous efficacy

Figure 14 to Figure 18 show the deviation between luminous efficacy and average efficacy values of the models with rated power of less than 15W. The average luminous efficacy was 55 lm/W. The lowest luminous efficacy was 36 lm/W at rated power of 9W, and the highest was 70 lm/W with rated power of 11W.

Figure 14 presents the deviation between efficacy of each model and the average efficacy value of all the models with rated power less than 15W. It can be seen that there are wide fluctuations ranging from -38% to 20%. Among all the models tested, there were 11 models of lamps with warm light, and 45 models with cool light. The average efficacy of warm light lamps was 57 lm/W and Figure 15 shows the deviation between each model and the average warm light lamp efficacy value. The average efficacy of cool light lamps was 55 lm/W and Figure 16 shows the deviations between each model and the average cool light lamp efficacy value. The warm light lamps show a slightly higher average efficacy than the cool light lamps. Comparing Figure 15 and Figure 16 The deviation between efficacy of each model and average efficacy value of models with rated power < 15W, cool lightFigure 16 with Figure 14, it can be seen that most of the large deviations (over than 20%) were from the warm light lamps.

Figure 14 The deviation between efficacy of each model and average efficacy value of all the models with rated power < 15W

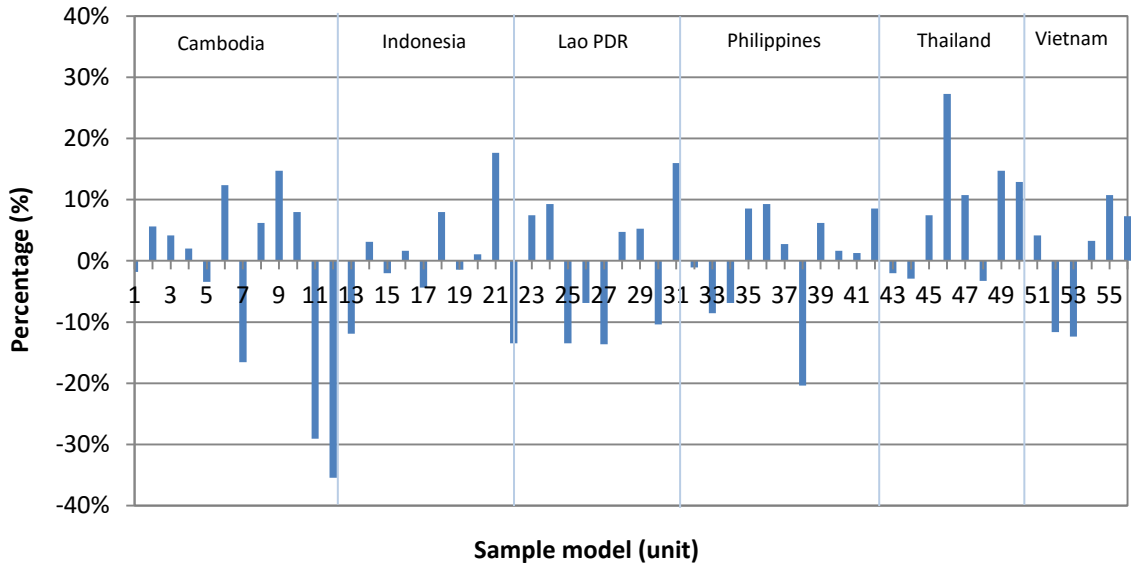


Figure 15 The deviation between efficacy of each model and average efficacy value of models with rated power < 15W, warm light

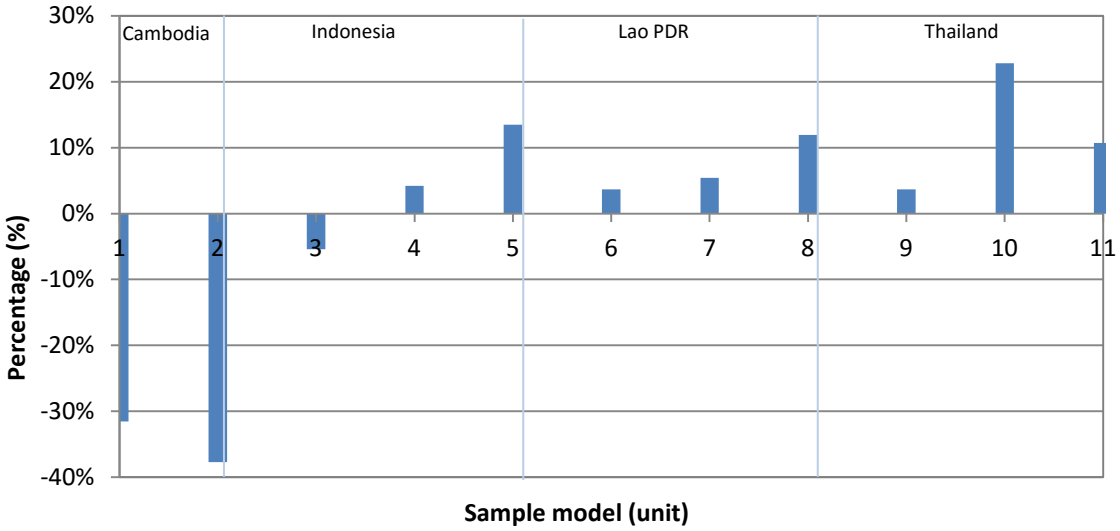


Figure 16 The deviation between efficacy of each model and average efficacy value of models with rated power < 15W, cool light

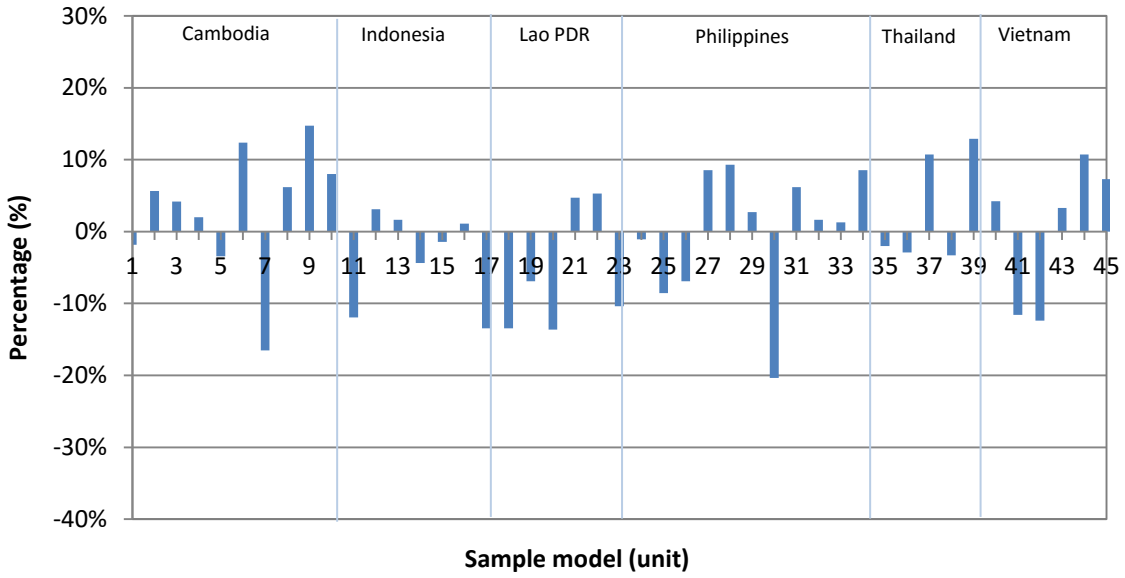


Figure 17 shows the deviation between luminous efficacy and the average efficacy value of the spiral shaped models with rated power less than 15W. Figure 18 shows the deviation between luminous efficacy and the average efficacy value of the stick shaped models with rated power less than 15W. The average efficacy of spiral lamps was 56 lm/W, and stick lamps was 55 lm/W. The results show in those models tested, spiral lamps have a slightly higher average efficacy than the stick lamps. The deviation of spiral lamps efficacies range from -37% to 25%, and stick lamps efficacies range from -20% to 15%.

Figure 17 The deviation between efficacy of each model and average efficacy value of models with rated power < 15W, spiral lamp

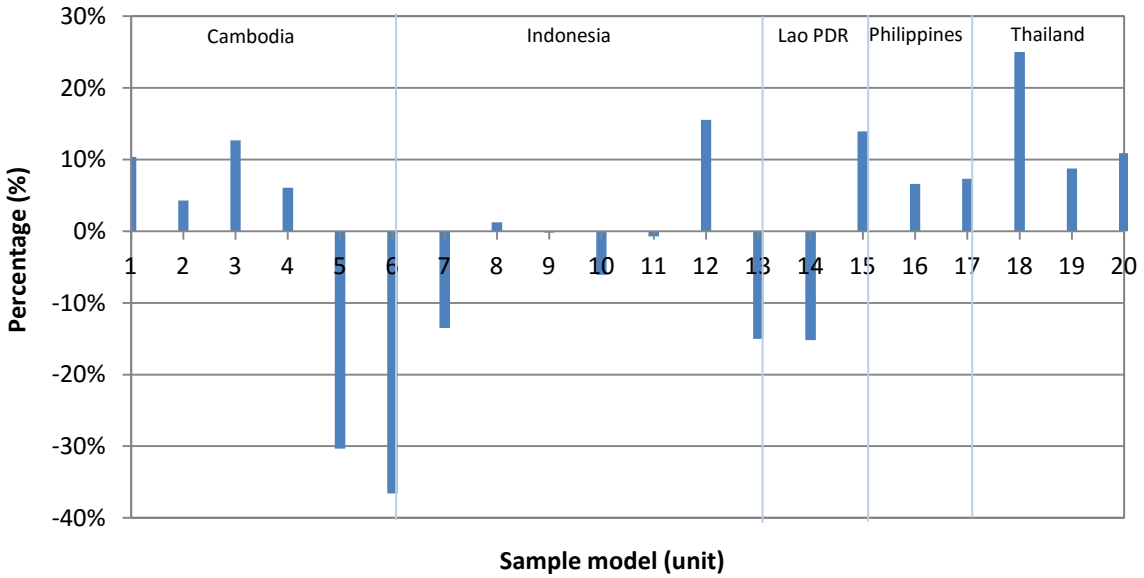


Figure 18 The deviation between efficacy of each model and average efficacy value of models with rated power < 15W, stick lamp

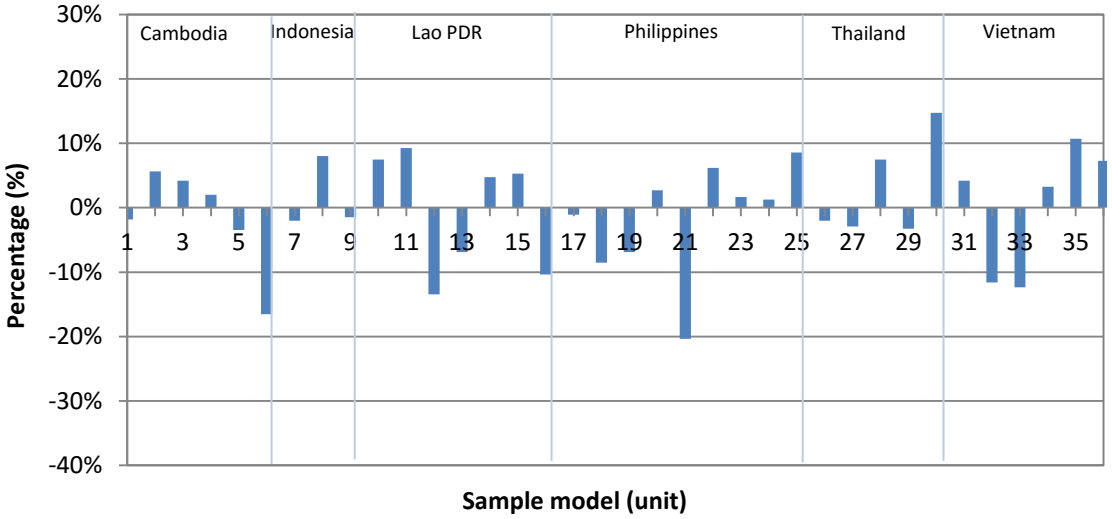


Figure 19 to Figure 23 show the deviation between luminous efficacy and average efficacy values of the models with rated power equal to, or greater than, 15W. The average luminous efficacy of these models was 62 lm/W. The lowest luminous efficacy was 56 lm/W at rated power 20W, and the highest was 70 lm/W with rated power 18W. Figure 19 presents the deviation between efficacy of each model and the average efficacy value of all the models with rated power equal to, or greater than 15W. From this, it can be seen that the deviations were in the range of -10% to 15%. Among all the models in Figure 19, there were two models of lamps with warm light, and 22 models with cool light. The average efficacy of warm light lamps were 67 lm/W and Figure 20 shows the deviation between each model and the average warm light lamp efficacy value. The average efficacy of cool light lamps were 62 lm/W and Figure 21 shows the deviation between each model and the average cool light lamp efficacy value. The warm light model results show a higher average efficacy than the cool light lamp and relatively less fluctuation.

Figure 19 The deviation between efficacy of each model and average efficacy value of models with rated power ≥ 15W

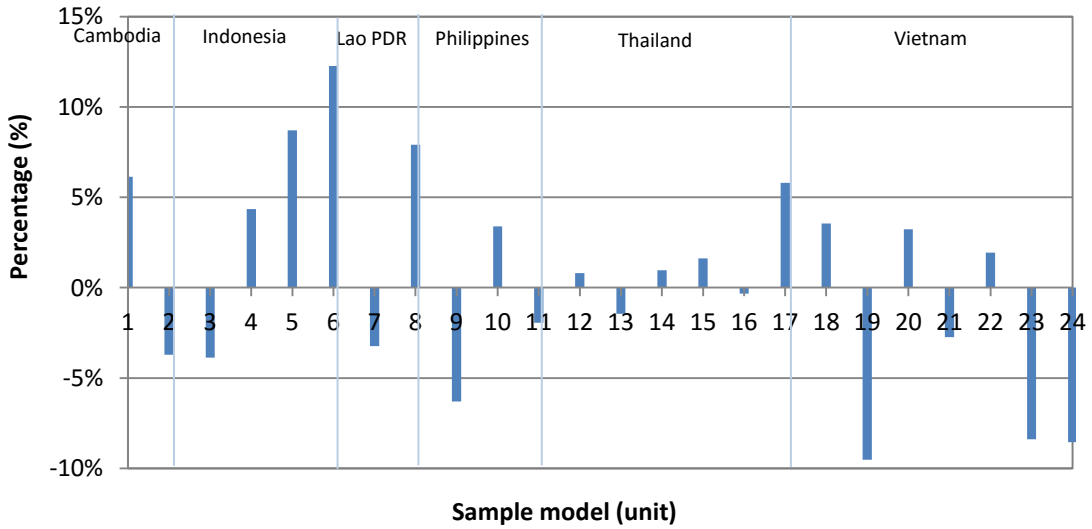


Figure 20 The deviation between efficacy of each model and average efficacy value of models with rated power ≥ 15W, warm light

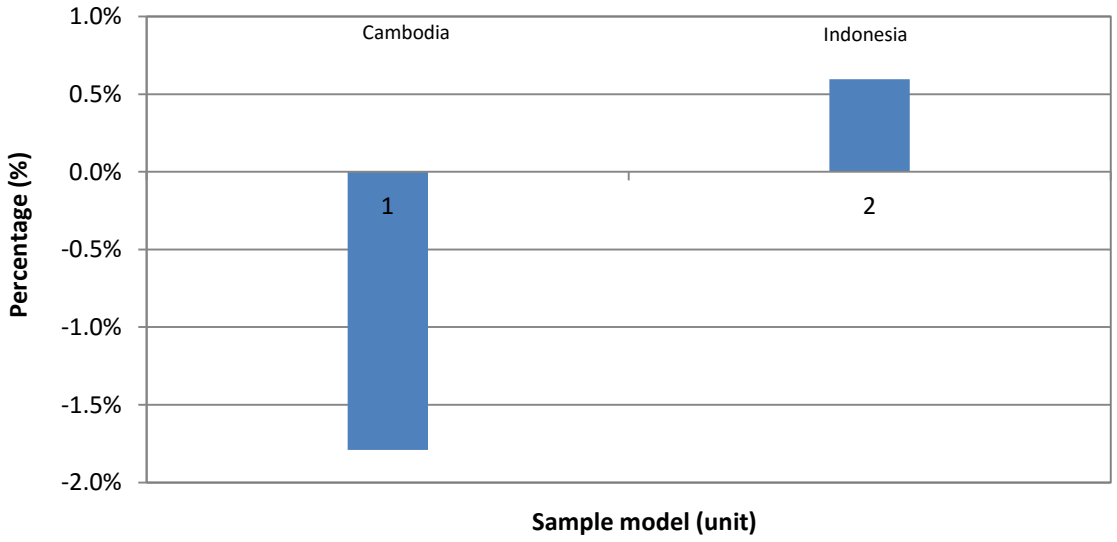


Figure 21 The deviation between efficacy of each model and average efficacy value of models with rated power ≥ 15W, cool light

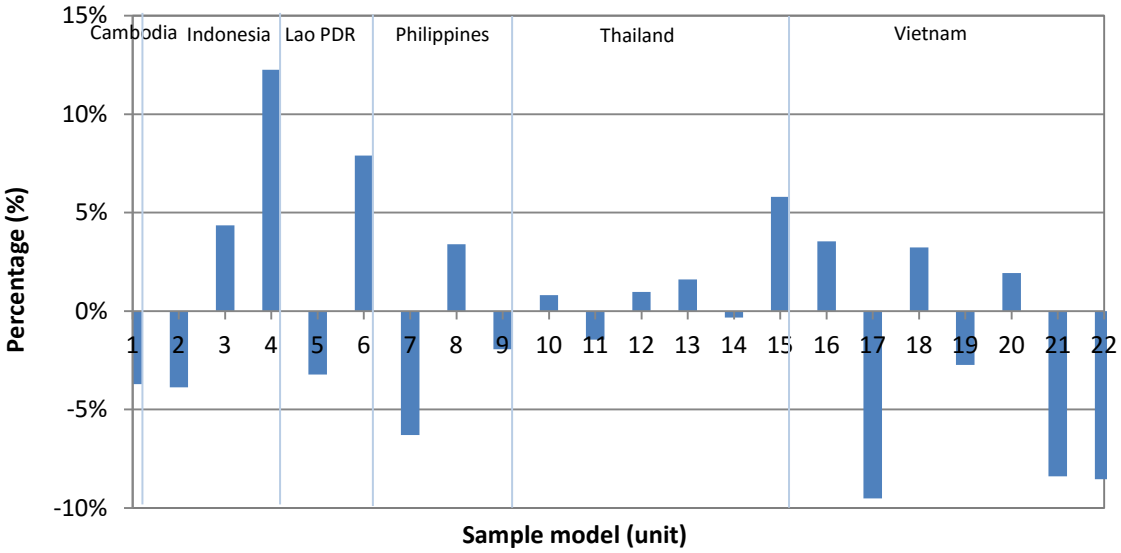


Figure 22 shows the deviation between luminous efficacy and the average efficacy value of the spiral shaped models with rated power equal to, or greater than 15W. Figure 23 shows the deviation between luminous efficacy and the average efficacy value of the stick shaped models with rated power equal to, or greater than 15W. The average efficacy of spiral lamps was 63 lm/W, and stick lamps was 61 lm/W. The results show in those samples tested that spiral lamps have a slightly higher average efficacy than the stick lamps. The deviation of spiral lamps ranged from -5.5% to 10.5%, and stick lamps ranged from -8% to 10.5%.

Figure 22 The deviation between efficacy of each model and average efficacy value of models with rated power ≥ 15W, spiral lamp

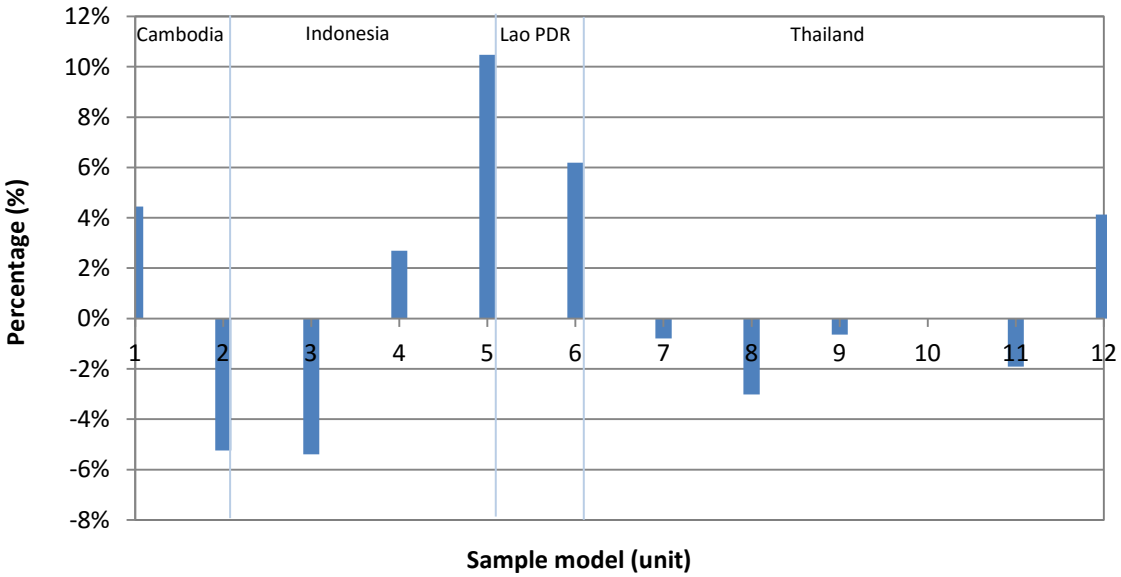
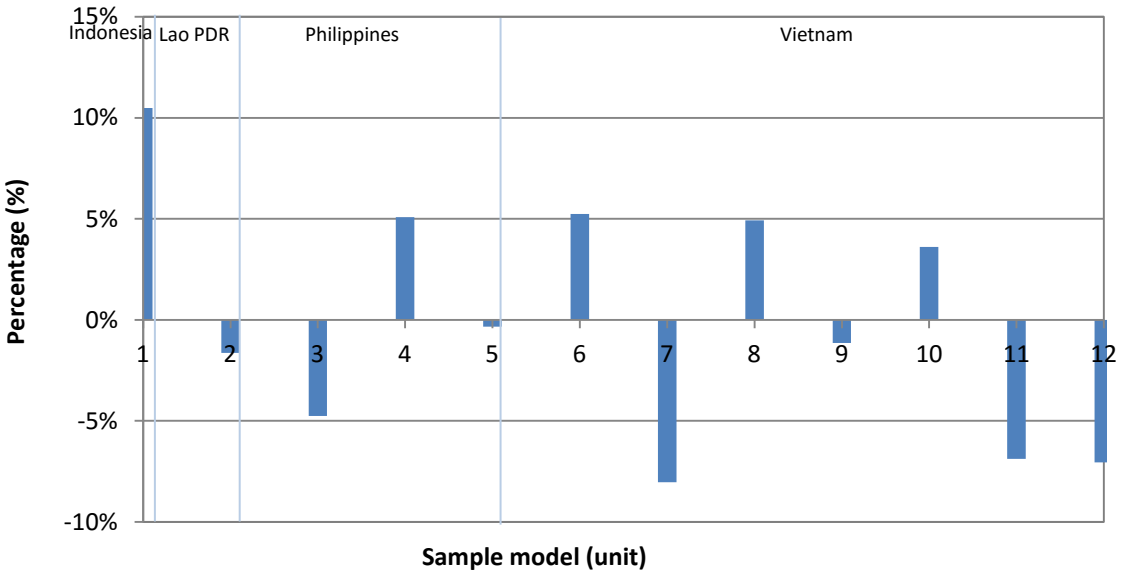


Figure 23 The deviation between efficacy of each model and average efficacy value of models with rated power ≥ 15W, stick lamp

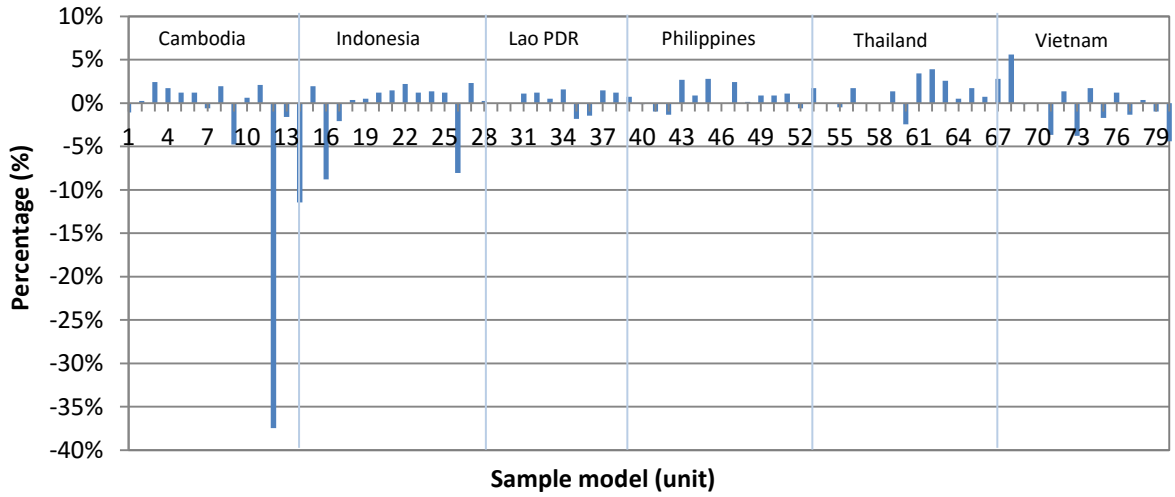


5.4 Colour rendering index (CRI)

Figure 24 shows the deviation between CRI of each model and the average CRI value of all models. The average CRI of all models is 82. It can be seen that 97.5% of the models were within a range of 10%, and 93.8% of the model were within the range of 5%. There were two models out of the 10% range, and one of models even had a deviation of -37%. CRI is an important element of the light

quality characteristics. If the CRI is low, it will not render the actual colour of the objects illuminated by the lamp.

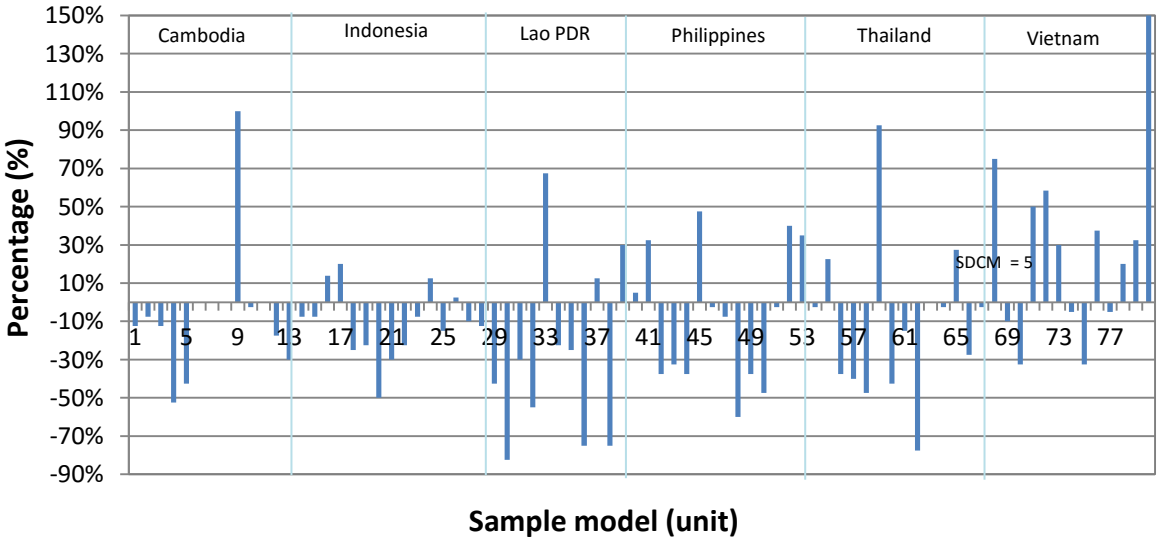
Figure 24 The deviation between CRI of each model and average CRI value of all models



5.5 Standard Deviation of Colour Matching (SDCM)

Figure 25 shows the deviation between SDCM of each model and the average SDCM value of all models. The average SDCM of all models is 4 steps. It can be seen that the SDCM has the highest deviations of all of the tested parameters, suggesting that maintaining colour consistency appears to b a challenge for many CFL manufacturers. 84% of the models were within the range of -50% to 50%. In particular, the blue columns with a positive variation means that their SDCM is higher than 4 steps, and most of the comparison standard required the maximum SDCM is 5 steps. The highest is 150% greater than the average value, which is far outside any allowable standards requirement.

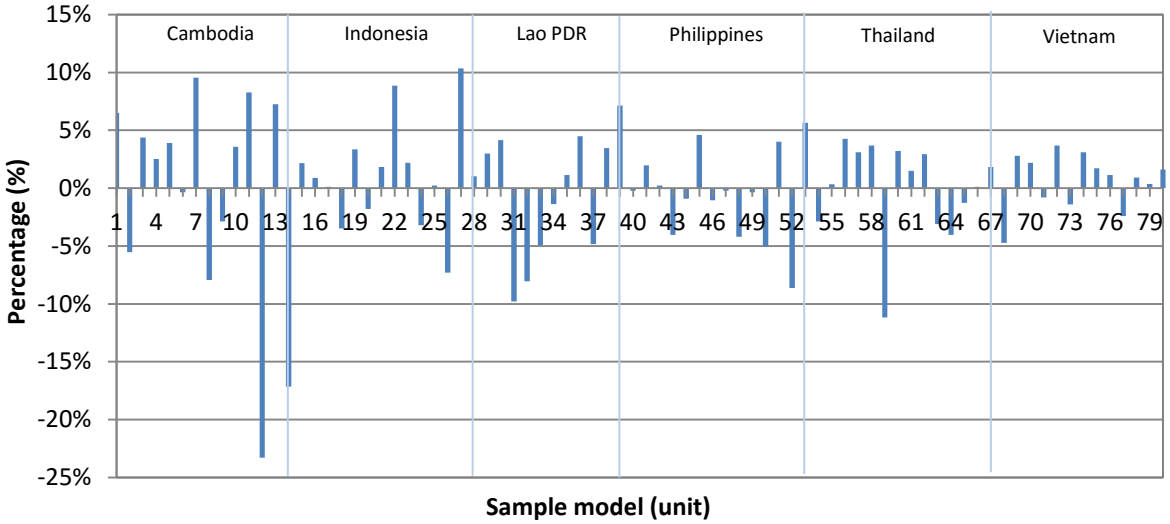
Figure 25 The deviation between SDCM of each model and average SDCM value of all models



5.6 Luminous (lumen) maintenance

Figure 26 shows the deviation between luminous maintenance of each model and the average luminous maintenance value of all models at 2,000 hours. The average luminous maintenance of all models is 87%. It can be seen that 95% of the tested models were within the range of -10% to 10%. There were only two models that had a luminous maintenance below 15% of the average value.

Figure 26 The deviation between luminous maintenance of each model and average luminous maintenance value of all models at 2,000 hours



5.7 Mercury content

The mercury test results show that 71% of the CFLs use amalgam technology and 29% of the CFLs use non-amalgam technology. The average mercury content of all 80 models of CFLs was less than 3 mg. However it can clearly be seen that there is a wide range among the tested samples. The lowest mercury content is less than 1 mg and the highest is more than 10 mg, 10 times higher. For the amalgam lamps, 81% of the models contain less than 2.5 mg of mercury, but two models still contain over 5 mg of mercury. For non-amalgam lamps, the average mercury content is 4.24 mg. Only 13% of these models contain less than 2.5 mg of mercury, and 22% of the models contain over 5 mg of mercury.

Figure 27 shows the average mercury content for each country. It can be seen that the lamps from Lao PDR have the lowest mercury content, and from Cambodia have the highest in the test group. In most of these countries, the average mercury content is less than 3.5 mg. However, in Cambodia the average value is 3.55 mg.

Figure 27 Average mercury content in each country

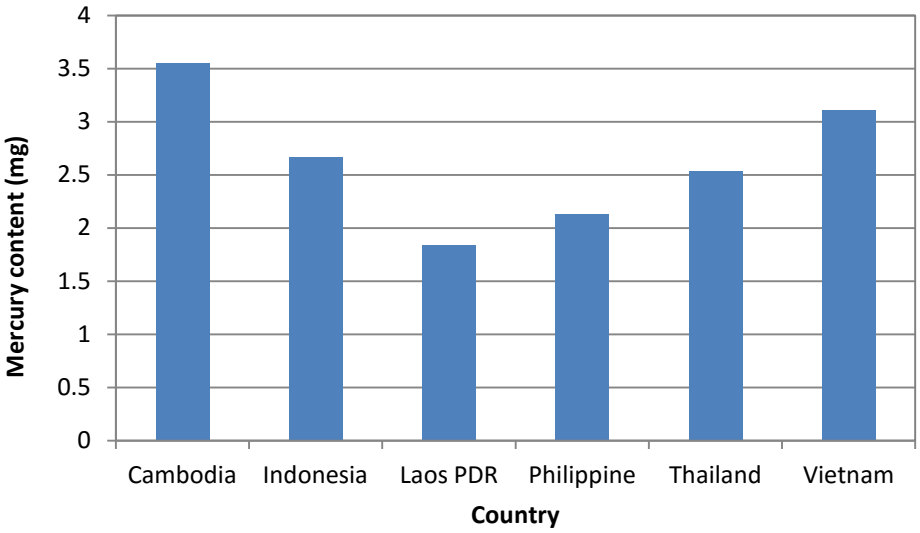
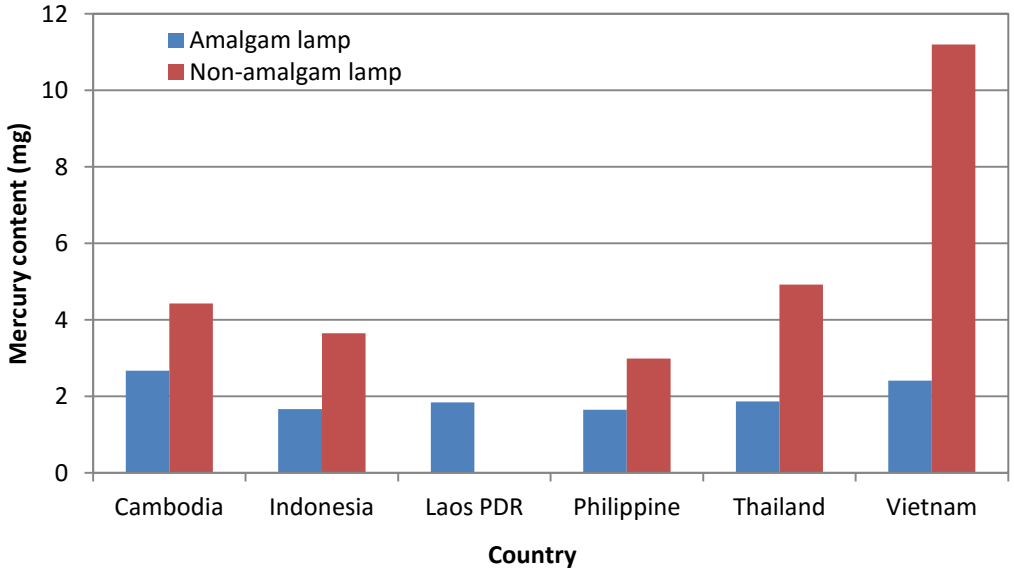


Figure 28 separates the amalgam and non-amalgam lamps, and gives the average data. The non-amalgam lamps show much higher mercury content than the amalgam lamps. Of the lamps tested, there were no amalgam lamps from Lao PDR.

Figure 28 Average mercury content of amalgam lamp and non-amalgam lamp in each country



Specific to mercury content of lamps, it can be seen that in some countries, there is still a high percentage of non-amalgam lamps, which needs the attention of governments, as it can be more challenging for manufacturers to control liquid mercury dosing. Therefore, countries may consider adding a maximum mercury content of CFLs (and other lamps) into their regulations.

5.8 Performance comparison with international standards

In order to have a better view of the lamps' performance quality relative to lamps available in other major markets globally, some international standards are referenced for comparison with the test results for each model. The details of these standards and the performance levels they specify are given in
Table 4, in Section 3.6 However, it should be understood that different standards may have differences in the test methods and sample size, therefore these reference comparison standards are only used to provide a general picture of the product quality levels.

Table 6 lists the number of models that did not meet the most strict requirements of the above listed comparison standards used, and Table 7 lists the number of models that did not meet the lowest requirement of the these comparison standards. From these two tables, it can be seen that luminous maintenance at 2,000 hours is the most challenging parameters for manufacturers, judging from the number of models not meeting this requirement. CRI and SDCM results are the same in both tables because the comparison standards are harmonized. Luminous efficacy shows a high non-compliance rate when compared with the most strict requirements, however the standards included two voluntary programmes intended to recognize the best performing lamps in the market (i.e. ENERGY STAR, Energy Saving Trust).

Table 6 The number of models that did not meet the most strict requirement of the comparison standards

Country.	No. of models tested	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	2	6	3	1	7	13
Indonesia	14	0	7	2	0	12	13
Lao PDR	11	0	5	0	2	7	11
Philippines	14	0	5	0	4	11	13
Thailand	14	1	5	0	2	11	14
Vietnam	13	0	7	3	6	12	13

Table 7 The number of models that did not meet the lowest requirement of the comparison standards

Country.	No. of models tested	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	0	2	3	1	5	2
Indonesia	14	0	0	2	0	3	7
Lao PDR	11	0	0	0	2	4	0
Philippines	14	0	2	0	4	4	0
Thailand	14	0	0	0	2	4	1
Vietnam	13	0	1	3	7	1	3

The tested lamps were randomly sampled from local markets, and therefore reflect the lamp quality of products for sale in those markets. The test results reveal that some models of lamps demonstrated high luminous efficacy and good colour characteristics, while other lamps had some problems, mainly on luminous maintenance, SDCM and luminous efficacy.

6 ADDITIONAL OBSERVATIONS AND RECOMMENDATIONS

The process of sample identification, collection and product testing documented in this report was intended primarily as a demonstration of these processes for CFLs, as well as to illustrate the analyses that can be carried out with the results from a national and regional perspective. To provide the report with further policy context, the UNEP-GEF en.lighten initiative has added this observations and recommendations section to supplement the technical analysis of the test results by GELC above.

Although the number of CFL models collected from each country were significant, they may or may not be statistically sufficient to represent each country's market composition, depending on the size of each country's lamp market. However, they do constitute a significant starting point for market and regional analysis, since they were sampled from a variety of locations and venues.[21]

Currently, information may be available regarding the current market size, penetration or take up rates of CFLs by consumers in some of the target countries country via import and production data. This information can be used for further analysis of the states of some target markets, should additional analyses are desired. However, this information can be inconsistent across the six target countries. For Cambodia and Lao PDR, less is known about their markets, however, countries that have MEPS or have had other energy efficient lighting policies in place, including Indonesia, Philippines, Thailand, and Vietnam, have more data regarding their market size, production volume (for those that have domestic lamp production), and distribution networks of products.

For Indonesia, Philippines, Thailand, and Vietnam, there are also available data on previous lamp testing that can be used for further analysis.[22] For these target markets, the lamp pricing, variety, and purchase locations, along with the test results can provide some insight into the performance and quality levels of the products that are currently available in each market, as well as any discernible trends. A summary of observations is provided below.

6.1 Observations

6.1.1 Pricing

In many markets, CFLs can be considered a mature product category, with established performance characteristics and benchmarks. CFL products tend to be available in many locations, with a developed distribution and retail network and pricing structure, giving consumers choices in price, brands, and shopping locations. This is particularly the case for both pricing and retail distribution in

[21] Note that 2,400 lamps represent a 0.1% sampling rate for a 2.4 million lamp/year market.

[22] *Testing for Quality: Benchmarking Energy-Saving Lamps in Asia*. USAID, Bangkok, Thailand, April 2010. Note that Philippines (Department of Energy) and Thailand (Electric Generation Authority of Thailand) also conduct their own product testing.

the markets of Indonesia, Philippines, Thailand, and Vietnam. Table 8 shows the CFL price ranges for the lamps selected for this exercise, and where the information is available, compares this to the price range information from the 2010 benchmarking exercise.

Table 8 CFL price ranges in USD (converted)

Country	2014 price range		2010 price range
	CFL < 11W (USD $)	CFL > 11W (USD $)	All lamps (USD $)
Cambodia	0.5 - 3	0.75 - 6	NA
Lao PDR	1.5 -5	2.5 - 11.5	NA
Indonesia	1.5 - 3	2 - 5	0.6 – 3.1
Philippines	1.5 - 3	1.75 - 6	1.0 – 3.5
Thailand	1.5 - 3	2 - 6	1.1 – 2.7
Vietnam	0.8 - 2	1.5 - 3.5	1.2 – 3.2

With respect to price, it can be seen from Table 8 that CFL pricing has changed for a number of countries in the last several years:

- The range of CFL prices in Indonesia has narrowed somewhat, with the lower range now more than twice of what it was in 2010, bringing Indonesia more in line with other developed markets in the region. This change could be due to a number of factors, including the fact that most CFLs are now made in Indonesia, and Indonesia currently has MEPS and safety regulations for CFLs in place to insure product quality and safety.

- A somewhat different trend is seen for the Philippines. The current price range in Philippines is wider than what it was for 2010 While the Philippines has no CFLs below USD 1 equivalent, the high end is close to twice the high end in 2010 But the high price in the Philippines is now also comparable to other developed markets in the region. One possible explanation is, that as the market developed, consumers are no longer just purchasing products on price, but on brand and quality.[23]

- For Thailand, which is arguably the most developed market in the region, the price range for products when considering only lower wattage CFLs, which are typically the most popular wattages (replacements for 40W and 60W incandescent lamps), has remained remarkably stable. This can be attributed to the fact that Thailand has had energy efficient lighting policies in place, as well as consistent promotion and testing of CFLs, for nearly 10 years.

- Vietnam is also showing remarkable stability in CFL pricing, with lower priced CFLs more in line with the other developed markets. Vietnam has been a CFL producer since early 2000's and currently also has MEPS in place for CFLs, which may account for this price stability.

[23] Note that in 2007, the Philippines Energy Efficient Lighting Programme (PEELP) was being implemented which provided incentives to over 5 million CFLs during that time period, which may also artificially have lowered CFL pricing.

- For Cambodia, there is no previous data for comparison, but the low ends of the price ranges are lower than others in the region, which can indicate that consumers in Cambodia are still focusing on price when selecting products.
- There is also no previous data for Lao PDR, but its pricing range is quite close to other countries in the region, with the exception being the high end of the >11W range, at nearly twice the high end price of other countries, which may be a case of opportunistic pricing.

While the retail locations were not broken down by country, the variety of CFL products available, and locations at which they were sold in each of the countries, seem to indicate that the market for CFLs to be quite developed in at least five, if not all of the six target countries.[24]

6.1.2 Compliance with national requirements

As CFLs have been in the market for quite some time, and are widely available currently, many countries have implemented standards or labelling schemes. Therefore it was possible to compare the levels of performance of these products relative to the existing national standards or labelling requirements, and not just international standards or labelling requirements. Table 9 shows the number of tested models and the percentage in each country that met the national requirements (where applicable and/or available). A complete listing of the relevant national requirements is included in the country analysis section. Because the lamps were not fully tested for all of the parameters required by the national standards, the comparison presented here is for indicative purposes only.

Table 9 Models meeting applicable national requirements

Country	No. of models tested	Power factor	Luminous efficacy	CRI	SDCM	Luminous maintenance at 2,000 hours	Mercury content
Cambodia	14	NA	NA	NA	NA	NA	NA
Indonesia	14	NA	14	NA	NA	14	NA
Lao PDR	11	NA	NA	NA	NA	NA	NA
Philippines	14	NA	11	NA	NA	13	NA
Thailand	14	NA	14	NA	NA	13	NA
Vietnam	13	NA	12	NA	NA	13	NA

6.1.3 Comparison with previous study

In addition to comparing the current lamps' performance to international and national standards' requirements, it was possible to compare the results from the performance and mercury testing of these lamps to results from an earlier benchmarking testing effort for Indonesia, Philippines, Thailand, and Vietnam. [25] Such a comparison can provide some indications of market progress in terms of performance or advancements in product designs. However, it should be noted that the sampling methods, the number of samples, and the number of parameters tested may not be

[24] It was not possible to link product pricing to performance results, as in the case of the 2010 study.
[25] *Testing for Quality: Benchmarking Energy-Saving Lamps in Asia*. USAID, Bangkok, Thailand, April 2010.

comparable between the studies, so that only a very broad interpretation can be made regarding any quality and performance trends (for example, no start up or warm up time or switching withstand tests were conducted in 2014).

Table 10 shows the comparison in the 2010 and 2014 testing results. This comparisons seem to indicate that products in Indonesia, Philippines, Thailand, and Vietnam have marginally improved in some areas, such as CRI. Lamps from Indonesia and Thailand show improvements in average lamp efficacy, those from the Philippines remain unchanged, and Vietnam's showed a slight decline. Lamps from Indonesia, Thailand and Vietnam have declined in average luminous maintenance, while Philippines improved. However, the noted changes are within the typical margin of laboratory error (~3%) for some categories. Specific to efficacy, the changes may be due to MEPS being in place in those countries, as most tested lamps are in compliance with national requirements, so this may indicate that manufacturers are focused more on compliance with established domestic requirements and product consistency, or maintaining parity with competitors, rather than increasing performance. This may also be the case for lumen maintenance, as most national requirements are set at 80%.

Most notable are the changes in average mercury content for lamps in each country, which has significantly reduced: lamps from Vietnam showed the most decline, going from an average of 7 mg in 2010 testing to an average of 3 mg today. Average mercury content of lamps from Indonesia, Philippines, and Thailand all showed a 50% decline (Vietnam is the only exception, with a decline of less than 30%). It is also worth noting that not only has the lamps' average content declined, but the maximum amount of mercury found in the lamps in each country has also reduced significantly. Specific to Cambodia and Lao PDR, the average mercury in lamps for these two markets is in line with the average of other countries in the region. This finding reinforces the fact that most of these markets are mature, and manufacturers serving these markets are more consistent in their production methods and quality assurance practices with respect to mercury dosing.

Table 10 Comparison of lamp test results from 2010 and 2014

Country	Average power factor		Average efficacy (lm/W)		Average CRI		Average luminous maintenance (%)		Average mercury (mg)		Maximum mercury (mg)	
	2010	2014	2010	2014	2010	2014	2010	2014	2010	2014	2010	2014
Indonesia	0.60	0.59	55	60	80	82	.92	.88	4.9	2.7	>20	9.6
Philippines	0.58	0.59	58	58	81	83	.77	.86	5.0	2.1	>13	7.0
Thailand	0.58	0.60	56	59	81	82	.90	.86	4.0	1.8	>20	10.9
Vietnam	0.57	0.59	62	58	80	82	.86	.88	7.0	3.1	>20	16.5
Cambodia	NA	0.59	NA	58	NA	82	NA	87	NA	3.1	NA	16.7
Lao PDR	NA	0.59	NA	55	NA	79	NA	87	NA	3.6	NA	13.3

6.2 Recommendations

It is expected this report will serve as a good reference to those countries and stakeholders to better understand lamp identification, collection and testing processes, as well as the availability, performance levels and overall quality of lamps in their market. While it was not possible to obtain a

complete picture of lamp quality without the results of lifetime testing and other parameters important to consumer satisfaction, such as start up and warm up time, there is sufficient information for countries without MEPS or labelling policies to consider their development, or for countries to consider a range of supporting policies, including MVE activities based on these test results.

Countries may consider which MVE measures, such as long-term testing, would be necessary to implement to improve and control lamp product quality, so that consumers are protected and receive the expected benefits from the products, and that the energy savings promised by efficient lighting are delivered. Even for countries with limited resources, the fact that CFLs are a mature technology in these markets means that there are numerous laboratories in the region experienced in CFL testing methodologies, which can compete to provide support for MVE efforts. Further, the results from this testing exercise show the value of having a regional market picture, which can further inform MEPS development and strengthen MVE activities.

Below are a number of policy steps that countries may wish to consider in order to follow up and build upon the successful completion of this region-wide effort:

- **Continue or increase product sampling and testing of national markets**: It can be seen that CFLs have achieved significant penetration in all the markets, with a wide range of model choices, wattages, form factors, and retail locations. More importantly, the overall quality seems to have improved or stabilized over what was available in the region nearly half a decade ago. In large part this is thanks to steps that have been taken by countries to address this issue. Yet, a comparison of results shows that luminous maintenance, for example, remains low relative to international requirements. A concerted follow up effort to continue the sampling, testing, and publicising results, building on the framework established by this project, and focusing on longer-term testing of products could go far toward improving verification capacities. Such actions can help to maintain, or to increase product quality for all energy efficient lighting products in the region.

- **Consider more stringent performance standards for CFLs**: Countries may wish to consider the development process of MEPS or labelling requirements for CFLs to include higher performance levels, aligning with international requirements, or comparable to those for LED lamps (or consider High Efficiency Performance Standards – HEPS in addition to the current requirements). This will help to guide CFL manufacturers by giving them clear indications of future policy directions, increase the focus on quality, while requiring emerging LEDs to meet or exceed performance and quality levels set for CFLs to protect consumers and drive the market.

- **Begin market transition and consumer outreach**: Governments could also consider a roadmap of how the market should transition to LED lamps. While CFLs remain a cost effective efficient option (and generally the lower first cost option), LED lamps can be a more preferable alternative in certain consumer applications, such as in hard to reach and/or long operation hour locations, for operation in a dimming circuit, applications where rapid starting or frequent switching are needed, or where CFL disposal can be an issue. Consumers and manufacturers alike will require more guidance as the new technology enters the market. A campaign to educate consumers about new energy efficient lighting choices may

be required. Such a campaign can also help to prepare the market for new or revised MEPS or labelling requirements.

- **Reduce or remove existing CFL incentives:** As CFLs are a mature technology, and the markets are transitioning with emerging efficient technologies, governments currently providing support for CFLs may consider reducing or gradually removing support for CFLs, as appropriate. Alternatively, for countries importing CFLs and other energy efficient technologies, governments may want to consider extending financial advantages, such as VAT tax exemption to all energy efficient lighting technologies.

- **Continue to reduce mercury in lamps through regulations**: As there is still a high percentage of non-amalgam lamps in some markets, countries should consider encouraging the use of amalgam mercury to reduce mercury content and improve recovery rates. This can be accomplished by adding requirements for maximum mercury content for lamps (for example, 2.5mg for "low mercury" lamps) as well as for run-up time for CFLs (amalgam lamps can be slower to reach steady operating conditions and to provide suitable light output), along with suitable testing and verification schemes to ensure compliance.

- **Consider a collection and disposal strategy for spent lamps:** As CFLs burn out or are broken in normal use, it is imperative that broken and spent lamps are properly handled and disposed of, in order to minimise mercury contamination and accumulation in the environment. Along with efforts to minimise lamp mercury content, governments may also want to consider working with stakeholders to develop a collection and disposal framework for spent lamps, which may include collection and recycling points around the country, as well as an outreach and educational campaign on proper handling and disposal methods.

- **Embrace regional cooperation**: As shown by the test results, many countries are in the same situation with respect to CFL performance, market development, recycling and disposal challenges, as well as emerging technologies. It could be a good juncture for the region as a whole to cooperate on these issues, building on international experience and establishing best policy practices for the region. Countries can build on the existing network, knowledge base, and international efforts, as well as with the regional exchanges and Asia-specific information networks that have been built to date.

7 COUNTRY RESULTS

7.1 Comparison standards

The individual country results are analysed in this chapter. In order to have a better view of the lamps' performance quality, some comparison standards covering requirements for other major markets globally, as well as national requirements, are referenced for comparison with the average test results for each model. However it should be understood that different standards may have differences in the test methods and sample size, therefore these reference comparison standards are only given to provide a general picture of the product quality levels. Details of these comparison standards and the parameters tested are given in Chapter 3. A summary of the relevant current national requirements is shown in Table 11. Note that applicable national standards are not yet in place in Cambodia or Lao PDR.

Table 11 Testing parameters and standards

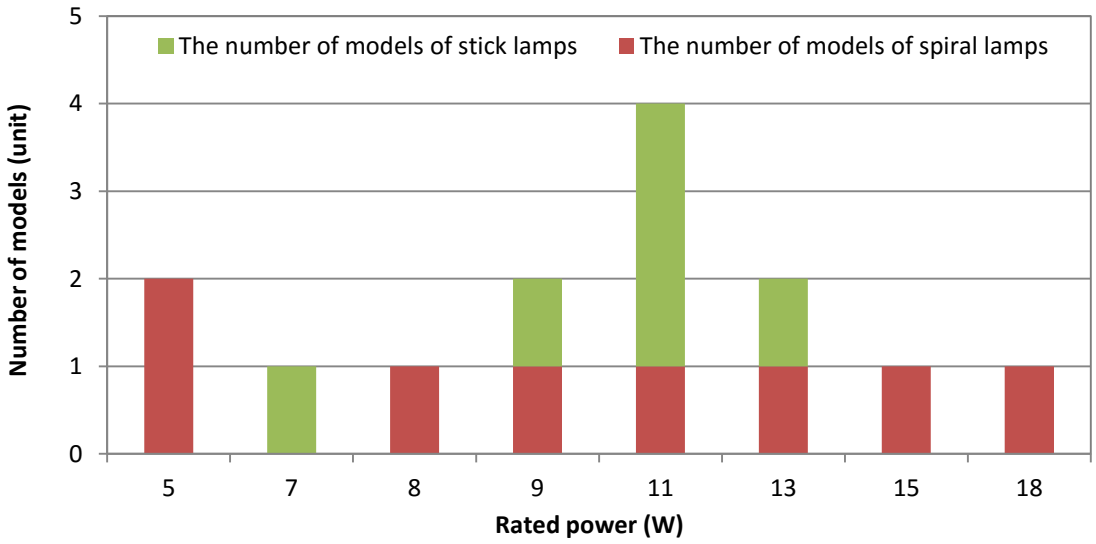
	Indonesia		Indonesia		Philippines		Thailand		Vietnam	
	MEPS		MEPS		MEPS		MEPS		MEPS	
Date	2003		Under revision		2010		Voluntary (2006)		Under consideration for revision	
Scope (other)	6500K lamps		2700K up to < 4400K ≥ 4400K up to 6500K							
Efficacy	Power (W) 5 – 9 10 – 15 16 – 25 ≥ 26	lumens/W 45 – 49 46 – 51 47 – 53 48 – 55	Power (W) **< 4400K:** ≤ 8 > 8 - 15 > 15 - 25 > 25 – 60 **≥ 4400K to 6500K:** ≤ 8 > 8 - 15 > 15 - 25 > 25 – 60	lumens/W < 34 < 38 < 42 < 46 < 33 < 37 < 41 < 45	Power (W) **≤ 4000K** ≥ 3 to < 5 ≥ 5 to < 9 ≥ 9 to < 15 ≥ 15 to < 25 ≥ 25 **> 4000K** ≥ 3 to < 5 ≥ 5 to < 9 ≥ 9 to < 15 ≥ 15 to < 25 ≥ 25	lumens/W 45 50 55 60 65 41 46 52 57 62	Power (W) **>4400K:** 5 - 8 9 -14 15 - 24 25 – 60 **4400K:** 5 - 8 9 -14 15 - 24 25 – 60	lumens/w 36 44 51 57 40 48 55 60	Power (W) **<4400 K** from 5 to 8 9 to 14 15 to 24 25 to 60 **≥ 4400 K** from 5 to 8 9 to 14 15 to 24 25 to 60	Lumens/W 45 (55) 50 (60) 55 (65) 60 (70) 40 (50) 45 (55) 50(60) 55(65)
Lumen maintenance	After 2,000 hours (including ageing period), the lumen value should be not less than 80% of its claim				After 2,000 hours of operation the lumen maintenance of the lamp shall not be less than 80%				CFL luminous flux after 2,000 hours operation must not be less than 80% of the initial luminous flux.	

Life time	Minimum lifetime 6,000 hours (2,000 hours test)	Minimum life time 6,000 hours (producer's claim) at 2,000 hours test	The average life time (the length of time during which 50% of the lamps reach the end of their individual life) shall not be less than 6,000 hours		Not less than 6,000 hours (it is permitted to use rapid test methods (cycle turn on - turn off) to assess life expectancy)

7.2 Cambodia

There were 14 CFL models sampled from Cambodia for performance testing, Cambodia currently has no MEPS for lamps. The wattage range is from 5W to 18W, as shown in Figure 29 In those samples, 79% are cool light (daylight), and 21% are warm light.

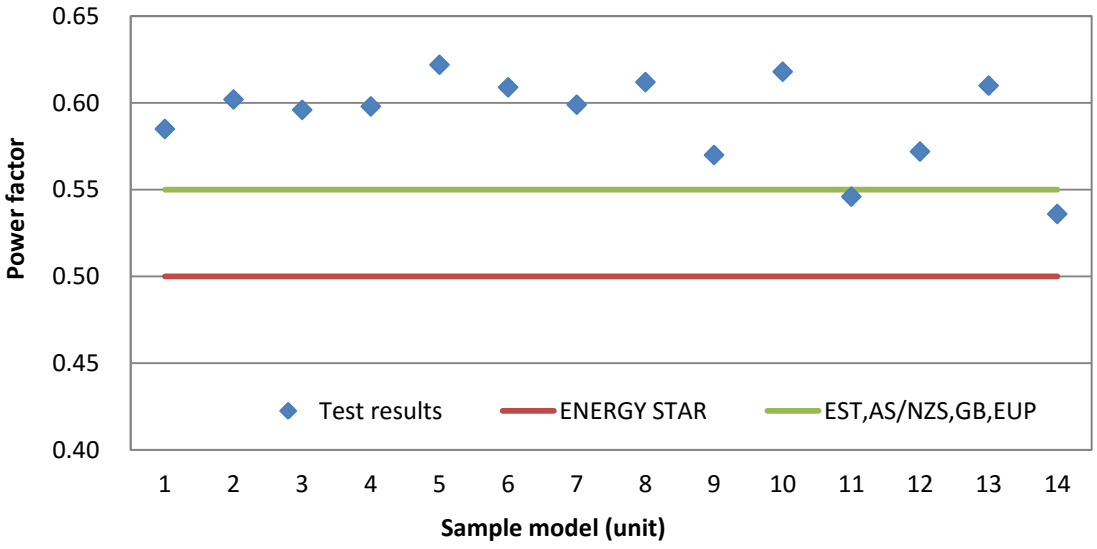
Figure 29 The CFL Lamps sampled from Cambodia



7.2.1 Power factor

Figure 30 shows the test results of the power factor against the comparison standards. It can be seen that all of the models meet the ENERGY STAR requirement (PF=0.5). There are two models that have an average power factor of less than 0.55, which do not meet the other comparison standards' requirements.

Figure 30 Test results for average (mean, n=10) power factor



7.2.2 Luminous efficacy

Different standards have different requirements for efficacy, for example, in the Energy Saving Trust specification different lamp shapes require different minimum efficacy values; and in the comparison standard GB/T 17263, the minimum efficacy required may be different for different CCTs, even for the same wattage. Therefore, in order to compare the efficacy data with specific conditions required by some standards, the comparison figures are separated for each.

Figure 31 shows the efficacy test results compared with AS/NZS 4847.2, EU regulation and ENERGY STAR Lamp specification V1.0 . There was a large difference among the test results. About 43% of the samples did not meet the ENERGY STAR[26] requirements and about 14% of the samples (9W and 13W) did not meet AS/NZS 4847.2 and EU regulation requirement.

Figure 31 Average (mean, n=10) test results of luminous efficacy (all lamp)

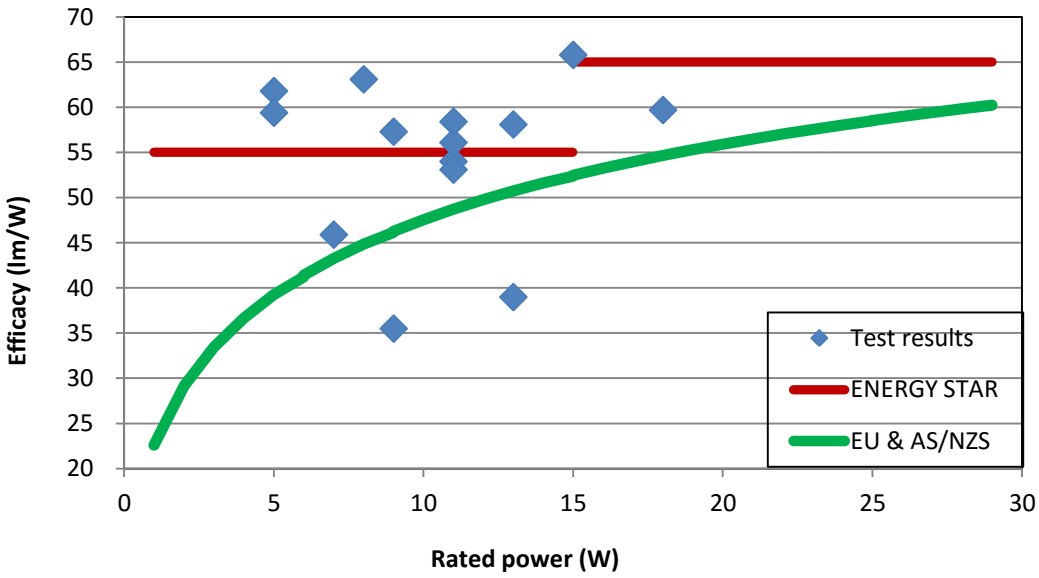


Figure 32 and Figure 33 show the efficacy test results compared with GB/T 17263. The efficacy requirement in this standard, has two levels according to the colour temperature. Therefore, the test samples here are divided into two groups, one is high colour temperature group (cool light) with a CCT equal or higher than 4000K, the other is low colour temperature with a CCT less than 4000K (warm light). From Figure 32 and Figure 33 it can be seen that all of the cool light lamp meet the GB standard requirement. For the warm light lamps, two thirds of the models did not meet the minimum requirement.

[26] ENERGY STAR is a voluntary programme. It aims to promote high energy efficiency products through an endorsement scheme in the market. Therefore ENERGY STAR is not a minimum performance standard.

Figure 32 Average (mean, n=10) test results of efficacy (cool light lamp)

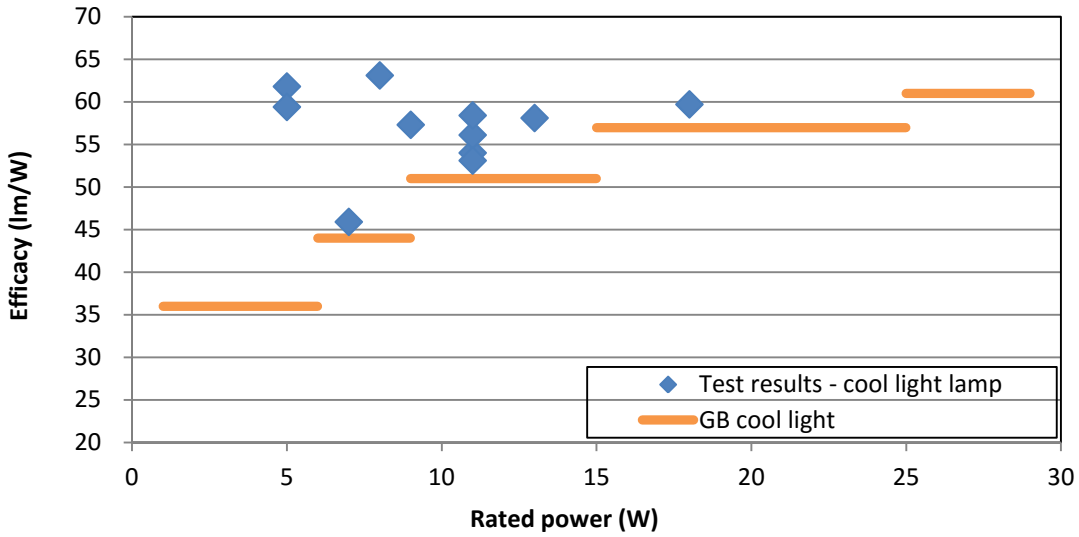


Figure 33 Average (mean, n=10) test results of efficacy (warm light lamp)

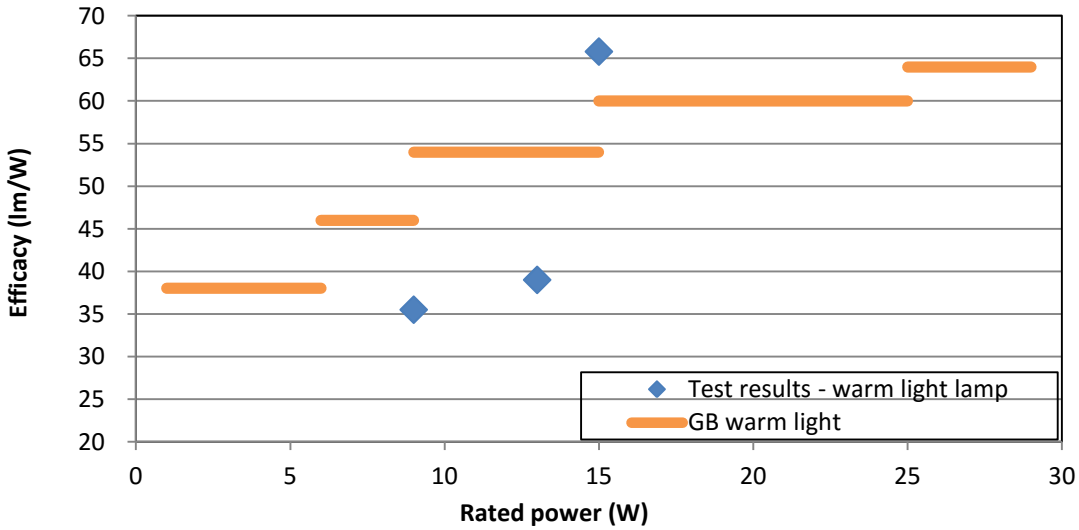


Figure 34 and Figure 35 show the efficacy test results compared with Energy Saving Trust lamp specification V7[27]. In the Energy Saving Trust specification, there are three Groups covering fluorescent lamps and 17 Classes defined for the electronically self-ballasted CFLs. The samples tested under this project all belong to Group 1 and Class 1, and are all types without a secondary covering or bulb with wattages up to and including 25W. However for efficacy, there are still two different required curves for stick shape lamp and spiral lamp in Group 1 and Class 1. From Figure 34 and Figure 35 it can be seen that 83% of the stick lamps and 50% of the

[27] Energy Saving Trust is a voluntary programme. It's lamp specification aims to promote the top energy efficiency products in the market. Therefore the Energy Saving Trust lamp specification is not a minimum performance standard, but a high efficiency performance requirement (HEPS).

spiral lamps meet the Energy Saving Trust requirements. There was a large difference between the non-compliance samples and the standard requirement, especially for spiral lamps.

Figure 34 Average (mean, n=10) test results of efficacy (stick lamp)

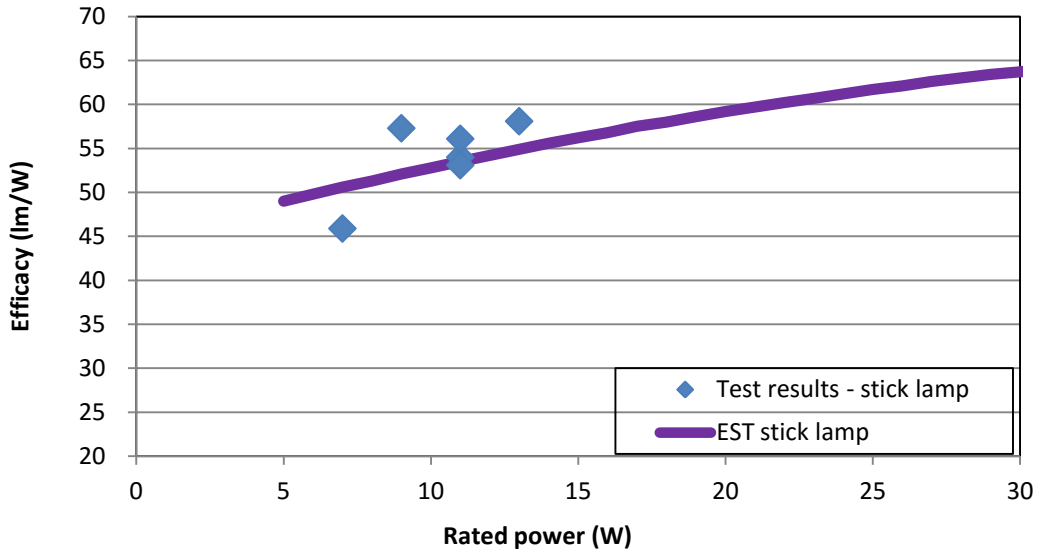
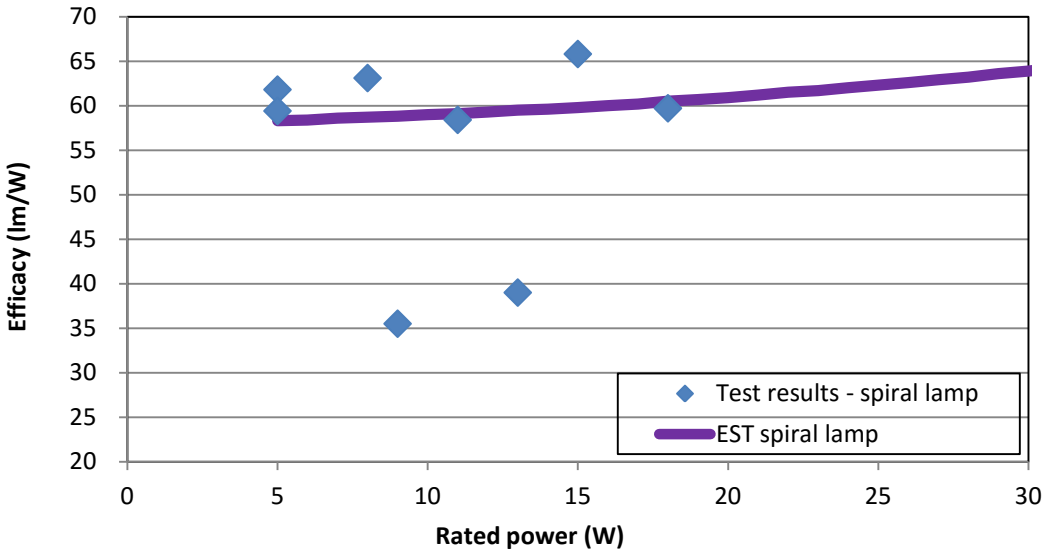


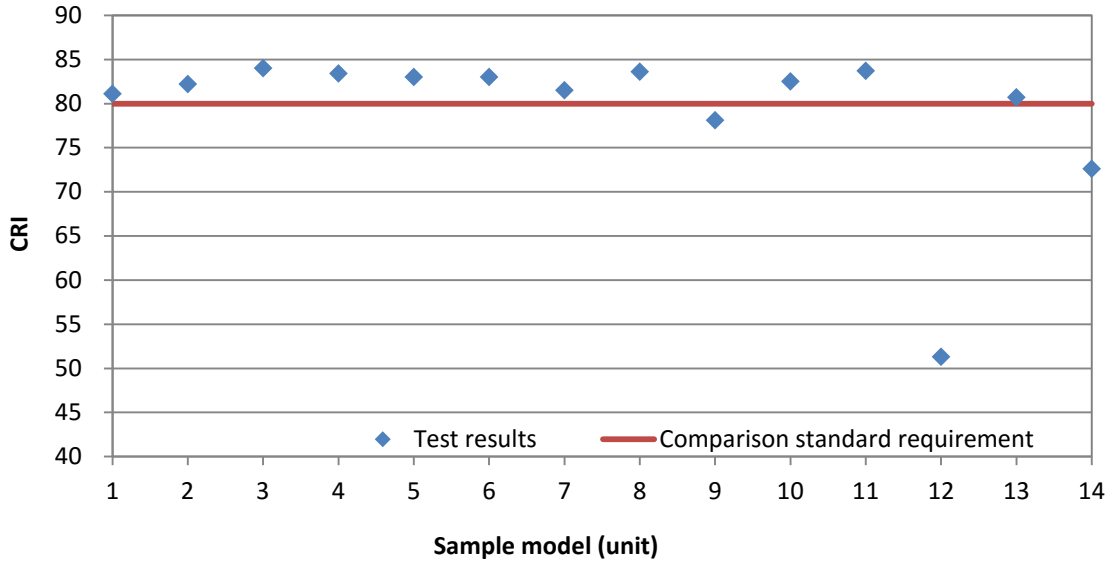
Figure 35 Average (mean, n=10) test results of efficacy (spiral lamp)



7.2.3 Colour rendering index

Figure 36 shows the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be no less than 80. It can be seen in Figure 37 that most of the samples met this requirement. However, there are also three models with a measured sample average CRI value less than 80 (under the red line), and some were lower than 75. The compliance rate of CRI for the samples purchased in Cambodia was about 79%.

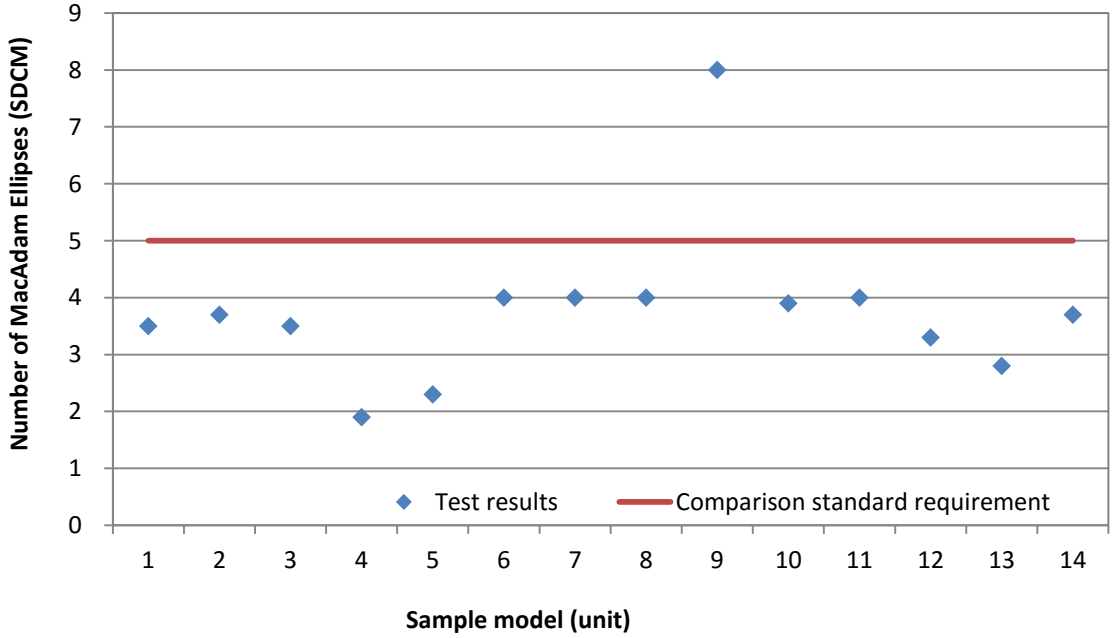
Figure 36 Average (mean, n=10) test results of CRI



7.2.4 Standard Deviation of Colour Matching (SDCM)

Figure 37 provides SDCM test results against the comparison standards. The comparison standards require that the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5. From Figure 37 it can be seen that there was one model which had an average SDCM of 8, which represents 7% of the total samples failing to meet the requirement (above the red line).

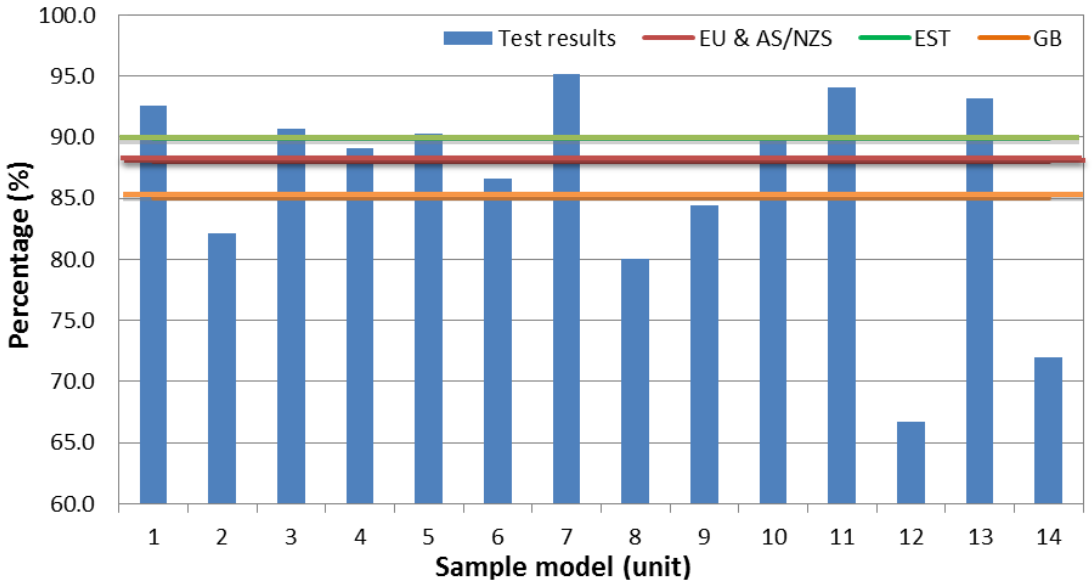
Figure 37 Average (mean, n=10) test results of SDCM



7.2.5 Luminous maintenance

Figure 38 shows the luminous maintenance results compared with the different comparison standards. From Figure 38, there were five models with average luminous maintenance test results under the orange line (less than 85% - the minimum requirement for the comparison standard GB/T 17263). Six models were under the red line (less than 88% - the minimum requirement for the EU and AS/NZS standard), and seven models were under the green line (less than 89.9% - the minimum requirement for the Energy Saving Trust standard).

Figure 38 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.2.6 Mercury format and content

Figure 39 presents the percentage of each mercury format of the CFLs from Cambodia; 50% of the CFLs adopted amalgam technology and 50% adopted non-amalgam technology. This is quite a high proportion for the non-amalgam lamps.

Figure 39 Test results for mercury format (percent of total lamps tested)

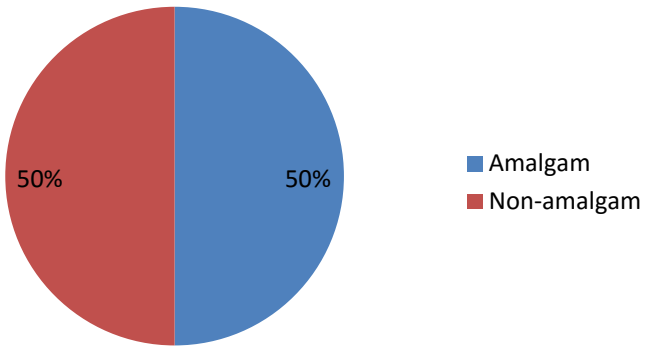
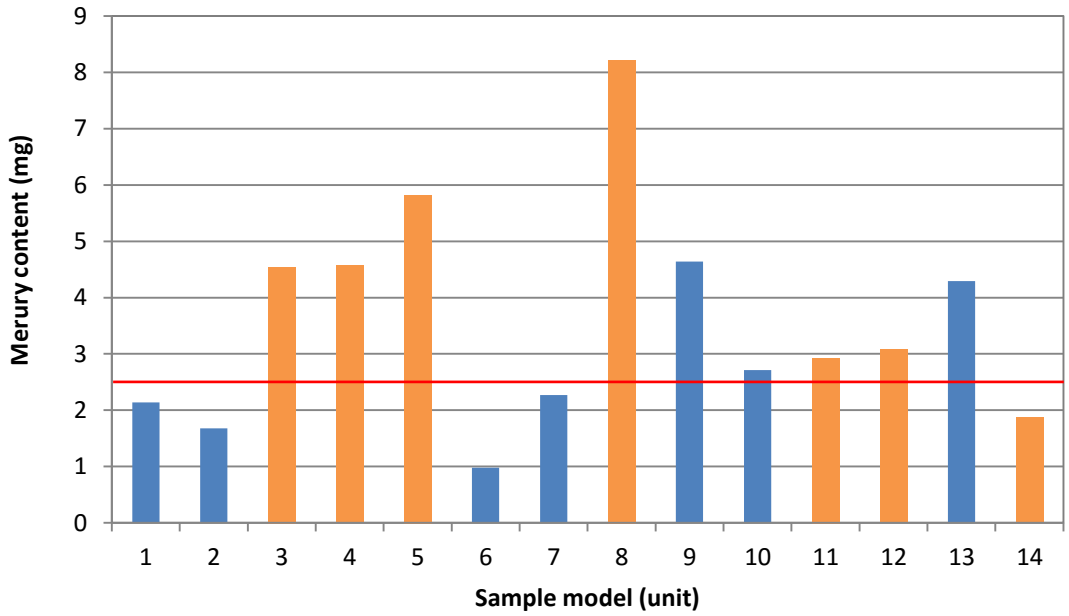


Figure 40 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. Averaged across the models tested, the amalgam lamps had 2.7 mg of mercury while the non-amalgam lamps had 4.4 mg. Thus, on average, the mercury content of non-amalgam lamps was about 1.6 times higher than that of amalgam lamps.

Figure 40 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps.

7.2.7 Summary of results for Cambodian lamps

Of the 14 models of CFLs tested from Cambodia, the testing identified a big difference in quality. The tested samples did not meet all the requirements of the comparison standards for efficacy, CRI, SDCM, luminous maintenance and mercury parameters. From Figures 32, 34 and 36, it can be seen that for the efficacy, the lowest two models were low power, warm light and spiral shape. Table 12 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 13 presents each parameter's compliance of each model compared with the minimum requirements of all the comparison standards.

Table 12 Summary of test results of the samples purchased in Cambodia

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	2 models do not meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	2 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	2 models do not meet the requirement
	EN ERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	2 models do not meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) 0,24√Φ+0,0103Φ	2 models do not meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, 1/(0,24√Φ+0,0103Φ) Where F = initial luminous flux	2 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7[28]	See Table 5	9 models meet the requirement

[28] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2"></td><td>ENERGY STAR lamp V1.0[29]</td><td><table><tr><td>Lamp Rated power (watts)</td><td>Minimum Lamp Efficacy (lm/W)</td></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td><td>8 models meet the requirement</td></tr>
<tr><td>GB/T17263</td><td><table><tr><td rowspan="2">Power（W)</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr><tr><td>≤5</td><td>36</td><td>38</td></tr><tr><td>6～8</td><td>44</td><td>46</td></tr><tr><td>9～14</td><td>51</td><td>54</td></tr><tr><td>15～</td><td>57</td><td>60</td></tr><tr><td>≥25</td><td>61</td><td>64</td></tr></table></td><td>2 models do not meet the requirement</td></tr>
<tr><td rowspan="4">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>3 models do not meet the requirement</td></tr>
</table>

[29] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

Testing parameters	comparison standards	Requirement	Results
	GB/T17263	80	3 models do not meet the requirement
Standard Deviation of Colour Matching	AS/NZS 4847.2	Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.	1 models does not meet the requirement
	Energy Saving Trust Lamp Specification V7	Within a tolerance limit of 5 steps of MacAdam Ellipses	1 model does not meet the requirement
	GB/T 17263	≤5 steps of MacAdam Ellipses	1 model does not meet the requirement
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	6 models do not meet the requirement
	AS/NZS 4847.2	2000 hrs = 0.88	6 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	7 models do not meet the requirement
	GB/T 17263	85%	5 models do not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	2 models do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	5 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	5 models meet the requirement

Testing parameters	comparison standards	Requirement	Results
	AZ/NZS 4847	≤5 mg	2 models do not meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	5 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	1 model meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	1 model meet the requirement

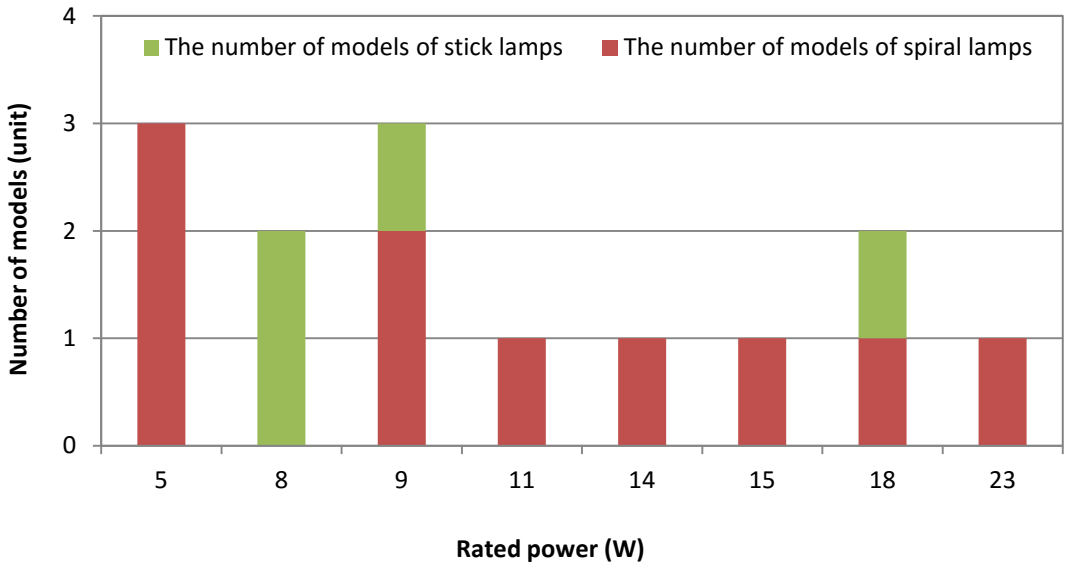
Table 13 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×
Colour rendering index	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	×	✓	×
Standard Deviation of Colour Matching	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
Luminous maintenance @2,000 hours	✓	×	✓	✓	✓	✓	✓	×	×	✓	✓	×	✓	×
Mercury content	✓	✓	✓	✓	×	✓	✓	×	✓	✓	✓	✓	✓	✓

7.3 Indonesia

There are 14 CFLs models sampled from Indonesia for performance testing. The wattage range is from 5W to 23W, see Figure 41. In those samples, 71% are cool light (daylight), and 29% are warm light. Indonesia currently has a voluntary labelling programme for CFLs (SNI 04-6958-2003), covering efficacy (tiered), lumen maintenance (80%), and lamp life for lamps from 2700 K to 6500 K (Table 11).

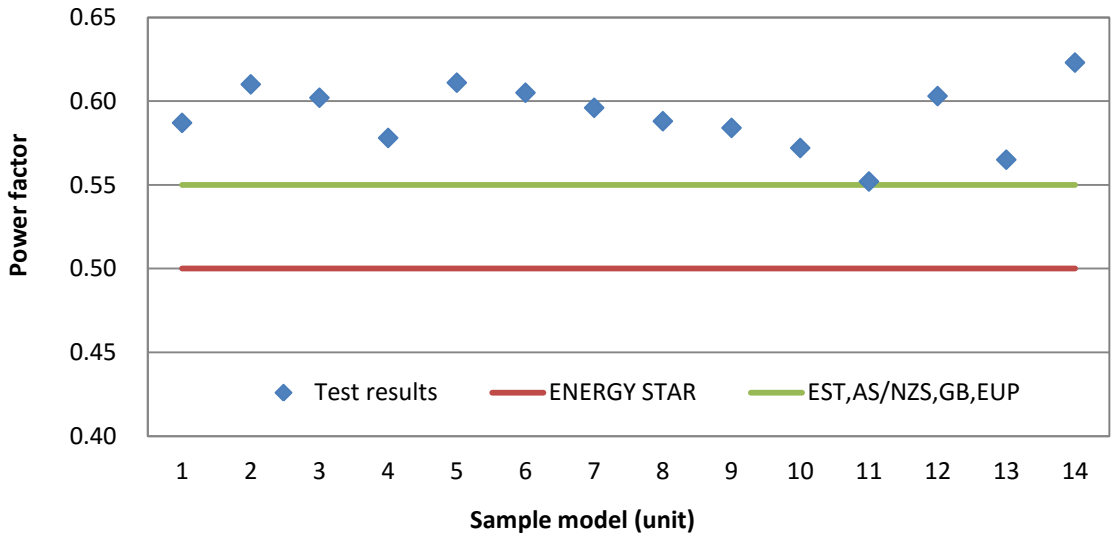
Figure 41 The CFL lamps sampled from Indonesia



7.3.1 Power factor

Figure 42 shows the test results of the power factor compared with the reference standards. It can be seen that all of the models met the highest requirement of 0.55.

Figure 42 Test results for average (mean, n=10) power factor



7.3.2 Luminous efficacy

Different standards have different requirements for efficacy, for example, in the Energy Saving Trust specification different lamp shapes require different minimum efficacy values; and in the comparison standard GB/T 17263, the minimum efficacy required maybe different for different CCTs, even for the same wattage. Therefore, in order to compare the efficacy data with some standards' specific conditions, the comparison figures must be separated for each standard.

Figure 43 shows the efficacy test results compared with AS/NZS 4847.2, EU regulation and ENERGY STAR Lamp specification V1.0 . It can be seen that all of the models meet AS/NZS 4847.2 and the EU regulation requirement. Several models did not meet the ENERGY STAR requirements[30] and the compliance rate is about 71%.

Figure 43 Average (mean, n=10) test results of luminous efficacy

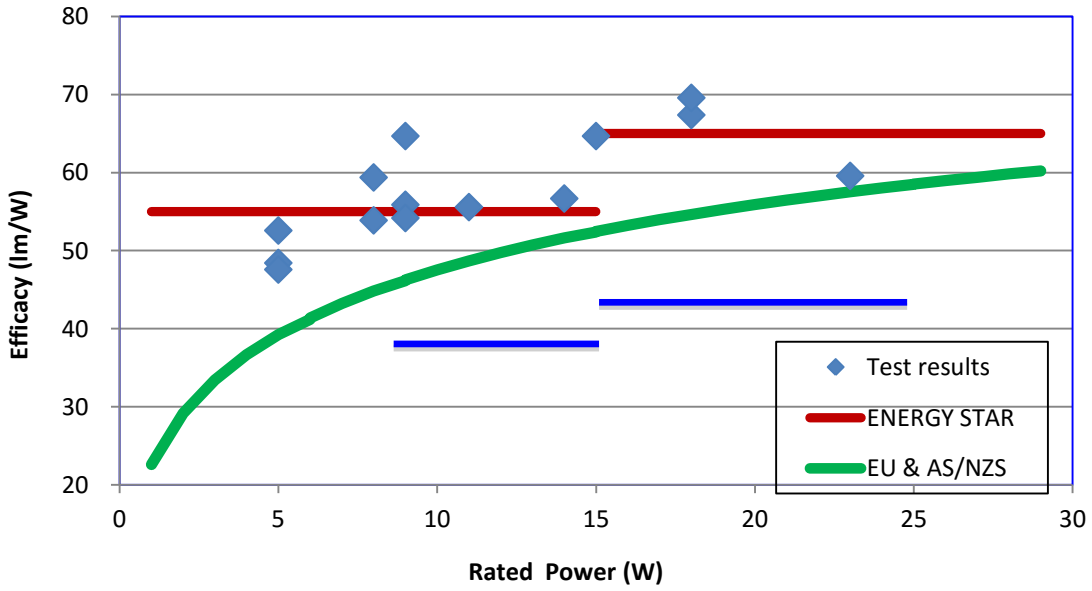


Figure 44 and Figure 45 show the efficacy test results compared with GB/T 17263. The efficacy requirement in the GB standard, has two levels according to the colour temperature. Therefore, the test samples here are divided into two groups, one is high colour temperature group (cool light) with a CCT equal or higher than 4000K, the other is low colour temperature with a CCT less than 4000K (warm light). From Figure 44 and Figure 45 it can be seen that all of lamps meet the GB standard requirement. For the Indonesian labelling requirements, lamps must meet the minimum efficacy levels by colour temperature and wattage bins as stated in SNI-04-6958 (Figure 44 and Figure 45). All tested models are in compliance.

[30] ENERGY STAR is not a MEPS programme, but is a voluntary programme designed to recognise the top performing lamps in the market.

Figure 44 Average (mean, n=10) test results of efficacy (cool light lamp)

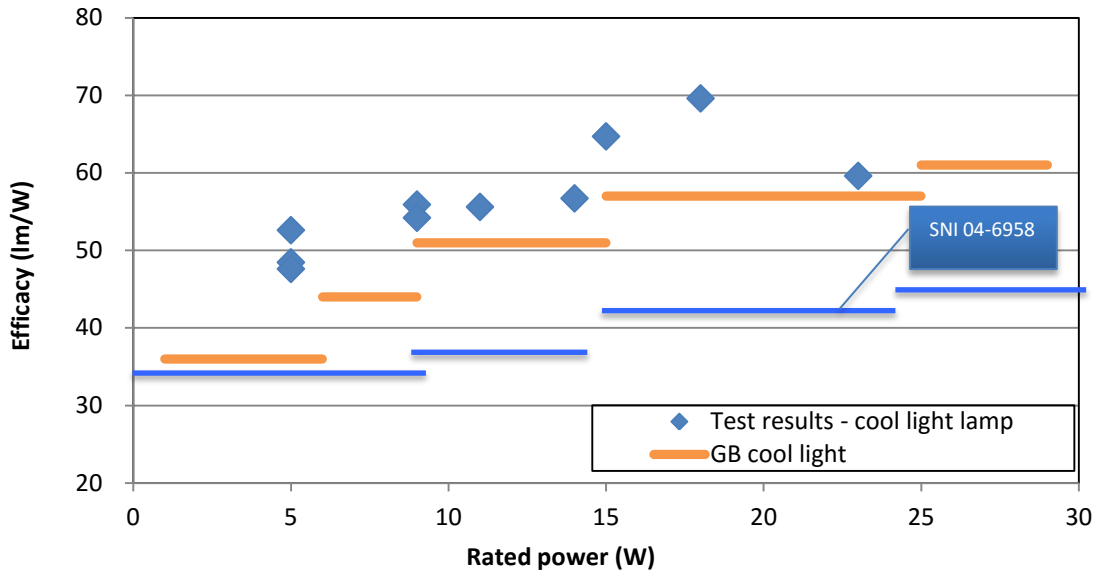


Figure 45 Average (mean, n=10) test results of efficacy (warm light lamp)

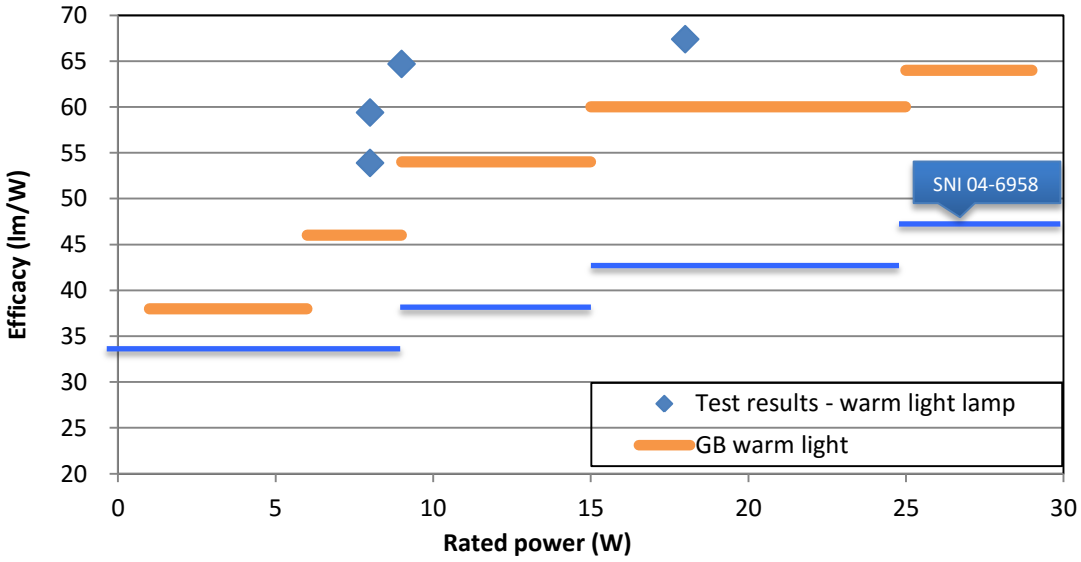


Figure 46 and Figure 47 show the efficacy test results compared with Energy Saving Trust lamp specification V7[31]. In the Energy Saving Trust specification, there are three groups covering fluorescent lamps and 17 classes defined for the electronically self-ballasted CFLs. The samples tested under this project all belonging to Group 1 and Class 1, and are all types without a secondary covering or bulb with wattages up to and including 25W. However for efficacy, there are still two different required curves for stick shape lamps and spiral lamp in Group 1 and Class 1. From Figure 46 and Figure 47, it can be seen that all of the stick lamps meet the

[31] Energy Saving Trust is a not a MEPS programme, but rather is a voluntary programme designed to recognise the top performing lamps in the market.

Energy Saving Trust requirement. However for the spiral lamps, the non-compliance rate is high at 70%.

Figure 46 Average (mean, n=10) test results of efficacy (stick lamp)

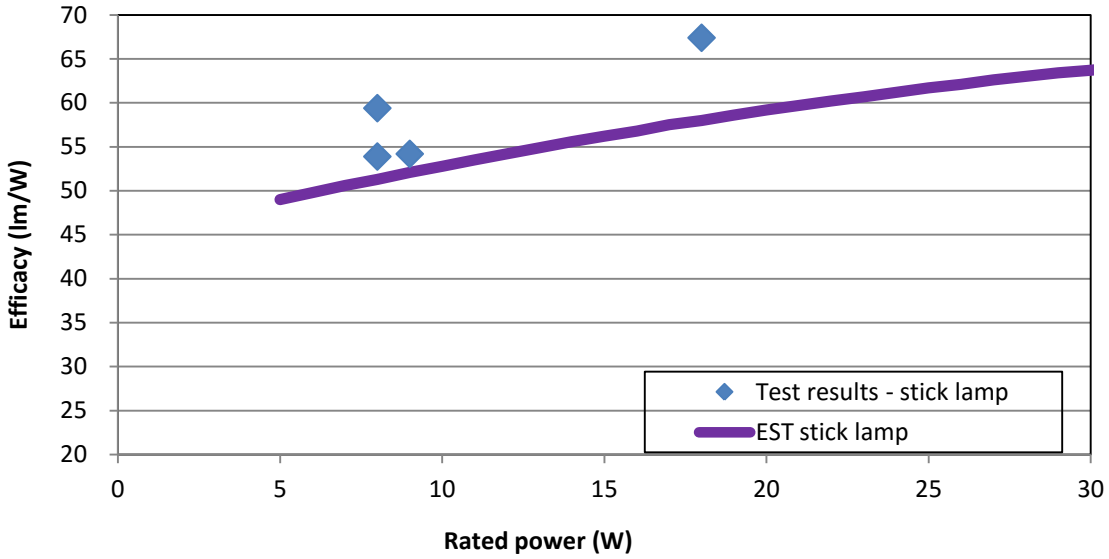
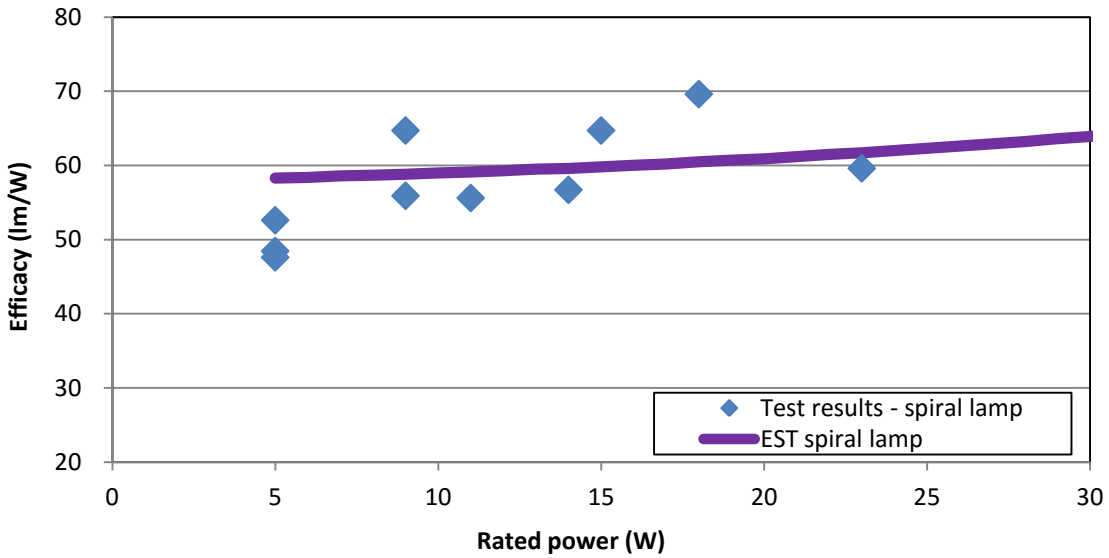


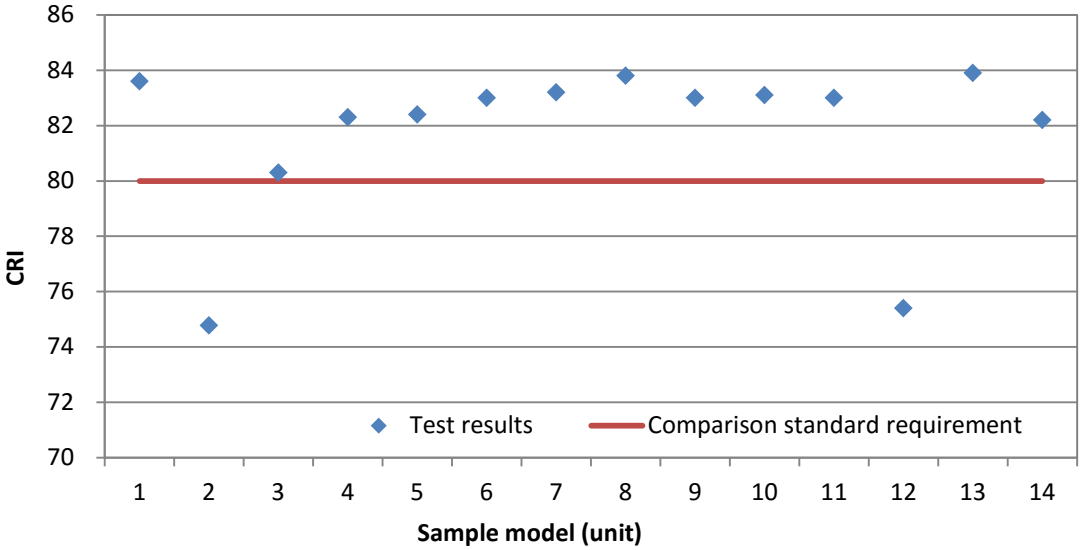
Figure 47 Average (mean, n=10) test results (spiral lamp)



7.3.3 Colour rendering index

Figure 48 presents the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be not less than 80. It can be seen in Figure 48 that most of the samples meet this requirement. However, there were also two models with a measured sample average CRI value less than 80 (under the red line). The compliance rate of CRI for the samples purchased in Indonesia is about 71%.

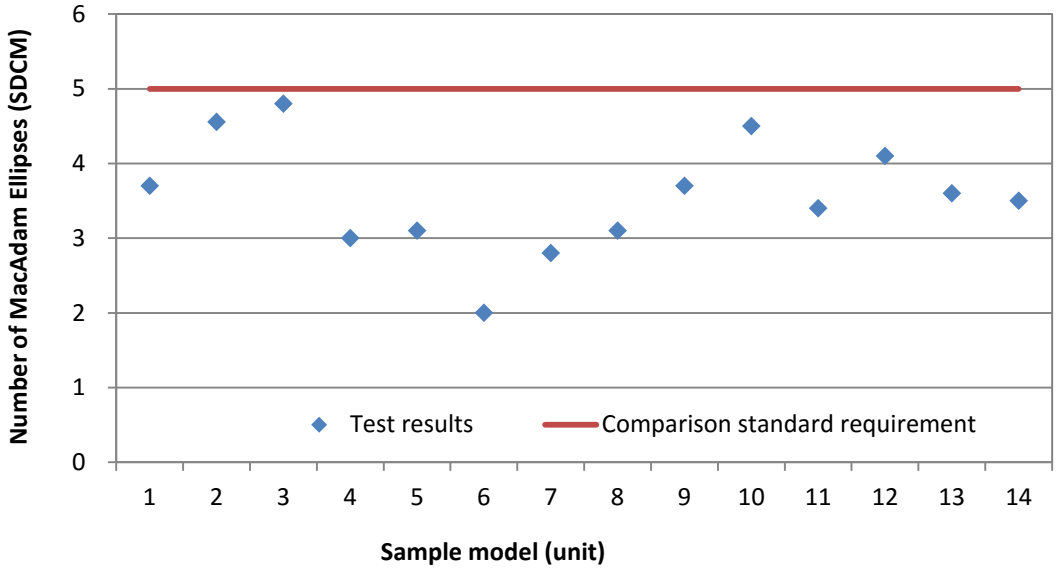
Figure 48 Average (mean, n=10) test results of CRI



7.3.4 Standard Deviation of Colour Matching (SDCM)

shows the SDCM) test results compared with the comparison standards. These standards require the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5 (under the red line). From Figure 49, it can be seen that all of the samples meet the standard's requirement.

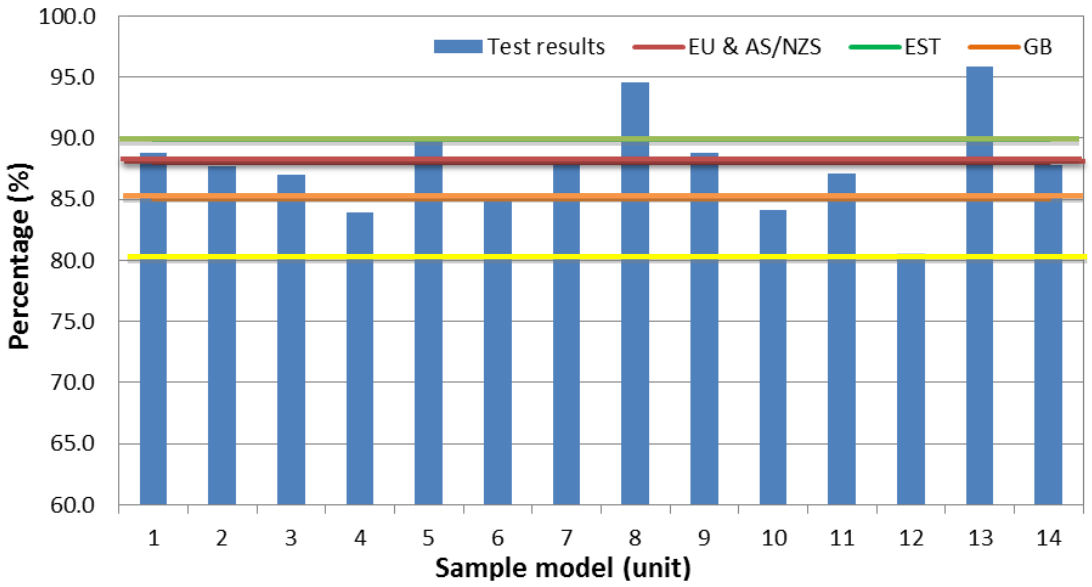
Figure 49 Average (mean, n=10) test results of SDCM



7.3.5 Luminous maintenance

Figure 50 shows the luminous maintenance results compared with the different comparison standards. From Figure 50, there were three models with the average luminous maintenance test results under the orange line (less than 85% - the minimum requirement of the comparison standard GB/T 17263). Six models were under the red line (less than 88% - the minimum requirement of the EU and AS/NZS standards), and twelve models were under the green line (less than 89.9% - the minimum requirement of the Energy Saving Trust standard). Note that Indonesia's labelling requirements for lumen maintenance is 80% (yellow line in Figure 50), and all 14 tested models met this criteria.

Figure 50 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.3.6 Mercury format and content

There are two main mercury dosing technologies adopted for CFLs which use two mercury formats: amalgam and non-amalgam lamps. Figure 51 presents the percentage of each mercury format of the CFLs from Indonesia; 50% of the CFLs adopted amalgam technology and 50% adopted non-amalgam technology. This is quite a high proportion for the non-amalgam lamps.

Figure 51 Test results for mercury format (percent of total lamps tested)

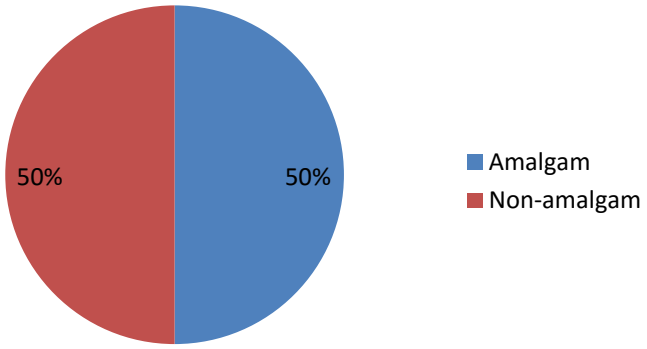
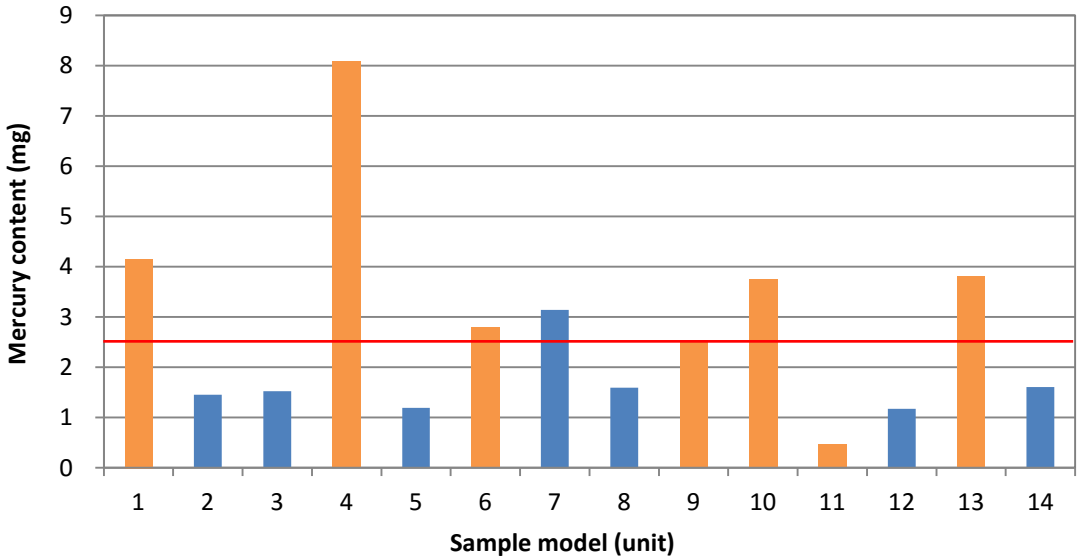


Figure 52 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. Averaged across the models tested, the amalgam lamps had 1.7 mg of mercury while the non-amalgam lamps had 3.7 mg. Thus, on average, the mercury content of non-amalgam lamps was about 2.2 times higher than that of amalgam lamps.

Figure 52 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

7.3.7 Summary of results for Indonesian lamps

Of the 14 models of CFLs tested from Indonesia, it can be seen that efficacy, luminous maintenance at 2,000 hours, CRI and mercury are the main parameters that some of samples did not meet the comparison standards, but all tested models met current national labelling requirements. Table 14 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 15 presents each parameter's compliance of each model compared with the minimum requirement of all the comparison standards.

Table 14 Summary of test results of the samples purchased in Indonesia

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	All models meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	All models meet the requirement
	ENERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	All models meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) $0{,}24\sqrt{\Phi}+0{,}0103\Phi$	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, $1/(0{,}24\sqrt{\Phi}+0{,}0103\Phi)$ Where F = initial luminous flux	All models meet the requirement
	Energy Saving Trust Lamp Specification V7[32]	See Table 5	7 models meet the requirement

[32] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2"></td><td>ENERGY STAR lamp V1.0[33]</td><td><table><tr><td>Lamp Rated power (watts)</td><td>Minimum Lamp Efficacy (initial lm/W)</td></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td><td>10 models meet the requirement</td></tr>
<tr><td>GB/T17263</td><td><table><tr><td rowspan="2">Power（W)</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr><tr><td>≤5</td><td>36</td><td>38</td></tr><tr><td>6～8</td><td>44</td><td>46</td></tr><tr><td>9～14</td><td>51</td><td>54</td></tr><tr><td>15～</td><td>57</td><td>60</td></tr><tr><td>≥25</td><td>61</td><td>64</td></tr></table></td><td>All models meet the requirement</td></tr>
<tr><td rowspan="5">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>2 models do not meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>2 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>2 models do not meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>2 models do not meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>80</td><td>2 models do not meet the requirement</td></tr>
</table>

[33] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

Testing parameters	comparison standards	Requirement	Results
Standard Deviation of Colour Matching	AS/NZS 4847.2	Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.	All models meet the requirement
	Energy Saving Trust Lamp Specification V7	Within a tolerance limit of 5 steps of MacAdam Ellipses	All models meet the requirement
	GB/T17263	≤5 steps of MacAdam Ellipses	All models meet the requirement
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	6 models do not meet the requirement
	AS/NZS 4847.2 S	2000 hrs = 0.88	6 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	12 models do not meet the requirement
	GB/T17263	85%	3 models do not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	1 model do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	7 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	7 models meet the requirement
	AZ/NZS 4847	≤5 mg	1 model does not meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	7 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	4 models meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	1 model meet the requirement

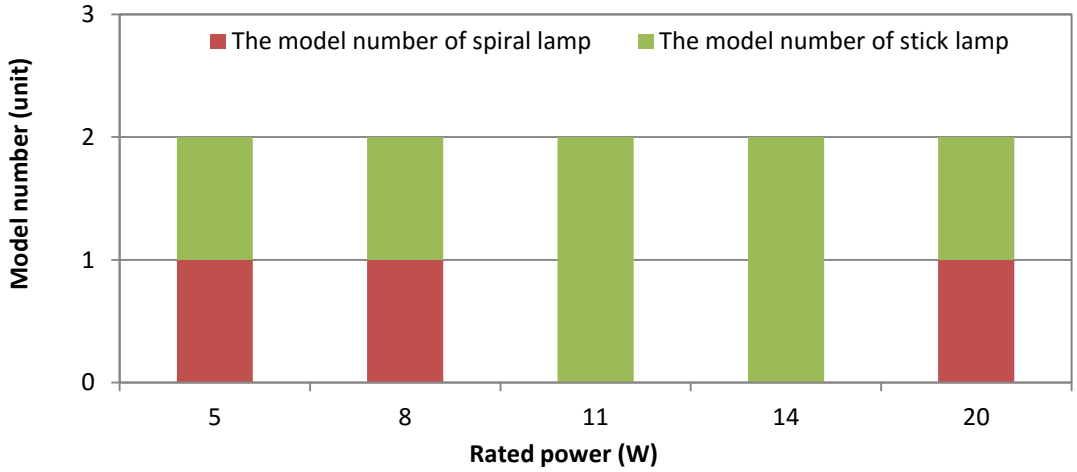
Table 15 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Colour rendering index	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓
Standard Deviation of Colour Matching	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Luminous maintenance @2,000 hours	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	×	✓	✓
Mercury content	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

7.4 Lao PDR

There are 11 CFL models sampled from Lao PDR for performance testing. The wattage range is from 5W to 20W, see Figure 53. In those samples, 73% are cool light (daylight), and 27% are warm light. Lao PDR currently does not have performance requirements for lamps.

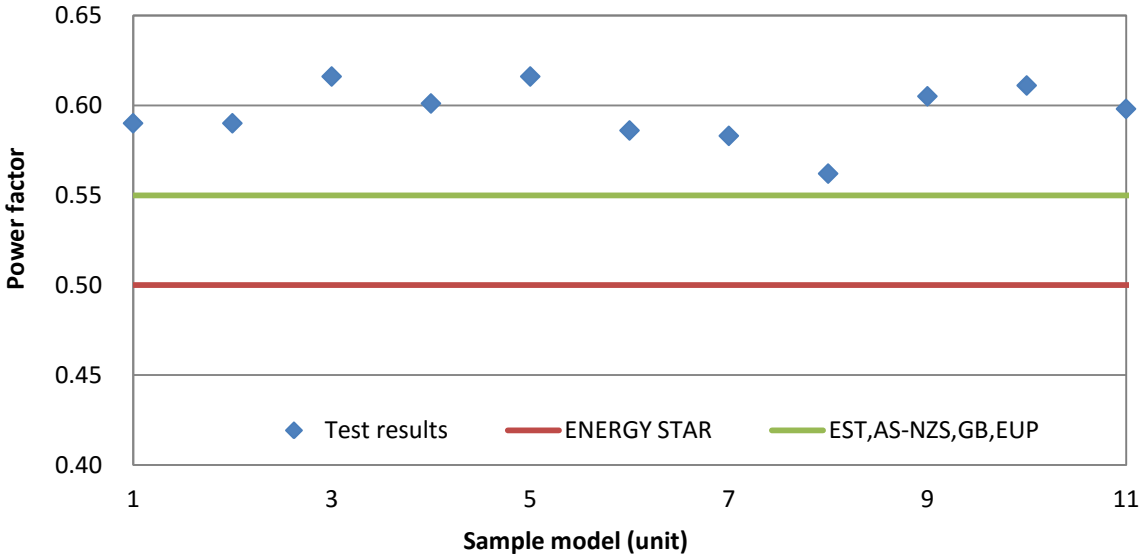
Figure 53 The CFL lamps sampled in Lao PDR



7.4.1 Power factor

Figure 54 shows the test results of the power factor and compares these with the comparison standards. It can be seen that all of the models met the highest requirement of 0.55.

Figure 54 Test results for average (mean, n=10) power factor



7.4.2 Luminous efficacy

Different standards have different requirements for efficacy, for example, in the Energy Saving Trust specification different lamp shapes require different minimum efficacy; and in the comparison standard GB/T 17263, the minimum efficacy required may be for different CCTs, even for the same wattage. Therefore, in order to compare the efficacy data with some standards' specific conditions, the comparison figures must be separated for each standard.

Figure 55 shows the efficacy test results compared with AS/NZS 4847.2, the EU regulation and ENERGY STAR Lamp specification V1.0 . It can be seen that all the models meet the AS/NZS 4847.2 and the EU regulation requirement; about 45% of the samples did not meet the ENERGY STAR requirements[34].

Figure 55 Average (mean, n=10) test results of luminous efficacy

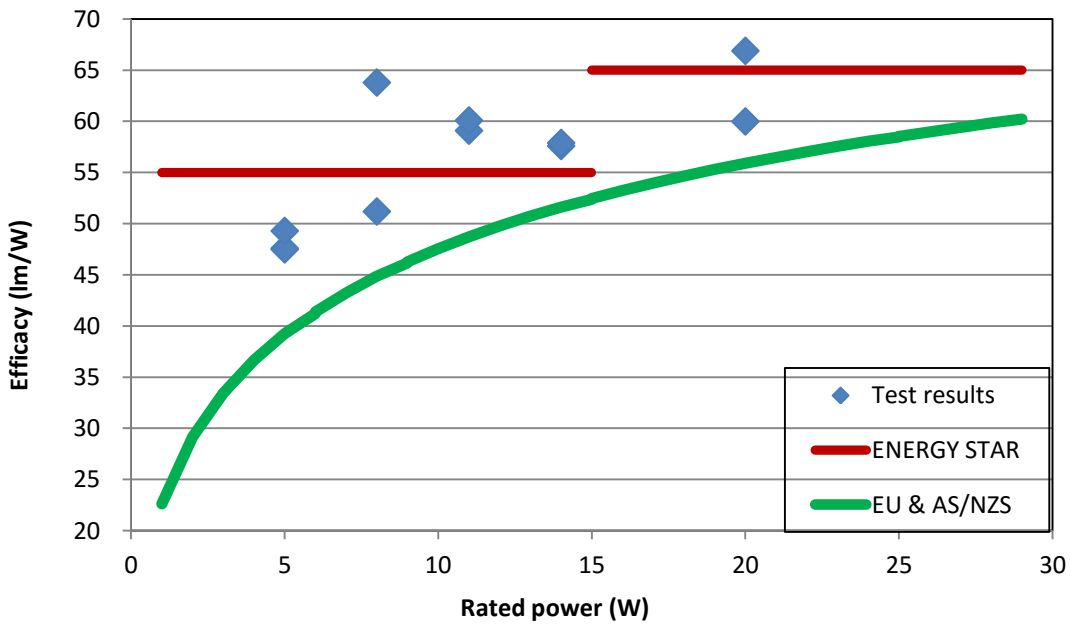


Figure 56 and Figure 57 show the efficacy test results compared with GB/T 17263. The efficacy requirement in the GB standard, has two levels according to the colour temperature. Therefore, the test samples here are divided into two groups, one is high colour temperature group (cool light lamp) with a CCT equal or higher than 4000K, the other is low colour temperature with a CCT less than 4000K (warm light lamp). From Figure 56 and Figure 57 it can be seen that all of samples could meet the GB standard requirement.

[34] ENERGY STAR is not a MEPS programme, but is a voluntary programme designed to recognise the top performing lamps in the market.

Figure 56 Average (mean, n=10) test results of efficacy (cool light lamp)

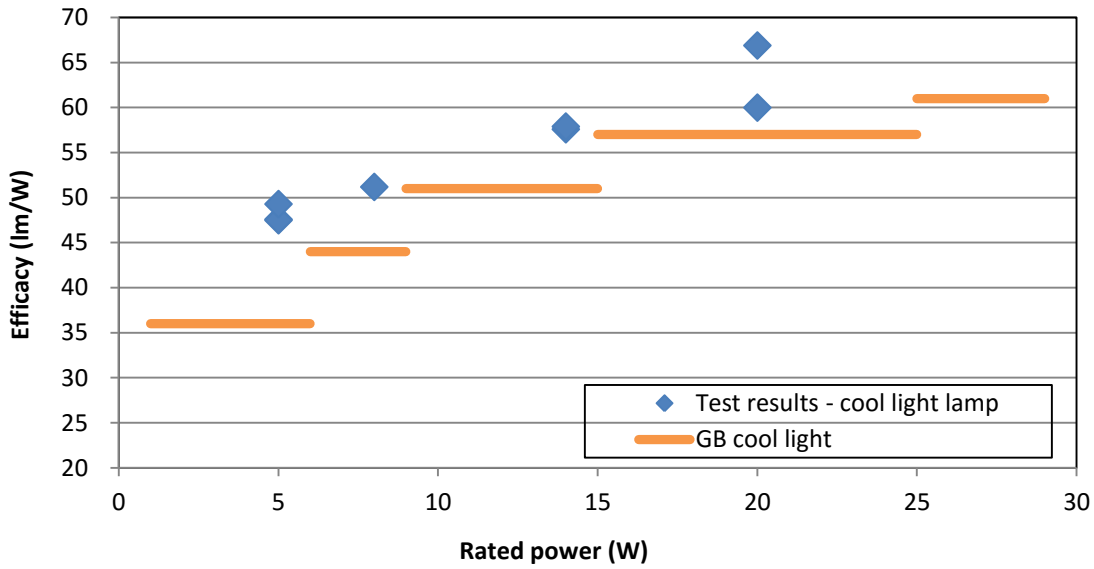


Figure 57 Average (mean, n=10) test results of efficacy (warm light lamp)

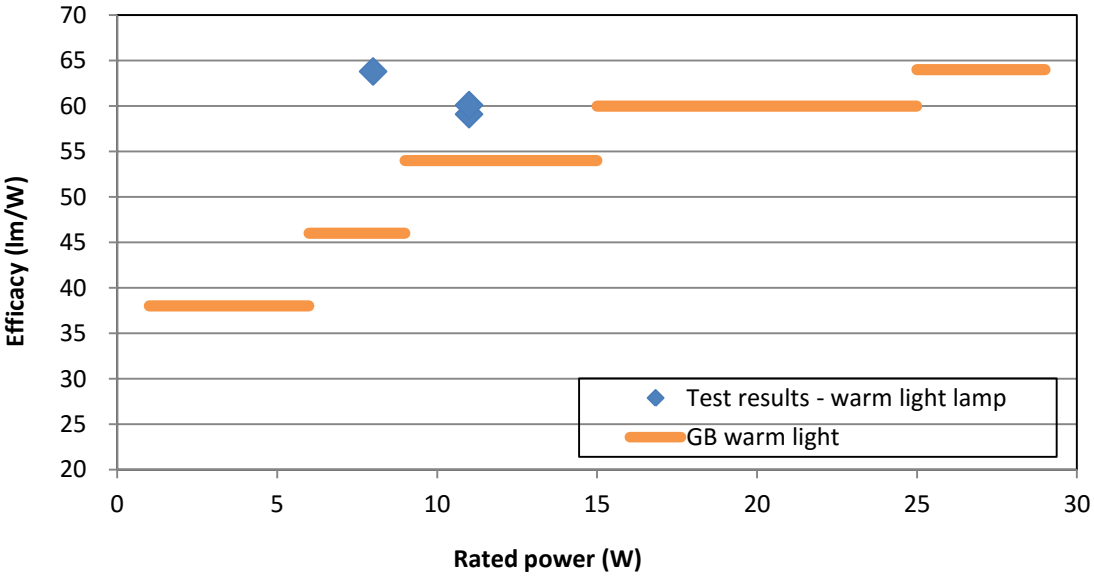


Figure 58 and Figure 59 show the efficacy test results compared with Energy Saving Trust lamp specification V7[35]. In the Energy Saving Trust specification, there are three groups covering fluorescent lamps and 17 classes defined for the electronically self-ballasted CFLs. The samples tested under this project all belonging to group 1 and Class 1, and are all types without a secondary covering or bulb with wattages up to and including 25W. However for efficacy, there are still two different required curves for stick shape lamps and spiral lamp in Group 1

[35] Energy Saving Trust is not a MEPS programme, but is a voluntary programme designed to recognise the top performing lamps in the market

and Class 1. From Figure 58 and Figure 59, it can be seen that one model of the stick lamps and one model of the spiral lamps did not meet the Energy Saving Trust requirement.

Figure 58 Average (mean, n=10) test results of efficacy (stick lamp)

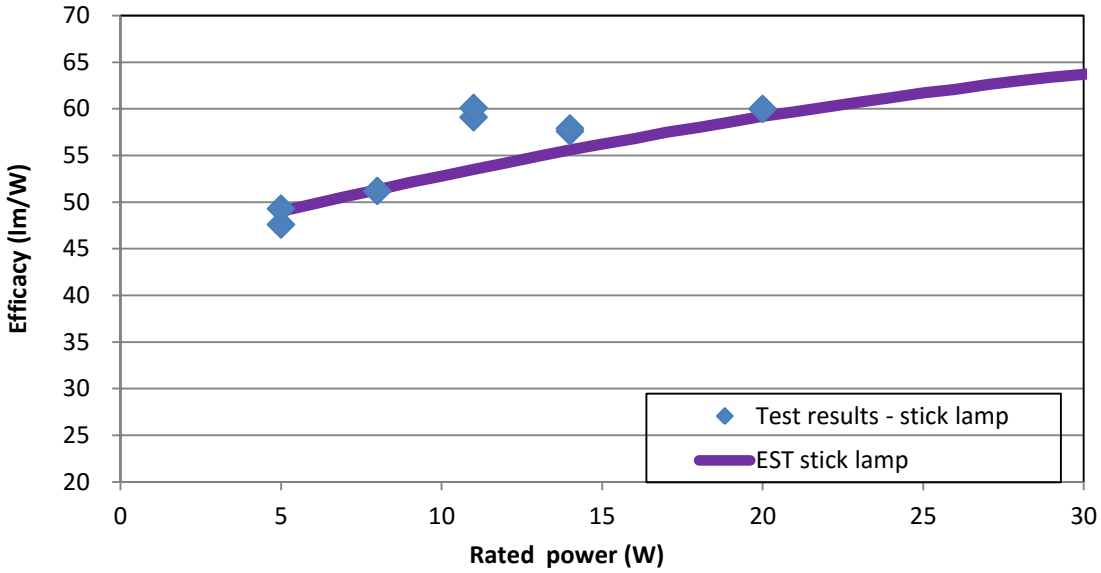
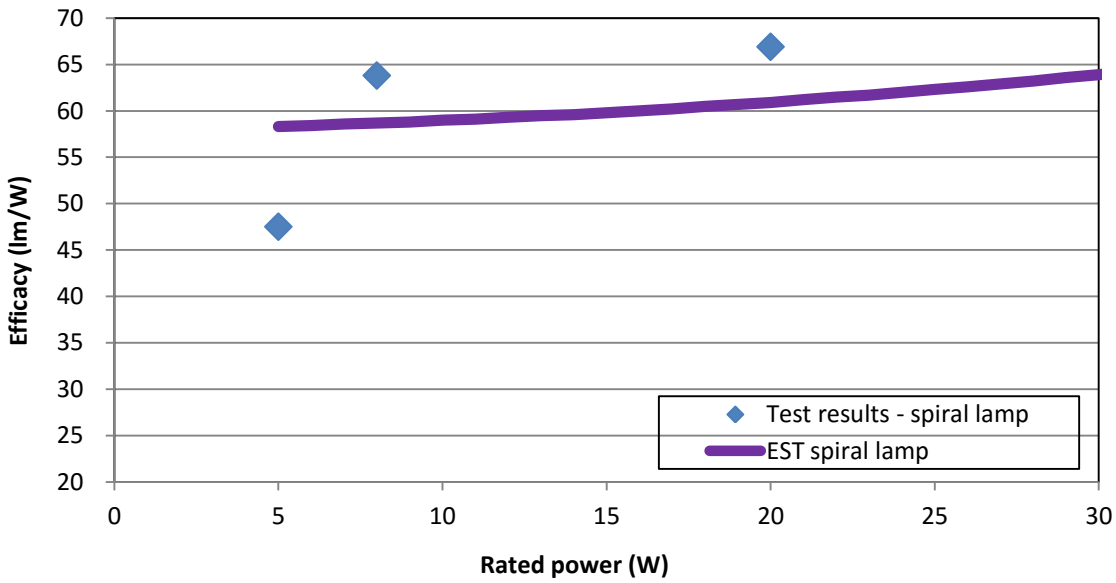


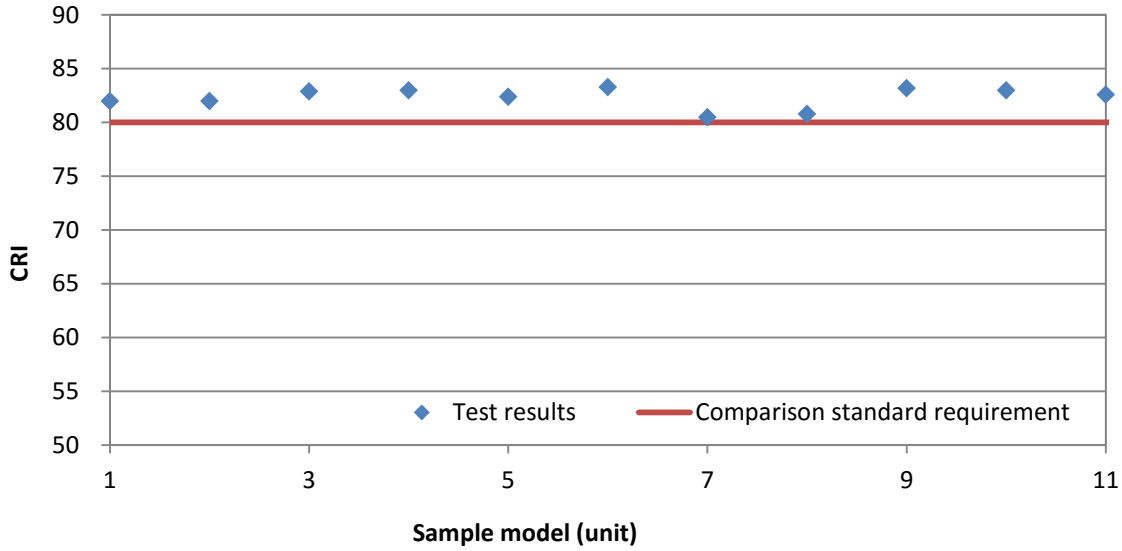
Figure 59 Average (mean, n=10) test results of efficacy (spiral lamp)



7.4.3 Colour rendering index

Figure 60 presents the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be not less than 80 (above the red line). It can be seen in Figure 60 that all of the samples could meet this requirement. The compliance rate of CRI for the samples purchased in Lao PDR was 100%.

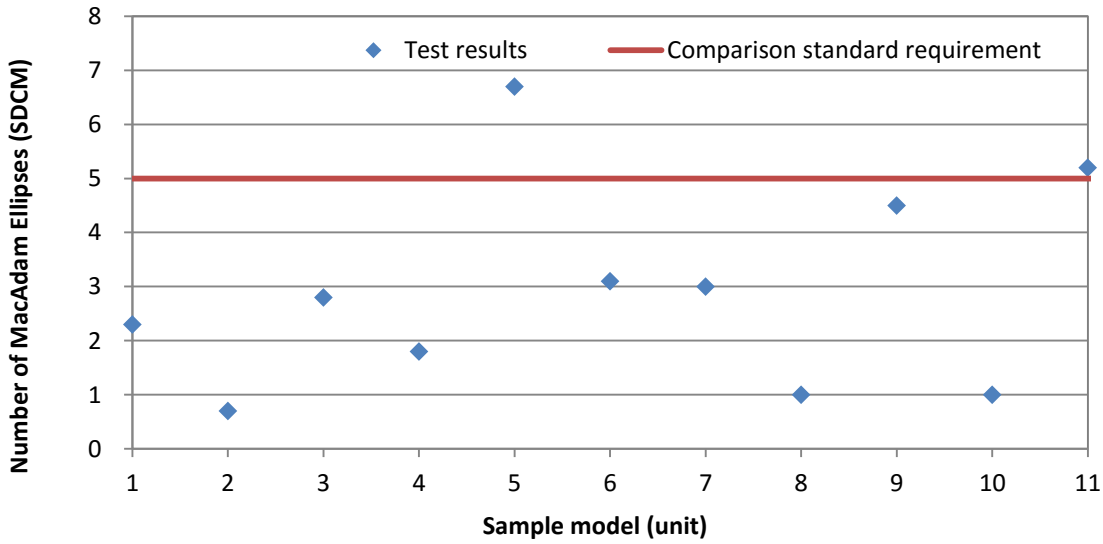
Figure 60 Average (mean, n=10) Test results of CRI



7.4.4 Standard Deviation of Colour Matching (SDCM)

Figure 61 provides the SDCM test results compared with the comparison standards. The comparison standards requires the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5 (under the red line). From Figure 61, it can be seen that there were two models that have an average SDCM over 5 steps, which represents 18% of the total samples.

Figure 61 Average (mean, n=10) test results of SDCM

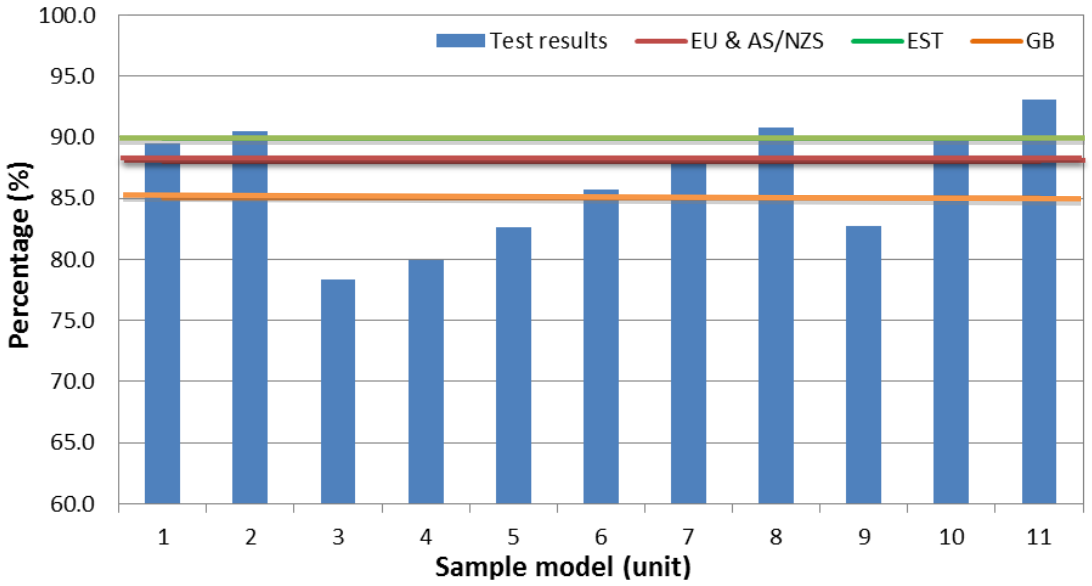


7.4.5 Luminous maintenance

Figure 62 shows the luminous maintenance results compared with the different comparison standards. From Figure 62, there were four models with the average luminous maintenance test results under the orange line (less than 85% - the minimum requirement of the GB

standard). Five models were under the red line (less than 88% - the minimum requirement of the EU and AS/NZS standard), and seven models were under the green line (less than 89.9% - the minimum requirement of the Energy Saving Trust standard).

Figure 62 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.4.6 Mercury format and content

There are two main mercury dosing technologies adopted for CFLs which use two mercury formats: amalgam and non-amalgam lamps. Figure 63 presents the percentage of each mercury format of the CFLs from Lao PDR; all of the CFLs tested in this project adopted the amalgam technology.

Figure 63 Test results for mercury format (percent of total lamps tested)

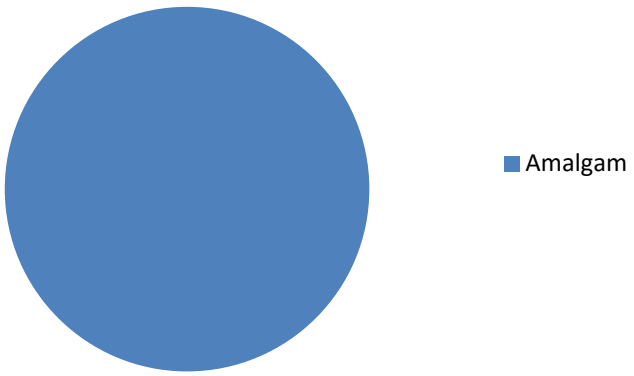
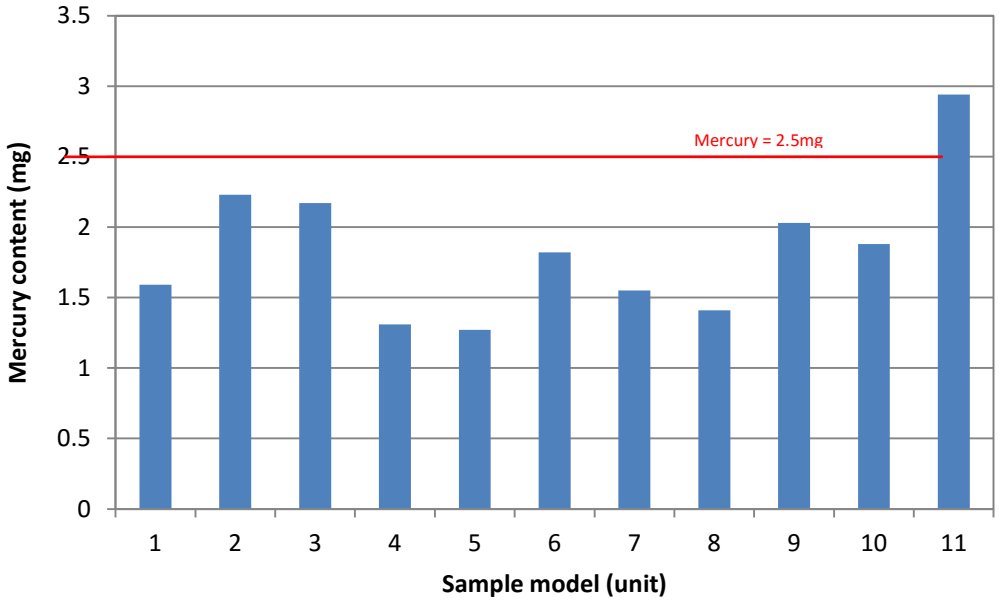


Figure 64 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. It can be seen that all of the models contained the mercury less than 3 mg, and with the average of 1.8 mg.

Figure 64 Test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

7.4.7 Summary of results of Lao PDR lamps

Of the 11 models of CFLs tested from Lao PDR, it can be seen that efficacy, luminous maintenance at 2,000 hours and SDCM are the main parameters where some samples did not meet all the comparison standards. Table 16 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 17 presents each parameter's compliance of each model compared with the minimum requirement of all the comparison standards.

Table 16 Summary of test results of the samples purchased in Lao PDR

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	All models meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	All models meet the requirement
	ENERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	All models meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) $0{,}24\sqrt{\Phi}+0{,}0103\Phi$	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, $1/(0{,}24\sqrt{\Phi}+0{,}0103\Phi)$ Where F = initial luminous flux	All models meet the requirement
	Energy Saving Trust Lamp Specification V7[36]	See Table 5	9 models meet the requirement
	ENERGY STAR lamp V1.0[37]	Lamp Rated power (watts) / Minimum Lamp Efficacy (initial lm/W) <15 / 55 ≥15 / 65	6 models meet the requirement

[36] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.
[37] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td></td><td>GB/T17263</td><td><table>
<tr><td rowspan="2">Power（W)</td><td colspan="2">Efficacy(lm/W)</td></tr>
<tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr>
<tr><td>≤5</td><td>36</td><td>38</td></tr>
<tr><td>6～8</td><td>44</td><td>46</td></tr>
<tr><td>9～14</td><td>51</td><td>54</td></tr>
<tr><td>15～</td><td>57</td><td>60</td></tr>
<tr><td>≥25</td><td>61</td><td>64</td></tr>
</table></td><td>All models meet the requirement</td></tr>
<tr><td rowspan="4">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>All models meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>All models meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>80</td><td>All models meet the requirement</td></tr>
<tr><td rowspan="3">Standard Deviation of Colour Matching</td><td>AS/NZS 4847.2</td><td>Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.</td><td>2 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>Within a tolerance limit of 5 steps of MacAdam Ellipses</td><td>2 models do not meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>≤5 steps of MacAdam Ellipses</td><td>2 models do not meet the requirement</td></tr>
</table>

Testing parameters	comparison standards	Requirement	Results
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	5 models do not meet the requirement
	AS/NZS 4847.2 S	2000 hrs = 0.88	5 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	7 models do not meet the requirement
	GB/T17263	85%	4 models do not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	All models meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	10 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	10 models meet the requirement
	AZ/NZS 4847	≤5 mg	All models meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	10 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	3 models meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	None meet the requirement

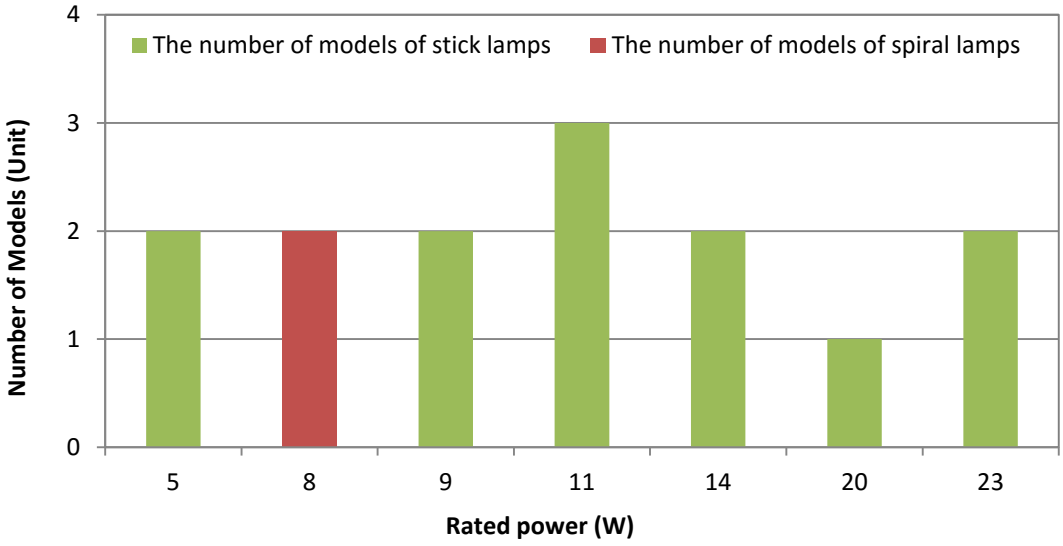
Table 17 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Colour rendering index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Standard Deviation of Colour Matching	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	✓	✓
Luminous maintenance @2,000 hours	✓	✓	×	×	×	✓	✓	✓	×	✓	✓	✓	✓	✓
Mercury content	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

7.5 Philippines

There are 14 CFL models sampled from the Philippines for performance testing. The wattage range is from 5W to 23W, see Figure 65. In those samples, all of them are cool light (daylight). The Philippines currently has a labelling programme for CFLs, covering efficacy (tiered), luminous maintenance (80%), and lifetime, per PNS 2050-2:2007, *Lamps and related equipment – Energy efficiency and labeling requirements*.

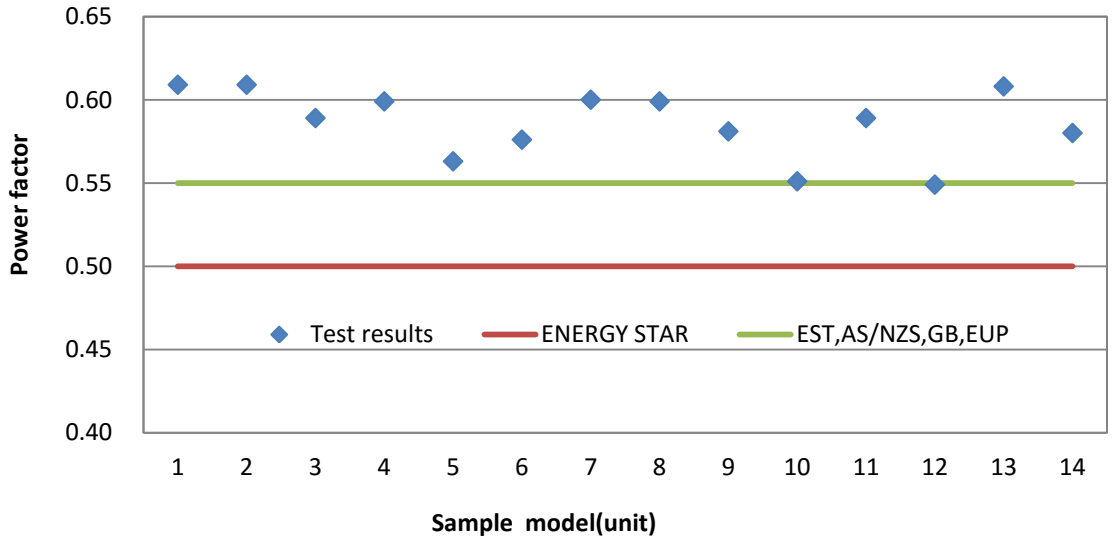
Figure 65 The CFL lamps sampled in Philippines



7.5.1 Power factor

Figure 66 shows the test results of the power factor and compared with the comparison standards. It can be seen that all of the models meet the highest requirement of 0.55.

Figure 66 Test results for average (mean, n=10) power factor



7.5.2 Luminous efficacy

Figure 67 shows the efficacy test results compared with AS/NZS 4847.2, EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 17263 (cool light). It can be seen that all of the samples met the AS/NZS 4847.2 and EU regulation requirement; about 14% of the lamps did not meet the GB/T 17263 requirement; and about 36% of the samples did not meet ENERGY STAR requirements[38]. For Philippines labelling requirements, lamps must meet the minimum efficacy levels by colour temperature and wattage bins as stated in PNS 2050-2 (Figure 67). Three models are not in compliance with PNS 2050-2.

Figure 67 Average (mean, n=10) test results of luminous efficacy

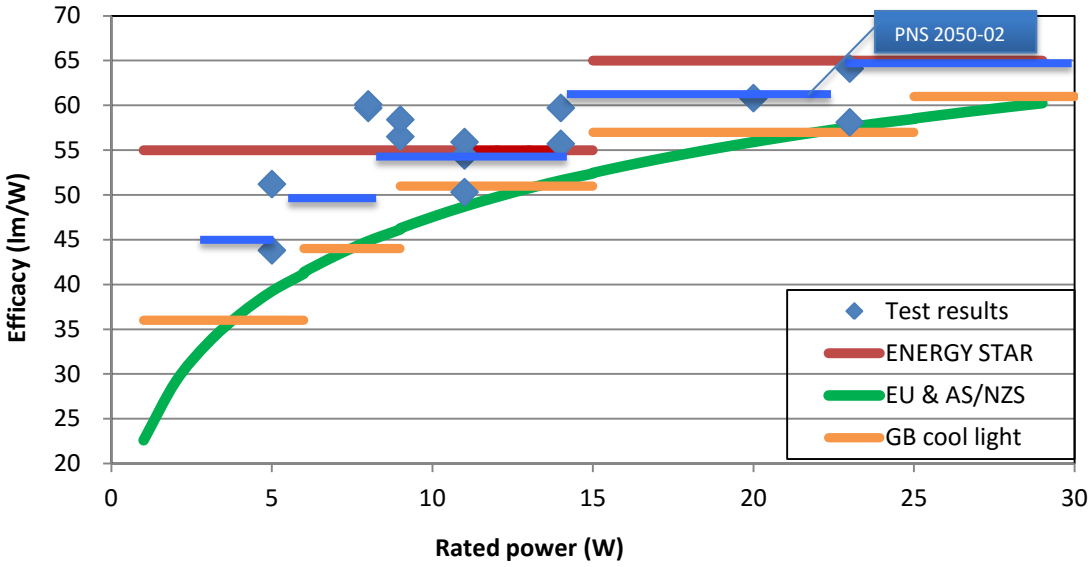


Figure 68 and Figure 69 show the efficacy test results compared with Energy Saving Trust lamp specification V7[39]. In the Energy Saving Trust specification, there are three groups covering fluorescent lamps and 17 classes defined for the electronically self-ballasted CFLs. The samples tested under this project all belonging to group 1 and Class 1, and are all types without a secondary covering or bulb with wattages up to and including 25W. However for efficacy, there are still two different required curves for stick shape lamps and spiral lamps in Group 1 and Class 1. From Figure 68 and Figure 69, it can be seen that 75% of the stick lamps and all of the spiral lamps meet the Energy Saving Trust requirement.

[38] ENERGY STAR is not a MEPS programme, but is a voluntary programme designed to recognise the top performing lamps in the market.
[39] Energy Saving Trust (EST) is not a MEPS programme, but is a voluntary programme designed to recognise the top performing lamps in the market.

Figure 68 Average (mean, n=10) test results of efficacy (stick lamp)

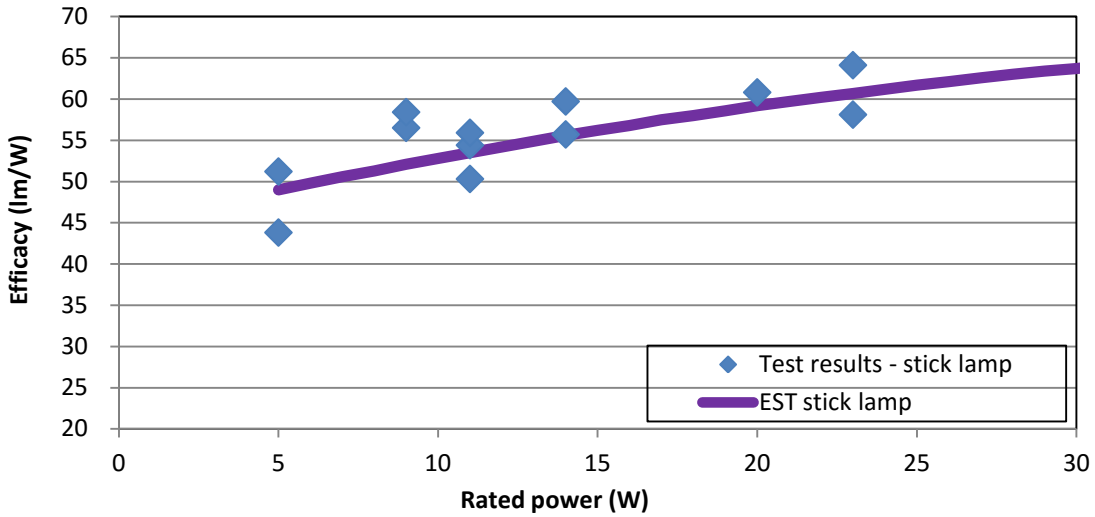
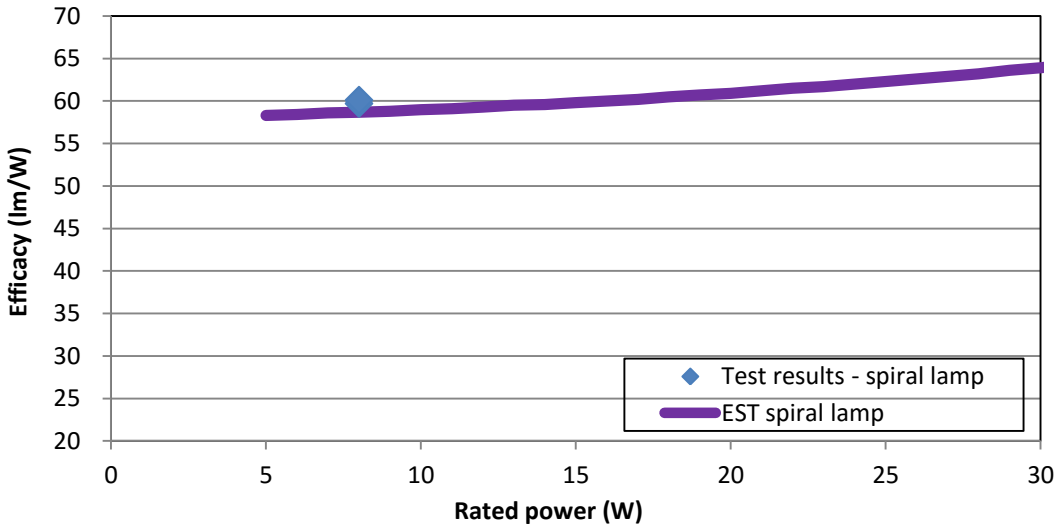


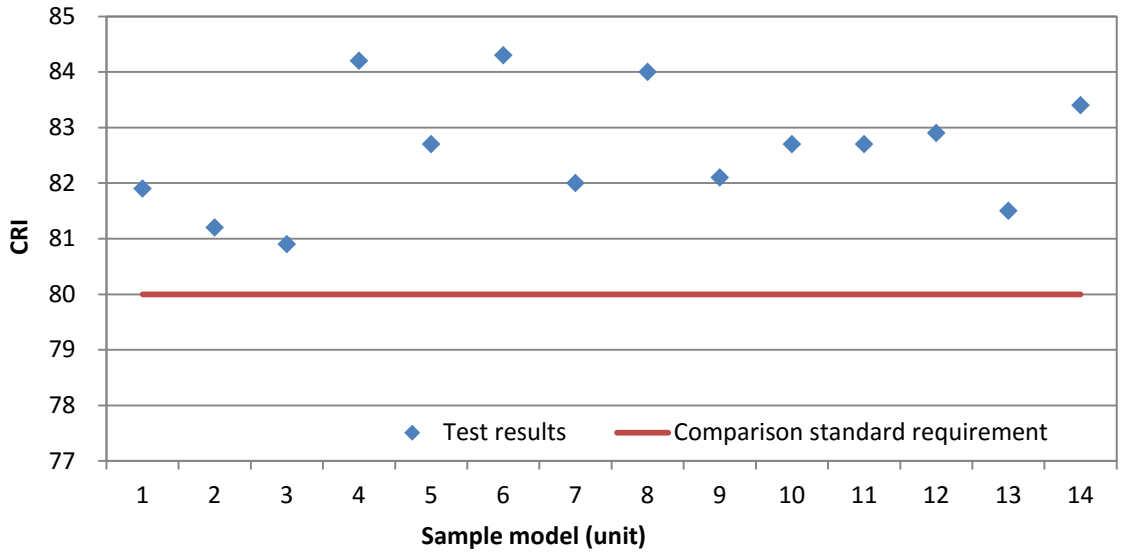
Figure 69 Average (mean, n=10) test results of efficacy (spiral lamp)



7.5.3 Colour rendering index

Figure 70 presents the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be not less than 80 (above the red line). It can be seen in Figure 70 that all of the samples could meet this requirement. The compliance rate of CRI for the samples purchased in the Philippines was 100%.

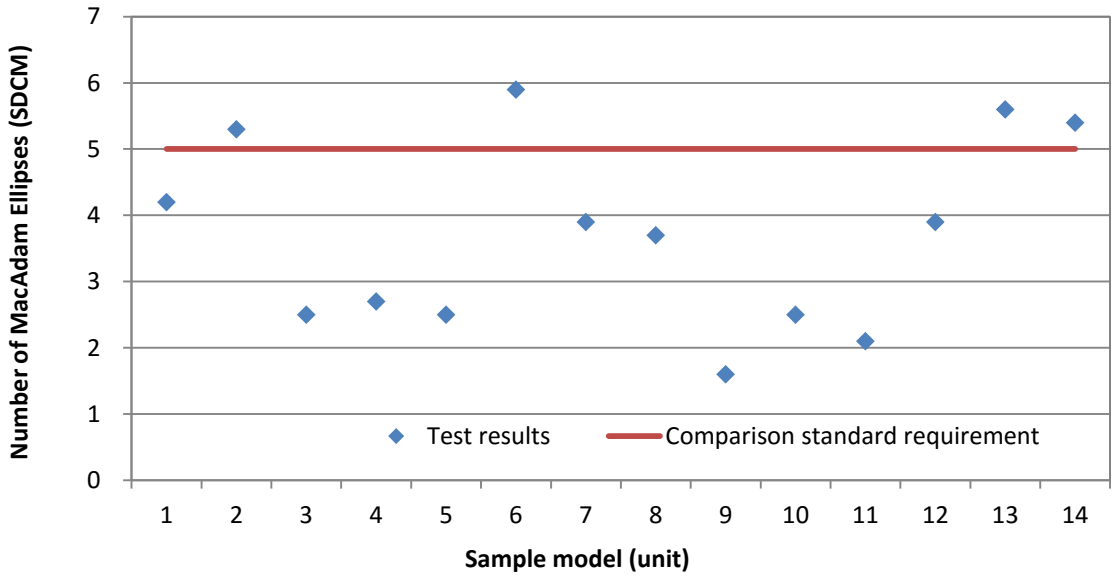
Figure 70 Average (mean, n=10) test results of CRI



7.5.4 Standard Deviation of Colour Matching (SDCM)

Figure 71 shows the SDCM test results compared with the comparison standards. The comparison standards requires the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5 (under the red line). From Figure 71 it can be seen that there were four models with a measured sample average SDCM value above 5 steps, which represents 29% of the samples.

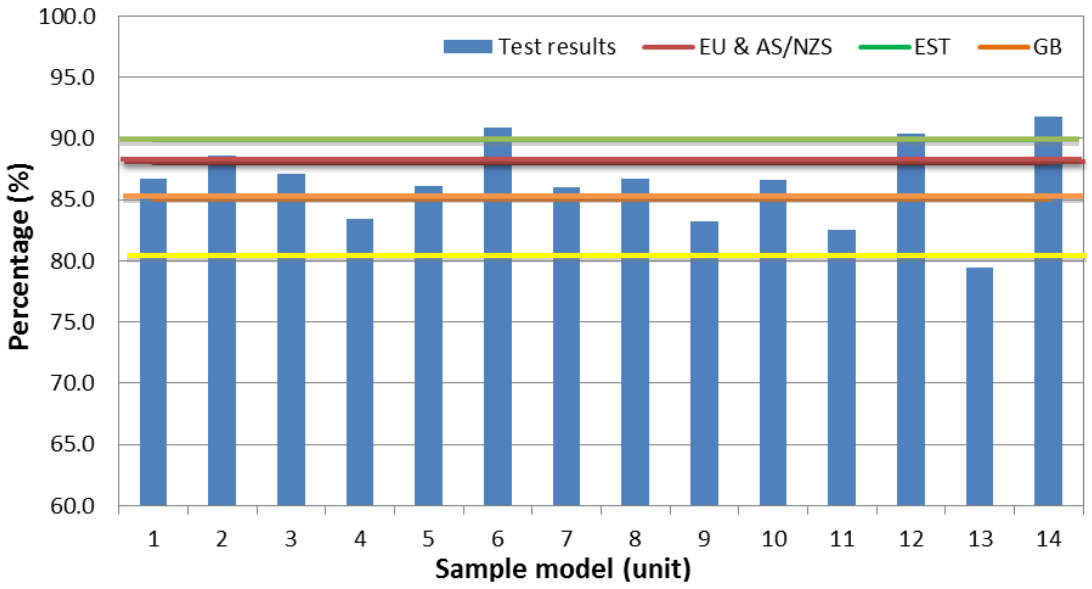
Figure 71 Average (mean, n=10) test results of SDCM



7.5.5 Luminous maintenance

Figure 72 shows the luminous maintenance results compared with the different comparison standards. From Figure 72, there are four models with average luminous maintenance test results under the orange line (less than 85% - the minimum requirement of the comparison standard GB/T 17263). Ten models were under the red line (less than 88% - the minimum requirement of the EU and AS-NZS standards), and eleven models were under the green line (less than 89.9% - the minimum requirement of the Energy Saving Trust standard). Note that Philippines' labelling requirement for lumen maintenance is set at 80% (yellow line), and only one model out of 14 failed this criteria.

Figure 72 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.5.6 Mercury format and content

There are two main mercury dosing technologies adopted for CFLs which use two mercury formats: amalgam and non-amalgam lamps. Figure 73 presents the percentage of each mercury format of the CFLs from the Philippines; 64% of the CFLs adopted amalgam technology and 36% adopted non-amalgam technology.

Figure 73 Test results for mercury format (percent of total lamps tested)

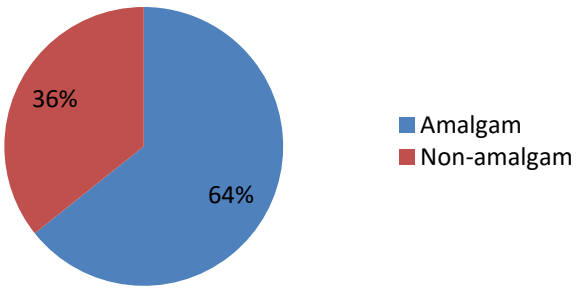
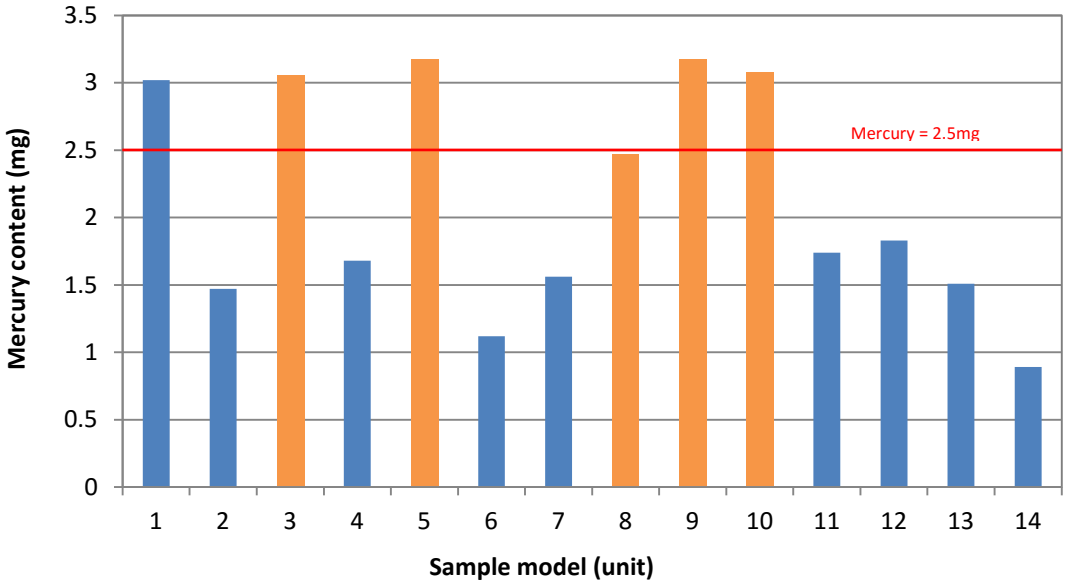


Figure 74 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. Averaged across the models tested, the amalgam lamps had 1.7 mg of mercury while the non-amalgam lamps had 3 mg. Thus, on average, the mercury content of non-amalgam lamps was about 1.8 times higher than that of amalgam lamps.

Figure 74 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

7.5.7 Summary of results for Philippine lamps

Of the 14 models of CFLs tested from the Philippines, it can be seen that efficacy, luminous maintenance at 2,000 hours, SDCM and mercury are the main parameters which some samples did not meet all the comparison standards. Only 78% of tested models met national labelling requirements for efficacy, and 92% met requirements for lumen maintenance. There are four models of CFLs that have a SDCM above 5 steps, which is the highest non-compliance rate in the six participating countries. Table 18 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 19 presents each parameter's compliance of each model compared with the minimum requirement of all the comparison standards.

Table 18 Summary of test results of the samples purchased in the Philippines

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	All models meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	All models meet the requirement
	ENERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	All models meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) $0{,}24\sqrt{\Phi}+0{,}0103\Phi$	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, $1/(0{,}24\sqrt{\Phi}+0{,}0103\Phi)$ Where F = initial luminous flux	All models meet the requirement
	Energy Saving Trust Lamp Specification V7[40]	See Table 5	11 models meet the requirement
	ENERGY STAR lamp V1.0[41]	Lamp Rated power (watts) / Minimum Lamp Efficacy (initial lm/W) <15 / 55 ≥15 / 65	9 models meet the requirement

[40] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.
[41] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td></td><td>GB/T17263</td><td><table>
<tr><td rowspan="2">Power（W）</td><td colspan="2">Efficacy(lm/W)</td></tr>
<tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr>
<tr><td>≤5</td><td>36</td><td>38</td></tr>
<tr><td>6～8</td><td>44</td><td>46</td></tr>
<tr><td>9～14</td><td>51</td><td>54</td></tr>
<tr><td>15～</td><td>57</td><td>60</td></tr>
<tr><td>≥25</td><td>61</td><td>64</td></tr>
</table></td><td>2 models do not meet the requirement</td></tr>
<tr><td rowspan="4">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>All models meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>All models meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>80</td><td>All models meet the requirement</td></tr>
<tr><td rowspan="3">Standard Deviation of Colour Matching</td><td>AS/NZS 4847.2</td><td>Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.</td><td>4 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>Within a tolerance limit of 5 steps of MacAdam Ellipses</td><td>4 models do not meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>≤5 steps of MacAdam Ellipses</td><td>4 models do not meet the requirement</td></tr>
</table>

Testing parameters	comparison standards	Requirement	Results
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	10 models do not meet the requirement
	AS/NZS 4847.2 S	2000 hrs = 0.88	10 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	11 models do not meet the requirement
	GB/T17263	85%	4 models do not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	All models meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	9 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	9 models meet the requirement
	AZ/NZS 4847	≤5 mg	All models meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	9 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	3 models meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	1 models meet the requirement

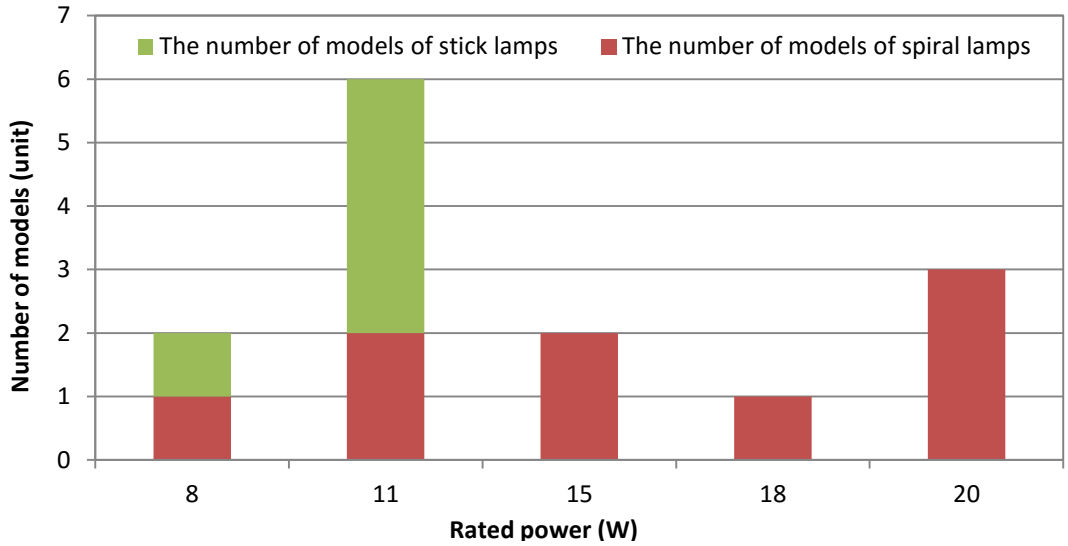
Table 19 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Colour rendering index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Standard Deviation of Colour Matching	✓	×	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	×	×
Luminous maintenance @2,000 hours	✓	✓	✓	×	✓	✓	✓	✓	×	✓	×	✓	×	✓
Mercury content	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

7.6 Thailand

There are 14 CFL models sampled from Thailand for performance testing. The wattage range is from 8W to 20W, see Figure 75. In those samples, 79% are cool light (daylight), and 21% are warm light. Thailand's MEPS for CFLs TIS 2310-2549 (2006), *Self-Ballasted Lamps for General Lighting Services: Energy Efficiency Requirements)*, covering efficacy (tiered), lumen maintenance (80%) and lifetime.

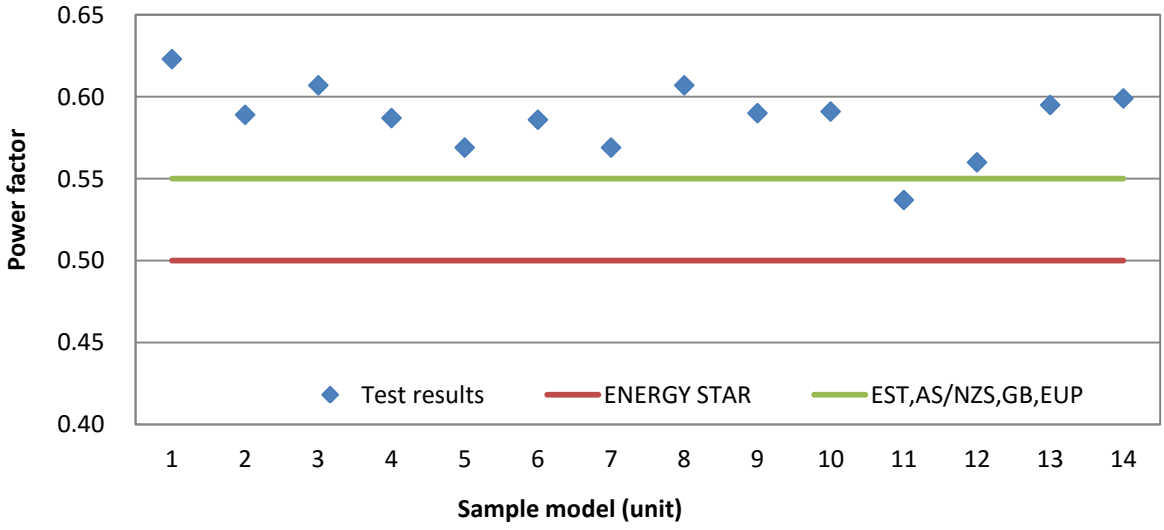
Figure 75 The CFL lamps sampled from Thailand



7.6.1 Power factor

Figure 76 shows the test results of the power factor, and compared with the comparison standards, it can be seen that all of the models meet with the ENERGY STAR requirement of 0.5 and that there is one model which did not meet the higher requirement of 0.55.

Figure 76 Test results for average (mean, n=10) power factor



7.6.2 Luminous efficacy

Different standards have different requirements for efficacy, for example, in the Energy Saving Trust specification different lamp shapes require different minimum efficacy values; and in the GB comparison standard GB/T 17263, the minimum efficacy required may be different for different CCTs, even for the same wattage. Therefore, in order to compare the efficacy data with some standards' specific conditions, the comparison figures must be separated for each standard.

Figure 77 shows the efficacy test results compared with AS/NZS 4847.2, EU regulation and ENERGY STAR Lamp specification V1.0. It can be seen that all of the samples met AS/NZS 4847.2 and EU regulation requirement. About 36% of the samples did not meet the ENERGY STAR requirement.

Figure 77 Average (mean, n=10) test results of efficacy

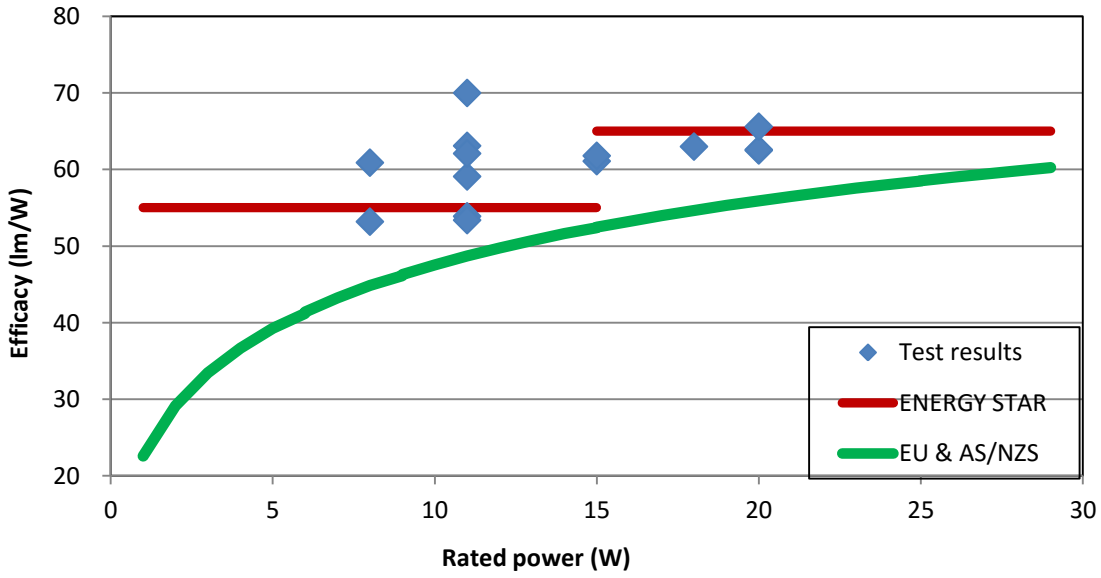


Figure 78 and Figure 79 show the efficacy test results compared with GB/T 17263. The efficacy requirement in GB standard, has two levels according to the colour temperature. Therefore, the test samples here are divided into two groups, one is high colour temperature group (cool light lamp) with a CCT equal or higher than 4000K, the other is low colour temperature with a CCT less than 4000K (warm light lamp). For Thai labelling requirements, lamps must meet the minimum efficacy levels by colour temperature and wattage bins as stated in TIS 2310-2549, which have the same efficacy requirements as GB/T 17263 (Figure 78 and Figure 79). From Figure 78 and Figure 79 it can be seen that all of the lamps meet the GB and TNS standards' requirements.

Figure 78 Average (mean, n=10) test results of efficacy (cool light lamp)

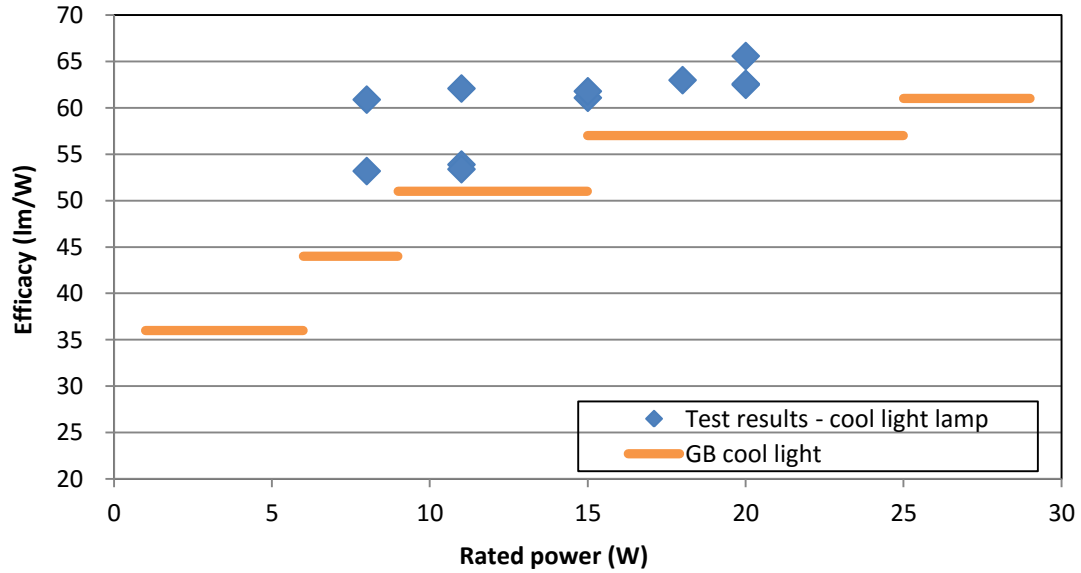


Figure 79 Average (mean, n=10) test results of efficacy (warm light lamp)

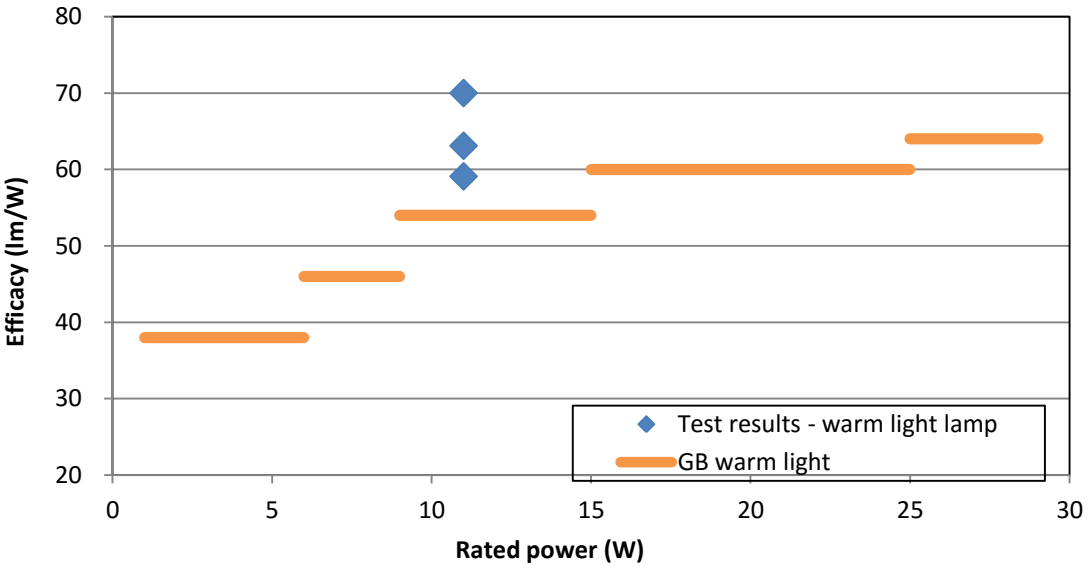


Figure 80 and Figure 81 show the efficacy test results compared with Energy Saving Trust lamp specification V7. In the Energy Saving Trust specification, there are three groups covering fluorescent lamps and 17 classes defined for the electronically self-ballasted CFLs. The samples tested under this project all belonging to Group 1 and Class 1, and are all types without a secondary covering or bulb with wattages up to and including 25W. However for efficacy, there are still two different required curves for stick shape lamps and spiral lamps in Group 1 and Class 1. From Figure 80 and Figure 81, it can be seen that all of the stick lamps and spiral lamps meet the Energy Saving Trust requirement.

Figure 80 Average (mean, n=10) test results of efficacy (stick lamp)

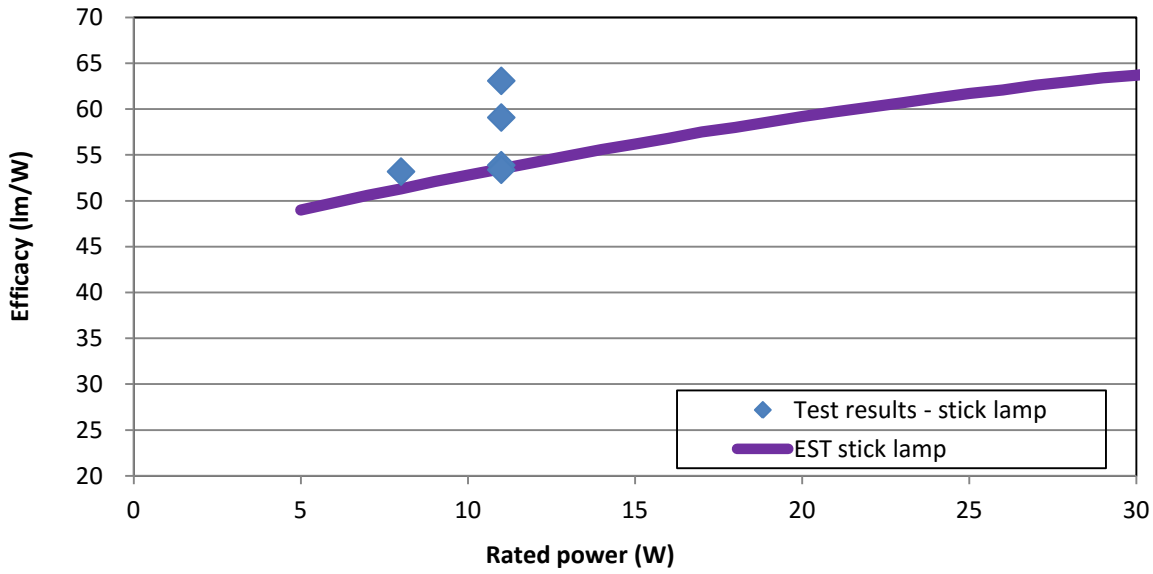
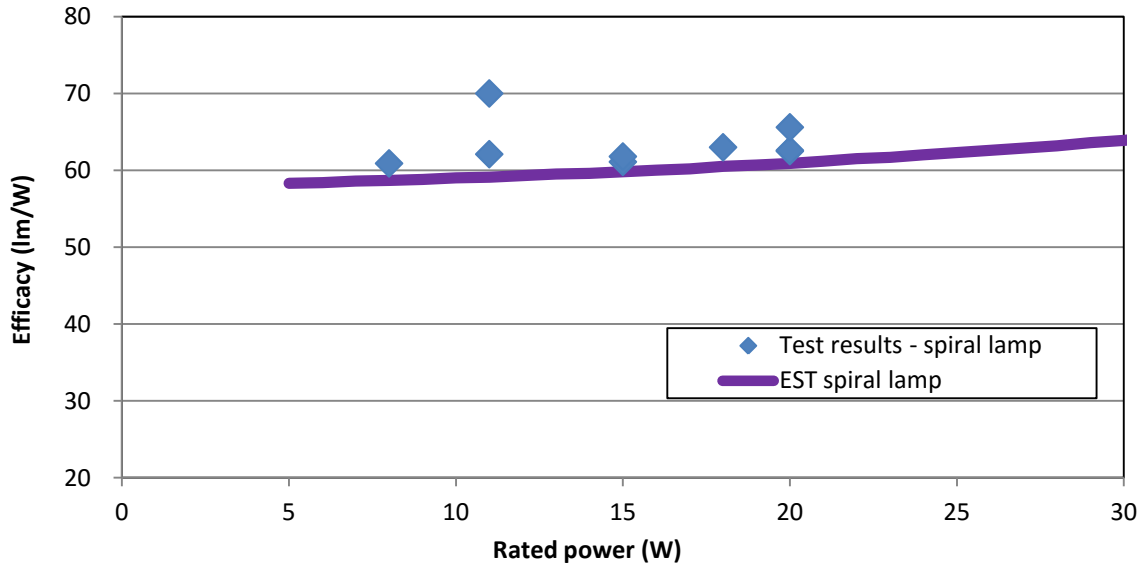


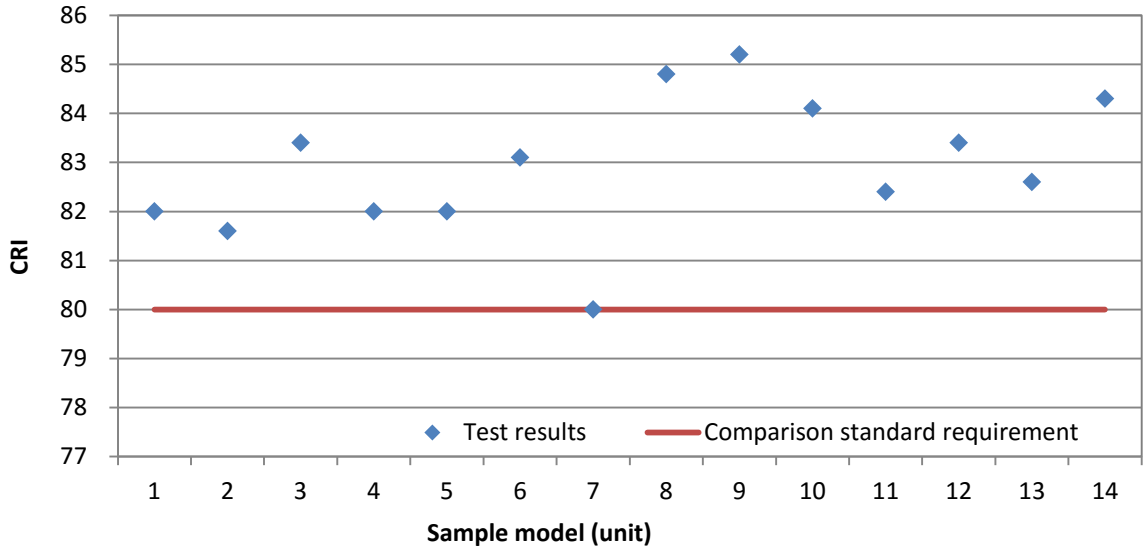
Figure 81 Average (mean, n=10) test results of efficacy (spiral lamp)



7.6.3 Colour rendering index

Figure 82 presents the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be not less than 80. It can be seen in Figure 82 that all of the samples meet this requirement, with a measured CRI value on or above the red line. The compliance rate of CRI for the samples purchased in Thailand is 100%.

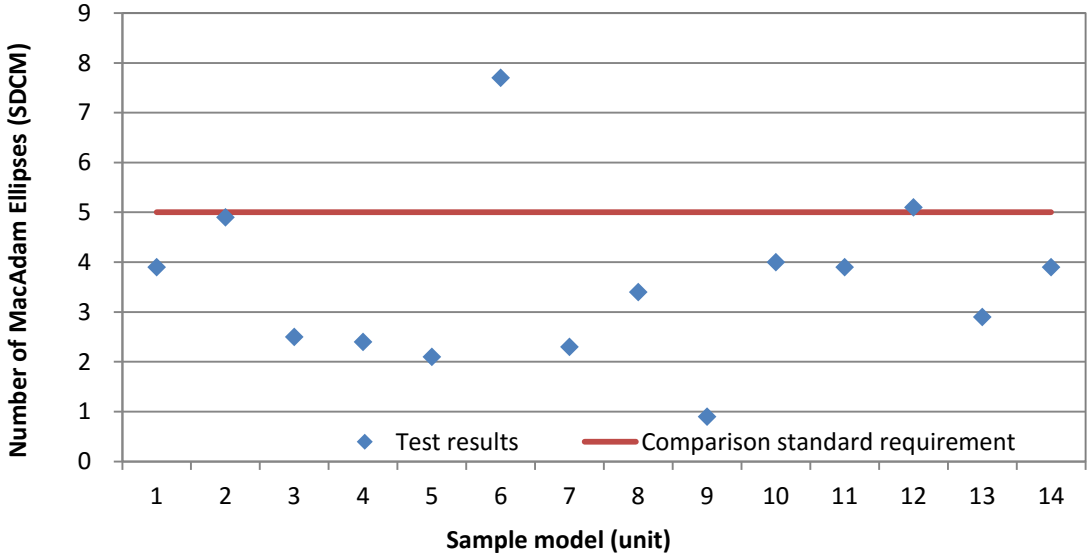
Figure 82 Average (mean, n=10) test results of CRI



7.6.4 Standard Deviation of Colour Matching (SDCM)

Figure 83 shows the SDCM test results compared with the comparison standards. The comparison standards requires the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5 (under the red line). From Figure 83 it can be seen that there were two of sample models that have an average SDCM above 5 steps, which represents 14% of the total samples.

Figure 83 Average (mean, n=10) test results of SDCM

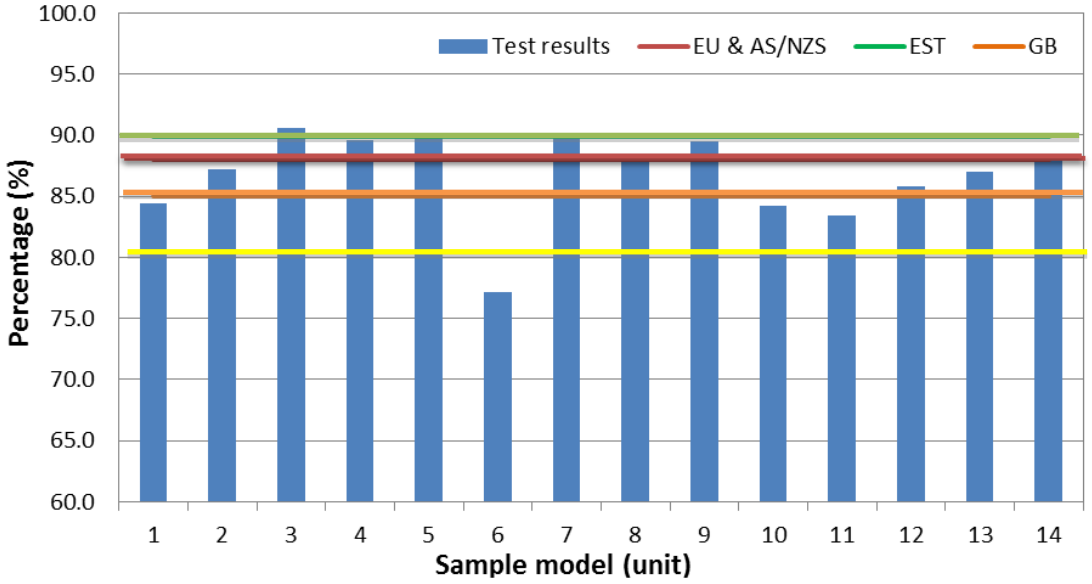


7.6.5 Luminous maintenance

Figure 84 shows the luminous maintenance results compared with the different comparison standards. From Figure 84, there are four models with average luminous maintenance test

results under the orange line (less than 85% - the minimum requirement of the GB standard). Seven models were under the red line (less than 88% - the minimum requirement of the EU and AS/NZS standard), and eleven models were under the green line (less than 89.9% - the minimum requirement of the Energy Saving Trust standard). Note that Thailand's labelling requirement for lumen maintenance is 80% (yellow line), and one out of 14 models tested did not meet this criteria.

Figure 84 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.6.6 Mercury format and content

There are two main mercury dosing technologies adopted for CFLs which use two mercury formats: amalgam and non-amalgam lamps. Figure 85 presents the percentage of each mercury format of the CFLs from Thailand; 79% of the CFLs adopted amalgam technology and 21% the non-amalgam technology.

Figure 85 Test results for mercury format (percent of total lamps tested)

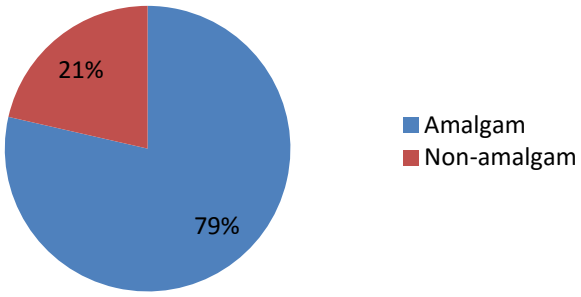
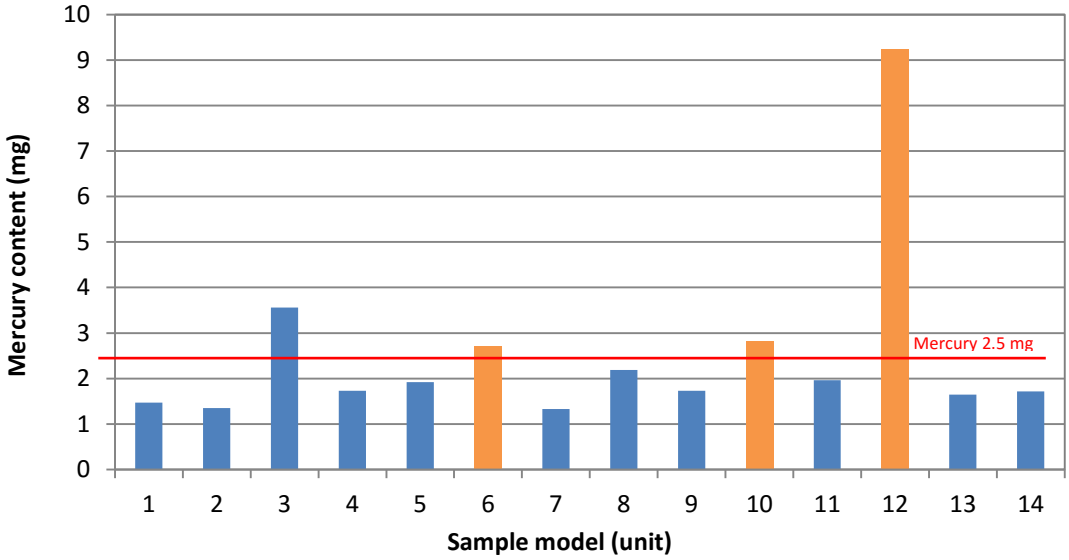


Figure 87 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. Averaged across the models tested, the amalgam lamps had 1.9 mg

of mercury while the non-amalgam lamps had 4.9 mg. Thus, on average, the mercury content of non-amalgam lamps was about 2.6 times higher than that of amalgam lamps.

Figure 86 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

7.6.7 Summary of results for Thai lamps

Of the 14 models of CFLs tested from Thailand, it can be seen that luminous maintenance at 2,000 hours, SDCM and mercury were the main parameters that the lamps did not meet all the comparison standards. All tested models met the national labelling requirements for efficacy, and 92% met requirements for lumen maintenance. The average efficacy results met all the comparison standards, which is the only one in the six participating countries to do so. Table 20 presents all the compliance rate of the testing parameters compared to the comparison standards. Table 21 presents each parameter's compliance of each model compared with the minimum requirement of all the comparison standards.

Table 20 Summary of test results of the samples purchased in Thailand

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	1 model does not meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	1 model does not meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	1 model does not meet the requirement
	ENERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	1 model does not meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) $0{,}24\sqrt{\Phi}+0{,}0103\Phi$	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, $1/(0{,}24\sqrt{\Phi}+0{,}0103\Phi)$ Where F = initial luminous flux	All models meet the requirement
	Energy Saving Trust Lamp Specification V7[42]	See Table 5	All models meet the requirement
	ENERGY STAR lamp V1.0[43]	Lamp Rated power (watts) / Minimum Lamp Efficacy (initial lm/W) <15 / 55 ≥15 / 65	9 models meet the requirement

[42] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.
[43] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td></td><td>GB/T17263</td><td><table>
<tr><td rowspan="2">Power（W)</td><td colspan="2">Efficacy(lm/W)</td></tr>
<tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr>
<tr><td>≤5</td><td>36</td><td>38</td></tr>
<tr><td>6～8</td><td>44</td><td>46</td></tr>
<tr><td>9～14</td><td>51</td><td>54</td></tr>
<tr><td>15～</td><td>57</td><td>60</td></tr>
<tr><td>≥25</td><td>61</td><td>64</td></tr>
</table></td><td>All models meet the requirement</td></tr>
<tr><td rowspan="4">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>All models meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>All models meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>80</td><td>All models meet the requirement</td></tr>
<tr><td rowspan="3">Standard Deviation of Colour Matching</td><td>AS/NZS 4847.2</td><td>Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.</td><td>2 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>Within a tolerance limit of 5 steps of MacAdam Ellipses</td><td>2 models do not meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>≤5 steps of MacAdam Ellipses</td><td>2 models do not meet the requirement</td></tr>
</table>

Testing parameters	comparison standards	Requirement	Results
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	7 models do not meet the requirement
	AS/NZS 4847.2	2000 hrs = 0.88	7 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	11 models do not meet the requirement
	GB/T17263	85%	4 models do not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	1 model does not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	10 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	10 models meet the requirement
	AZ/NZS 4847	≤5 mg	1 model does not meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	10 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	3 models meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	None meet the requirement

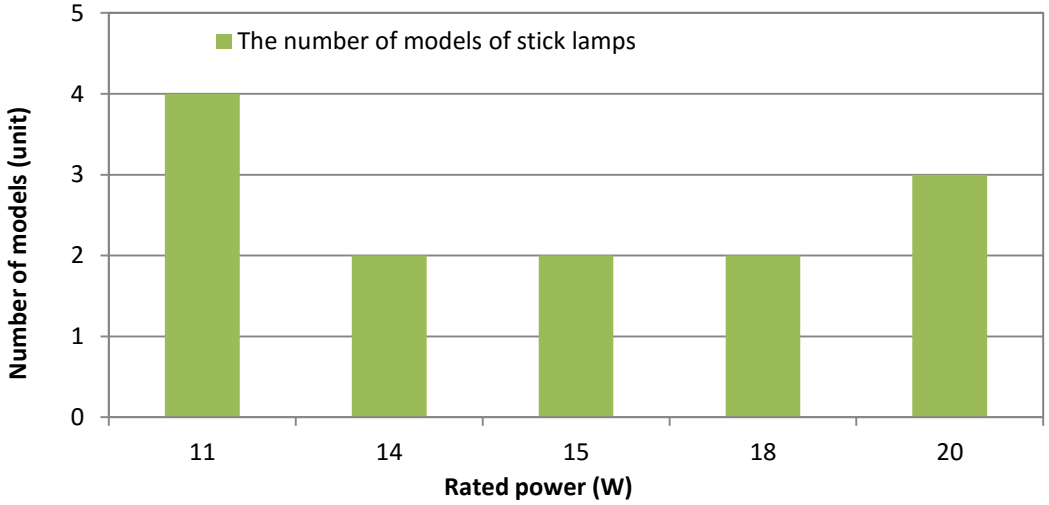
Table 21 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Colour rendering index	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Standard Deviation of Colour Matching	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	×	✓	✓
Luminous maintenance @2,000 hours	×	✓	✓	✓	✓	×	✓	✓	✓	×	×	✓	✓	✓
Mercury content	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓

7.7 Vietnam

There are 13 CFL models sampled from Vietnam for performance testing. The wattage range is from 11W to 20W, see Figure 87. In those samples, all of them are cool light (daylight). Vietnam currently is considering an update to its existing voluntary CFL labelling programme (TCVN 7896, 2008, *Compact fluorescent lamps – Energy efficiency*), covering efficacy (tiered), luminous maintenance (80%), and lamp life.

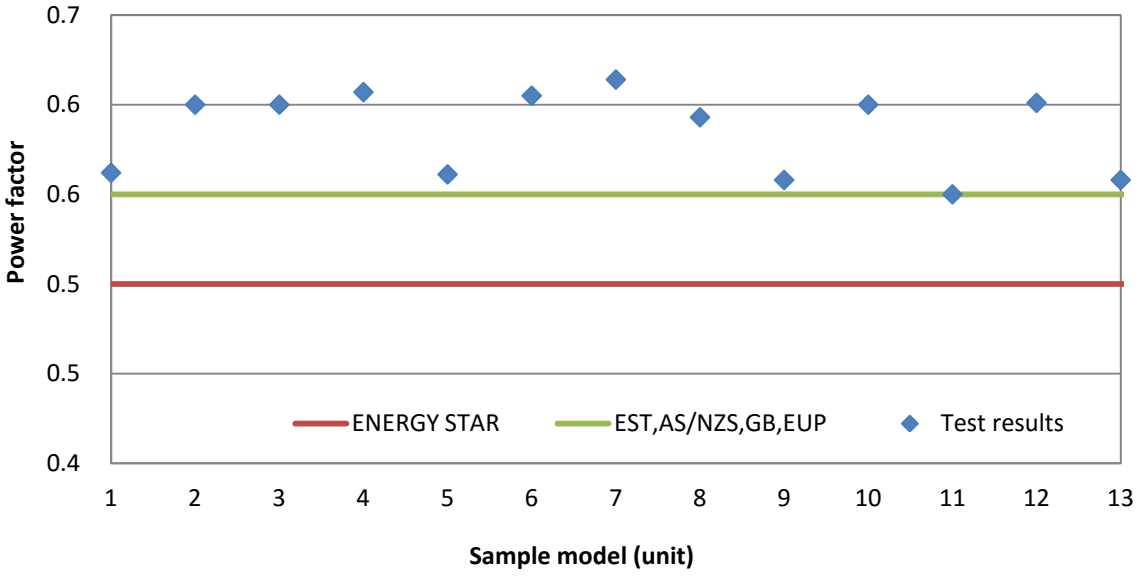
Figure 87 The CFL lamps sampled from Vietnam



7.7.1 Power factor

Figure 88 shows the test results of the power factor, and compared them with the comparison standards. It can be seen that all of the models met the highest requirement of 0.55.

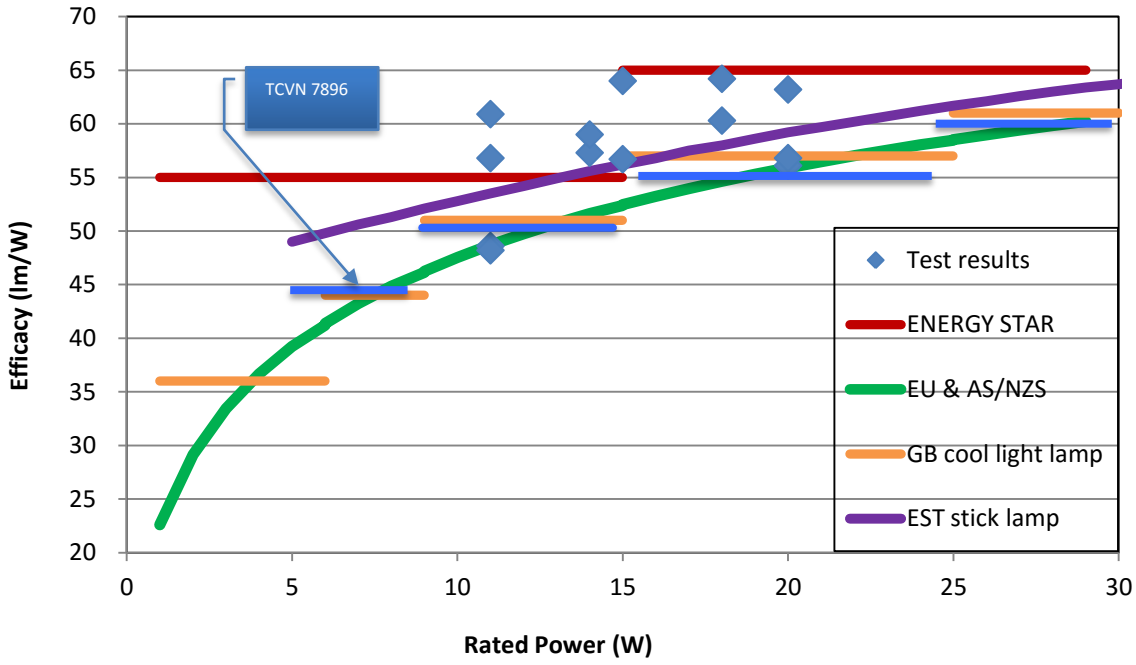
Figure 88 Test results for average (mean, n=10) power factor



7.7.2 Luminous efficacy

The samples from Vietnam are all stick lamps and with high colour temperature (CCT >=4000K), therefore, the efficacy test results can be shown with all the comparison standards in one figure (AS/NZS 4847.2, EU regulation, ENERGY STAR Lamp specification V1.0, GB/T 17263 and Energy Saving Trust lamp specification V7, as well as TCVN 7896), see Figure 89. The compliance rates were about 92%, 92%, 46%, 77%, and 69% compared with the above international standards, and one unit failing the Vietnamese standard.

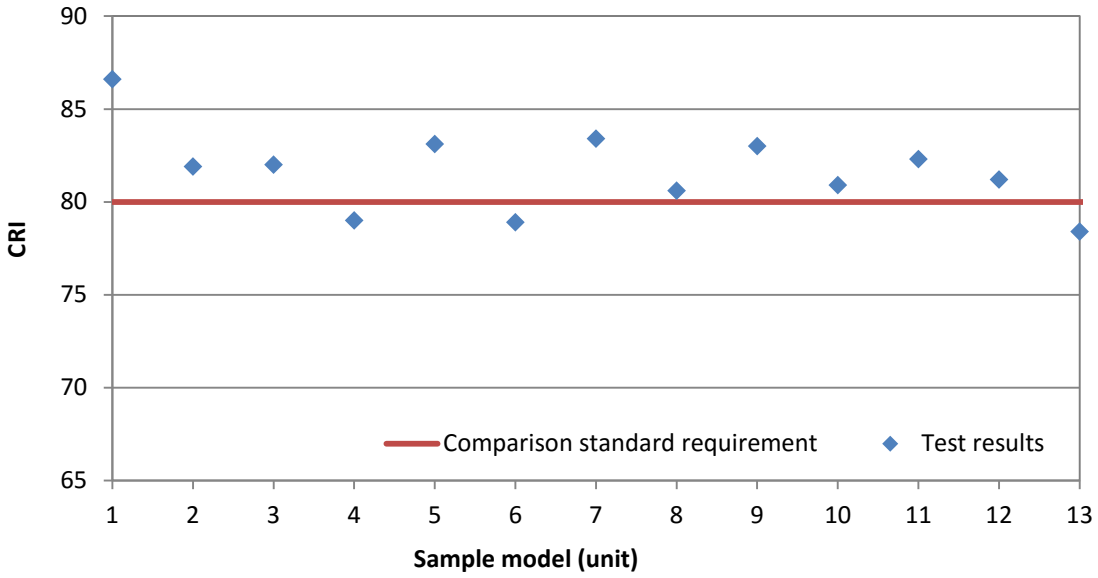
Figure 89 Average (mean, n=10) test results of efficacy



7.7.3 Colour rendering index

Figure 90 presents the average test results for the colour rendering index (CRI). All of the comparison standards require that the CRI should be not less than 80. It can be seen in Figure 90 that most of the samples could meet this requirement. However, there are three models with a measured average CRI value less than 80 (under the red line). The compliance rate of CRI for the samples purchased in Vietnam was 77%.

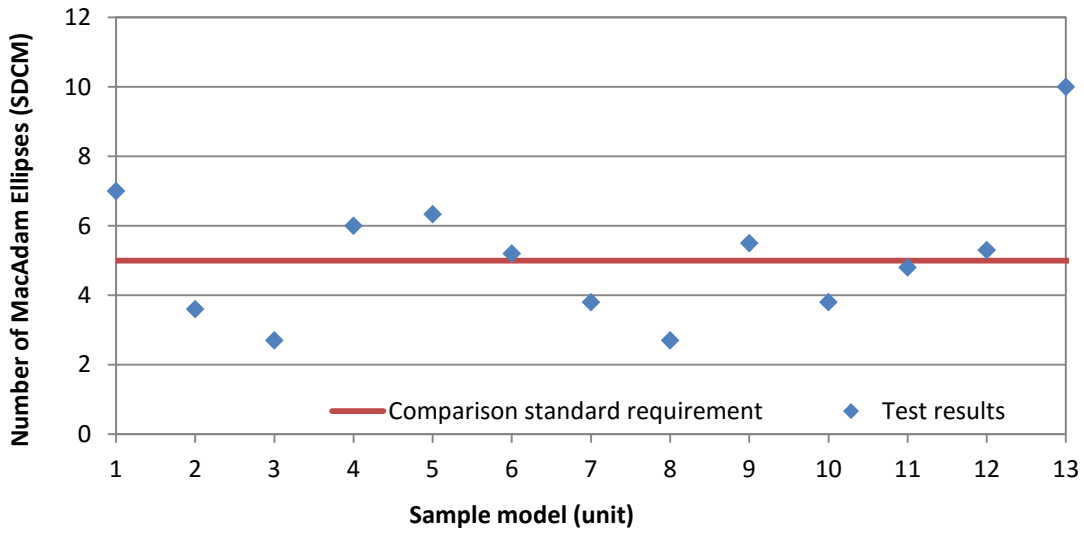
Figure 90 Average (mean, n=10) test results of CRI



7.7.4 Standard Deviation of Colour Matching (SDCM)

Figure 91 shows the SDCM test results compared with the comparison standards. The comparison standards requires the SDCM should be within 5 steps, which means the SDCM value should not be higher than 5 (under the red line). From Figure 91 it can be seen that there were six models of samples have an average SDCM above 5 steps (above the red line), which represents 46% of the total samples. There is even one model which has a SDCM of 10 steps, which is the highest results in this testing.

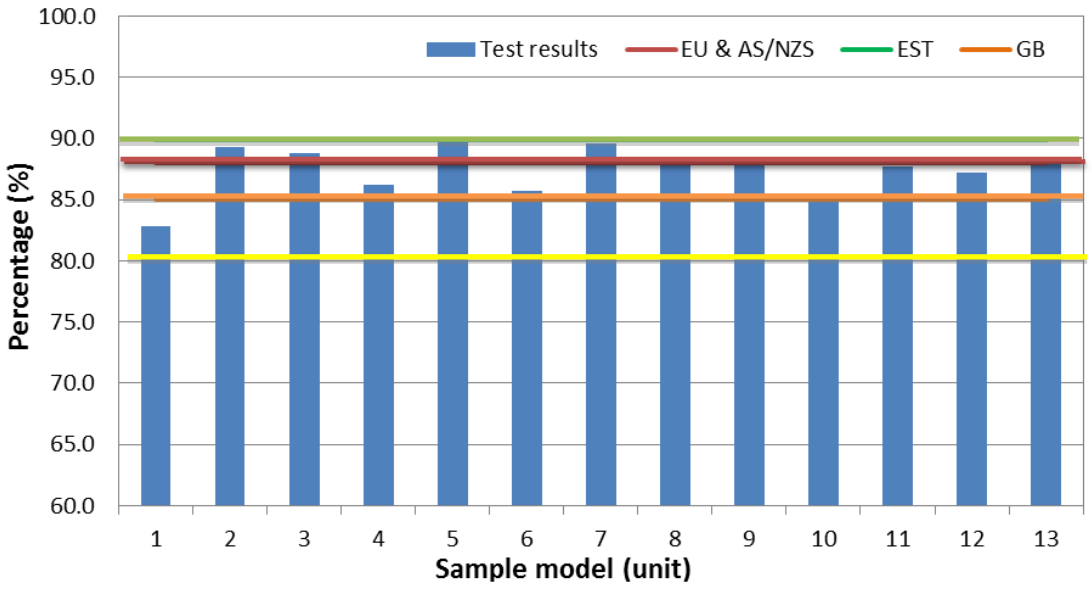
Figure 91 Average (mean, n=10) test results of SDCM



7.7.5 Luminous maintenance

Figure 92 shows the luminous maintenance results compared with the different comparison standards. From Figure 92, there is one model with average luminous maintenance test results under the orange line (less than 85% - the minimum requirement of the GB standard). Five models were under the red line (less than 88% - the minimum requirement of the EU and AS/NZS standard), and twelve models were under the green line (less than 89.9% - the minimum requirement of the Energy Saving Trust standard). Note that Vietnam's labelling requirement for lumen maintenance is 80% (yellow line), and all 14 tested models satisfied this criteria.

Figure 92 Average (mean, n=10) test results of luminous maintenance at 2,000 hours



7.7.6 Mercury format and content

There are two main mercury dosing technologies adopted for CFLs which use two mercury formats: amalgam and non-amalgam lamps. Figure 93 presents the percentage of each mercury format of the CFLs from Vietnam; 92% of the CFLs adopted amalgam technology and 8% the non-amalgam technology.

Figure 93 Test results for mercury format (percent of total lamps tested)

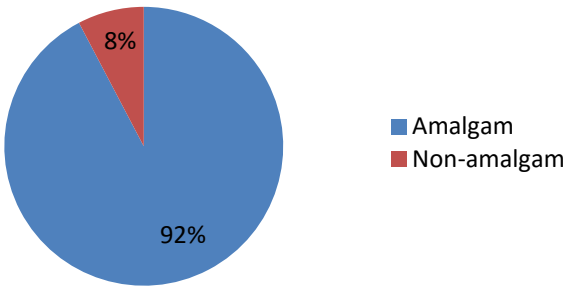
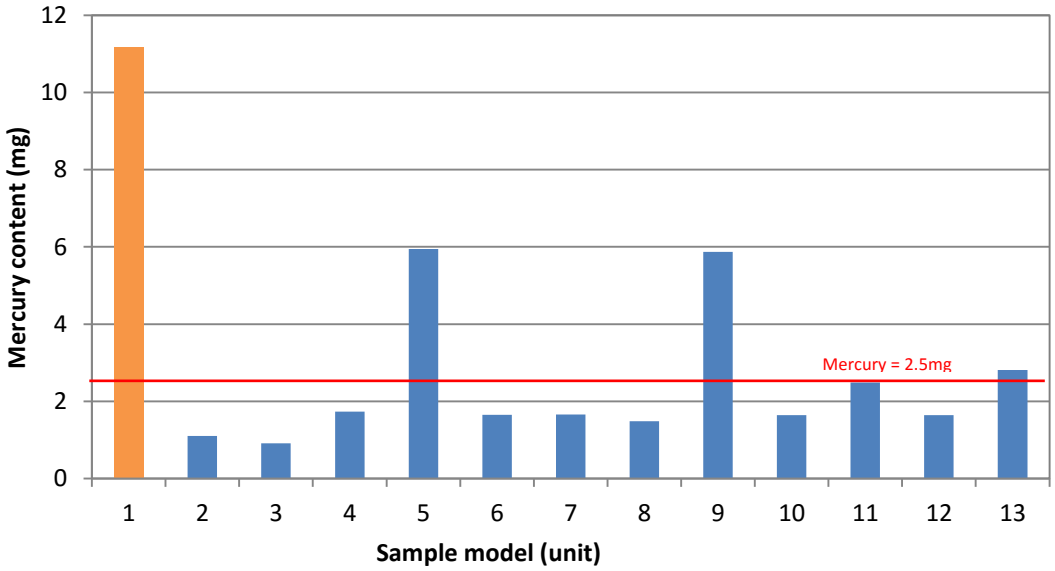


Figure 94 shows the average mercury content of each model, the blue bars represent the amalgam lamps, and the orange bars represent the non-amalgam lamps. The red line shows the requirement of 2.5 mg. Averaged across the models tested, the amalgam lamps had 2.4 mg of mercury while the non-amalgam lamps had 11.2 mg. Thus, on average, the mercury content of non-amalgam lamps was about 4.7 times higher than that of amalgam lamps.

Figure 94 Average (mean, n=5) test results for mercury content



Note: Blue bars represent the amalgam lamps; orange bars represent the non-amalgam lamps

7.7.7 Summary of results for Vietnamese lamps

Of the 13 models of CFLs tested from Vietnam, it can be seen that efficacy, luminous maintenance at 2,000 hours, CRI, SDCM and mercury are the main parameters that all the samples did not meet all the comparison standards. 92% of the tested models met the national labelling requirements for efficacy, and all 100% met requirements for lumen maintenance. Over half of the models have a SDCM above 5 steps, which shows the highest non-compliance rate in the six participating countries. Table 22 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 23 presents each parameter's compliance of each model compared with the minimum requirement of all the comparison standards.

Table 22 Summary of test results of the samples purchased in Vietnam

Testing parameters	comparison standards	Requirement	Results
Power factor	EU Regulation No. 244/2009	≥ 0,55 if P < 25 W	All models meet the requirement
	AS/NZS 4847.2 Part 2	Minimum True Power Factor 0.55	All models meet the requirement
	Energy Saving Trust Lamp Specification V7	Shall not be less than 0.55	All models meet the requirement
	ENERGY STAR lamp V1.0	Reported value for each lamp model shall have a power factor ≥ 0.5.	All models meet the requirement
	GB/T17263	0.55	All models meet the requirement
Initial luminous flux/Initial efficacy	EU Regulation No. 244/2009	Maximum rated power (Pmax) for a given rated luminous flux (Φ) (W) 0,24√Φ+0,0103Φ	1 model does not meet the requirement
	AS/NZS 4847.2 Part 2	Minimum efficacy in lm/W, 1/(0,24√Φ+0,0103Φ) Where F = initial luminous flux	1 model does not meet the requirement
	Energy Saving Trust Lamp Specification V7[44]	See Table 5	9 models meet the requirement
	ENERGY STAR lamp V1.0[45]	Lamp Rated power (watts) / Minimum Lamp Efficacy (initial lm/W) <15 / 55 ≥15 / 65	6 models meet the requirement

[44] Energy Saving Trust Lamp Specification V7 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.
[45] ENERGY STAR lamp V1.0 is not a MEPS programme, but is a voluntary programme designed to recognize the top performing lamps in the market.

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td></td><td>GB/T17263</td><td><table>
<tr><td rowspan="2">Power（W）</td><td colspan="2">Efficacy(lm/W)</td></tr>
<tr><td>Colour</td><td>Colour RL/RB/RN/RD</td></tr>
<tr><td>≤5</td><td>36</td><td>38</td></tr>
<tr><td>6～8</td><td>44</td><td>46</td></tr>
<tr><td>9～14</td><td>51</td><td>54</td></tr>
<tr><td>15～</td><td>57</td><td>60</td></tr>
<tr><td>≥25</td><td>61</td><td>64</td></tr>
</table></td><td>3 models do not meet the requirement</td></tr>
<tr><td rowspan="5">Colour rendering index</td><td>EU Regulation No. 244/2009</td><td>≥ 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>AS/NZS 4847.2</td><td>Minimum CRI 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>The measured general colour-rendering index (Ra) shall not be less than 80</td><td>3 models do not meet the requirement</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ≥ 80. The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77. No unit shall have Ra < 75.</td><td>3 models do not meet the requirement</td></tr>
<tr><td>GB/T17263</td><td>80</td><td>3 models do not meet the requirement</td></tr>
<tr><td rowspan="2">Standard Deviation of Colour Matching</td><td>AS/NZS 4847.2</td><td>Colour co-ordinates of all lamps shall be within the tolerance area on the chromaticity chart as declared by the manufacturer, importer or responsible vendor, but shall in any case be within 5 SDCM from the target values.</td><td>7 models do not meet the requirement</td></tr>
<tr><td>Energy Saving Trust Lamp Specification V7</td><td>Within a tolerance limit of 5 steps of MacAdam Ellipses</td><td>7 models do not meet the requirement</td></tr>
</table>

Testing parameters	comparison standards	Requirement	Results
	GB/T17263	≤5 steps of MacAdam Ellipses	7 models do not meet the requirement
Luminous maintenance at 2,000 hours	EU Regulation No. 244/2009	At 2,000 hrs: ≥ 88 %	5 models do not meet the requirement
	AS/NZS 4847.2	2000 hrs = 0.88	5 models do not meet the requirement
	Energy Saving Trust Lamp Specification V7	89.9%	12 models do not meet the requirement
	GB/T17263	85%	1 models does not meet the requirement
Mercury content	Minamata Convention on Mercury	≤5 mg	3 models do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	≤2.5mg, for lamp power ≤ 23W	9 models meet the requirement
	EU ROHS Directive	≤2.5mg, for lamp power <30W	9 models meet the requirement
	AZ/NZS 4847	≤5 mg	3 models do not meet the requirement
	GB/T 17263	≤2.5mg, for lamp power ≤ 30W Compliance	9 models meet the requirement
		≤1.5mg, for lamp power ≤ 30W Low mercury	3 models meet the requirement
		≤1.0mg, for lamp power ≤ 30W Micro mercury	None meet the requirement

Table 23 Compliance of each model compared with the minimum requirement of all the comparison standards

Model number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Power Factor	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Efficacy	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓	✓	✓
Colour rendering index	✓	✓	✓	×	✓	×	✓	✓	✓	✓	✓	✓	×	✓
Standard Deviation of Colour Matching	×	✓	✓	×	×	×	✓	✓	×	✓	✓	×	×	✓
Luminous maintenance @2,000 hours	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mercury content	×	✓	✓	✓	×	✓	✓	✓	×	✓	✓	✓	✓	✓