UNEP Collaborating Centre for Energy Efficient Lighting

Southeast Asia
Light Emitting Diode Lamps Performance Testing Report and Analysis

January 2016

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-GEF 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 Southeast 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, 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

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

Chromaticity coordinates: ratio 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, with suitable allowance having been made for the state of chromatic adaptation. 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.

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. (IEC)

Integrated LED lamp: LED lamp, incorporating control gear, and any additional elements necessary for stable operation of the light source, designed for direct connection to the supply voltage.

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.

Light emitting diode (LED): solid state device embodying a p-n junction, emitting incoherent optical radiation when excited by an electric current.

LED lamp: LED light sources provided with (a) cap(s) incorporating one or more LED module(s) and possibly including one or more of the following; electrical, optical, mechanical, and thermal components, interfaces and control gear.

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 (human vision under well lit conditions) this 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 $$\frac{d\phi_e(\lambda)}{d\lambda}$$

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 or voltage range at which a piece of electrical equipment is designed to operate.

Self-ballast LED –lamp: unit which cannot be dismantled without being permanently damaged, provided with a lamp cap conforming to IEC 60061-1 and incorporating a LED light source and any additional elements necessary for starting and stable operation of the light source.

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 are identical in photometric and electrical rating, independent of the type of cap.

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 suitable for their particular market conditions.

Light emitting diode (LED) lamps have been selected as one of the target technologies for this testing activity[1]. The main reasons for this selection are:

- LED technology has rapidly developed to become one of today's most energy efficient and long-lasting lighting products, using at least 75% less energy and lasting 15-25 times longer than traditional incandescent lamps. The widespread adoption of LEDs can lead to significant reduction in energy use and emissions.
- Currently, LED lighting is becoming more widespread in the residential and commercial/industrial sectors in many regions.
- LEDs is a new technology entering the market, and therefore it is imperative that consumers have a good first experience with this new technology.
- Testing methods for the safety, quality and performance of LED lamps are now available from a number of international and regional standards bodies, are being widely adopted, with testing laboratories becoming proficient.

For these reasons, this study was designed to focus on the parameters that can help to determine the quality of LED lamps currently available in the six targeted countries. The LED lamps selected for testing are of the Integral (self-ballasted), non-directional type used for indoor lighting, general lighting service applications.

Summary of results

This report provides an overview of the LED lamp 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 analysis of the results for each of the markets, as well as a comparison of results across the markets.[2] 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. However, 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.

A total of 20 LED lamp 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

[1] Compact fluorescent lamps (CFLs) were also tested as part of this exercise. The results of this testing are in a separate report, *Global Compact Fluorescent Lamp Check Test Results and Analysis Report*.

[2] A detailed description of the market review, sample identification, collection process, and lessons learned are contained in a companion UNEP-GEF en.lighten report, *Lamp Sampling in Cambodia, Indonesia, Lao PDR, the Philippines, Thailand and Viet Nam*.

markets. Testing of the lamp performance parameters of lamp power, power factor, initial luminous flux (and initial efficacy), and colour rendering index (CRI), were conducted according to the International Electrotechnical Commission (IEC) standard IEC/PAS 62612 *Self-ballasted LED-lamps for general lighting services - Performance requirements*. Testing of light distribution was conducted according to IESNA LM79 - *Electrical and Photometric Measurements of Solid-State Lighting Products*.[3]

Because CIE, IEC and IES standards only cover testing methodologies, a number of international standards specifying lamp performance and quality parameters, as well as their minimum levels, are used to evaluate the lamp test results.[4] Only international criteria and requirements are referenced here because national or regional standards or requirements are either not available or under development. These international reference standards are listed below (the specific parameters are referenced in Table 7 in Section 5):

- International Energy Agency, Efficient Electrical End-Use Equipment (4E), *Solid State Lighting Annex: Product Quality and Performance Tiers. Non-Directional Lamps.* September 2012;[5]
- IEC/PAS 62612, *Self-ballasted LED-lamps for general lighting services - Performance requirements*;
- EU Regulation No. 244/2009, *Ecodesign requirements for non-directional household lamps*;
- EU Regulation No.1194/2012, *Ecodesign requirements for directional lamps, light emitting diode lamps and related equipment*;
- ENERGY STAR *Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0*;
- GB/T 24908, *Self-ballasted LED-lamps for general lighting service – performance requirements*.

Table ES 1 shows the country of origin and number of tested models meeting all the comparison standards used in this report for the tested parameters. During testing, it was also observed that there were deviations between the results at 0 hour and 1,000 hours for a number of models. Compared with the test results at 0 hour, the luminous efficacy values experienced the most significant changes (increased for 11 models, and decreased for 9 models). With respect to the light distribution patterns of the lamps tested, four have quasi-omnidirectional light distribution, and the remainder have semi-spatial light distribution. Both of these light distribution patterns provide uneven light output at the high angle zones.

The performance of the tested lamp models from the six target countries are mixed, with a number of models meeting suggested efficacy and CRI parameters of the IEA 4E SSL Annex's Tier 1. However, as can be seen in Table ES 1, the lamps' tested results are generally below the minimum levels required by a number of international standards for more developed markets. Four of the tested models (20%) met the requirements of luminous efficacy (>65 lm/W) and nine of the tested models (45%) met the requirements for CRI (>80), two of the most critical parameters having to do with energy efficiency and light quality. Wide adoption of lamps with low luminous efficacy levels can

[3] Although LM - 79 is a North American standard, it is one of the internationally recognized methods for photometric testing of LED lighting products. The other internationally recognized method is CIE S025/E2015, which was not finalized at the time of this project initiation.

[4] Test results for each individual model are averages of results from multiple samples of each model tested.

[5] The international Energy Agency's Energy Efficient End-use Equipment (IEA 4E) Solid-State Lighting Annex has developed these recommended Performance Tiers covering most of the tested parameters in escalating stringency, they could be adopted by countries depending on the state of their market development.

lead to less than expected energy savings, and lamps with lower CRI (and other light quality characteristics) may create dissatisfaction among consumers.[6]

Table ES1. Country of origin and number of tested models meeting reference comparison standards' criteria requirements

Country of origin	Tested models	Power	Power factor	Luminous efficacy	CRI
Cambodia	3	1	1	2	2
Indonesia	4	1	3	0	2
Lao PDR	2	1	1	0	1
Philippines	4	0	2	0	1
Thailand	4	1	1	1	0
Vietnam	3	1	1	1	3

Recommendations

Based on the result of this indicative, region-wide effort, countries should consider a number of policy steps in order to follow up and build upon the successful prosecution of this project:

- **Continue or increase product sampling and testing of national markets**: As can be seen from the product identification and sampling process, LEDs are now beginning to achieve more prominence. However, if no policy actions are taken, there is the possibility that manufacturers may sacrifice quality and performance to compete only on price. Therefore, a concerted follow up effort to sample, test, and publicise results, building on the framework established by this project, would go far toward building verification capacities. Such actions can help to drive LEDs product quality, as well as to avoid a repeat of the early CFL experience.[7]

- **Develop minimum energy performance standards (MEPS) or labelling requirements for LED lamps**: It is imperative that countries should begin the development process for MEPS or labelling requirements, or expand their current efficient lighting MEPS or labelling requirements to include LED lamps. One consideration is to adopt at least a minimum level of product quality, such as those recommended by the International Energy Agency's Energy Efficient End-use Equipment, Solid State Lighting Annex (IEA 4E SSL Annex), which include efficacy and light quality, as well as critical parameters such as lifetime, lumen maintenance, endurance, colour maintenance, and light distribution requirements.

- **Implement targeted incentive or other promotion programmes**: Along with MEPS or labelling development effort, countries could put in place a targeted, high visibility incentive programme or procurement effort to highlight qualified/quality products using international or regional requirements. Such a programme can increase awareness in the supply chain, help pull the market towards quality products, or at least help to make more quality products available.

[6] This is similar to the situation documented by a USAID report about CFLs in the Asian market in its early development, due to lack of testing and quality standards (USAID 2007).

[7] The early CFL experience was characterized by a lack of common quality and performance standards, and manufacturers competing only on price, which led to poor quality products and dissatisfied consumers.

- **Governments should clearly communicate their intent to develop MEPS as soon as they are able**. This clear communication can help to increase awareness of the issue, and lead to greater involvement of all relevant stakeholders.

- **Initiate consumer outreach and education**: Until MEPS or labelling requirements can be developed, which will take time, consumers will need help in choosing quality products. As when CFLs were first introduced, consumers may associate LEDs with energy efficiency without knowing what to look for (other than price or brands). A campaign to educate consumers using, for example, the *lites.asia* publication, *Consumer Guide to Buying LEDs*[8], can also help to increase awareness and push retailers towards providing better products, which can also help to prepare the market for MEPS or labelling requirements.

- **Embrace regional cooperation and leverage the international experience**: As many countries in Asia are in the same situation with respect to MEPS or labelling requirements for LED lamps, this can be an opportunity for the region as a whole to cooperate on this issue. The region can build on the existing network, knowledge base, and international efforts discussed in this report, as well as with the regional exchanges and Asia-specific information that *lites.asia*[9] and the Southeast Asia and Pacific MVE project have built to date.

2 INTRODUCTION

2.1 Project background and objectives

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 LEDs lamp 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.[10] It provides a summary and analysis of the results for each of the market, as well as a comparison of results across the markets. A detailed

[8] Available at: www.lites.asia/downloads/led-consumer-guide

[9] *lites.asia* (lighting information and technical exchange – Asia) is a network of standards agencies and technical personnel who focus on lighting issues.

[10] 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.

description of the market review, sample identification, collection process, and lessons learned are contained in a companion UNEP-GEF en.lighten report.[11] 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. 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.[12]

3 METHODOLOGY

3.1 Lamp types

Light emitting diode (LED) lamps have been selected as one of the target technologies for this testing activity[13]. The main reasons for this selection are:

- In the last ten years, LED lighting technology has rapidly developed to become one of today's most energy efficient and long-lasting lighting products, using at least 75% less energy and lasting 15-25 times longer than traditional incandescent lamps. The widespread adoption of LEDs can lead to significant reduction in energy use and emissions.
- Currently, LED lighting is becoming more widespread in the residential and commercial/industrial sectors in many regions.
- LEDs, is a new technology entering the market, and therefore it is imperative that consumers have a good first experience with this new technology.
- Testing methods for the safety, quality and performance of LED lamps are now available from a number of international and regional standards bodies, are being widely adopted, with testing laboratories becoming proficient.

For these reasons, this study was designed to focus on the parameters that can help to determine the quality of LED lamps currently available in the six targeted countries.
The LED lamps selected for testing had the following characteristics:

- **Lamp type:** Integral (self-ballasted), non-directional lamps;
- **Application:** These are general lighting service lamps, for replacement of incandescent lamps in typical uses;
- **Rated power:** 5 to 15 Watts, inclusive;
- **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).

[11] *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.
[12] More information on market sampling can be found in the UNEP-GEF en.lighten initiative guidance notes, *Efficient Lighting Market Baselines and Assessment* and *Product Selection and Procurement for Lamp Performance Testing* .
[13] Compact fluorescent lamps (CFLs) were also tested as part of this exercise. The results of this testing are in a separate report, *Global Compact Fluorescent Lamp Check Test Results and Analysis Report.*

3.2 Lamp sampling

A total of 20 LED 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 locations in the six target markets, as shown in Table 1.

Table 1 Country of origin, the number of LED lamp models collected, and their apparent condition received at GELC

Country of origin	LED lamp models collected & received (20 lamps per model[14])	Number of broken lamps (apparent condition)
Cambodia	3 models (60 lamps)	0
Indonesia	4 models (80 lamps)	0
Lao PDR	2 models (40 lamps)	0
Philippines	4 models (80 lamps)	0
Thailand	4 models (80 lamps)	0
Vietnam	3 models (60 lamps)	3 lamps
Total	20 models (400 lamps)	3 lamps

An 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, 20 lamps were purchased at random, based on IIEC's initial surveys and country representatives' selection of the most popular models. A total of 20 lamp models (400 lamps) were collected for testing.[15]

3.3 Overview of lamp samples collected for performance tests

Tested lamps were collected and shipped by IIEC and participating country representatives. A a total of 20 models of LED lamps were received at GELC for performance testing from Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Vietnam. According to the sampling sheets provided by IIEC and participating countries, about 45% of the lamps were sampled from specialized lighting shops, 40% were from electrical/hardware shops, and 10% were from others (for example, shopping mall). There was one model where it was not specified from which outlet it was purchased. Observed lamp pricing ranged from about USD $1.5 to $13, as summarised in Table 2 and Figure 1.

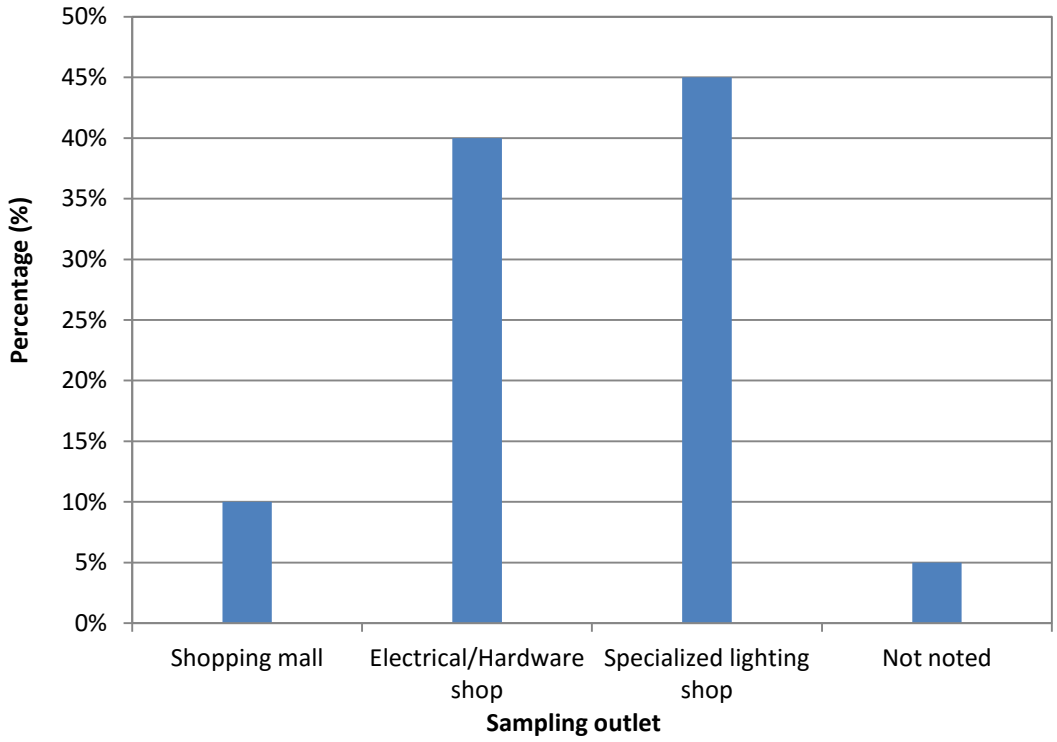
[14] Note: Although protective measures were taken for packaging and shipping, the lamp is a fragile product and may be broken or damaged during the long shipping process. Therefore, in order to make sure there were enough samples for the testing, the sample size purchased for each model was larger than needed for testing.

[15] For the sampling process, GELC developed the "Description of Lamp Selection and Test" and "Lamp Sampling and Shipping Procedures" for the participating countries. From September to October 2014, six teleconferences were conducted by IIEC and GELC with each country focal point/designee who was to be involved in sampling. During the teleconference, the sampling and shipping procedures, market questionnaire and sampling schedule were explained in detail, GELC also addressed related questions posted by each country. From September to the end of November 2014, IIEC and the participating countries shipped the sampled lamps to GELC in Beijing, China for testing.

Table 2 Range of LED lamp pricing (rounded)

Country of origin	Price range (USD $) LEDs < 7W	Price range (USD $) LEDs >7W
Cambodia	1.5 - 8	1.5 - 13
Lao PDR	3 - 6	3.5 - 11.5
Indonesia	2.5 - 4	4 - 10
Philippines	2.5 - 5	3 - 11
Thailand	2.5 - 5	4 - 10
Vietnam	1.5 - 4	2 - 6

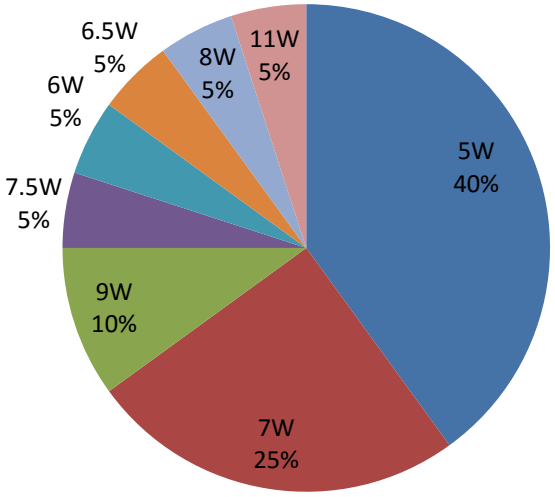
Figure 1 Retail Channels through which IIEC Procured the LED Samples Tested



The information documented for each lamp model included: model number, rated power, rated voltage, rated CCT, lamp base and lamp shape.[16] The information was taken firstly from the lamp itself, however if the information could not be found then the missing information was taken from the lamp packaging. During the documenting process, if it was found that 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 samples received, 40% of the lamps have a rated power of 5W; and 25% of the lamps are 7W, see Figure 2.

[16] An indicative comparison can be made from the claimed versus tested values, and manufacturers' claims versus actual lamp performance, however, the labeling of the lamps' packages lacked consistency, and was not recorded by GELC prior to testing.

Figure 2 Percentage of each wattage of total models received and tested



3.4 Testing parameters

As stated in the introduction, the focus for this project is to demonstrate the lamp selection and collection process, testing, and interpretation of results to assess the quality of the lamps currently available on the markets. Therefore, the most critical parameters related to lamp performance and quality were selected for testing. These included:

- Lamp power (Watt, W),
- Power factor,
- Initial luminous flux (lumen, lm) and initial efficacy (lm/W),
- Colour rendering index (CRI), and
- Light distribution (photometric measurement results in polar coordinates format).

These five parameters were tested both at 0 hour and after 1,000 hours of operation. Due to the limited timeframe available for testing, it was not possible to test all of the parameters covered in the lighting standards.

3.5 Reference test standards

The International Electrotechnical Commission (IEC), and International Commission on Illumination (CIE) standards are the most recognized and widely referenced by national standards. Therefore, in this project, testing of the identified performance parameters (except light distribution) were conducted according to the IEC standard *IEC/PAS 62612 Self-ballasted LED-lamps for general lighting services - Performance requirements*.[17] The light distribution test was conducted according to IESNA *LM79 - Electrical and Photometric Measurements of Solid-State Lighting Products*[18]. Although it is primarily a North American standard, LM - 79 is one of the internationally recognized methods for

[17] IEC/PAS 62612 "This standard specifies the performance requirements for self-ballasted LED lamps with a supply voltage up to 250 V, together with the test methods and conditions required, intended for domestic and similar general lighting purposes"

[18] This standard provides test methods addressing the requirements for measurement of SSL products. This approved method covers LED-based SSL products with control electronics and heat sinks incorporated.

photometric testing of LED lighting products, and was used for this project as the international test method was being finalized by the CIE.[19] It should be noted that for IEC/PAS 62612, the required number of lamps per model to be tested, or the "sample size" is 10, so the reported results are actually the average of 10 samples. IESNA LM-79, on the other hand, only requires one sample to be tested, and the results are reported as absolute values. This is summarised in Table 3.

Table 3 Testing parameters and sample size

Testing Parameter	Sample size (unit)
Lamp power	10
Power factor	10
Initial luminous flux	10
Initial efficacy	10
Colour rendering index	10
Light distribution	1

[19] At the time of testing for this report, CIE international Standard S025/E:2105, *Test Method for LED Lamps, LED Luminaires and LED Modules* has not been finalized, therefore LM -79 was used, although it is primarily a North American standard.

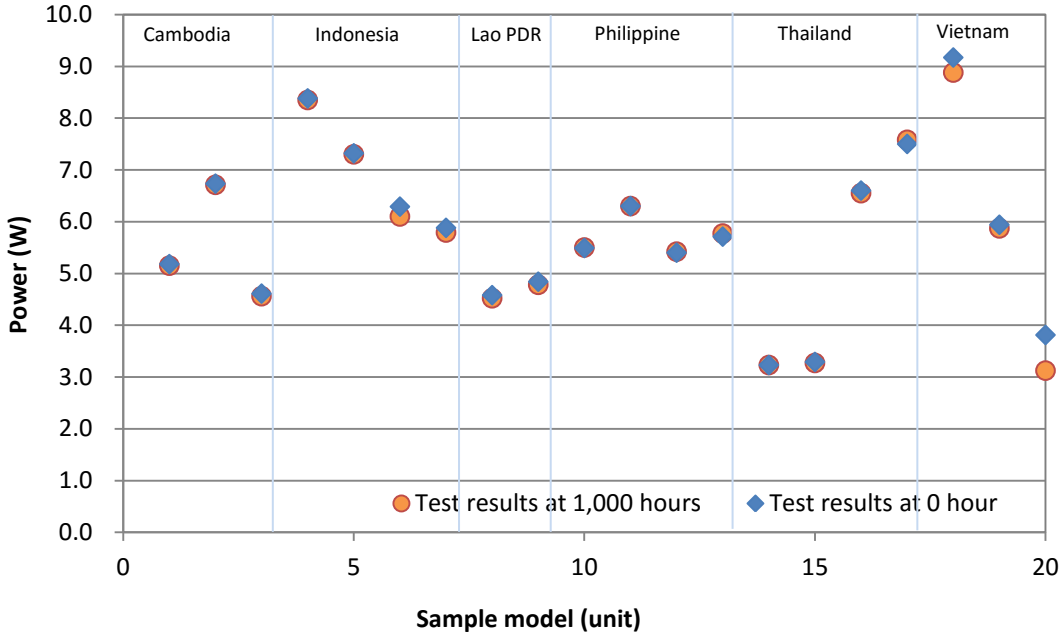
4 SUMMARY OF TEST RESULTS

As per the requirements of IEC/PAS 62612, the initial performance tests were conducted at 0 hour without aging; while a second stage of performance tests were conducted at 1,000 hours, to compare with the initial test results. Due to the limited timeframe, the lumen maintenance and colour maintenance tests were not conducted. A total of 20 models of LED lamps were tested; for each model, a sample size of 10 lamps were tested.

4.1 Lamp power

Figure 3 shows the test results of average lamp power both at 0 hour (square blue points) and 1,000 hours (round orange points). It can be seen from Figure 3 that most of the test results for the same model at 0 hour and at 1,000 hour overlap.

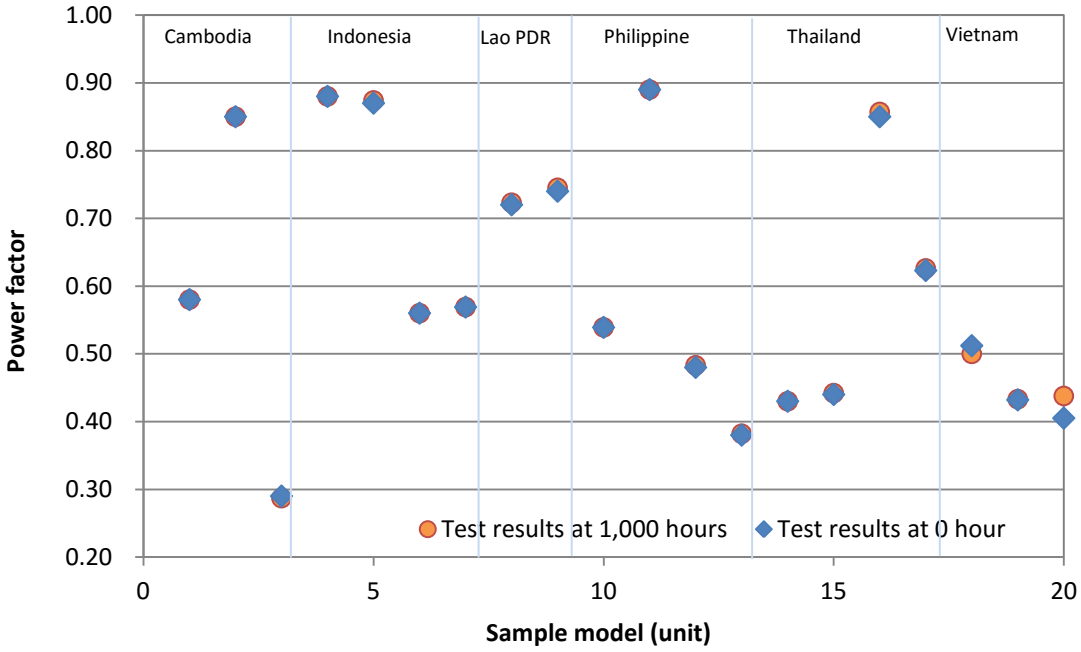
Figure 3 Test results for average (mean, n=10) lamp power



4.2 Power factor

Figure 4 shows measured average (mean) power factor test results and shows a big difference among the different models. The lowest power factor is less than 0.3, while the highest is over 0.8. There was very little difference in power factor between 0 hour test results (blue points) and 1,000 hours test results (orange points).

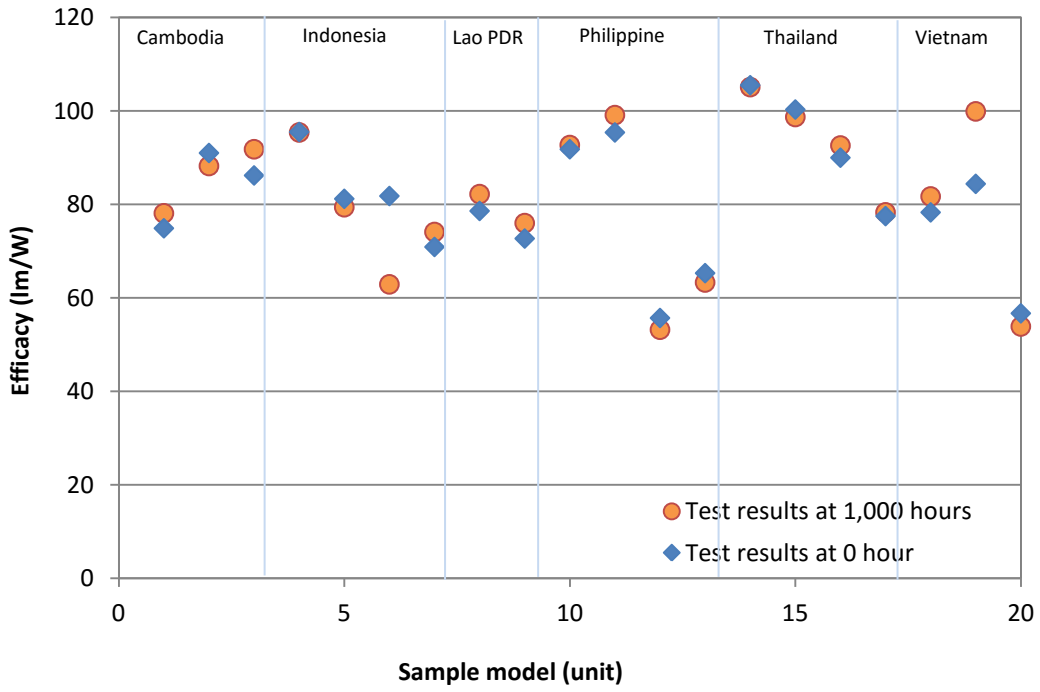
Figure 4 Test results for average (mean, n=10) power factor



4.3 Luminous efficacy

Figure 5 shows the average luminous efficacy results of 20 models of LED lamps. It can be seen that the efficacy results have large differences and are found in the range of 50-110 lm/W. For most of the models, there are also small differences between the test results at 0 hour and 1,000 hours. The results show some increased in efficacy and some decreased but there were no significant patterns to this behaviour.

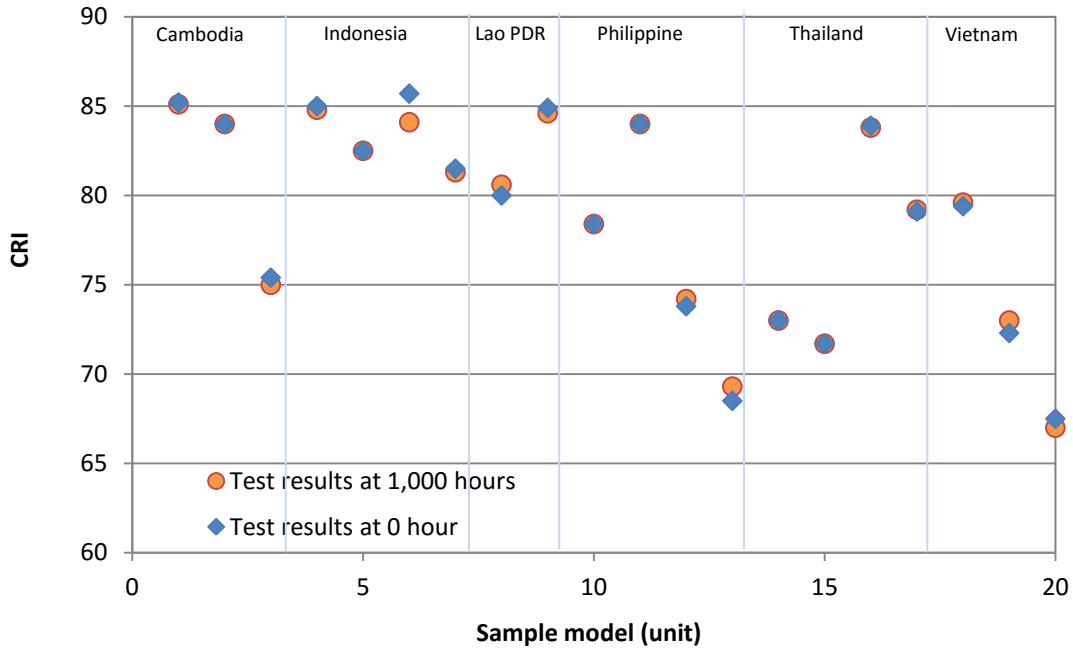
Figure 5 Test results for average (mean, n=10) efficacy



4.4 Colour rendering index

Figure 6 presents the test results for the average colour rendering index (CRI) value. It can be seen that half of the samples had a CRI less than 80 for both 0 hour and 1,000 hours test results.

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



4.5 Light distribution

There are three types of light distribution for omnidirectional LED lamps. They are omnidirectional light distribution, quasi-omnidirectional light distribution and semispatial light distribution:

- For omnidirectional light distribution, the luminescence angle is greater than 180°, and in the zone from 0° to 135°, the deviation between the luminous intensity at each testing point and the average luminous intensity should be no more than 20%; and in the zone from 135° to 180°, the luminous flux should be no less than 5% of the total luminous flux.
- For quasi-omnidirectional light distribution, the luminescence angle is greater than 180°, but the light distribution does not meet with the other requirements of the omnidirectional light distribution.
- For semispatial light distribution, the luminescence angle is 180° or less.

The specific characteristics of each lamp model is presented in Chapter 5.

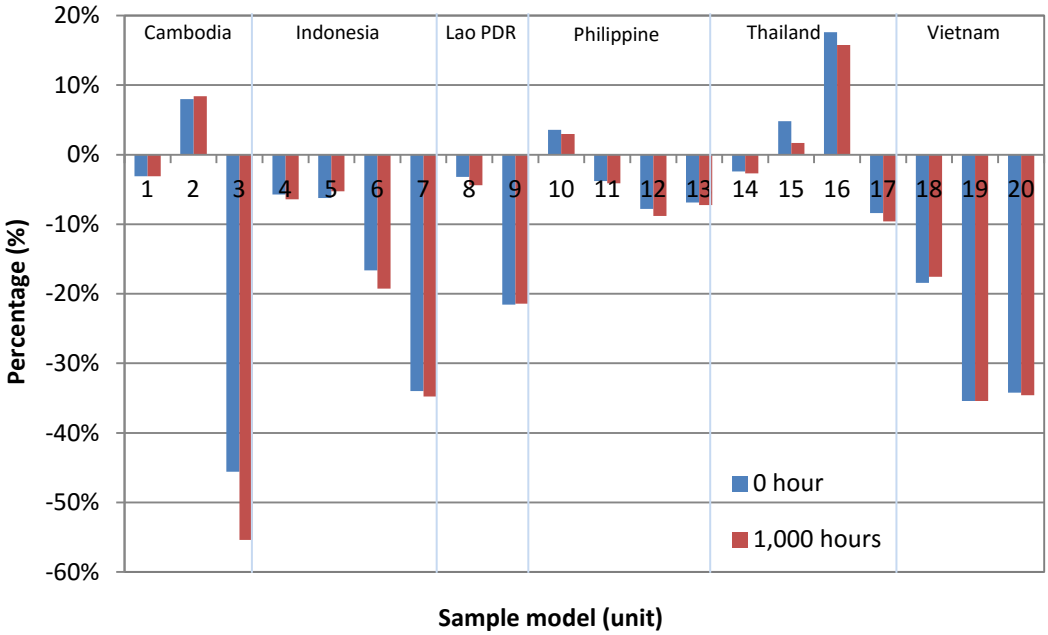
5 SUMMARY AND OBSERVATIONS ON LAMP TESTING RESULTS

20 LED lamp models were collected for performance testing from six countries. Five main parameters were tested: power, power factor, luminous efficacy, colour rendering index and light distribution. The sections below summarize comparisons between the tested results (measured) and rated (claimed), or average values for these parameters at 0 and 1000 hours. Generally, better quality products tend to have a more stable operation. Therefore, the below comparisons showing how these products performed compared to manufacturers' claims, to the group average, and to their performance when new, can provide insight into their quality and likelihood of adoption, as consumers prefer stable-operating products. The performance of these products are also compared to the requirements of a number of international standards, which are further discussed in the country sections.

5.1 Measured and rated power

Figure 7 shows the deviation between measured power and rated power. It can be seen that in 80% of the models, their measured power values were less than their rated power. The maximum difference was over than 50%. This can mean that the manufacturers claimed a higher rated power than the actual power, or it may indicate that their production controls are not capable of matching their design specifications. In any case, inaccurately rated information may cause confusion for the consumer which decreases their confidence in LED lighting products.

Figure 7 Deviation between measured power and its rated power



5.2 Power factor

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. For some regions, the requirements for power factor of LED lamps are based on their rated wattage: 5W and below, or over 5W. The average power factor value of all models rated at 5W and below models is 0.53, and of all other

models with rated power greater than 5W is 0.65. Figure 8 shows the deviation between the power factor of each model and average value of all models with rated wattage no greater than 5W. Three models have deviation less than 10%, while two models have differences of more than 30%, with the highest up to 40%.

Figure 8 Deviation between power factor of each model and average value of all models with rated wattage no greater than 5W

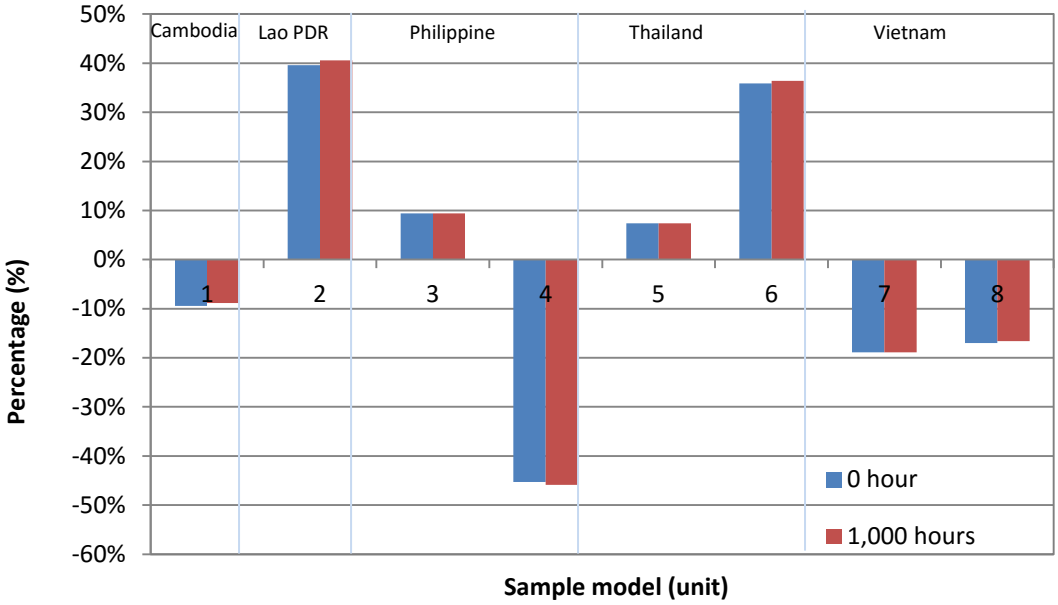
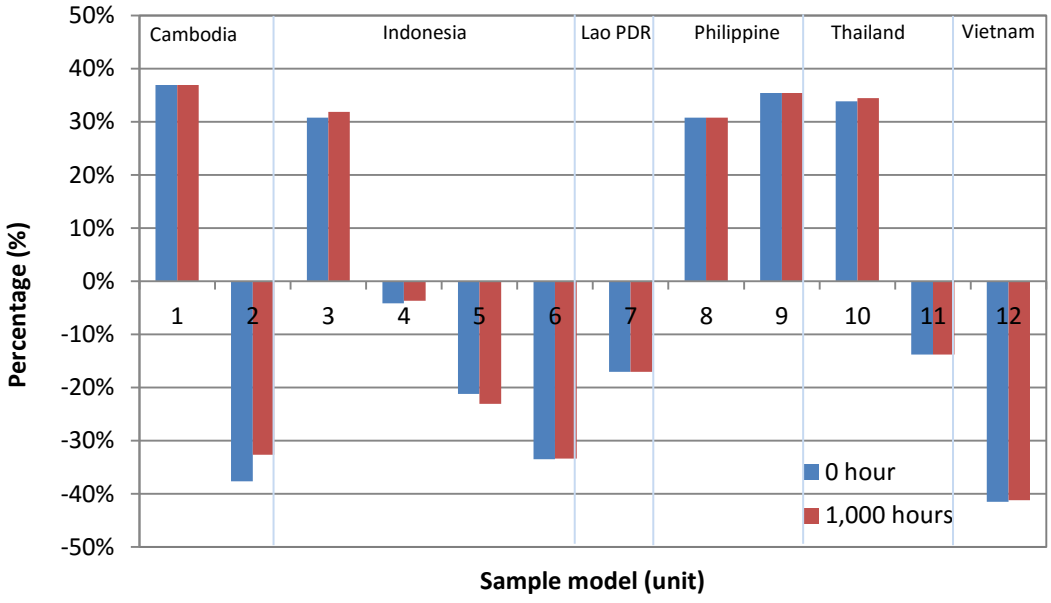


Figure 9 shows the deviation between the power factor of each model and average value of all models with rated wattage greater than 5W. One model had deviation less than 10%, while eight models had differences of more than 30%, and one with over 40%.

Figure 9 Deviation between power factor of each model and average value of all models with rated wattage greater than 5W



5.3 Luminous efficacy

According to the reference standards, efficacy requirements differ by the rated power and rated colour. Since all the models have a rated power less than 15W, they all fall into the same power category. Therefore, the deviation shown in Figures 10 and 11 below are only separated by the rated colour. Of all 20 models of LED lamps, 15 models were cool light and the other 5 models were warm light. Figure 10 shows the deviation between luminous efficacy of each model and the average efficacy of all models with cool light. It can be seen that four models have differences of less than 10%, and two models have the differences of more than 30%.

Figure 10 Deviation between efficacy of each model and average efficacy of all models with cool light

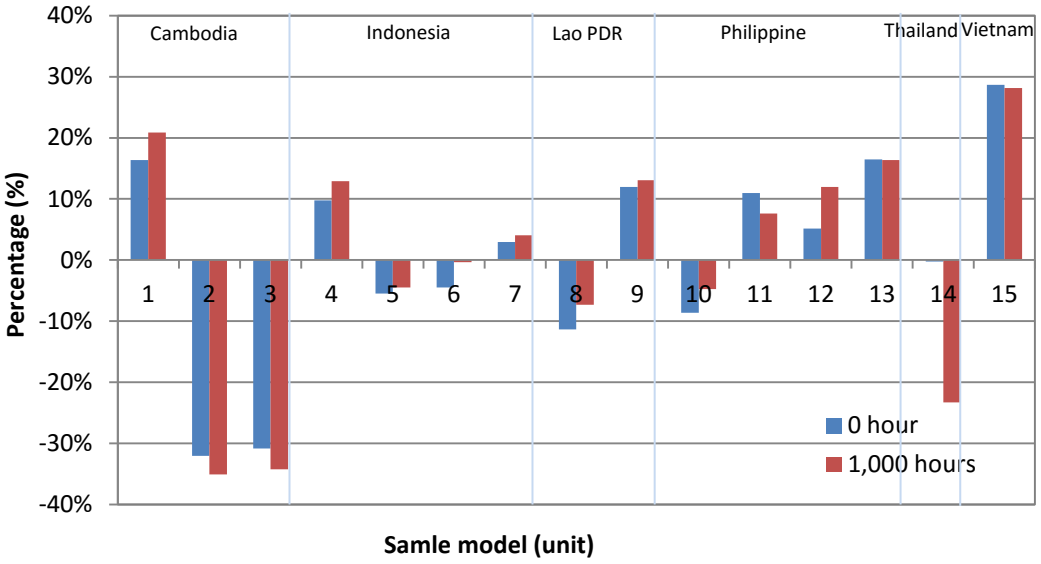
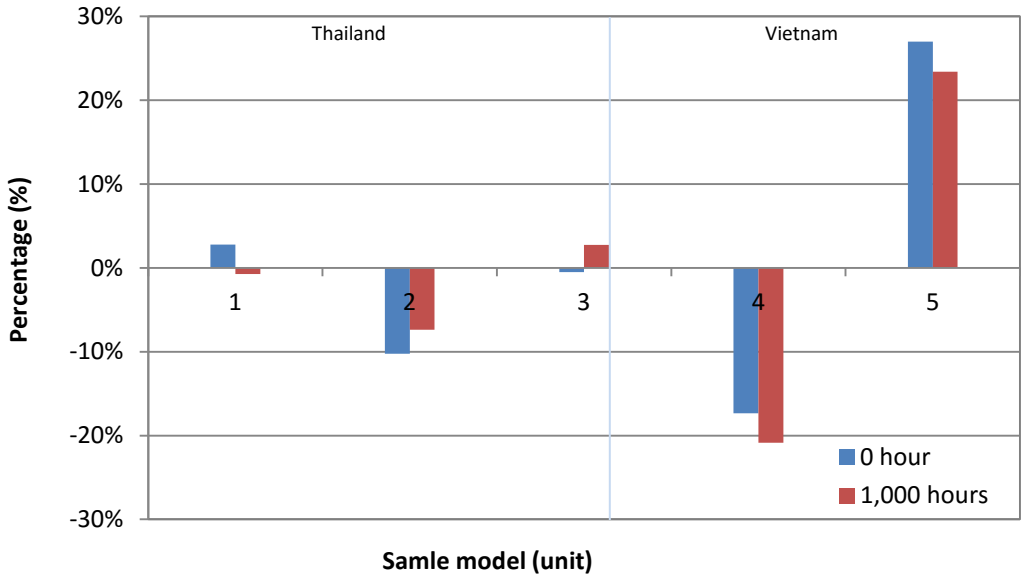


Figure 11 shows the deviation between luminous efficacy of each model and the average efficacy of all models with warm light. It can be seen that two models have the differences of less than 10%, and two models have differences of more than 20%.

Figure 11 Deviation between efficacy of each model and average efficacy of all models with warm light

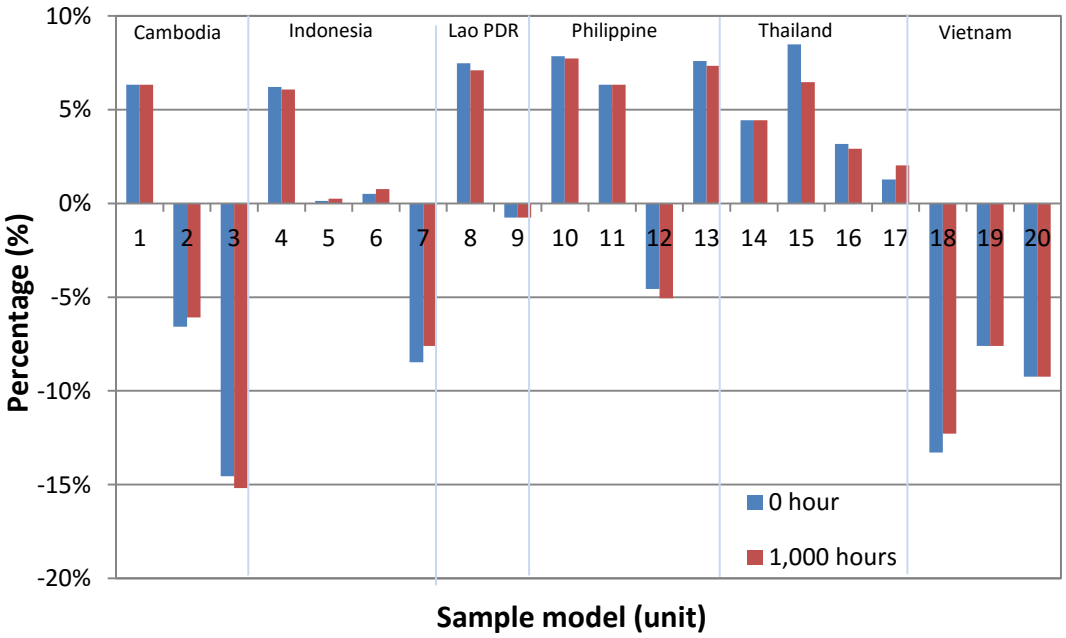


Unique from the rest of parameters tested, some of the models show clear differences between the test results at 0 hour and at 1,000 hours. One possible reason for this is the particular characteristics of LEDs, which require time to reach stability. Another reason may be that in order to make a "bright" lamp, the lamp was designed to be driven at a higher current, but it is not able to sustain operation at such a high current over its operational lifetime. This can then cause unstabilities in luminous flux, which can be seen as the difference in the luminous efficacy test results at 0 hour and at 1,000 hours.

5.4 Colour rendering index

Figure 12 shows the deviation between the measured CRI of each model as compared to the average CRI results of all 20 tested models from Cambodia, Indonesia, Lao PDR, Philippines, Thailand and Vietnam respectively. It can be seen that the maximum differences was about 15% and nearly 60% of the models were in the range of 5%-10%. CRI is the 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 12 The deviation between CRI of each model and average CRI results of all the models



5.5 Deviation of results: 0 and 1000 Hour

Table 4 presents the deviation between the average test results at 0 hour and 1,000 hours. Compared with the test results at 0 hour, the luminous efficacy shows the largest differences. And CRI shows the smallest differences. For the power, 70% of the test results at 1,000 hours were decreased compared with the test results at 0 hour. For power factor, most of the models had very small changes (less than 1%) at the different times, except model 3 which increased by 8.1%. For luminous efficacy, 11 models shows results increased at 1,000 hours and 9 models show decreases, and the change in efficacy were higher than the power, which means during the 1,000 hours, the total luminous flux had increased or decreased more than the power.

Table 4 Deviation between average test results at 0 hour and 1,000 hours

Model number	Power	Power factor	Luminous efficacy	CRI
Model 1	0.0%	0.0%	3.9%	0.0%
Model 2	0.4%	0.6%	-4.5%	0.5%
Model 3	-18.1%	8.1%	-5.0%	-0.7%
Model 4	-0.8%	0.8%	2.9%	-0.1%
Model 5	1.1%	0.5%	1.0%	0.1%
Model 6	-3.2%	-2.3%	4.3%	0.3%
Model 7	-1.2%	0.2%	1.1%	1.0%
Model 8	-1.2%	0.7%	4.5%	-0.4%
Model 9	0.2%	0.0%	1.0%	0.0%
Model 10	-0.6%	0.0%	4.3%	-0.1%
Model 11	-0.3%	0.0%	-3.1%	0.0%
Model 12	-1.1%	-1.0%	6.5%	-0.5%
Model 13	-0.4%	0.0%	-0.1%	-0.2%
Model 14	-0.3%	0.5%	-2.2%	0.0%
Model 15	-3.0%	0.0%	-23.1%	-1.9%
Model 16	-1.5%	0.0%	4.5%	-0.2%
Model 17	-1.3%	0.4%	4.6%	0.7%
Model 18	1.1%	0.5%	-3.1%	1.2%
Model 19	0.0%	0.0%	-0.4%	0.0%
Model 20	-0.6%	0.5%	-1.6%	0.0%

From the analysis above, it can be concluded for 20 models of LED lamps, there is a range of different quality levels over different parameters. Some models have stable power, low power factor, high efficacy, and high CRI, and can be assumed to be of higher quality. However, others have large variations in the rated power, low power factor, low efficacy and low CRI. The comparison Figures 8-12 show these differences. It should be noted that even if a lamp model is tested twice under the same conditions, the results may not be exactly the same. Similarly, two lamps of the same model tested under the same conditions may not provide identical results, which is why many standards call for more than one sample. Certain variations between one result to another on the same model are acceptable if they are within allowable tolerances (typically 0 and 3%) by many standards.

5.6 Performance comparison with international standards

Table 5 shows for each participating country, how many models met all the comparison standards used in this report for the tested parameters. It can be seen that in general the samples from Thailand show higher performance levels than the LED lamps purchased in other countries. The samples from Philippines and Indonesia also exhibited good luminous efficacy results. Overall, power factor and CRI had the lowest compliance rates.

Table 5 Country or origin and number of models not meeting comparison standards

Country	No. of models purchased	Power	Power factor	Luminous efficacy	CRI
Cambodia	3	1	1	2	2
Indonesia	4	1	3	0	2
Lao PDR	2	1	1	0	1
Philippines	4	0	2	0	1
Thailand	4	1	1	1	0
Vietnam	3	1	1	1	3

5.7 Light distribution

Table 6 summarises the light distribution patterns of all 20 models of LED lamps tested. It can be seen that 4 of them have quasi-omnidirectional light distribution, and the rest are all semispatial light distribution. Light distribution is not only a very important parameters for lighting design, but it will also create different effects for the users. Omnidirectional light distribution is regarded as giving the same or very similar lighting service as incandescent lamps. However, for quasi-omnidirectional light distribution and semispatial light distribution patterns, the light output is not even, with the output at high angle zones reduced or affected. Since different applications can require different light distributions, this information can be useful information for the expert users or lighting designers to take into consideration in order to utilise the light produced from the lamp most effectively.

Table 6 Summary of light distribution patterns

Country	Models	Light distribution pattern
Cambodia	Model 1	Quasi-omnidirectional light distribution
	Model 2	Semispatial light distribution
	Model 3	Semispatial light distribution
Indonesia	Model 1	Semispatial light distribution
	Model 2	Semispatial light distribution
	Model 3	Semispatial light distribution
	Model 4	Semispatial light distribution
Lao PDR	Model 1	Quasi-omnidirectional light distribution
	Model 2	Quasi-omnidirectional light distribution
Philippines	Model 1	Semispatial light distribution
	Model 2	Semispatial light distribution
	Model 3	Semispatial light distribution
	Model 4	Semispatial light distribution
Thailand	Model 1	Semispatial light distribution
	Model 2	Semispatial light distribution
	Model 3	Semispatial light distribution
	Model 4	Quasi-omnidirectional light distribution
Vietnam	Model 1	Semispatial light distribution
	Model 2	Semispatial light distribution
	Model 3	Semispatial light distribution

6 ADDITIONAL OBSERVATIONS AND POLICY RECOMMENDATIONS

As noted earlier, the process of sample identification, collection and testing documented in this report was intended to primarily demonstrate the sample identification collection and testing process for LED lamps, as well as to illustrate the technical analyses that can be carried out with the test results. While the samples collected from each country were not sufficient to be representative of each country's market composition, they still can provide some insight and policy implications into the types of products that are currently available in each market, as well as the region overall.[20] Therefore, in order to provide the report with further policy context, UNEP has added this observations and recommendations section to supplement the technical analysis of the test results by GELC.

6.1 Observations

One clear observation is that a market for LEDs is just beginning to develop within each of the six target countries. While not much is known about market penetration rates or take up rates of LED lamps by consumers in each country, the fact that they are available, and the sampling teams were able to find them in local shops – in sufficient quantities – indicates that there is some awareness of LEDs by retailers and consumers.

However, as with many new products, these markets are constrained in many ways, including: no available consumer information about product quality and proper usage; somewhat limited choices, high price, lack of incentives; and for some markets and the region, an absence of any standards or labelling schemes.

As can be seen in Table 2 (Section 3.2), LEDs products are currently two to three times as expensive as the next most energy efficient alternatives (CFLs), and thus represent a significant investment for consumers in the target countries. From the report of the sample collection team, it was also possible to gain some information about how the supply chain is structured in some markets. For example, it seemed to indicate that importers generally are not making direct purchases of products from the manufacturers, and products are more likely to be purchased from a 3rd party by smaller shops. This may indicate that these markets are currently not being served by larger, more reputable manufacturers. Further, the current labelling and consumer information on product packages are neither consistent nor informative, and can make it difficult for consumers to choose appropriately.

It is also useful to compare the levels of performance of these products relative to a number of international standards or labelling requirements, as well as any national standards, as applicable. As noted, while the samples collected may not be representative of each country's market, they constitute a good starting point, since they were sampled from a variety of locations and venues, and it can be assumed that they are typical products that are being seen and bought by consumers.

[20] For a more detailed discussion on how to conduct market sampling, establishing a baseline, and interpreting test results, please refer to the following UNEP-GEF en.lighten initiative guidance notes (available from http://www.enlighten-initiative.org/ResourcesTools/Publications.aspx):

- *Developing Minimum Performance Standards for Lighting Products*
- *Developing Lighting Product Registration Systems*
- *Performance Testing of Lighting Products*
- *Efficient Market Baselines and Assessment*

With respect to the international standards or requirements for lamp performance and quality, a number of international standards are referenced for comparing the average test results of each model due to the lack of national or regional standards or requirements. Because of the different parameters tested, more than one standard was referenced. It should be noted that the IEA 4E Solid-State Lighting Annex currently has a comprehensive set of recommended Performance Tiers covering most of the tested parameters, that can be adopted by countries depending on the state of their market development. These reference standards are listed below, and the specific parameters are referenced in Table 7.

- Solid State Lighting Annex: *Product Quality and Performance Tiers for Non-Directional Lamps*. International Energy Agency, Efficient Electrical End-Use Equipment (4E), September 2012;
- IEC/PAS 62612, *Self-ballasted LED-lamps for general lighting services - Performance requirements*;
- EU Regulation No. 244/2009, *Ecodesign requirements for non-directional household lamps*;
- EU Regulation No.1194/2012, *Ecodesign requirements for directional lamps, light emitting diode lamps and related equipment*;
- *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0;*[21]
- GB/T 24908, *Self-ballasted LED-lamps for general lighting service – performance requirements*.

Table 7 Reference Standards and requirements for tested parameters

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td></tr>
<tr><td rowspan="4">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td></tr>
<tr><td>IEA 4E SSL Annex</td><td>≤5W: no requirement; >5W, PF >0.50</td></tr>
<tr><td rowspan="2">Initial luminous flux /Initial efficacy</td><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>ENERGY STAR lamp V1.0[22]</td><td>
<table>
<tr><th>Lamp Rated power (watts)</th><th>Minimum Lamp Efficacy (initial lm/W)</th></tr>
<tr><td><15</td><td>55</td></tr>
<tr><td>≥15</td><td>65</td></tr>
</table>
</td></tr>
</table>

[21] ENERGY STAR is a voluntary programme. It aims to promote high energy efficiency products through a certification scheme in the market. Therefore ENERGY STAR is not a minimum requirement standard.

[22] 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></tr>
<tr><td></td><td>GB/T 24908</td><td><table>
<tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr>
<tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr>
<tr><td>III</td><td>70</td><td>65</td></tr>
</table></td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>Tier 1: >50 lm/W
Tier 2: >65 lm/W</td></tr>
<tr><td rowspan="4">Colour rendering index</td><td>EU Regulation No. 1194/2012</td><td>⩾ 80</td></tr>
<tr><td>ENERGY STAR Lamp V1.0 Specification</td><td>Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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></tr>
<tr><td>GB/T 24908</td><td>⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77</td></tr>
<tr><td>IEA 4E SSL Annex</td><td>Tier 1: ≥70
Tier 2: ≥80, R9> 0</td></tr>
</table>

It should be noted that standards can differ in test methods requirements and sample sizes, therefore these referred comparison standards are only used to compare the general performance of the lamp models to international requirements.

As shown in Table 5 (Section 5.6) and Table 9, the performance of the tested lamp models from the six target countries are generally below the minimum levels required by a number of international standards for more developed markets. Very few of the tested models met the requirements of luminous efficacy and CRI, two of the most critical parameters having to do with energy efficiency and light quality. Wide adoption of lamps with low luminous efficacy levels can lead to less than expected energy savings, and lamps with lower CRI (and other light quality characteristics) may create dissatisfaction among consumers.

Table 8 Number of tested models meeting IEA 4E SSL Annex efficacy and CRI requirements

Country of origin	No. of models purchased	No. of models meeting IEA 4E SSL Tier 1	No. of models meeting IEA 4E SSL Tier 2
Cambodia	3	2	1
Indonesia	4	2	1
Lao PDR	2	2	1
Philippines	4	4	2
Thailand	4	4	4
Vietnam	3	0	0

However, a number of the lamps tested above do meet the efficacy and CRI levels of the SSL Annex' Tier 1, being the minimum acceptable performance level comparable to a low-cost compact fluorescent lamp. Products meeting all of the requirements in this Tier (not just efficacy and CRI), including rated life, lumen maintenance, endurance test, luminous intensity distribution, colour maintenance, among others can "provide reliable lighting, use less energy and last longer than the traditional sources they are replacing."

6.2 Recommendations

It should be recognized that this project has been an ambitious undertaking, and represents a solid first step in helping the six target countries understand the process of analysing their markets, identifying products available from various market channels, selecting and collecting products, and most importantly, testing and interpretation of the test results, in the context of their own markets. In combination with the parallel effort to identify, sample and test available LED lamps in each of the six target countries, the outcome has provided significant insights into each of the efficient lighting markets, and the region as a whole.

As a result of this indicative, region-wide effort, countries should consider a number of policy steps in order to follow up and build upon the successful prosecution of this project:

- **Continue or increase product sampling and testing of national markets**: As can be seen from the product identification and sampling process, LEDs are now beginning to achieve more prominence. However, if no policy actions are taken, there is the possibility that manufacturers may sacrifice quality and performance to compete only on price. Therefore, a concerted follow up effort to sample, test, and publicise results, building on the framework established by this project, would go far toward improving verification capacities. Such actions can help to drive LEDs product quality, as well as to avoid a repeat of the early CFL experience. [23]

- **Develop MEPS or labelling requirements for LED lamps**: It is imperative that countries should begin the development process for MEPS or labelling requirements, or expand their current efficient lighting MEPS or labelling requirements to include LED lamps. One consideration is to adopt at least a minimum level of product quality, such as those recommended by the International Energy Agency's Energy Efficient End-use Equipment, Solid State Lighting Annex (IEA 4E SSL Annex), which include efficacy and light quality, as well as critical parameters such as lifetime, lumen maintenance, endurance, colour maintenance, and light distribution requirements.

- **Implement targeted incentive or other promotion programmes**: Along with MEPS or labelling development effort, countries could put in place a targeted, high visibility incentive programme or procurement effort to highlight qualified/quality products using international or regional requirements. Such a programme can increase awareness in the supply chain, help pull the market towards quality products, or at least help to make more quality products available.

- **Governments should clearly communicate their intent develop MEPS as soon as they are able**. This clear communication can help to increase awareness of the issue, and lead to greater involvement of all relevant stakeholders.

- **Initiate consumer outreach and education: Until MEPS or labelling requirements can be de**veloped, which will take time, consumers will need help in choosing quality products. As when CFLs were first introduced, consumers may associate LEDs with energy efficiency without knowing what to look for (other than price or brands). A campaign to educate consumers using, for example, the *lites.asia* publication, *Consumer Guide to Buying LEDs*[24],

[23] The early CFL experience was characterized by a lack of common quality and performance standards, and manufacturers competing only on price, which led to poor quality products and dissatisfied consumers.
[24] Available at: www.lites.asia/downloads/led-consumer-guide

can also help to increase awareness and push retailers towards providing better products, which can also help to prepare the market for MEPS or labelling requirements.

- **Embrace regional cooperation and leverage the international experience**: As many countries in Asia are in the same situation with respect to MEPS or labelling requirements for LED lamps, this can be an opportunity for the region as a whole to cooperate on this issue. The region can build on the existing network, knowledge base, and international efforts discussed in this report, as well as with the regional exchanges and Asia-specific information that *lites.asia* has built to date.[25]

[25] *lites.asia* (lighting information and technical exchange – Asia) is a network of standards agencies and technical personnel who focus on lighting issues.

7 COUNTRY RESULTS

7.1 Comparison standards

This chapter analyses the lighting performance test results country by country. In order to have a better view of the lamp performance quality, some comparison standards are referenced for comparing the average test results of each model; however it should understood that different standards may have some differences in the test methods and sample size, therefore these referred comparison standards (see Section 6.1) are only used to give a general picture of the product quality levels.

7.2 Cambodia

There are three models of LED lamps sampled from Cambodia for performance testing (see Table 9). In those samples, all of them are cool light (daylight).

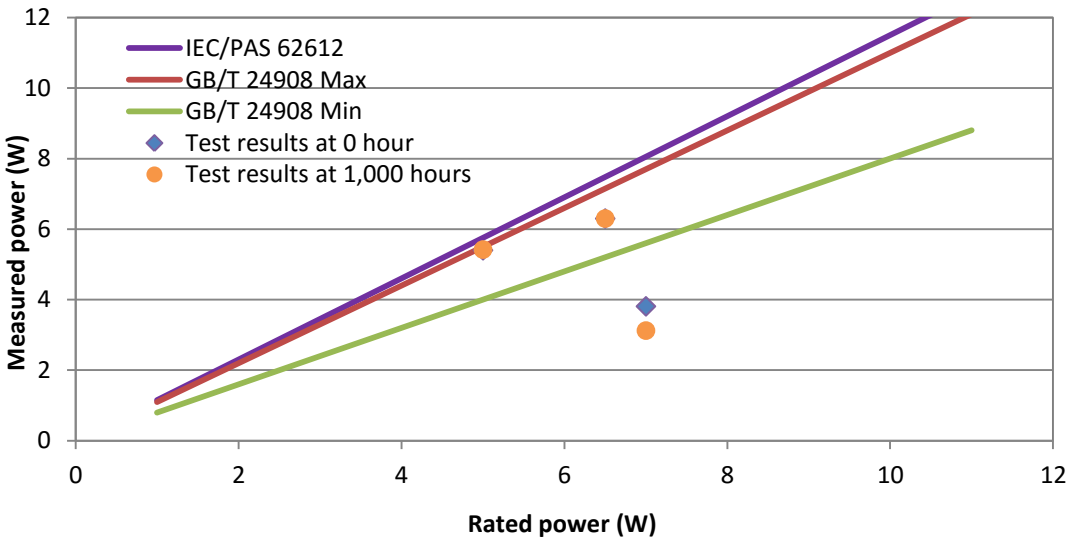
Table 9 LED lamps received from Cambodia

Model number	Rated wattage (W)	Rated colour
Model 1	6.5	Cool light
Model 2	5	Cool light
Model 3	7	Cool light

7.2.1 Lamp power

Among the comparison standards, only IEC/PAS 62612 and GB/T 24908 have requirements for the lamp power. IEC/PAS 626132 requires the power dissipated by the LED lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 13 shows the test results for average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 13 that the test results for two models at 0 hour and at 1,000 hour overlap, and they are both located within the range of three limitation lines. There is a gap for one 7W lamp model and it is under the minimum value line based on GB/T 24908.

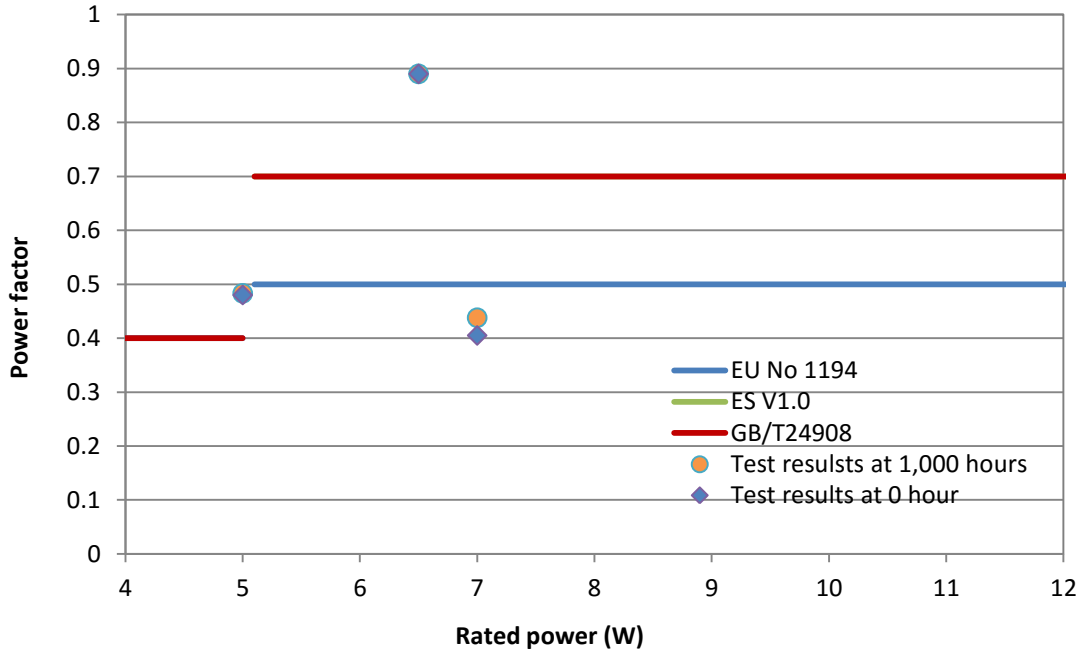
Figure 13 Test results of average (mean, n=10) lamp power



7.2.2 Power factor

Figure 14 shows the test results of the power factor, and compares them with the comparison standards. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194, and recommended by IEA 4E SSL Annex is greater than 0.5, while the minimum value required by ENERGY STAR lamp specification V1.0[26] and GB/T24908 is 0.7. Figure 14 shows two lamp models meet the EU regulation No. 1194 and GB/T 24908. There is one model which has an average power factor less than 0.5 both at 0 hour (blue points) and 1,000 hours (orange points).

Figure 14 Test results for average (mean, n=10) power factor

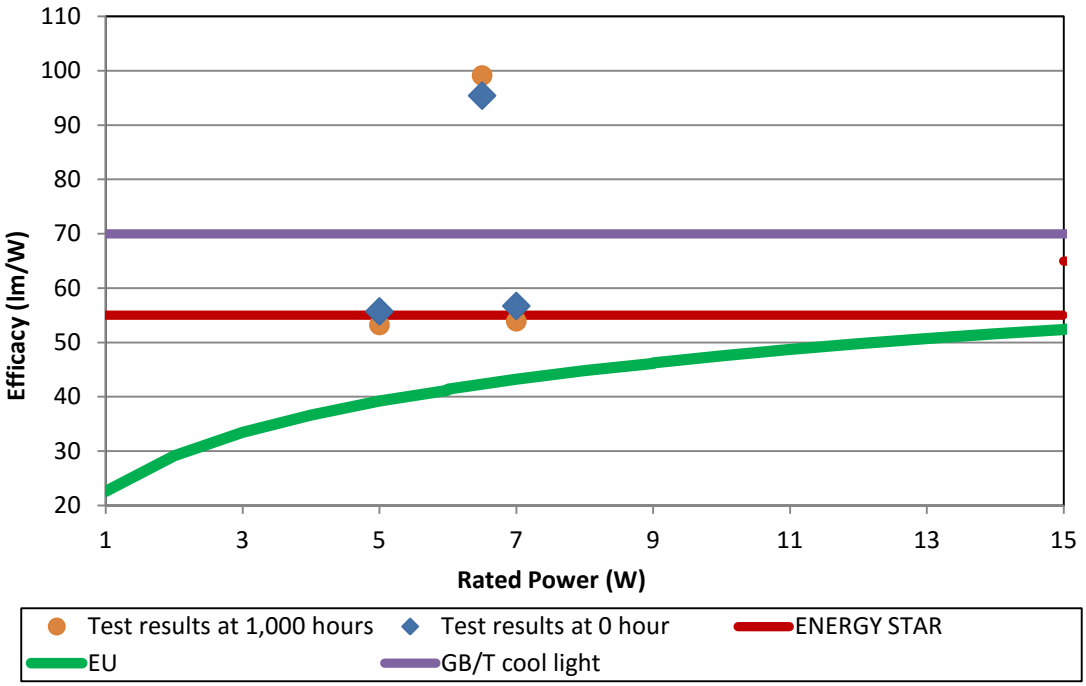


7.2.3 Luminous Efficacy

Figure 15 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet the EU regulation. All of the models tested at 0 hour meet the ENERGY STAR lamps specification V1.0 and IEA 4E SSL Tier 1 requirements, two models tested meet the ENERGY STAR requirement at 1,000 hours. One model meets all three standard requirements and the IEA 4E SSL Tier 2 requirements, and its efficacy was nearly 100 lm/W.

[26] It did not specify the requirement in ENERGY STAR lamp specification V1.0 for lamps with the power equal to and less than 5 watts.

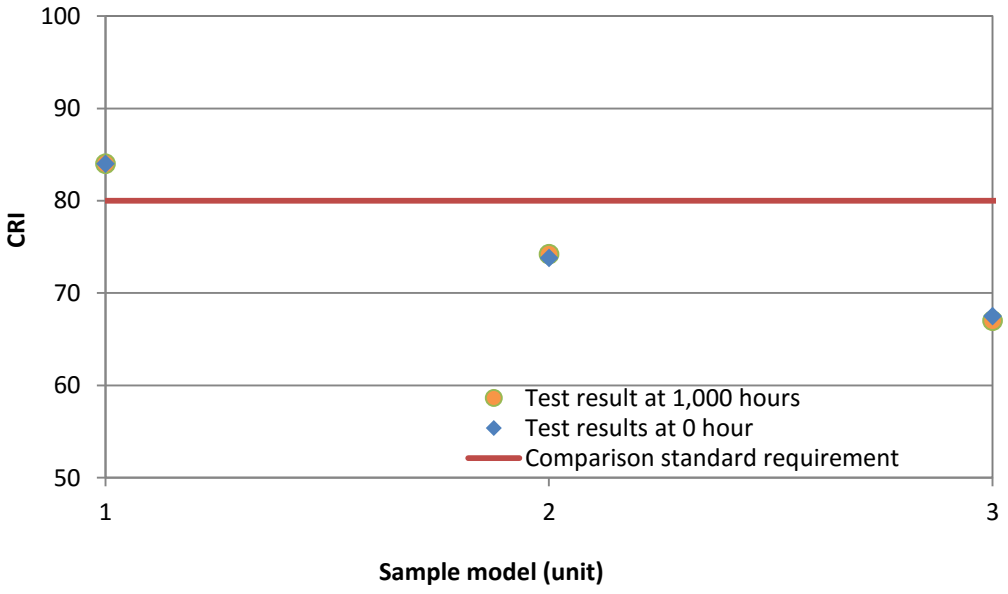
Figure 15 Test results for average (mean, n=10) luminous efficacy



7.2.4 Colour rendering index

Figure 16 presents the average test results for the colour rendering index (CRI) where all of the referred standards require that the CRI should be no less than 80 (except for IEA 4E SSL Annex Tier 1, which is 70). It can be seen in Figure 16 that one sample model meets this requirement. The other two models measured sample average CRI value are less than 80 (under the red line), with one model also less than 70.

Figure 16 Test results for average (mean, n=10) CRI



7.2.5 Light distribution

Light distribution was tested at 0 hour. Figures 17 – 19 show the light distribution pattern for the three models purchased in Cambodia. They all have axial symmetry. The maximum lighting intensity for these three models are 85 cd, 60 cd and 38 cd respectively. The test results shows Model 1 has quasi-omnidirectional light distribution and Models 2 and 3 have semispatial light distribution.

Figure 17 Light distribution – Model 1 purchased in Cambodia (polar coordinate system, unit: cd)

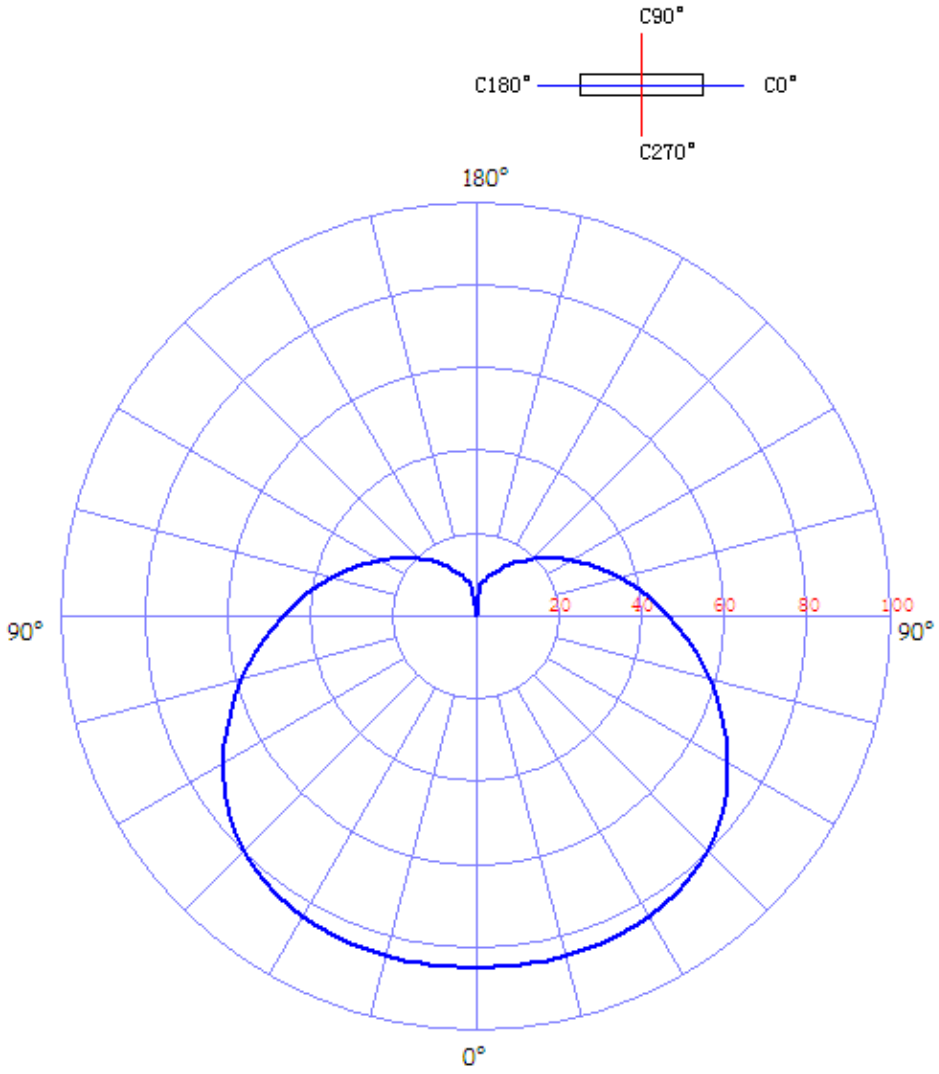


Figure 18 Light distribution – Model 2 purchased in Cambodia (polar coordinate system, unit: cd)

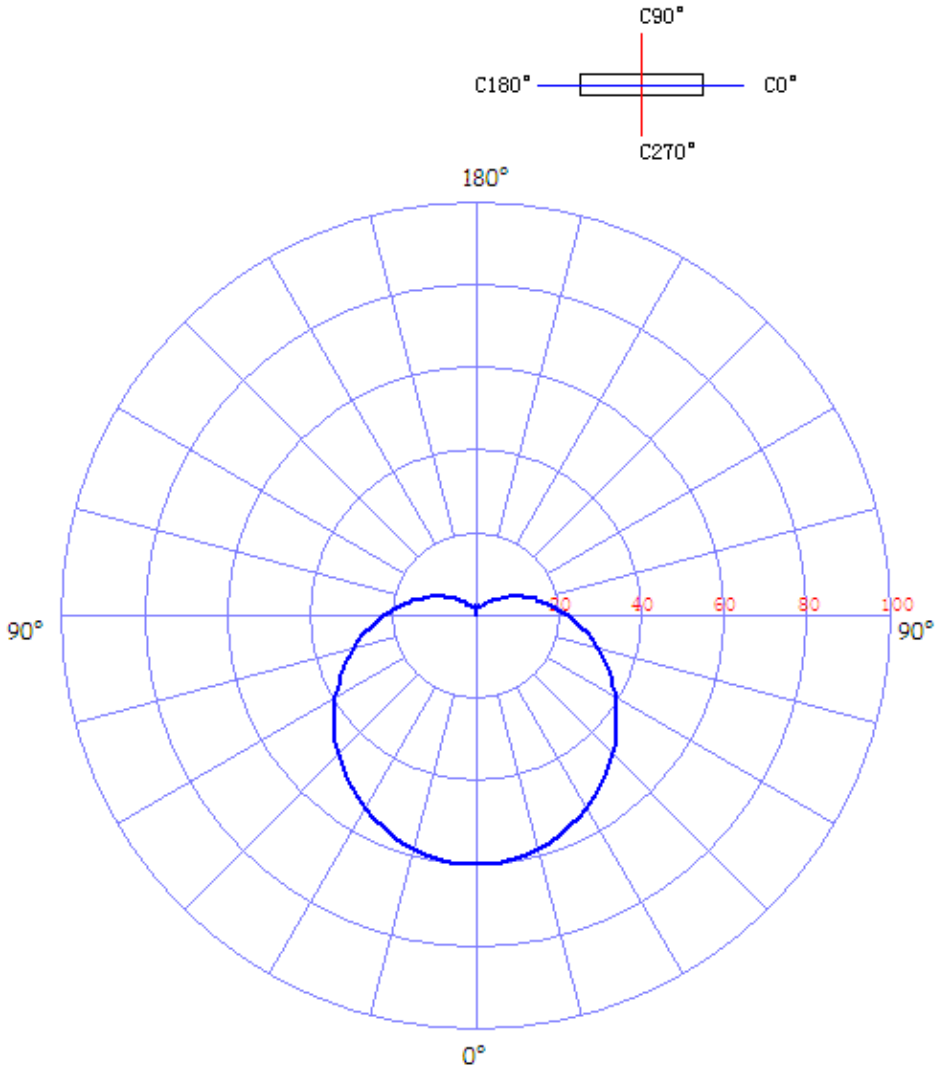
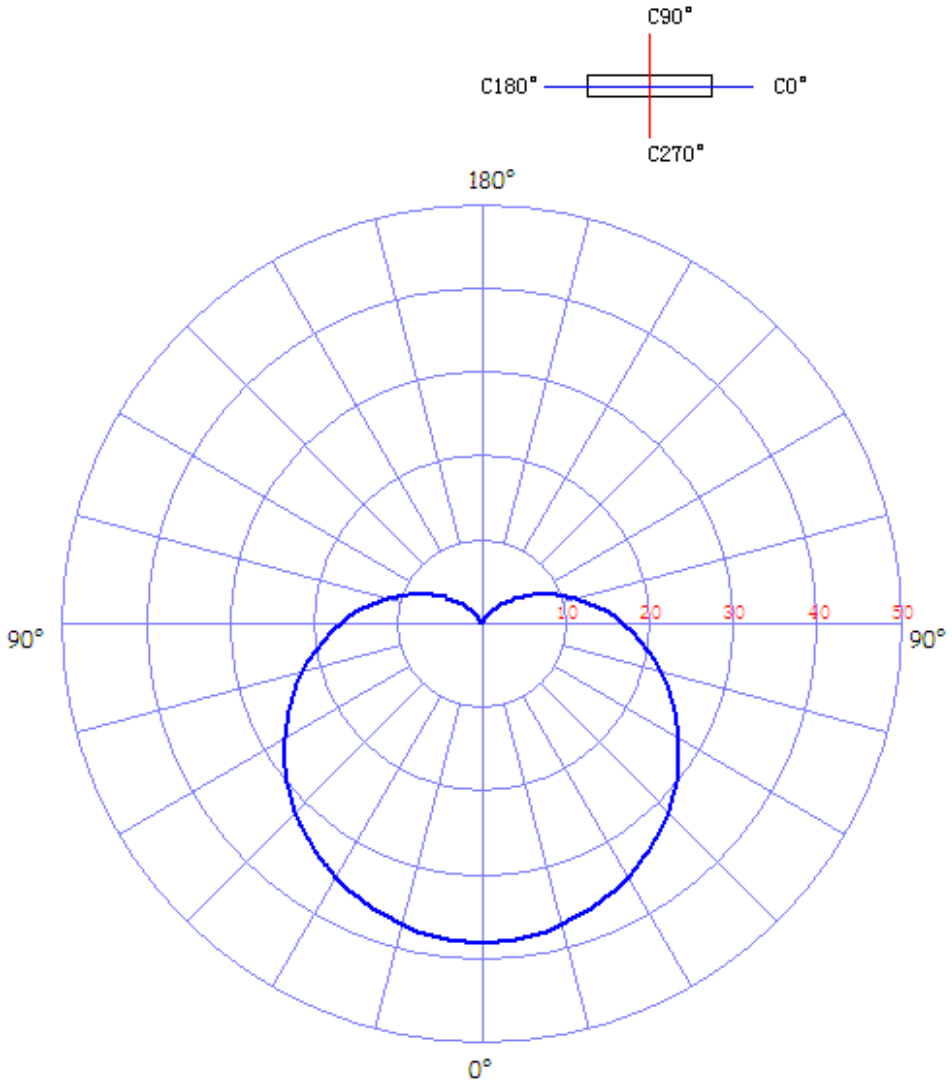


Figure 19 Light distribution – Model 3 purchased in Cambodia (polar coordinate system, unit: cd)



7.2.6 Summary of results for lamps purchased in Cambodia

Of the three models of LED lamps purchased in Cambodia, the testing identified CRI was the main issues existing in the samples. In addition the 7W lamp also shows both low power and power factor. Table 10 presents all the results of the testing parameters compared to the comparison standards. Table 11 presents each parameter's compliance for each model with the minimum requirements of all the comparison standards.

Table 10 Summary of test results of the three models of LED lamps purchased in Cambodia

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="4">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>1 model does not meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>1 model does not meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>1 model does not meet the requirement</td></tr>
<tr><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="2">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[27]</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>All of the models tested at 0 hour meet requirement, while two models tested at 1,000 hours meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>2 models do not meet the requirement</td></tr>
</table>

[27] 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
	IEA 4E SSL Annex	Tier 1: > 50 lumen/watt Tier 2: > 65 lumen/watt	3 models meet Tier 1 1 model meets Tier 2
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	2 models do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	2 models do not meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	2 models do not meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	2 models meet Tier 1 2 models meet Tier 2 (CRI only)

Table 11 Cambodia: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour rendering index
1	✓	✓	✓	✓
2	✓	✓	✓	×
3	✓	×	✓	×

7.3 Indonesia

There are four models of LED sampled from Indonesia for performance testing (see Table 12). In those samples, all of them are cool light (daylight).

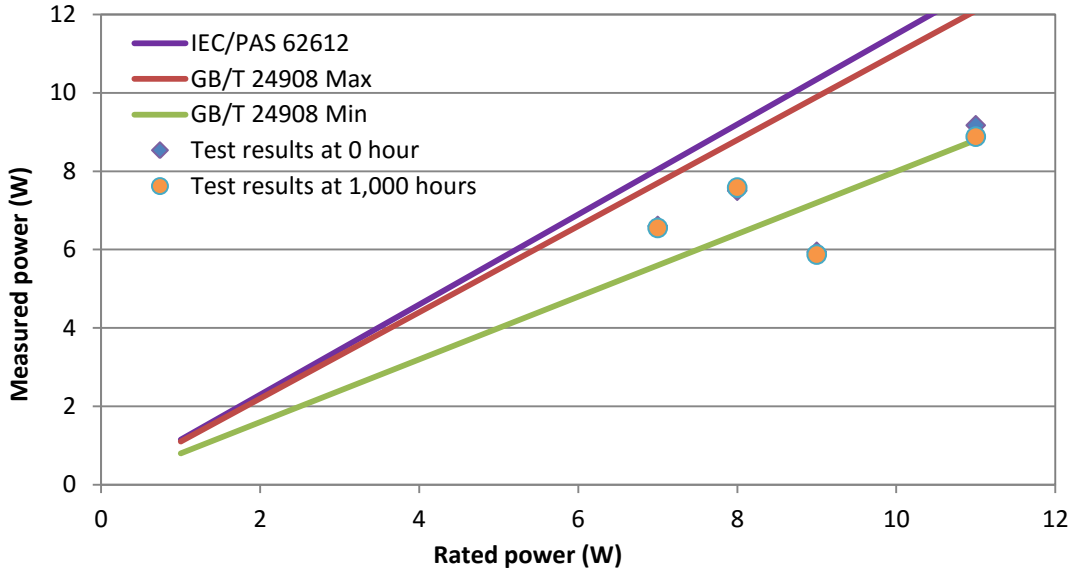
Table 12 LED lamps received from Indonesia

Model	Rated wattage (W)	Rated colour
Model 1	7	Cool light
Model 2	8	Cool light
Model 3	11	Cool light
Model 4	9	Cool light

7.3.1 Lamp power

Among the referred comparison standards, IEC/PAS 62612 and GB/T 24908 only have a requirement on the lamp power. IEC/PAS 626132 requires the power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 20 shows the test results of average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 14 three sample models are located within the range of three limitation lines. Only the 9W lamp dropped under the minimum value line based on GB/T 24908.

Figure 20 Test results of average (mean, n=10) lamp power

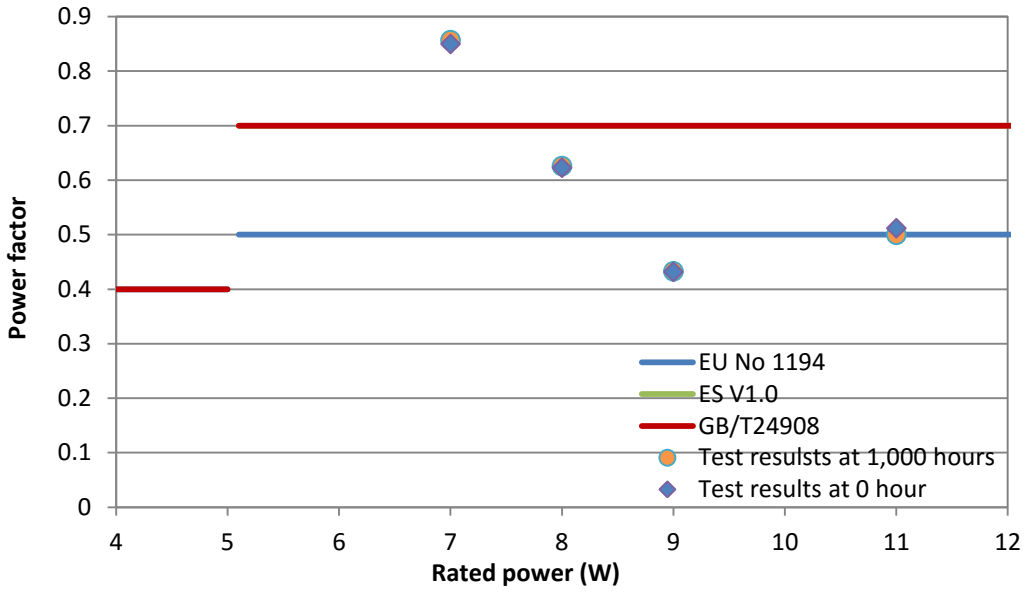


7.3.2 Power factor

Figure 21 shows the test results of the power factor (PF), and compares them with the comparison standards. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194 is greater than 0.5, while the minimum value

required by ENERGY STAR lamp specification V1.0[28] and GB/T24908 is 0.7. Figure 21 shows one lamp model did not meet the EU regulation No. 1194 and three models did not meet ENERGY STAR lamp specification V1.0 and GB/T24908.

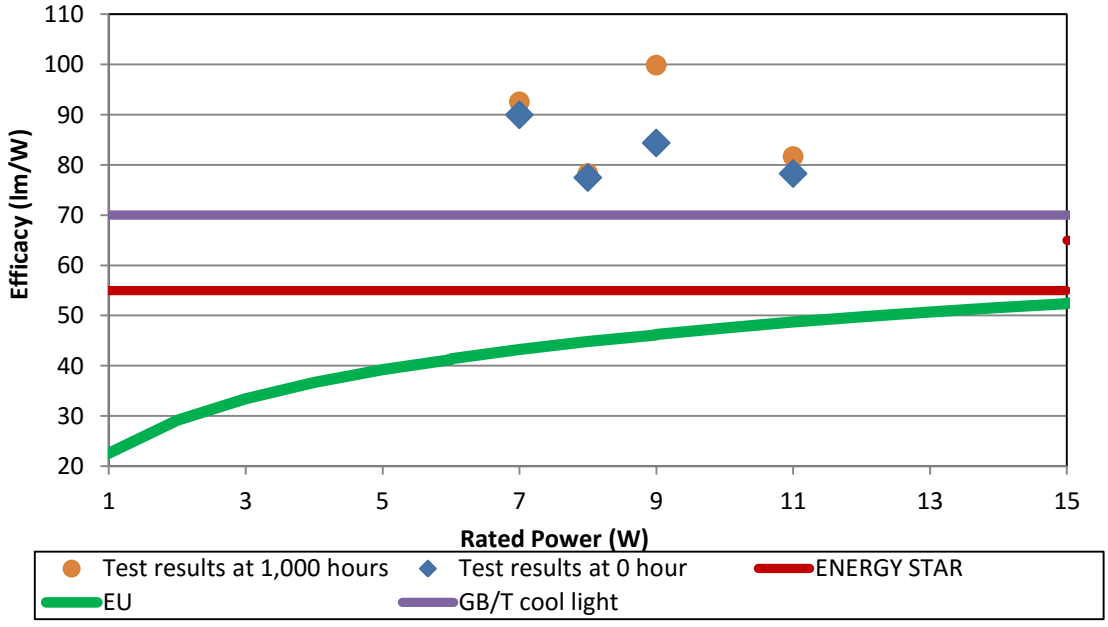
Figure 21 Test results for average (mean, n=10) power factor



7.3.3 Luminous efficacy

Figure 22 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet the three standard requirements. There is also big difference for the 9W lamps results at 0 hour and at 1,000 hours.

Figure 22 Average (mean, n=10) test results of luminous efficacy

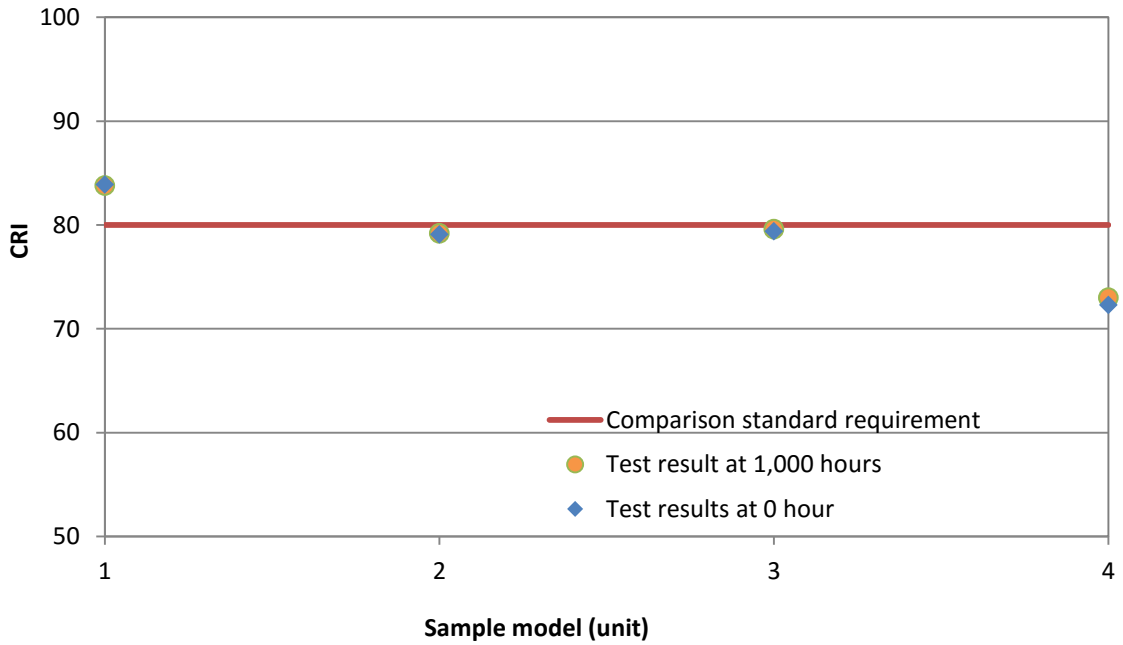


[28] ENERGY STAR lamp specification V1.0 for lamps does not specify requirement for lamps with a power equal to or less than 5 watts.

7.3.4 Colour rendering index

Figure 23 presents the average test results for the colour rendering index (CRI). All of the referred standards require the CRI should be not less than 80. It can be seen in Figure 23 that most of the samples could meet this requirement (above the red line). However, there are also two models with a measured CRI value less than 80 (under the red line).

Figure 23 Test results for average (mean, n=10) CRI



7.3.5 Light distribution

Light distribution was tested at 0 hour. Figure 24 – 27 shows the light distribution pattern for the four models purchased in Indonesia. They all have axial symmetry. The maximum lighting intensity for these four models are 111 cd, 147 cd, 147 cd and 114 cd respectively. The test results shows that Models 1, 2, 3 and 4 all have semispatial light distribution.

Figure 24 Light distribution – Model 1 purchased in Indonesia (polar coordinate system, unit: cd)

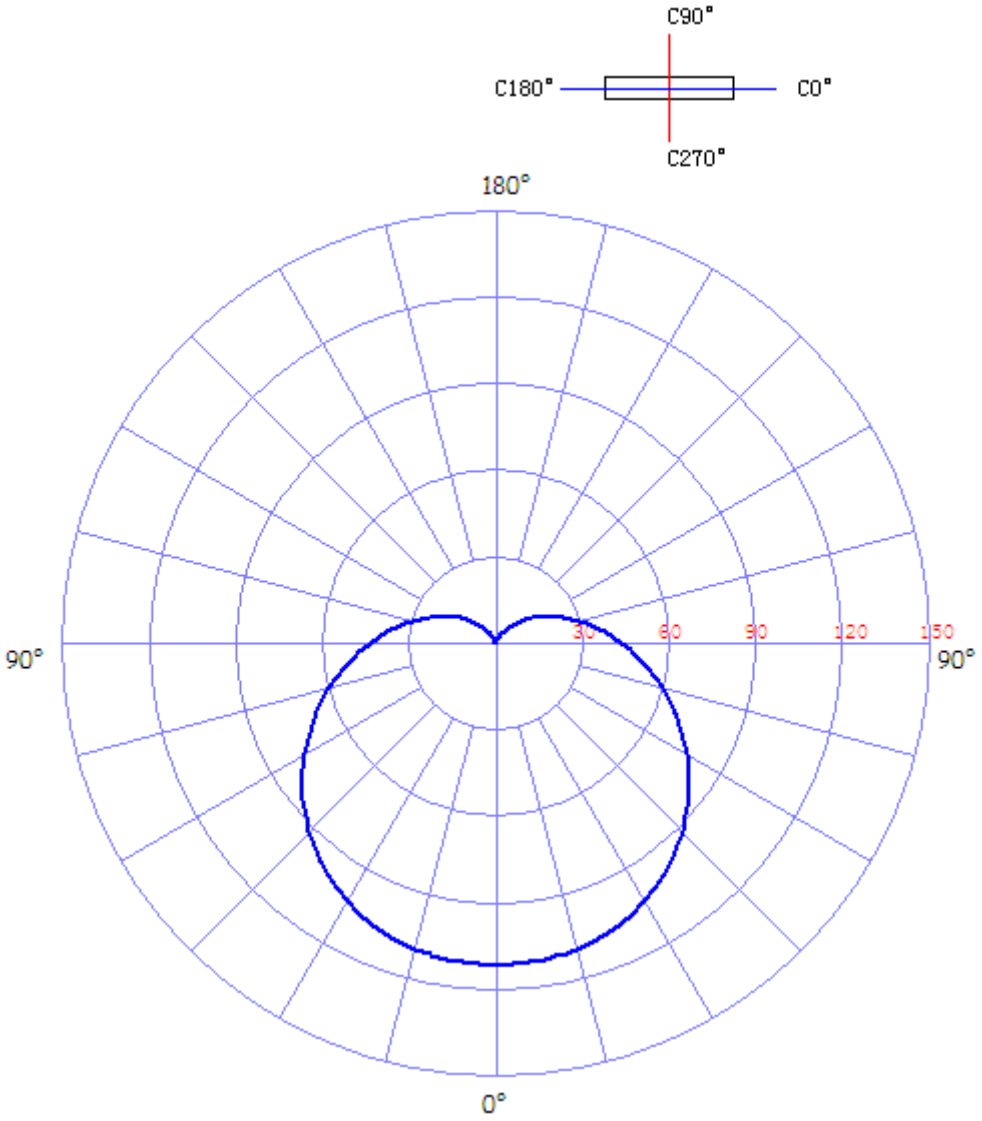


Figure 25 Light distribution – Model 2 purchased in Indonesia (polar coordinate system, unit: cd)

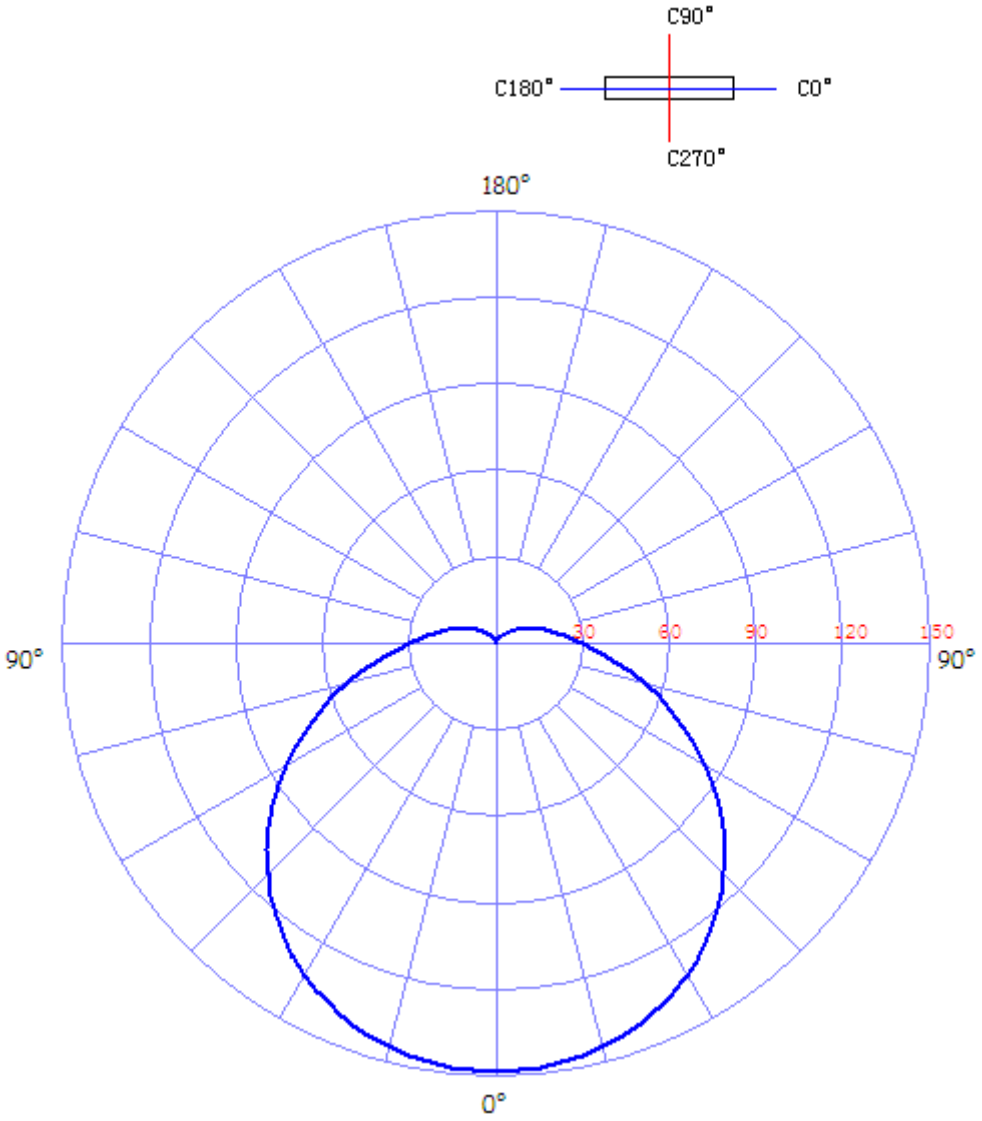


Figure 26 Light distribution – Model 3 purchased in Indonesia (polar coordinate system, unit: cd)

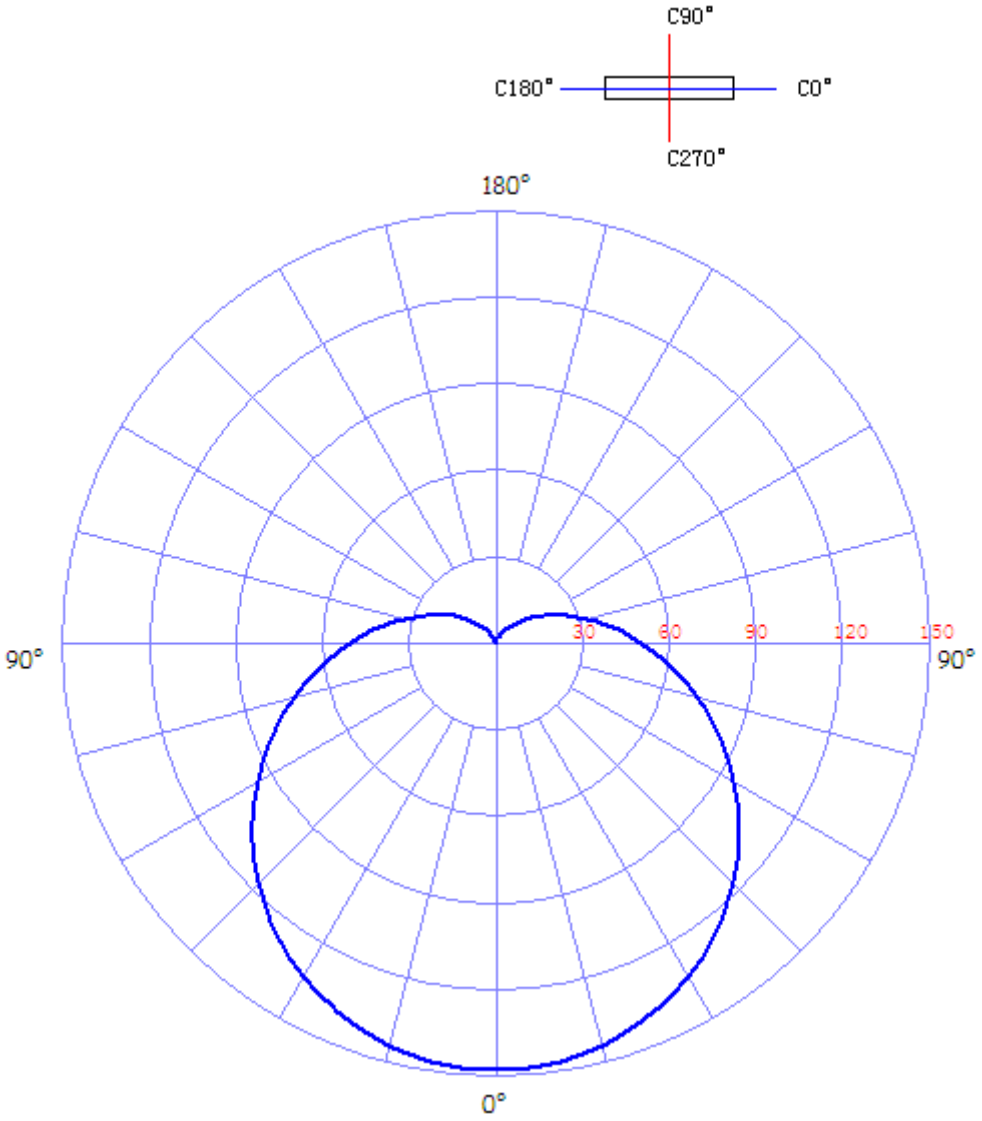
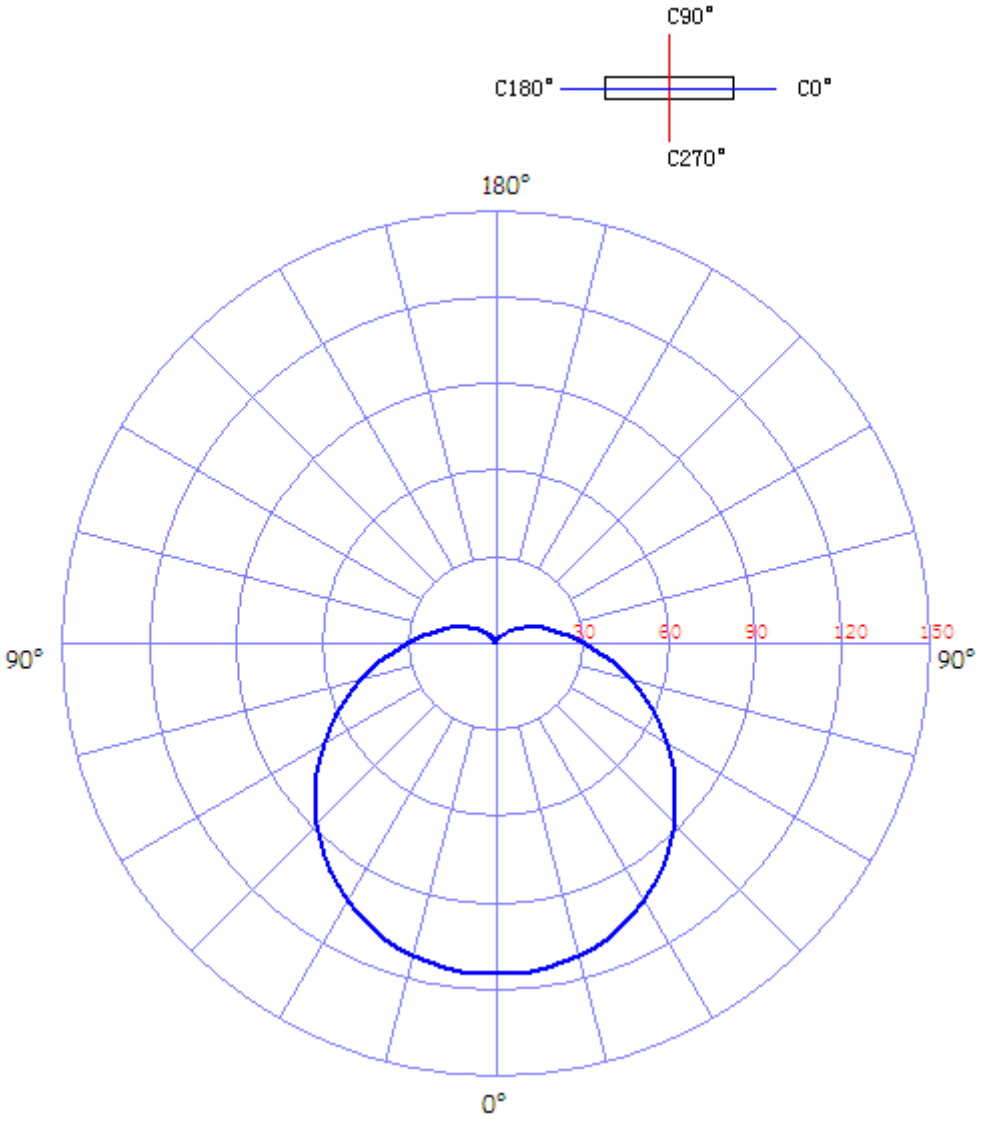


Figure 27 Light distribution – Model 4 purchased in Indonesia (polar coordinate system, unit: cd)



7.3.6 Summary of results for lamps purchased in Indonesia

Of the four models of LED lamps tested from Indonesia, it can been seen that power factor and CRI were the main parameters that shows low compliance compared with all the standards requirements. Table 13 presents all the compliance rate of the testing parameters compared to the comparison standards. Table 14 presents each parameter's compliance for each model with the minimum requirements of all the comparison standards

Table 13 Summary of test results of four models of LED lamps purchased in Indonesia

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="4">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>1 model does not meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>3 models do not meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>3 models do not meet the requirement</td></tr>
<tr><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>3 models meet requirement</td></tr>
<tr><td rowspan="3">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[29]</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>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>All models 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
	IEA 4E SSL Annex	Tier 1: > 50 lumen/watt Tier 2: > 65 lumen/watt	4 models meet requirements 4 models meet requirements
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	2 models do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	2 models do not meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	2 models do not meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	4 models meet requirement 1 model meet requirement

Table 14 Indonesia: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour rendering index
1	✓	✓	✓	✓
2	✓	✓	✓	×
3	✓	✓	✓	✓
4	✓	×	✓	×

7.4 Lao PDR

There are two models of LED lamps sampled from Lao PDR for performance testing (see Table 15). They are both cool light (daylight).

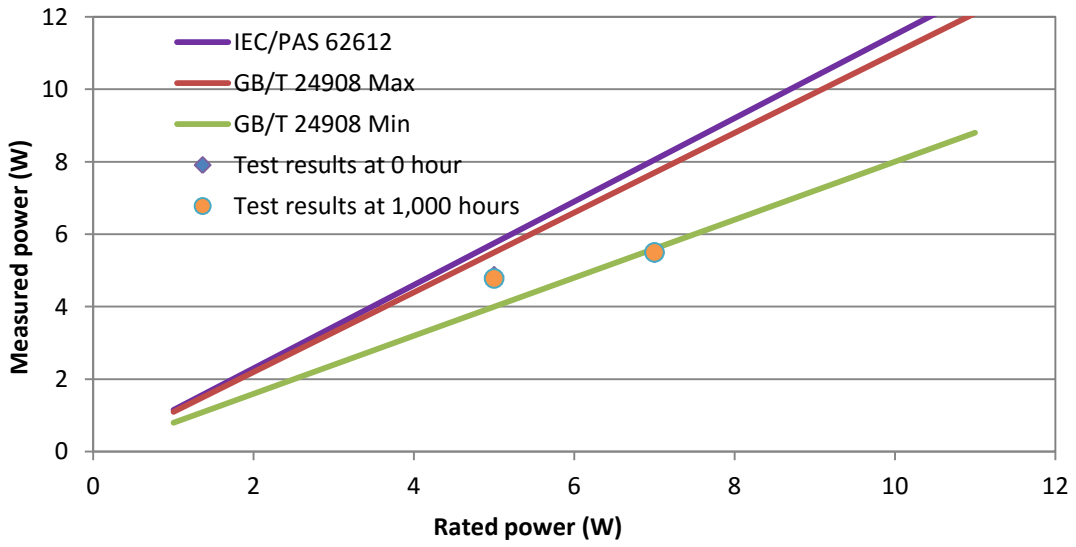
Table 15 LED lamps received from Lao PDR

Model number	Rated wattage (W)	Rated Colour
Model 1	5	Cool light
Model 2	7	Cool light

7.4.1 Lamp power

Among the referred comparison standards, only IEC/PAS 62612 and GB/T 24908 have a requirement on the lamp power. IEC/PAS 626132 requires the power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 28 shows the test results of average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 28 that the test results for two models at 0 hour and at 1,000 hour overlap and one model is located within the requirements of the three limitation lines. The other lamp model was only slightly below the minimum value line based on GB/T 24908.

Figure 28 Test results of average (mean, n=10) lamp power

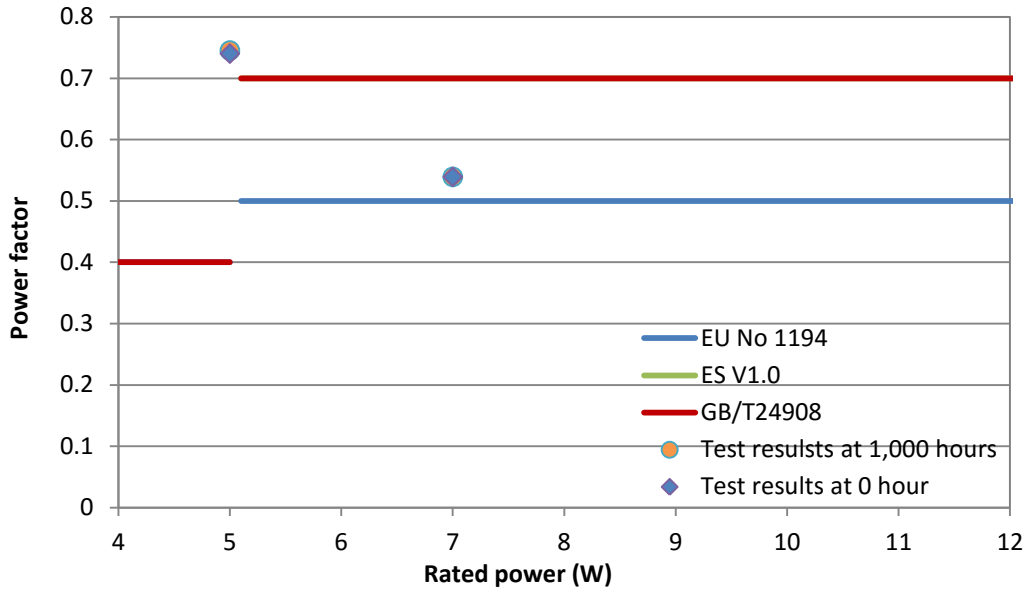


7.4.2 Power factor

Figure 29 shows the test results of the power factor, and compares them with the comparison standards. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194 is greater than 0.5, while the minimum value required by ENERGY STAR lamp

specification V1.0[30] and GB/T24908 is 0.7. Figure 29 shows both models meet the EU regulation No. 1194. One model did not meet the ENERGY STAR lamp specification V1.0 and GB/T24908.

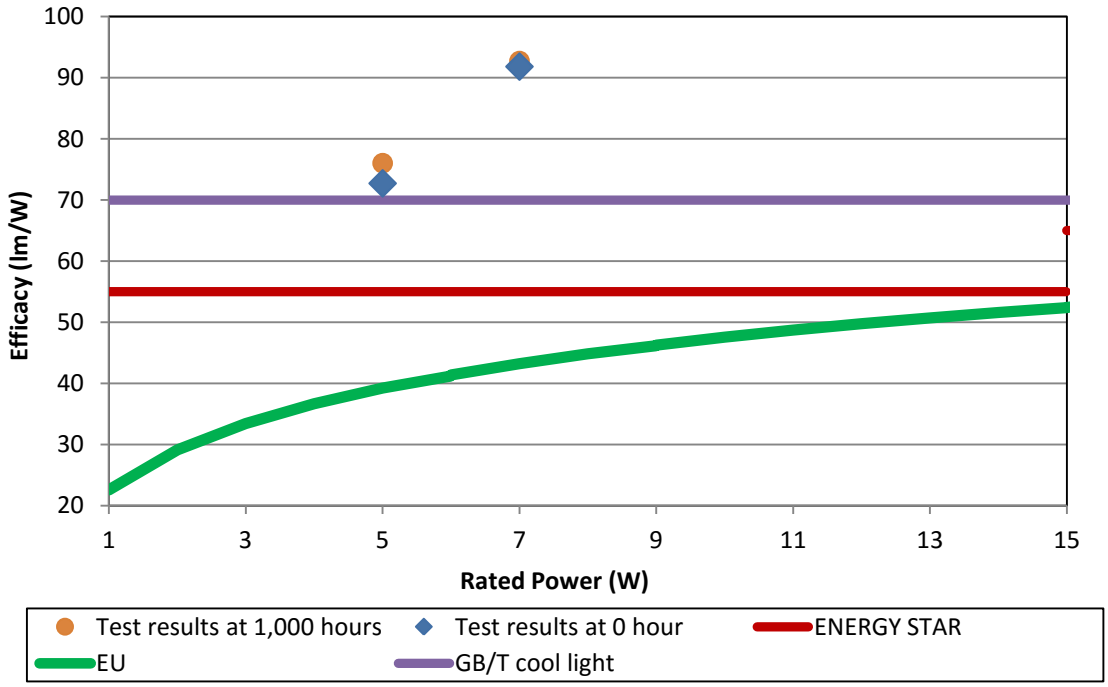
Figure 29 Test results for average (mean, n=10) power factor



7.4.3 Luminous Efficacy

Figure 30 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet EU regulation. All of the models tested at 0 hour meet the three standards.

Figure 30 Test results for average (mean, n=10) luminous efficacy

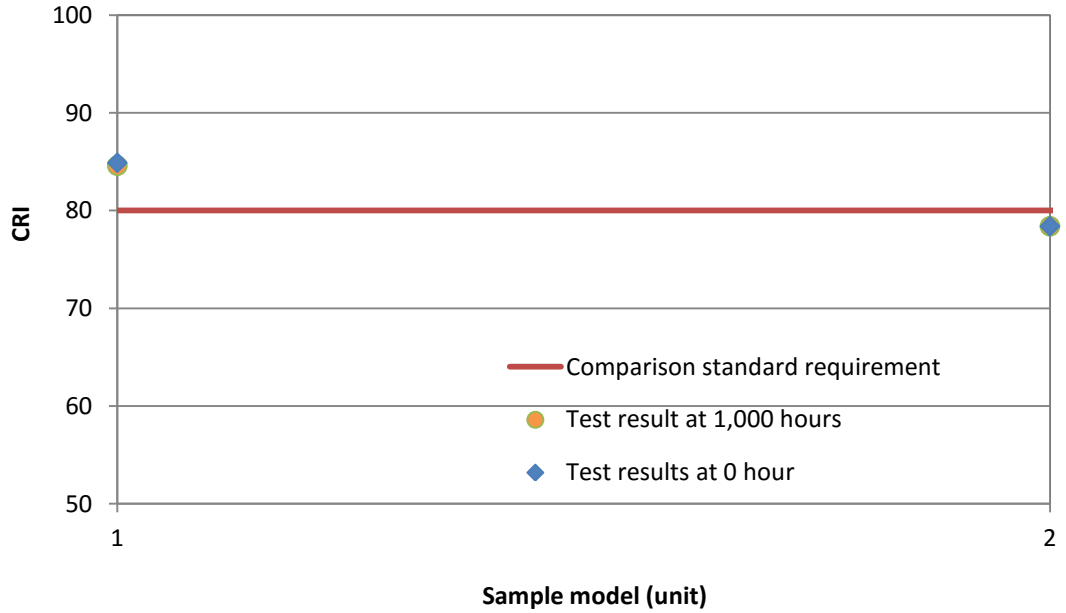


[30] ENERGY STAR lamp specification V1.0 for lamps does not specify requirement for lamps with a power equal to or less than 5 watts.

7.4.4 Colour Rendering Index

Figure 31 presents the average test results for the colour rendering index (CRI). All of the referred standards require the CRI should be not less than 80 (above the red line). It can be seen in Figure 31 that half of the samples could meet this requirement and half did not (which are under the red line). The compliance rate of CRI for the samples purchased in Lao PDR is 50%.

Figure 31 Test results for average (mean, n=10) CRI



7.4.5 Light distribution

Light distribution was tested at 0 hour. Figures 32 – 33 show the light distribution pattern for the two models purchased in Lao PDR. They all have axial symmetry. The maximum lighting intensity for these two models are 46 cd, and 63 cd respectively. The test results shows both Model 1 and 2 have quasi-omnidirectional light distribution.

Figure 32 Light distribution – Model 1 purchased in Lao PDR (polar coordinate system, unit: cd)

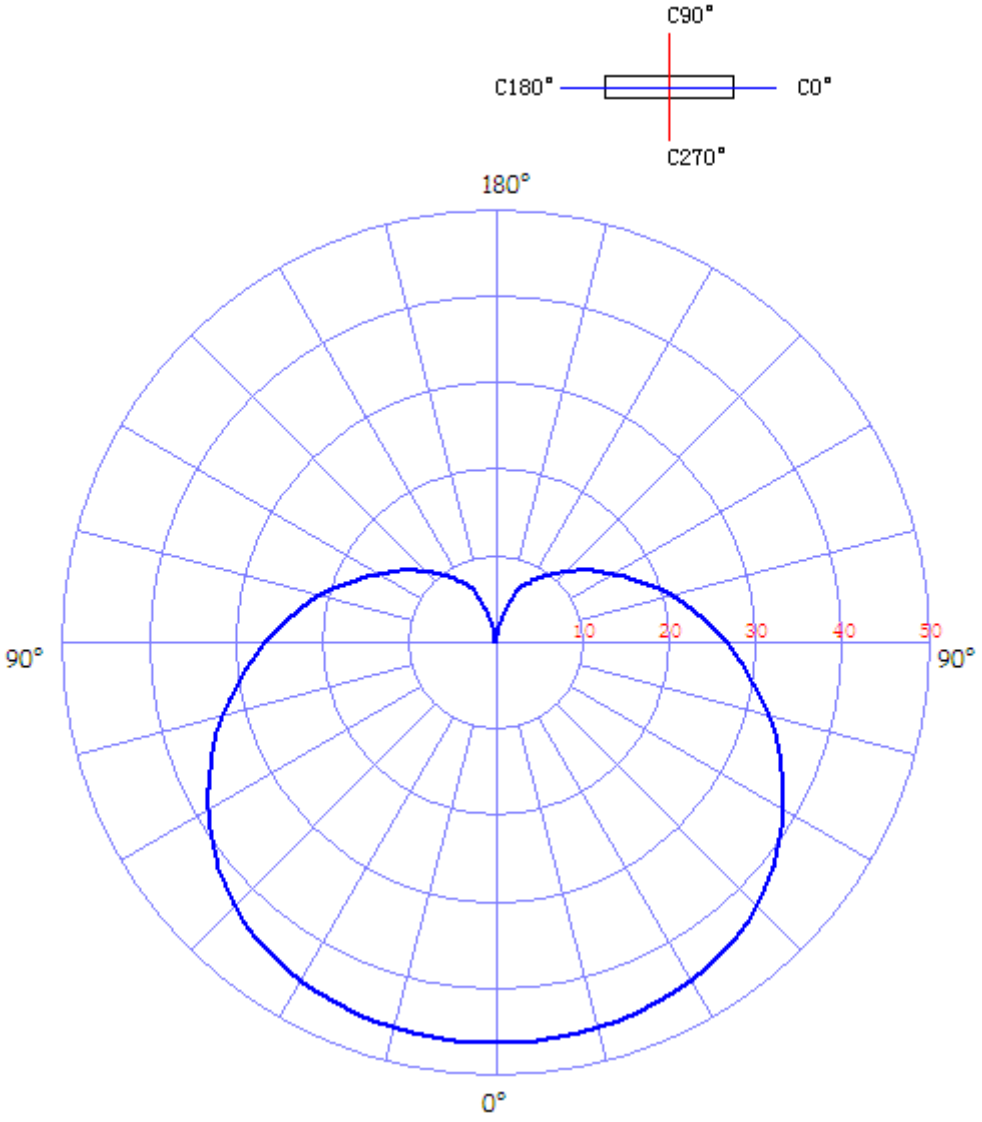
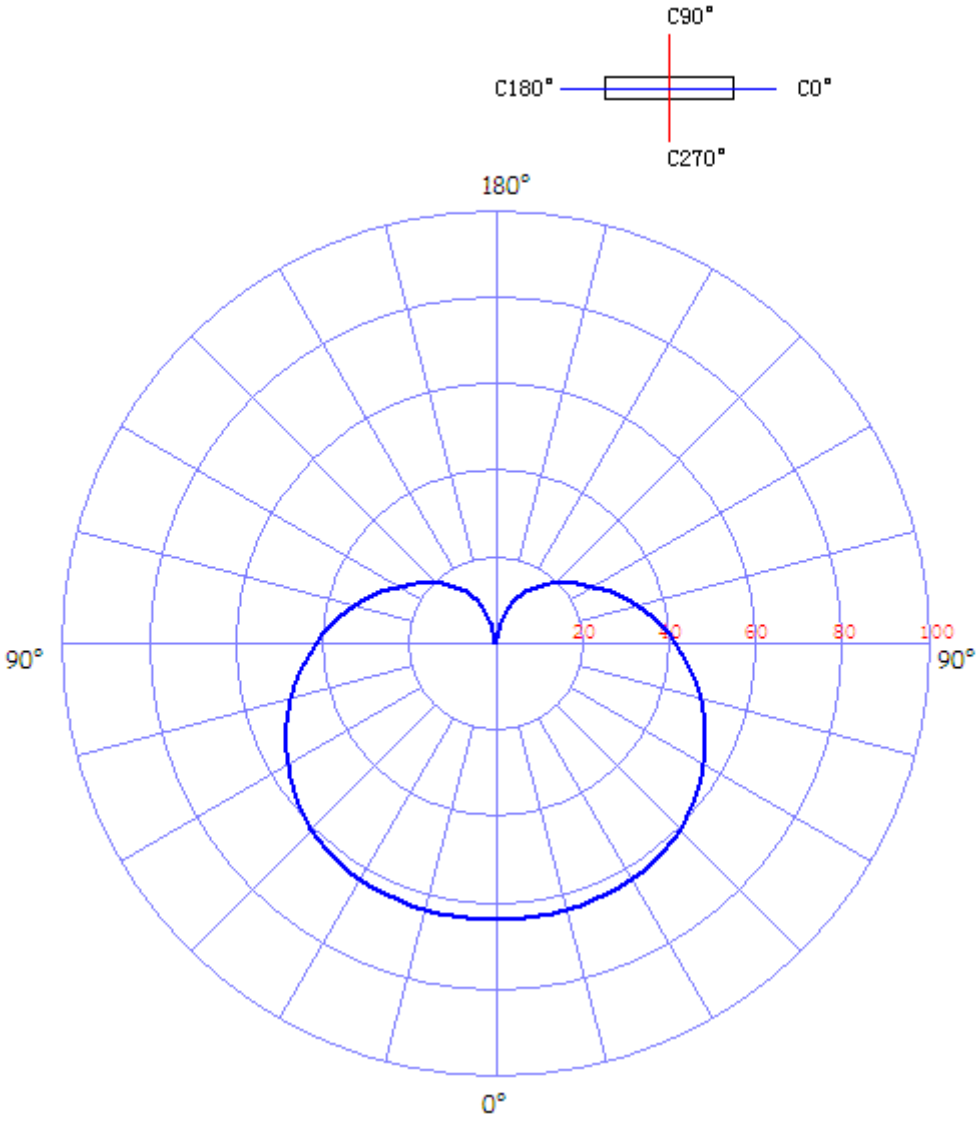


Figure 33 Light distribution – Model 2 purchased in Lao PDR (polar coordinate system, unit: cd)



7.4.6 Summary results for lamps purchased in Lao PDR

Of the two LED models tested from Lao PDR, it can be seen that power factor and CRI were the parameters that one model for each did not meet all the comparison standards. Table 16 presents all the compliance rate of the testing parameters compared to the comparison standards. Table 17 present each parameter's compliance for each model with the minimum requirements of all the comparison standards.

Table 16 Summary of test results of two models of LED lamps purchased in Lao PDR

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="3">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>1 model does not meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>1 model does not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>1 model meets requirement</td></tr>
<tr><td rowspan="3">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[31]</td><td><table><tr><th>Lamp Rated power (watts)</th><th>Minimum Lamp Efficacy (initial lm/W)</th></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><th rowspan="2">Grade</th><th colspan="2">Efficacy(lm/W)</th></tr><tr><th>Colour 65/50/40</th><th>Colour 35/30/27</th></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>All models meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>Tier 1: > 50 lumen/watt
Tier 2: > 65 lumen/watt</td><td>2 models meet requirement
2 models meet requirement</td></tr>
</table>

[31] 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
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	1 model does not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	1 model does not meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	1 model does not meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	2 models meet requirement 1 model meet requirement

Table 17 Lao PDR: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour rendering index
1	✓	✓	✓	✓
2	✓	✓	✓	×

7.5 Philippines

There are 4 LED lamp models sampled from Philippines for performance testing (see Table 18). All of them were cool light (daylight).

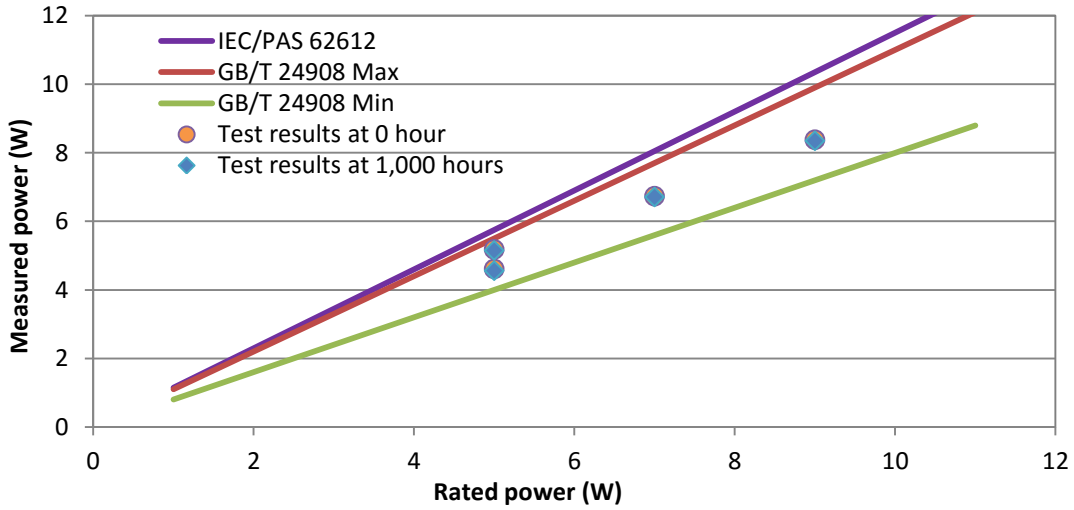
Table 18 LED lamps received from Philippines

Model number	Rated wattage (W)	Rated colour
Model 1	5	Cool light
Model 2	7	Cool light
Model 3	5	Cool light
Model 4	9	Cool light

7.5.1 Lamp power

Among the referred comparison standards, only IEC/PAS 62612 and GB/T 24908 have a requirement on the lamp power. IEC/PAS 62612 requires the power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 34 shows the test results of average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 34 that the test results at 0 hour and at 1,000 hour overlap, and all of them were located within the requirements of the three limitation lines.

Figure 34 Test results of average (mean, n=10) lamp power



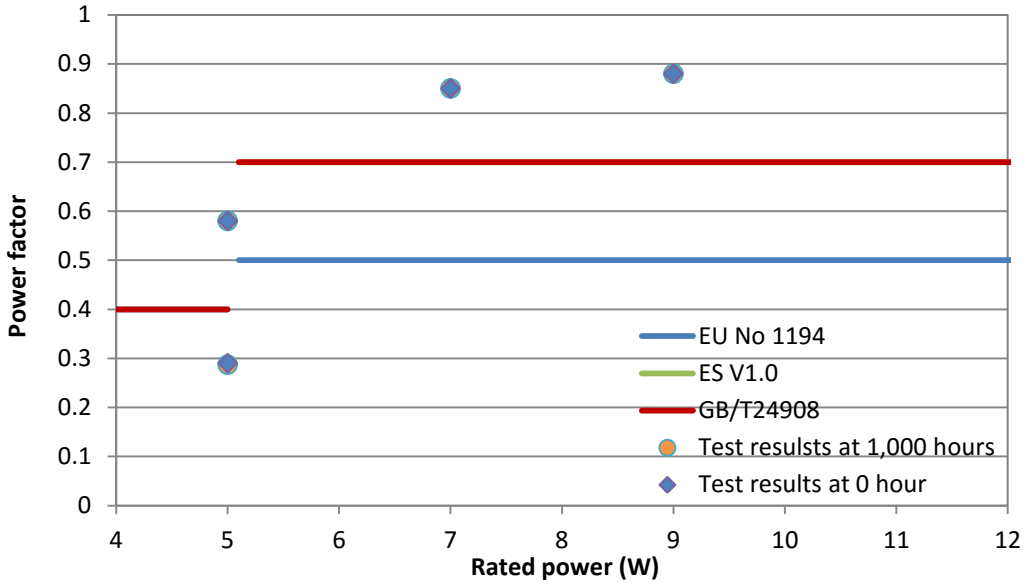
7.5.2 Power factor

Figure 35 shows the test results of the power factor, and compares them with the comparison standards. It can be seen that the test results at 0 hour and at 1,000 hour overlap. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194 is greater than 0.5, while the minimum value required by ENERGY STAR lamp specification V1.0[32] and

[32] ENERGY STAR lamp specification V1.0 for lamps does not specify a requirement for lamps with a power equal to or less than 5 watts.

GB/T24908 is 0.7. From Figure 35, it shows three lamp models meet the EU regulation No. 1194 and two models meet the GB/T24908.

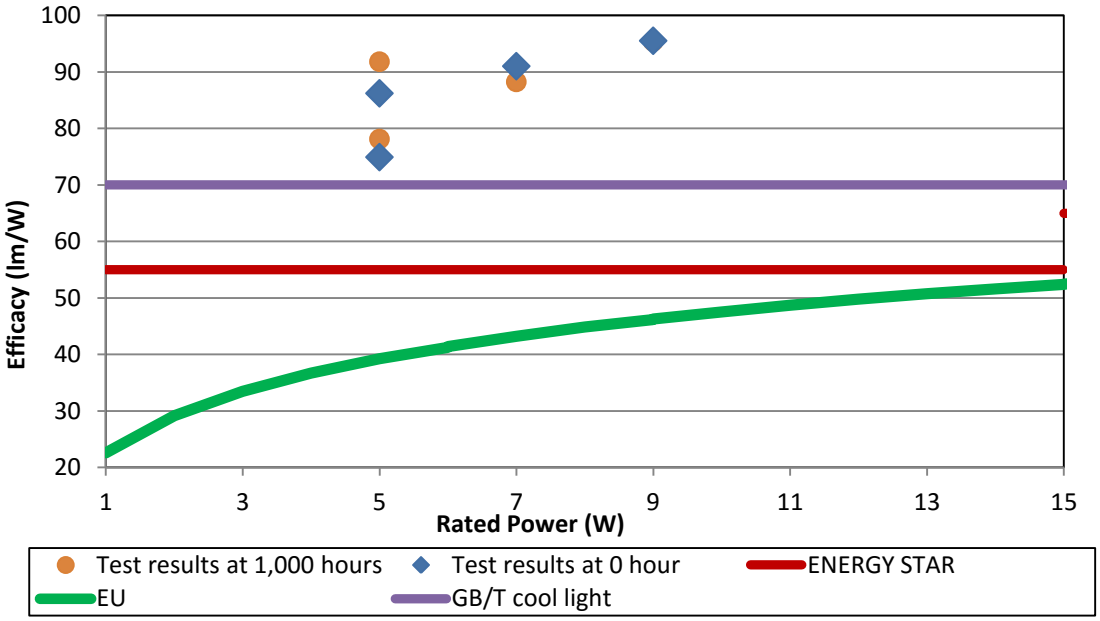
Figure 35 Test results for average (mean, n=10) power factor



7.5.3 Luminous efficacy

Figure 36 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet these three standards. It also shows for the two 5W models, the test results at 1,000 hours was a bit higher than the test results at 0 hour, while for 7W model, it was opposite. For the 9W model, both of the test results at 0 hour and at 1,000 hours overlap.

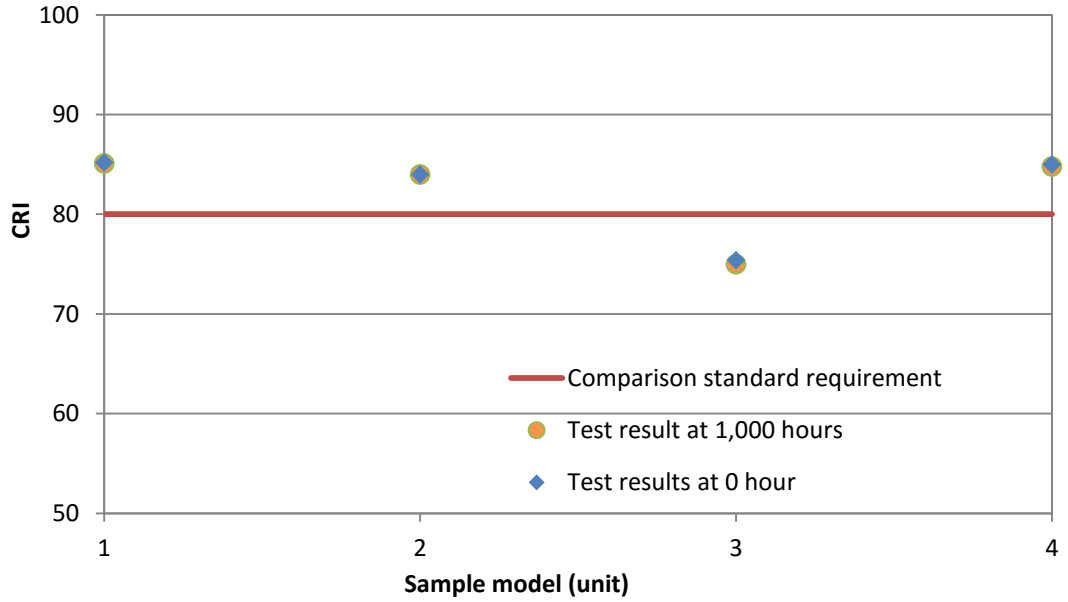
Figure 36 Test results for average (mean, n=10) luminous efficacy



7.5.4 Colour rendering index

Figure 37 presents the average test results of the colour rendering index (CRI). Both of the test results at 0 hour and at 1,000 hours almost overlap. All of the referred standards require the CRI should be not less than 80 (above the red line). It can be seen in Figure 37 that one model did not meet this requirement, which is seen by the test result under the red line.

Figure 37 Test results for average (mean, n=10) CRI



7.5.5 Light distribution

Light distribution was tested at 0 hour. Figure 38 – 41 shows the light distribution pattern for the four models purchased in Philippines. They all have axial symmetry. The maximum lighting intensity for these four models are 63 cd, 118 cd, 78 cd and 159 cd respectively. The test results shows Models 1, 2, 3 and 4 are all semispatial light distribution.

Figure 38 Light distribution – Model 1 purchased in Philippines (polar coordinate system, unit: cd)

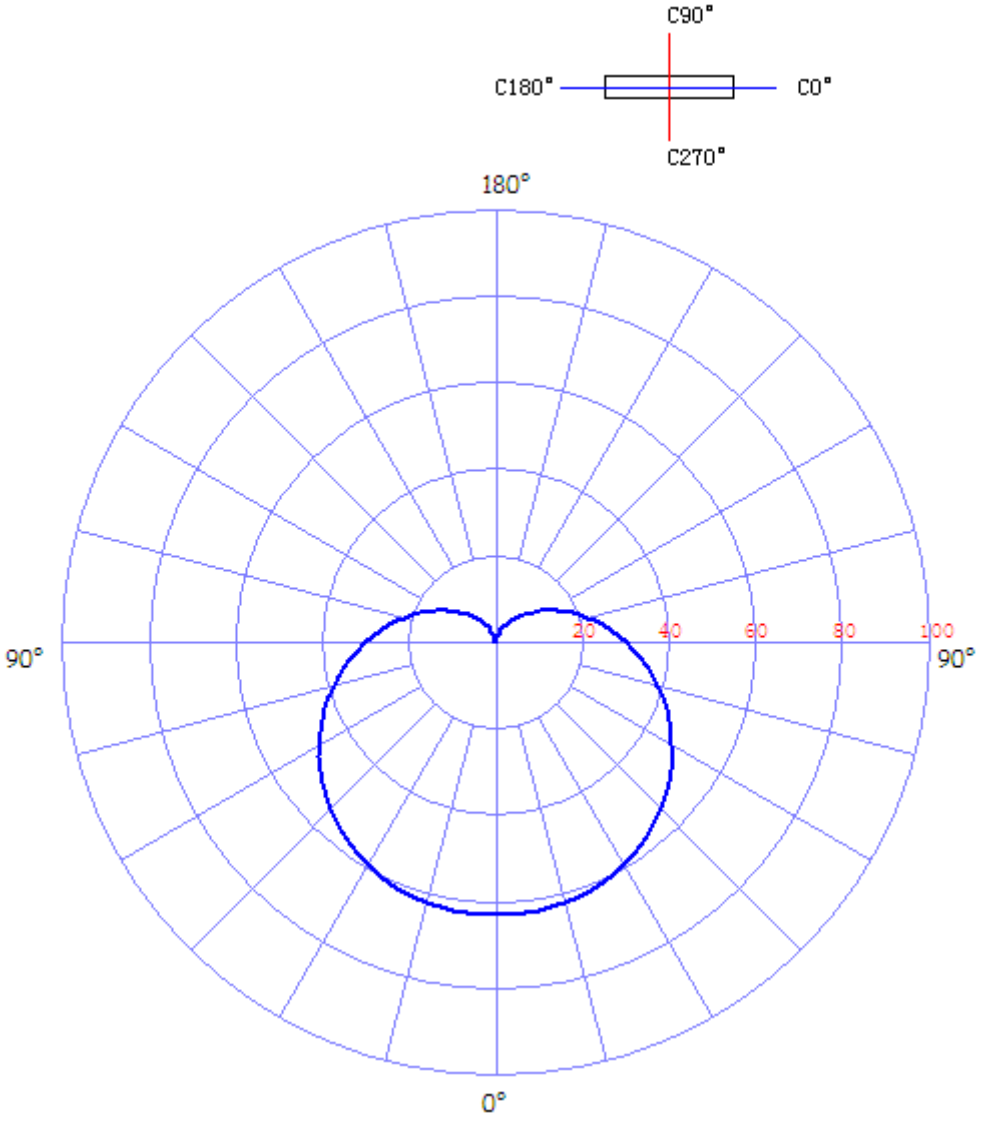


Figure 39 Light distribution – Model 2 purchased in Philippines (polar coordinate system, unit: cd)

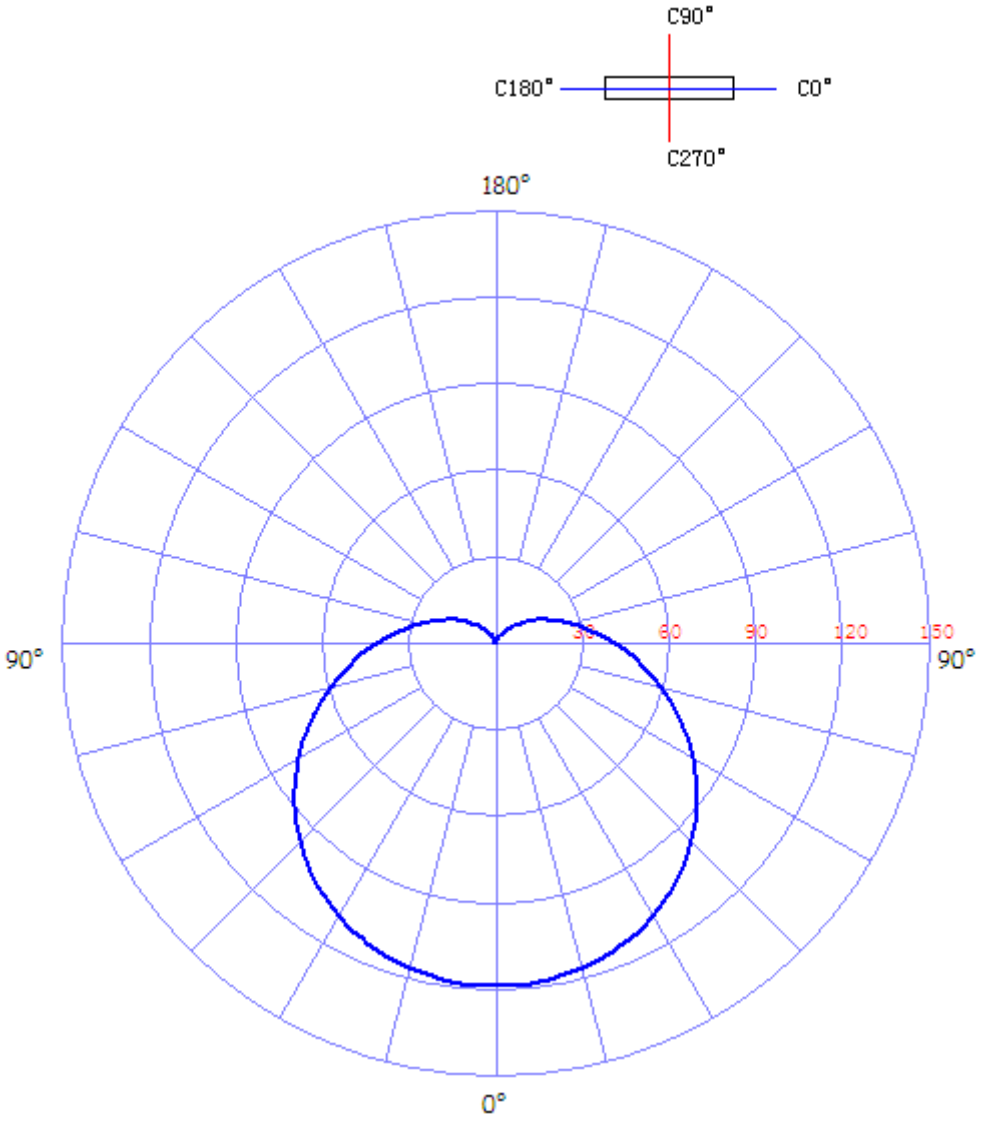


Figure 40 Light distribution – Model 3 purchased in Philippines (polar coordinate system, unit: cd)

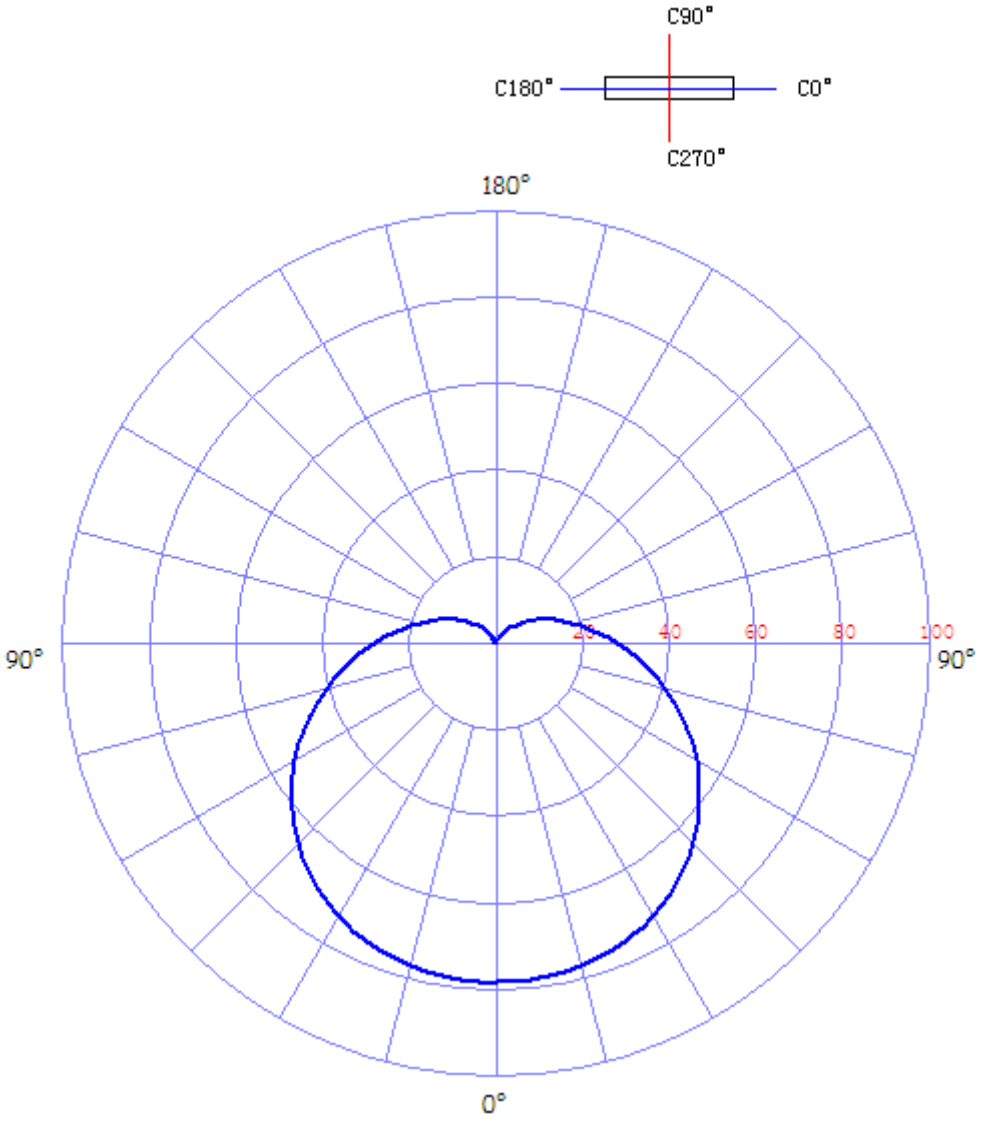
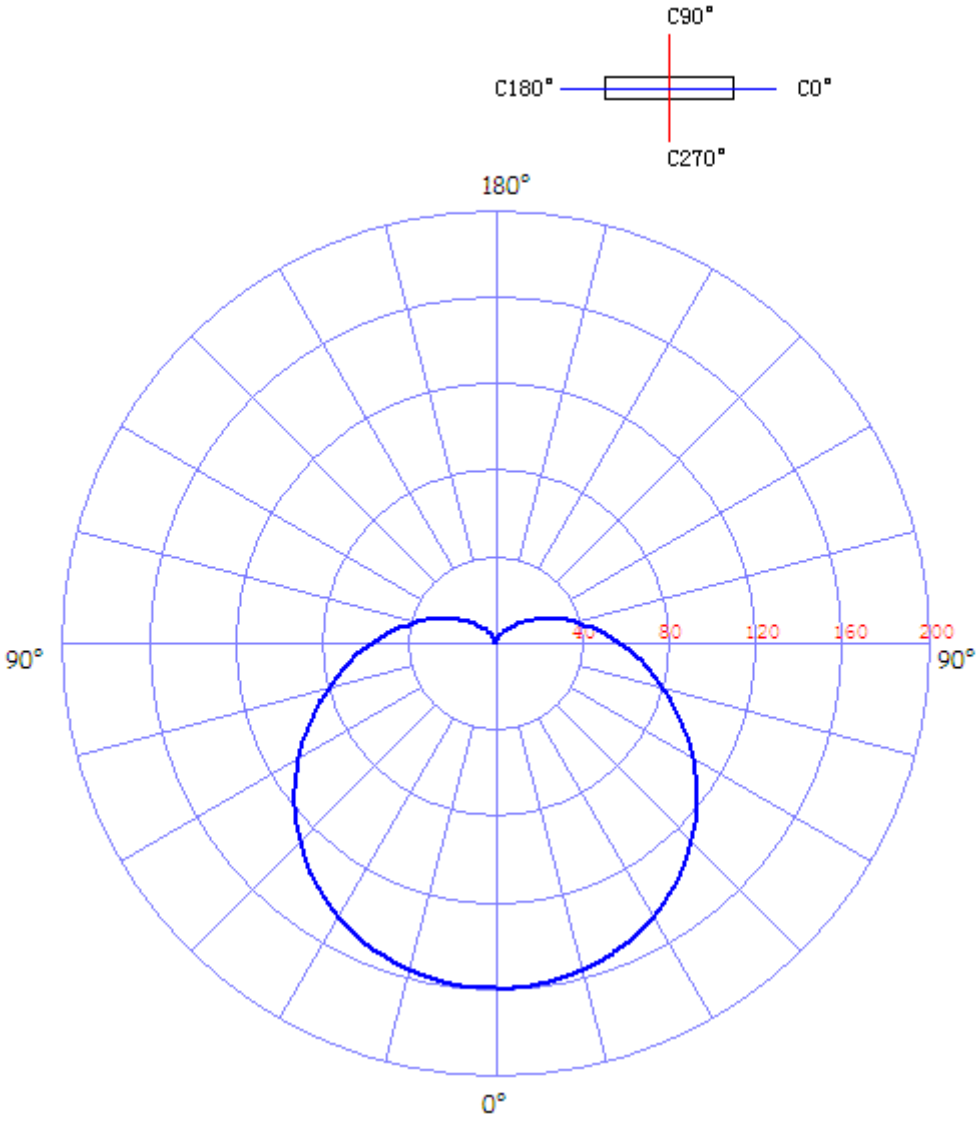


Figure 41 Light distribution – Model 4 purchased in Philippines (polar coordinate system, unit: cd)



7.5.6 Summary of results for lamps purchased in Philippines

Of the four models of LED lamps tested from Philippines, it has been seen that power factor and CRI were the main parameters did not meet all of the comparison standards. Table 19 presents all the compliance rate of the testing parameters compared to the comparison standards. Table 20 presents each parameter's compliance for each model with the minimum requirements of all of the comparison standards.

Table 19 Summary of test results of four models of LED lamps purchased in Philippines

<table>
<tr><th>Testing parameters</th><th>Comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>All models meet the requirement</td></tr>
<tr><td rowspan="3">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>1 model does not meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>2 models do not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>3 models meet requirements</td></tr>
<tr><td rowspan="3">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[33]</td><td><table><tr><th>Lamp Rated power (watts)</th><th>Minimum Lamp Efficacy (initial lm/W)</th></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>All models 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
	IEA 4E SSL Annex	Tier 1: > 50 lumen/watt Tier 2: > 65 lumen/watt	4 models meet requirement 4 models meet requirement
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	1 model does not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	1 model does not meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	1 model does not meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	4 models meet requirement 3 models meet requirement

Table 20 Philippines: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour Rendering Index
1	✓	✓	✓	✓
2	✓	✓	✓	✓
3	✓	×	✓	×
4	✓	✓	✓	✓

7.6 Thailand

There were four LED lamp models sampled from Thailand for performance testing (see Table 21). In these samples, 75% were warm light, and 25% were cool light (daylight).

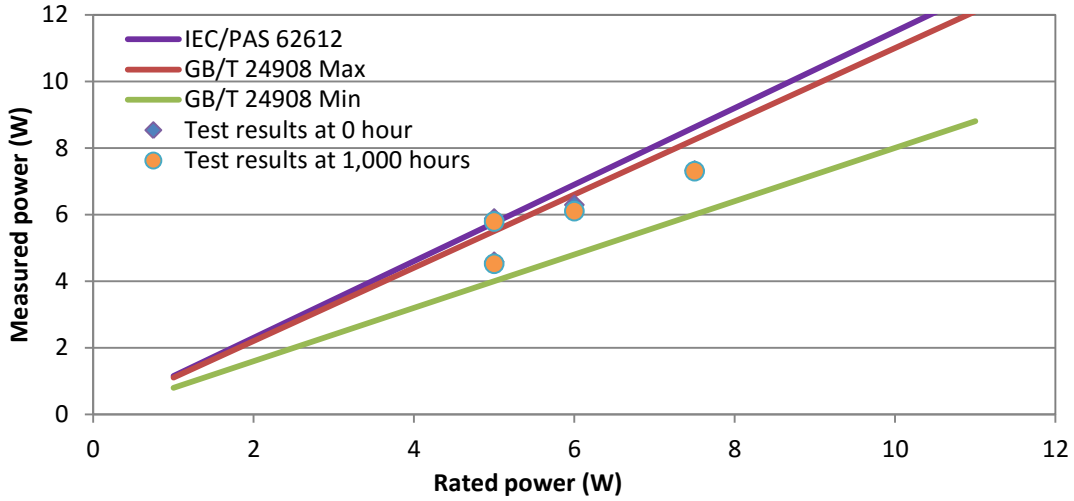
Table 21 LED lamps received from Thailand

Model number	Rated wattage (W)	Rated colour
Model 1	7.5	Warm light
Model 2	6	Cool light
Model 3	5	Warm light
Model 4	5	Warm light

7.6.1 Lamp power

Among the referred comparison standards, only IEC/PAS 62612 and GB/T 24908 have a requirement on the lamp power. IEC/PAS 626132 requires the power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 42 shows the test results of average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 42 that the test results at 0 hour and at 1,000 hour almost overlap, and three of them were located within the requirements of the three limitation lines. There was one model of 5W beyond the maximum value line based on GB/T 24908.

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



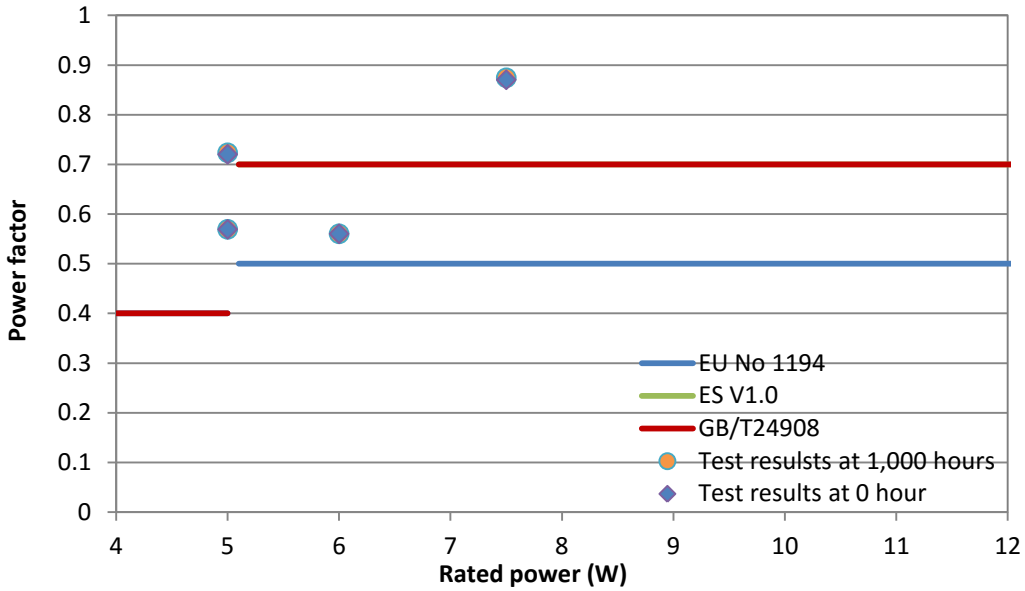
7.6.2 Power factor

Figure 43 shows the test results of the power factor, and compares them with the comparison standards. The average lamp power factor at 0 hour (blue points) and 1,000 hours (orange points) almost overlap. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194 is greater than 0.5, while the minimum value required by ENERGY STAR lamp specification V1.0[34] and GB/T24908 is 0.7. Figure 43 shows all of the lamps meet the EU regulation

[34] ENERGY STAR lamp specification V1.0 for lamps does not specify a requirement for lamps with a power equal to or less than 5 watts.

No. 1194. There was one model of 6W which did not meet ENERGY STAR lamp specification V1.0 and GB/T24908.

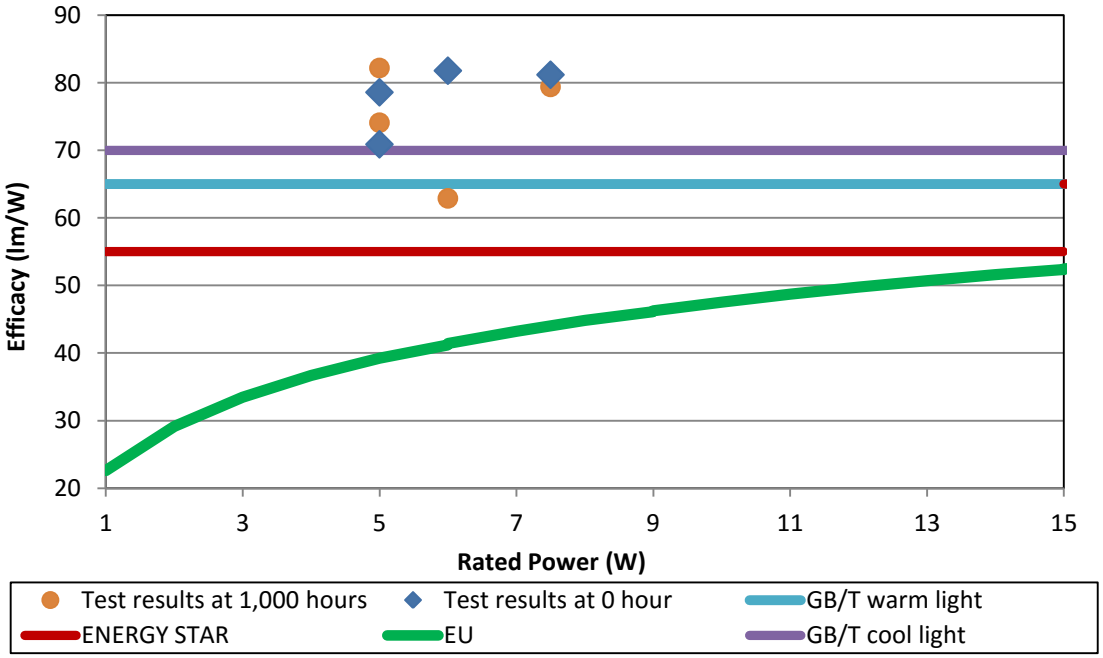
Figure 43 Test results for average (mean, n=10) power factor



7.6.3 Luminous Efficacy

Figure 44 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet EU regulation and ENERGY STAR lamps specification V1.0. Of the 4 models purchased in Thailand, the 6W lamps were cool light and the other three models were warm light. From Figure 44, the warm light lamps meet the GB/T 24908, while for the cool light lamps, only the test results at 0 hour meet GB/T 24908. There was a large difference between the two average test results for this model.

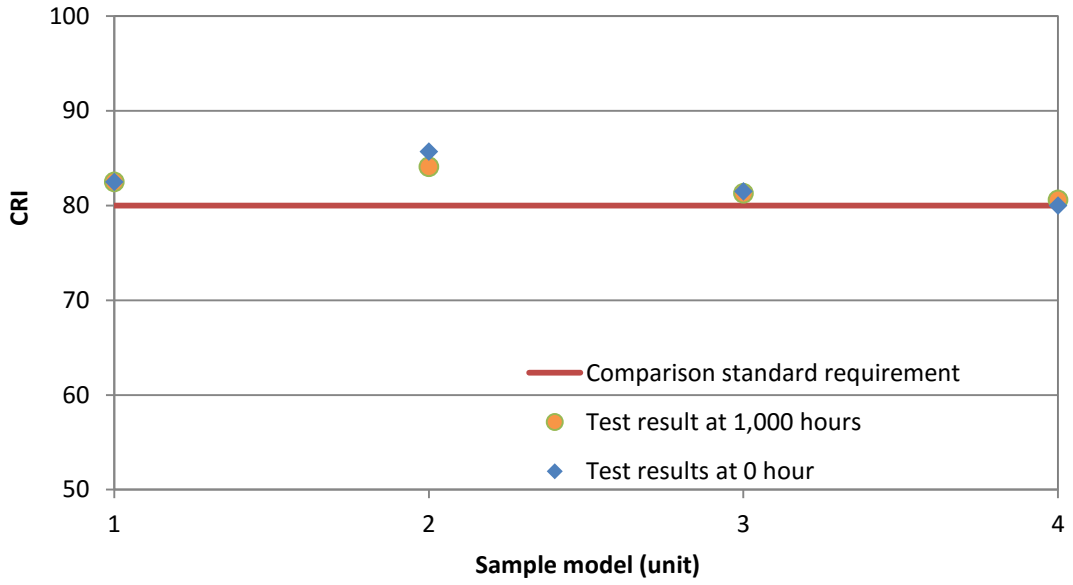
Figure 44 Test results for average (mean, n=10) luminous efficacy



7.6.4 Colour rendering index

Figure 45 presents the average test results of the colour rendering index (CRI). All of the referred standards require the CRI should be not less than 80. It can be seen in Figure 45 that all of the samples meet this requirement, with a measured CRI value on or above the red line and the compliance rate of CRI for the samples purchased in Thailand is 100%.

Figure 45 Test results for average (mean, n=10) CRI



7.6.5 Light distribution

Light distribution was tested at 0 hour. Figure 46 – 49 shows the light distribution pattern for the four models purchased in Thailand. They all have axial symmetry. The maximum lighting intensity for these four models are 118 cd, 107 cd, 98 cd and 53 cd respectively. The test results shows Modesl 1, 2 and 3 have semispatial light distribution; but Model 4 has quasi-ominidirectional light distribution.

Figure 46 Light distribution – Model 1 purchased in Thailand (polar coordinate system, unit: cd)

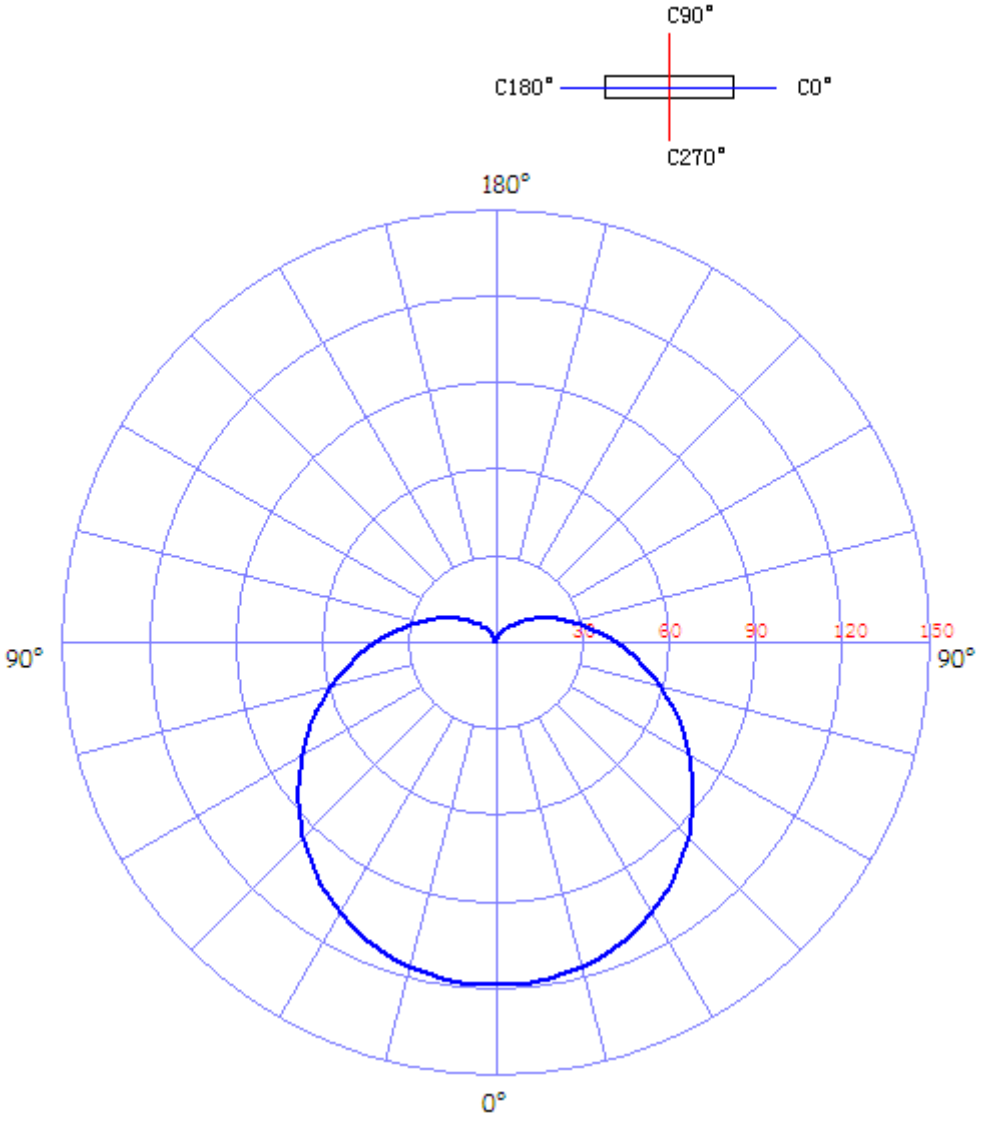


Figure 47 Light distribution – Model 2 purchased in Thailand (polar coordinate system, unit: cd)

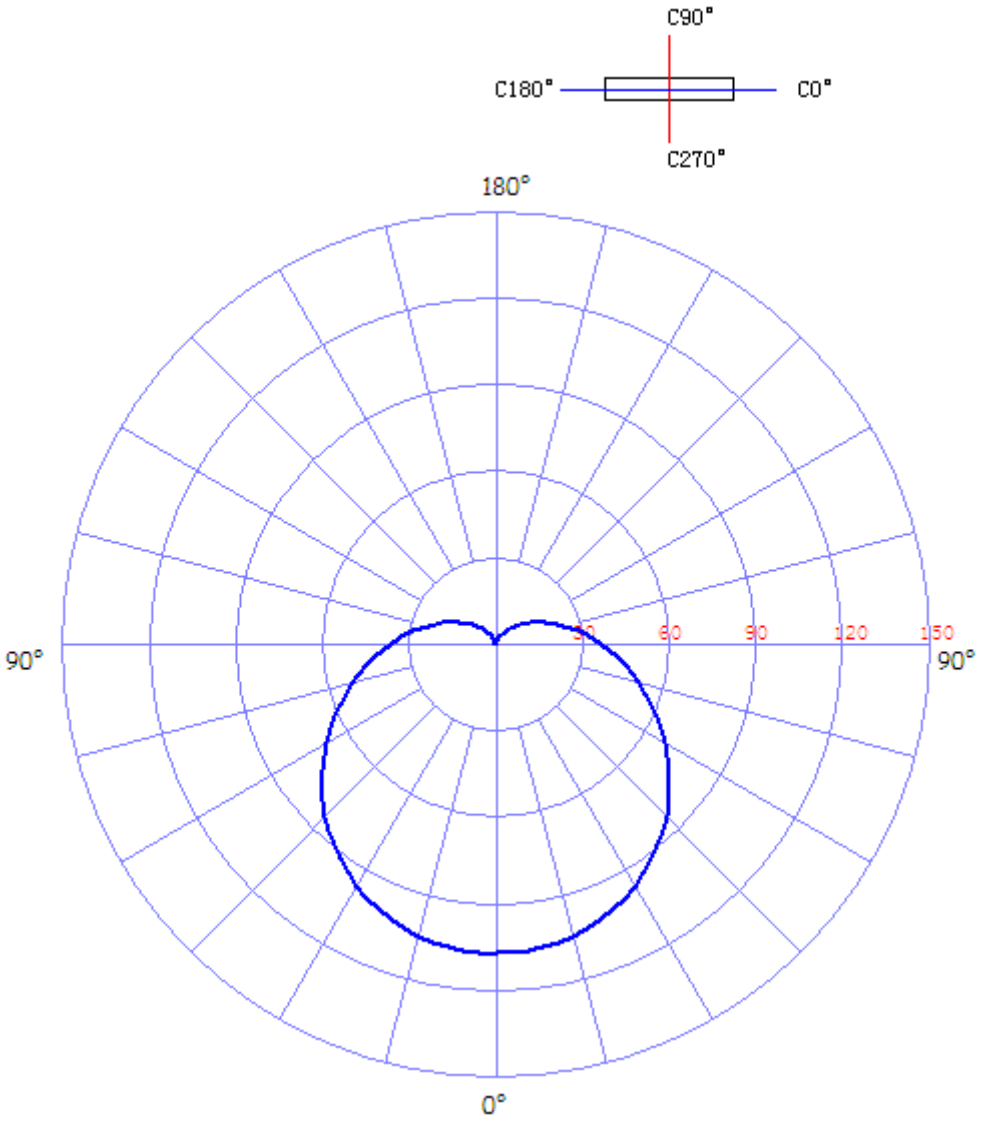


Figure 48 Light distribution – Model 3 purchased in Thailand (polar coordinate system, unit: cd)

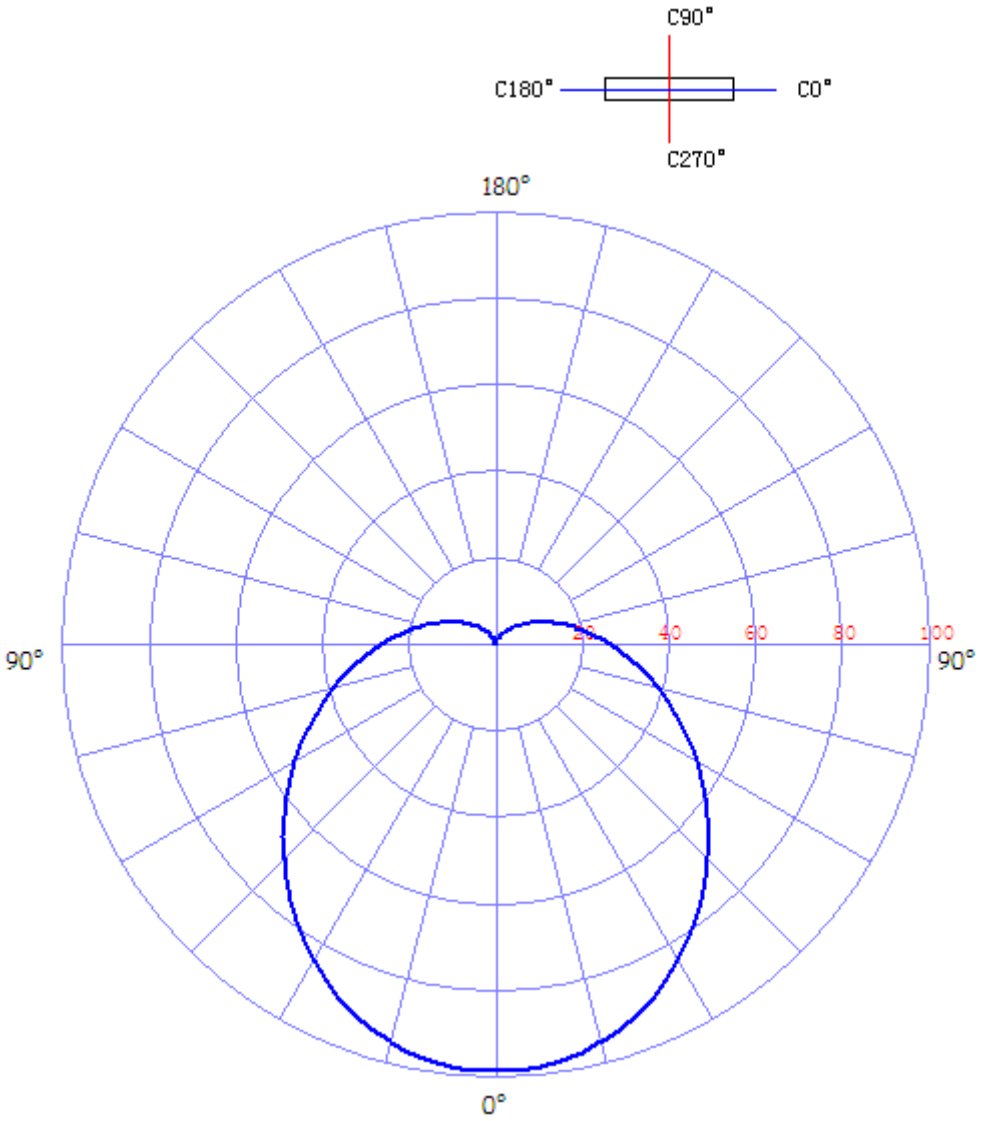
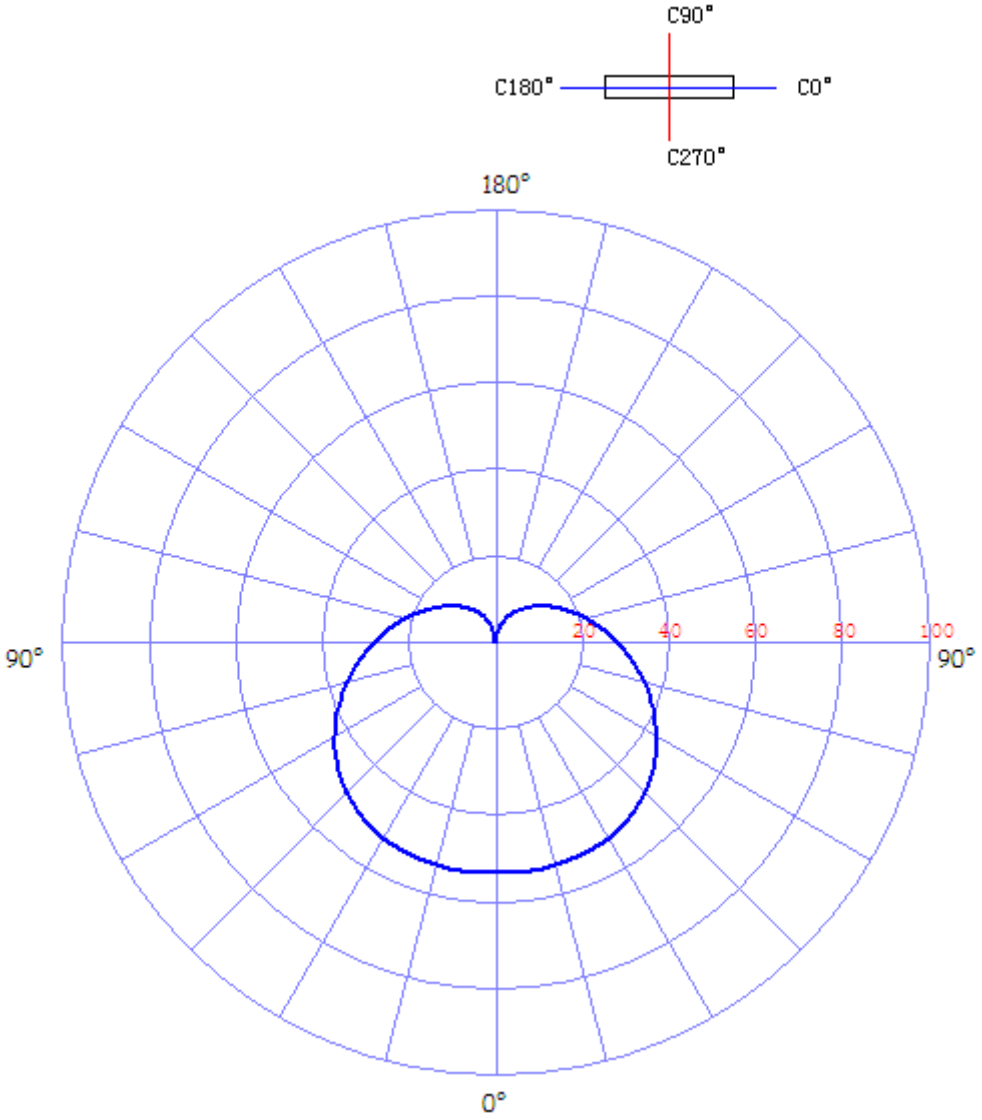


Figure 49 Light distribution – Model 4 purchased in Thailand (polar coordinate system, unit: cd)



7.6.6 Summary of results for lamps purchased in Thailand

Of the four models of LED lamps tested from Thailand, it can be seen that the non compliance appears on power, power factor and luminous efficacy. Table 22 presents all the compliance rates of all the testing parameters compared to the standards. Table 23 presents each parameters compliance for each model with the minimum requirements of the comparison standards. Table 22 presents each parameter's compliance for each model with the minimum requirements of all of the comparison standards.

Table 22 Summary of test results of four models of LED lamps purchased in Thailand

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="3">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>1 model does not meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>1 model does not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>4 models meet requirement</td></tr>
<tr><td rowspan="3">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[35]</td><td><table><tr><th>Lamp Rated power (watts)</th><th>Minimum Lamp Efficacy (initial lm/W)</th></tr><tr><td><15</td><td>55</td></tr><tr><td>≥15</td><td>65</td></tr></table></td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>1 model does not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>Tier 1: > 50 lumen/watt
Tier 2: > 65 lumen/watt</td><td>4 models meet requirement
3 models meet requirement</td></tr>
</table>

[35] 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
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	All models meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	All models meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	All models meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	4 models meet requirement 4 models meet requirement

Table 23 Thailand: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour Rendering index
1	✓	✓	✓	✓
2	✓	✓	✓	✓
3	✓	✓	✓	✓
4	✓	✓	✓	✓

7.7 Vietnam

There are three models of LED lamps sampled from Vietnam for performance testing (see Table 24). In those samples, one model is cool light (daylight), and two models are warm light.

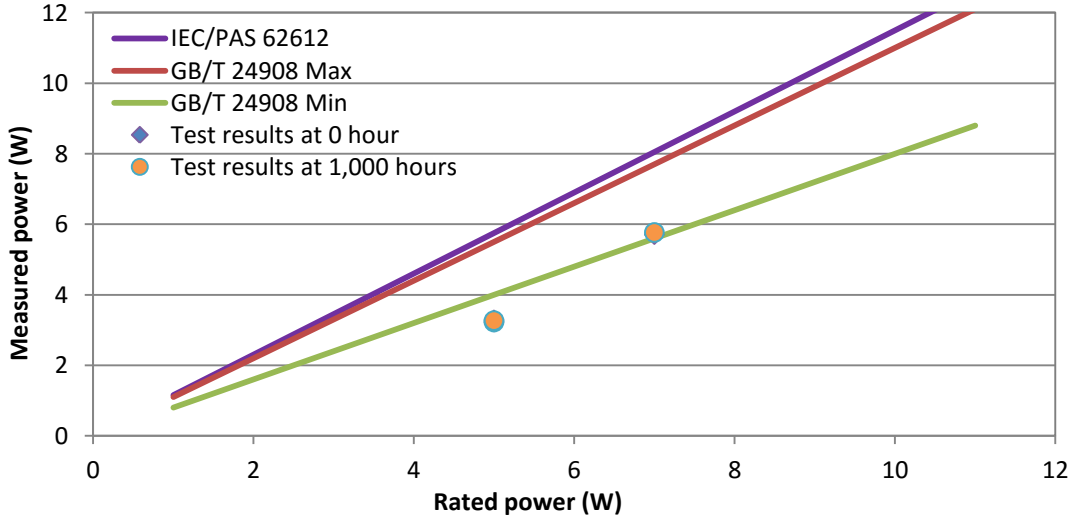
Table 24 LED lamps received from Vietnam

Model number	Rated wattage (W)	Rated colour
Model 1	7	Warm light
Model 2	5	Cool light
Model 3	5	Warm light

7.7.1 Lamp power

Among the referred comparison standards, only IEC/PAS 62612 and GB/T 24908 have a requirement on the lamp power. IEC/PAS 626132 requires the power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%, while GB/T 24908 requires the measured power should be within the 80%-110% of the rated power. Figure 50 shows the test results of average lamp power both at 0 hour (blue points) and 1,000 hours (orange points). It can be seen from Figure 50 that the test results at 0 hour and at 1,000 hour overlap. The 7W lamp is located within the range of three limitation lines. Both of the 5W lamps were below the minimum value line based on GB/T 24908.

Figure 50 Test results for average (mean, n=10) lamp power



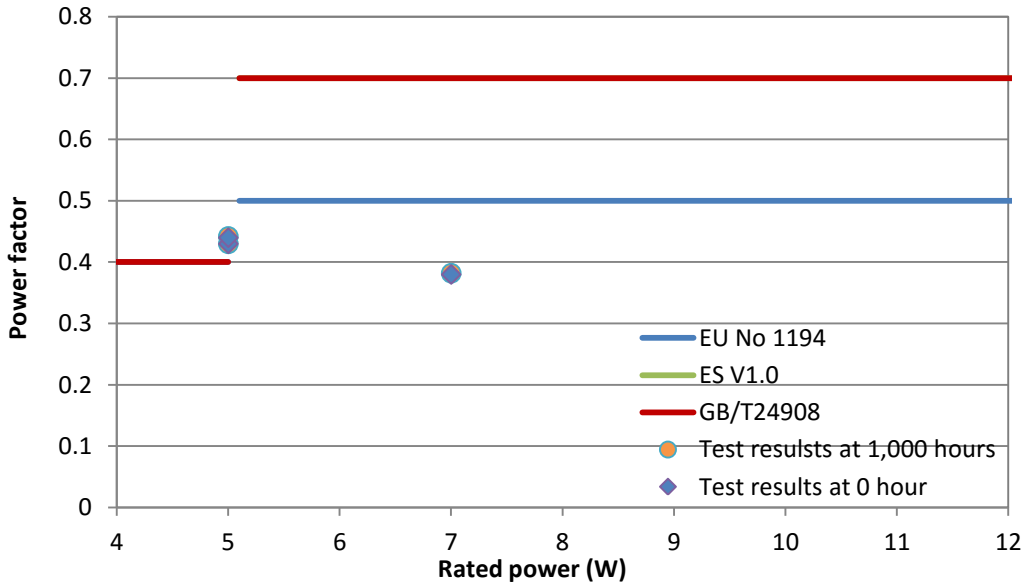
7.7.2 Power factor

Figure 51 shows the test results of the power factor, and compares them with the comparison standards. It can be seen from Figure 51 that the test results at 0 hour and at 1,000 hour almost overlap. For lamps with a power equal to or less than 5 watts, the PF value required by EU regulation No.1194 and GB/T24908 is greater than 0.4. For the other lamps, the PF value required by EU regulation No. 1194 is greater than 0.5, while the minimum value required by ENERGY STAR lamp specification V1.0[36] and GB/T24908 is 0.7. Figure 51 shows the two 5W

[36] ENERGY STAR lamp specification V1.0 for lamps does not specify requirement for lamps with a power equal to or less than 5 watts.

lamps models meet the EU regulation No. 1194 and GB/T24908. The 7W model is under the blue line which means it did not meet any of the three comparison standards.

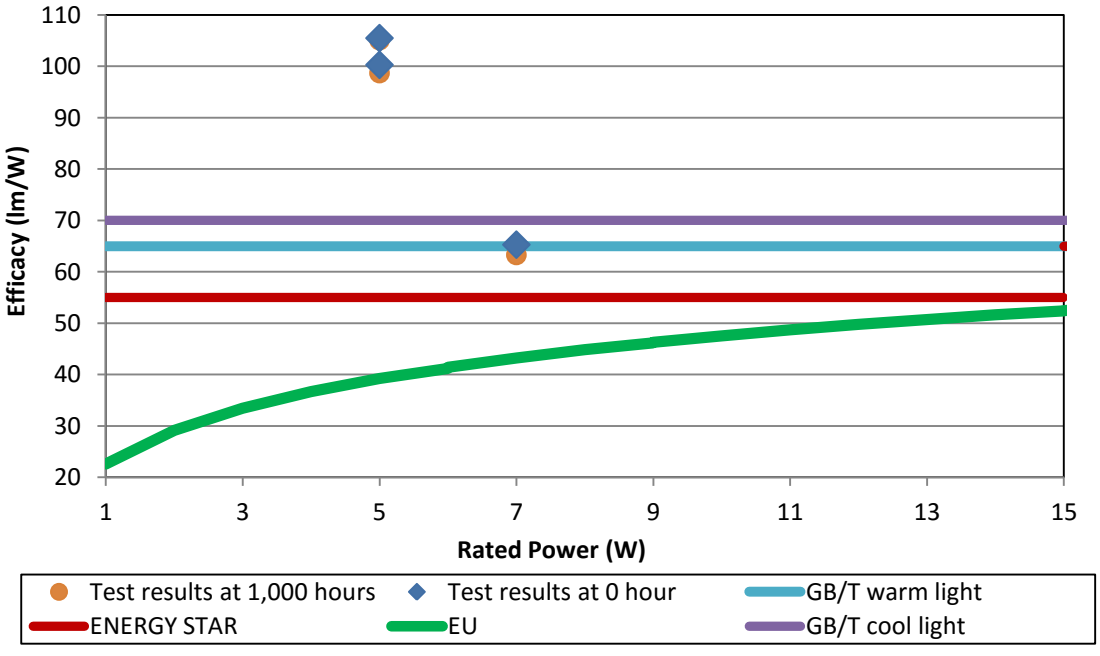
Figure 51 Test results for average (mean, n=10) power factor



7.7.3 Luminous efficacy

Figure 52 shows the efficacy test results compared with EU regulation, ENERGY STAR Lamp specification V1.0 and GB/T 24908. It can be seen that all of the samples tested meet EU regulation. All of the models tested meet the three comparison standards, except the 7W lamps because the average test results of the 7W lamp at 1,000 hours did not meet GB/T 24908. However it can also be seen that both the 5W lamp models show a very high efficacy, up to and even higher than 100 lm/W.

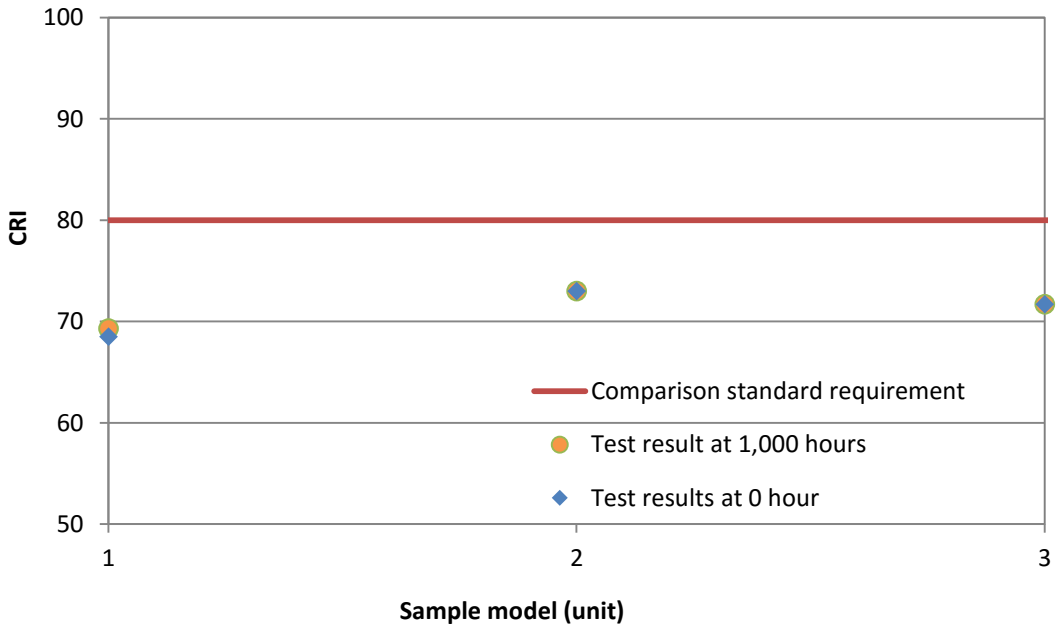
Figure 52 Test results for average (mean, n=10) luminous efficacy



7.7.4 Colour rendering index

Figure 53 presents the average test results of the colour rendering index (CRI). It shows the test results at 0 hour and 1,000 hours nearly overlap. All of the referred standards require the CRI should be not less than 80 (above the red line). It can be seen in Figure 53 that none of samples meet this requirement, which can be seen by the test results all falling under the red line.

Figure 53 Test results for average (mean, n=10) CRI



7.7.5 Light distribution

Light distribution was tested at 0 hour. Figure 54 – 56 shows the light distribution pattern for the three models purchased in Vietnam. They all have axial symmetry. The maximum lighting intensity for these four models are 68 cd, 81 cd, and 76 cd respectively. The test results show Model 1, 2 and 3 all have semispatial light distribution.

Figure 54 Light distribution – Model 1 purchased in Vietnam (polar coordinate system, unit: cd)

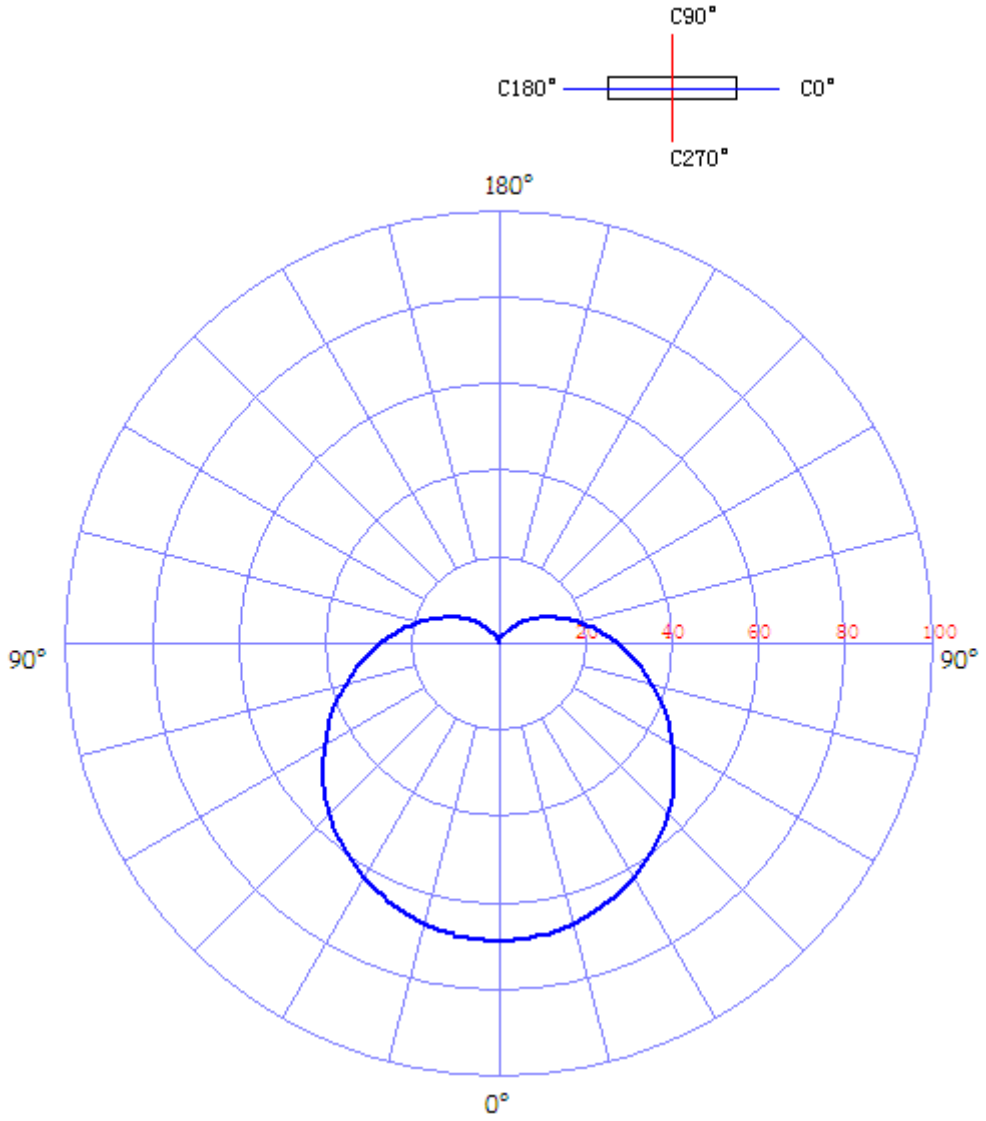


Figure 55 Light distribution – Model 2 purchased in Vietnam (polar coordinate system, unit: cd)

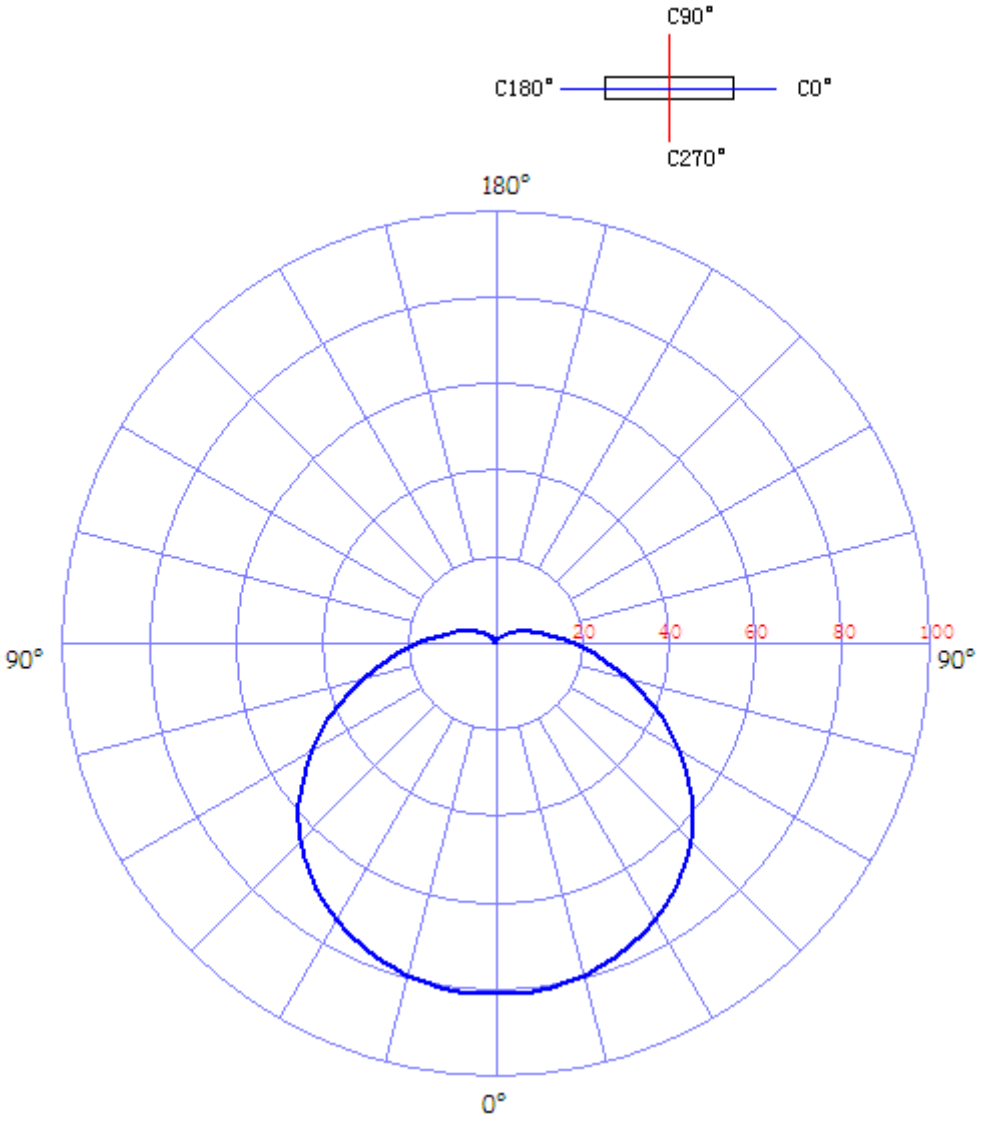
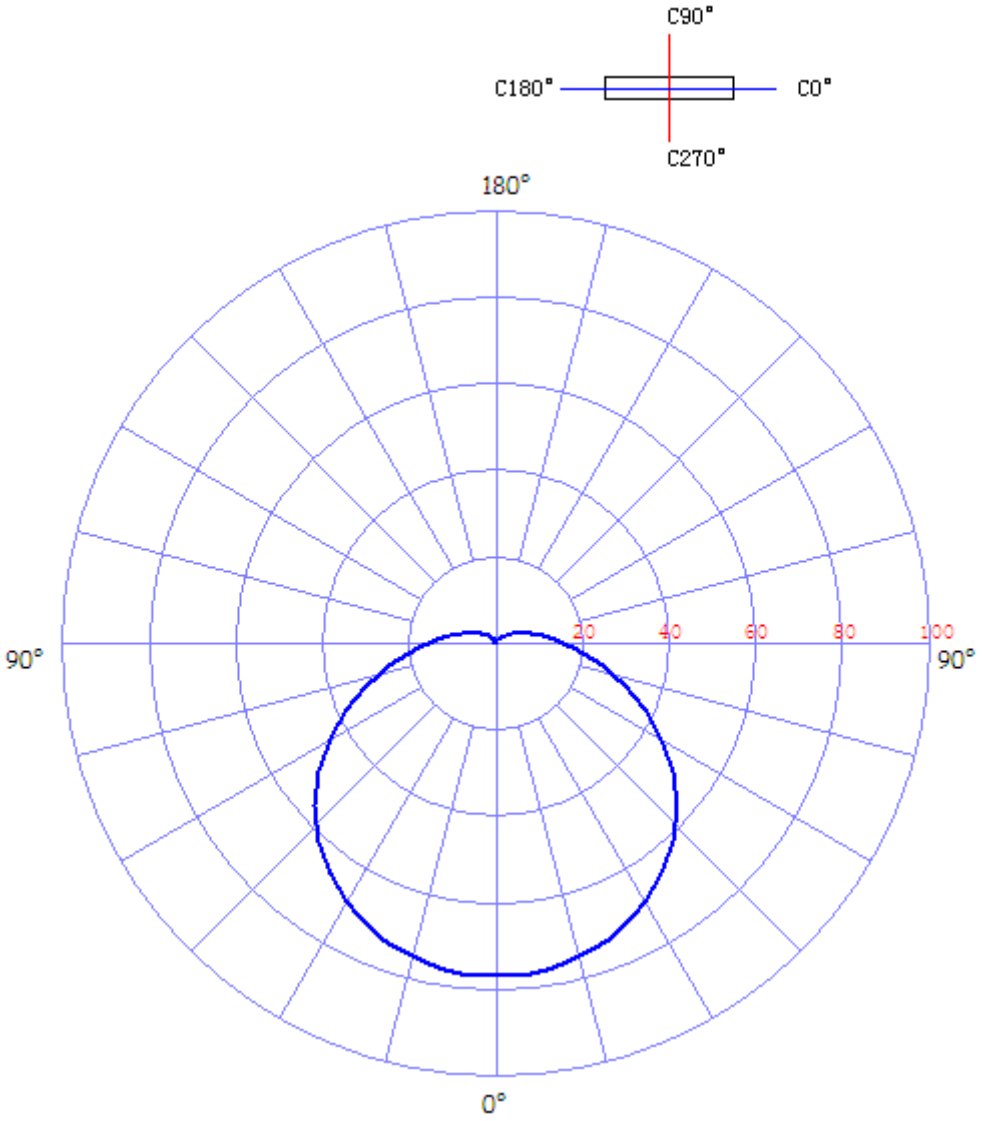


Figure 56 Light distribution – Model 3 purchased in Vietnam (polar coordinate system, unit: cd)



7.7.6 Summary of results for lamps purchased in Vietnam

Of the three models of LED lamps purchased in Vietnam, it can be seen that power, power factor, luminous efficacy and CRI were the main parameter that not all the samples can meet against the comparison standards. Table 25 presents all the compliance rates of the testing parameters compared to the comparison standards. Table 26 presents each parameters compliance for each model with the minimum requirements of all the comparison standards.

Table 25 Summary of test results of three models of LED lamps purchased in Vietnam

<table>
<tr><th>Testing parameters</th><th>comparison standards</th><th>Requirement</th><th>Results</th></tr>
<tr><td rowspan="2">Power</td><td>IEC/PAS 62612</td><td>The power dissipated by the LED-lamp shall not exceed the rated wattage by more than 15%</td><td>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩽110%Pr, ⩾80%Pr (Pr=rated power)</td><td>1 model does not meet the requirement</td></tr>
<tr><td rowspan="3">Power factor</td><td>EU Regulation No. 1194/2012</td><td>P ⩽ 2 W: no requirement
2 W < P ⩽ 5 W: PF > 0,4
5 W < P ⩽ 25 W: PF > 0,5</td><td>1 model does not meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0</td><td>Reported value for each lamp model shall have a power factor ⩾ 0.7 (Exemption: lamps ⩽ 5 Watts)</td><td>1 model does not meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td>⩾ 0,4, if P ⩽ 5 W
⩾ 0,7, if P＞5W</td><td>1 model does not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>>5W, PF >0.50</td><td>No model meet requirements</td></tr>
<tr><td rowspan="3">Initial luminous flux /initial efficacy</td><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><td>All models meet the requirement</td></tr>
<tr><td>ENERGY STAR lamp V1.0[37]</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>All models meet the requirement</td></tr>
<tr><td>GB/T 24908</td><td><table><tr><td rowspan="2">Grade</td><td colspan="2">Efficacy(lm/W)</td></tr><tr><td>Colour 65/50/40</td><td>Colour 35/30/27</td></tr><tr><td>III</td><td>70</td><td>65</td></tr></table></td><td>1 model does not meet the requirement</td></tr>
<tr><td></td><td>IEA 4E SSL Annex</td><td>Tier 1: > 50 lumen/watt</td><td>3 models meet requirement</td></tr>
</table>

[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.

Testing parameters	comparison standards	Requirement	Results
		Tier 2: > 65 lumen/watt	2 models meet requirement
Colour rendering index	EU Regulation No. 1194/2012	⩾ 80	3 models do not meet the requirement
	ENERGY STAR Lamp V1.0 Specification	Lamp shall have a colour rendering index (Ra) ⩾ 80, and R9>0. 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.	3 models do not meet the requirement
	GB/T 24908	⩾80, R9>0, The average of units tested shall meet the requirements and no more than 3 units shall have Ra < 77	3 models do not meet the requirement
	IEA 4E SSL Annex	Tier 1: ≥70 Tier 2: ≥80, R9> 0	No model meet requirement No model meet requirement

Table 26 Vietnam: Compliance of tested models with minimum requirements of comparison standards

Model number	Power	Power factor	Efficacy	Colour rendering index
1	✓	×	✓	×
2	✓	✓	✓	×
3	✓	✓	✓	×