



# **Inter-laboratory Comparison Test Analysis Report**

Prepared by Jing Wang  
Global Efficient Lighting Centre  
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## About GELC

**Global Efficient Lighting Centre** - UNEP Collaborating Centre for Efficient Lighting was launched in partnership between the United Nations Environment Programme (UNEP) and National Lighting Test Centre (NLTC) in October 2012. GELC is a non-profit organization that is operated as an independent third party. It is a specialized and accredited facility that provides quality control, one-stop shop for energy conservation services, lab capacity building, training, research and coordination for global efficient lighting standards. The organization has been established to promote the rapid development of energy efficient lighting technologies around the world.

### Contact details:

Global Efficient Lighting Centre

No. A3 Changpocun, Dabeyao, Chaoyang District

Beijing 100022, China

+86 10 6770 8989

[www.gelc.com](http://www.gelc.com)

[wangjing@gelc.com](mailto:wangjing@gelc.com)

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## Executive summary

This is under the project “Establishing the Foundations of a partnership to accelerate the Global Market Transformation for Efficient Appliances and Equipment”, and entitled “Building capacities of the national energy efficiency laboratory to perform testing of lighting technologies, in line with international standards”, which is part of the United for Efficiency Initiative (U4E). One of the activities in this project is to conduct an Inter-laboratory Comparison test (IC) with Jordan Standards and Metrology Organization (JSMO) Energy Efficient Laboratory (EEL). The IC test is intent to investigate and understand the measurement capacities on efficient lighting products. Through the IC test, it is also intended to find out the potential improvements.

The IC activity was organized in compliance with ISO/IEC 17043 Conformity Assessment – General requirements for proficiency testing. The Global Efficient Lighting Centre (GELC) is the reference laboratory.

Two different types of artefacts were used in this IC: Non-directional LED lamp (High CCT), and Omni-directional LED lamp which are operated on AC voltage. RMS voltage (V) and current (A), Electrical active power (W), Total luminous flux (lm), Luminous efficacy (lm/W), Chromaticity coordinates: x, y, Correlated colour temperature (CCT) (K), Colour Rendering Index (CRI) Ra, Power factor were measured and compared. The z-scores (defined in ISO 13528) and  $E_n$  numbers (defined in ISO 13528 and ISO/IEC 17043) were evaluated.

For Laboratory JSMO EEL, the test results of most photometric parameters are showed satisfactory. The obvious deviations were presented generally in electrical parameters and colorimetric parameters. The findings and recommendations based on this IC testing results are summarized:

- 1) Having a further check on SPD of standard lamp, and the applicability of spectrometer at the short wavelength;
- 2) Re-evaluating the uncertainty by considering as many components as possible;
- 3) Taking care of the temperature, which should be the temperature inside of the integrating sphere, while during the conversations with JSMO EEL, it was told the recorded temperature was monitored outside of the sphere.

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## Acronyms and Abbreviations

A	Amperes
AC	Alternating Current
CCT	Correlated Color Temperature
CIE	Commission Internationale de l'Eclairage
CRI	Color Rendering Index
CTCN	Climate Technology Centre & Network
EEL	Energy Efficient Laboratory
GELC	Global Efficient Lighting Centre
HCCT	High Correlated Color Temperature
Hz	Hertz
IC	Inter-laboratory Comparison
ISO	International Standard Organization
JSMO	Jordan Standards and Metrology Organization
K	Kelvin
LED	Light Emitting Diode
lm	Lumens
OD	Omni-Directional
SPD	Spectral Power Distribution
SSL	Solid-State Lighting
U4E	United for Efficiency Initiative
UN Environment	United Nations Environment Programme
V	Voltage
W	Watt

## 1 Introduction

The Inter-laboratory comparison (IC) tests are known to be one of the most reliable indicators to assess the technical competence of a participating laboratory.

This is under the project “Establishing the Foundations of a partnership to accelerate the Global Market Transformation for Efficient Appliances and Equipment”, and entitled “Building capacities of the national energy efficiency laboratory to perform testing of lighting technologies, in line with international standards”, which is part of the United for Efficiency Initiative (U4E). One of the activities in this project is to conduct an Inter-laboratory Comparison test (IC) with Jordan Standards and Metrology Organization (JSMO) Energy Efficient Laboratory (EEL). The IC test is intent to investigate and understand the measurement capacities on efficient lighting products. Through the IC test, it is also intended to find out the potential improvements.

This IC activity was organized in compliance with the ISO/IEC 17043 Conformity Assessment – General requirements for proficiency testing. The General Protocol was developed by GELC and distributed to JSMO EEL, which specified the two types of comparison artefacts, stability check, measurement quantities, assigned values, evaluation of performance using z-scores (defined in ISO 13528<sup>1</sup>) and  $E_n$  numbers (defined in ISO 13528 and ISO/IEC 17043), reporting, testing period, operation conditions and measurement procedures, uncertainty calculation, result templates and other details.

The IC adopted the CIE S 025 – 2015 “Test Method for LED lamps, luminaires and modules” as of the test method. The Global Efficient Lighting Centre (GELC) is the reference laboratory.

## 2 Timetable

**Table 1 IC Timetable**

Event	Date
Completion of the IC protocol and related documents	22 May 2017
Completion of lamp selection and pre-testing	
Completion of 1st measurement of artefacts by GELC	
Delivery the artefacts to JSMO EEL laboratory	
Measurements by JSMO EEL laboratory	14 June 2017
Completion of measurements of JSMO EEL laboratory and ship back the artifacts to GELC	
Submit measurement results	22 June 2017
2nd measurements of artefacts by GELC	23 June 2017
Completion of Formal Results Notification	12 July 2017
Initial reporting the results and findings to JSMO EEL laboratory	22 August 2017
Completion of the final report	30 August 2017

<sup>1</sup> ISO 13528 Statistical method for use in proficiency testing by interlaboratory comparisons

### 3 Description of the Artefacts

The Generic Protocol specified two types of artefacts used in this IC:

- 1) Non-directional LED lamp (High CCT)
- 2) Omni-directional LED lamp

**Table 2 Specifications of the artefacts**

Identifier	Type	Rated (or nominal) value			Other Conditions
		Voltage	Power	CCT	
NLTC-HCCT-19#	Non-directional LED lamp (High CCT)	220 V AC	6 W	5000 K	AC frequency: 50 Hz  Operating position: base up for all lamps
NLTC-OD1-15#	Omni-directional LED lamp		5 W	2700 K	

### 4 Measurement Quantities

The scope of measurements and comparisons shall consist of:

One (1) Non-directional LED lamp (High CCT), one (1) Omni-directional LED lamp:

- RMS voltage (V) and current (A)
- Electrical active power (W)
- Power factor
- Total luminous flux (lm)
- Luminous efficacy (lm/W)
- Chromaticity coordinates: x, y
- Correlated colour temperature (CCT) (K)
- Colour Rendering Index (CRI) Ra

Reporting measurement uncertainties was required by the Generic Protocol for all results.

### 5 Assigned Value and Data Analysis

The assigned values in this IC were given by the reference laboratory. Each quantity of the artefacts was measured by GELC before shipping and after being returning. The assigned values for the measurement quantities were determined as the average of the two measurements by GELC.

$$X = \frac{X_1 + X_2}{2}$$

Formula (1)

Where,

X: assigned value

X1: the value tested by GELC before shipping artefacts;

X2: the value tested by GELC after being returning;

The criteria used in this IC to analyze and evaluate the performance are z-score and  $E_n$  numbers.

### 5.1 Relative differences

The relative differences between JSMO EEL results and the assigned values are calculated by the following formulas:

For RMS Current, Active Power, Luminous Flux and Luminous Efficacy, the relative differences between the average test results of JSMO EEL and the assigned values are given by:

$$\Delta X = \frac{x - X}{X} \quad \text{Formula (2)}$$

Where,

$x$  : results measured by JSMO EEL (average of the three measurements).

For Power factor, Chromaticity Coordinate ( $x, y$ ), Correlated Color Temperature (CCT), Color Rendering Index (CRI), the relative differences between the average test results of JSMO EEL and the assigned values are given by:

$$\Delta X = x - X \quad \text{Formula (3)}$$

### 5.2 z-scores

The z-score is calculated for all testing results, and is determined by:

$$z = \frac{x - X}{\hat{\sigma}} \quad \text{Formula (4)}$$

where

$\hat{\sigma}$  is Standard Deviation for Proficiency Assessment (SDPA value). In this IC,  $\hat{\sigma}$  is determined as nIQR (normalized interquartile range), and it is calculated as in formula (5):

$$nIQR(x) = 0.7413 \times (Q_3(x) - Q_1(x)) \quad \text{Formula (5)}$$

Where,

$Q_1(x)$ : the 25<sup>th</sup> percentile of  $x_i$  ( $i=1,2, \dots,p$ );

$Q_3(x)$ : the 75<sup>th</sup> percentile of  $x_i$  ( $i=1,2, \dots,p$ );

Generally, the value of  $|z| \leq 2.0$  is considered to be satisfactory; the value of  $2.0 < |z\text{-score}| < 3.0$  is considered to be questionable; and  $|z\text{-score}| \geq 3.0$  is considered to be unsatisfactory,

### 5.3 $E_n$ number

In accordance with ISO 13528,  $E_n$  numbers are calculated by

$$E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_x^2}} \quad \text{Formula (6)}$$

Where

$x$  : results measured by JSMO EEL (average of the three measurements);

$X$ : assigned value (average of the reference laboratory measurement, before and after);

$U_{lab}$ : expanded uncertainty (k=2) of JSMO EEL's result;

$U_x$ : expanded uncertainty (k=2) of the assigned value.

If the equations are given in relative expanded uncertainties  $U_{lab,rel}$ ,  $U_{x,rel}$ , then  $E_n$  is calculated by:

$$E_n = \frac{\Delta X_{rel}}{\sqrt{U_{lab,rel}^2 + U_{x,rel}^2}} \quad \text{Formula (7)}$$

Generally,  $|E_n| \leq 1.0$  is considered to be satisfactory,  $|E_n| > 1.0$  is considered to be unsatisfactory.

## 6 Results of JSMO EEL Measurements

In this report, the JSMO EEL's results are presented in (relative) differences to the assigned values. This is a kind note that the RMS voltage is a set parameter in the test. As it would not make sense to compare a set parameter, therefore the results of RMS voltage are not included in the following analyses.

In Section 6.1, the differences between the JSMO EEL's measurement values and the assigned values are presented, with JSMO EEL's reported uncertainties. The relative differences in percentage are presented for all photometric and electrical quantities except for power factor (reported in absolute difference) and colorimetric quantities (presented in absolute units).

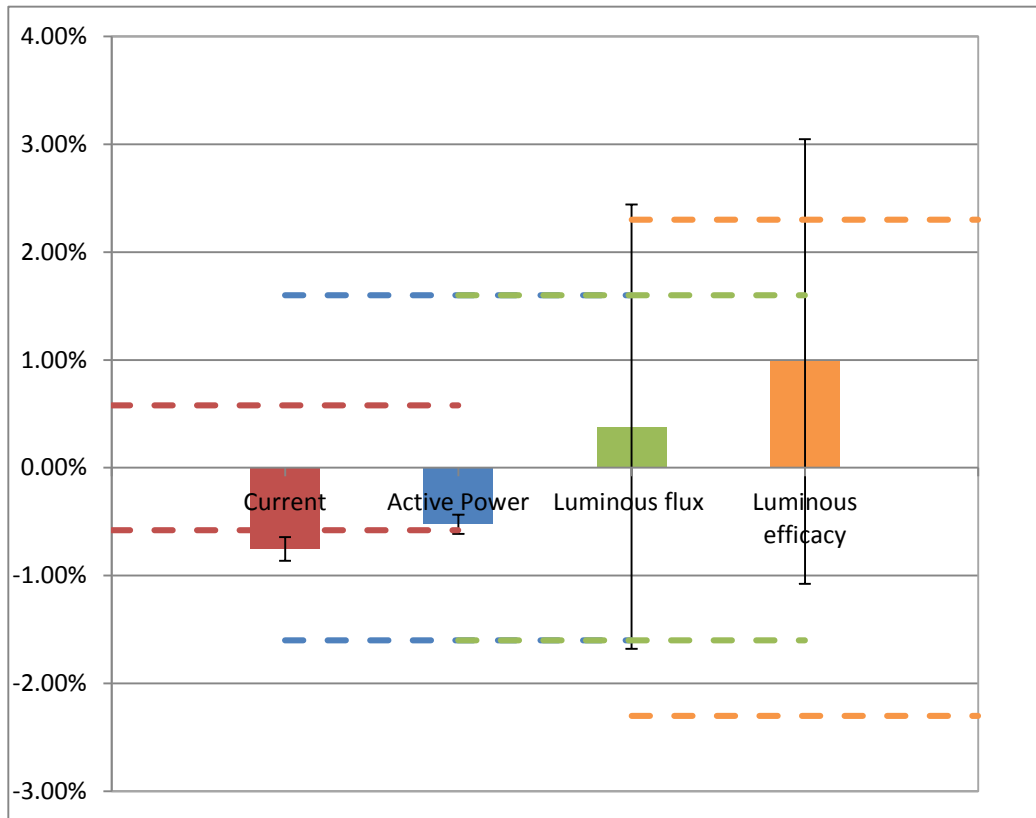
In Sections 6.2 and 6.3, the z-scores and  $E_n$  numbers are presented for the both artefacts.

### 6.1 Differences in measurement results

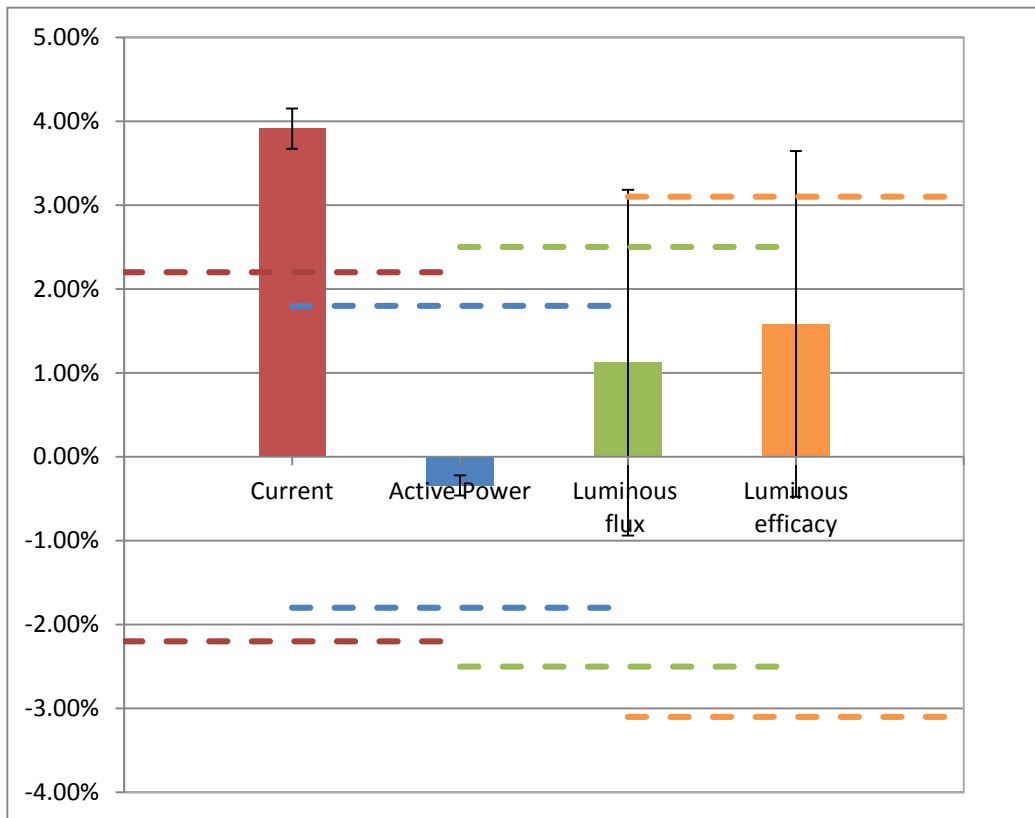
The (relative) differences of results between the JSMO EEL and the reference laboratory for all artefact types are presented in graphic forms in the following subsections.

The error bars in the figures show the uncertainties of measurement (expanded uncertainty by a coverage factor, k=2) by the JSMO EEL. The dashed lines in the figures (in color) show the uncertainties values (expanded uncertainty by a coverage factor, k=2) by the reference laboratory for all points plotted.

### 6.1.1 RMS Current, Active Power, Luminous flux, Luminous Efficacy.

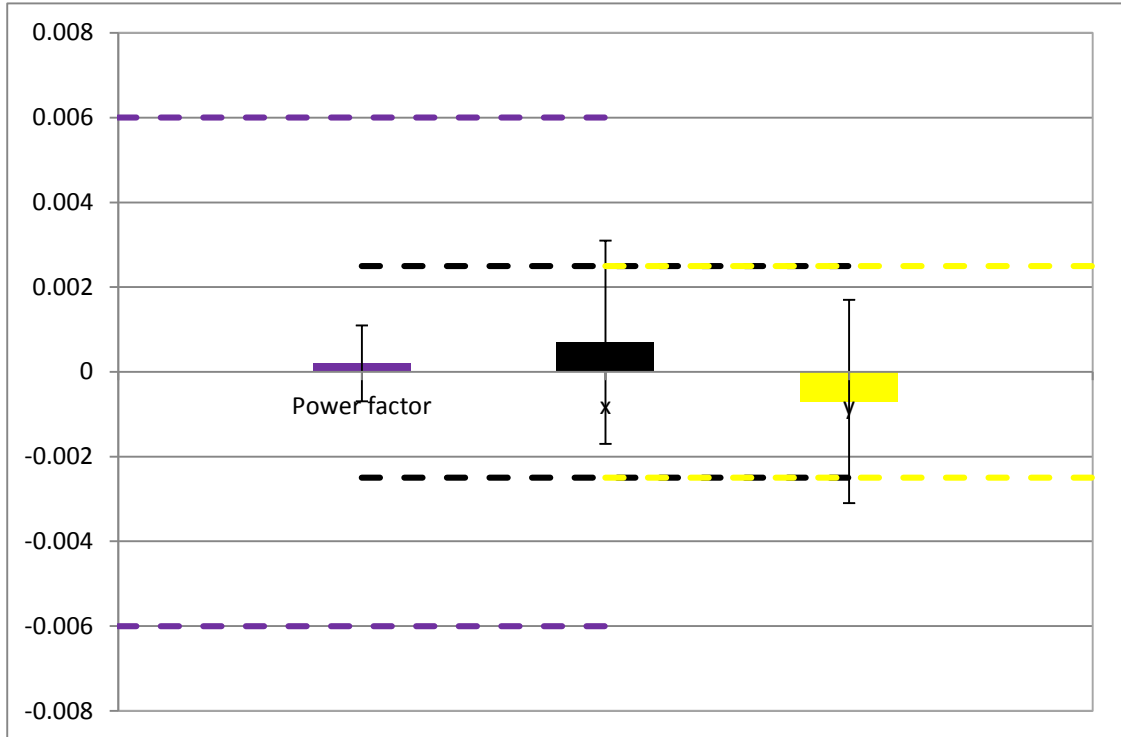


**Figure 1 Relative differences of Current, Active Power, Luminous Flux and Luminous Efficacy for Non-directional LED lamp (High CCT)**

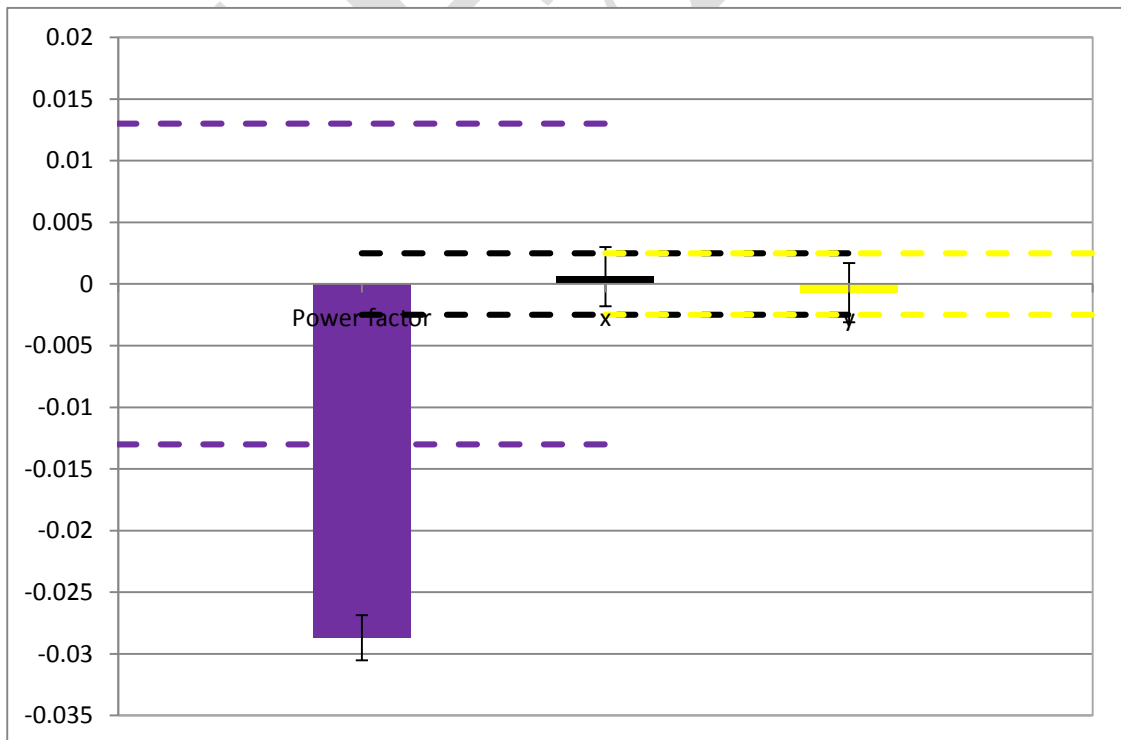


**Figure 2 Relative differences of Current, Active Power, Luminous Flux and Luminous Efficacy for Omni-directional LED lamp**

### 6.1.2 Power factor, Chromaticity $x, y$

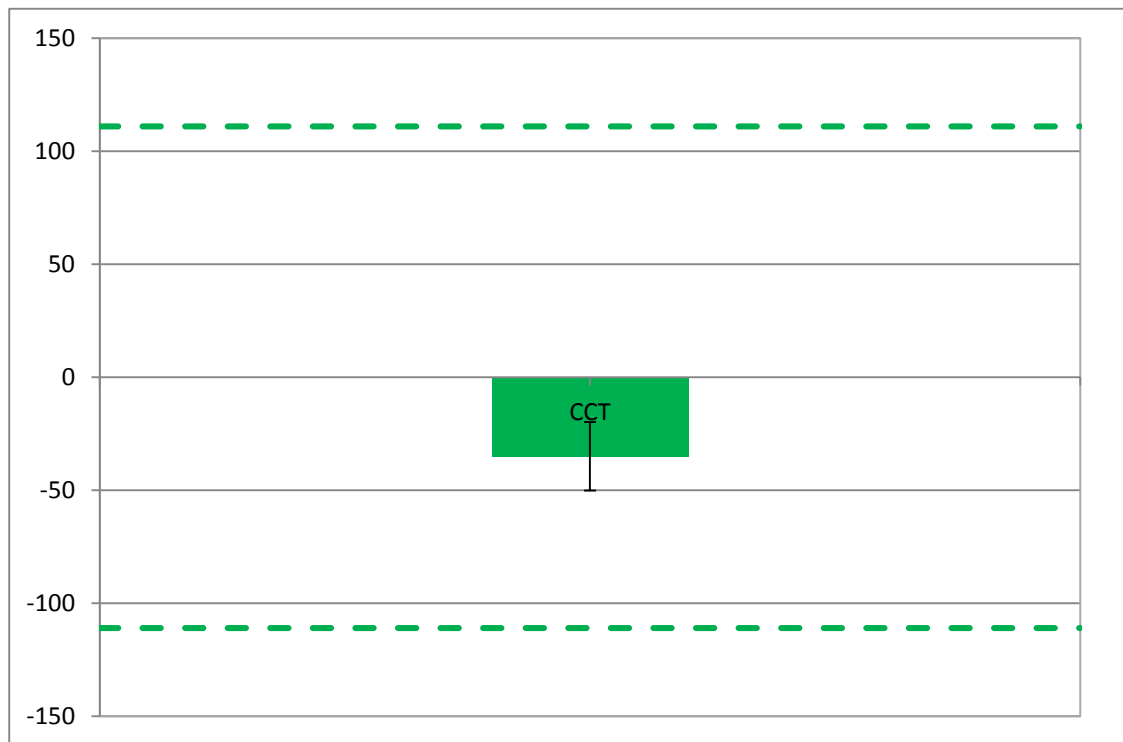


**Figure 3** Relative differences of Power factor, Chromaticity  $x, y$  for Non-directional LED lamp (High CCT)

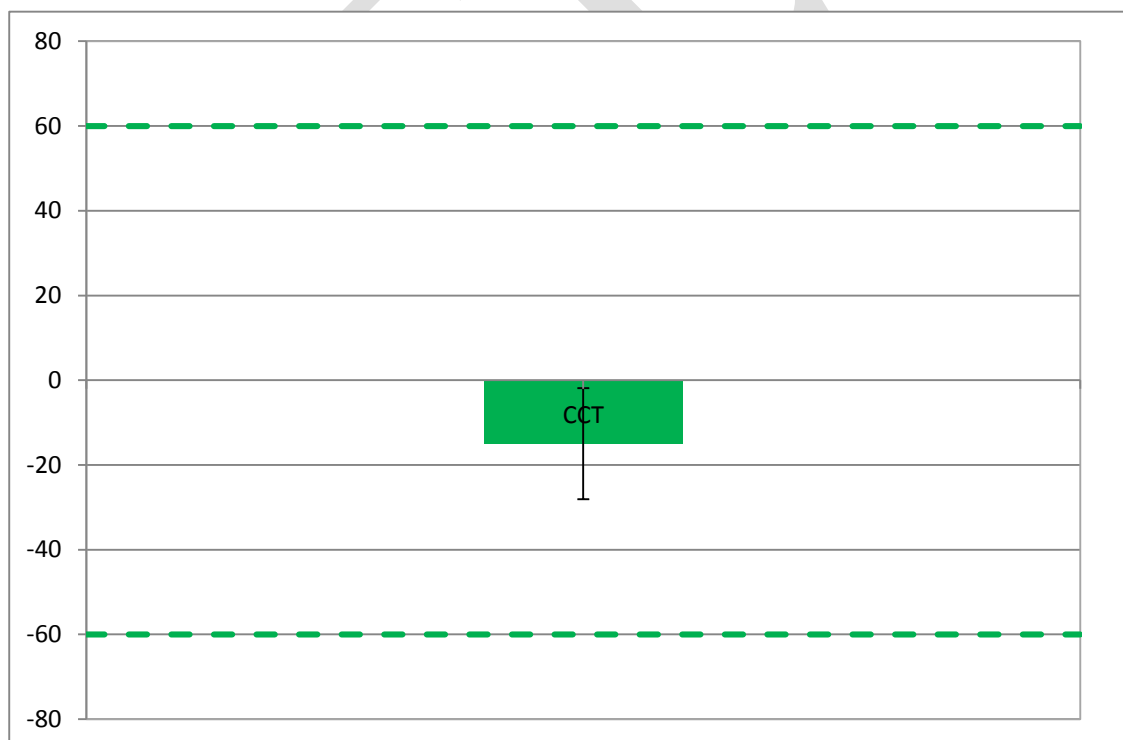


**Figure 4** Relative differences of Power factor, Chromaticity  $x, y$  for Omni-directional LED lamp

### 6.1.3 CCT

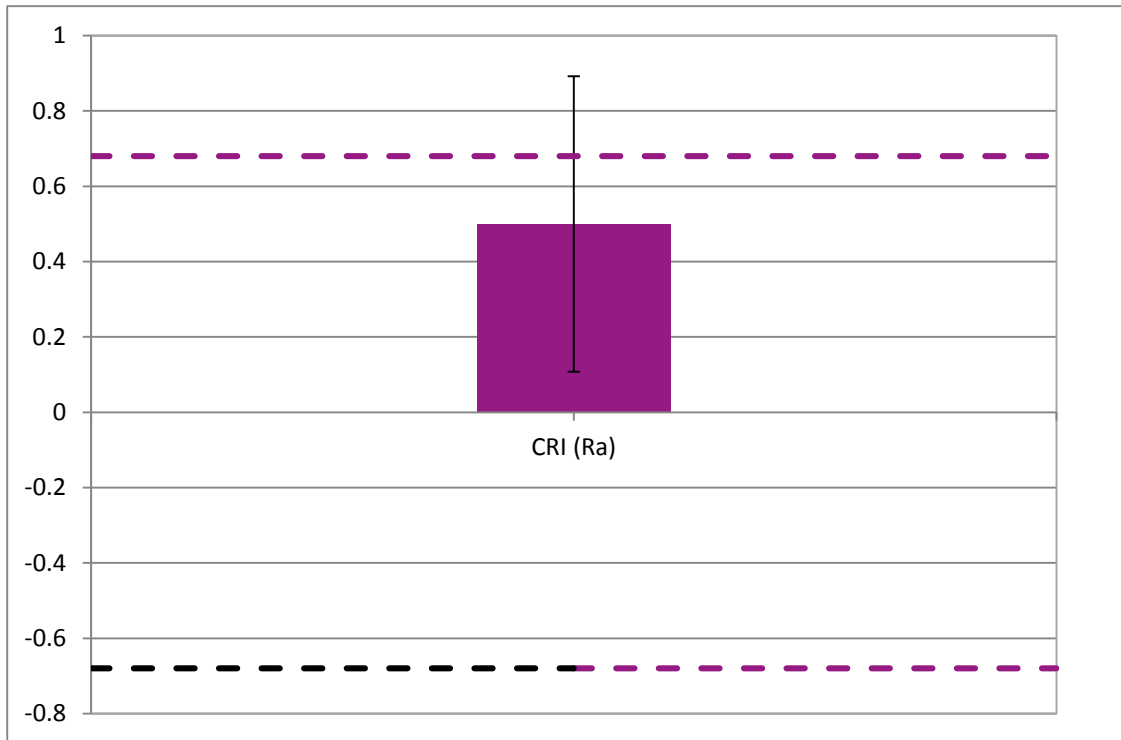


*Figure 5 Relative differences of CCT for Non-directional LED lamp (High CCT)*

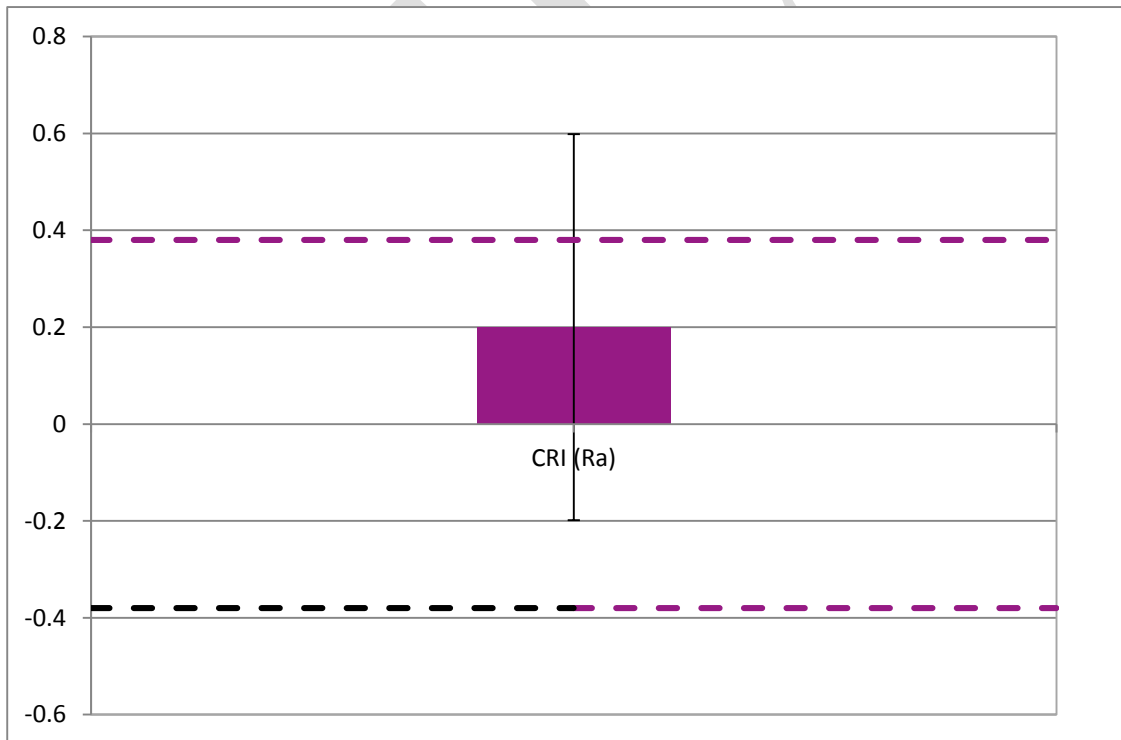


*Figure 6 Relative differences of CCT for Omni-directional LED lamp*

### 6.1.4 CRI



**Figure 7 Relative differences of CRI for Non-directional LED lamp (High CCT)**



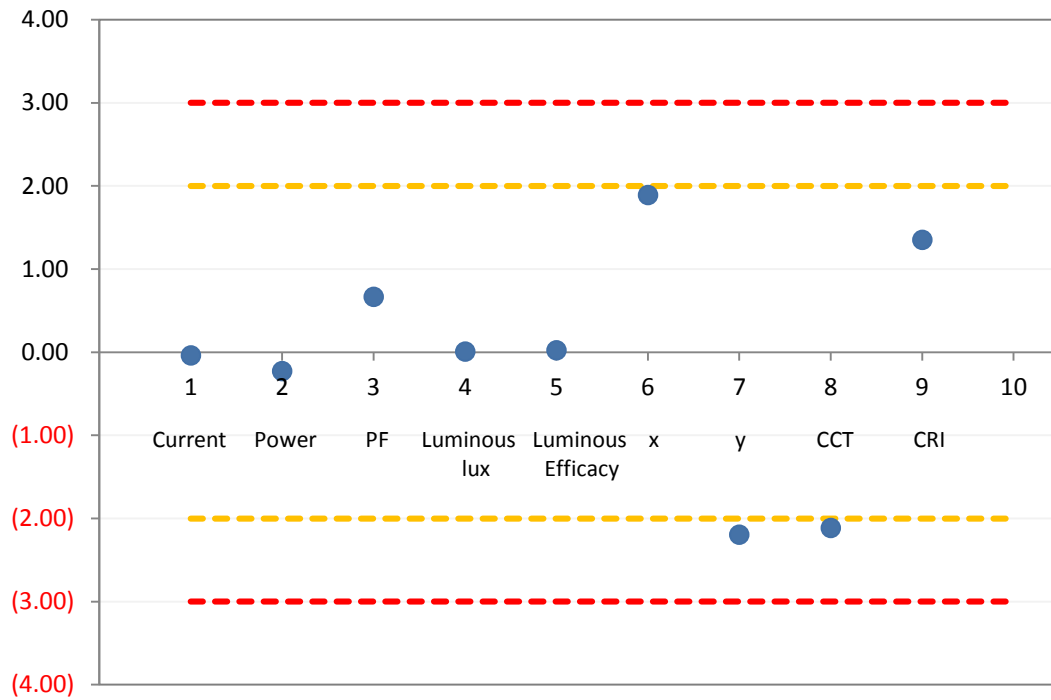
**Figure 8 Relative differences of CRI for Omni-directional LED lamp**

## 6.2 z-scores

In the following sections, the z-scores are presented. The dashed lines (in red) in each figure show  $z\text{-score} = \pm 3$ ; the dashed lines (in orange) in each figure show  $z\text{-score} = \pm 2$ . The results outside of  $\pm 3$  are generally judged unsatisfactory, and  $|z| \leq 2.0$  is considered to be satisfactory;

the value of  $2.0 < |z\text{-score}| < 3.0$  is considered to be questionable.

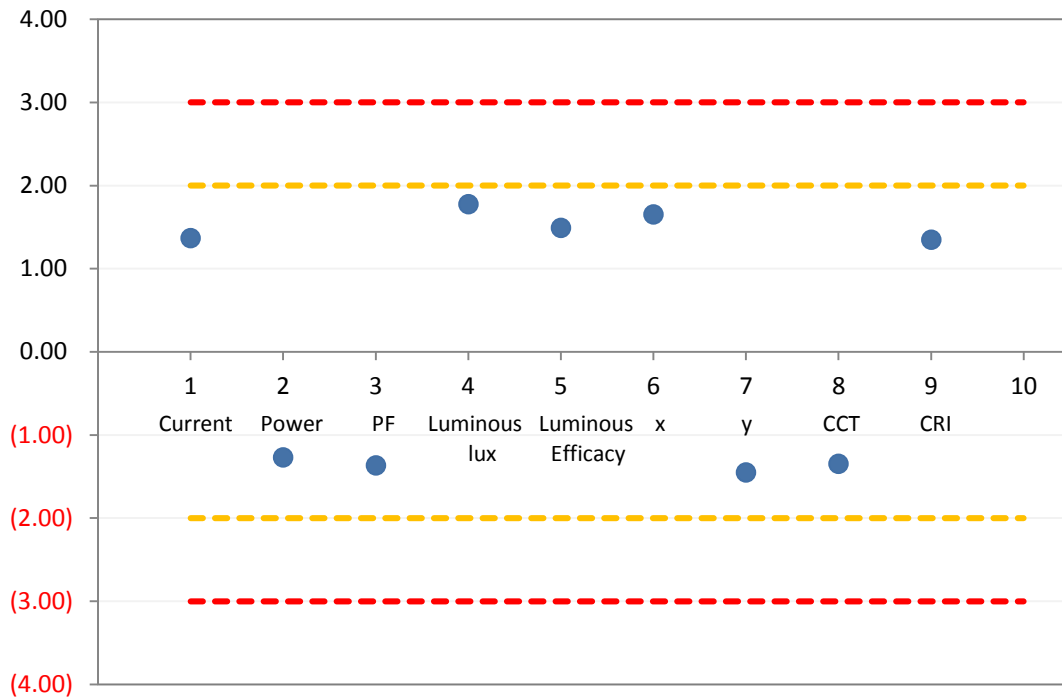
### 6.2.1 Non-directional LED lamp (High CCT)



**Figure 9 z- score for Non-directional LED lamp (High CCT)**

It could see from Figure 9 that all of the z-scores are within  $\pm 2.0$  for non-directional LED lamp (High CCT), expect two parameters Chromaticity y and CCT, which are out of the line  $\pm 2.0$ . The line  $\pm 2.0$  are normally regarded as the “warning signals”, which means the laboratory may have to take a look at those parameters to find out if any improvements would be necessary.

## 6.2.2 Omni-directional LED lamp



**Figure 10 z-score for Omni-directional LED lamp**

It could see from Figure 10 that all of the z-scores are within  $\pm 2.0$  for Omni-directional LED lamp. This means, in general, the results of the Omni-directional lamp look OK.

## 6.3 $E_n$ numbers

The  $E_n$  numbers are related to the relative differences of the testing results between the participating laboratories and the reference laboratory, as well as the uncertainties reporting by the participating laboratories. However with the purpose of limiting the measurement variations among the laboratories during the testing activities, the  $E_n$  may be problematic when the laboratory has difficulty in uncertainty evaluation. Therefore, sometimes, the  $E_n$  numbers are used together with the others methods.

In the following sections, the  $E_n$  numbers are presented. The dashed lines (in black) in each figure show  $E_n = \pm 1$ , within which the results are generally judged satisfactory.

### 6.3.1 Non-directional LED lamp (High CCT)

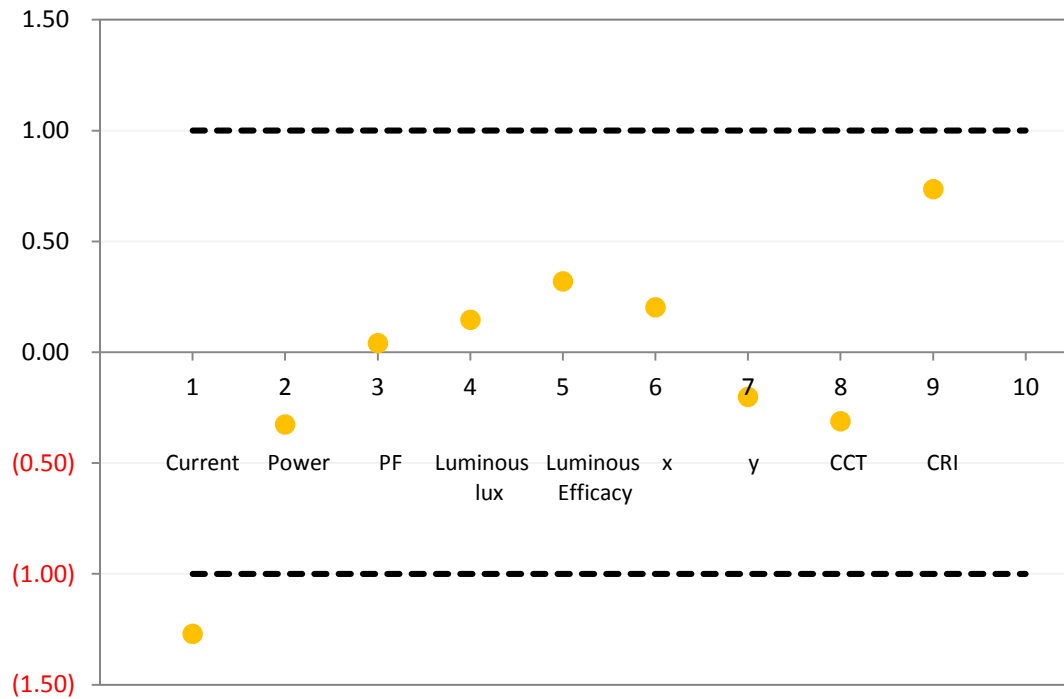


Figure 11  $E_n$  numbers for Non-directional LED lamp (High CCT)

Figure 11 shows the  $E_n$  numbers for non-directional LED lamp (High CCT). It could find that only the current has  $E_n$  numbers outside of  $\pm 1.0$ . The others are all within the black dashed lines.

### 6.3.2 Omni-directional LED lamp

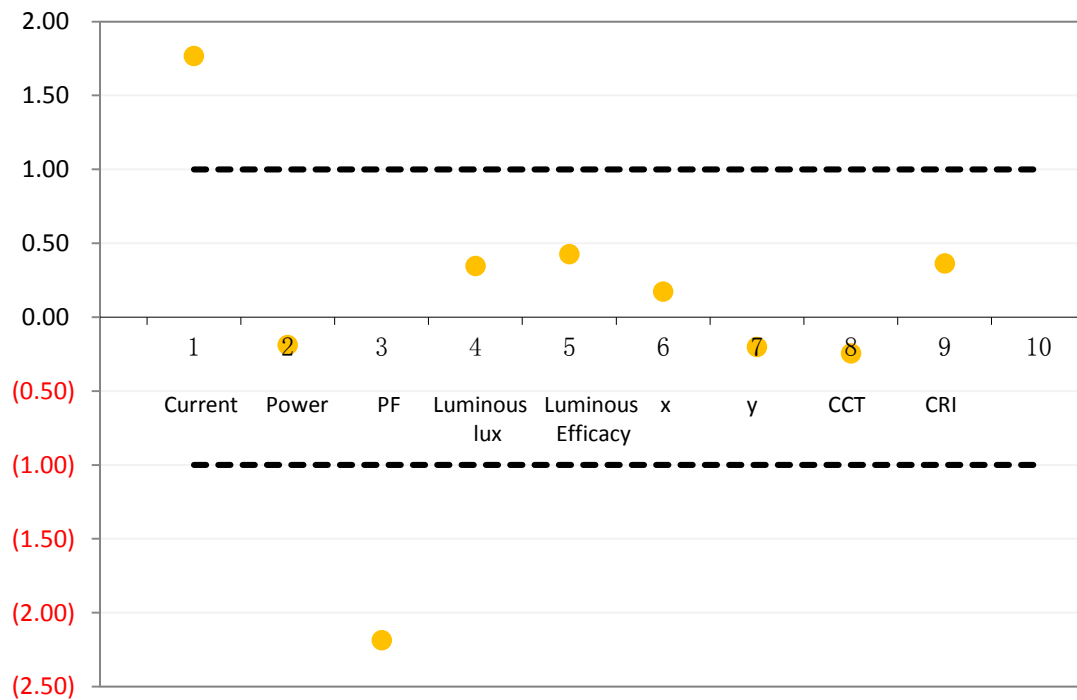


Figure 12  $E_n$  numbers for Omni-directional LED lamp

Figure 12 presents the  $E_n$  numbers for omni-directional LED lamp. It could see that the current and Power factor have  $E_n$  numbers outside of  $\pm 1.0$ . The others are all within the black dashed lines.

## 6.4 Discussion

Table 3 shows the z-scores and  $E_n$  numbers of the Non-directional LED lamp (High CCT). It could find that the  $E_n$  numbers are over than 1.0 for current. The z-scores are over than 2.0 but less than 3.0 for chromaticity y and CCT. It is unknown the Spectral Power Distribution (SPD) of the Standard lamp used in JSMO EEL, therefore it would not know if the standard lamp is a standard Illuminate A. From the results showed, it may be related to the reliability of the spectrometer at the short wavelength. As for the Omni-directional LED lamp, which has a low CCT, the results does not reflect this issue (see table 4), while for this high CCT product, it showed the problem. That is normally happened if the spectrometer is weak at the short wavelength when testing the high CCT product. However this will need to be verified through the SPD of the Standard lamp (for example, use the original SPD of the standard lamp to check the data measured by the spectrometer, especially at the short wavelengths).

**Table 3 Non-directional LED lamp (High CCT)**

	Current	Power	Power factor	Luminous flux	Luminous efficacy	x	y	CCT	CRI (Ra)
z	-0.04	-0.23	0.66	0.01	0.02	1.89	-2.20	-2.12	1.35
$E_n$	-1.27	-0.33	0.04	0.15	0.32	0.20	-0.20	-0.31	0.74

Table 4 shows the z-scores and  $E_n$  numbers of the Omni-directional LED lamp. It could find that the  $E_n$  numbers of Current and Power factor are over than 1.0. All of the z-scores are less than 2.0. In general, the results of the Omni-directional lamp look ok, however the  $E_n$  numbers for current and power factor are not good, it may be related to the uncertainty evaluation, as the uncertainty values of current and power factor reported by JSMO EEL are very small, which gave a high effect to the  $E_n$  numbers.

**Table 4 Omni-directional LED lamp**

	Current	Power	Power factor	Luminous flux	Luminous efficacy	x	y	CCT	CRI (Ra)
z	1.38	-1.27	-1.40	1.77	1.49	1.65	-1.45	-1.35	1.35
$E_n$	1.77	-0.19	-2.19	0.35	0.43	0.17	-0.20	-0.24	0.53

## 7 Conclusions and recommendations

Supported by the CTCN, an Inter-laboratory comparison test was conducted by the GELC (the reference laboratory) and JSMO EEL, from the May 2017 and completed by July 2017. This IC activity was organized in compliance with ISO/IEC 17043 Conformity Assessment – General

requirements for proficiency testing. The IC used the CIE S 025 – 2015 “Test Method for LED lamps, luminaires and modules” as the test method. The General Protocol was developed by GELC and distributed to JSMO EEL, which specified the two types of comparison artefacts, stability check, measurement quantities, assigned values, evaluation of performance using z scores (defined in ISO 13528) and  $E_n$  numbers (defined in ISO 13528 and ISO/IEC 17043), reporting, testing period, operation conditions and measurement procedures, uncertainty calculation, result templates and other details.

The scope of measurements and comparisons in the IC consisted of:

Non-directional LED lamp (High CCT), Omni-directional LED lamp:

- RMS voltage (V) and current (A)
- Electrical active power (W)
- Power factor
- Total luminous flux (lm)
- Luminous efficacy (lm/W)
- Chromaticity coordinates: x, y
- Correlated colour temperature (CCT) (K)
- Colour Rendering Index (CRI) Ra

For Laboratory JSMO EEL, the test results of most photometric parameters are showed satisfactory. The obvious deviations were presented generally in electrical parameters and colorimetric parameters. Based on the testing results and measurement information provided by JSMO EEL, the further actions and possible improvements it would recommend to JSMO EEL are:

- 4) Having a further check on SPD of standard lamp, and the applicability of spectrometer at the short wavelength;
- 5) Re-evaluating the uncertainty by considering as many components as possible;
- 6) Taking care of the temperature, which should be the temperature inside of the integrating sphere, while during the conversations with JSMO EEL, it was told the recorded temperature was monitored outside of the sphere.

## References

- [1] ISO/IEC 17043:2010, Conformity assessment - General requirements for proficiency testing.
- [2] ISO 13528:2015, Statistical methods for use in proficiency testing by interlaboratory comparisons.
- [3] CIE S 025: 2015: Test Method for LED Lamps, LED Luminaires and LED Modules.
- [4] APLAC PT002-2003, Testing interlaboratory comparisons.
- [5] APLAC PT088 APLAC Proficiency Testing Program - Photometric measurement of Solid State Lighting Product.

## Annex 1 Results of Reference Laboratory Measurement

Table 5 Assigned value of the Artefacts

Identifier	Measurement results									
	Voltage (V)	Current (mA)	Active Power (W)	Power factor	Luminous flux (lm)	Luminous efficacy (lm/W)	x	y	CCT (K)	CRI (Ra)
NLTC-HCCT-19#	220.0	33.20	5.925	0.8122	499.1	84.24	0.3244	0.3322	5885	79.55
NITC-HCCT (Relative) Expanded Uncertainty	/	0.58%	1.6%	0.006	2.3%	2.2%	0.0025	0.0025	111	0.68
NLTC-OD1-15#	220.0	31.20	4.705	0.6854	222.9	47.37	0.4518	0.4053	2775	82.75
NITC-OD1 (Relative) Expanded Uncertainty	/	2.2%	1.8%	0.013	2.5%	3.1%	0.0025	0.0025	60	0.38

## Annex 1 Results of JSMO EEL

Table 6 Test results of JSMO EEL

Identifier		Measurement results									
		Voltage (V)	Current (mA)	Active Power (W)	Power factor	Luminous flux (lm)	Luminous efficacy (lm/W)	x	y	CCT (K)	CRI (Ra)
NLTC-HCCT-1 9#	1st	220.02	32.93	5.887	0.8126	500.2	84.97	0.3252	0.3316	5843	80.1
	2nd	220.03	32.95	5.891	0.8126	501.2	85.09	0.3251	0.3315	5850	80.1
	3rd	220.03	32.96	5.889	0.8121	501.5	85.16	0.325	0.3313	5856	80.1
	Ave.	220.03	32.95	5.889	0.8124	501	85.07	0.3251	0.3315	5850	80.1
	Relative U (k=2)	0.10%	0.12%	0.11%	0.11%	2.06%	2.06%	0.0024	0.0024	15.1	0.49%
	$\Delta X$	0.01%	-0.75%	-0.52%	0.0002	0.38%	0.99%	0.0007	-0.0007	-35	0.5
NLTC-OD1-15 #	1st	220.01	32.37	4.687	0.6581	225.8	48.17	0.4525	0.4047	2759	83
	2nd	220.04	32.39	4.681	0.6569	225.1	48.09	0.4523	0.4046	2760	83
	3rd	220.03	32.49	4.683	0.6551	225.3	48.11	0.4523	0.4045	2761	83
	Ave.	220.03	32.42	4.684	0.6567	225.4	48.12	0.4524	0.4046	2760	83
	Relative U (k=2)	0.10%	0.24%	0.12%	0.28%	2.06%	2.06%	0.0024	0.0024	13.1	0.48%
	$\Delta X$	0.01%	3.91%	-0.34%	-0.0287	1.12%	1.58%	0.0006	-0.0007	-15	0.2



**The Climate Technology Centre and Network (CTCN)** fosters technology transfer and deployment at the request of developing countries through three core services: technical assistance, capacity building and scaling up international collaboration. The Centre is the operational arm of the UNFCCC Technology Mechanism, it is hosted and managed by the United Nations Environment and the United Nations Industrial Development Organization (UNIDO), and supported by more than 300 network partners around the world.

**CTCN contact details:**

Climate Technology Centre and Network

UN City, Marmorvej 51

DK-2100 Copenhagen, Denmark

+45 4533 5372

[www.ctc-n.org](http://www.ctc-n.org)

[ctcn@unep.org](mailto:ctcn@unep.org)