Inter-laboratory Comparison of Light Emitting Diode (LED) Lamps

Final Report

Prepared for United Nations Environment Programme (UNEP)

Reference Laboratory: Global Efficient Lighting Centre (GELC)

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Executive Summary

This Inter-laboratory Comparison testing project is one of a series of efficient lighting compliance activities under the United Nations Environment Programme (UNEP)-Global Environment Facility (GEF) en.lighten initiative project "*Securing climate change benefits of efficient lighting in Southeast Asia and Pacific economies via MVE capacity building activities*", which is funded by the Australian Government. It was designed in compliance with ISO/IEC 17043, *Conformity assessment - General requirements for proficiency testing*. The purpose of this project is to identify the differences among the participating laboratories and analyze the potential technical issues that exist in these laboratories.

Three different types of light emitting diode (LED) lamps were selected to be tested against the key photometric, colorimetric, and electrical parameters. The Global Efficient Lighting Centre (GELC), as the reference laboratory, organized this inter-laboratory comparison test with six laboratories from four countries in Southeast Asia (Indonesia, Philippines, Thailand and Vietnam).

The photometric, colorimetric, and electrical parameters were tested by GELC and the six participating laboratories. This report analyzes the deviations of the test results between the reference values from GELC and test results from each participating laboratory. It found that all the electrical test results from the six participating laboratories are generally considered to be satisfactory; while the photometric and colorimetric parameters showed high deviations between the reference values and participating laboratories' test results. The improvements for the participating laboratories recommended in this report are to check their traceability of standard artifacts, check data correction (e.g. sphere special non-uniformity correction, self-absorption corrections, near-field absorption), improve test procedures, check ambient temperature, check calculation software, and to check the response of the photodetector, etc.

Acknowledgements

The authors are grateful for the reviews by and support from all UNEP and GELC experts. Particular thanks to WANG Jing, Marie Leroy and Michael Scholand, who provided help for editing of text and figures. Thanks also to ZHANG Wei, XIN Hongzheng and Yoshi Ono, who provided technology support.

1. Introduction

This Inter-laboratory comparison testing project is one of a series of efficient lighting compliance activities under the UNEP-GEF en.lighten initiative project, "*Securing climate change benefits of efficient lighting in Southeast Asia and Pacific economies via monitoring, verification and enforcement capacity building activities*," which is funded by the Australian Government. In order to better understand the measurement capacity of te existing lighting laboratories in the Southeast Asia region, the UNEP-GEF en.lighten initiative and GELC initiated this project and invited six lighting laboratories to participate.

The main purpose of this project was to analyze the test results from the participating laboratories, and by comparison with the reference laboratory, to identify potential testing issues in the participating laboratories and help the participating laboratories to identify differences between their own laboratory and the other participating laboratories. The project results and findings will then be beneficial for improving their testing capacity.

GELC, as the reference laboratory, developed the testing protocol (see Annex E) and the measurement methodology for the participating laboratories (Annex D); and organized all the comparison test activities in compliance with ISO/IEC 17043, *Conformity assessment - General requirements for proficiency testing*.

2. Description of Comparison Samples

This project was carried out through a star-type approach, as illustrated in Figure 2-1. GELC prepared six sets of samples and, as the reference laboratory, conducted tests twice for all six sets of sample. The first series of tests at GELC were carried out before the samples were shipped to the participating laboratories. Once the participating laboratories finished their testing, the test results, and the original set of samples, were returned to GELC. After receiving the samples back from the laboratories, GELC conducted the second series of tests.

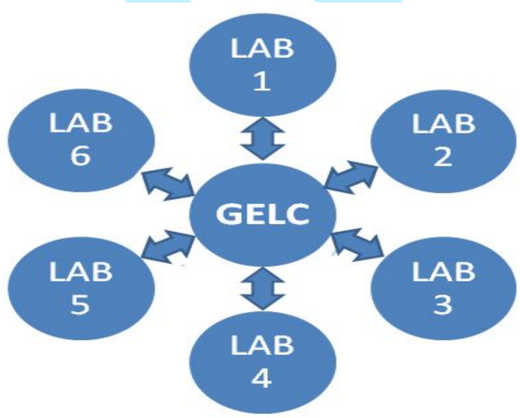

Figure 2-1 Star-type comparison

Each set of samples included three different kinds of LED lamps: omnidirectional, directional and high CCT. Table 2.1 gives the detailed rated parameters of each lamp and Table 2.2 summarizes the details of the individual lamps sent to each laboratory.

Table 2.1 Properties of comparison samples

Identifier	Lamp Type	Rated Voltage	Rated Power	Nominal CCT	Other Conditions
GELC-OD	Omnidirectional LED lamp	12V	4 W	2,700 K	Constant current: DC 0.330 A; Operating position: base up. ***Note: The center pin is positive "+"***
GELC-D	Directional LED lamp	220 V AC	8 W	3,000 K	AC frequency: 50 Hz; Operating position: base up
GELC-HCCT	High CCT LED lamp	220 V AC	6 W	5,000 K	
Note: The information listed above is the rated value of the sample.					

Table 2.2 Samples sent to each participating laboratory

Laboratory code	Samples sent to each laboratory
GELC-LAB-1	GELC-OD-1; GELC-D-1; GELC-HCCT-1
GELC-LAB-2	GELC-OD-2; GELC-D-2; GELC-HCCT-2
GELC-LAB-3	GELC-OD-8; GELC-D-3; GELC-HCCT-3
GELC-LAB-4	GELC-OD-7; GELC-D-4; GELC-HCCT4
GELC-LAB-5	GELC-OD-5; GELC-D-5; GELC-HCCT-5
GELC-LAB-6	GELC-OD-6; GELC-D-6; GELC-HCCT-6
Note 1: GELC-OD-3 was damaged by LAB-3 and GELC-OD-8 was sent to replace the damaged sample. *Note 2: GELC-OD-4 was damaged by LAB-4 and GELC-OD-7 was sent to replace the damaged sample.*	

3. Measurands

The following parameters were measured and recorded by each laboratory:

(1) Total luminous flux (lm)*

(2) RMS voltage (V) and RMS current (mA)

(3) Active power (W)*

(4) Luminous efficacy (lm/W)*

(5) Chromaticity x*and y*

(6) Correlated colour temperature (K)*

(7) General colour rendering index[1], referred to in this report as CRI*

(8) Power factor*

Note 1: Only the parameters marked with an asterisk (*) were compared and analyzed.

Note 2: Participating laboratories were requested to give all decimal places, providing at least four significant digits.

Note 3: All laboratories were requested to report uncertainty values for analyzing the test results. However, results without uncertainty values were also accepted.

Note 4: GELC-OD samples were tested by Direct Current (DC) and therefore power factor was not tested. GELC-D samples and GELC-HCCT samples were tested by Alternating Current(AC) and the power factor was tested.

4. Reference Values and Analysis Calculations

4.1 Reference Values

In this project, the comparison samples were tested twice by GELC. The first time before delivering to each participating laboratory, and the second time after they were returned from those laboratories. The test results obtained by GELC are presented in Annex A.

The reference value *(X)* is the average value of X_1 and X_2, and is calculated by:

$$X = \frac{X_1 + X_2}{2} \quad \text{Equation (1)}$$

Where:

X_1 is the value tested by GELC before delivering the comparison samples to participating

[1] Mean of the CIE 1974 special colour rendering indices for a specified set of 8 test colour samples

laboratories;

X_2 is the value tested by GELC after receiving comparison samples returned from the participating laboratories.

4.2 Analysis Calculations

The test results from participating laboratories are presented in Annex C. In accordance with *ISO 13528, Statistical methods for use in proficiency testing by inter-laboratory comparisons,* the relative differences of these test results to the reference values are calculated by Equations (2) and (3):.

For the value of active power consumption, total luminous flux and luminous efficacy, the relative difference ($\Delta X_{relative}$) between the results from each laboratory and the reference values is given by:

$$\Delta X_{relative} = \frac{x - X}{X} \qquad \text{Equation (2)}$$

Where:

x is the average testing result of each participating laboratory;
X is the GELC reference value.

For the value of power factor, chromaticity coordinates (x, y), correlated colour temperature (CCT), colour rendering index (CRI), the relative difference (ΔX) between the results from each laboratory and the assigned values is given by:

$$\Delta X = x - X \qquad \text{Equation (3)}$$

Where:

x is the average testing result of the participating laboratory;
X is the GELC reference value

5. Evaluation Calculations

In addition to the uncertainty values associated with their test results, the participating laboratories were requested to report the uncertainty values relating to more general laboratory factors, such as the equipment, standard artifact, and burning position.; Unfortunately, as not all of the participating laboratories provided these additional uncertainty values, it was not possible to use E_n *or z'* criteria to analyze the results[2]. For that reason, in this report, the test results were analyzed by *z*-score to give an evaluation of their performance. The uncertainties provided were used as additional information to evaluate the testing capacities of the participating laboratories that provided them.

The *z*-score (z) is calculated and determined by Equation (4):

$$z = (x - X)/\sigma \qquad \text{Equation (4)}$$

Where:

σ is the SDPA value (standard deviation for proficiency assessment). In this inter-laboratory comparison test, σ = 0.7413 x IQR (interquartile range)[3] of test results provided by participating laboratories;
x is the average testing result of the participating laboratory;
X is the reference value calculated by GELC.

If $|z| \leq 2$, it means the results are generally considered to be satisfactory;
If $2 < |z| < 3$, it means the results are considered to be questionable; and
If $|z| \geq 3$, it means the results are considered to be unsatisfactory.

6. Analysis of Relative Differences Between Participating Laboratory Results and GELC Reference Values for Each Laboratory

The relative differences between the measurement values of participating laboratories and the GELC reference values are shown in Tables 6.1 to 6.6. Each table refers to an individual laboratory and lists the differences of every parameter tested of each type of sample.

Table 6.1 Differences between GELC-LAB-1 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-1	-6.61%	-1.01%	0.0016	-5.66%	0.0059	0.0022	-74	-0.0232
GELC-OD-1	-3.20%	0.48%	/	-3.66%	-0.0010	-0.0002	14	-0.0277
GELC-HCCT-1	-5.66%	-0.95%	-0.0122	-4.76%	0.0042	0.0044	-174	0.1915

2 For detailed information about E_n *or* z', please refer to ISO 13528, Chapters 7.5 and 7.6.
3 Reference: APLAC PT 002, *Testing Interlaboratory Comparisons,* and CNAS GL02: 2014, *Guidelines for Verifying the Results of Statistical Processing and Capacity Assessment*.

Table 6.2 Differences between GELC-LAB-2 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-2	-8.94%	-1.40%	0.0204	-7.65%	-0.0024	-0.0047	1	0.8562
GELC-OD-2	-4.64%	1.47%	/	-4.90%	-0.0011	-0.0029	-6	0.6035
GELC-HCCT-2	-5.24%	-1.66%	-0.0118	-3.64%	-0.0035	-0.0065	209	2.5112

Table 6.3 Differences between GELC-LAB-3 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-3	-3.32%	0.75%	0.0242	-4.05%	-0.0023	-0.0020	22	0.3649
GELC-OD-8	-1.07%	1.42%	/	-2.45%	-0.0021	-0.0012	22	0.2570
GELC-HCCT-3	-3.46%	0.72%	0.0047	-4.15%	-0.0030	-0.0043	175	0.8433

Table 6.4 Differences between GELC-LAB-4 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-4	-5.40%	0.25%	0.0044	-5.64%	0.0014	-0.0002	-25	0.0559
GELC-OD-7	-2.02%	0.25%	/	-2.27%	-0.0003	-0.0006	0	0.4331
GELC-HCCT-4	-7.85%	0.40%	-0.0021	-8.22%	-0.0004	-0.0009	37	0.1660

Table 6.5 Differences between GELC-LAB-5 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-5	1.32%	0.12%	0.0155	1.21%	-0.0024	-0.0058	-16	0.7448
GELC-OD-5	1.34%	-0.01%	/	1.35%	-0.0005	-0.0043	-21	1.1845
GELC-HCCT-	0.63%	0.25%	-0.0048	0.37%	-0.0029	-0.0079	154	1.4440

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Table 6.6 Differences between GELC-LAB-6 measured values and the GELC reference values

Identifier	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI
GELC-D-6	-5.33%	-1.22%	0.0254	-4.16%	-0.0002	0.0032	30	-0.7569
GELC-OD-6	0.18%	1.14%	/	-0.95%	-0.0048	0.0007	79	-0.5892
GELC-HCCT-6	-3.05%	-2.26%	0.0007	-0.81%	-0.0024	0.0006	108	-0.5908

7. Analysis of Relative Differences Between Participating Laboratory Results and GELC Reference Values for Each Measurand

The (relative) differences of results for each measurand between each participating laboratory and GELC are summarized in the following subsections. In each figure:

······ represents relative expanded uncertainty of the GELC reference value, X (where the coverage factor, $k = 2$);

◆ represents the relative difference between the participating laboratories' measurement values and the GELC reference values, (x - X)/X;

I represents the error bars which show the uncertainties of measurement (expanded uncertainty with a coverage factor, k =2) of the participating laboratories

7.1 Total Luminous Flux

Figure 7-1 shows the relative differences in total luminous flux for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-1 shows that the test result deviation of GELC-LAB-5 is within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of the GELC-LAB-3 test result is within the reference laboratory uncertainty. However, the test result uncertainty bars of the other four laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-4 and GELC-LAB-6) are outside the uncertainty of the reference laboratory.

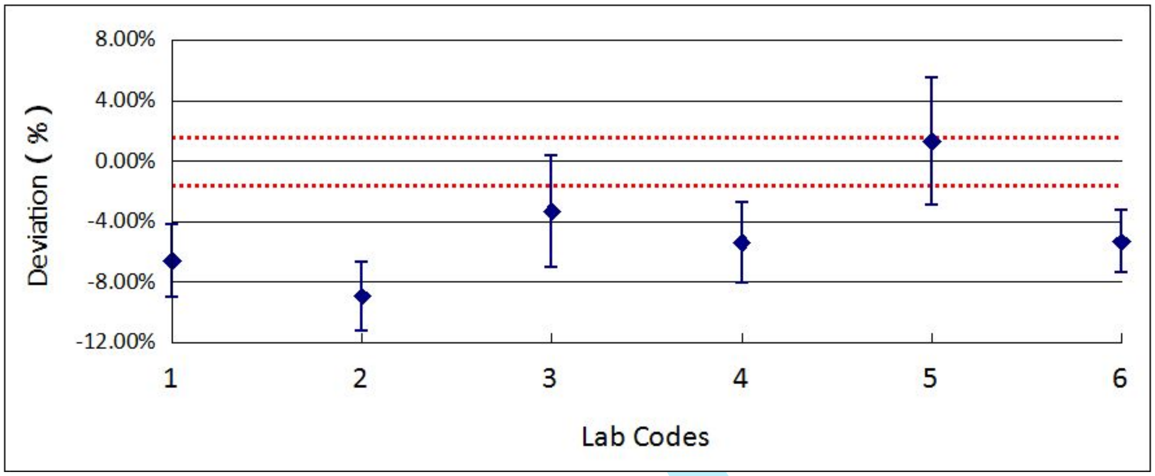

Figure 7-1 Relative differences (participant) of total luminous flux for GELC-D samples

Figure 7-2 shows the relative differences in total luminous flux for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-2 shows that the test result deviations of GELC-LAB-3, GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6 are within the uncertainty of reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-1 is within the reference laboratory uncertainty. However, the test result uncertainty bar of GELC-LAB-2 is outside the uncertainty of the reference laboratory.

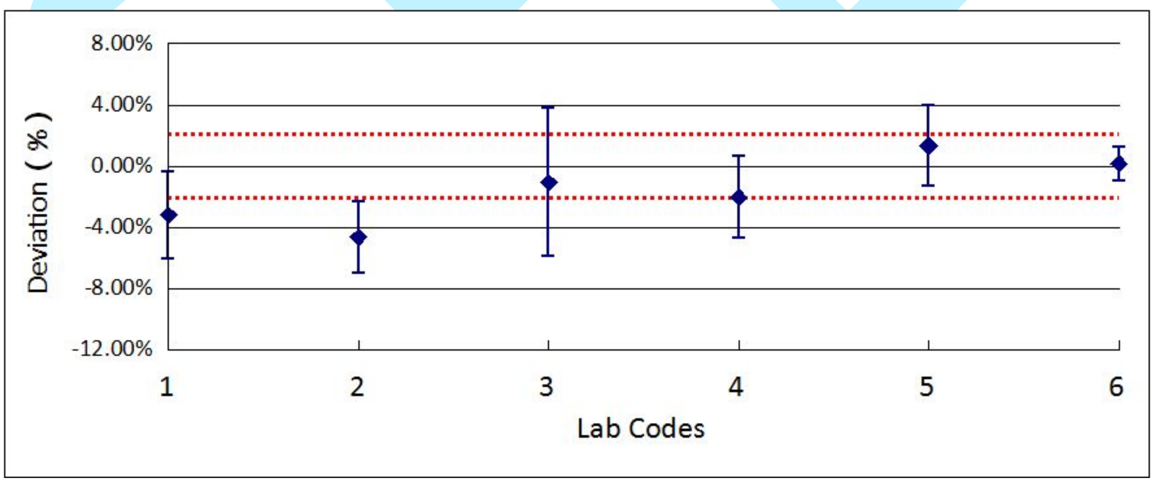

Figure 7-2 Relative differences (participant) of total luminous flux for GELC-OD samples

Figure 7-3 shows the relative differences in total luminous flux for the GELC-HCCT samples between the participants' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-3 shows that the test result deviation of GELC-LAB-5 is within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of the GELC-LAB-3 and GELC-LAB-6 are within the reference laboratory uncertainty. However, the test result uncertainty bars of the other three laboratories (GELC-LAB-1, GELC-LAB-2 and GELC-LAB-4) are outside the uncertainty of the reference laboratory.

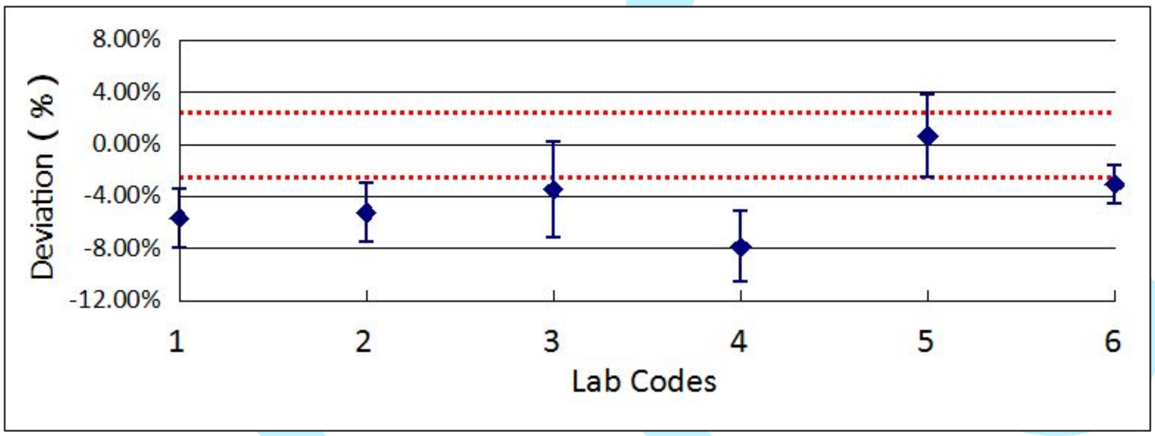

Figure 7-3 Relative differences (participant) of total luminous flux for GELC-HCCT samples

7.2 Active Power

Figure 7-4 shows the relative differences in active power consumption for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-4 shows that the test result deviations of three laboratories, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-5, are inside the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of the other three laboratories (GELC-LAB-1, GELC-LAB-2 and GELC-LAB-6) are within the reference laboratory uncertainty.

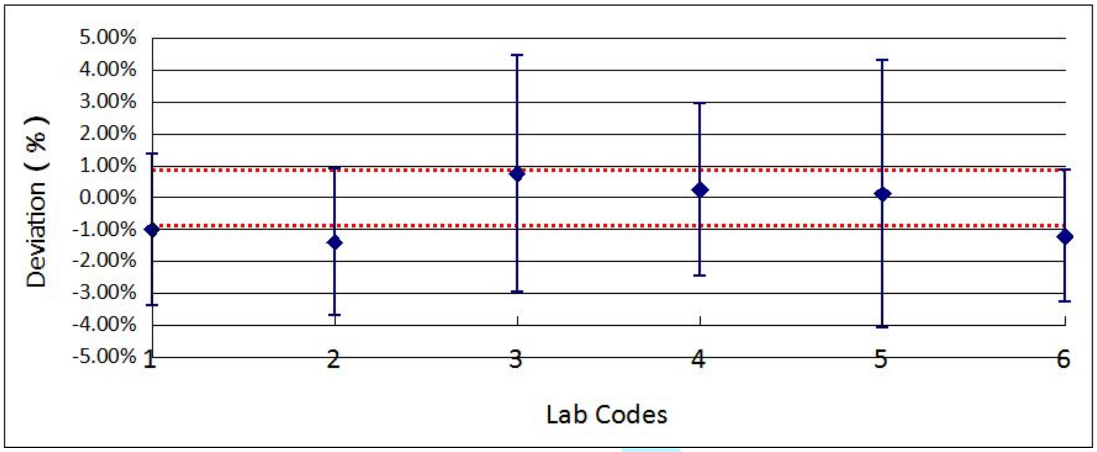

Figure 7-4 Relative differences (participant) of active power for GELC-D samples

Figure 7-5 shows the relative differences in active power consumption for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-5 shows that the test result deviations of three laboratories (GELC-LAB-1, GELC-LAB-4 and GELC-LAB-5) are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-3 is within the reference laboratory uncertainty. However, the test result uncertainty bars of GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It can also be seen that the reported uncertainty values of GELC-LAB-1, GELC-LAB-2 and GELC-LAB-6 are very small.

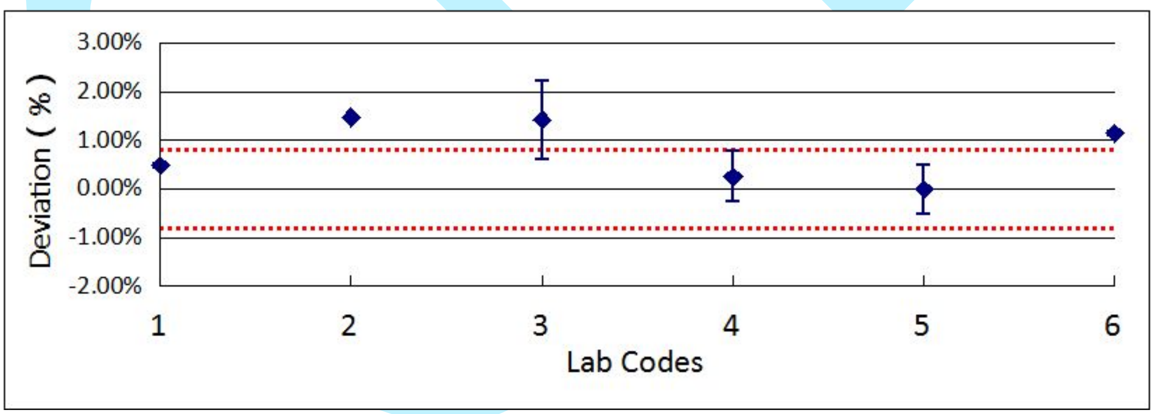

Figure 7-5 Relative differences (participant) of active power for GELC-OD samples

Figure 7-6 shows the relative differences in active power consumption for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-6 shows that the test result deviation of two laboratories (GELC-LAB-4 and GELC-LAB-5) are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-3 is within the reference laboratory uncertainty. However, the test result uncertainty bars of GELC-LAB-1, GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It can also be seen that the reported uncertainty values of GELC-LAB-1, GELC-LAB-2 and GELC-LAB-6 are very small.

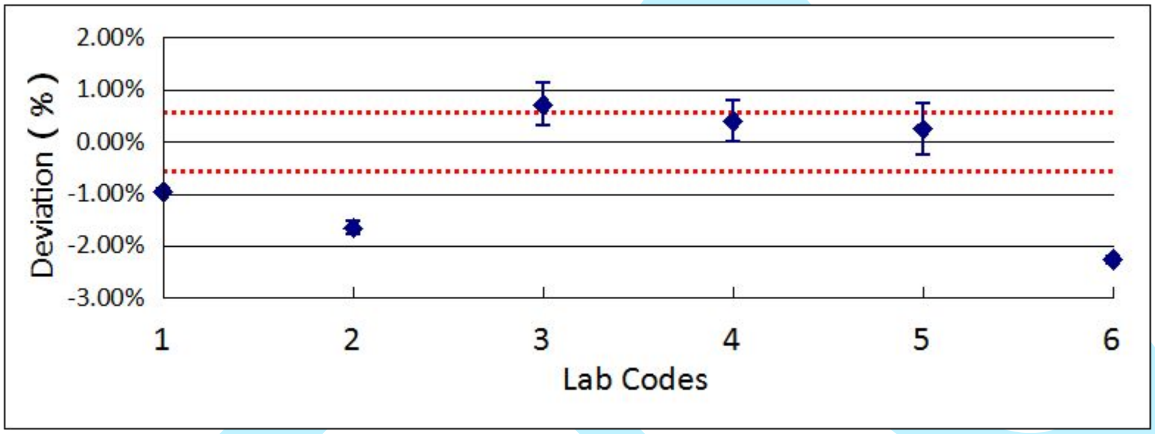

Figure 7-6 Relative differences (participant) of active power for GELC-HCCT samples

7.3 Luminous Efficacy

Figure 7-7 shows the relative differences in luminous efficacy for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-7 shows that the test result deviation of GELC-LAB-5 was within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-3 is within the reference laboratory uncertainty. However, the test result uncertainty bars of the other four laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-4 and GELC-LAB-6) are outside the uncertainty of the reference laboratory.

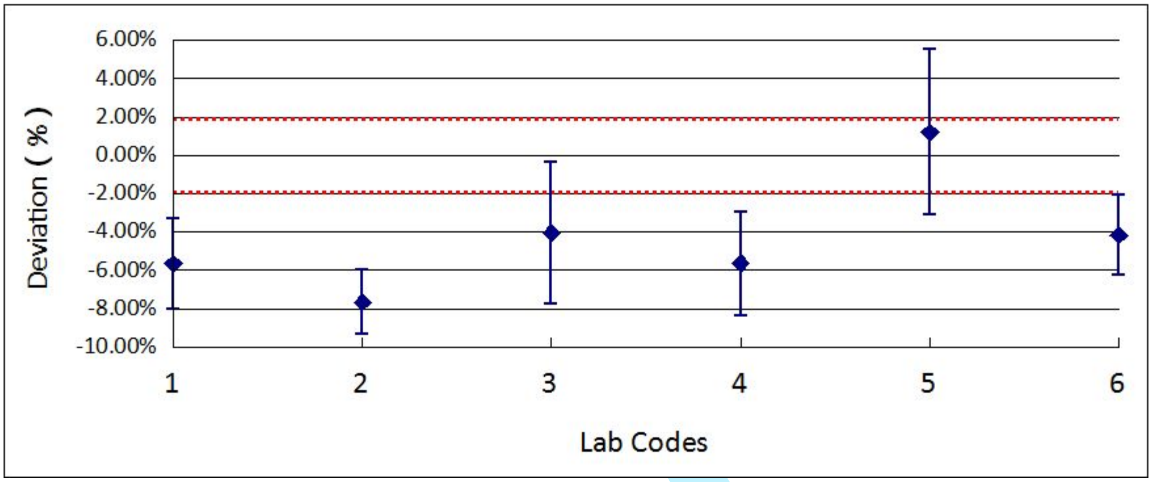

Figure 7-7 Relative differences (participant) of luminous efficacy for GELC-D samples

Figure 7-8 shows the relative differences in luminous efficacy for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-8 shows that the test result deviations of GELC-LAB-5 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-1, GELC-LAB-3 and GELC-LAB-4 are within the reference laboratory uncertainty. However, the test result uncertainty bar of GELC-LAB-2 is outside the uncertainty of the reference laboratory.

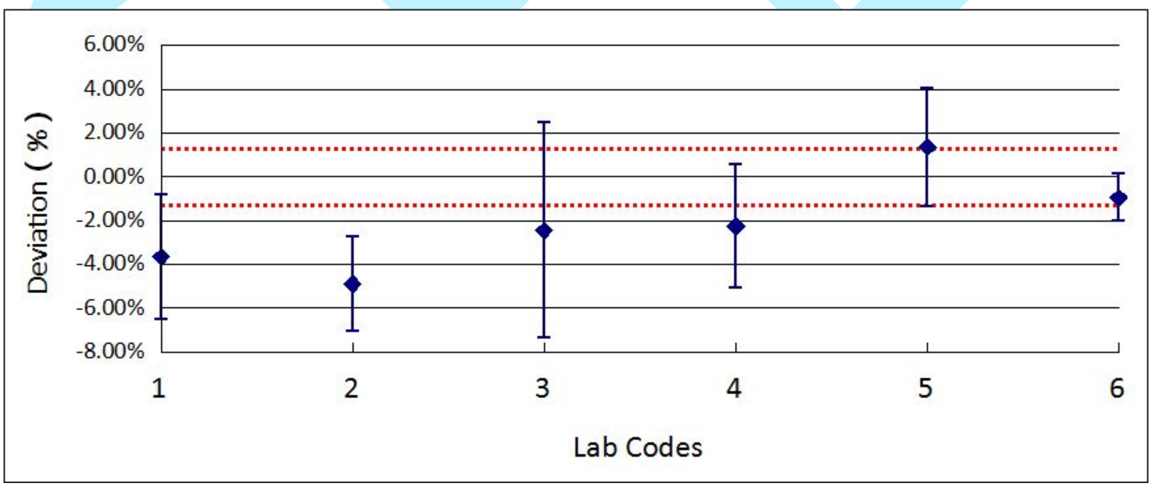

Figure 7-8 Relative differences (participant) of luminous efficacy for GELC-OD samples

Figure 7-9 shows the relative differences in luminous efficacy for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The relative differences are calculated by Equation (2). Figure 7-9 shows that the test result deviations of GELC-LAB-5 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-1, GELC-LAB-2 and GELC-LAB-3 are within the reference laboratory uncertainty. However, the test result uncertainty bar of GELC-LAB-4 is outside the uncertainty of the reference laboratory.

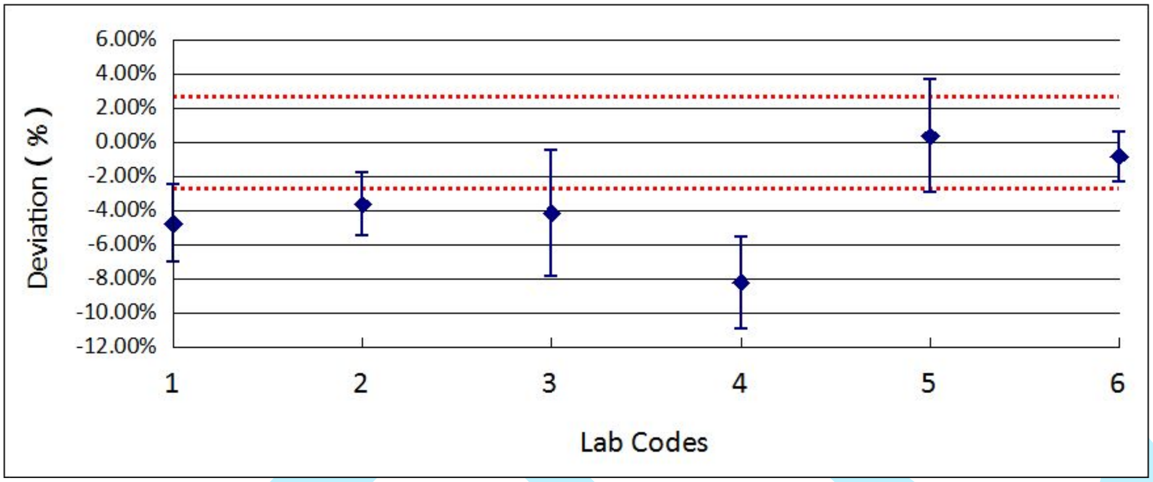

Figure 7-9 Relative differences (participant) of luminous efficacy for GELC-HCCT samples

7.4 Chromaticity x

Figure 7-10 shows the deviation in chromaticity x for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-10 shows the test result deviations of GELC-LAB-2, GELC-LAB-3, GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-1 is within the reference laboratory uncertainty.

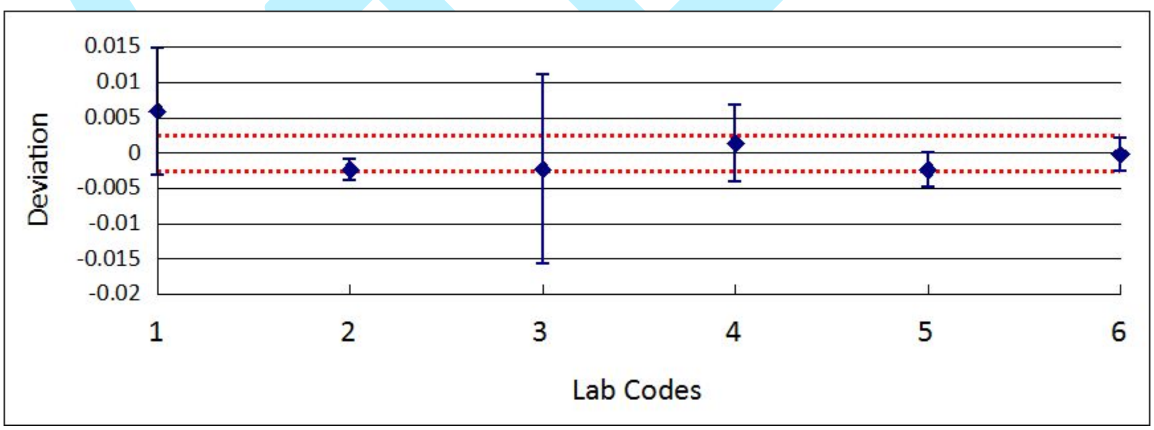

Figure 7-10 Differences (participant) of chromaticity x for GELC-D samples

Figure 7-11 shows the deviation in chromaticity x for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-11 shows the test result deviation of GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-5 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-6 is within the reference laboratory uncertainty.

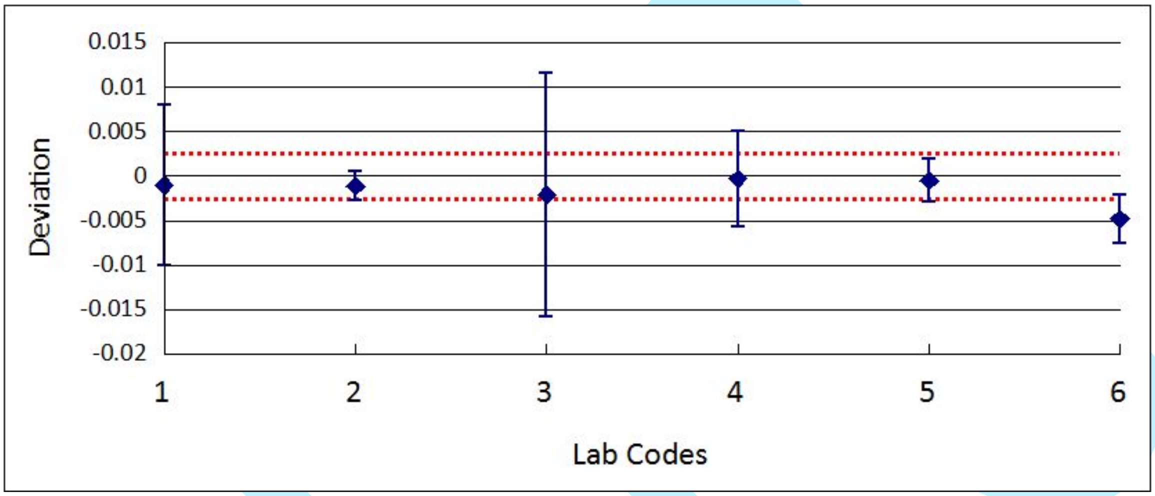

Figure 7-11 Differences (participant) of chromaticity x for GELC-OD samples

Figure 7-12 shows the deviation in chromaticity x for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-12 shows that the test result deviations of GELC-LAB-4 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of other four laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-3 and GELC-LAB-5) are within the reference laboratory uncertainty.

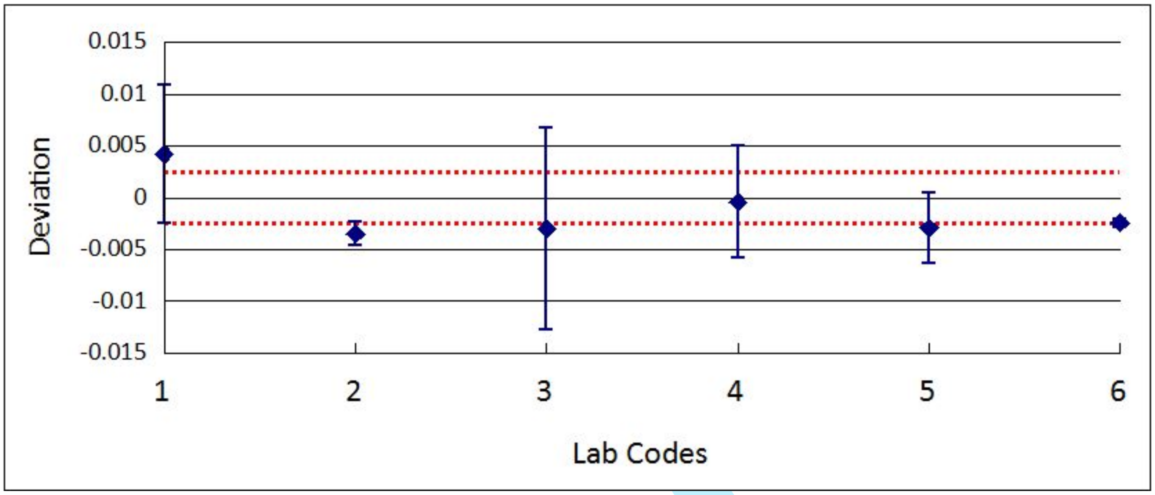

Figure 7-12 Differences (participant) of chromaticity x for GELC-HCCT samples

7.5 Chromaticity y

Figure 7-13 shows the deviation in chromaticity y for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-13 shows that the test result deviation of GELC-LAB-1, GELC-LAB-3 and GELC-LAB-4 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-5 and GELC-LAB-6 are within the reference laboratory uncertainty. However, the test result uncertainty bar of GELC-LAB-2 is outside the uncertainty of the reference laboratory.

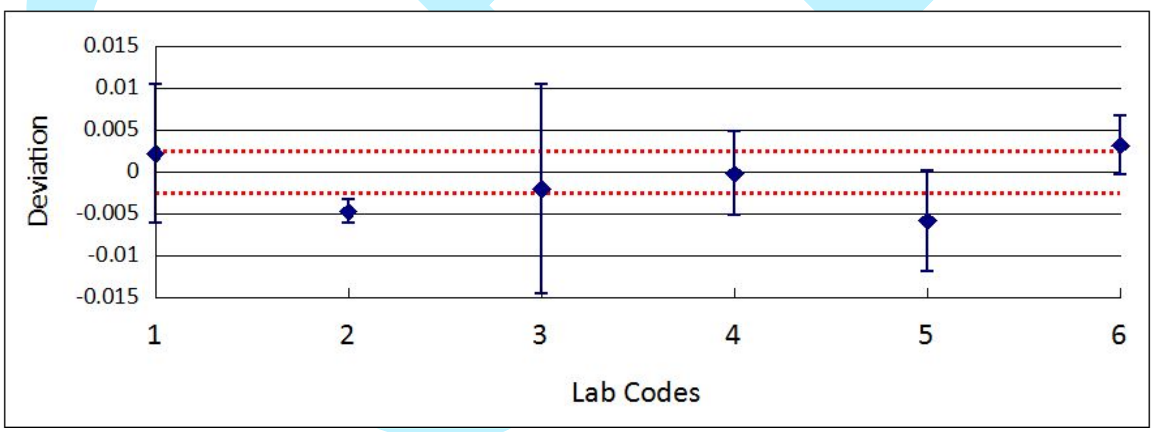

Figure 7-13 Differences (participant) of chromaticity y for GELC-D samples

Figure 7-14 shows the deviation in chromaticity y for the GELC-OD samples between the participant's measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-14 shows that the test result deviation of GELC-LAB-1, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of the other two laboratories (GELC-LAB-2 and GELC-LAB-5) are within the reference laboratory uncertainty.

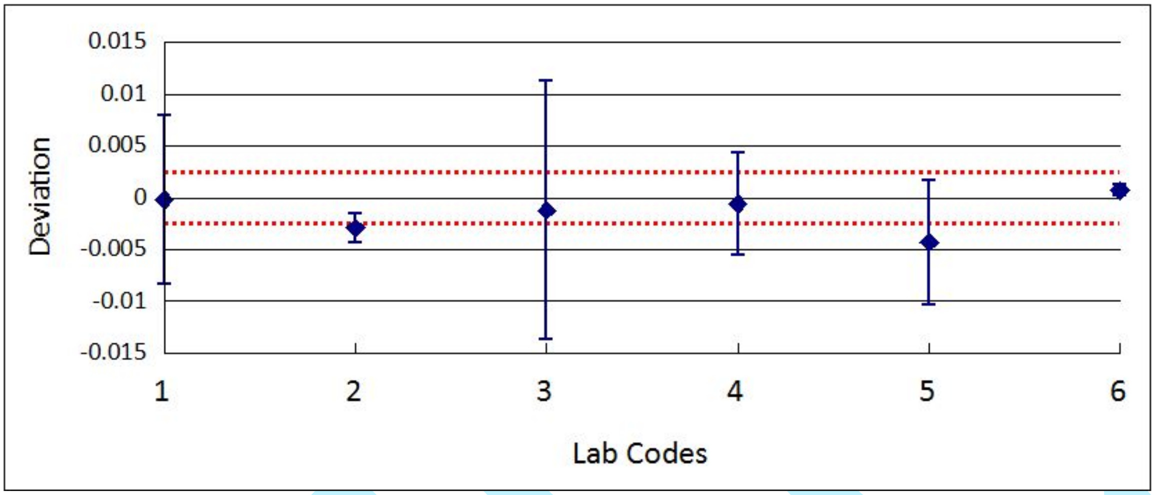

Figure 7-14 Differences (participant) of chromaticity y for GELC-OD samples

Figure 7-15 shows the deviation in chromaticity y for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-15 shows that the test result deviations of GELC-LAB-4 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-1, GELC-LAB-3 and GELC-LAB-5 are within the reference laboratory uncertainty. However, the test result uncertainty bar of GELC-LAB-2 is outside the uncertainty of the reference laboratory.

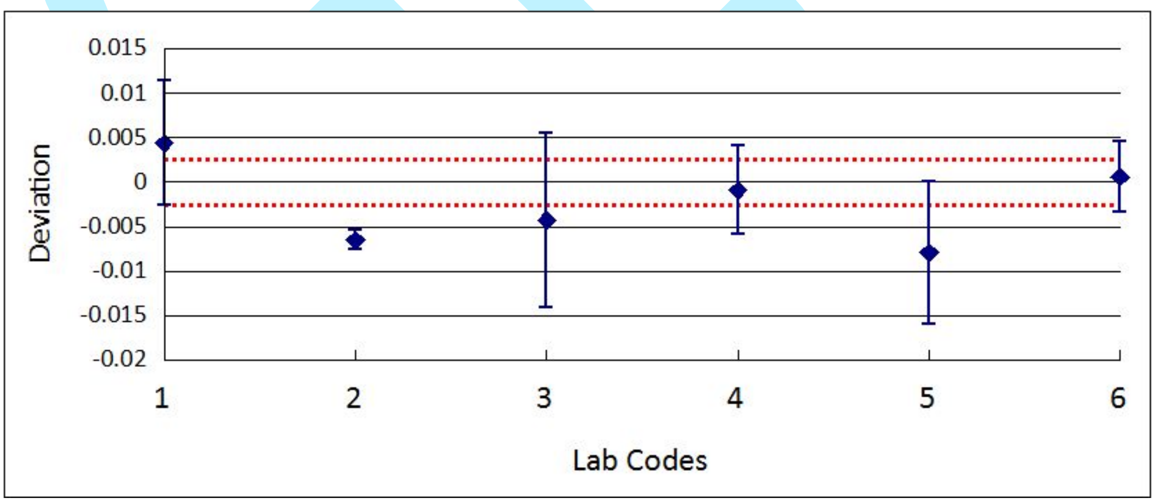

Figure 7-15 Differences (participant) of chromaticity y for GELC-HCCT samples

7.6 Correlated Color Temperature (CCT)

Figure 7-16 shows the deviation in CCT for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-16 shows that the test result deviations of GELC-LAB-2, GELC-LAB-3, GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the test result uncertainty bar of GELC-LAB-1 is within the reference laboratory uncertainty.

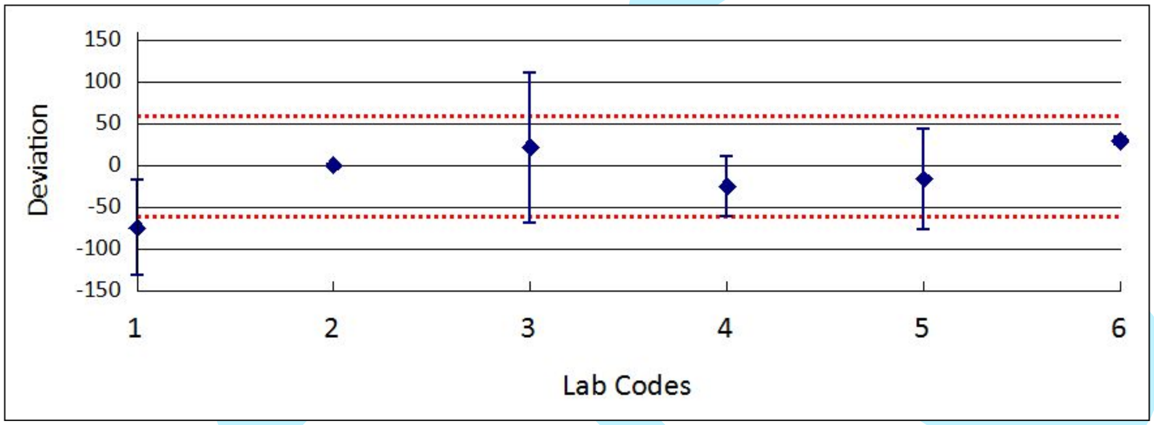

Figure 7-16 Differences (participant) of CCT for GELC-D samples

Figure 7-17 shows the deviation in CCT for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-17 shows that the test result deviations of GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-5 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the test result uncertainty bar of GELC-LAB-6 is within the reference laboratory uncertainty.

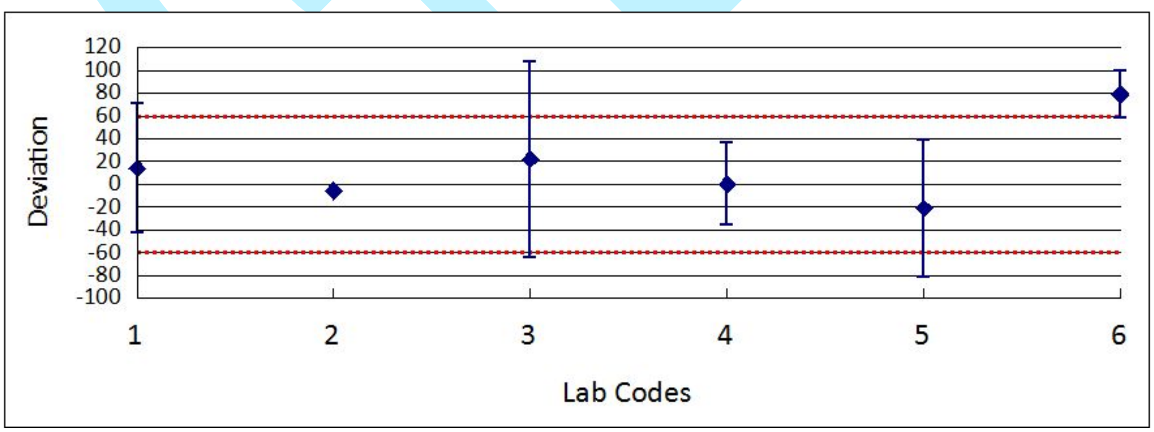

Figure 7-17 Differences (participant) of CCT for GELC-OD samples

Figure 7-18 shows the deviation in CCT for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-18 shows the test result deviation of GELC-LAB-4 is within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-3 and GELC-LAB-5 are within the reference laboratory uncertainty. However, uncertainty bars of GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It can also be seen that the reported uncertainty values of GELC-LAB-2 and GELC-LAB-6 were very small.

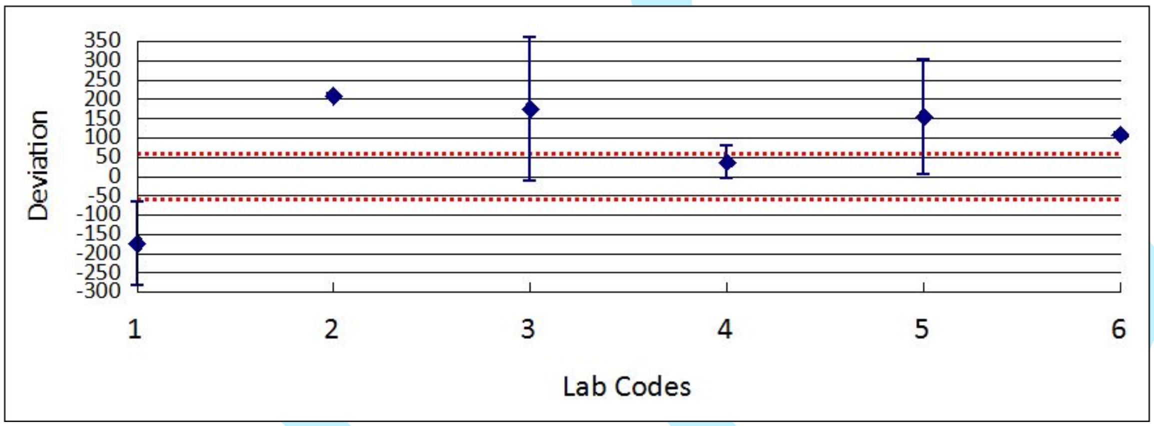

Figure 7-18 Differences (participant) of CCT for GELC-HCCT samples

7.7 Colour Rendering Index (CRI)

Figure 7-19 shows the differences of CRI results for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-19 shows the test result deviations of GELC-LAB-1, GELC-LAB-3 and GELC-LAB-4 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bar of GELC-LAB-5 is within the reference laboratory uncertainty. However, the uncertainty bars of GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It can also be seen that the reported uncertainty values of GELC-LAB-2 and GELC-LAB-6 were very small.

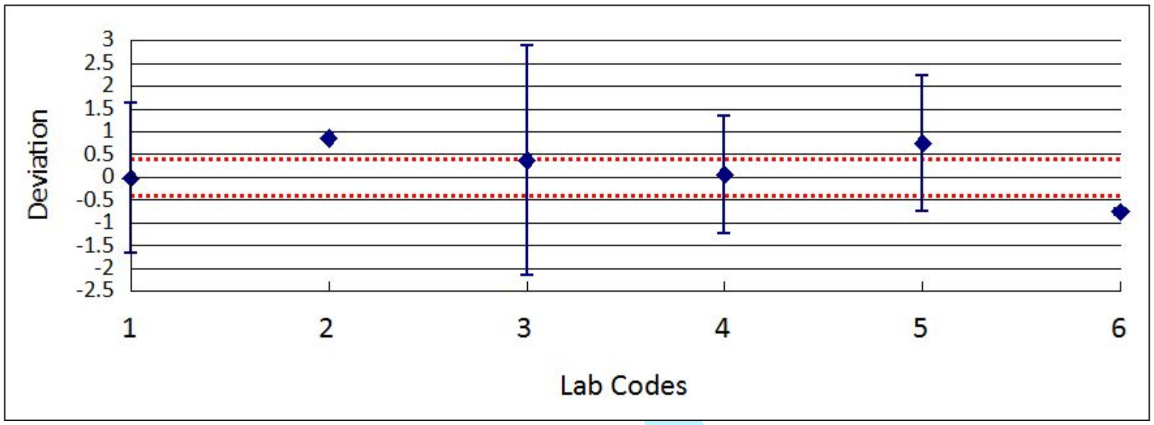

Figure 7-19 Differences (participant) of CRI for GELC-D samples

Figure 7-20 shows the deviation in CRI for the GELC-OD samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-20 shows that the test result deviations of GELC-LAB-1 and GELC-LAB-3 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-4 and GELC-LAB-5 are within the reference laboratory uncertainty. However, the uncertainty bars of GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It can also be seen that the reported uncertainty values of GELC-LAB-2 and GELC-LAB-6 were very small.

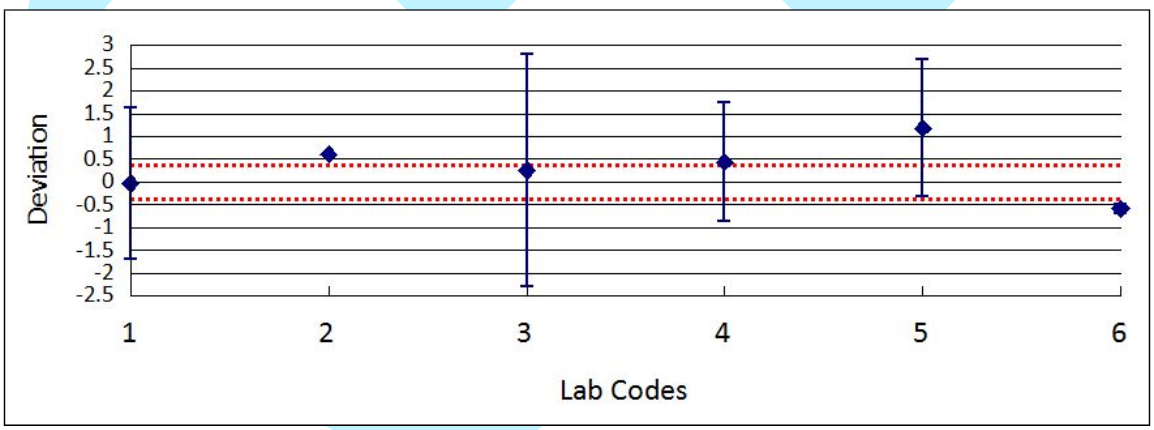

Figure 7-20 Differences (participant) of CRI for GELC-OD

Figure 7-21 shows the deviation in CRI for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-21 shows that the test result deviations of GELC-LAB-1 and GELC-LAB-4 are within the uncertainty of the reference laboratory. Considering the uncertainty of the participating laboratories, the uncertainty bars of GELC-LAB-3 and GELC-LAB-5 are within the reference laboratory uncertainty. However, the uncertainty bars of GELC-LAB-2 and GELC-LAB-6 are outside the uncertainty of the reference laboratory. It also can be seen that the reported uncertainty values of GELC-LAB-2 and GELC-LAB-6 were very small.

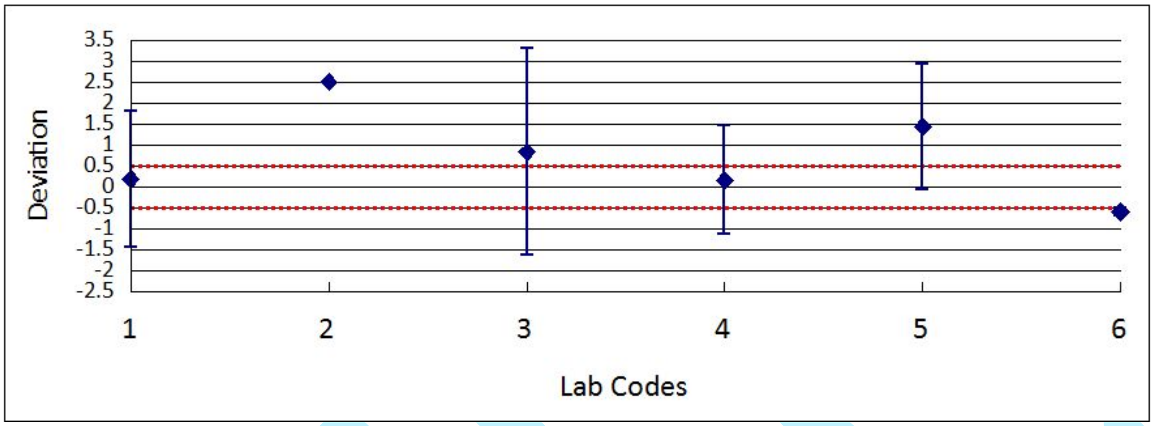

Figure 7-21 Differences (participant) of CRI for GELC-HCCT samples

7.8 Power Factor

Figure 7-22 shows the deviation in power factor for the GELC-D samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-22 shows that the test result deviations of GELC-LAB-1 and GELC-LAB-4 are within the uncertainty scope of reference laboratory. The participating laboratories were not required to submit uncertainty values for power factor measurements to the reference laboratory.

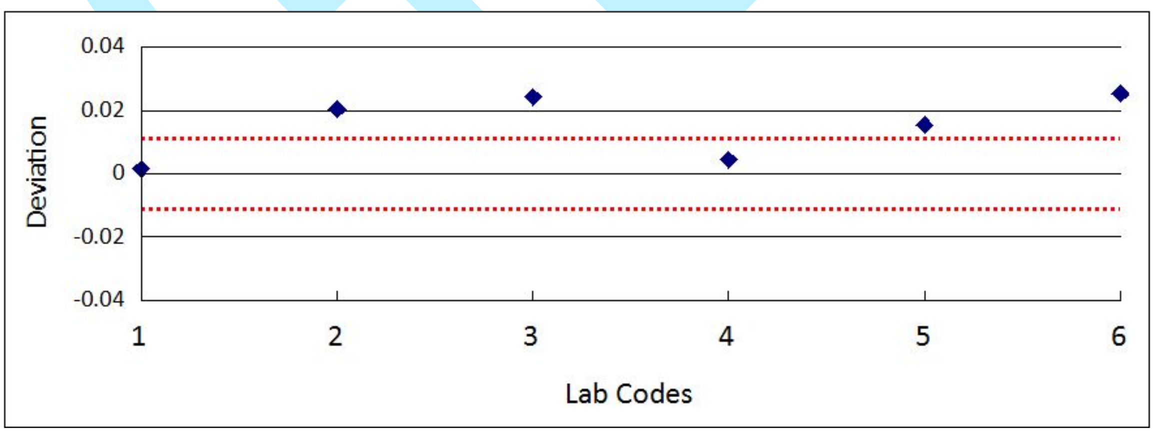

Figure 7-22 Differences (participant) of power factor for GELC-D samples

Figure 7-23 shows the deviation in power factor for the GELC-HCCT samples between the participating laboratories' measurement values and the GELC reference values. The differences are calculated by Equation (3). Figure 7-23 shows that the test result deviations of GELC-LAB-4 and GELC-LAB-6 are within the uncertainty scope of reference laboratory. The participating laboratories were not required to submit uncertainty values for power factor measurements to the reference laboratory.

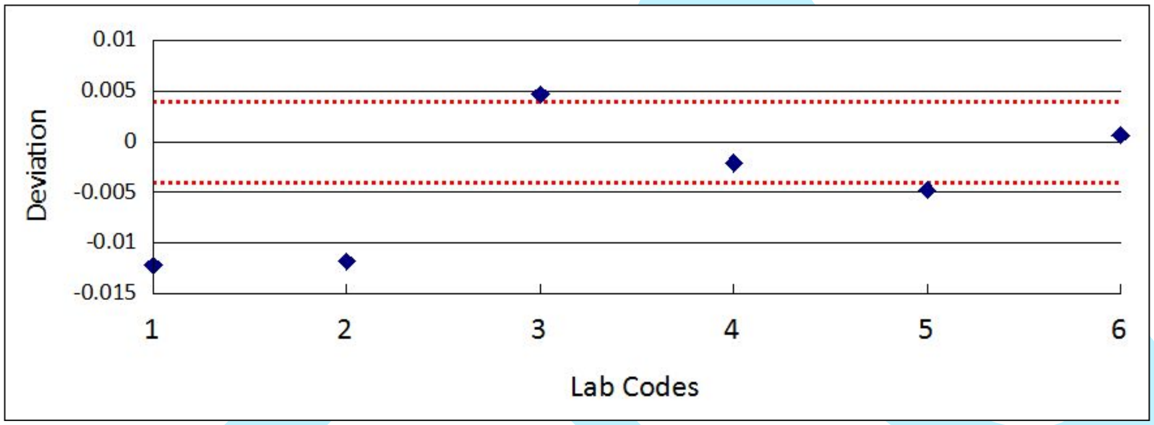

Figure 7-23 Differences (participant) of power factor for GELC-HCCT samples

8. Evaluation of Performance

As discussed in Section 5, some laboratories provided the uncertainty values along with the test results, but other laboratories did not calculate their uncertainties. Therefore, in this report the z-score is used to analyze the test results and provide an evaluation of the performance of the participating laboratories. The z-score is calculated by Equation (4), as described in Section 5, and:

$|Z|$≤2 is generally considered to be satisfactory.

2$<|Z|<$3 is considered to be questionable.

$|Z|$≥3 is considered to be unsatisfactory.

This section discusses the z-score analysis for the results from the participating laboratories and possible reasons for the deviations in the photometric, electrical and colour parameters.

8.1 Laboratory z-score Analysis, by Type of Sample Lamp

Table 8.1 shows the z-score of each participating laboratory for sample GELC-D (directional LED lamps). For the total luminous flux measurement, the test results of GELC-LAB-3 and GELC-LAB-5 are satisfactory; the test results of GELC-LAB-4 and GELC-LAB-6 are questionable; and the test results of GELC-LAB-1 and GELC-LAB-2 are unsatisfactory. For the active power, chromaticity y and CRI measurements, all of the test results are satisfactory. For power factor, the test results of GELC-LAB-3 and GELC-LAB-6 are questionable and the other four laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-4 and GELC-LAB-5) are satisfactory. For the luminous efficacy measurement, the test results of GELC-LAB-5 are satisfactory, but the test results of the other five laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-6) are unsatisfactory. For chromaticity x and CCT, the test result of GELC-LAB-1 is questionable and other five laboratories are satisfactory.

Table 8.1 z-score for GELC-D samples

	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT	CRI
GELC-LAB-1	-3.59	-0.99	0.13	-4.84	2.36	0.53	-2.53	-0.05
GELC-LAB-2	-4.85	-1.37	1.70	-6.54	-0.96	-1.13	0.03	1.77
GELC-LAB-3	-1.80	0.73	2.03	-3.46	-0.92	-0.48	0.75	0.75
GELC-LAB-4	-2.93	0.24	0.37	-4.82	0.56	-0.05	-0.85	0.12
GELC-LAB-5	0.72	0.12	1.30	1.03	-0.96	-1.39	-0.55	1.54
GELC-LAB-6	-2.89	-1.19	2.12	-3.56	-0.08	0.77	1.02	-1.56

Table 8.2 shows the z-score of each participating laboratory for sample GELC-OD (omnidirectional LED lamps). For the total luminous flux measurement, the test result of GELC-LAB-2 is questionable; the test results of other five laboratories are satisfactory. For active power, the test results of all the participating laboratories are satisfactory. For luminous efficacy, the test results of four laboratories (GELC-LAB-3, GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6) are

satisfactory; the test result of GELC-LAB-1 is questionable; and the test results of GELC-LAB-2 is unsatisfactory. For chromaticity x, the test results of four laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-4 and GELC-LAB-5) are satisfactory; the test results of GELC-LAB-3 is questionable; and the test results of GELC-LAB-6 is unsatisfactory. For chromaticity y, the test result of GELC-LAB-5 is questionable and those of the other five laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-6) are satisfactory. For CCT, the test result of GELC-LAB-6 is unsatisfactory and results of the other five laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-5) are satisfactory. For CRI, the test results of GELC-LAB-5 is unsatisfactory and the results of the other five laboratories (GELC-LAB-1, GELC-LAB-2, GELC-LAB-3, GELC-LAB-4 and GELC-LAB-6) are satisfactory.

Table 8.2 z-score for GELC-OD samples

	Total luminous flux	Active power	Luminous efficacy	Chromaticity x	Chromaticity y	CCT	CRI
GELC-LAB-1	-1.56	0.62	-2.38	-1.10	-0.12	0.77	-0.07
GELC-LAB-2	-2.26	1.91	-3.18	-1.21	-1.80	-0.33	1.57
GELC-LAB-3	-0.52	1.84	-1.59	-2.31	-0.74	1.21	0.67
GELC-LAB-4	-0.98	0.33	-1.47	-0.33	-0.37	0.00	1.13
GELC-LAB-5	0.65	-0.02	0.88	-0.55	-2.67	-1.16	3.09
GELC-LAB-6	0.09	1.48	-0.62	-5.29	0.43	4.35	-1.54

Table 8.3 shows the z-score of each participating laboratories for sample GELC-HCCT (high CCT LED lamps). For the total luminous flux measurement, the test results of GELC-LAB-3, GELC-LAB-5 and GELC-LAB-6 are satisfactory; the test results of GELC-LAB-2 is questionable; and the test results of GELC-LAB-1 and GELC-LAB-4 are unsatisfactory. For active power, power factor and chromaticity y, the test results of all participating laboratories are satisfactory. For luminous efficacy, the test results of four laboratories (GELC-LAB-2, GELC-LAB-3, GELC-LAB-5 and GELC-LAB-6) are satisfactory; the test result of GELC-LAB-1 is questionable; and the test results

of GELC-LAB-4 are unsatisfactory. For chromaticity x, the test results of GELC-LAB-1 and GELC-LAB-2 are questionable; the test results of other four laboratories (GELC-LAB-1, GELC-LAB-3, GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6) are satisfactory. For CCT, the test results of three laboratories (GELC-LAB-4, GELC-LAB-5 and GELC-LAB-6) are satisfactory; the test results of other three laboratories (GELC-LAB-1, GELC-LAB-2 and GELC-LAB-3) are questionable. For CRI, the test result of GELC-LAB-2 is unsatisfactory and the results for the other five laboratories (GELC-LAB-1, GELC-LAB-3, GELC-LAB-4 GELC-LAB-5 and GELC-LAB-6) are satisfactory.

Table 8.3 z-score for GELC-HCCT samples

	Total luminous flux	Active power	Power factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT	CRI
GELC-LAB-1	-3.18	-0.70	-1.64	-2.08	2.73	0.96	-2.04	0.23
GELC-LAB-2	-2.94	-1.21	-1.59	-1.59	-2.28	-1.42	2.45	3.02
GELC-LAB-3	-1.94	0.52	0.63	-1.81	-1.95	-0.94	2.05	1.01
GELC-LAB-4	-4.40	0.29	-0.28	-3.59	-0.26	-0.20	0.43	0.20
GELC-LAB-5	0.35	0.18	-0.64	0.16	-1.89	-1.73	1.81	1.74
GELC-LAB-6	-1.71	-1.65	0.09	-0.35	-1.56	0.13	1.27	-0.71

8.2 Photometric Quantities Measurements

Table 9.1 shows the z-scores for total luminous flux. For sample GELC-D, the z-score calculated from the test results reported by GELC-LAB-1 and GELC-LAB-2, are greater than 3, which is considered to be unsatisfactory; the z-score calculated from test results reported by GELC-LAB-4 and GELC-LAB-6 are between 2 and 3, which means they are questionable. For samples GELC-HCCT, the z-score calculated from test results reported by GELC-LAB-1 and GELC-LAB-4, are greater than 3, which is considered to be unsatisfactory; the z-score calculated from test results reported by GELC-LAB-2 is between 2 and 3, which means they are questionable. For samples GELC-OD, there is no z-score above 3, and only the calculation from the test results reported by GELC-LAB-2 is between 2 and 3, which means it is questionable.

Table 8.4 z-score for total luminous flux

	z-score of GELC-D	z-score of GELC-OD	z-score of GELC-HCCT
GELC-LAB-1	-3.59	-1.56	-3.18
GELC-LAB-2	-4.85	-2.26	-2.94
GELC-LAB-3	-1.80	-0.52	-1.94
GELC-LAB-4	-2.93	-0.98	-4.40
GELC-LAB-5	0.72	0.65	0.35
GELC-LAB-6	-2.89	0.09	-1.71

The possible reasons for the deviations found in the test results are:

A) Traceability of the standard artifact

Laboratories should ensure that traceability of the standard artifact is reliable. This includes two aspects:

1) The calibration laboratory can provide highly reliable data.
2) Laboratories calibrate the integrating sphere system using the standard artifacts at the state at which the artifact was calibrated.

In this inter-laboratory comparison testing, the main purpose of testing GELC-OD sample is to inspect the traceability of the standard artifact. From the above analysis, GELC-LAB-2 showed a questionable test results on GELC-OD lamps. It is likely that GELC-LAB-2 needs to check their traceability process.

B) Sphere spatial non-uniformity correction

The integrating sphere system does not always stay at an ideal condition. For example, if there is too much dirt inside the sphere or there is an irregular stained or blemished area on the sphere, the reflectance of the sphere will be non-uniform. When there is a different light distribution between the standard artifacts and tested artifacts, the non-uniform reflection will lead to test errors. If a laboratory does not consider this element, and makes no data correction, it will cause a large numerical deviation. In general, as the light distribution difference increases, the luminous flux deviation will increase, especially for samples which have a narrow beam angle (such as the GELC-D tested in this project). So when using a sphere system to test the samples with narrow beam angle, more attention must be paid to the spatial non-uniformity correction.

In this project, the total luminous flux test results of GELC-D-1# and GELC-D-2# reported by GELC-LAB-1 and GELC-LAB-2 are much smaller than the reference values. While the other two samples, GELC-OD and GELC HCCT, tested by these two laboratories also have smaller results than the reference values. For the GELC-D samples, the relative deviations are both over than 6%. We would suggest GELC-LAB-1 and GELC-LAB-2 check their integrating spheres, especially at the bottom.

C) Self-absorption correction

Normally, the standard artifacts and the tested artifacts have differences in shapes, size, colour, etc. If a laboratory does not make a self-absorption correction, test results will deviate. In this project, it is not clear if GELC-LAB-2 and GELC-LAB-3 have made a self-absorption correction on their test data, as it wasn't mentioned in their final test report. However we would suggest that the laboratories conduct a self-absorption correction for all samples.

D) Near-Field absorption

If the lamp holder is very big, or there are other objects hanging near the sample, it will cause some light to be absorbed by those objects and lead to luminous flux data errors.

E) Others

All the factors mentioned above are problems that have been found in the test results of this project. However, in general testing there may be other influences on the test result. Although they are not obvious from this project, it is very important they are included in this report for the laboratories. Namely, the laboratories also need to focus on the following factors in their testing:

a) Testing procedures. During the testing, the precise details of the operation steps will directly affect the testing results. The burning position and direction of the sample in the sphere may lead to larger deviations from reference value(s).

b) Ambient temperature has an influence on the sample and solid state lighting products are sensitive to temperature. Only considering the temperature outside of the sphere during the testing, without paying attention to the temperature inside, will affect the photometric quantities measurements. Small sized integrating spheres in particular may have this problem due to the heat accumulating when burning the lamps inside.

8.3 Colorimetric Quantities Measurements

Table 8.5 shows the z-score for colour parameters. For GELC-LAB-6, the z-score of chromaticity x and CCT are greater than 3 on sample GELC-OD, which is considered to be unsatisfactory. For GELC-LAB-5, the z-score of CRI is greater than 3 on sample GELC-OD, which is considered to be unsatisfactory. For GELC-LAB-2, the z-score of CRI is greater than 3 on sample GELC-HCCT, which is considered to be unsatisfactory.

For GELC-LAB-1, the z-score for chromaticity x and CCT on samples GELC-D and GELC-HCCT are between 2 and 3, which means questionable. For GELC-LAB-2, the z-score for chromaticity x and

CCT on samples GELC-HCCT is between 2 and 3, which means questionable. For GELC-LAB-3, the z-score for chromaticity x on samples GELC-OD and z-score for CCT on GELC-HCCT are between 2 and 3, which means questionable. For GELC-LAB-5, the z-score for chromaticity y on samples GELC-OD is between 2 and 3, which means questionable.

Table 8.5 z-score for colour parameters

	Chromaticity x			Chromaticity y			Correlated Color Temperature (CCT)			Colour Rendering Index		
	GELC-D	GELC-OD	GELC-HCCT	GELC-D	GELC-OD	GELC-HCCT	GELC-D	GELC-OD	GELC-HCCT	GELC-D	GELC-OD	GELC-HCCT
GELC-LAB-1	2.36	-1.10	2.73	0.53	-0.12	0.96	-2.53	0.77	-2.04	-0.05	-0.07	0.23
GELC-LAB-2	-0.96	-1.21	-2.28	-1.13	-1.80	-1.42	0.03	-0.33	2.45	1.77	1.57	3.02
GELC-LAB-3	-0.92	-2.31	-1.95	-0.48	-0.74	-0.94	0.75	1.21	2.05	0.75	0.67	1.01
GELC-LAB-4	0.56	-0.33	-0.26	-0.05	-0.37	-0.20	-0.85	0.00	0.43	0.12	1.13	0.20
GELC-LAB-5	-0.96	-0.55	-1.89	-1.39	-2.67	-1.73	-0.55	-1.16	1.81	1.54	3.09	1.74
GELC-LAB-6	-0.08	-5.29	-1.56	0.77	0.43	0.13	1.02	4.35	1.27	-1.56	-1.54	-0.71

As shown in Table 8.5 only the results of GELC-LAB-4 are satisfactory for all colour parameters. The reasons for unsatisfactory and questionable results might be caused by:

A) Traceability of the standard artifact

As mentioned in 8.2, laboratories should ensure that the traceability of the standard artifact is reliable. It includes two aspects:

a) The calibration laboratory can provide highly reliable data.

b) Laboratories calibrate the sphere system with standard artifacts perfectly.

The traceability of the standard artifact not only affects the photometric test results, but also the colour test results. This project found that GELC-LAB-2 also showed some unsatisfactory or questionable results on the colour parameter tests. Therefore, we would suggest GELC-LAB-2 checks their traceability process.

B) Software for calculation

The software algorithm has a big effect on the test results. If the test results show a small deviation of chromaticity x and chromaticity y, but a big deviation of CCT and CRI, the reason is probably the software algorithm.

Based on the test results reported by the participating laboratories, GELC-LAB-2, GELC-LAB-3 and GELC-LAB-5 need to check and pay closer attention to the software used to calculate the CCT and CRI.

C) Response of photodetector

All the factors mentioned above are problems that have been found in the test results of this project. In general testing, there may be other influences on the test result. Although they are not obvious in this project, it is also necessary to present them here for the laboratories, including the response of photodetector.

Laboratories may use different types of detecting devices (photometer / spectroradiometer, etc.). If the device is ideal, then there is no effect on the test results. However sometimes, response problems of devices can be found which will cause a deviation of colorimetric quantities measurements.

8.4 Electrical Quantities Measurements

Table 8.6 shows the z-score for electrical quantities measurements in this project. It can be seen that electrical parameters have fewer unsatisfactory values than the photometric and colorimetric quantities. For all the participating laboratories, the z-score of active power is no greater than 2, which is generally considered to be satisfactory. For power factor, only the z-scores of GELC-LAB-3 and GELC-LAB-6 are a little greater than 2. Generally the test result could also be considered to be acceptable.

Table 8.6 z-score for electrical parameters

LAB	Active Power			Power Factor	
	GELC-D	GELC-OD	GELC-HCCT	GELC-D	GELC-HCCT
GELC-LAB-1	-0.99	0.62	-0.70	0.13	-1.64
GELC-LAB-2	-1.37	1.91	-1.21	1.70	-1.59
GELC-LAB-3	0.73	1.84	0.52	2.03	0.63
GELC-LAB-4	0.24	0.33	0.29	0.37	-0.28
GELC-LAB-5	0.12	-0.02	0.18	1.30	-0.64
GELC-LAB-6	-1.19	1.48	-1.65	2.12	0.09

The cause of the active power deviations might be because the four-terminal method was not used to connect the circuit. The four-terminal method is important to enable a high quality measurement for electrical testing on lighting products. The voltage line should be connected directly to the positive and negative electrode of the lamp holder, in order to reduce the effect of the contacting resistance of the voltage measurement. We suggest all the participating laboratories pay closer attention to the four-terminal method.

9. Conclusion

This inter-laboratory comparison testing project was designed in compliance with ISO/IEC 17043, *Conformity Assessment – General Requirements for Proficiency Testing*, for the purpose of identifying the differences in test results among the participating laboratories and analyzing the potential testing issues that exist. Six lighting laboratories from Southeast Asia countries were invited by the UNEP-GEF en.lighten initiative to participate in this inter-laboratory comparison testing activity.

In this comparison test, three different types of LED lamps were selected to measure their photometric, colorimetric, and electrical parameters in each laboratory. This report analyzed each participating laboratory's test results against the reference laboratory (GELC)'s reference values. As mentioned in the Section 9, all the electrical test results from the six participating laboratories are generally considered to be satisfactory. However, the test results also showed that deviations exist between the reference values and the test results of the participating laboratories, especially for the photometric and colorimetric parameters. Based on the result analysis, it suggests the participating laboratories pay closer attention to the factors listed in Table 10.1, such as the traceability of the standard lamp, sphere spatial non-uniformity correction, self-absorption correction, etc., which may help to make improvements to testing accuracy. It is probable that training will be needed to improve these factors.

Table 9.1 Summary of Potential Improvements

Photometric Quantities Measurements	Colorimetric Quantities Measurements
Traceability of the standard artifact	Traceability of the standard artifact
Sphere spatial non-uniformity correction	Software for calculation
Self-absorption correction	Response of photodetector
Near-Field absorption	/
Testing procedures/working instruction	/
Ambient temperature	/

This inter-laboratory comparison testing project found several issues that some participating laboratories may have. However, these findings are based solely on the test results provided by the laboratories and there are many other factors that could influence the test results during the actual testing. Therefore, further cooperation with the laboratories is recommended to help to identify more solutions and provide specific recommendations to the laboratories for their capacity enhancement.

10. Reference

[1] ISO/IEC 17043:2010, *Conformity Assessment – General Requirements for Proficiency Testing*.
[2] ISO 13528:2005, *Statistical Methods for Use in Proficiency Testing by Inter-laboratory Comparisons*.
[3] ISO, *Guide to the Expression of Uncertainty in Measurement, 1st Edition, 1993*.
[4] CIE 198:2011: Determination of Measurement Uncertainties in Photometry.
[5} APLAC PT 002, *Testing Interlaboratory Comparisons.*
[6] CNAS GL02: 2014, *Guidelines for Verifying the Results of Statistical Processing and Capacity Assessment*.

Annex A: GELC Reference Value(s)

Table A.1 Reference values for GELC-LAB-1 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U (%)	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-1	514.1	1.6	7.071	0.88	0.9244	0.011	72.71	1.9	0.4430	0.0025	0.4075	0.0025	2927	60	81.99	0.39
GELC-OD-1	260.9	2.1	3.927	0.80	/	/	66.43	1.3	0.4511	0.0025	0.4070	0.0025	2798	60	82.59	0.38
GELC-HCCT-1	535.6	2.5	6.058	0.56	0.8122	0.004	88.42	2.7	0.3305	0.0025	0.3426	0.0025	5586	60	80.01	0.49

(Relative) expanded uncertainty (*k*=2)

Table A.2 Reference values for GELC-LAB-2 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U (%)	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-2	501.2	1.6	6.914	0.88	0.8450	0.011	72.50	1.9	0.4422	0.0025	0.4068	0.0025	2935	60	82.04	0.39
GELC-OD-2	246.9	2.1	3.862	0.80	/	/	63.91	1.3	0.4508	0.0025	0.4070	0.0025	2802	60	83.40	0.38
GELC-HCCT-2	519.6	2.5	5.915	0.56	0.8105	0.004	87.85	2.7	0.3234	0.0025	0.3307	0.0025	5938	60	79.99	0.49

(Relative) expanded uncertainty (*k*=2)

Table A.3 Reference values for GELC-LAB-3 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-3	510.4	1.6	7.059	0.88	0.8534	0.011	72.30	1.9	0.4446	0.0025	0.4118	0.0025	2935	60	82.54	0.39
GELC-OD-8	243.5	2.1	3.805	0.80	/	/	64.00	1.3	0.4527	0.0025	0.4104	0.0025	2801	60	83.44	0.38
GELC-HCCT-3	526.7	2.5	5.945	0.56	0.8127	0.004	88.59	2.7	0.3231	0.0025	0.3292	0.0025	5957	60	80.16	0.49

(Relative) expanded uncertainty (*k*=2)

Table A.4 Reference values for GELC-LAB-4 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-4	529.8	1.6	7.134	0.88	0.9209	0.011	74.26	1.9	0.4440	0.0025	0.4086	0.0025	2921	60	81.91	0.39
GELC-OD-7	241.5	2.1	3.790	0.80	/	/	63.71	1.3	0.4511	0.0025	0.4086	0.0025	2811	60	83.90	0.38
GELC-HCCT-4	537.8	2.5	5.946	0.56	0.8133	0.004	90.45	2.7	0.3276	0.0025	0.3357	0.0025	5721	60	79.47	0.49

(Relative) expanded uncertainty (*k*=2)

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Table A.5 Reference values for GELC-LAB-5 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-5	531.9	1.6	7.109	0.88	0.9033	0.011	74.82	1.9	0.4412	0.0025	0.4070	0.0025	2953	60	82.26	0.39
GELC-OD-5	245.5	2.1	3.769	0.80	/	/	65.13	1.3	0.4529	0.0025	0.4113	0.0025	2805	60	82.82	0.38
GELC-HCCT-5	537.2	2.5	5.868	0.56	0.8099	0.004	91.54	2.7	0.3283	0.0025	0.3360	0.0025	5688	60	79.56	0.49

(Relative) expanded uncertainty (*k*=2)

Table A.6 Reference values for GELC-LAB-6 samples

Identifier	Measurement results															
	Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
	Result	U (%)	Result	U (%)	Result	U	Result	U (%)	Result	U	Result	U	Result	U	Result	U
GELC-D-6	530.1	1.6	7.158	0.88	0.8536	0.011	74.05	1.9	0.4439	0.0025	0.4089	0.0025	2924	60	82.16	0.39
GELC-OD-6	233.9	2.1	3.809	0.80	/	/	61.41	1.3	0.4526	0.0025	0.4099	0.0025	2799	60	83.69	0.38
GELC-HCCT-6	536.6	2.5	5.891	0.56	0.8147	0.004	91.08	2.7	0.3298	0.0025	0.3417	0.0025	5618	60	79.99	0.49

(Relative) expanded uncertainty (*k*=2)

Annex B:The differences between the first and second measurement by the reference laboratory

Table B.1 Thedifferences between OD lamp measurements

Identifier	Total luminous flux	Active Power	Power Factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI (Ra)
GELC-OD-1	0.08%	-0.04%	/	-0.04%	-0.0002	0.0003	5.0340	-0.0675
GELC-OD-2	-0.94%	-0.01%	/	-0.93%	0.0001	0.0003	1.2983	-0.0283
GELC-OD-5	0.19%	0.00%	/	0.19%	0.0000	0.0002	0.8570	-0.0237
GELC-OD-6	0.32%	0.03%	/	0.29%	0.0000	0.0001	1.3317	-0.0144
GELC-OD-7	0.07%	0.07%	/	0.00%	0.0001	0.0002	0.2353	-0.0214
GELC-OD-8	0.31%	-0.07%	/	0.38%	0.0002	0.0003	-1.2207	-0.0336
Note: "-"means the second test result is smaller than the first time by reference laboratory.								

Table B.2 Thedifferences between D lamp measurements

Identifier	Total luminous flux	Active Power	Power Factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI (Ra)
GELC-D-1	-0.21%	0.00%	0.09%	-0.01%	0.0000	0.0003	3.0643	-0.0573
GELC-D-2	-0.08%	0.17%	-0.37%	-0.25%	0.0003	0.0002	-2.3397	-0.0148
GELC-D-3	-0.71%	-0.01%	-0.44%	-0.70%	0.0002	0.0001	-2.1700	0.0049
GELC-D-4	-0.46%	-0.01%	0.18%	-0.45%	0.0002	0.0002	-1.9177	-0.0257
GELC-D-5	-0.25%	-0.02%	0.51%	-0.23%	0.0001	0.0002	-0.6543	-0.0167
GELC-D-6	-0.27%	-0.01%	-0.09%	-0.26%	0.0002	0.0002	-1.6523	-0.0147
Note: "-"means the second test result is smaller than the first time by reference laboratory.								

Table B.3 Thedifferences between HCCT lamp measurements

Identifier	Total luminous flux	Active Power	Power Factor	Luminous efficacy	Chromaticity x	Chromaticity y	CCT (K)	CRI (Ra)
GELC-HCCT-1	0.02%	0.46%	0.12%	-0.01%	0.0000	-0.0002	0.9610	0.0795
GELC-HCCT-2	-0.21%	-0.05%	0.04%	-0.16%	0.0000	-0.0001	-0.8700	0.0239
GELC-HCCT-3	-0.12%	-0.02%	0.11%	-0.10%	0.0000	0.0000	1.4947	0.0049
GELC-HCCT-4	-0.04%	-0.06%	0.05%	0.03%	-0.0001	-0.0002	5.5120	0.0265
GELC-HCCT-5	0.53%	-0.37%	-0.02%	0.90%	-0.0001	-0.0001	2.8787	0.0191
GELC-HCCT-6	-0.17%	-0.06%	0.01%	-0.11%	0.0000	0.0001	0.0207	0.0131

Note: "-"means the second test result is smaller than the first time by reference laboratory.

Annex C: Results of Participating Laboratories

Table C.1 Test results of GELC-LAB-1

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-1	1	479.9476	/	7.0000	/	0.9260	/	68.5639	/	0.4490	/	0.4097	/	2853	/	81.9	/
	2	480.1985	/	7.0000	/	0.9260	/	68.5998	/	0.4490	/	0.4097	/	2853	/	82.0	/
	3	480.2487	/	7.0000	/	0.9260	/	68.6070	/	0.4488	/	0.4096	/	2855	/	82.0	/
	Avg.	480.1316	2.38	7.0000	0.06	0.9260	/	68.5902	2.38	0.4489	2.01%	0.4097	2.01%	2854	2.01%	82.0	2.01%
GELC-OD-1	1	252.3033	/	3.9468	/	/	/	63.9260	/	0.4501	/	0.4067	/	2811	/	82.6	/
	2	252.6301	/	3.9468	/	/	/	64.0088	/	0.4501	/	0.4068	/	2812	/	82.6	/
	3	252.6301	/	3.9435	/	/	/	64.0624	/	0.4501	/	0.4068	/	2812	/	82.5	/
	Avg.	252.5212	2.84	3.9457	0.04	/	/	63.9991	2.84	0.4501	2.01%	0.4068	2.01%	2812	2.01%	82.6	2.01%
GELC-HCCT-1	1	505.2175	/	6.0000	/	0.8000	/	84.2029	/	0.3347	/	0.3471	/	5410	/	80.2	/
	2	505.3676	/	6.0000	/	0.8000	/	84.2279	/	0.3347	/	0.3471	/	5410	/	80.2	/
	3	505.2175	/	6.0000	/	0.8000	/	84.2029	/	0.3345	/	0.3467	/	5415	/	80.2	/
	Avg.	505.2675	2.27	6.0000	0.06	0.8000	/	84.2113	2.27	0.3346	2.01%	0.3470	2.01%	5412	2.01%	80.2	2.01%

(Relative) expanded uncertainty (*k*=2)

Table C.2 Test results of GELC-LAB-2

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-2	1	457.5	/	6.810	/	0.8650	/	67.18	/	0.4398	/	0.4021	/	2936	/	82.90	/
	2	456.2	/	6.840	/	0.8700	/	66.69	/	0.4399	/	0.4022	/	2935	/	82.90	/
	3	455.5	/	6.800	/	0.8640	/	66.99	/	0.4398	/	0.4021	/	2937	/	82.90	/
	Avg.	456.4	2.30	6.817	0.13	0.8663	/	66.95	1.70	0.4398	0.35%	0.4021	0.35%	2936	0.03%	82.90	0%
GELC-OD-2	1	234.9	/	3.919	/	/	/	62.10	/	0.4500	/	0.4042	/	2792	/	84.00	/
	2	234.1	/	3.919	/	/	/	59.73	/	0.4496	/	0.4041	/	2798	/	84.00	/
	3	237.1	/	3.919	/	/	/	60.50	/	0.4496	/	0.4040	/	2797	/	84.00	/
	Avg.	235.4	2.30	3.919	0.00	/	/	60.78	2.16	0.4497	0.35%	0.4041	0.35%	2796	0.02%	84.00	0%
GELC-HCCT-2	1	493.1	/	5.790	/	0.7980	/	85.17	/	0.3199	/	0.3242	/	6144	/	82.50	/
	2	491.8	/	5.800	/	0.7990	/	84.79	/	0.3199	/	0.3243	/	6144	/	82.50	/
	3	492.3	/	5.860	/	0.7990	/	84.00	/	0.3198	/	0.3242	/	6152	/	82.50	/
	Avg.	492.4	2.30	5.817	0.13	0.7987	/	84.65	1.86	0.3199	0.35%	0.3242	0.35%	6147	0.08%	82.50	0%

(Relative) expanded uncertainty (*k*=2)

Table C.3 Test results of GELC-LAB-3

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-3	1	493.4	/	7.113	/	0.8777	/	69.37	/	0.4423	/	0.4098	/	2957	/	82.9	/
	2	493.4	/	7.112	/	0.8776	/	69.38	/	0.4423	/	0.4098	/	2957	/	82.9	/
	3	493.4	/	7.111	/	0.8777	/	69.37	/	0.4423	/	0.4098	/	2957	/	82.9	/
	Avg.	493.4	3.70	7.112	0.41	0.8777	/	69.37	3.72	0.4423	3.04%	0.4098	3.04%	2957	3.04%	82.9	3.04%
GELC-OD-8	1	240.9	/	3.859	/	/	/	62.43	/	0.4506	/	0.4092	/	2823	/	83.7	/
	2	240.5	/	3.857	/	/	/	62.35	/	0.4506	/	0.4092	/	2823	/	83.7	/
	3	241.4	/	3.861	/	/	/	62.52	/	0.4506	/	0.4093	/	2824	/	83.7	/
	Avg.	240.9	4.84	3.859	0.80	/	/	62.43	4.91	0.4506	3.04%	0.4092	3.04%	2823	3.04%	83.7	3.04%
GELC-HCCT-3	1	508.5	/	5.987	/	0.8174	/	84.93	/	0.3201	/	0.3249	/	6132	/	81.0	/
	2	508.4	/	5.989	/	0.8176	/	84.89	/	0.3201	/	0.3249	/	6132	/	81.0	/
	3	508.4	/	5.986	/	0.8173	/	84.93	/	0.3201	/	0.3249	/	6132	/	81.0	/
	Avg.	508.4	3.70	5.987	0.41	0.8174	/	84.92	3.72	0.3201	3.04%	0.3249	3.04%	6132	3.04%	81.0	3.04%

(Relative) expanded uncertainty (*k*=2)

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Table C.4 Test results of GELC-LAB-4

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-4	1	501.4	/	7.1519	/	0.92527	/	70.107	/	0.4454	/	0.4085	/	2896	/	81.90	/
	2	499.2	/	7.1526	/	0.92532	/	69.793	/	0.4454	/	0.4083	/	2895	/	82.00	/
	3	502.9	/	7.1520	/	0.92538	/	70.316	/	0.4454	/	0.4084	/	2896	/	82.00	/
	Avg.	501.2	2.7	7.1522	0.40	0.92532	/	70.072	2.7	0.4454	0.0054	0.4084	0.005	2896	36	81.97	1.3
GELC-OD-7	1	235.8	/	3.7934	/	/	/	62.161	/	0.4507	/	0.4078	/	2811	/	84.40	/
	2	237.4	/	3.8125	/	/	/	62.269	/	0.4510	/	0.4084	/	2811	/	84.30	/
	3	236.6	/	3.7940	/	/	/	62.362	/	0.4506	/	0.4078	/	2812	/	84.30	/
	Avg.	236.6	2.7	3.8000	0.52	/	/	62.264	2.8	0.4508	0.0054	0.4080	0.005	2811	36	84.33	1.3
GELC-HCCT-4	1	495.2	/	5.9716	/	0.81123	/	82.926	/	0.3272	/	0.3350	/	5757	/	79.60	/
	2	495.6	/	5.9682	/	0.81131	/	83.040	/	0.3273	/	0.3348	/	5756	/	79.60	/
	3	496.0	/	5.9699	/	0.81123	/	83.083	/	0.3271	/	0.3346	/	5760	/	79.70	/
	Avg.	495.6	2.7	5.9699	0.40	0.81126	/	83.016	2.7	0.3272	0.0054	0.3348	0.005	5758	41	79.63	1.3

(Relative) expanded uncertainty (*k*=2)

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Table C.5 Test results of GELC-LAB-5

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-5	1	539.47	/	7.120	/	0.9189	/	75.77	/	0.4388	/	0.4012	/	2936	/	83	/
	2	538.75	/	7.120	/	0.9188	/	75.67	/	0.4388	/	0.4012	/	2937	/	83	/
	3	538.41	/	7.110	/	0.9188	/	75.73	/	0.4387	/	0.4011	/	2938	/	83	/
	Avg.	538.88	4.2	7.117	0.5	0.9188	/	75.72	4.3	0.4388	0.0024	0.4012	0.0060	2937	60	83	1.5
GELC-OD-5	1	249.29	/	3.7696	/	/	/	66.13	/	0.4524	/	0.4071	/	2784	/	84	/
	2	248.41	/	3.7675	/	/	/	65.93	/	0.4524	/	0.4070	/	2784	/	84	/
	3	248.49	/	3.7674	/	/	/	65.96	/	0.4523	/	0.4070	/	2784	/	84	/
	Avg.	248.73	2.6	3.7682	0.5	/	/	66.01	2.7	0.4524	0.0024	0.4070	0.0060	2784	60	84	1.5
GELC-HCCT-5	1	540.15	/	5.890	/	0.8052	/	91.71	/	0.3255	/	0.3283	/	5837	/	81	/
	2	540.86	/	5.880	/	0.8050	/	91.98	/	0.3254	/	0.3281	/	5842	/	81	/
	3	540.73	/	5.880	/	0.8052	/	91.96	/	0.3253	/	0.3280	/	5846	/	81	/
	Avg.	540.58	3.2	5.883	0.5	0.8051	/	91.88	3.3	0.3254	0.0034	0.3281	0.0080	5842	150	81	1.5

(Relative) expanded uncertainty (*k*=2)

Table C.6 Test results of GELC-LAB-6

Identifier		Measurement results															
		Total luminous flux (lm)		Power (W)		Power factor		Luminous efficacy (lm/W)		x		y		CCT (K)		CRI (Ra)	
		Result	U(%)	Result	U(%)	Result	U	Result	U(%)	Result	U	Result	U	Result	U	Result	U
GELC-D-6	1	501.8000	/	6.9854	/	0.8820	/	71.8351	/	0.4428	/	0.4110	/	2959	/	81.4	/
	2	502.3000	/	7.1469	/	0.8780	/	70.2820	/	0.4450	/	0.4141	/	2949	/	81.4	/
	3	501.4000	/	7.0809	/	0.8770	/	70.8102	/	0.4432	/	0.4112	/	2955	/	81.3	/
	Avg.	501.8333	2.0661	7.0713	0.0690	0.8790	/	70.9680	2.0681	0.4437	0.0023	0.4121	0.0035	2954	5.1070	81.4	0.0646
GELC-OD-6	1	233.8000	/	3.8491	/	/	/	60.7412	/	0.4463	/	0.4106	/	2901	/	83.00	/
	2	233.6000	/	3.8511	/	/	/	60.6580	/	0.4481	/	0.4103	/	2871	/	83.20	/
	3	235.6000	/	3.8577	/	/	/	61.0727	/	0.4489	/	0.4108	/	2862	/	83.10	/
	Avg.	234.3333	1.0921	3.8526	0.0378	/	/	60.8241	1.0931	0.4478	0.0027	0.4106	0.000507	2878	20.4345	83.10	0.1041
GELC-HCC T-6	1	519.0000	/	5.7985	/	0.8160	/	89.5060	/	0.3276	/	0.3423	/	5719	/	79.5	/
	2	520.7000	/	5.7376	/	0.8150	/	90.7522	/	0.3273	/	0.3421	/	5729	/	79.4	/
	3	520.9000	/	5.7376	/	0.8150	/	90.7871	/	0.3273	/	0.3425	/	5729	/	79.3	/
	Avg.	520.2000	1.4707	5.7579	0.0690	0.8153	/	90.3457	1.4734	0.3274	0.0004	0.3423	0.0040	5726	6.2433	79.4	0.1041

(Relative) expanded uncertainty (*k*=2)

Annex D: Measurement Method for the Inter-laboratory Comparison Program

This measurement method is prepared for use by this inter-laboratory comparison test. Refer to *Test Method for LED Lamps, LED Luminaires and LED Modules, CIE Draft International Standard DIS 025/E:2014*. In order to maintain consistency, this measurement method focuses on the test method for three kinds of LED samples. This Annex also includes some notes for this inter-laboratory comparison test.

1. Environmental Conditions

1.1 Ambient temperature

(1) The ambient temperature during the measurement of the sample shall be maintained at (25 ± 1) °C. If a laboratory does not meet this requirement, outside the range (25 ± 1) °C and within 21 °C to 27 °C is allowed only if the results are corrected to the values for 25 °C, using the ambient-temperature dependence data for the particular device under test for particular measurement quantities. In this case, the actual measured ambient temperature, method (formula) of correction, and temperature dependence data of the device shall be reported.

(2) The temperature sensor shall be placed at the same height and within 1 m for LED lamps under test.

(3) The temperature sensor shall be shielded from direct optical radiation from the LED lamp product and from any other light source. Environment of the temperature sensor and the lamp should not be isolated.

(4) The thermometer shall have resolution of 0.1 °C or less.

Note: It is recommended that the thermometer has a calibration uncertainty of 0.2 ℃ or less.

1.2 Air movement

Air flow around the LED lamp product being tested should be such that normal convective air flow induced by the device under test is not affected. The air flow shall be less than 0.2 m/s.

Note 1: Air flow in an integrating sphere (without forced air cooling system) when closed is considered to be satisfying this requirement.

Note 2: Portable anemometers are commercially available with measurement uncertainty of 0.05 m/s.

Note 3: In case the light source is moved on the goniophotometer during measurements, the moving speed should be chosen adequately to meet the requirement above.

1.3 Laboratory humidity

Relative humidity of the laboratory should be 65% or less.

2. Mounting Conditions

2.1 Operating position

The operating position of the samples used for the CT are specified in the program description. Measurement shall be made with the artifact operated accordingly.

2.2 Supporting objects

LED lamp products with a screw base or bayonet shall be supported only by the socket.

3. Electrical conditions and measurement

3.1 Operation of LED lamp product

(1) The LED lamp product under test shall be operated at the rated voltage (AC or DC) and frequency (for AC operation, normally 50 Hz or 60 Hz) according to the specification of the product under test for its normal use.

(2) The tolerance of the test voltage is ±0.2% of the rated value and the tolerance of frequency is ±0.2%.

(3) The voltage shall be measured at the socket (for screw-base or bayonet-base lamps), or at the power input line as close to the product as possible. The measurement position (length from the socket or the power input line) shall be reported.

Note: This is critical especially for low-voltage lamps. For screw base lamps, 4-pole socket is commercially available, which allows measurement of voltage directly across the cap with no effect of contact resistance.

(4) Care should be taken when applying the power to the product under test.

Note 1: When applying a constant DC voltage, the voltage should be ramped up slowly to protect the device. Large frame power supplies can apply a surge before recovering to an appropriate DC power.

Note 2: When applying AC voltage, the power supply should be set to come on at a zero degree phase. A few LED drivers that involve capacitors may have a large in-rush current if the AC voltage is applied at a non-zero degree phase.

(5) The voltage (V), current (A), power (W) (RMS for AC operation), and power factor for AC operation, shall be measured at the time photometric measurements are taken.

3.2 Electrical instrumentation

(1) The voltage of an AC power supply or DC power supply applied to the product under test shall be regulated to within ±0.2% (AC) or ±0.1% (DC) under load.
(2) AC voltage ripple of the DC power supply shall be 0.5% or less.
(3) The AC power supply shall have a sinusoidal voltage waveshape at the prescribed frequency with the total harmonic distortion not exceeding 3% under a resistive load.
(4) For AC-input LED lamp products, an AC power meter shall be connected between the AC power supply and the LED lamp product under test, and AC power as well as input voltage and current shall be measured.
(5) The AC power meter shall have the capability of measuring power factor.
(6) The AC power meter shall have a sampling rate that is capable of resolving the current wave for the LED lamp product. Many LED drivers based on capacitors and diode bridges have very sharp current waves requiring a high sampling rate. Analogue AC power meters will not measure these properly.

Note: IEC 61000-3-2 states that the electrical characteristics of lighting products should be analyzed in a frequency range covering the fundamental (50 Hz or 60 Hz) and up the 40th order (2 kHz or 2.4 kHz). IEC 61000-4-7 [14] indicates that power measurement equipment should be able to analyze components up to 9 kHz.

(7) The calibration uncertainties of the instruments for AC voltage and AC current shall be ⩽ 0.2%. The calibration uncertainty of the AC power meter shall be ⩽ 0.5% and that for DC voltage and current shall be ⩽ 0.1%.

Note: Uncertainty here, and throughout this document, refers to relative expanded uncertainty with a 95% confidence interval, normally with a coverage factor k=2, as prescribed in ISO Guide for expression of uncertainties in measurement.

4. Seasoning

No seasoning is needed for the comparison samples.

5. Stabilization

After constructing the circuit, please burn a similar lamp to confirm the circuit.
Prior to taking measurements, the product under test shall be operated at the rated condition to stabilize so that the changes of electrical power and total luminous flux (for integrating sphere) or luminous intensity (for a goniophotometer setup) in a fixed direction are less than 0.5% over a 30 minute window by monitoring the signal every minute. The actual stabilization time shall be reported for each LED lamp product tested.

6. Photometric and colorimetric measurement

The following instruments may be used:
(1) Sphere-spectroradiometer (for total luminous flux, colour quantities, CRI);

(2) Sphere-photometer (for total luminous flux);
(3) Goniophotometer with a photometer head [luminous intensity distribution, total luminous flux (if configured for absolute photometry)];
(4) Gonio-spectroradiometer (luminous intensity distribution, total luminous flux, colour quantities, CRI, chromaticity spatial uniformity); and,
(5) Gonio-colorimeter (luminous intensity distribution, total luminous flux, chromaticity spatial uniformity).

6.1 Total luminous flux

Total luminous flux of an LED lamp product shall be measured using an integrating sphere system (a sphere-spectroradiometer and/or a sphere-photometer) or a goniophotometer (configured for absolute photometry).

Integrating sphere systems

(1) A sphere-spectroradiometer shall be calibrated with a total spectral radiant flux standard traceable to a National Metrology Institute (NMI).

Note 1: If total spectral radiant flux standard lamps are not available from the local NMI, the standard may be derived by the user from spectral irradiance standard lamp(s) and total luminous flux standard lamp(s), both shall be traceable to an NMI. In this case, the derivation methods and related data (e.g., angular uniformity of spectrum or CCT of the standard lamp) shall be reported.

Note 2: It would not be acceptable if the spectroradiometer used with the integrating sphere is calibrated for spectral irradiance only without considering the relative spectral throughput of the integrating sphere. The integrating sphere and the spectroradiometer together shall be calibrated as one system for total spectral radiant flux.

(2) The spectroradiometer used for the sphere-spectroradiometer system shall cover the wavelength range of at least 380 nm to 780 nm, and the bandwidth (full width half maximum) and scanning interval to be no greater than 5 nm. Wavelength scale uncertainty shall be within 0.3 nm.
(3) A sphere-photometer system or sphere-spectroradiometer system shall be equipped with an auxiliary lamp and self-absorption measurement shall be carried out and correction made for each product under test.
(4) A sphere-photometer shall be calibrated with a total luminous flux standard traceable to an NMI.
(5) A sphere-photometer shall have a total relative spectral responsivity (sphere plus photometer head) that meets the f1' value of 2% or less. If f1' of the sphere-photometer exceeds 2%, then f1' no greater than 6% is acceptable if spectral mismatch correction is applied to each product tested. For this correction, the relative spectral distribution of the product and the relative spectral responsivity of the

sphere-photometer is necessary. In this case, the correction factor and data for spectral mismatch correction shall be reported.

(6) A combination of a photometer head and a spectroradiometer may also be used, with the photometer head used for luminous flux measurement and the spectroradiometer used for spectral mismatch correction determinations and for measurement of colour quantities.

Note: In this case, the spectroradiometer measures only the relative total spectral radiant flux and needs to be calibrated only for relative total spectral radiant flux scale.

(7) The photometer head of a sphere-photometer and the spectroradiometer input optics at integrating sphere detector port (normally equipped with a diffuser) shall have approximate cosine correction, with the f2 value of 15% or less.

Goniophotometer

(1) The goniophotometer to be used shall be the type in which the operating position of the LED lamp product under test with respect to gravity is not changed.

Note: Type C goniophotometers include the moving detector type for relatively short photometric distances (for smaller LED lamp products) and the moving mirror type for larger photometric distances (larger LED lamp products).

(2) For goniophotometers employing a photometer head, the relative spectral responsively of the photometer head (plus mirror if used) shall have an f1’ value of 1.5% or less. If the f1’ of the photometer head (or the Y channel of a colorimeter head) of a goniophotometer exceeds 1.5% (but < 6%), the spectral mismatch correction shall be applied to each product under test. For this correction, the relative spectral distribution of the product is necessary.

(3) Scanning resolution fine enough to accurately define the test sample shall be used. For typical wide-angle, smooth intensity distributions, a 22.5° lateral (horizontal) and 5° longitudinal (vertical) grid may be acceptable.

Note: For SSL products having rapidly changing intensity distribution, measurements may be repeated with another randomly selected vertical reference plane to ensure that results are within the laboratory's uncertainty budget for the test.

(4) The goniophotometer used for total luminous flux measurement shall be calibrated for luminous intensity standard or illuminance standard traceable to an NMI, and measured total luminous flux value (lm) shall be verified by measuring a total luminous flux standard traceable to an NMI. Alternately, the goniophotometer system may be calibrated against a total luminous flux standard traceable to an NMI, if the dead angle of the goniophotometer does not affect the measurement of the total luminous flux standard lamp.

Note 1: For mirror type goniophotometers, a luminous intensity standard lamp is normally used to calibrate the photometer head, in which case, the photometric distance and the reflectance of *mirror are automatically included in the calibration.*

Note 2: Illuminance (lx) integration method may be used only for a goniophotometer with the photometer head rotating (no mirror). In this case, the photometric distance needs to be determined accurately.

(5) Goniophotometers shall have an angular scan range covering the entire solid angle to which the LED lamp product emits light.

Note: Goniophotometers in general have some angular region (called dead angle) where emission from a light source is blocked by its mechanism, e.g., an arm to hold the light source. Goniophotometers having a large dead angle (exceeding ±10°) should not be used to measure total luminous flux of omnidirectional lamps unless appropriate correction procedures are implemented.

(6) Care should be taken to minimize stray light errors.

Note 1: The goniophotometers should be installed in a dark room with low reflectance wall surfaces, and should preferably be equipped with a light trap or light absorbing surface on the opposite side of the mirror or detector on the rotating arm, so that the errors due to reflections and stray light from surrounding surfaces are minimized.

Note 2: The photometer head or spectroradiometer input should be equipped with a hood or aperture screens to receive the light only from the effective angle range of the LED lamp product under test.

6.2 Luminous efficacy

(1) The electrical input power P_{TEST} (W) of the SSL product under test shall be measured according to section 3.

(2) The luminous flux Φ_{TEST} (lm) shall be measured according to section 5.A.

(3) The luminous efficacy η_V (lm/W) of the product under test shall be determined by

$$\eta_V \frac{\Phi_{TEST}}{P_{TEST}} \qquad \text{Equation(9)}$$

6.3 Colorimetric quantities

(1) Colour quantities to be measured for LED lamp products include chromaticity coordinates (x, y) and/or (u', v'), correlated colour temperature (CCT), Duv, and general Colour Rendering Index (CRI Ra). Colour quantities are calculated from the measured relative spectral power distribution of the LED lamp product according to the definitions given in CIE 13.3 and CIE 15.

(2) The colour quantities of LED lamp products shall be measured as spatially averaged values, with its value at each point weighted by the intensity and the solid angle, over the angular range where light is intentionally emitted from the LED lamp product.

Note 1: A sphere-spectroradiometer automatically measures the spatially averaged spectral power distribution, from which spatially averaged colour quantities can be calculated. The sphere-spectroradiometer to be used shall meet the requirements in section 5.A.

Note 2: Spatially averaged colour quantities can also be measured with a gonio-spectroradiometer or a gonio-colorimeter. In this case, the angular scan shall be made for at least two vertical planes at 90° apart (φangle), and at 10° increments for a vertical angle scan (ϑangle) in each vertical plane. For reflector lamps, theϑangle increments shall be 1/10 or less of the beam angle (diameter of the angular cone emitting more than 1/2 of the peak intensity) but no larger than 10°. The colour quantities and (relative) luminous intensity at each goniometer angle shall be recorded over the angle range where the luminous intensity is more than 10% of the peak intensity, which are used for the calculation of spatially averaged colour quantities. The colour quantity values are weighted by the solid angle (represented by the angle) and the luminous intensity of the point.

(3) If a gonio-colorimeter is used, the chromaticity at one of the angular points shall be measured with a spectroradiometer to calibrate the colorimeter head, and all measured results by the colorimeter shall be corrected based on the spectroradiometer reading.

7. Notes during the test process

(1) No seasoning is needed for all samples.
(2) Pick up the samples with plastic gloves and check the samples. If they are covered by dust, please clean them and ensure that there are no scratches on the samples.
(3) After constructing the circuit, please burn a similar lamp to confirm the circuit before measurements.
(4) Intense vibration or shocking during burning process should be avoided.
(5) Please transfer the samples to the test position after 3h preheating, and ensure the transfer time shall be no more than 20s. The ambient temperature of the preheating position shall be close to the test ambient temperature in order to avoid long time for re-stabilization.
(6) "Power off" is necessary between the 1st measurement, 2nd measurement and 3rd measurement for the same sample.

8. Measurement Uncertainty

The uncertainties should be reported for all measurement results. In reporting uncertainties, the international recommendation, *Guide to the Expression of Uncertainty in Measurement (ISO GUM),* should be followed to evaluate and express uncertainties of measurement. For all measurements covered in this document, a coverage factor of *k*=2 (generally corresponding to a confidence interval of 95%) shall be used. Guidance on evaluation of uncertainty in photometry is available in *CIE 198*.

9. References

International Commission on Lighting (CIE). 2014. *Test Method for LED Lamps, LED Luminaires and LED Modules, CIE Draft International Standard DIS 025/E:2014*. Available for purchase through each country's CIE committee, or, for immediate download as a pdf, via the CIE webshop: <http://www.techstreet.com/cie/?>

ibid. Determination of Measurement Uncertainties in Photometry, CIE 198:2011. Also see: *Supplement 1: Modules and Examples for the Determination of Measurement Uncertainties.*

International Standards Organization (ISO). *Evaluation of measurement data – Guide to the expression of uncertainty in measurement, JCGM 100:2008 (GUM 1995 with minor corrections).* JCGM 100:2008 is available in HTML form from the Joint Committee for Guides in Metrology (JCGM) portal on ISO's website: < http://www.iso.org/sites/JCGM/GUM-introduction.htm>

Annex E: Testing Protocol of Inter-Laboratory Comparison Test: LED Lamps

1. Introductions

This inter-laboratory comparison test is one of a series of efficient lighting compliance activities under the UNEP en.lighten initiative ("en.lighten") project, "Securing climate change benefits of efficient lighting in Southeast Asia and Pacific economies via monitoring, verification and enforcement capacity building activities," which is funded by the Australian government. According to the contract between UNEP and the Global Efficient Lighting Centre (GELC), GELC will organize this inter-laboratory comparison test in compliance with ISO/IEC 17043[1]. The inter-laboratory comparison test involves six laboratories that agreed to participate upon invitation from UNEP.

This inter-laboratory comparison test is intended to make an investigation on the measurement capacity of the six participating laboratories, in order to understand the differences among the laboratories and to analyze testing issues existing in the participating laboratories. By solving those potential testing issues, the capacities of the lighting laboratories should be strengthened.

The contact details of this CT are given as follows.

Coordinator for GELC:

Name: Mr. ZHANG Debao

Address: No. A3 Changpocun, Dabeiyao, Choyang District, Beijing, 100022, China

E-mail address: zhangdebao@gelc.com

Phone number: +86 10 67708989 (EXT) 4112

All the emails during the CT process should be copied to the UNEP liaison:

Mrs. Marie Leroy, Consultant, email: Marie.Leroy.affiliate@unep.org

2. Description of comparison samples

In this inter-laboratory comparison test, a star-type comparison will be conducted. Each set of samples including three different kinds of LED lamp products will be sent from GELC to each participating lab. Each lab will return the products and the results to GELC after testing. The detailed specifications of the comparison samples in each set are given in Table 1.

Table E-1. Properties of comparison samples

Identifier	Lamp Type	Rated Voltage	Rated Power	Nominal CCT	Other Conditions
GELC-OD	Omnidirectional LED lamp	12V	4 W	2700 K	Constant current: DC 0.330 A; Operating position: base up. *Note: The center pin is positive "+"*
GELC-D	Directional LED lamp	220 V AC	8 W	3000 K	AC frequency: 50 Hz; Operating position: base up for all lamps.
GELC-HCCT	High CCT LED lamp	220 V AC	6 W	5000 K	
Note: Performance parameters are not the test result.					

3. Measurands

The following parameters will be measured and recorded in this inter-laboratory comparison test.

(1) Total luminous flux (lm)*
(2) RMS voltage (V) and RMS current (mA)
(3) Active power (W)*
(4) Luminous efficacy (lm/W)*
(5) Chromaticity x*and y*
(6) Correlated colour temperature (K)*
(7) Colour rendering index (CRI) Ra*
(8) Power factor (PF)

Note 1: Only the parameters marked with an asterisk (*) will be compared and analyzed applying the criteria in chapter 6.0 in this inter-laboratory comparison test.
Note 2: Participating labs should show all decimal places, with at least four significant digits.

4. Reference values

In this inter-laboratory comparison test, the comparison samples will be tested by GELC before and after delivery to each participating laboratory. The reference value *X* is the average value of before delivery, X_1 and after receiving comparison samples, X_2.

$$X = \frac{X_1 + X_2}{2}$$ Formula (1)

X_1: the value tested by GELC before delivering comparison samples;
X_2: the value tested by GELC after receiving comparison samples.

5. Evaluation of the performance

The measurement results with an asterisk (*) in chapter 4.0 by GELC (the reference laboratory) are used as the reference values of each sample. The criteria used to analyse and evaluate the performance are E_n number and *z* score. The calculation process is given below.

5.1 E_n number

Participating laboratories' performance will be assessed using the E_n number, calculated as follows:

$$E_n = \frac{x - X}{\sqrt{U_{lab}^2 + U_{ref}^2}}$$ Formula (2)

Where

x is the participant result;

X is the reference value;

U_{lab} is the expanded uncertainty (*k*=2) of a participating laboratory's result;

U_{ref} is the expanded uncertainty (*k*=2) of the reference value.

For the value of chromaticity coordinate *(x, y)*, CCT, and Color Rendering Index, the E_n number could be calculated directly by formula (2).

However, for the value of active power assumption, total luminous flux and luminous efficacy, the relative differences of the results from each laboratory and the reference value of the same test lamp are calculated by:

$$\Delta X_{relative} = \frac{x - X}{X}$$ Formula (3)

Therefore, the formula (2) would be changed to:

$$E_n = \frac{\Delta X_{relative}}{\sqrt{(U_{lab,rel} \bullet x / X)^2 + (U_{ref,rel})^2}}$$ Formula (4)

Where

$U_{lab,rel}$: the relative expanded uncertainty of *x*;

$U_{ref,rel}$: the relative expanded uncertainty of *X*.

The value *x/X* is very close to 1; for simplified calculation, the formula (4) would be replaced by:

$$E_n = \frac{\Delta X_{relative}}{\sqrt{U^2_{lab,rel} + U^2_{ref,rel}}}$$ Formula (5)

With *ISO 13528[1]* in reference, E_n number will be applied to evaluate the test results that given by the participants.

If a value of $|E_n|$ ≤ 1.0 is obtained, this is generally considered to be satisfactory.

The value of $|E_n|$ > 1.0 is considered to be unsatisfactory. However, the judgment will depend on the potential Accreditation Bodies (ABs).

5.2 z score

The *z score* is calculated for test results, and is determined by:

$$z=(x-X)/\sigma$$ Formula (6)

Where

σ: the standard deviation for proficiency assessment, 0.7413 x IQR (interquartile range) of test results provided by participating laboratories).

If a value of $|Z| \leq 2$ is obtained, this is generally considered to be satisfactory.
The value of $2 < |Z| < 3$ is considered to be questionable and $|Z| \geq 3$ is considered to be unsatisfactory. Similar to the E_n number, the judgment will depend on the potential ABs.

6. Test period and delivery instructions

(1) The period of this inter-laboratory comparison test is from July 2014 to May 2015.
(2) The contact of GELC will confirm the receiving time with the participants and then GELC will ship the comparison samples to the laboratories;

(3) When receiving the comparison samples, the participant laboratory contact should confirm the condition of the samples and immediately send the "Receipt Form" (Annex 1) to the GELC contact.

(4) There are four weeks to conduct the comparison test after receipt of the samples. The participants should send to GELC the "Measurement Results Report Form" (Annex 2) and any supporting documentation to assist in the interpretation of the results.

(5) The GELC contact will confirm the test data and give instructions to participants for return shipping of the samples.

(6) Upon receiving the instructions, the participating laboratory must send the "Return Form" (Annex 3) and the samples to GELC.

(7) IMPORTANT: The samples are fragile. They will be shipped in a robust transport case. They should be stored at a room temperature between 15 °C and 35 °C and a relative humidity less than 75%. They must be returned in the same case. The shipment must be insured for the full value of the samples.

7. Stability check

Before sending the samples to participants, GELC will conduct a stability check.

In order to evaluate the stability of inter-laboratory comparison test samples under the premise of not getting the data of this inter-laboratory comparison test, the experience value of standard deviation obtained in the last APLAC proficiency testing (PT) program T088 will be used.

The initial value X_0 and the measurement value X_{100} after aging 100 hours (h) should satisfy the following formula:

$$|x_0 - x_{100}| \leqslant 0.3\sigma_0 \quad \text{Formula (7)}$$

Where

σ_0 : the standard deviation for APLAC proficiency testing (PT) program T088:

Photometric Measurement of Solid State Lighting Products held during 2013.

8. Test procedure

The participating laboratories shall use the Measurement Method for the Comparison Test Program (Annex 4).

During the inter-laboratory comparison test, if the participating laboratories have any questions or unclear points about the test method provided by GELC, they should immediately contact the GELC coordinator.

9. Test results and feedback information provided by participants

(1) Participant laboratories shall answer all questions on the data sheets (Annex 2). The original electronic data sheets and scanning documents with signature of Supervisor or Reviewer shall be sent to the GELC contact. If there is some supplemental information to the test results, please use extra sheets.

(2) If the participating laboratories use different testing systems, such as both a photometric sphere and a goniophotometer system, please provide two sets of test results and indicate the testing system on each of the result documents, respectively.

(3) Unless data values are whole numbers, participants should show all decimal places. Participants should also enter the measurement units where appropriate.

(4) Participants will report all measured values in at least four significant digits. The uncertainty values, if reported, should be given in two significant digits.

(5) Please provide a copy of your measurement circuit diagram in Annex 2.

(6) Please provide a set of digital photos that show the comparison artefacts mounted in the test instruments in Annex 2.

10. Uncertainties calculation by participants

Uncertainty is required to be calculated and reported by the participating laboratories; the *ISO Guide [3]* and *CIE 198 [4]* should be followed. The total uncertainty of each measured quantity shall be expressed in (relative) expanded uncertainty with a confidence interval of 95% or a coverage factor *k*=2. The reported uncertainty should be given in two significant digitals.

To evaluate photometric and colorimetric quantity measurement uncertainty, many affecting factors and their uncertainty contributions shall be considered, as listed in Table 3 and Table 4. In order to analyse the possible issues for calculating uncertainties, the uncertainty component of each affecting factor for each quantity should be provided by participating laboratories.

Table D-2. Affecting factors list for uncertainties calculation of photometric quantities

No.	Affecting Factor
1	Standard lamp calibration data
2	Current control for standard lamp
3	Aging of the standard lamp
4	Response of spectrometer, random noise, etc.
5	Position and direction of sample in sphere
6	Auxiliary lamp (state shift between self-absorption tests)
7	Spatial non-uniformity of sphere
8	Ambient temperature influence on the sample
9	System repeatability
10	Any other factors

Table D-3. Affecting factors list for uncertainties calculation of colorimetric quantities

No.	Affecting factor
1	System repeatability
2	Standard lamp calibration data
3	Response of spectrometer (nonlinearity, stray light, noise, etc.)
4	Wavelength error of spectrometer
5	Any other factors
Note: "Any other factors" means any other affecting factors to be considered except for the above factors.	

11. Reporting to the participants

After submitting test results and returning the samples to GELC, the participating laboratories will receive a *Formal Confirming Report (FCR).* This FCR will inform them of how their individual test results on samples compare to those of GELC. After confirming FCR by participants, the *Comparison Test Report* will be distributed to participants and UNEP.

12. Confidentiality

Participants in the reports will only be indicated by the lab code, which will be communicated to participants by GELC at the beginning of this inter-laboratory comparison test.

13. Delivery fee

According to the inter-laboratory comparison test test rules, the participants shall undertake customs duties when receiving the samples from GELC and the shipping and delivery fees when sending the samples to GELC.

14. Timetable of this CT programme

Table D-4. Timetable of this CT programme

Event	Period
Samples preparation (GELC)	Aug-Nov 2014
Samples distribution (GELC)	Dec 2014
Comparison testing with the laboratories	Feb 2015
Second testing with GELC	Feb-Apr 2015
Statistical analysis of results (GELC)	Apr 2015
Formal Confirming Report to participants and UNEP	May 2015
Summary report to participants and UNEP	Nov 2015
Explain the results and answer questions (GELC)	Nov 2015

15. References

[1] *ISO/IEC 17043:2010, Conformity Assessment – General Requirements for Proficiency Testing.*
[2] *ISO 13528:2005, Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparisons.*
[3] *ISO, Guide to the Expression of Uncertainty in Measurement, 1st Edition, 1993.*
[4] *CIE 198:2011: Determination of Measurement Uncertainties in Photometry.*